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AS DETERMINED FROM PLAYA LAKE SEDIMENTS.

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SECULAR VARIATION OF THE GEOMAGNETIC FIELD AS DETERMINED FROM PLAYA LAKE SEDIMENTS

A DISSERTATION

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EDWIN THOMAS GREEN

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SECULAR VARIATION OF THE GEOMAGNETIC FIELD AS DETERMINED FROM PLAYA LAKE SEDIMENTS

APPROVED BY

DISSERTATION COMMITTEE

ABSTRACT

Geomagnetic field characteristics for the past 2000 years have been accurately established from studies of baked clays associated with archaeological sites. This investigation was to test the hypothesis that geomagnetic field variations recorded in recent playa sediments would correlate with those time-varying geomagnetic field changes found in the baked clays.

Oriented specimens were taken in vertical columns from the sediments of two dry lakes (playas) in Arizona and one dry lake in Nevada. These locations were chosen because they lie in the same geographic region of the United States for which archaeomagnetic data are available. This permitted a comparison of paleomagnetic data derived from two independent sources.

When the magnetic data from the dry lake sediments were compared to the archaeomagnetic data for the southwestern United States, there appeared to be a general agreement. Correlation coefficients as high as 0.84 and 0.85 were calculated for the relationship between the archaeomagnetic declination curve and the sediment declination curves from the two Arizona playas. By using points on curves derived from the playa sediment data (which gave a measure of depth in centimeters below the present lake-bed surface) and matching them with similar points on curves derived from baked clay data (which gave a measure of

time in years before the present) it was possible to calculate average sedimentation rates for the playas. These were: Willcox Playa, Arizona, 0.073 cm/year; Red Lake Playa, Arizona, 0.053 cm/year; Smith Creek Valley Playa, Nevada, 0.030 cm/year.

The time varying characteristics of the baked clay curves were confirmed by the results obtained from the playa sediments, and no new "excursions" of the field were found.

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INTRODUCTION

This investigation into the paleomagnetism of recent sediments in the dry lake beds (playas) of the Basin and Range Province was to test the hypothesis that time-related magnetic changes in playa sediments could be correlated with temporal changes of the geomagnetic field that have been found in baked clays from the same general region of the United States.

Dr. Robert L. DuBois has accurately established the ancient geomagnetic (archaeomagnetic) field characteristics for the southwestern United States from analyses of baked clays associated with archaeological sites (Weaver, 1967 and DuBois, 1974). These baked clays were predominately from fire pits, hearths, and baked walls or floors. As the materials were heated to temperatures above their Curie points and then cooled, the magnetic minerals within them recorded the declination (D) and inclination (I) of the ambient geomagnetic field existing at that instant in time. When oriented specimens of fired clay were taken from these ancient objects (whose time of use had been dated by dendrochronology), and magnetic data were derived from measurement by magnetometers, Dr. DuBois was able to plot curves relating changes in declination and inclination of the earth's magnetic field to absolute times before the present. Although the baked clays provide geomagnetic data for points in time, the spacing between these data points is larger for samples from pre-Christian years, for which archaeological sites containing baked clays are scarce. Should playa geomagnetic data prove reliable by correlation with the established archaeomagnetic curves of more recent years, the longer age range of the playa sediments would aid in extending the archaeomagnetic curves back into that time when data from fire pits is poorly represented. In this way, paleomagnetic information from playa sediments might become important to the archaeologist, or anthropologist, in helping to date the sites of early man's activities.

Playa geomagnetic data may become important to the geophysicist, if the data add to existing knowledge about the behavior of the paleomagnetic field and aid in understanding the earth's core characteristics. Reliable playa data might also provide a means for correlation with other sedimentary features in the same geographic region. Comparisons of the geomagnetic data from two or more sedimentary features could be made in much the same manner as oil well log comparisons. Another possibility is that when points on the D & I curves from playa sediments, at known depths below the surface, correlate well with similar points on D & I curves from other sources, such as baked clays or lava flows, and the baked clays or lava flows can be accurately dated in years before the present, the paleomagnetic data provide a means for determining age and sedimentation rates for the playa.

Griffiths et al. (1960) reported that minute magnetic grains settling in quiet water, such as lake water, tended to be aligned in the direction of the ambient geomagnetic field in the same manner as a compass needle is aligned. As these grains became incorporated into the sediments at the lake bottom, they were presumed to be held in the aligned position by the other sedimentary particles which surrounded them, and were "locked into position" even though the direction of the geomagnetic field may have subsequently changed. Later, Irving and Major (1964) found that post-depositional realignment was possible within the soft, water-filled, unconsolidated sediments. Some packing and consolidation of the sediments had to occur before the magnetic particle position were "fixed." I assumed during this investigation that magnetic grains carried by the intermittent flow of streams into the temporary lake waters of a playa would behave similarly. Through the passage of time, as successive and continuous layers of sediment built up on the lake bottom each time the playa was covered with water, the direction of magnetization of the magnetic particles in the sediments would provide a continuous record of the changing direction of the earth's magnetic field. This study was undertaken to determine whether or not such materials could be used to provide reliable data with sufficient precision to be useful.

By taking oriented specimens in vertical columns from the playa lake beds and measuring their magnetization with a magnetometer, it was possible to plot curves showing changes in the declination and inclination of the geomagnetic field with depth. It was also possible to determine the changing magnetic field intensities throughout the depth of the columns, however, these could only be directly related to changing intensities of the earth's paleomagnetic field if one assumed a uniform distribution of magnetic particles. The magnetic moment of each grain was determined at a much earlier time when its source rock cooled through its Curie temperature. Increases or decreases in the number or size of the grains could have made any particular specimen of the playa sediments magnetically stronger or weaker than any adjacent specimen.

Those playa lakes chosen for sampling, to test the above hypotheses and assumptions, lie in a geographic region for which reliable archaeomagnetic data are available. This permitted a comparison of magnetic declination and inclination data from independent sources, and provided some control for that part of the playa sediment data which covered the same span of time as the baked clays.

PREVIOUS STUDIES

This section is a chronologically arranged summary of work done by other investigators. Particular emphasis is placed upon the problems and results these investigators encountered as they might apply to the research for this project. This section is meant to be neither an extensive bibliography nor an historical review of the literature on the subject. Rather, I have been selective and have included only information from those papers and books which I felt had been some direct bearing. Consequently, much literature concerning the magnetization of sedimentary rocks has not been summarized here, as it did not relate directly to this research.

Studies of the remanent magnetism in lavas had been in progress for some years before investigation into the paleomagnetism of sediments began. Jacobs (1967) commented in his book about Chevallier's classic early work (1925) with lava flows from Mount Etna. Chevallier showed that the remanent magnetization of these lavas was parallel to the geomagnetic field measured at nearby observatories at the time of the flows' eruption.

An important early study into remanent magnetism of relatively recent sediments was done on varved clays by McNish and Johnson (1938). They hypothesized that particles of magnetized magnetic minerals settling in quiet water should, on an average, be aligned with the direction of the earth's magnetic field, thus producing a measurable magnetic direction in the sediments. They suggested that alignment with the direction of geomagnetic declination should be close, but because their elongate shapes would probably determine the axis of magnetization, the particles would tend to lie flat rather than in the direction of geomagnetic inclination, thereby introducing inclination error. These researchers found consistent differences between the direction of magnetic moment in the summer varves and in the winter varves of the same couplets. Their explanation was that during the summer the energy of stream runoff moved larger particles to the site of deposition in the lakes, with the result that the summer varves were more porous. The authors suggested that the porosity of the summer varves permitted groundwater to realign the magnetic grains in the direction of more recent geomagnetic fields. In contrast, the grains which had settled beneath the protective cover of the surface ice during the winter season were much smaller and less likely to be disturbed later by groundwater, and thereby more representative of the geomagnetic field at the time of deposition.

Another researcher to recognize the problem of inclination error was Benedickt (1943). He, too, found that the inclination component of an external field was unreliable in sediments because of what he called "gravitational torque" acting upon the magnetic particles at the instant of their contact with the bottom. Benedickt also suggested that the shape of the sedimentary particle might influence its movements while settling through water, possibly resulting in misalignment with the geomagnetic field when it came to rest at the bottom.

Later, a team of researchers (Johnson, Murphy and Torreson, 1948) investigated New England varved clays. Again the problem of inclination error was discussed. This group found that laboratory deposited sediments showed an error between remanent inclination and ambient field inclination of about 20°. They did an earthquake disturbance simulation, which was relevant to sediments from the Basin and Range Province. Samples of both natural varves and artificial sediments were placed on a shaking-table and shaken for several hours at varying amplitudes to simulate the equivalent of several centuries of earthquake disturbance. No change in the direction of the magnetic moment occurred as a result of the shaking. They also used a proportional method for determining ancient field strength by redepositing sediments under various amplitudes of magnetic field. The intensity of the moment versus ambient field strength was plotted to form a curve from which the presumed ambient field strength at the time of deposition could be calculated.

Griffiths (1955) worked with varved clays from sites in Sweden. He selected these materials for study because they could be accurately dated, and varved clays, being unconsolidated sediments, permitted later resettling experiments under controlled laboratory conditions. He reported that those varves which showed characteristics of having been laid down under quiet conditions possessed direction of magnetization consistent with the ambient field direction. Magnetic "irregularities and deviations" found in younger varves were attributed to the presence of bottom currents in the lake during sedimentation. Griffiths concluded that varved clay deposited under quiet-water conditions will possess a magnetic moment such that the declination will closely approximate the geomagnetic field direction of the time, but magnetic inclination will be less reliable.

Two years later Griffiths et al. (1957), working with varved clays from both Sweden and Iceland, studied some of the factors thought to be the cause of the errors found in field specimens. Their laboratory deposited clays gave reliable declination results, but produced an inclination shallower than the ambient field in which the artificial sediments were deposited. The amount of inclination error was from 10° to 30° for an ambient field inclination of 65°. While Johnson et al. (1948) had reported that inclination error decreased with increasing field strength, Griffiths et al. found little effect of a change in field strength on inclination error. Coarse layers within the Icelandic varves produced a larger incinlation error than did fine material. There were other reported results from the investigations of this group, which could have some relationship to paleomagnetic studies in playa sediments. (1) They found large deviations in the directions of the magnetic remanence of sediments laid down in currents of only a few centimeters per second. (2) When comparing rounded particles with flattened particles, they found that flattened particles settled horizontally and thereby induced inclination error. (3) There was a close dependence of inclination error on grain size, which was independent of the source of the sediment. Although in a later paper (1960) by these same people, the dependence of inclination error on particle size could not be confirmed. (4) Rolling of spherical particles may take place not only on deposition, but also as a result of changes from open to close packing in the sediment.

The following year (1958), Griffiths et al. reported that the important variables which produce secular variation errors in sediments are grain size (this could not be confirmed according to their 1960 paper), dip of the bedding plane (which is not a factor in playa sedimentation), and bottom currents during deposition. (This latter might be a factor during intense precipitation and runoff into a playa, or when strong winds drive sheets of shallow water across the playa surface.) Again, as in their 1957 paper, they suggested that the inclination error observed was due to flattened particles settling horizontally. The particles may have been aligned with the horizontal component of the geomagnetic field (declination), but they were out of alignment with the vertical component (inclination). Griffiths et al. hypothesized that particles which are more nearly spherical may have an inclination error introduced by rotation of the grains as they settle into spaces between other grains. The team found from experimentation that the effect of spherical magnetic particles rolling about a horizontal axis, for any reason, while settling would also result in inclination errors. Rolling while settling might be caused by bottom currents, deposition on an inclined plane, or rolling into the nearest hollow on a bed of similar spheres.

Runcorn (1959) made a statement which is relevant to magnetism in playa sediments. In a hot climate in which there are at times heavy rains (this fits the playa environment well), it is possible that in the surface layers some of the hematite grains become hydrolized.

Later on, the hydroxide again decomposes to hematite which then picks up a magnetization parallel to the ambient field. This process might be particularly important in porous sediments. Runcorn's statement appeared to be an hypothesis, as there was no mention that it had been tested either by himself or by others.

In a paper published in 1960, Griffiths, et al. again reported findings of remanent magnetism in recent varved sediments. The field specimens, as before, were taken from Swedish and Icelandic varves. These sediments were redeposited under controlled conditions in the laboratory and measurements made of the remanence. In the artificially deposited sediments, the inclination of the remanence was as much as 20° less than that of the applied magnetic field, whereas the inclination error was never more than 5° to 10° in varved sediments deposited under natural conditions. Size and shape analyses showed that the magnetic particles had a size distribution similar to that of the sediment as a whole. The grains were not clearly divided into well contrasted groups of spherical and plate-like particles as was suggested in their 1957 paper. They stated that the magnetic moment of the sediments was from grains of magnetite and submicroscopic magnetic inclusions in quartz and feldspar grains, and that a considerable part of the magnetization of the sediment was present in the inclusions rather than as free magnetic particles. The differences between the remanence directions and the direction of the ambient field were explained mainly as an effect of rolling of the particles on the bed during the last stage of settling when the spherically shaped particles rolled into depressions on the horizontal surface of the bed. The direction of remanence acquired during this settling process appeared to remain unaltered after compaction of the sediments. From these investigations, Griffiths et al. derived an equation to show the relationship between inclination error in natural sediments and these same materials when redeposited under controlled laboratory conditions:

$$\tan I_0 = f \tan I_F,$$

where I_0 is the inclination of the remanent magnetization found in the sediments, I_F is the inclination of the ambient field at the site of deposition, and f is a constant equal to 0.4. The inclination error (δ) can be defined as

$$\delta = I_F - I_0.$$

As mentioned previously in this section, McNish and Johnson (1938) suggested that groundwater within the pore spaces of the coarse, summer-deposited sediments of a varve couplet permitted realignment of the magnetic grains to a geomagnetic field direction different from that at the time of deposition. Irving and Major (1964) tested the hypothesis in a laboratory investigation in which they used mixtures of quartz particles and magnetic grains (magnetite and hematite) to determine whether or not an external field would turn randomly oriented magnetic grains in the direction of a field applied after deposition. Their experiments showed post-depositional realignment to be physically possible. Magnetic grains (they used magnetite and hematite separately), whose moments were at first randomly oriented, became aligned with the applied field during a few tens of hours in which the sediments were wet. This post-depositional remanent magnetization (PDRM) was thought to result from bodily rotation of the magnetic particles within the soft, water-filled, unconsolidated sediment into the direction of an externally applied field. The PDRM showed good agreement with the direction of the applied field, and remained stable during progressive demagnetization.

Jacobs (1967) assessed the status of knowledge of paleomagnetism in sedimentary rocks at the time, when he commented that the magnetic grains tend to align themselves along the direction of the geomagnetic field while the sediment is still wet and unconsolidated. Later, these magnetic grains may get locked into position to form a measurable magnetic moment in specimens taken from the sedimentary rock. When interpreting paleomagnetic data derived from such sediments, one of the principal uncertainties was in deciding what physical and chemical changes the rocks had undergone since they were laid down as sediments. Although Jacobs was writing about long-term sedimentary rock formation, his comments were applicable to more recent unconsolidated sediments such as those found in playas.

In a later book, Strangway (1970) recapitulated some of the work done in the field of paleomagnetism in sediments. Small particles of magnetic material tend to have a high degree of magnetic stability. Mineralogical studies of sediments indicated that the main magnetic mineral was magnetite, usually in particle sizes of just a few microns. In those experiments involving a range of grain sizes, the inclination error was generally reduced. Apparently, as the moist sediment dried out and compacted, many of the smaller magnetic particles settled into the spaces between the larger grains.

The Basin and Range Province, from which the sediments for this research project were taken, is a tectonically active region (Atwater, 1970). Earthquakes of various intensities are presently centered in the region, and there is little doubt that moderate to severe earthquakes have been experienced regularly within the Province throughout the past several million years. This raises the question as to what disturbances earthquakes may have caused within the sediments of the playas in a way that affected the accuracy of the paleomagnetic record. As mentioned earlier, Johnson et al. (1948) performed a shaking-table experiment to determine the probable effects of seismic waves upon the magnetic moment of sediments, and found no changes in the direction of the moment. Francis (1971) introduced another consideration. His paper dealt with the possible effect of earthquakes on deep-sea sediments, particularly those sediments filling the oceanic trenches. However, a few of the points he made might be applicable to playa sediments under certain conditions. Francis hypothesized that earthquakes caused periodic liquefaction of the oceanic sediments, which kept them essentially horizontal rather than deformed or folded. The oceanic sediments are thixotropic, that is, they change from a semi-solid, jelly-like condition to a liquid state while being shaken by seismic waves, and revert back to the semi-solid condition after cessation of the seismic waves. Francis cited Boswell (1949), who showed that, except for coarse, clean sands and gravels, all unconsolidated sediments are to some degree thixotropic. Thixotropy is increased by an increase in the proportion of finely divided particles and platy grains within the sediment. This phenomenon is possible in playa sediments only during the rainy season when the sediments are wet, and then only to a depth of a few centimeters in those playas where the sediments are relatively impermeable to groundwater and surface water.

In a study of baked clays, Barbetti and McElhinny (1972) used dune sands to determine the geomagnetic field direction above and below clay firepits. Loose dune sands would seem to be an unreliable means for paleomagnetic studies, but for five of the dune specimens below the firepit level they had an alpha-95 (Fisher, 1953) of 4.9°, and for four dune specimens above the level of the firepit clays they obtained an alpha-95 of 3.9°. The wind-deposited sediments appeared to be at least as reliable indicators of secular variation as lake sediments. This is relevant to playa sediments for the reason that, during the dry season, a few loose particles at the surface of the playa are often moved by winds. The possibility of particle alignment with the geomagnetic field by winds at the surface of a playa must be considered, even though the more active depositional agent is likely to be intermittent surface waters as attested to by the flatness of playa surfaces. If winds were more effective than the occasional surface water, there would be evidence of ripple marks, small dunes, and deflation hollows. While some of these features, particularly dunes, can be found at the edges of playas, they are not found on the smooth, hard surface of the interior of the playa.

Kent (1973) studied remanent magnetism in synthetically deposited sediments. He found the results were unreliable, if the sediments were too wet. He postulated that the physical origin of post-detrital remanent magnetism was likely to be closely related to Brownian motion within wet sediments. The small grain diameters of the magnetic minerals and the lack of inclination error in most deep-sea sediments were offered in support of his model of magnetic grain alignment in an external field by Brownian movement. Kent's preliminary laboratory investigations indicated that only a small decrease in the water content of sediments was necessary to "lock in" any post depositional remanent magnetism. This suggested to him that PDRM was acquired at a shallow depth below the sediment surface. He also found deviation from the control field in those sediments where there was visible deformation resulting from partial drying of the otherwise damp sediments. Deformation due to dessication is an important consideration in the case of playa sediments. Kent reported, as others had previously, that the intensity of remanent magnetization in the sediments was linearly proportional to the intensity of the control field.

Thompson (1973) also concluded that the NRM in sediments becomes stabilized soon after the time of deposition, and alternating field demagnetization showed this NRM to be of high stability. In his study of cores taken from the sediments of Lake Windermere in England, Thompson learned by comparison of measurements from the top one meter of the lake cores with observatory and archaeomagnetic data for the past 500 years that the stable remanent magnetization occurred shortly after deposition. Thompson used pollen assemblages to date sediments from another lake, Lough Neagh. He found the pollen dates in good agreement with the magnetic ages. (We tried to use this method of dating for the playa sediments, but Dr. L. R. Wilson, a palynologist at The University of Oklahoma, could find no pollen in the particular specimens I provided.)

A comment was made about the intensity of magnetism in sediments by Creer and Kopper (1974), who suggested that intensity of the magnetic moment depends upon the mineralogical composition of the sediment as well as on the strength of the earth's field at the time of deposition. Their comments about mineralogical composition as a factor influencing the intensity of magnetization in sediments is understandable, as magnetite, for example, is more strongly magnetic than hematite. And certainly the intensity of the moment in sediments would be stronger or weaker depending upon the proportion of magnetic to non-magnetic particles for a given volume. The detritus, usually of igneous origin, contributing to the magnetic moment of a sediment has acquired its original magnetization at the time of its formation. Therefore, its intensity is proportional to the strength of the ambient field at the time of its formation.

It may be that during sedimentation a strong ambient field aligns more magnetic particles, thus contributing to the total moment of the sediments. Possibly a weaker field would align fewer particles, thereby decreasing the number of particles contributing to the measurable moment of the sediment. To my knowledge this last hypothesis has not been tested.

Graham (1974) determined the remanent magnetization of modern tidal flat sediments. He concluded that the remanent magnetization of the tidal flat sediments was stable under conditions of repeated wetting and drying as it would occur in nature. Rewetting did not remobilize the tidal flat sediment. He postulated that this was because of the sediment's fine-grained, cohesive characteristic. His results have applications to playa sediments, which are seasonally wetted and dried, and are also fine-grained and cohesive away from the shoreline.

Peach and Perrie (1975) in their study of grain size distribution within glacial varves concluded that the coarseness or fineness of the sediment reflected the rate of deposition, which in turn was a direct result of such factors as changes in rainfall, changes in stream currents, and changes in the direction and velocity of lake currents. The internal structure of the varves was thus related to seasonal variations in rainfall and runoff. These same factors would affect somewhat the particle sizes to be found in nearshore playa sediments, but probably less so toward the middle of the playa far removed from the coarse material at the shorelines.

In their investigation of an ancient playa-lake complex, Eugster and Hardie (1975) used present-day processes occurring in the sedimentary environment of a modern playa to interpret the ancient playa deposits. Some of their comments are applicable to this research. They suggested that thin sheets of water on the surface of a playa deposited the fine grains mainly as a traction load, that is, as bed-load moved by the wind-blown sheet of surface water. They suggested that this is the principal means of deposition of the playa sediments, rather than settling out of standing water. I have observed the movement of wind-blown sheets of shallow water on the playa surface, but I have also observed long periods of quiet water standing on the playa surface for extended periods (three or four days) during nearly continuous light rain. This usually occurs in the Spring rainy season. The playa surface is subjected to wind-blown sheets of surface water, but there are periods of relative quiet when a few centimeters of standing surface water might allow microscopic size particles of magnetic minerals to settle out in alignment with the geomagnetic field.

GEOGRAPHIC LOCATIONS OF THE SAMPLING SITES

Playas in western United States are located principally in the Basin and Range Physiographic Province. The Province is characterized by isolated, nearly parallel, fault-block mountain ranges. The desert floors separating the mountain ranges lie in topographically enclosed basins, with interior drainage, in an environment where annual evaporation exceeds precipitation. The average evaporation from open lakes in the principal playa regions ranges from 40 to 90 inches per year. Three-quarters of this evaporation occurs between May and October (Neal, 1965). Within this arid region there are several hundred playas, each with a surface area in excess of three square miles, and perhaps thousands of smaller playas.

The specimens used in this research project were taken from three large playas in the Basin and Range Province. Site A and Site B specimens were from Willcox Playa, Arizona. Site C and Site D specimens were from Red Lake Playa, Arizona. Site E specimens were from Smith Creek Valley Playa, Nevada (Figure 1). The geographic coordinates of each site are:

Site A	-	32° 04'	North	109° 50'	West
Site B	-	32° 08'	North	109° 53'	West
Site C	-	35° 40'	North	114° 06'	West
Site D	-	35° 40'	North	114° 06'	West
Site E	-	39° 22'	North	117° 11'	West

Site A and Site B: Willcox Playa

Site C and Site D: Red Lake Playa

Site E: Smith Creek Valley Playa

Figure 1. Geographic Locations of the Sampling Sites

Willcox Playa is near Willcox, Arizona, in the northern part of Sulphur Springs Valley, located in Cochise County in the southeast corner of Arizona.

Red Lake Playa lies approximately 40 miles north of Kingman, Arizona, in the Hualapai Valley of Mohave County in the northwestern part of Arizona.

Smith Creek Valley Playa is about 25 miles southwest of Austin in Lander County, Nevada, in the central part of the state.

The straight line distance between Willcox Playa and Red Lake Playa is 342 miles, and the straight line distance between Red Lake Playa and Smith Creek Valley Playa is 320 miles.

GEOLOGY OF THE SAMPLING SITES

Originally, the Spanish word "playa" had the meaning "beach." Different usage of the word in the United States has changed the meaning here. By definition, the flat-floored bottom of a desert lake basin is called a playa. Locally, such terms as dry pan, salt pan, salt flat, alkali flat, salina, and salt marsh are used. These local terms often reveal variations in playa composition, but most playas contain fine-grained silt and clay with variable quantities of secondary saline, sulfate, and carbonate minerals (Neal, 1965). Seasonally, a playa may be covered with shallow water. It is then more accurately called a playa lake.

Many playas of western United States were the sites of larger, more permanent lakes during the Pleistocene Epoch when they were receiving large quantities of detritus from the nearby mountains. Today's playas are remnants of those ancient lakes. Geophysical studies (Cabaniss, 1965) of eighteen Basin and Range playas revealed thicknesses of the sediments ranging from 1,000 to 12,000 feet. Smith Creek Valley Playa, Nevada, one of those included in Cabaniss's study, and from which specimens for this paleomagnetic research project were taken, contains sediments 2,000 feet thick; the relatively thin upper level being more recent than Pleistocene. The fine-grained, closely packed character of the sediments away from the shoreline makes them generally impervious to surface water infiltration, although I did find playa sediments moist to depths of one meter following prolonged rain. The coarse detritus at the edges of the playa is quite permeable.

The amount of deflation of playas during the long dry season is a matter for debate. The effect of wind erosion must certainly depend upon the character of the surface, which differs among playas according to their mineral content, depth to the groundwater table, and groundwater discharge. Variations in these factors can produce playas with moist, dry, or flaky surfaces. Flaky surfaces are the most prone to wind erosion, and moist surfaces the least. The dry playa surface has been described (Kerr and Langer, 1965) as having a hard, dry, impermeable crust containing in excess of 50 percent clay minerals, high in carbonate content, and low in soluble salines. These dry surfaces have a high bearing strength (they supported the weight of our fully loaded station wagon, leaving virtually no wheel tracks), and are broken by tools only with difficulty. Kerr and Langer explained this phenomenon as being caused by the strong molecular forces of attraction between adjacent colloidal particles which come in contact when the dispersing medium (water) is removed by evaporation. It is difficult to imagine much wind erosion on such a surface, and, in fact, I observed little. The hard, dry, compact crust has only a negligible microrelief caused by mud shrinkage. Playas are the flattest of all landforms, often sloping only one foot, or less, per mile.

Motts (1965) stated that the principal depositional agent for "dry type" playas is surface water, in contrast to "moist type" playas where groundwater is the dominant depositional agent. Most of the sediments deposited by surface water are clastics, although evaporite minerals and non-clastic carbonates may also be deposited by surface waters. Two of the playas (Red Lake and Smith Creek Valley), from which the specimens for this paleomagnetic research were taken, are dry surface type. Photographs of Willcox Playa show flaky surfaces (Cowgill, 1969), dunes, and "blowouts" (Schreiber et al., 1972). Motts believed capillary rise and discharge of groundwater to be responsible for the flaky crust of Willcox Playa. I have not personally observed the surface of Willcox Playa during the dry season.

Atwater (1970) considered the Basin and Range Province to be a wide, soft boundary between two rigid plates. According to her, Late Tertiary deformation of the Province occurred as a "megashear" in the same direction and sense as the San Andreas fault. Some of the faults within this "megashear" show strike-slip motion, and others, such as those in the Basin and Range, are at angles to the strike-slip faults, which produced opening or tension. Atwater theorized this would account for the Tertiary volcanics and the fault block mountains of the province. Hot springs are found along some of the faults, many of which extend down through the basin sediments into the bedrock beneath. Hot springs occur along the western edge of Smith Creek Valley Playa, Nevada. No paleomagnetic specimens were taken within several miles of these hot springs.

Willcox Playa, Arizona

See Figure 2. The following bordering highlands have supplied sedimentary material to the playa:

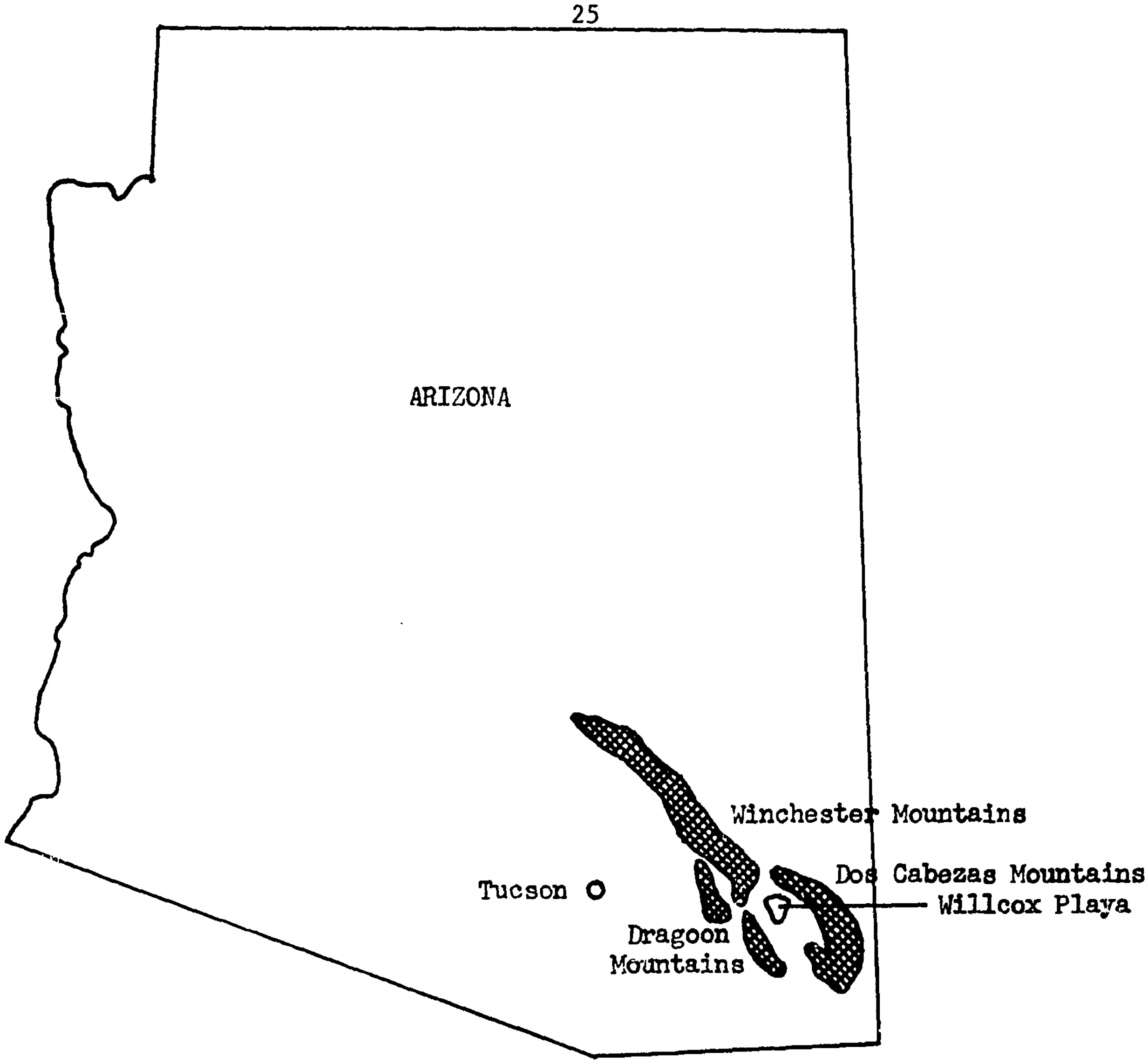

Figure 2. Geology of the Sampling Sites. Dos Cabezas Mountains: Precambrian and Tertiary volcanics and intrusives. Winchester Mountains: Precambrian and Tertiary volcanics and intrusives. Dragoon Mountains: Tertiary intrusives and Penn-Permian carbonates. (Source: A.A.P.G. Geological Highway Map)

Dos Cabezas Mountains: Seven miles northeast. Tertiary granite and granodiorite intrusives. Tertiary andesitic and rhyolitic volcanics. Precambrian schist and granite.

Winchester Mountains: Seven miles northwest. Tertiary intermediate volcanics. Tertiary silicic volcanics. Precambrian granite.

Red Bird Hills: Three miles west. Cretaceous sedimentary rocks. Permian limestones.

Little Dragoon Mountains: Twelve miles west. Tertiary granite and granodiorite intrusives. Precambrian limestone with associated basalt flows. Precambrian schist.

Dragoon Mountains: Seven miles southwest. Pennsylvanian-Permian dolomite and limestone. Tertiary granite and granodiorite intrusives.

Sulphur Hills: Nine miles south-southeast. Tertiary silicic volcanics.

Pat Hills: Fourteen miles southeast. Tertiary-Cretaceous granite and granodiorite intrusives. Tertiary-Cretaceous andesitic and rhyolitic volcanics.

(Source: U.S.G.S. Geologic Map of Arizona, 1969.)

None of these rock types is a particularly good source of the iron-bearing minerals necessary to produce sediments with a strong magnetic component. The fraction of magnetic minerals in the sialic rocks is small. The basalt flows of the Little Dragoon Mountains are the one exception, and these flows are twelve miles from the nearest shoreline of the playa.

Red Lake Playa, Arizona

See Figure 3. The following mountains and hills have provided the source material for the sediments in the playa:

Grand Wash Cliffs of the Music Mountains: Six miles east-northeast. Precambrian granites. Precambrian gneiss. Cambrian-Ordovician limestones. Tertiary silicic volcanics. Quarternary-Tertiary basaltic flows, tuffs, and cinders.

White Hills: Seven miles west. Precambrian gneiss. Cretaceous rhyolitic and andesitic flows and tuffs. Quarternary-Tertiary basaltic flows, tuffs, and cinders.

Cerbat Mountains: Four miles southwest. Precambrian gneiss. Cretaceous andesitic flows and tuffs.

Unnamed outliers of the Cerbat Mountains: Less than one-half mile from the west edge of the playa. Precambrian gneiss. Quarternary-Tertiary basaltic flows, tuffs, and cinders.

Lone Mountains: Eighteen miles south-southeast. Precambrian gneiss. Cretaceous andesitic flows and tuffs.

(Source: U.S.G.S. Geologic Map of Arizona, 1969.)

Many of these highland rocks are rich in iron-bearing minerals, and the playa sediments derived from them show a relatively strong magnetization.

Smith Creek Valley Playa, Nevada

See Figure 4. The playa sediments are predominately from the mountains listed below:

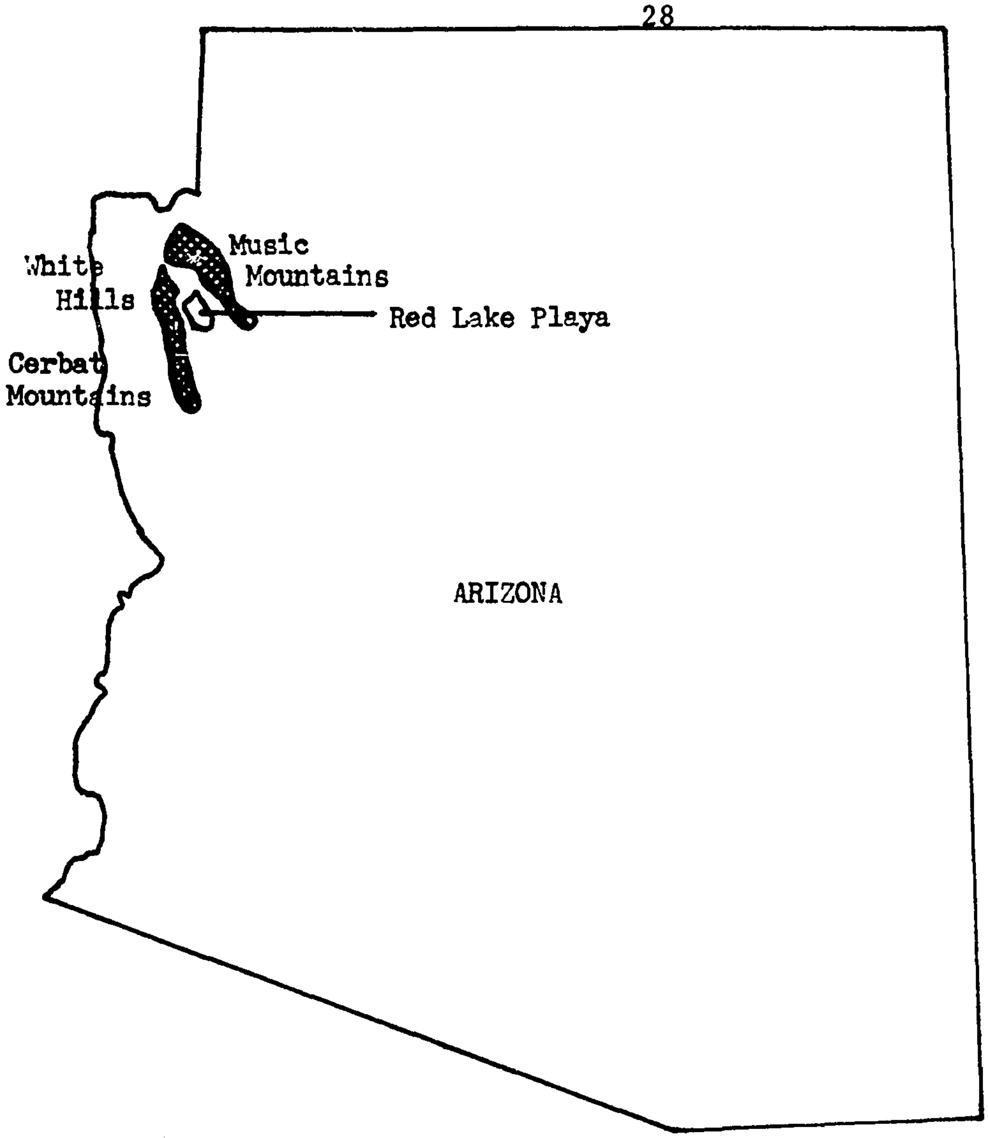

Figure 3. Geology of the Sampling Sites. White Hills: Tertiary volcanics. Cerbat Mountains: Precambrian intrusives and Tertiary volcanics. Music Mountains: Precambrian intrusives and Tertiary volcanics. (Source: A.A.P.G. Geological Highway Map)

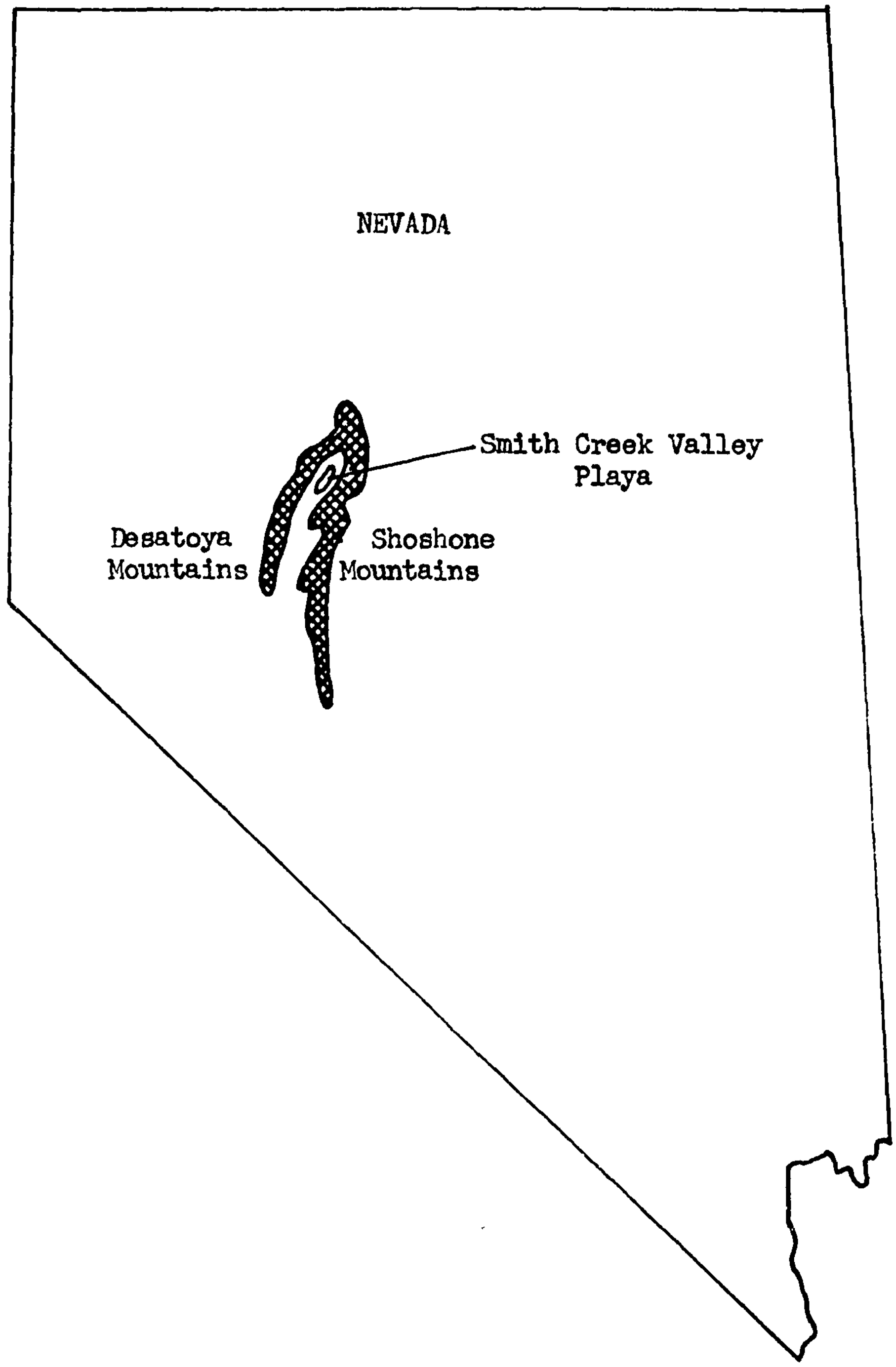

Figure 4. Geology of the Sampling Sites. Both the Desatoya Mountains and the Shoshone Mountains are Tertiary volcanics: Miocene lavas. (Source: A.A.P.G. Geological Highway Map)

Desatoya Mountains: Five miles west and as close as three miles at the nearest point. Tertiary volcanics.

Shoshone Mountains: Five miles east and as close as two miles at the nearest point. Tertiary volcanics.

New Pass Mountains: Thirteen miles north. Tertiary volcanics.

The Tertiary volcanics which comprise the highlands consist of rhyolite, latite, dacite, andesite, basalt and tuff. There are minor outcrops of Mesozoic sedimentary rocks such as limestone, shale, sandstone, conglomerate, and water-laid tuffs.

(Source: American Association of Petroleum Geologists Geological Highway Map of the Pacific Southwest Region.)

It was not just a fortunate circumstance that specimens taken from both Red Lake Playa and Smith Creek Valley Playa for paleomagnetic study had a relatively strong magnetization. The Site A and Site B specimens were collected in Willcox Playa, but when both the chemical analyses and magnetometer measurements indicated that the sediments were deficient in iron and had a weak magnetic moment, the other two playas were carefully chosen from geologic maps of the region to ensure that the surrounding highlands were predominately basaltic. These latter two dry lakes are nearly surrounded by mountains and hills of Tertiary volcanics, which have been providing magnetically rich sediments to the lake beds during thousands of seasonal rains.

MODERN GEOMAGNETIC DATA AT SAMPLING SITES[1]

Willcox Playa, Arizona

Declination: 12.75° East. Annual change: 2.25' westward.

Inclination: 60° North. Annual change: -2.0'.

Field Intensity: 50,750 gamma. Annual change: Decrease 52 gamma.

Red Lake Playa, Arizona

Declination: 15.0° East. Annual change: 2.0' westward.

Inclination: 61° North. Annual change: -2.2'.

Field Intensity: 52,000 gamma. Annual change: Decrease 51 gamma.

Smith Creek Valley Playa, Nevada

Declination: 17.2° East. Annual change: 2.0' westward.

Inclination: 65° North. Annual change: -2.2'.

Field Intensity: 53,500 gamma. Annual change: Decrease 47 gamma.

Sources of information.

Declination: U.S. Coast and Geodetic Survey
Isogonic Chart of the United States, 1965.0.

Inclination: U.S. Naval Oceanographic Office
Map of the Magnetic Inclination or Dip, Epoch 1965.0.

Field Intensity: U.S. Coast and Geodetic Survey
Total Intensity Chart of the United States, 1965.0.

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[1] 1965.0 Epoch.

METHODS USED IN CONDUCTING THE RESEARCH

Sampling Considerations

This research was to test the hypothesis that temporal changes in the magnetization of playa sediments could be correlated with temporal changes of the geomagnetic field that have been found in baked clays from the southwestern United States. To carry out this test, it was necessary to sample playa sediments from the same general area, which would insure that both the sediments and baked clays had been exposed to approximately the same paleomagnetic field variations. For more significant comparisons, specimens were collected from three different playas in the same general region as the baked clay studies.

The sampling had to be done in such a manner that the specimens would be representative of sediments that became progressively older in time, beginning with the present, as they were to be compared with archaeomagnetic data which also became progressively older in time. Assuming that the surface represented present-day deposition, the specimens would be collected at regular intervals vertically downward. It was not certain that the surface of the playa represented present-day deposition, as there was the possibility that wind erosion had lowered the surface to expose older sediments.

It was necessary to collect specimens at sites that showed no visible evidence of having been disturbed, as disordered sediments would not provide a reliable record of the paleomagnetic field. At each site, a location was chosen for sampling which was distant enough from the present shore of the playa to have been undisturbed by such things as cattle, ranchers' trucks, and plant roots. Dessication cracks, mounds, and depressions were also avoided. The true playa, unlike the surrounding highlands, is so hostile to life that animal burrows were no problem.

Some of the specimens were collected horizontally at the same distance below the surface in order that the results could be compared statistically by Fisher's (1953) method, for it was assumed that all sediments from the same horizontal layer would record the same paleomagnetic field direction. A cone of confidence (alpha-95) could then be calculated such that the true mean direction of the paleomagnetic field at that level lay within that cone of confidence with a probability of 95 percent. The scatter, or dispersion, of the individual magnetic directions would be determined by the precision parameter k. (See Appendix.) Eight horizontal specimens were considered a good number for reliability, as the variance does not decrease significantly beyond that number.

In paleomagnetic work, a cone of confidence (alpha-95) of half-angle from 1° to 10° is considered useful. For this research project a precision within 5° was considered necessary in order that the deflections in the declination and inclination curves would be recognizable when compared to the archaeomagnetic curves.

Method by Which Specimens Were Taken at Each Site

Specimens were taken from Site A (Willcox Playa) to develop a sampling procedure, and to work out details of sample preservation.

Both Site A and Site B at Willcox Playa were visited in late December 1972. It had been raining in the vicinity for some weeks, to the playa sediments were moist to a depth just below 100 centimeters. The moist condition of the sediments made it possible to use plastic vials for collection. A large hole (140 cm x 100 cm) was dug manually with a shovel into the playa sediments forming a vertical north wall. Plastic collecting vials were pushed at right angles into the face of the north wall, such that a specimen was taken each five centimeters below the playa surface down to the 100-centimeter depth. Beyond that depth the sediments were too dry and hard to permit further collection. At the 65-centimeter depth, a horizontal row of six additional specimens was taken to provide a test of the lateral uniformity of the direction of magnetization. Each vial was oriented and marked in strike and dip with a Brunton compass prior to its removal (Figure 5).

Specimens were collected from Site C, Red Lake Playa, Arizona, during March 1973, near the end of the rainy season. The sediments were moist to a depth of about 45 centimeters, which permitted the use of plastic vials for collection. A large hole was dug with a shovel to expose a vertical north wall, in the same maner as at Site B. This vertical wall was aligned magnetically east-west. The plastic collecting vials were pushed perpendicularly into the north wall in two vertical rows in such a way that a specimen was taken each five centimeters below the playa surface down to the 40-centimeter depth. Immediately below

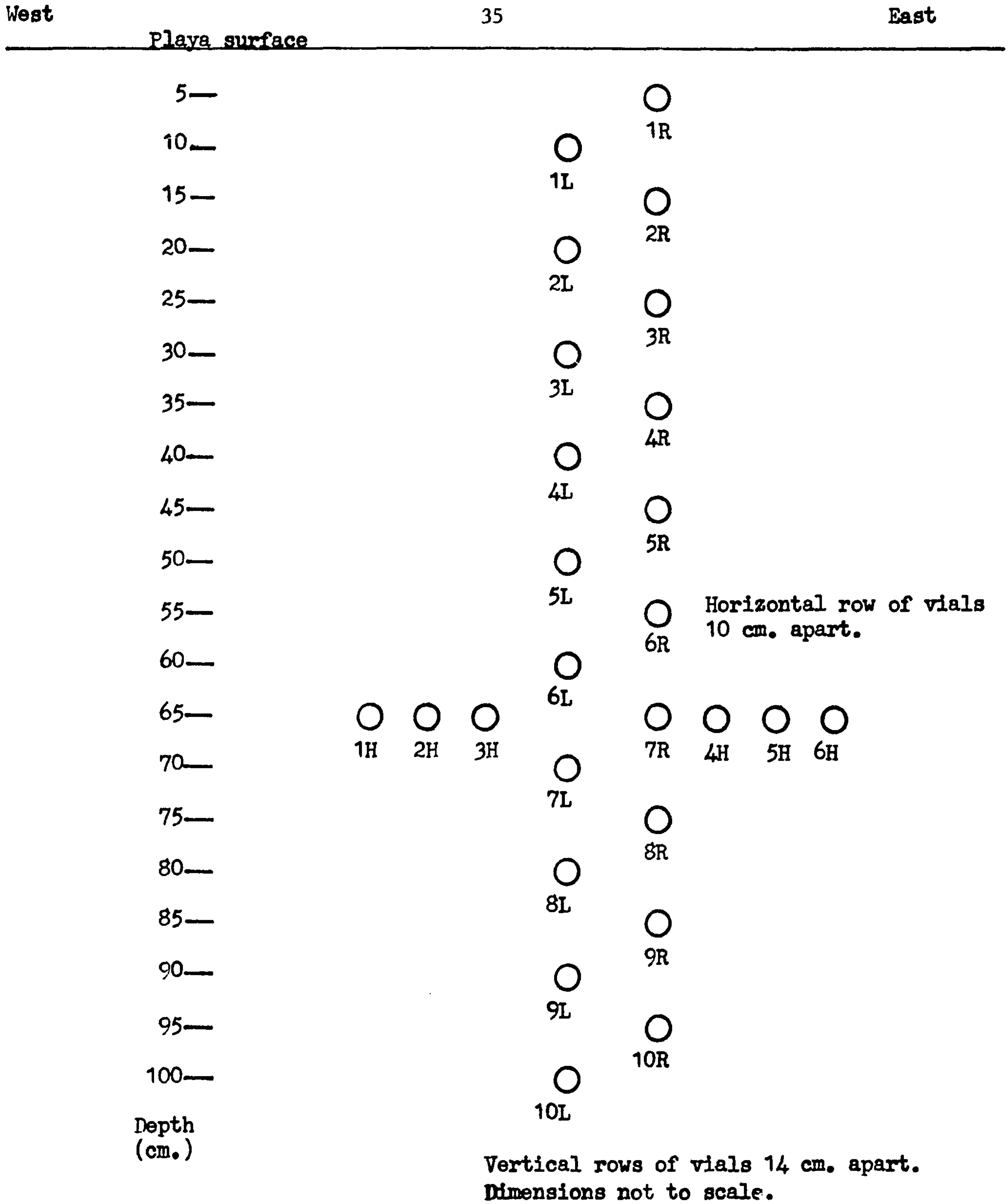


Figure 5. The manner in which Willcox Playa, Arizona (Site B) sediments were sampled by plastic vials pushed into a vertical north wall, then measured in strike and dip before removal.

that, dry hardpan was encountered and no further specimens could be taken using plastic vials. Twenty centimeters below the surface, a horizontal row of eight additional specimens was taken to provide statistical data as to the uniformity of the magnetic moment. Each vial was oriented with a Brunton compass and marked in strike and dip before retrieval (Figure 6).

More specimens were collected in plastic vials from Red Lake Playa (Site D) in August 1973. The lack of significant rainfall since the end of the rainy season, coupled with the high rate of evaporation in that area, had caused the sediments to become dry and hard from the surface down. It was necessary to wet the sediments enough to permit collection in plastic vials by making a trench behind the collecting wall and filling the trench with water. During the night, enough water had permeated the upper ten centimeters of the sediments that it was possible to collect one horizontal row of ten specimens at the 8.5-centimeter depth in the cooler early-morning hours (Figure 7). During the daytime, evaporation was too rapid for the method to work.

Site E at Smith Creek Valley Playa, Nevada, was also sampled in August 1973. The sediments at this location were so dry and hard that it was impossible to use plastic vials for collection. Instead, a hole 50-centimeters deep was dug around a vertical column. The column was gradually made smaller in diameter until it fitted inside a Plexiglass container which had been manufactured for such an eventuality. Melted paraffin wax was poured into the space between the sediment column and the container walls to aid in protecting the column against breakage during transport, and to provide a means for retaining its orientation (Figure 8).

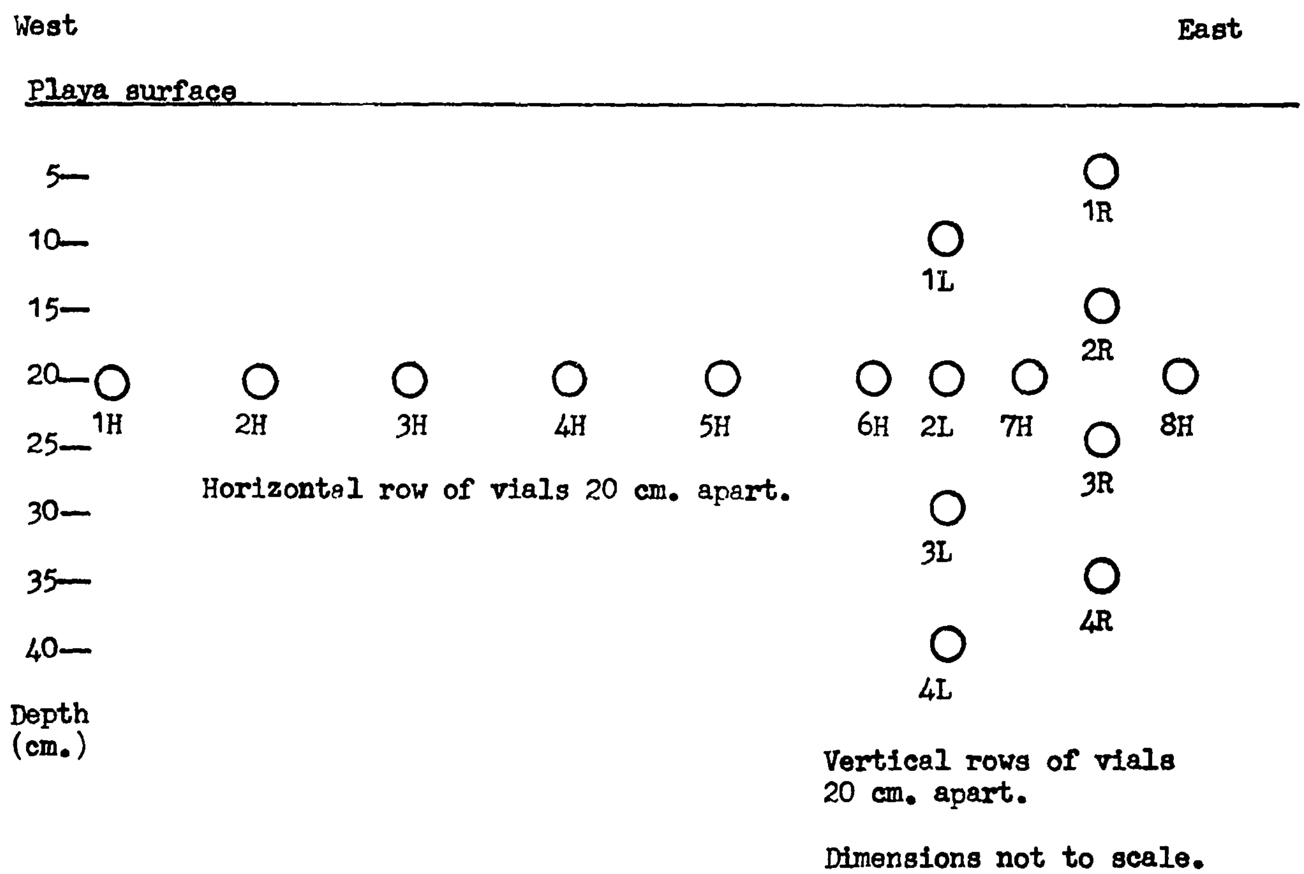


Figure 6. The manner in which Red Lake Playa, Arizona (Site C) sediments were sampled by plastic vials pushed into a north wall, then measured in strike and dip before removal.

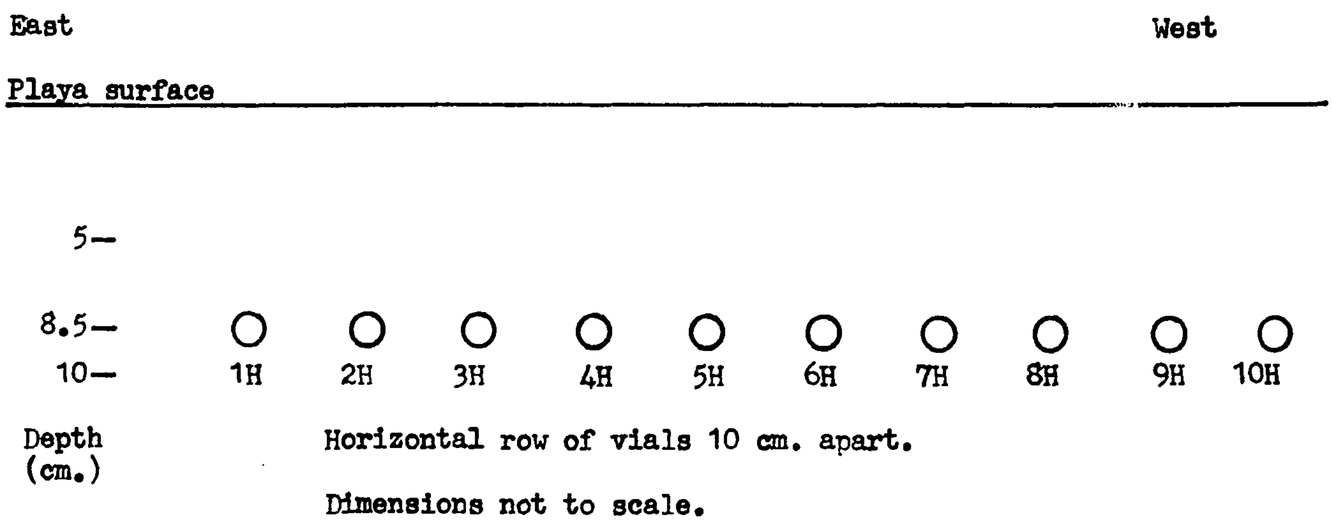


Figure 7. The manner in which Red Lake Playa, Arizona (Site D) sediments were sampled by plastic vials pushed into a vertical south wall, then measured in strike and dip before removal.

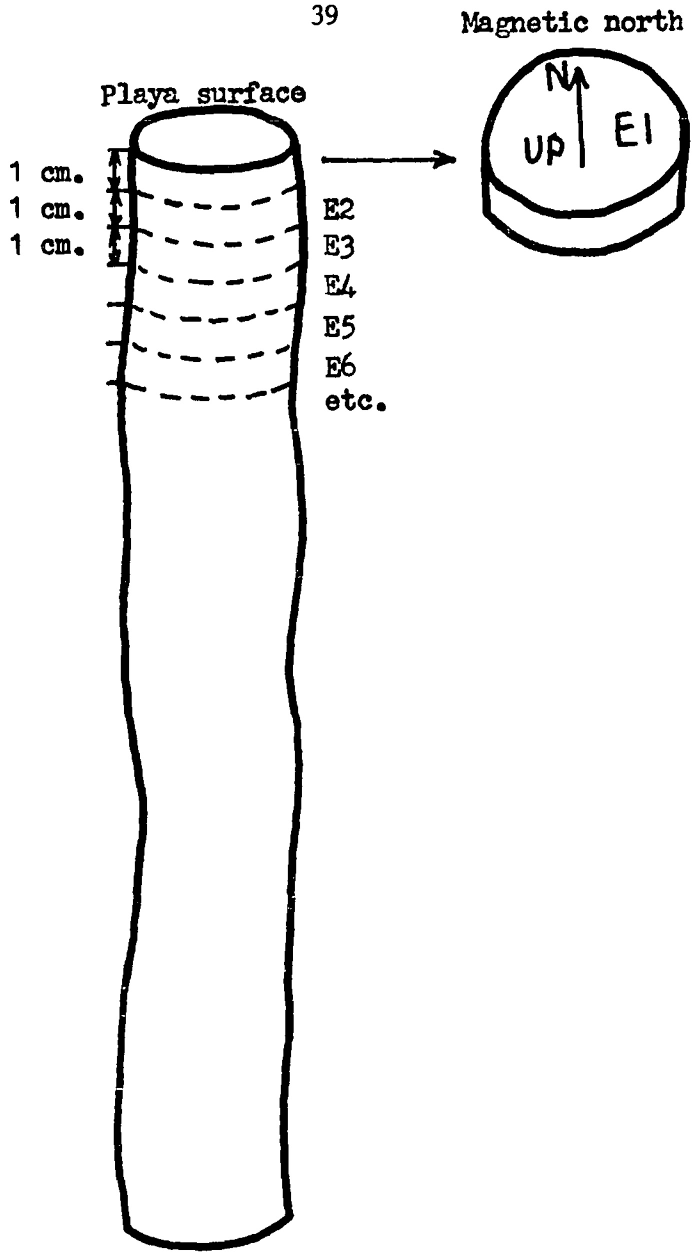


Figure 8. The manner in which a column of dry sediments from Smith Creek Valley Playa, Nevada (Site E) was oriented, cut, and marked for identification prior to measurement on the astatic magnetometer.

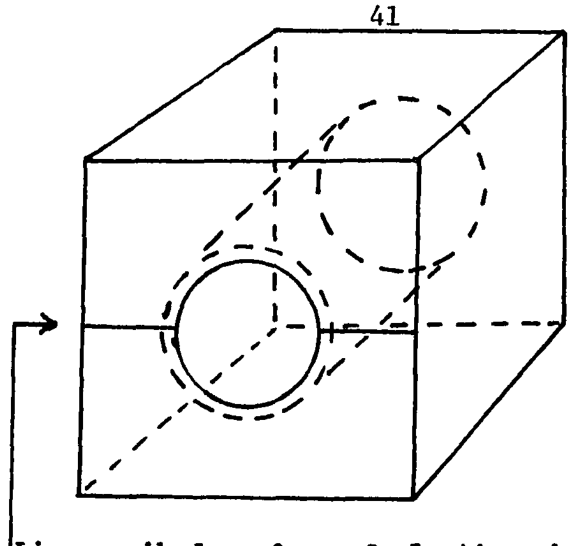
Method by Which Specimens Were Measured with a Magnetometer

All specimens were measured on an astatic magnetometer, as the astatic proved to be more sensitive than the spinner magnetometer (rock generator) to the magnetic component of the sediments. To facilitate measurement of the specimens collected in vials, each was placed in a plastic cube especially made for the purpose. The cube provided the necessary means of orientation while on the magnetometer, and held each specimen securely during rotation in the cup of the demagnetizing coil. Before use, the plastic cubes had been leached in a 20 percent solution of hydrochloric acid to remove any trace of steel that might have become attached to the surface while being machined (Figure 9).

Because of the difference in their geometry, the discs cut from the dry column of Smith Creek Valley Playa sediments could not be measured by use of plastic cubes. A rotatable plastic stage was designed and manufactured which could be offset from the on-center position. This made possible measurement of the magnetic moments of the flat discs in the manner described by Creer (1967) (Figure 10).

Cleaning of "Soft" Secondary Magnetic Components

One of the basic assumptions of paleomagnetism is that once the natural remanent magnetization (NRM) is acquired it remains unaltered, at least in direction (Thellier, 1966). Such forms of NRM are considered to be stable, or "hard," and remain virtually unchanged for millions of years. Thermal remanent magnetization (TRM), chemical remanent magnetization (CRM), and detrital remanent magnetization (DRM) in undisturbed sediments are three forms of NRM which have been



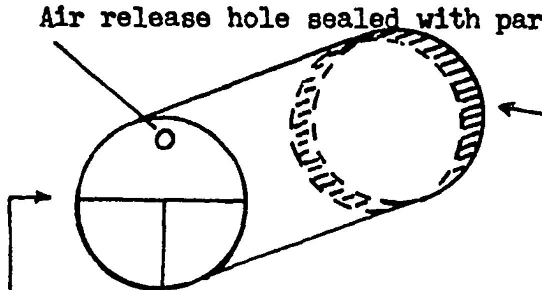


Figure 9. Plastic cube for measurement of sediments on the magnetometer (top). Plastic vial used for collecting moist playa sediments (bottom).

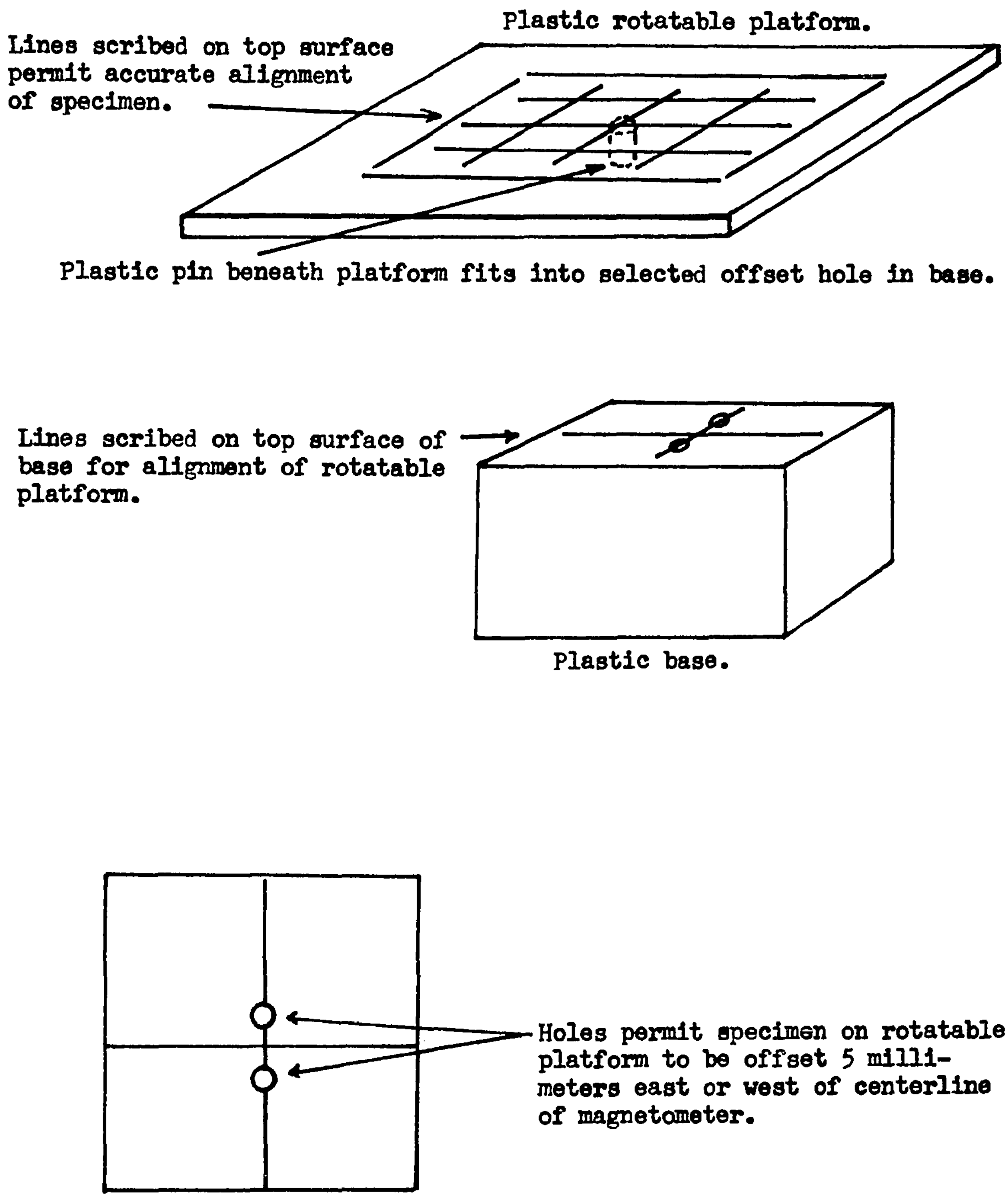


Figure 10. Rotatable plastic platform for measurement of dry sediments on the astatic magnetometer.

demonstrated to be stable, or "hard" (Runcorn, 1969, and Strangway, 1970).

A rock, or sediment, may acquire a secondary, or "soft," component of magnetization at some time after acquisition of its stable NRM. The secondary component may be acquired slowly as viscous remanent magnetization (VRM), when the rock or sediment has been exposed for a long period of time to an ambient field different from its internal "hard" component. Or, the "soft" component may be acquired quickly by lightning strikes as anhysteritic remanent magnetization (ARM). Runcorn (1969) referred to lightning-induced magnetization in rocks as isothermal remanent magnetization (IRM).

If the secondary magnetization has a direction different from the primary magnetization, it will produce "scatter," or unreliable results. Fortunately, it is possible to remove the "soft" components by either thermal or alternating field demagnetization without destroying all of the stable primary component. This is because the stable magnetization is a result of high coercivity of the magnetic material within the specimens, whereas the secondary, or "soft," magnetization exists as a less stable fraction (Neel, 1955).

Partial demagnetization is fundamental to obtaining useful paleomagnetic results. Garland (1971) claimed that the recognition of paleomagnetism as a scientific technique dates from the recognition of the importance of "magnetic cleaning" of secondary components.

Alternating field demagnetization was the more appropriate of the two methods for "cleaning" the playa sediments, because the temperatures required for thermal demagnetization would have melted both plastic vials and paraffin plugs. Destruction of the vials and drying of the sediments would have caused crumbling and loss of magnetic orientation. Heating of the sediments might also have caused a chemical change, affecting the magnetization. This partial demagnetization was accomplished by subjecting each speciment to an alternating magnetic field of predetermined strength which was gradually decreased to zero while the orientation of the specimen was continuously being changed. Rotation of each specimen about three perpendicular axes while it was being demagnetized was necessary to insure that demagnetization was equal in all directions within the specimen (Collinson and Creer, 1960).

The Willcox Playa (Site B) specimens were progressively demagnetized at peak fields of 0, 50, and 100 Oersted, then measured on the astatic magnetometer following each demagnetization. When demagnetized at 100 Oersted, some of these specimens became too weak to provide reliable data. At higher demagnetizing fields, it was often impossible to know whether one was reading a magnetic moment from the sediments, or "noise" in the magnetometer's system.

Red Lake Playa (Site C) specimens were progressively demagnetized at peak fields of 0, 50, 100, 200, 400, and 800 Oersted and measured after each step. Site D specimens from Red Lake Playa were demagnetized at 0, 50, and 100 Oersted. Smith Creek Valley Playa (Site E) sediments were demagnetized at 0, 100, and 200 Oersted. All specimens were measured on the astatic magnetometer after each step in the demagnetization process. (See Appendix.)

Reliability Tests

Paleomagnetic investigations can be considered reliable only if it can be demonstrated that the specimens used, whether rock or sediment, have a high degree of magnetic stability. In other words, are the magnetic directions measured in a specimen the original "hard" magnetic components acquired at the time of cooling (or deposition) in the ancient field being studied, or is the investigator receiving false information because of magnetic instability in the specimens with which he is working?

As the science of paleomagnetism progressed, researchers learned that a good test for magnetic stability was the increasing demagnetization of the specimens at progressively higher fields (or temperatures) to determine their ability to retain magnetic intensity and a consistent direction of magnetization. When specimens pick up a secondary "soft" component, the resultant magnetic directions are usually dispersed, or "scattered." For those specimens which are magnetically stable, demagnetization in steps will recover the original magnetization at relatively low fields or temperatures. The resultant directions are then more nearly constant throughout increasingly higher demagnetization.

Tests for reliability of direction and intensity were made on the playa sediments with the following results.

Willcox Playa Specimens

Stability of magnetic intensity. Specimen B1R was increasingly demagnetized in an alternating field with peak values of 50, 100, 200, and 400 Oersted. At high peak demagnetizing fields the specimen became too weak to give reliable data. The percent of the original magnetic intensity remaining at each step during the demagnetization of this specimen is shown in Table 1, and plotted in Figure 11.

TABLE 1

Peak Field (Oersted)	Total Moment/cm^3 ($x\ 10^{-5}$ emu)	Percent of Original Intensity Remaining
0	5.82	----
50	5.77	99.1
100	5.47	94.0
200	4.90	84.2
400	3.53	60.7

Stability of magnetic direction. The change in direction of magnetization at each step during demagnetization of Specimen B1R is shown in Table 2, and plotted in Figure 12.

TABLE 2

Peak Field (Oersted)	Declination (Degrees)	Inclination (Degrees)
0	21.5	71.4
50	13.1	70.4
100	8.1	71.6
200	11.8	72.3
400	3.0	70.2

The semi-angle of a cone about the mean direction which would contain 95 percent of the direction vectors (theta-95) is 5.5° when k = 640 (Fisher, 1953). This small angle implies stability in direction of magnetization. (See Appendix for an explanation of theta-95 and k.)

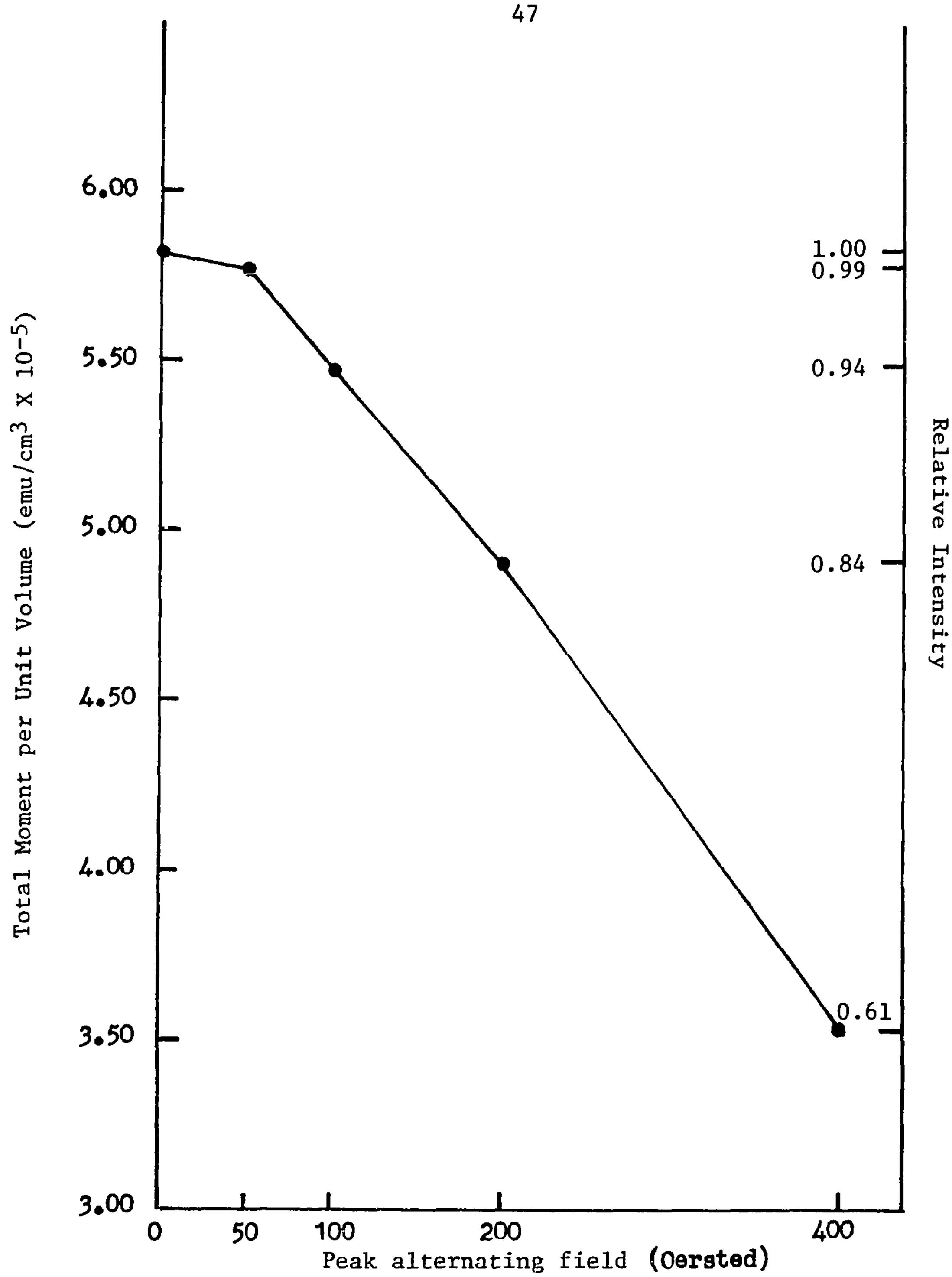


Figure 11. Progressive demagnetization of Willcox Playa Specimen B1R.

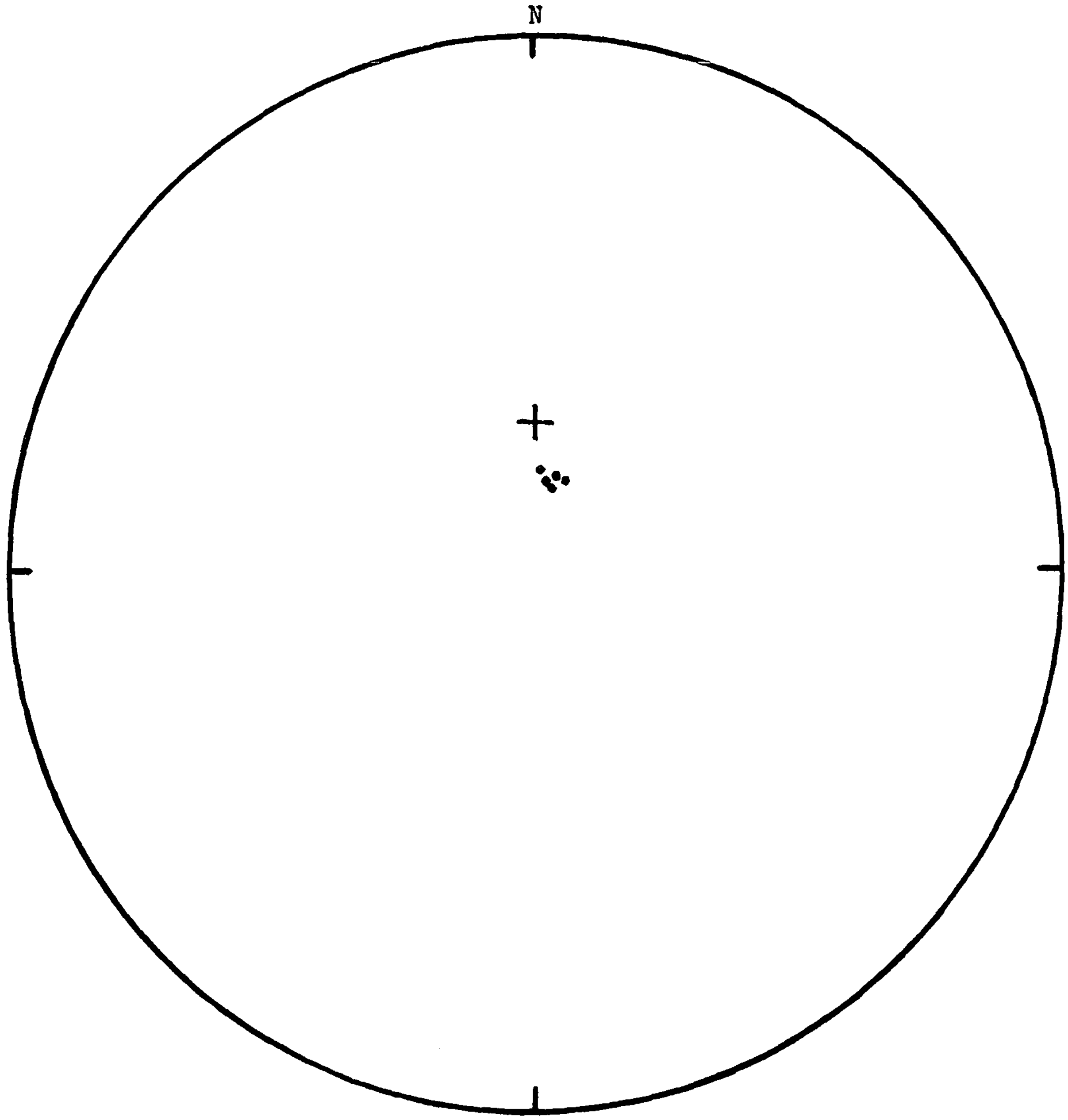


Figure 12. Stability of magnetic direction during progressive demagnetization of Willcox Playa Specimen B1R. Theta-95 = 5.5°; k = 640. Plotted from data in Table 2. (+ marks position of 1965.0 epoch field direction)

Red Lake Playa Specimens

Stability of magnetic intensity. Specimen C1L was increasingly demagnetized in an alternating field with peak field values of 50, 100, 200, 400, 800, 1600, and 3200 Oersted. The percent of the original magnetic intensity remaining at each step during the demagnetization of this specimen is shown in Table 3, and plotted in Figure 13.

TABLE 3

Peak Field (Oersted)	Total Moment/cm^3 ($\times 10^{-5}$ emu)	Percent of Original Intensity Remaining
0	41.9	----
50	41.7	99.5
100	40.1	95.7
200	38.9	92.8
400	27.8	66.3
800	14.6	34.8
1600	5.3	12.6
3200	3.2	7.6

Stability of magnetic direction. The change in direction of magnetization at each step during demagnetization of Specimen C1L is shown in Table 4, and plotted in Figure 14.

TABLE 4

Peak Field (Oersted)	Declination (Degrees)	Inclination (Degrees)
0	11.0	61.1
50	9.9	61.0
100	8.9	59.1
200	9.2	60.5
400	8.8	60.4
800	17.7	64.0
1600	67.0	62.5
3200	162.0	59.5

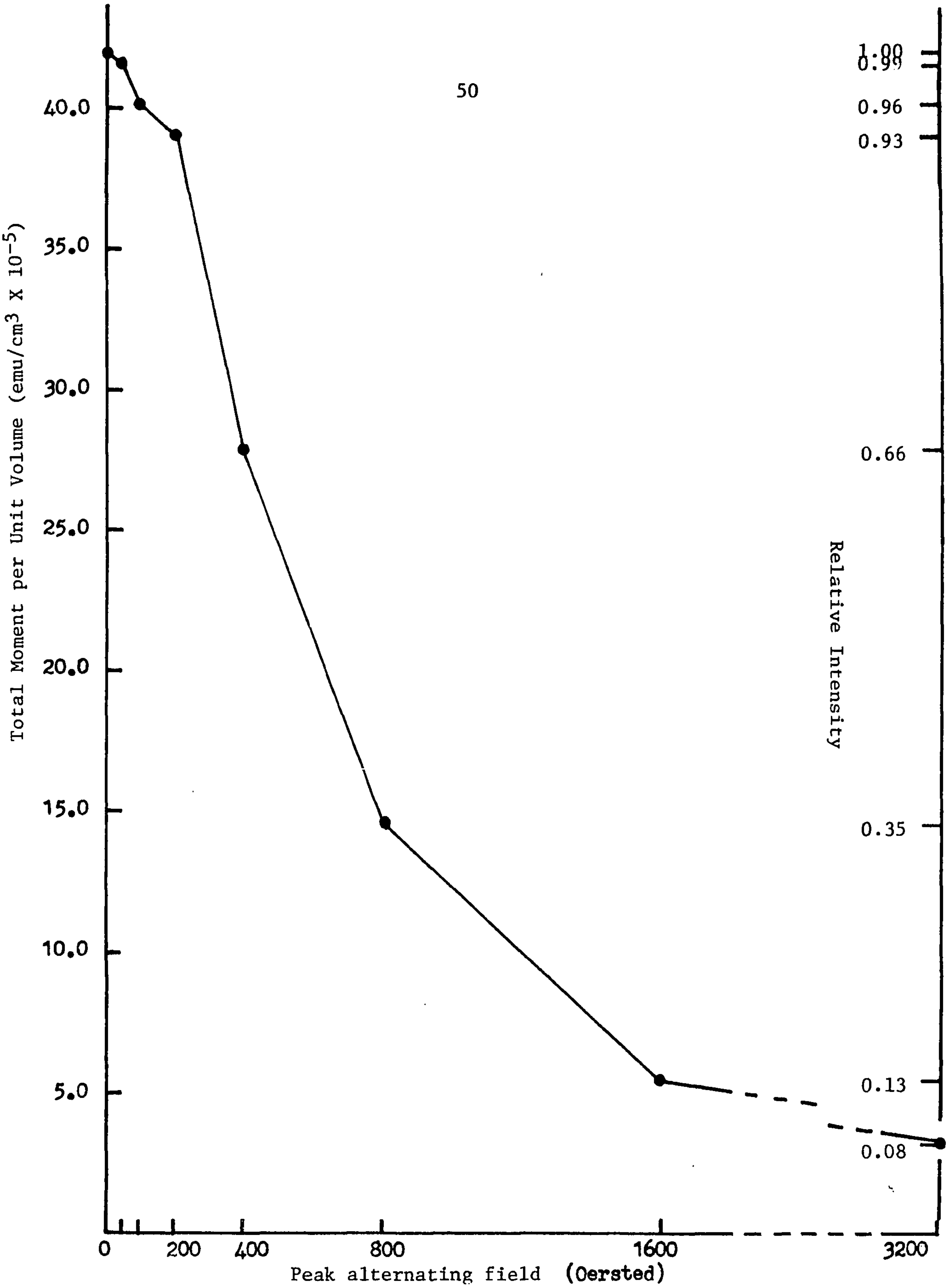


Figure 13. Progressive demagnetization of Red Lake Playa Specimen C1L.

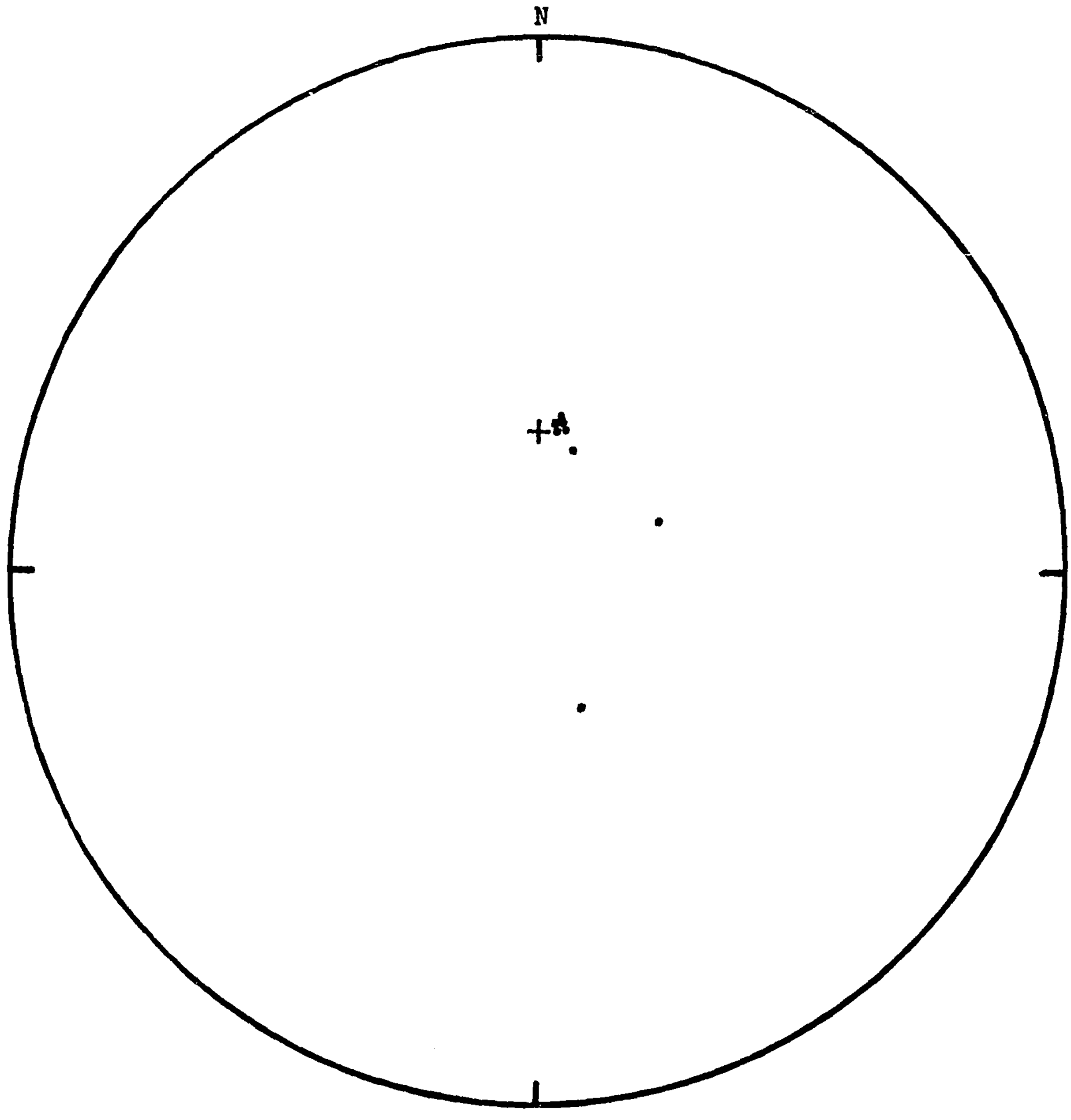


Figure 14. Stability of magnetic direction during progressive demagnetization of Red Lake Playa Specimen C1L. Theta-95 (0-400 Oe) = 1.4°; k = 9638. Theta-95 (0-800 Oe) = 3.9°; k = 1280. Plotted from data in Table 4. (+ marks position of 1965.0 epoch field direction)

Theta-95 (0-400 Oe) = 1.4°; k = 9638

Theta-95 (0-800 Oe) = 3.9°; k = 1280

Theta-95 (0-1600 Oe) = 17.1°; k = 67

Theta-95 (0-3200 Oe) = 36.3; k = 15

The magnetic stability from 0 to 400 Oe peak fields is considered excellent; to 800 Oe the magnetic stability in direction is good; above 800 Oe (1600 to 3200 Oe) the variance becomes excessive. This is an indication that the magnetic directions from the sediments were probably most reliable between 100 and 400 Oe peak demagnetizing fields. At a peak field of 1600 Oe only 12.6 percent of the original magnetic intensity of the specimen remained. At 3200 only 7.6 percent remained. These low intensities were in a range where it was possible that "noise" in the magnetometer's system was being read rather than the magnetic moment of the sediments. It is unlikely that a 3200 Oe peak field was required to remove a "soft" component of VRM. Neither is it likely that an actual field reversal had occurred so recently. The demagnetizing coil was in a null field which excluded the possibility of an ARM being imposed at 3200 Oe.

Stability of magnetic intensity. A second specimen from Site C at Red Lake Playa was increasingly demagnetized to higher values. Specimen C2L was "cleaned" in an alternating field with peak field values of 50, 100, 200, 400, 800, and 1600 Oe. The percentage of the original magnetic intensity remaining at each step is shown in Table 5, and plotted in Figure 15.

TABLE 5

Peak Field (Oersted)	Total Moment/cm^3 (x 10^{-5} emu)	Percent of Original Intensity Remaining
0	27.7	----
50	26.5	95.7
100	25.8	93.1
200	23.1	83.4
400	13.9	50.2
800	8.6	31.0
1600	2.3	8.3

Stability of magnetic direction. The change in direction of magnetization at each step during demagnetization of Specimen C2L is shown in Table 6, and plotted in Figure 16.

TABLE 6

Peak Field (Oersted)	Declination (Degrees)	Inclination (Degrees)
0	7.0	69.9
50	4.3	69.2
100	1.0	69.2
200	8.1	69.2
400	9.6	69.2
800	24.7	67.9
1600	45.0	69.9

Theta-95 (0-400 Oe) = 2.4°; k = 3390

Theta-95 (0-800 Oe) = 5.4°; k = 681

Theta-95 (0-1600 Oe) = 9.4°; k = 221

This specimen exhibits stability in magnetic direction up to 800 Oe demagnetization, and appears most reliable to 400 Oe.

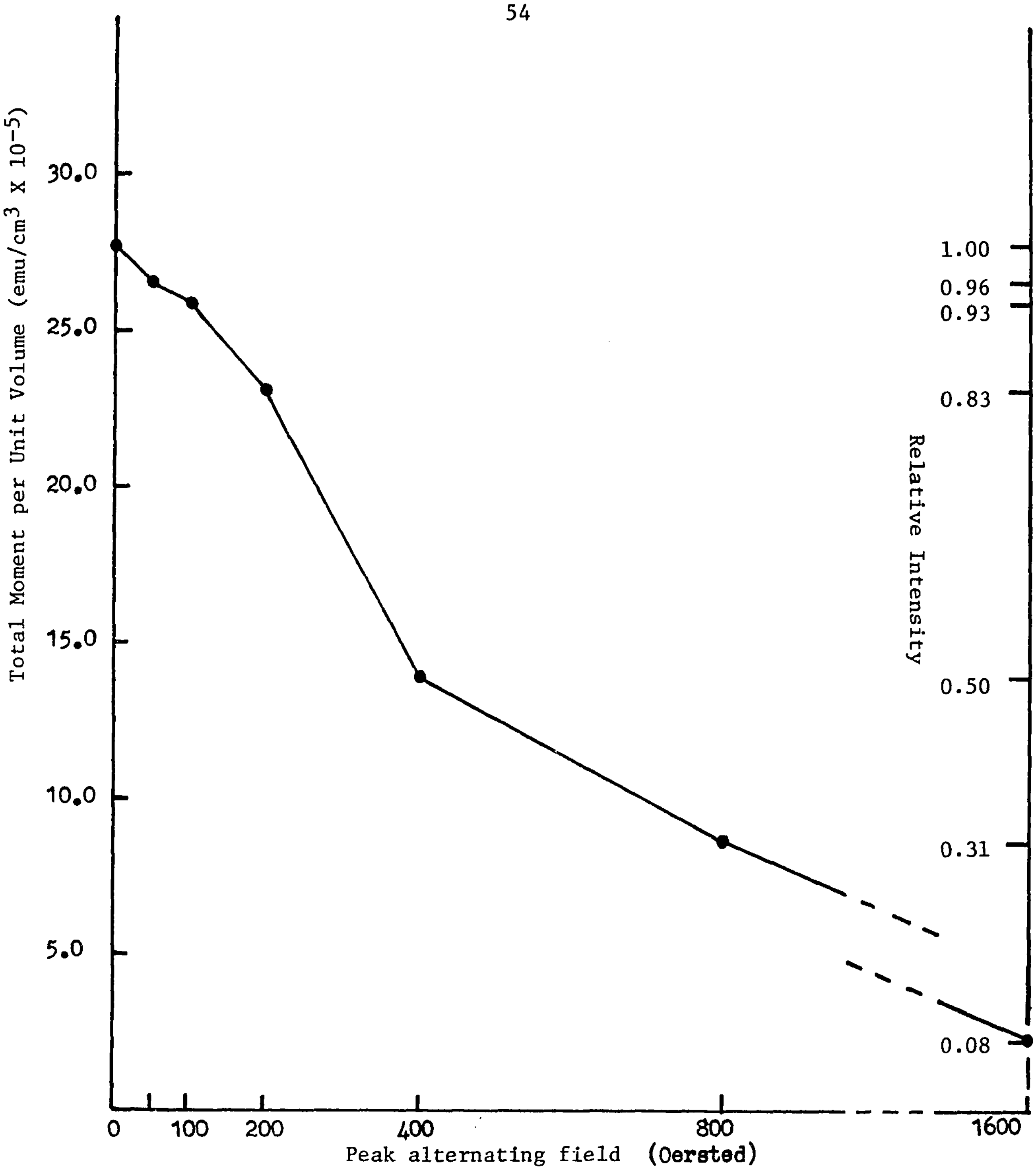


Figure 15. Progressive demagnetization of Red Lake Playa Specimen C2L.

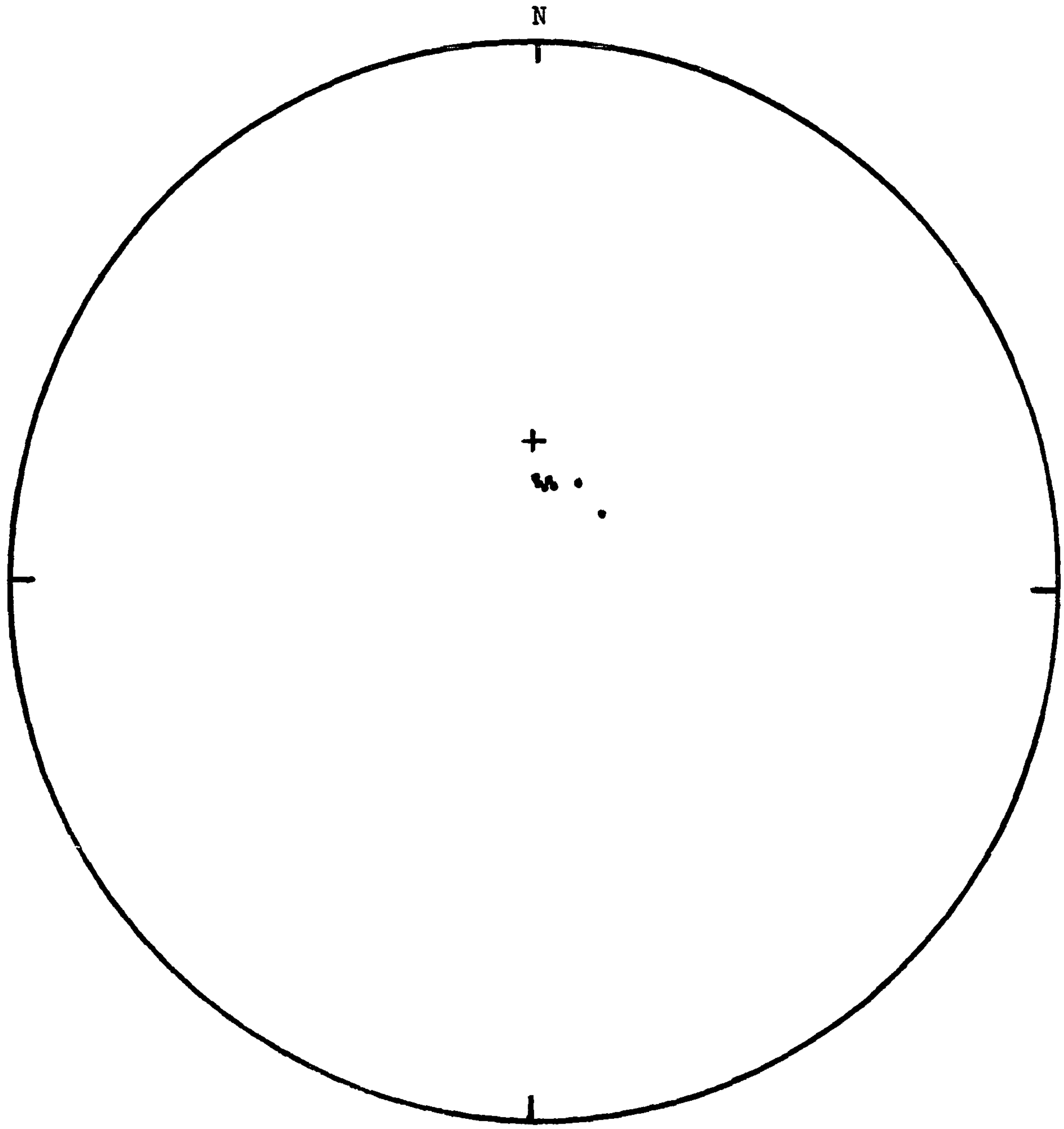


Figure 16. Stability of magnetic direction during progressive demagnetization of Red Lake Playa Specimen C2L. Theta-95 (0-400 Oe) = 2.4°; k = 3390. Theta-95 (0-800 Oe) = 5.4°; k = 681. Theta-95 (0-1600 Oe) = 9.4°; k = 221. Plotted from data in Table 6. (+ marks position of 1965.0 epoch field direction)

Magnetic stability of the other specimens collected from Site C, Red Lake Playa, is summarized in Table 7.

TABLE 7

Specimen Number (Site C)	Percent of Original Intensity Remaining after Demagnetization (Oersted)				Theta-95 of Magnetic Directions with Demagnetization (0-400 Oe)
	50	100	200	400	
C1H	96.3	91.9	83.5	58.6	1.9°; k = 5195
C2H	97.9	96.5	87.4	63.3	2.9°; k = 2260
C3H	97.3	92.5	82.3	59.8	1.5°; k = 8366
C4H	98.2	92.6	82.0	59.2	3.2°; k = 1878
C5H	99.3	92.9	83.3	57.6	1.1°; k = 16913
C6H	96.2	91.6	78.7	55.4	1.6°; k = 8010
C7H	99.0	93.4	84.7	63.3	3.8°; k = 1326
C8H	96.5	91.9	76.7	58.3	2.8°; k = 2514
C1R	99.4	96.5	86.2	61.7	1.6°; k = 7236
C2R	98.7	96.2	86.7	61.7	2.7°; k = 2677
C3R	98.1	93.7	83.6	56.2	3.4°; k = 1729
C4R	101.5	93.0	80.4	56.3	3.7°; k = 1434
C1L	99.5	95.7	92.8	66.3	1.4°; k = 9638
C2L	95.7	93.1	83.4	50.2	2.4°; k = 3390
C3L	96.8	89.4	80.9	52.1	5.6°; k = 625
C4L	93.5	81.5	72.0	52.4	3.1°; k = 2030

All specimens collected at Site C exhibit stability in magnetic direction.

Similar results were obtained from the one row of horizontally collected sediment specimens at Site D, Red Lake Playa. Because of the satisfactory results obtained with the previous sediments, measurements were made following demagnetization at peak field values of 0, 50 and 100 Oersted only. The magnetic stability of the specimens from Site D, Red Lake Playa, is summarized in Table 8.

TABLE 8

Specimen Number (Site D)	Percent of Original Intensity Remaining after Demagnetization (Oersted) 50	100	Theta-95 of Magnetic Directions with Demagnetization (0-100 Oe)
D1H	99.6	98.4	0.3°; k = 190476
D2H	98.8	96.7	1.1°; k = 10817
D3H	100.9	99.9	0.5°; k = 68493
D4H	99.7	98.4	0.2°; k = 392157
D5H	99.2	96.8	0.4°; k = 160000
D6H	100.3	99.6	0.8°; k = 28777
D7H	100.1	98.5	0.8°; k = 32000
D8H	99.0	96.7	0.6°; k = 61920
D9H	100.3	98.7	0.5°; k = 79681
D10H	99.3	97.3	0.4°; k = 104167

The specimens collected at Site D are magnetically stable.

Stability of magnetic intensity. Specimen E2 was increasingly demagnetized in an alternating field with peak field values of 50, 100, 200, 400, 800 and 1600 Oersted. The percentage of the original magnetic intensity remaining at each step during the demagnetization of Specimen E2 is shown in Table 9, and plotted in Figure 17.

TABLE 9

Peak Field (Oersted)	Total Moment/cm^3 (x 10^{-5} emu)	Percent of Original Intensity Remaining
0	15.1	-----
50	15.6	103.3
100	15.6	103.3
200	13.1	86.8
400	9.0	59.6
800	4.4	29.1
1600	1.7	11.3

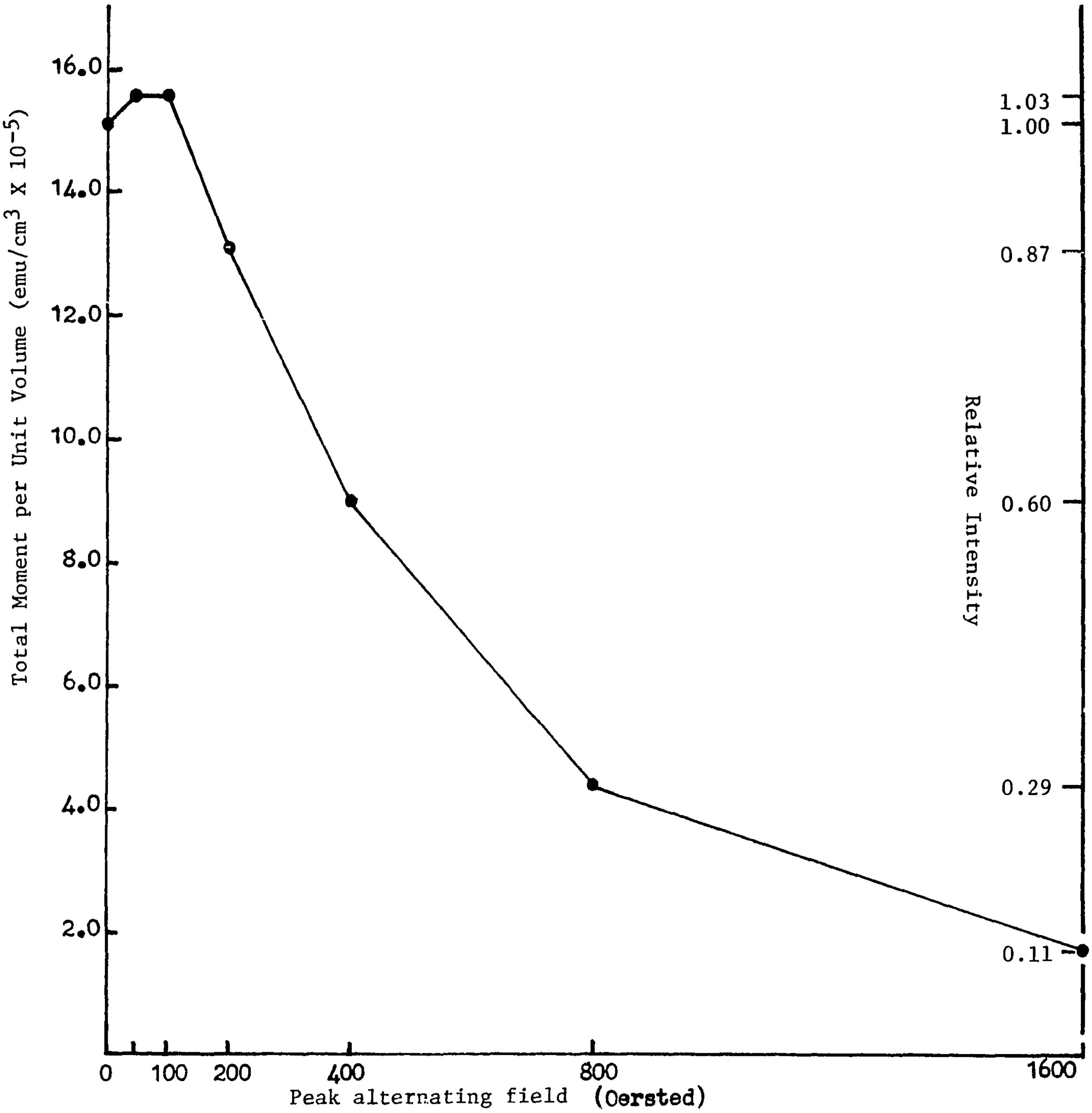


Figure 17. Progressive demagnetization of Smith Creek Valley Specimen E2.

The apparent increase in intensity at 50 and 100 Oersted peak fields may have been a result of removal of a "soft" secondary component which had a direction such that it reduced the vector sum of the moments prior to its removal. Although the cause of such a "soft" component is not known, lightning induced IRM is a possibility. Except for those results, the magnetic intensity behaved similarly to previous results from other specimens, such as Tables 3 and 5.

Stability of magnetic direction. The change in direction of magnetization at each step during demagnetization of Specimen E2 is shown in Table 10, and plotted in Figure 18.

TABLE 10

Peak Field (Oersted)	Declination (Degrees)	Inclination (Degrees)
0	351.8	17.9
50	347.4	13.4
100	348.2	18.3
200	351.2	7.7
400	352.9	5.8
800	351.2	16.6
1600	338.7	6.8

Theta-95 (0-200 Oe) = 6.3°; k = 489

Theta-95 (0-400 Oe) = 7.2°; k = 383

Theta-95 (0-800 Oe) = 6.6°; k = 445

Theta-95 (0-1600 Oe) = 10.0°; k = 194

Declination remained relatively constant. The greater degree of variance in inclination is explained in the notes following Table 11. (The under side of the specimen was not flat.) The semi-angle of the cone

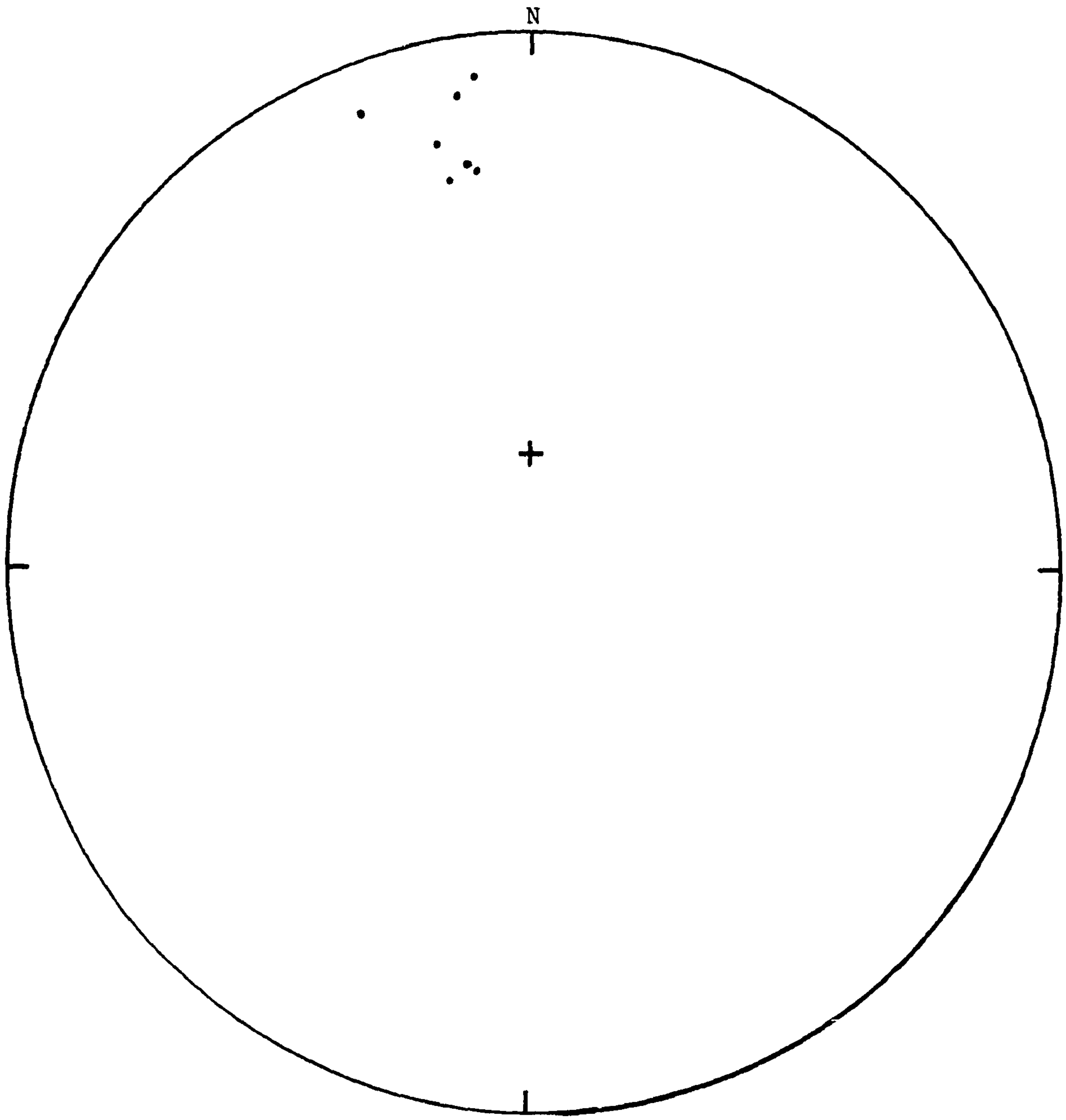


Figure 18. Stability of magnetic direction during progressive demagnetization of Smith Creek Valley Specimen E2. Theta-95 (0-200 Oe) = 6.3°; k = 489. Theta-95 (0-400 Oe) = 7.2°; k = 383. Theta-95 (0-800 Oe) = 6.6°; k = 445. Theta-95 (0-1600 Oe) = 10.0°; k = 194. (+ marks position of 1965.0 epoch field direction) Plotted from data in Table 10.

TABLE 11

Specimen Number (Site E)	Percent of Original Intensity Remaining after Demagnetization (Oersted) 50	100	200	Theta-95 of Magnetic Directions with Demagnetization (0-200 Oe)
E1	(see note below)			
E2	103.3	103.3	86.8	6.3°; k = 489
E3	95.3	98.4	100.0	5.1°; k = 755
E4	98.0	97.0	93.9	6.1°; k = 524
E5		102.0	93.1	7.1°; k = 393
E6		93.4	81.0	2.2°; k = 3948
E7		96.8	92.8	1.8°; k = 5817
E8		97.4	91.2	4.8°; k = 855
E9		97.7	96.5	3.1°; k = 2034
E10		91.7	84.4	3.4°; k = 1653
E11		89.4	88.1	5.2°; k = 718
E12		98.3	86.1	3.3°; k = 1776
E13		101.6	8916	4.9°; k = 815
E14		96.6	96.8	5.2°; k = 722
E15		93.8	89.4	2.0°; k = 4876
E16		97.1	91.5	1.4°; k = 9775
E17		103.6	95.5	2.4°; k = 3452
E18		93.5	92.5	2.4°; k = 3511
E19		94.8	90.3	3.6°; k = 1523
E20		100.7	94.9	4.3°; k = 1036
E21		95.3	90.6	6.0°; k = 536
E22		97.6	87.2	3.7°; k = 1441
E23		103.9	93.6	7.2°; k = 382
E24		97.6	95.8	9.7°; k = 209
E25		93.7	91.9	4.8°; k = 846
E26		98.5	93.7	4.2°; k = 1118
E27		96.7	88.3	3.5°; k = 1572
E28		95.8	89.8	2.3°; k = 3853

E1 - This specimen is a broken fragment of the top 1.0 centimeter of the playa. The specimen has NRM, but cannot be accurately oriented. Therefore, magnetic directions were not determined.

E2 - This specimen was partially broken while trying to find a suitable curring method. The volume is estimated, but it was possible to correctly orient the specimen horizontally. The under surface is not level. Inclination unreliable.

E24 - Where drift of the magnetometer is excessive there appears to be unreliable inclination, which would account for the large Theta-95 angle.

TABLE 11--(Continued)

Specimen Number (Site E)	Percent of Original Intensity Remaining after Demagnetization (Oersted) 50	100	200	Theta-95 of Magnetic Directions with Demagnetization (0-200 Oe)
E29		104.3	102.3	10.2°; k = 188
E30		98.4	95.0	4.1°; k = 1150
E31		98.1	88.2	2.3°; k = 3558
E32		103.6	97.2	3.3°; k = 1831
E33		106.6	94.0	4.0°; k = 1205
E34		100.3	90.6	2.7°; k = 2651
E35		100.3	92.2	1.7°; k = 6433
E36		96.1	89.7	3.6°; k = 1488
E37		94.8	88.4	3.4°; k = 1746
E38		98.8	94.3	1.8°; k = 5727
E39		97.8	89.5	4.2°; k = 1104
E40		95.1	88.7	1.7°; k = 6460
E41		92.0	88.3	3.8°; k = 1360
E42		100.0	91.4	3.7°; k = 899
E43		96.6	89.0	2.0°; k = 4687
E44		96.6	85.5	4.5°; k = 978
E45		100.3	91.2	4.6°; k = 920
E46		100.8	89.5	3.7°; k = 1406
E47		92.9	85.7	1.3°; k =11215
E48		97.7	85.2	5.4°; k = 674
E49		99.0	94.0	13.0°; k = 116
E50	(See note below)			

E29 - Magnetometer drift up to ± 1.0 cm.

E44 - During the 200 Oe A.F. demagnetization step, there was a disturbance of some kind. The magnetometer drifted more than usual: up to 2.0 cm.

E45 - Some disturbance causing more drift than usual.

E48 - Specimen not uniformly thick. About one-half has sediments missing top and bottom. Specimen may not sit flat on platform because of this, which could cause erroneous D & I.

E49 - Pieces of specimen crumbled away from these discs near the bottom of the column. Top and bottom surfaces are not uniform. May affect accuracy of data and D & I. Specimen is not horizontal on the platform.

E50 - This is a thin crust of a specimen from the bottom of the column. It does not sit flat on the platform, consequently D & I are probably not accurate. Thickness varies from one edge to the others, and over the surface.

about the mean direction (theta-95) was somewhat larger at the lower values of peak field (200 and 400 Oersted) when compared to those in Table 4 and Table 6. This was probably due to the variance in the inclination, or a "soft" secondary component which caused scatter until it was removed. The angles were not excessive, however, and the specimen was considered magnetically stable.

The magnetic stability of other specimens cut from the column of dry sediments collected at Site E, Smith Creek Valley Playa, is summarized in Table 11. Only specimens E2 through E4 were measured following demagnetization at peak field values of 0, 50, 100 and 200 Oerstad. The remaining specimens from the column were measured after demagnetizating at peak field values of 0, 100 and 200 Oersted. The 50 Oersted step was omitted, as it produced little change. Between 80 and 90 percent of the original magnetic intensity remained following demagnetization at a peak field value of 200 Oersted, and any late age secondary magnetic component in the sediments should have been removed at that peak field value.

The magnetic stability of these Smith Creek Valley Playa specimens appeared to be good. Anomalous intensities and directions may be attributed to "soft" secondary components with directions such that they reduced the vector sum of the moments prior to "cleaning" by demagnetization, or the anomalies may be related to instrument error caused by disturbances of the magnetometer. The bottom two specimens from the column (E49 and E50) were considered unreliable because of their non-uniform dimensions.

General Comments

A problem, applicable to both the moist sediments in vials and the dry discs, was getting the sediments thin enough to represent a specific point in time. If, for example, the sedimentation rate for a playa was 0.05 centimeters per year, a one centimeter thick slab then represented 20 years deposition. During those 20 years the ambient geomagnetic field was certain to have changed direction due to secular variation. Because of that, the direction of magnetization obtained from the disc was an average of the changes that might have occurred during the time of deposition. When interpreting the data, one must consider the possibility of such an averaging effect. Cutting the discs thinner would have reduced the time of sedimentation involved, but it would also have made the discs more fragile as well as reducing the total magnetic intensity.

In the case of plastic vials, the inside diameter of a vial (of the type used for this project) is two centimeters. At a sedimentation rate of 0.05 centimeters per year, this would represent a difference of 40 years from the bottom side of the vial to the top side. I calculated that 60.9 percent of the volume of the sediments in the vial lay within the one centimeter along the central axis of the vial. This 60.9 percent of the total volume was contributing most to the direction of magnetization, but the 19.5 percent above and the 19.5 percent below may well have caused some error in the calculated direction of magnetization for the levels at which the specimens were collected (Figure 19).

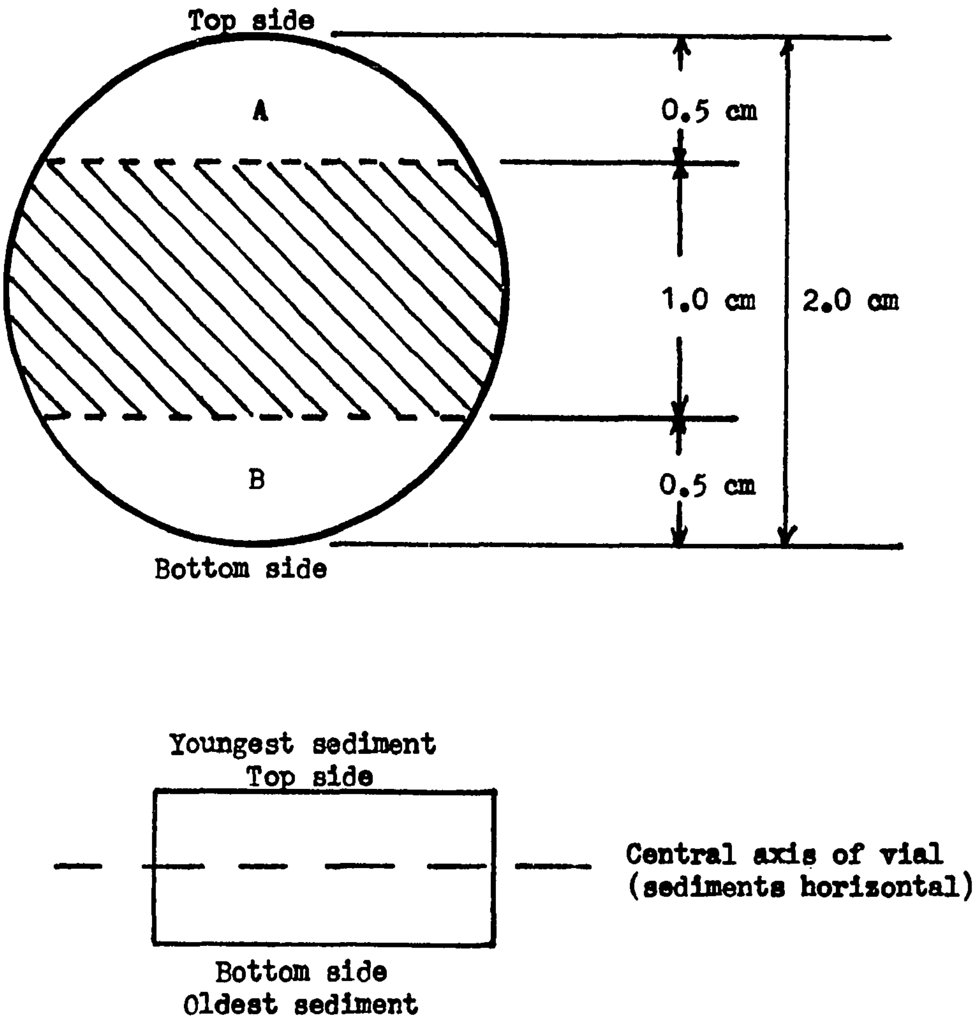


Figure 19. Because the height (length) of the sediments is constant within the vial, the volumes being considered are proportional to the areas shown. Area segment A = area segment B. That area of the vial which lies 0.5 centimeters above and 0.5 centimeters below the central axis is the interior cross-sectional area of the vial minus area segment A minus area segment B. This central 1.0 centimeter thickness of sedimenta within the vial is equal to 60.9% of their total volume. Dimensions not to scale.

ORIGIN OF MAGNETIZATION

The question which usually arises when paleomagnetic data are obtained from recent sediments is this: Is one looking at Detrital Remanent Magnetization (DRM) acquired at the time of deposition by mechanical alignment of magnetic particles settling out of water, or is one seeing Chemical Remanent Magnetization (CRM) which was acquired by the sediments at some time after deposition as a result of chemical transformation of the original minerals, occurring below the Curie temperatures? It is not easy to determine the answer. Because of its stability, any CRM acquired after deposition would be difficult to remove from the sediments by alternating field demagnetization without also removing the DRM.

As mentioned earlier under Previous Studies, Runcorn (1959) wrote that in a hot climate in which there are at times heavy rains (which would describe the playa environment during thunderstorm activity), it is possible that some of the hematite in the surface layers is hydrolized. Later this hydroxide would decompose to become hematite again, and at that time the hematite would pick up a magnetic moment parallel to the ambient field. Runcorn expected this process to be particularly important in porous sediments, although there was no mention that his hypothesis had been tested and found to be the actual case. More recently, Larson and Walker (1975) found that fine-grained, red Baja California sediments, about 2 to 5 million years old, had begun to acquire a CRM that obscured the original DRM. From their studies they concluded that the authigenic minerals goethite, hematite, and "hydropsilomelane" (an informal name the authors gave to a manganese-rich, opaque mineral) were the carriers of CRM in the Baja California sediments. They concluded that these authigenic magnetic oxides were still forming, and as each crystal grew to a critical grain size it would acquire a CRM parallel to the geomagnetic field of that time. The process would continue until all of the unstable iron and manganese-bearing detrital magnetic grains were completely altered, or alteration was stopped by cementation or a change in the chemistry of the interstitial water.

Strangway (1970) commented that magnetic tends to oxidize to hematite, while hematite will reduce to magnetite. Magnetite is more strongly magnetic than hematite. Strangway also suggested that it is necessary to consider the time scale in which any such chemical changes might take place. "If CRM is important in natural processes, it must take place in less than one million years, and it is, therefore, likely that it is not an important process."

Graham (1974) worked with sediments from a modern tidal flat in which he collected from both an "oxidized setting" and a "reduced setting." He found in the tidal flat sediments that the Natural Remanent Magnetization (NRM) was uniform in both chemical environments. Because of the presence of chemically unaffected iron oxides in the sediments and the uniformity of magnetization across a range of chemical environments, Graham concluded that the remanent magnetization of his specimens was detrital in origin and not chemical, and that detrital hematite was relatively unreactive.

I cannot say with certainty that the remanent magnetization found in the playa sediments was not at least part chemical in origin. The playa environment is one of oxidation and not reduction, but the deepest sediments collected and measured were quite likely less than 10,000 years old. With no contrary evidence, I must conclude from the studies of these earlier researchers that CRM was not a significant component of the magnetization which was measured in the playa sediments.

The primary carrier of the magnetization within the playa sediments was assumed to be magnetite. The probable origin of the magnetite was in the basaltic rocks of the highlands surrounding the playas, although the andesitic and rhyolitic volcanics may also have contributed magnetite grains. The locations of these rock types and their distances to the playas is discussed in greater detail under Geology of the Sampling Sites.

The assumption that magnetite was the primary carrier is supported by comparison of the playa sediment demagnetization curves with demagnetization curves of known specimens. Strangway (1970) published alternating field demagnetization curves of some typical rock specimens, which are shown here as Figure 20. When the demagnetization curves from the playa sediments were plotted on Strangway's graph, as in Figure 21, it was apparent that the magnetic component of playa sediments responded to demagnetization most like "basalt with magnetite as the main magnetic mineral, broken up into small grains by exsolution."

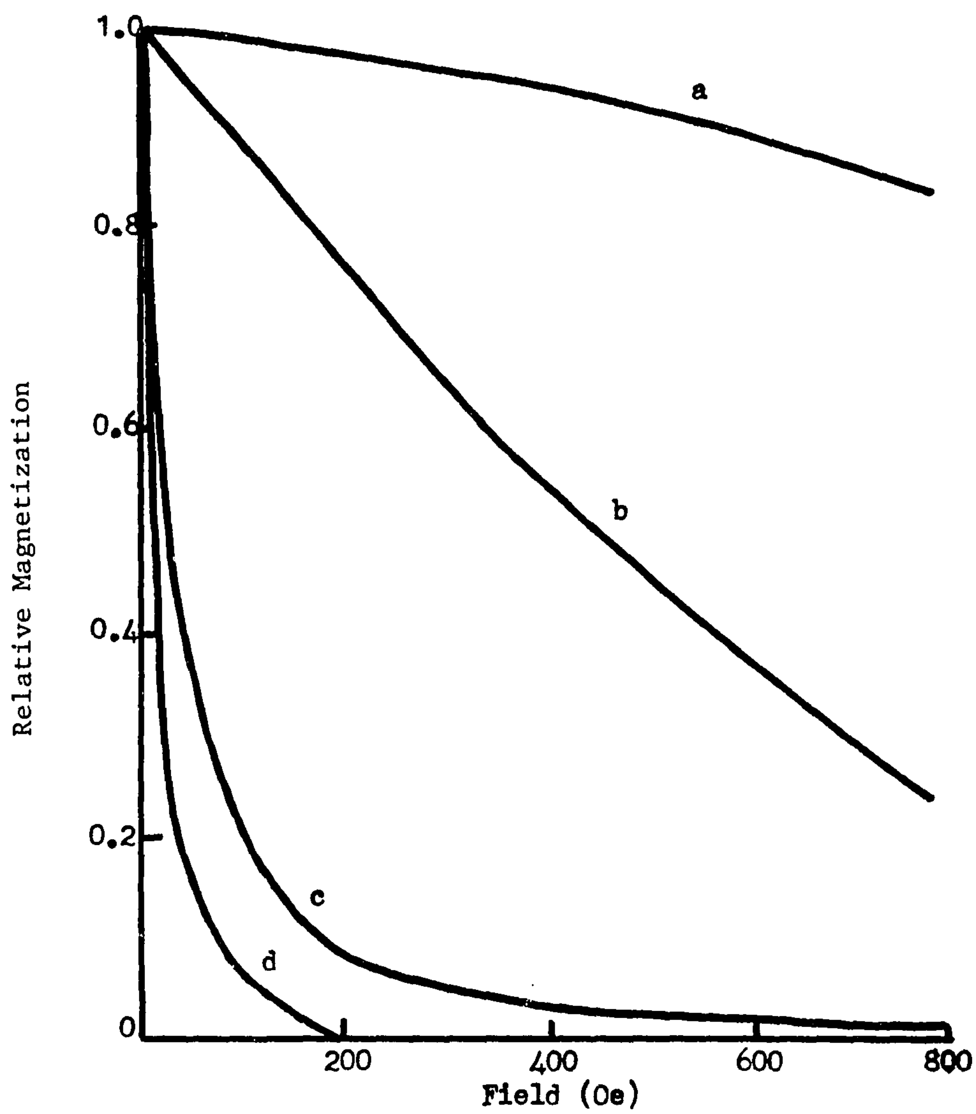


Figure 20. Alternating field demagnetization curves of some typical rock specimens.

a "redbed" sedimentary rock with hematite as the magnetic mineral.

b basalt with magnetite as the main magnetic mineral, broken up into small grains by exsolution.

c basalt with magnetite as the main magnetic mineral without exsolution so that grains are about 20 microns in size.

d granite with very large grains of magnetite.

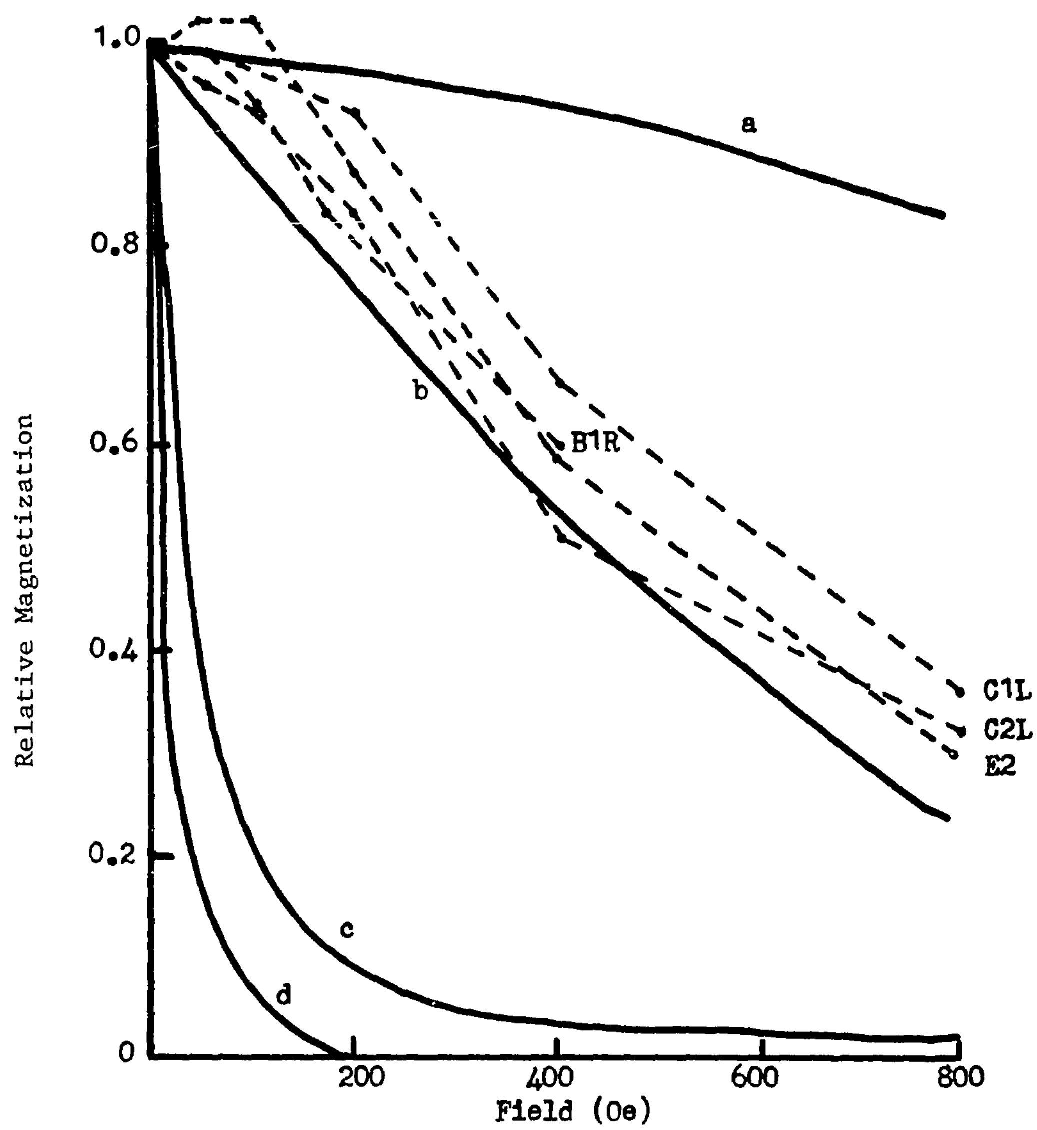


Figure 21. Comparison of playa sediment demagnetization curves with Strangway's (1970) alternating field demagnetization curves of some typical rock specimens.

Typical rock demagnetization curves are from Strangway, D.W., 1970, History of the earth's magnetic field, McGraw-Hill publishers. (Used with permission.)

RESULTS

The information for this section is presented in written, tabular and graphic form to facilitate understanding and comparisons.

Willcox Playa, Arizona

Site A

This was the first location from which specimens were taken. It was a "trial run" intended to work out the sampling techniques to be used and the usefulness of the results obtained. Six oriented specimens were taken at random distribution, but no attempt was made to obtain paleomagnetic data from them for this study.

Site B

The results obtained from sediments collected at this location are shown in Table 12. These data are arranged within the table in order of increasing depth from the playa surface. Table 12 presents both the NRM data, and that for 50 Oersted peak field demagnetization. The data are shown in graphic form in Figures 22, 23 and 24.

Reliability of Data

The NRM data (no demagnetization) are not considered reliable for making interpretations. The specimens had not been magnetically "cleaned" at this stage and probably contained secondary components. The accuracy of the 50 Oersted peak field data is questionable. The

TABLE 12

Specimen Number	Depth (cm.)	Declination[a] (Degrees)	Inclination (Degrees)	Total Moment/cm^3 (X 10^{-5} emu)
		(No Demagnetization)		
B1R	5	22	71	5.8
B1L	10	355	59	5.2
B2R	15	341	52	9.2
B2L	20	336	66	5.1
B3R	25	3	63	6.2
B3L	30	350	64	2.4
B4R	35	327	62	1.7
B4L	40	331	58	1.9
B5R	45	320	56	3.1
B5L	50	334	58	6.5
B6R	55	328	56	2.9
B6L	60	322	56	3.9
B7R	65	No data. Specimen too weak to be reliable		
B7L	70	326	58	1.9
B8R	75	No data. No reliable magnetic component could be read		
B8L	80	353	58	1.4
B9R	85	No data. No readable magnetic component		
B9L	90	No data. Too weak to measure with existing instrument		
B10R	95	No data. Too weak to measure with existing instrument		
B10L	100	No data. Too weak to measure with existing instrument		
		(50 Oersted Peak Demagnetizing Field)		
B1R	5	13	70	5.8
B1L	10	344	62	4.7
B2R	15	344	54	9.2
B2L	20	330	66	5.1
B3R	25	5	62	6.4
B3L	30	345	59	2.2
B4R	35	346	59	1.6
B4L	40	332	61	1.9
B5R	45	327	54	2.8
B5L	50	335	56	6.0
B6R	55	328	59	2.8
B6L	60	334	64	4.1
B7R	65	No data. Specimen too weak magnetically to be reliable		
B7L	70	342	65	2.0
B8R	75	No data. Specimen too weak		
B8L	80	326	51	2.7
B9R	85	No data. Specimen too weak		
B9L	90	No data. Specimen too weak		
B10R	95	No data. Specimen too weak		

[a]Declination here and in the following tables is from magnetic north at the collecting site.

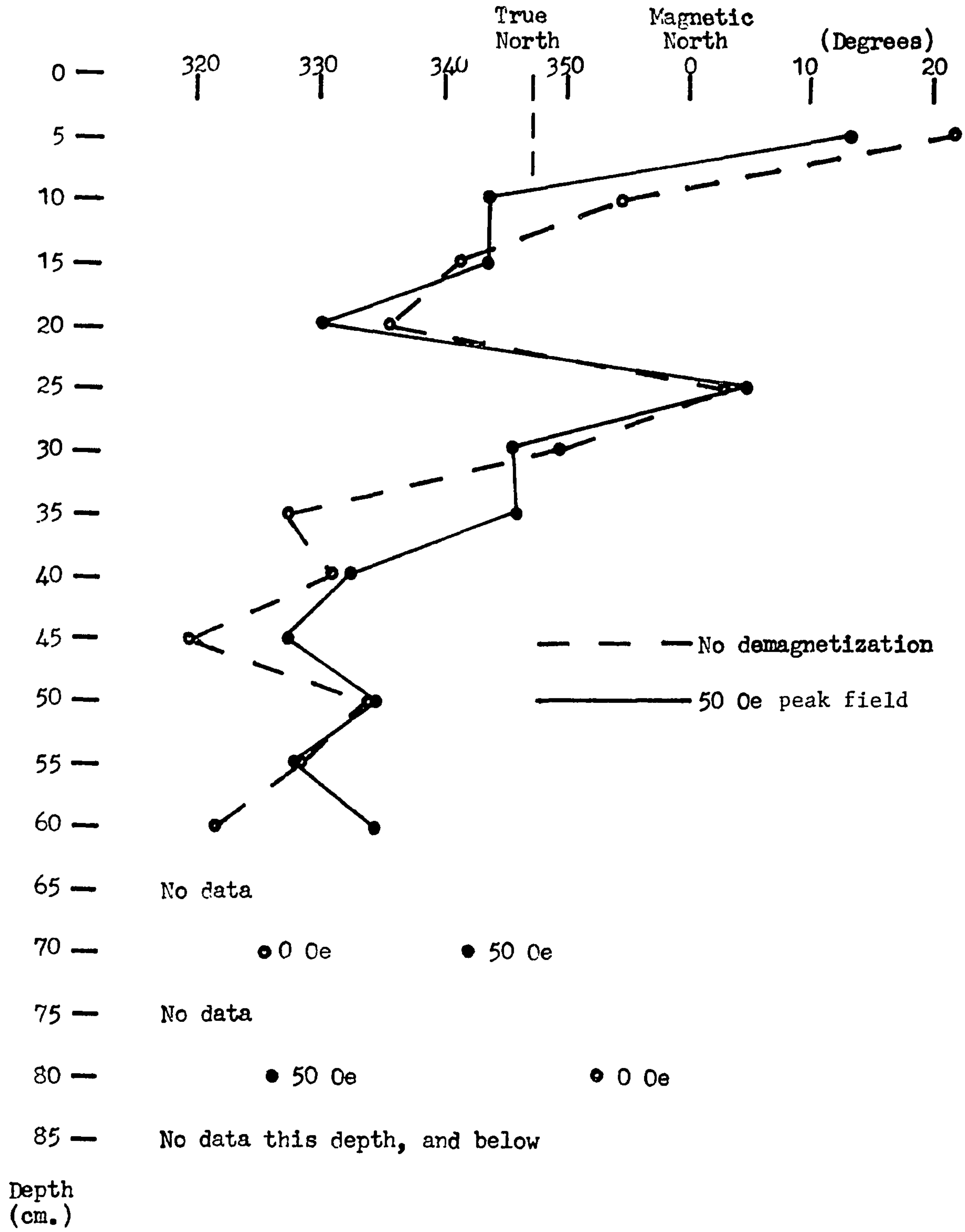


Figure 22. Declination at Site B, Willcox Playa, Arizona. Plotted from data in Table 12.

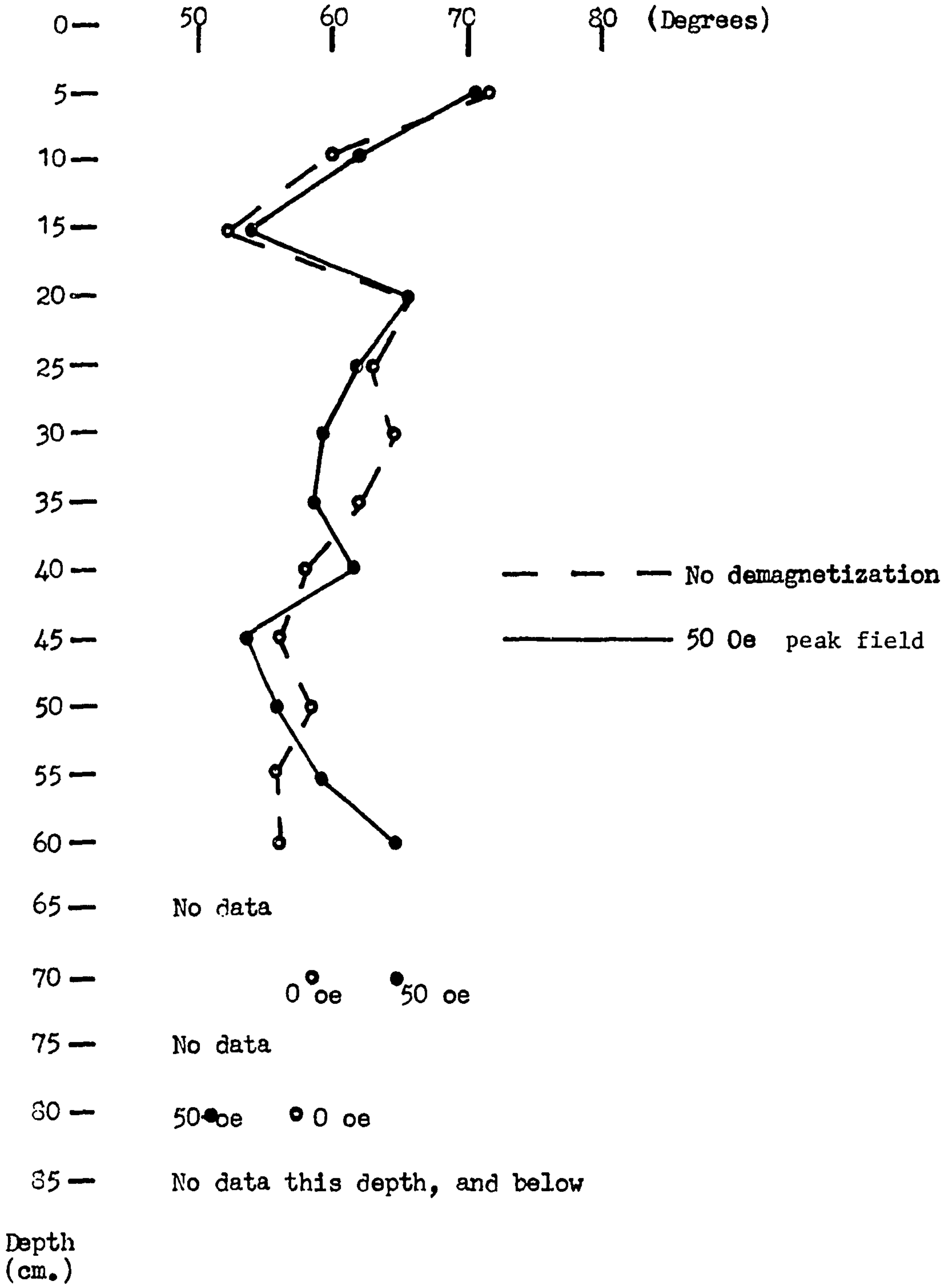


Figure 23. Inclination at Site B, Willcox Playa, Arizona. Plotted from data in Table 12.

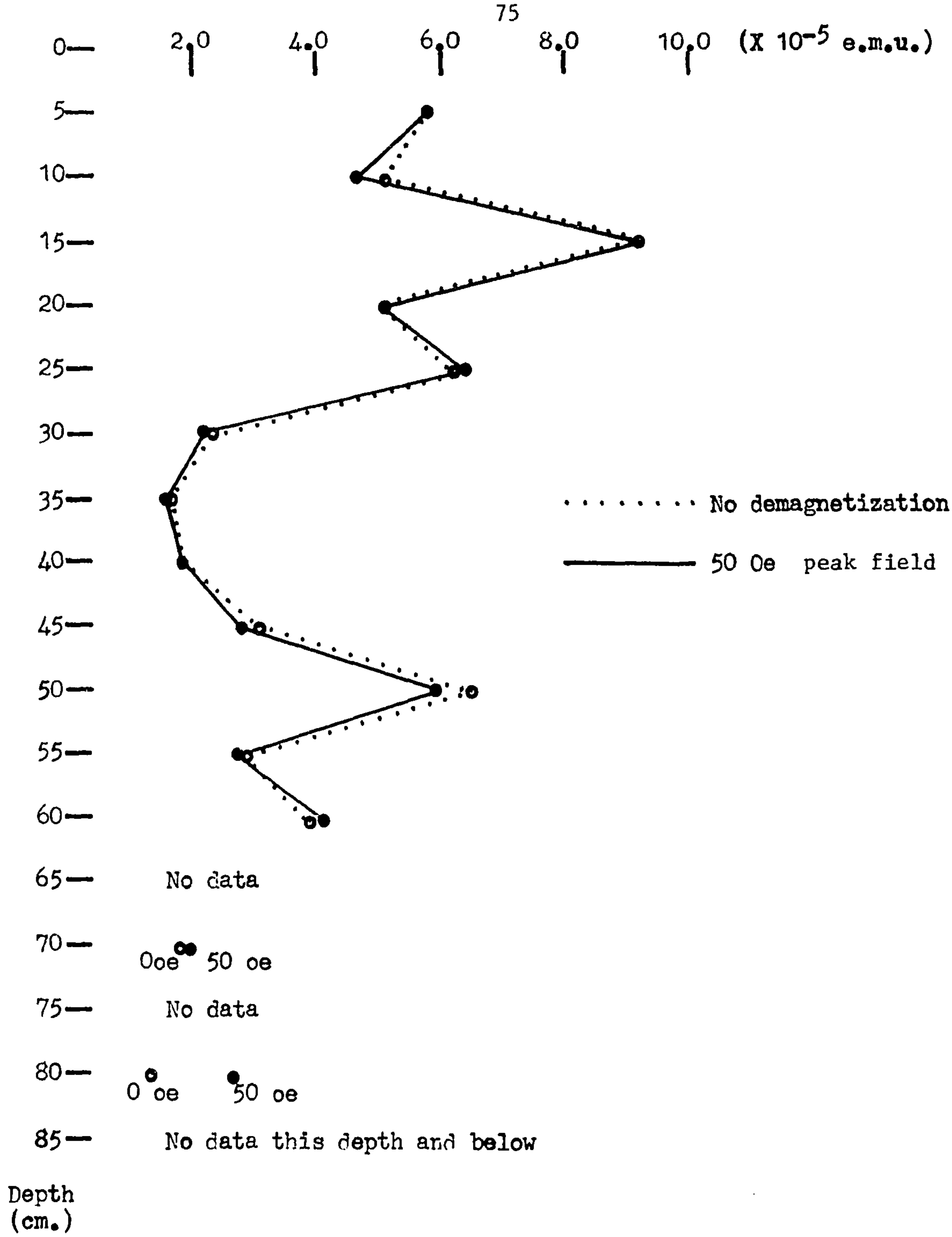


Figure 24. Total moment per unit volume (cm^3) at Site B, Willcox Playa, Arizona. Plotted from data in Table 12.

magnetic moment of the sediments appeared to be at, or below, the "noise" level of the astatic magnetometer. This was particularly true for those sediments below the 60-centimeter depth. Because of these experimental limitations, I decided not to continue demagnetization of the Willcox Playa sediments.

Comparisons of the declination and inclination results from this site will be made with those from the other sites and with those from the southwest United States archaeomagnetic studies under Discussion of Data, and sedimentation rates for Willcox Playa will be calculated and compared with other published rates. But the limits of reliability of the above data must be considered when making any such comparisons.

Red Lake Playa, Arizona

Site C

The results obtained from sediments collected at this location are shown in Tables 13 and 14. The data are arranged within Table 13 in order of increasing depth from the playa surface. These same data are presented graphically in Figures 25 through 29.

TABLE 13

Specimen Number	Depth (cm.)	Declination (Degrees)	Inclination (Degrees)	Total Moment/cm^3 (X 10^{-5} emu)
		(No Demagnetization)		
C1R	5	1	44	71.0
C1L	10	11	61	41.9
C2R	15	339	67	47.5
C2L	20	7	70	27.7
C3R	25	28	68	42.7
C3L	30	341	62	18.8
C4R	35	351	60	19.9
C4L	40	334	67	16.8
		(50 Oersted Peak Demagnetizing Field)		
C1R	5	1	43	70.6
C1L	10	10	61	41.7
C2R	15	341	68	46.9
C2L	20	4	69	26.5
C3R	25	26	67	41.9
C3L	30	347	64	18.2
C4R	35	348	58	20.2
C4L	40	328	66	15.7
		(100 Oersted Peak Demagnetizing Field)		
C1R	5	1	42	68.4
C1L	10	9	59	40.1
C2R	15	341	68	45.7
C2L	20	1	69	25.8
C3R	25	26	68	40.0
C3L	30	349	64	16.8
C4R	35	344	58	18.5
C4L	40	328	66	13.7

TABLE 13--(Continued)

Specimen Number	Depth (cm.)	Declination (Degrees)	Inclination (Degrees)	Total Moment/cm^3 (X 10^{-5} emu)
		(200 Oersted Peak Demagnetizing Field)		
C1R	5	2	42	61.2
C1L	10	9	60	38.9
C2R	15	342	69	41.2
C2L	20	8	69	23.1
C3R	25	22	67	35.7
C3L	30	352	65	15.2
C4R	35	345	58	16.0
C4L	40	326	67	12.1
		(400 Oersted Peak Demagnetizing Field)		
C1R	5	2	44	43.8
C1L	10	9	60	27.8
C2R	15	346	70	29.3
C2L	20	10	69	13.9
C3R	25	19	65	24.0
C3L	30	357	67	9.8
C4R	35	342	58	11.2
C4L	40	324	65	8.8
		(800 Oersted Peak Demagnetizing Field)		
C1R	5	1	49	20.3
C1L	10	18	64	14.6
C2R	15	345	72	14.9
C2L	20	25	68	8.6
C3R	25	16	63	12.0
C3L	30	349	73	6.2
C4R	35	334	57	6.1
C4L	40	318	68	4.7

The following specimens were collected as a series in a horizontal row 20 centimeters below the playa surface. They are from the same level as Specimen C2L.

TABLE 14

Specimen Number	Depth (cm.)	Declination (Degrees)	Inclination (Degrees)	Total Moment/cm^3 (X 10^{-5} emu)
		(No Demagnetization)		
C1H	20	353	65	40.6
C2H	20	345	65	42.7
C3H	20	355	64	44.0
C4H	20	356	71	28.4
C5H	20	352	67	40.6
C6H	20	38	63	28.7
C7H	20	337	65	39.2
C8H	20	31	68	28.3
C2L	20	7	70	27.7
For the above specimens taken from the same level, alpha-95 = 5.0°; k = 87.				
		(50 Oersted Peak Demagnetizing Field)		
C1H	20	358	64	39.1
C2H	20	347	66	41.8
C3H	20	356	64	42.8
C4H	20	353	70	27.9
C5H	20	354	68	40.3
C6H	20	37	64	27.6
C7H	20	340	66	38.8
C8H	20	27	68	27.3
C2L	20	4	69	26.5

For the above nine specimens, alpha-95 = 4.5°; k = 109.

TABLE 14--(Continued)

Specimen Number	Depth (cm.)	Declination (Degrees)	Inclination (Degrees)	Total Moment/cm^3 (X 10^{-5} emu)
		(100 Oersted Peak Demagnetizing Field)		
C1H	20	354	65	37.3
C2H	20	350	66	41.2
C3H	20	358	63	40.7
C4H	20	348	72	26.4
C5H	20	355	68	37.7
C6H	20	35	64	26.3
C7H	20	342	66	36.6
C8H	20	23	70	26.0
C2L	20	1	69	25.8
For the above nine specimens, alpha-95 = 4.2°; k = 126.				
		(200 Oersted Peak Demagnetizing Field)		
C1H	20	355	66	33.9
C2H	20	352	67	37.3
C3H	20	358	63	36.2
C4H	20	349	70	23.3
C5H	20	355	68	33.8
C6H	20	37	64	22.6
C7H	20	343	67	33.2
C8H	20	22	69	21.7
C2L	20	8	69	23.1
For the above nine specimens, alpha-95 = 3.9°; k = 141.				
		(400 Oersted Peak Demagnetizing Field)		
C1H	20	357	66	23.8
C2H	20	351	68	27.2
C3H	20	354	64	26.3
C4H	20	344	70	16.8
C5H	20	356	68	23.4
C6H	20	37	64	15.9
C7H	20	350	68	24.8
C8H	20	22	70	16.5
C2L	20	10	69	13.9
For the above nine specimens, alpha-95 = 3.9°; k = 143.				

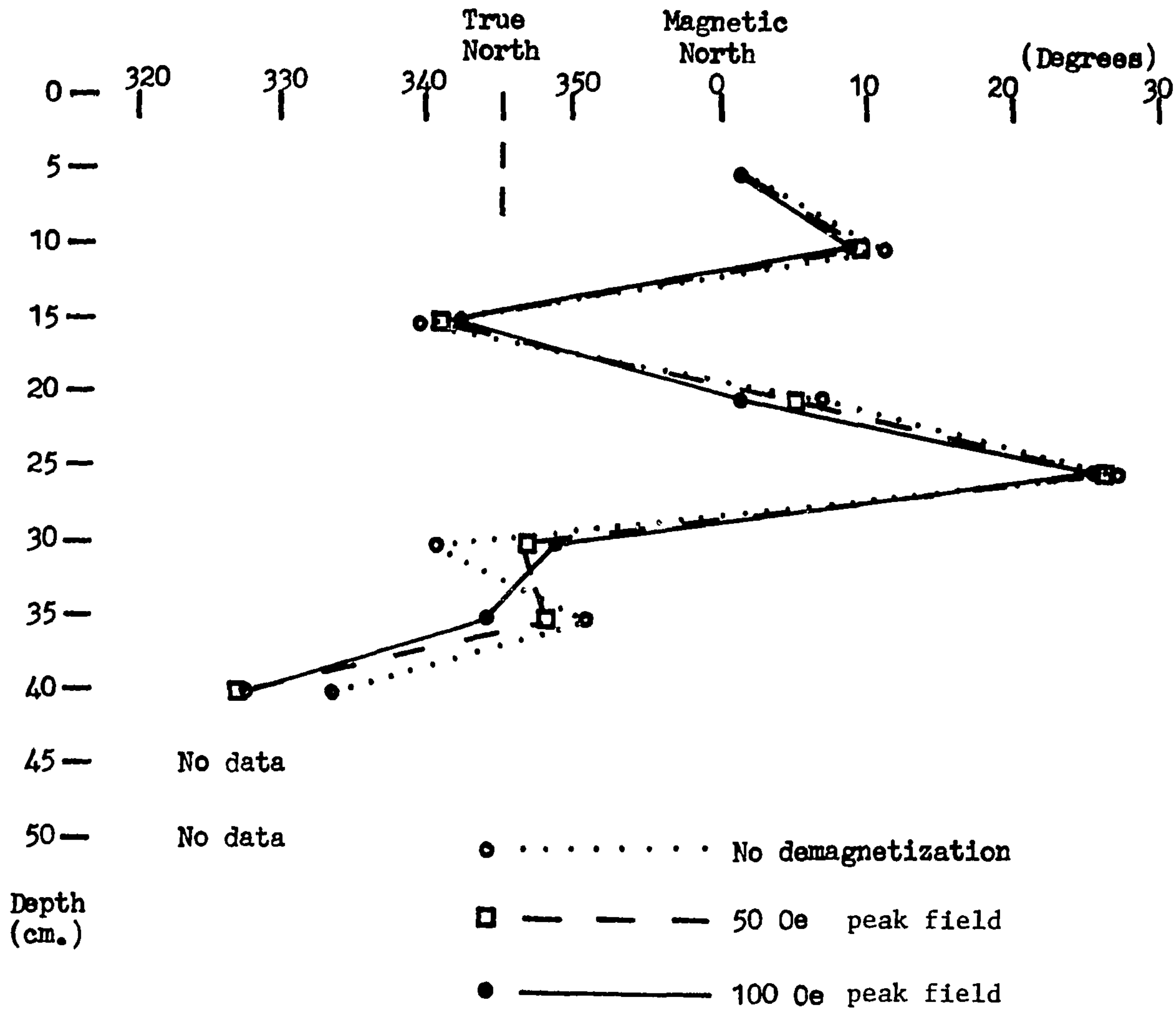


Figure 25. Declination at Site C, Red Lake Playa, Arizona. Plotted from data in Table 13.

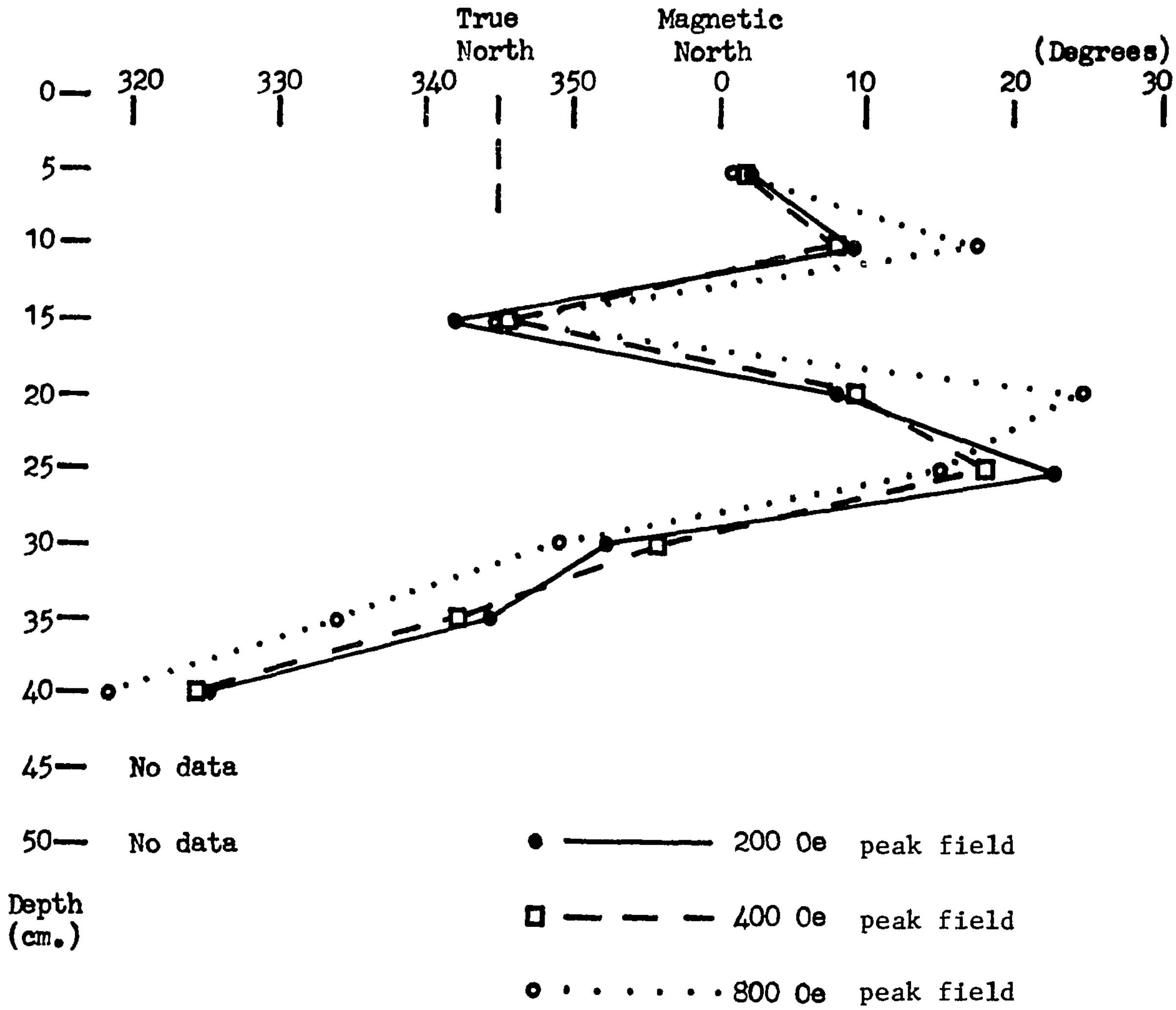


Figure 26. Declination (continued) at Site C, Red Lake Playa, Arizona. Plotted from data in Table 13.

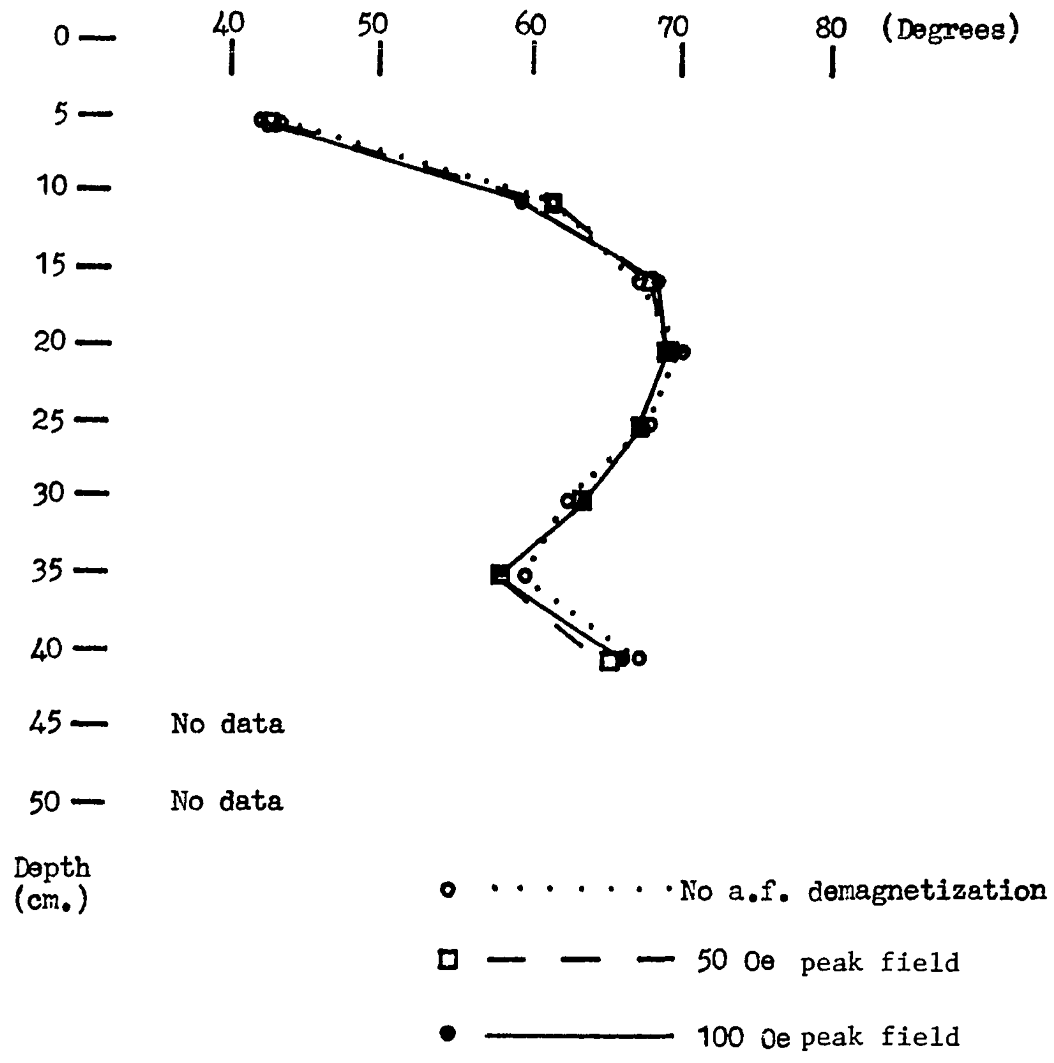


Figure 27. Inclination at Site C, Red Lake Playa, Arizona. Plotted from data in Table 13.

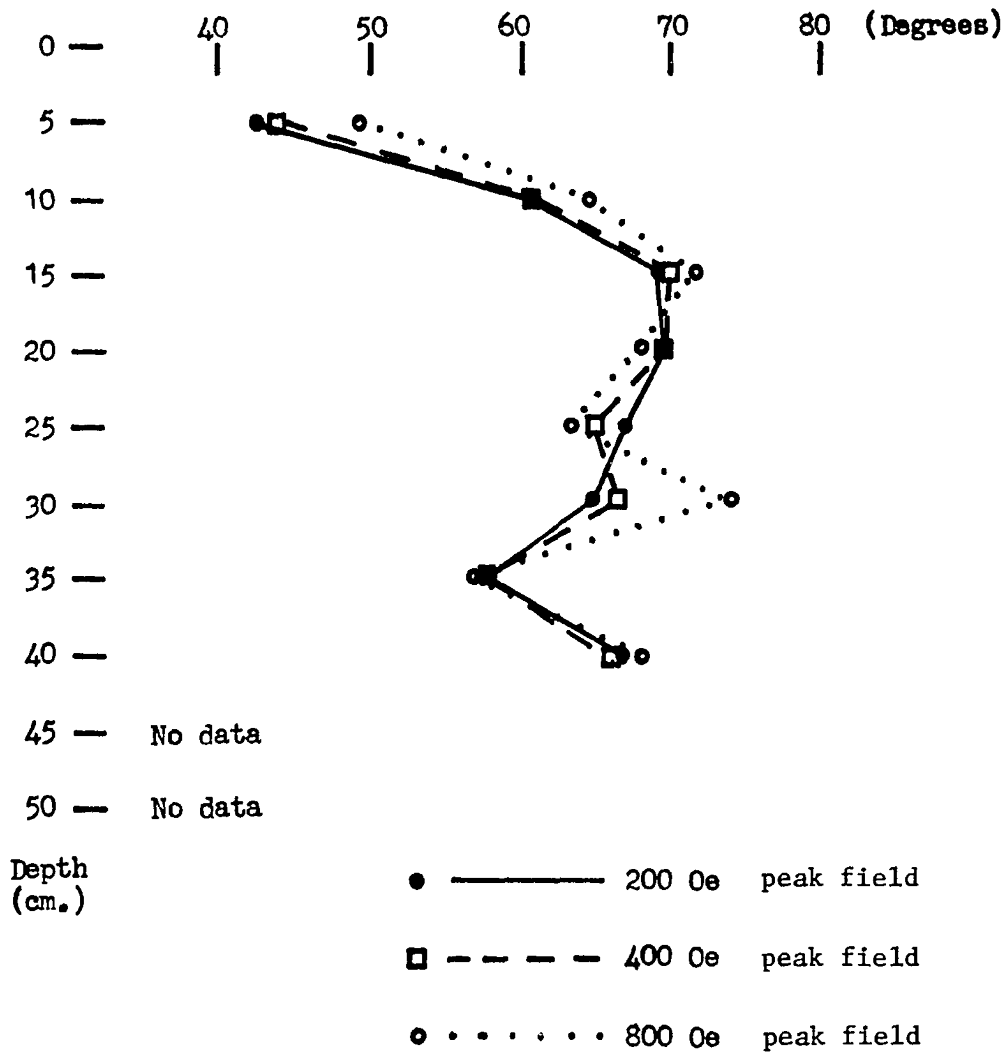


Figure 28. Inclination (continued) at Site C, Red Lake Playa, Arizona. Plotted from data in Table 13.

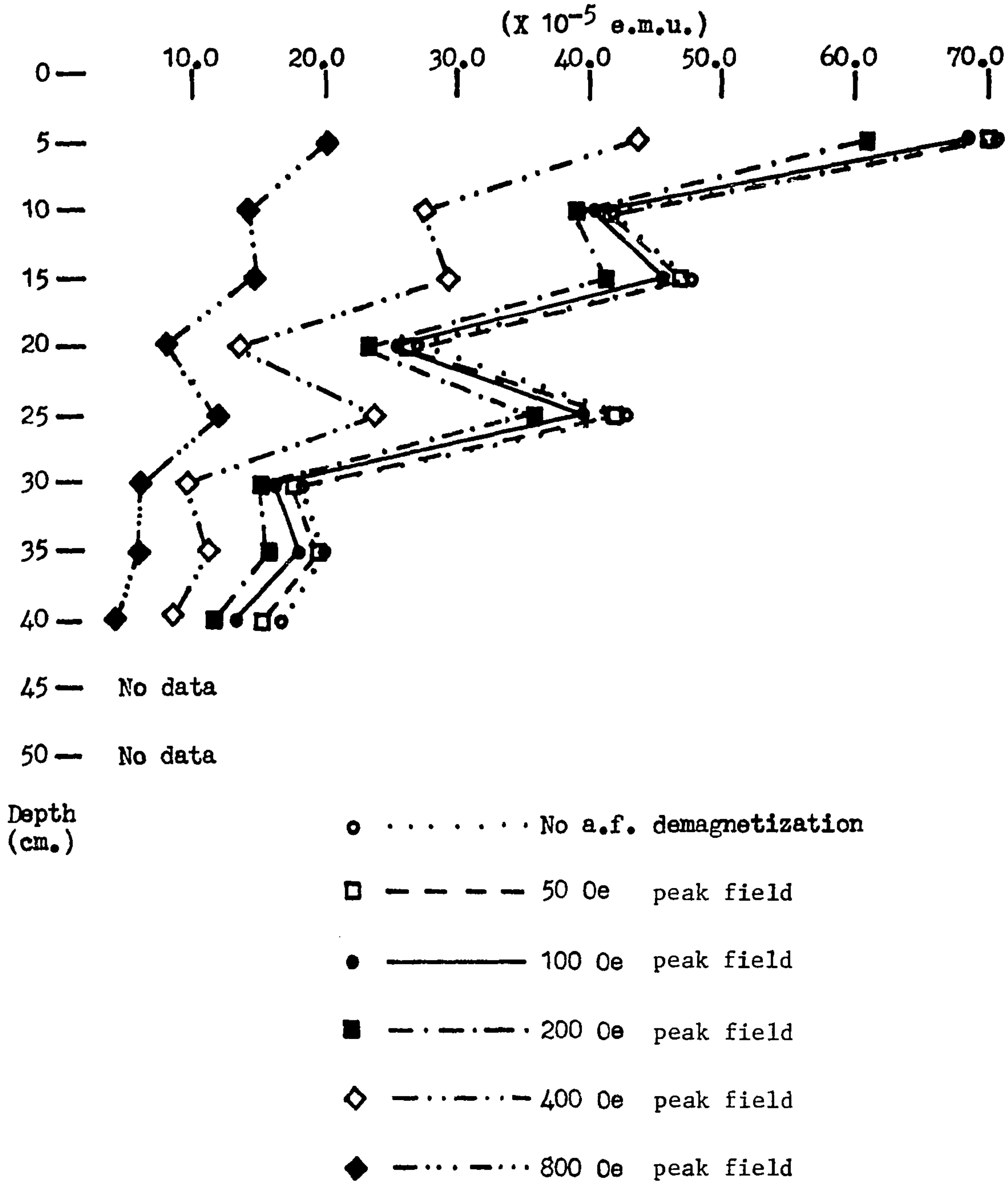


Figure 29. Total moment per unit volume (cm^3) at Site C, Red Lake Playa, Arizona. Plotted from data in Table 13.

Reliability of Data

The alpha-95's calculated for the horizontal row of sediments suggest that the direction of magnetization was consistent and reliable at that level below the surface. This does not imply that the specimens had accurately recorded the true paleomagnetic field of the time. However, is there was some difference between the true direction and the direction recorded in the sediments at the 20-centimeter depth, that difference was uniform.

Site D

The results obtained from sediments collected at this location are shown in Table 15. The specimens were taken from a horizontal row 8.5 centimeters below the playa surface.

Reliability of Data

The alpha-95's calculated for this horizontal row of sediments at three stages of demagnetization suggest that the direction of magnetization was consistent and reliable at that level below the surface. This does not imply that the specimens had accurately recorded the paleomagnetic field which existed at the time. If there were some difference between the true paleomagnetic field direction and the direction recorded in the sediments at the 8.5 centimeter depth, that difference was uniform.

Table 16 compares the directions of magnetization and intensity of Site C specimens from directly above and below the level of the Site D specimens. (Both sets of specimens were from the same playa, but from locations on the playa about one-fourth mile apart.) There was a reasonable agreement in direction, although the magnetic intensity was

TABLE 15

Specimen Number	Depth (cm.)	Declination (Degrees)	Inclination (Degrees)	Total Moment/cm^3 (X 10^{-5} emu)
		(No Demagnetization)		
D1H	8.5	34	66	162.7
D2H	8.5	359	65	162.8
D3H	8.5	360	59	151.5
D4H	8.5	3	50	166.5
D5H	8.5	4	62	185.8
D6H	8.5	359	58	155.9
D7H	8.5	13	57	163.6
D8H	8.5	352	66	184.9
D9H	8.5	344	67	182.9
D10H	8.5	350	59	189.3
For the above ten specimens, alpha-95 = 4.4°; k = 100.				
		(50 Oersted Peak Demagnetizing Field)		
D1H	8.5	33	66	162.1
D2H	8.5	360	64	160.9
D3H	8.5	358	59	152.9
D4H	8.5	3	50	166.0
D5H	8.5	4	61	184.3
D6H	8.5	358	58	156.4
D7H	8.5	12	57	163.8
D8H	8.5	353	66	183.1
D9H	8.5	346	67	183.5
D10H	8.5	349	59	187.9
For the above ten specimens, alpha-95 = 4.3°; k = 105.				
		(100 Oersted Peak Demagnetizing Field)		
D1H	8.5	33	66	160.1
D2H	8.5	2	64	157.4
D3H	8.5	358	59	151.4
D4H	8.5	2	50	163.9
D5H	8.5	5	61	179.9
D6H	8.5	357	58	155.2
D7H	8.5	10	57	161.1
D8H	8.5	354	65	178.8
D9H	8.5	347	67	180.5
D10H	8.5	349	58	184.2
For the above ten specimens, alpha-95 = 4.3°; k = 108.				

much stronger at Site D. Unless this large difference in intensities was due to experimental error, it may be that there was a greater concentration of magnetic minerals at Site D. The comparisons were made with specimens magnetically cleaned at peak fields of 100 Oersted.

TABLE 16

Specimen Number	Depth (cm.)	Declination (Degrees)	Inclination (Degrees)	Total Moment/cm^3 (X 10^{-5} emu)
C1R	5	1	42	68.4
Site D	8.5	2(mean)	61 (mean)	167.3(mean)
C1L	10	9	59	40.1

The above comparisons further suggest that the data are, in general, consistent.

Smith Creek Valley Playa, Nevada

Site E

The results obtained from the column of dry sediments collected at this location are shown in Table 17. These data are arranged in order of increasing depth from the playa surface. The column was cut into one centimeter slabs. The depths listed in Table 17 were to the center of each slab's thickness. The data are in graphic form as Figures 30, 31 and 32.

Reliability of Data

There is obviously a large inclination difference in the dry sediments from the damp sediments of Sites B, C, and D. The 1965.0 value

TABLE 17

Specimen Number	Depth (cm.)	Declination (Degrees)	Inclination (Degrees)	Total Moment/cm^3 ($X 10^{-5}$ emu)
		(No Demagnetization)		
E1	0.5	Broken fragments.	Could not be accurately oriented.	
E2	1.5	356	18	15.1
E3	2.5	358	1	12.7
E4	3.5	357	6	9.9
E5	4.5	353	-2	10.1
E6	5.5	350	1	12.1
E7	6.5	350	1	12.5
E8	7.5	355	-3	11.4
E9	8.5	347	-1	8.6
E10	9.5	350	-2	9.6
E11	10.5	358	4	11.3
E12	11.5	8	3	11.5
E13	12.5	3	0	12.5
E14	13.5	3	2	12.7
E15	14.5	6	1	12.0
E16	15.5	4	5	16.7
E17	16.5	5	5	18.7
E18	17.5	0	2	15.4
E19	18.5	4	-4	18.1
E20	19.5	8	-3	13.6
E21	20.5	12	0	16.5
E22	21.5	14	-6	14.5
E23	22.5	358	-0	10.6
E24	23.5	356	-8	9.1
E25	24.5	348	-1	8.1
E26	25.5	358	-10	9.5
E27	26.5	12	-9	11.4
E28	27.5	15	-10	9.4
E29	28.5	9	6	8.4
E30	29.5	9	-4	9.8
E31	30.5	9	-7	12.7
E32	31.5	13	-10	13.8
E33	32.5	19	-6	11.7
E34	33.5	20	-5	11.2
E35	34.5	15	-10	12.2
E36	35.5	16	-4	13.7
E37	36.5	19	-2	13.0
E38	37.5	17	-1	12.0
E39	38.5	18	-2	11.6
E40	39.5	20	-5	12.8

TABLE 17--(Continued)

Specimen Number	Depth (cm.)	Declination (Degrees)	Inclination (Degrees)	Total Moment/cm^3 ($X 10^{-5}$ emu)
		(No Demagnetization)		
E41	40.5	17	-6	12.5
E42	41.4	12	-3	11.3
E43	42.5	14	-2	10.9
E44	43.5	15	-1	9.9
E45	44.5	13	-7	7.3
E46	45.5	9	2	7.4
E47	46.5	4	5	6.7
E48	47.5	14	6	6.1
E49	48.5	16	5	6.9
E50	49.5	Thin crust from bottom of column. Could not be oriented.		
		(100 Oersted Peak Demagnetizing Field)		
E1	0.5	Broken fragments. Could not be accurately oriented.		
E2	1.5	352	18	15.6
E3	2.5	357	0	12.5
E4	3.5	359	-3	9.6
E5	4.5	349	-8	10.3
E6	5.5	352	0	11.3
E7	6.5	350	3	12.1
E8	7.5	351	2	11.1
E9	8.5	349	-2	8.4
E10	9.5	351	-2	8.8
E11	10.5	3	4	10.1
E12	11.5	5	3	11.3
E13	12.5	7	2	12.7
E14	13.5	8	5	12.2
E15	14.5	7	2	11.3
E16	15.5	4	7	16.2
E17	16.5	6	4	19.4
E18	17.5	359	1	14.4
E19	18.5	7	-5	17.2
E20	19.5	9	-7	13.7
E21	20.5	15	-1	15.7
E22	21.5	13	-9	14.2
E23	22.5	359	5	11.0
E24	23.5	1	-8	8.9
E25	24.5	349	-4	7.6
E26	25.5	0	-5	9.4
E27	26.5	11	-11	11.0
E28	27.5	14	-8	9.0
E29	28.5	10	-9	8.8
E30	29.5	11	-5	9.7

TABLE 17--(Continued)

Specimen Number	Depth (cm.)	Declination (Degrees)	Inclination (Degrees)	Total Moment/cm^3 (X 10^{-5} emu)
		(100 Oersted Peak Demagnetizing Field)		
E31	30.5	10	-11	12.4
E32	31.5	14	-8	14.3
E33	32.5	18	-12	12.5
E34	33.5	21	-7	11.2
E35	34.5	15	-7	12.2
E36	35.5	16	-6	13.2
E37	36.5	20	-2	12.3
E38	37.5	16	-2	11.9
E39	38.5	18	-1	11.3
E40	39.5	19	-4	12.2
E41	40.5	16	-7	11.5
E42	40.5	16	0	11.3
E43	42.5	15	-1	10.6
E44	43.5	17	1	9.5
E45	44.5	17	-2	7.3
E46	45.5	9	6	7.4
E47	46.5	4	5	6.2
E48	47.5	16	14	6.0
E49	48.5	21	-4	6.9
E50	49.5	Thin crust from bottom of column. Could not be oriented.		
		(200 Oersted Peak Demagnetizing Field)		
E1	0.5	Broken fragments. Could not be accurately oriented.		
E2	1.5	355	8	13.1
E3	2.5	351	-2	12.7
E4	3.5	0	12	9.3
E5	4.5	347	2	9.4
E6	5.5	350	3	9.8
E7	6.5	351	1	11.6
E8	7.5	352	-2	10.4
E9	8.5	349	2	8.3
E10	9.5	347	-4	8.1
E11	10.5	3	3	10.0
E12	11.5	6	4	9.9
E13	12.5	9	2	11.2
E14	13.5	9	4	12.3
E15	14.5	5	0	10.7
E16	15.5	4	6	15.3
E17	16.5	8	2	17.8
E18	17.5	0	-2	14.3
E19	18.5	8	-3	16.4
E20	19.5	9	2	12.9

TABLE 17—(Continued)

Specimen Number	Depth (cm.)	Declination (Degrees)	Inclination (Degrees)	Total Moment/cm^3 (X 10^{-5} emu)
		(200 Oersted Peak Demagnetizing Field)		
E21	20.5	14	9	14.9
E22	21.5	13	-2	12.7
E23	22.5	358	-1	9.9
E24	23.5	1	-22	8.7
E25	24.5	352	-8	7.5
E26	25.5	1	-11	8.9
E27	26.5	13	-5	10.0
E28	27.5	16	-11	8.5
E29	28.5	7	-11	8.6
E30	29.5	13	-3	9.4
E31	30.5	10	-10	11.2
E32	30.5	10	-8	13.4
E33	32.5	16	07	11.0
E34	33.5	21	-10	10.1
E35	34.5	16	-7	11.2
E36	35.5	20	-4	12.3
E37	36.5	16	0	11.5
E38	37.5	16	0	11.3
E39	38.5	22	-2	10.4
E40	39.5	21	-3	11.4
E41	40.5	17	0	11.0
E42	41.5	16	-6	10.3
E43	42.5	14	-2	9.7
E44	43.5	13	4	8.4
E45	44.5	16	-4	6.7
E46	45.5	6	2	6.6
E47	46.5	5	6	5.7
E48	47.5	16	14	5.2
E49	48.5	17	20	6.5
E50	49.5	Thin crust from bottom of column. Could not be oriented.		

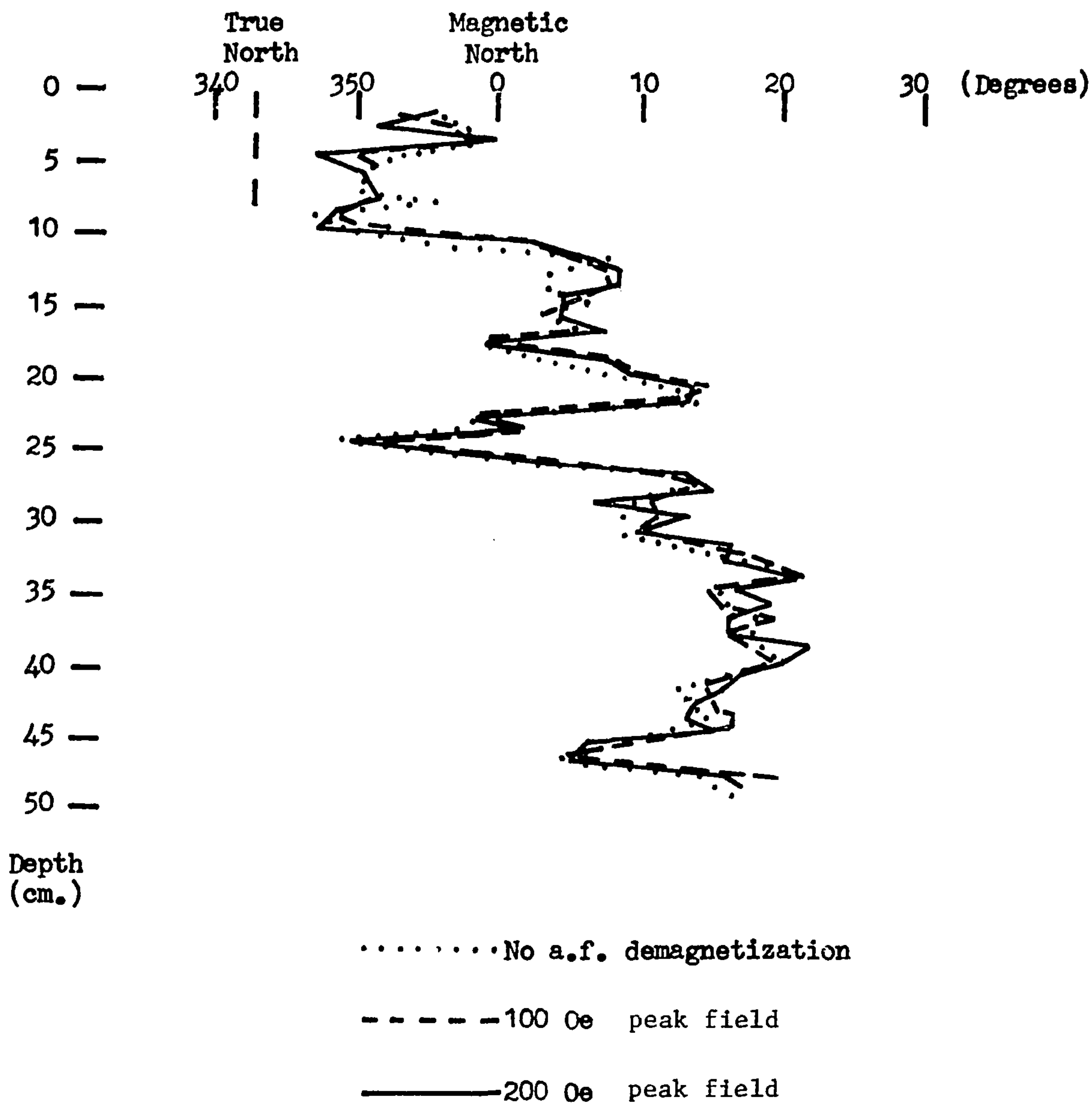


Figure 30. Declination at Site E, Smith Creek Valley Playa, Nevada. Plotted from data in Table 17.

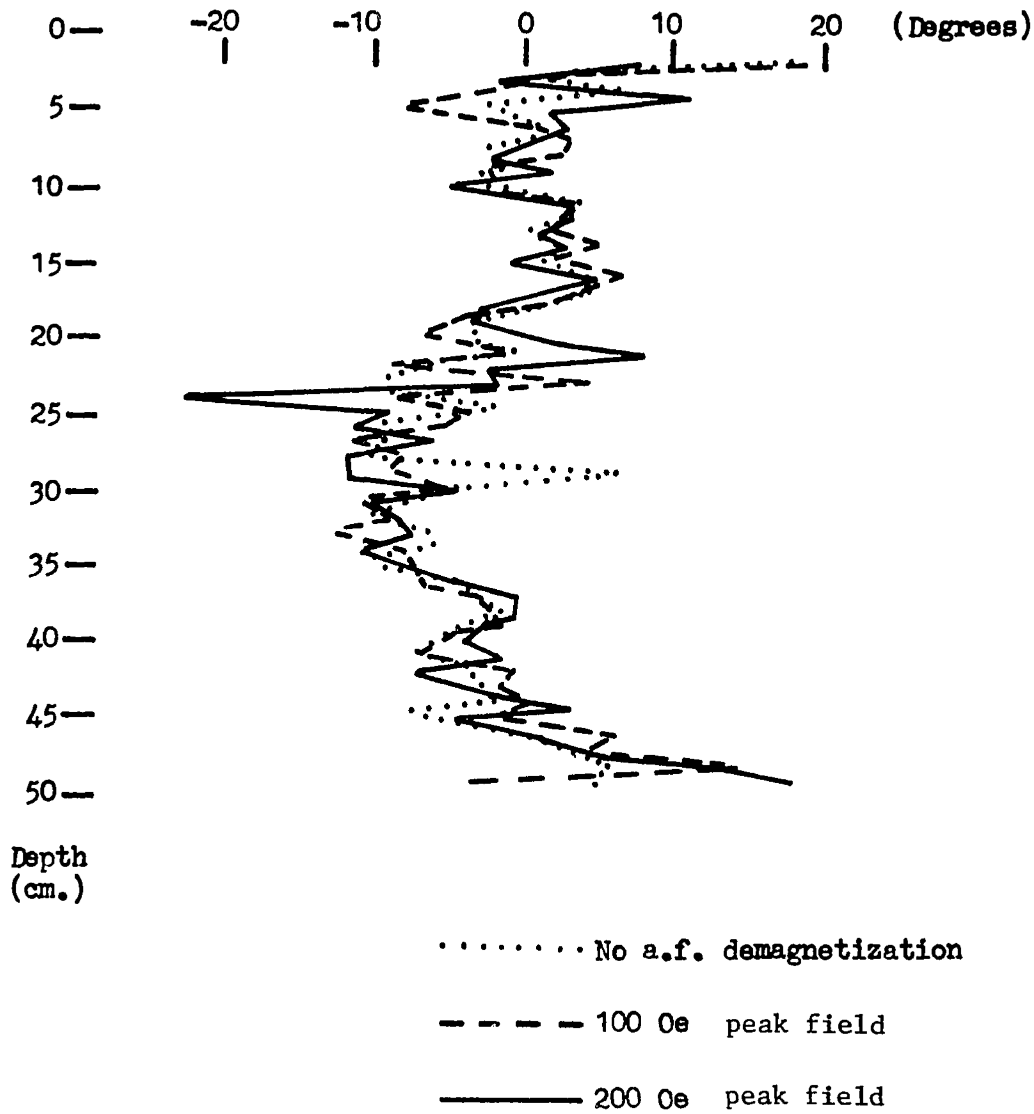


Figure 31. Inclination at Site E, Smith Creek Valley Playa, Nevada. Plotted from data in Table 17.

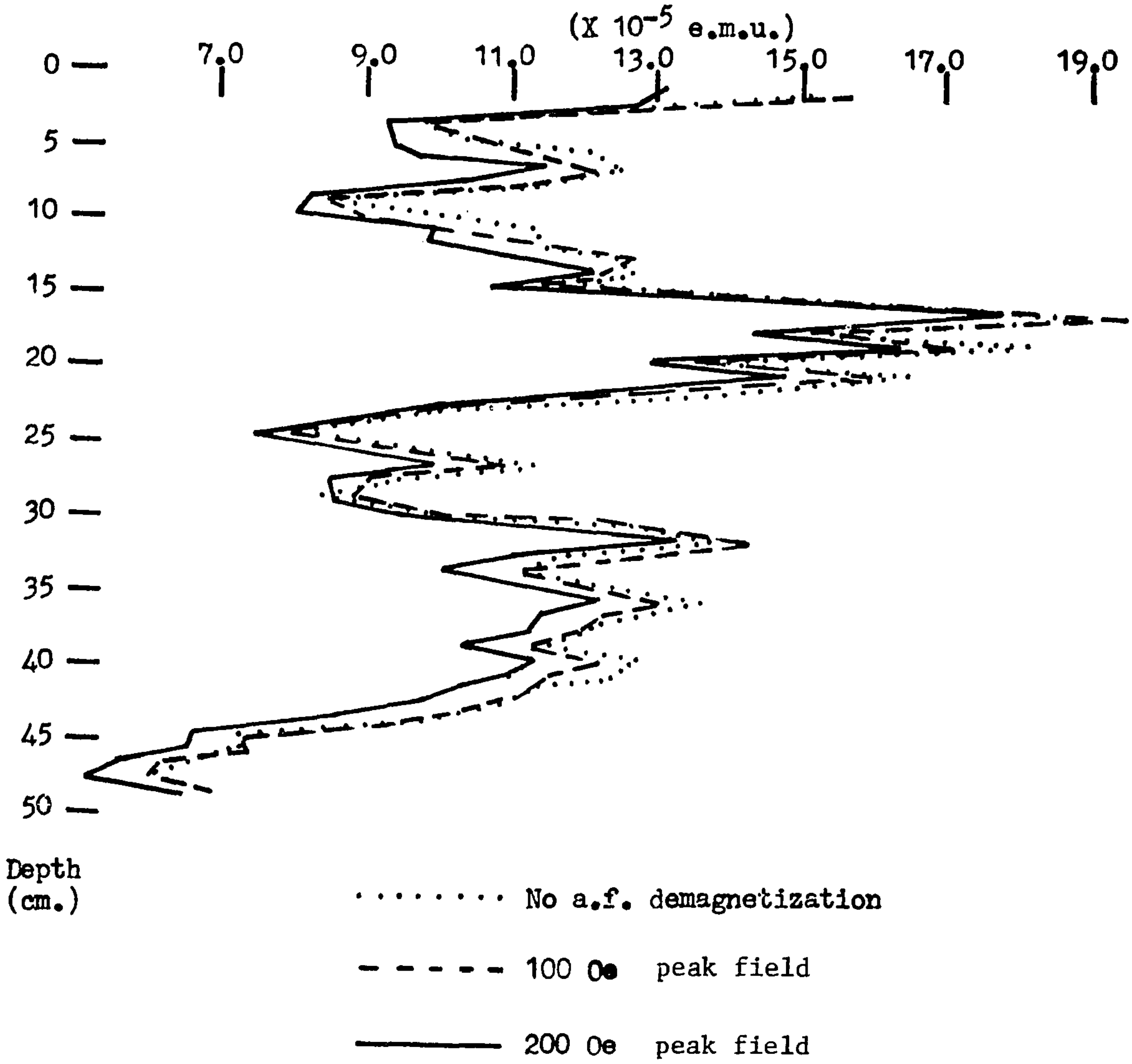


Figure 32. Total moment per unit volume (cm^3) at Site E, Smith Creek Valley Playa, Nevada. Plotted from data in Table 17.

of inclination for this location was 65° North with an annual change of -2.2 minutes. (H. O. 1700, U.S. Naval Oceanographic Office). Unless there was an experimental error in measurement of the inclination, the sediments may have compacted upon drying causing the magnetic grains to lose their orientation with respect to inclination. Compaction might account for both the low angles and negative indications of inclination (Table 17).

All declinations listed in Table 17 were corrected +4° to compensate for the slight misalignment from magnetic north of the plastic container in which the dry sediment column was removed from its original position in the playa lake bed. The uppermost layers of the column should have shown magnetic directions close to 0° declination from magnetic north, as the annual change in declination at this location was reported at 2.0 minutes westward (Isogonic Chart of the United Stages, 1965.0, U.S. 3077, Coast and Geodetic Survey). It would take thirty years for a one-degree change in direction. The topmost one centimeter slab should have been closest to 0° in magnetic direction. Unfortunately, it was broken while cutting it from the column of sediments and could not be measured. As shown in Table 17, those sediments just below the top of the column had magnetic vectors from five to ten degrees west of the present magnetic north. It is possible that the whole column rotated a few degrees during transportation. The August temperature in the desert often exceeded 100° F. Although wrapped in aluminum foil to reflect as much heat as possible, the paraffin, which surrounded the column and held it in place within the plastic container, could have become soft enough to permit the column to turn slightly and thus lose its original orientation with respect to the North-South edge of the container. The column was not broken, so if any slight rotation did occur, it was uniform throughout the depth of the column. Major deflections in magnetic direction to the east or west can still be compared in similar deflections from other sources.

Alpha-95's could not be calculated for this site, as only one column was taken. Consequently, there was only one specimen for each level.

DISCUSSION OF DATA

With the limitations on the reliability of certain of these data in mind, such as Site B specimens and those few Site E specimens noted in Table 11, it is possible to compare the results from each site, and to compare the results from each site to the archaeomagnetic declination and inclination curves for the Southwestern United States derived by R. L. DuBois (1974) from the study of baked clays.

Comparison of Data between Sites

These comparisons are most easily seen in graphic form. In Figures 33, 34, and 35, declination, inclination, and magnetic intensity curves of magnetically "cleaned" specimens from the three sampling sites are plotted on the same graphs for comparison. The plots are all to the same scale in depth below the playa surfaces. Such a comparison is valid only if the sedimentation rate at each site has been the same throughout the identical period of time at each location. Because of differences in climate, topography, and other factors affecting sedimentation, it is unlikely that the rate of deposition at each playa would be the same. Figures 33, 34, and 35 show that the widest variation appears in the data from Site E. After several trial and error attempts to obtain a better fit, I found that by expanding the depth of the Site E curves by a factor of 2.5, the major deflection points in the Site E curves more nearly agreed with those of the other two sites, although

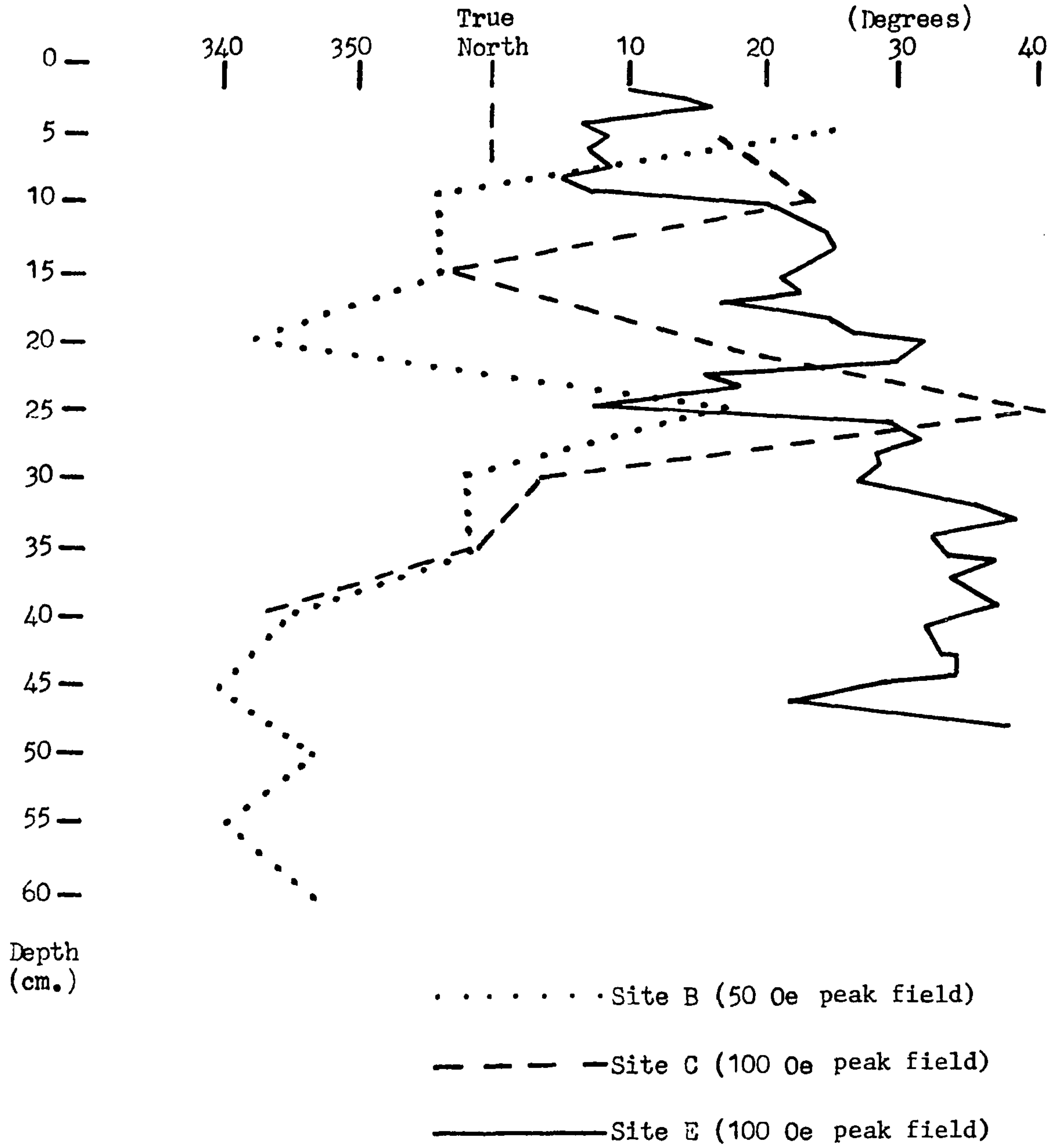


Figure 33. Declination comparison. Curves adjusted to true north. No adjustment for depth, which assumes identical rates of deposition at each playa.
Site B - Site C correlation coefficient (r) = 0.55; n = 8
Site B - Site E r = -0.83; n = 9
Site C - Site E r = -0.76; n = 8

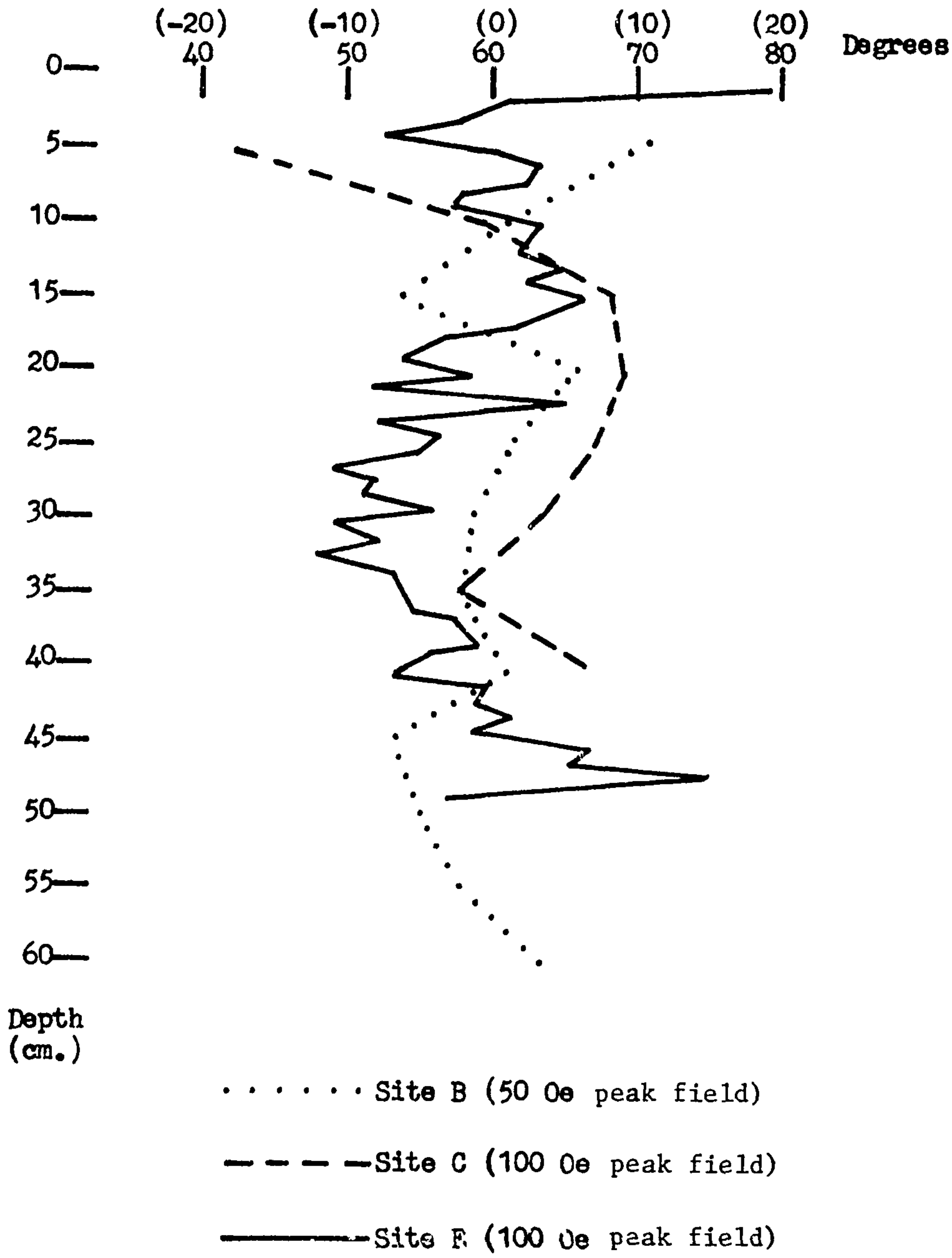


Figure 34. **Inclination comparison. Angles in parentheses at top of graph are those found in the Site E specimens. No adjustment for depth, which assumes identical rates of deposition at each playa.**
Site B - Site C correlation coefficient (r) = -0.60; n = 8
Site B - Site E r = -0.41; n = 9
Site C - Site E r = 0.09; n = 8

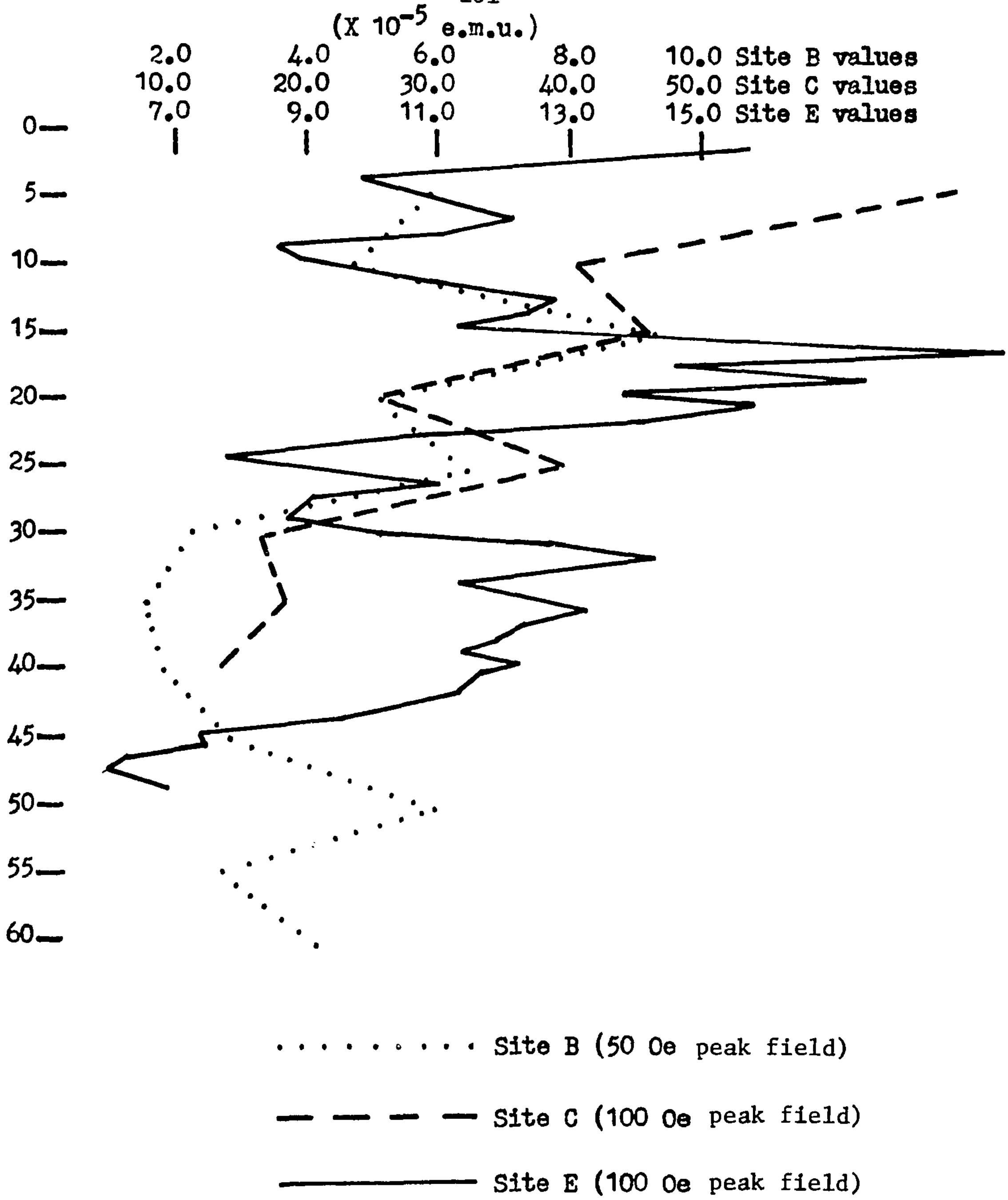


Figure 35. Total moment per cm^3 comparison. No adjustment for depth, which assumes identical rates of deposition at each playa.
Site B - Site C correlation coefficient (r) = 0.72; n = 8
Site B - Site E r = 0.20; n = 9
Site C - Site E r = -0.27; n = 8

the agreement was far from perfect in any case. Expansion of the Site E depth by 2.5 implies that the rate of sedimentation at Site E was only about two-fifths the rate of sedimentation at the Arizona sites. The climate at the Nevada site appears to have been drier during the time of deposition. As it turned out later, when making comparisons with the archaeomagnetic curves, I had to expand the Site C curves by a factor of 1.5, implying that the rate of sedimentation at Site C was only two-thirds the rate of sedimentation at Site B. The climate at the northwest Arizona site appears to have been drier than the climate at the southeast Arizona site during the time of deposition. If my data are valid, it can be said that the climate became more arid from southeast Arizona, near present-day Willcox, northwestward through present-day Kingman, Arizona, up into Nevada near present-day Austin.

Declination

An examination of Figure 33, which is a comparison of the declination curves from the three playas with no adjustment in depth, shows that the deflection points in the Site B and Site C curves align rather well, but the Site E curve fits poorly. In Figure 36, the Site E declination curve has been expanded by 2.5 in depth, which improved somewhat the alignment of the deflection points. In comparing these curves, one must remember that the Site B and Site C specimens were taken five centimeters apart in depth, while the Site E specimens were taken one centimeter apart from a continuous column. This difference in sampling methods might be expected to produce more detail on the Site E curve than are found on the other two, as they, in fact, do.

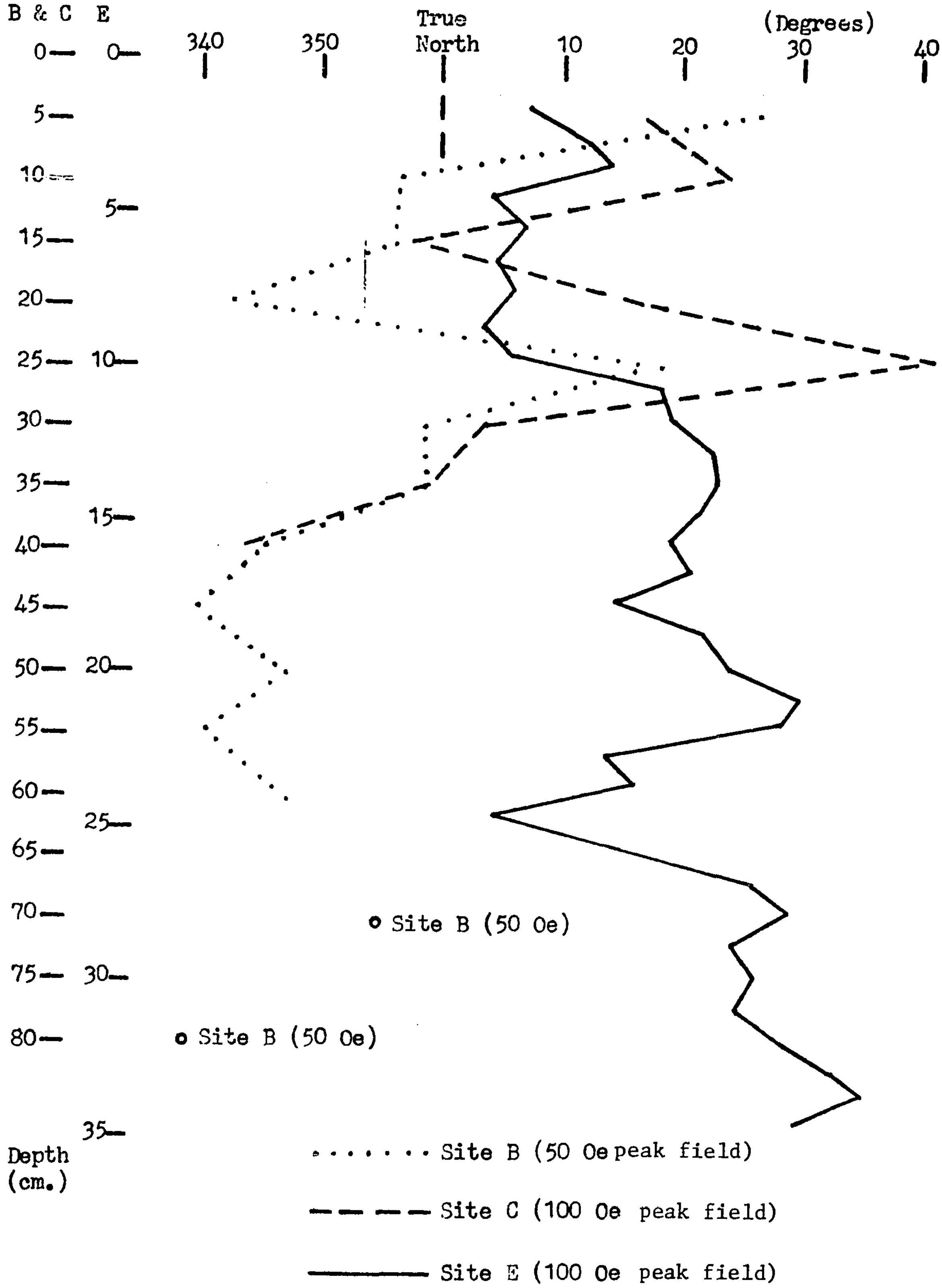


Figure 36. Declination comparison. Curves aligned at true north. No adjustment for depth Site B and Site C curves, but Site E curve depth expanded by 2.5 which assumes a slower rate of deposition at Site E. Site B - Site C correlation coefficient (r) = 0.55; n = 8. Site B - Site E r = -0.24; n = 12. Site C - Site E r = -0.45; n = 8.

Inclination

Figure 34, a comparison of the inclination curves from the three playas with no adjustment in depth, confirms that magnetic inclination in sediments is generally less reliable than declination. In Figure 37, where the Site E inclination curve has been expanded by 2.5 in depth to conform with the declination curve, there is slightly better agreement among the major deflection points on the curves. Although this expansion in depth produced a better fit in both declination and total moment curves, there remains the greater inclination difference between the moist and dry sediments.

Total Moment

Figure 35 compares the magnetic intensities of the three curves with no adjustment for depth. As in the case of the declination curves in Figure 33, the Site B and Site C curves align rather well, but the Site E curve fits poorly. However, when the Site E curve is expanded in depth by 2.5, as in Figure 38, the alignment of the major deflection points in the Site E curve improves. From the Site B and Site C intensity curves it appears that the ambient magnetic field was weaker at the 35-40 centimeter depth. (This relates to somewhere between 600 and 800 years ago on the archaeomagnetic curves.) But at about this same time, the Site E intensity curve appears anomalously high. This could have been an experimental error, or possibly a higher concentration of magnetic minerals in the sediments at that depth.

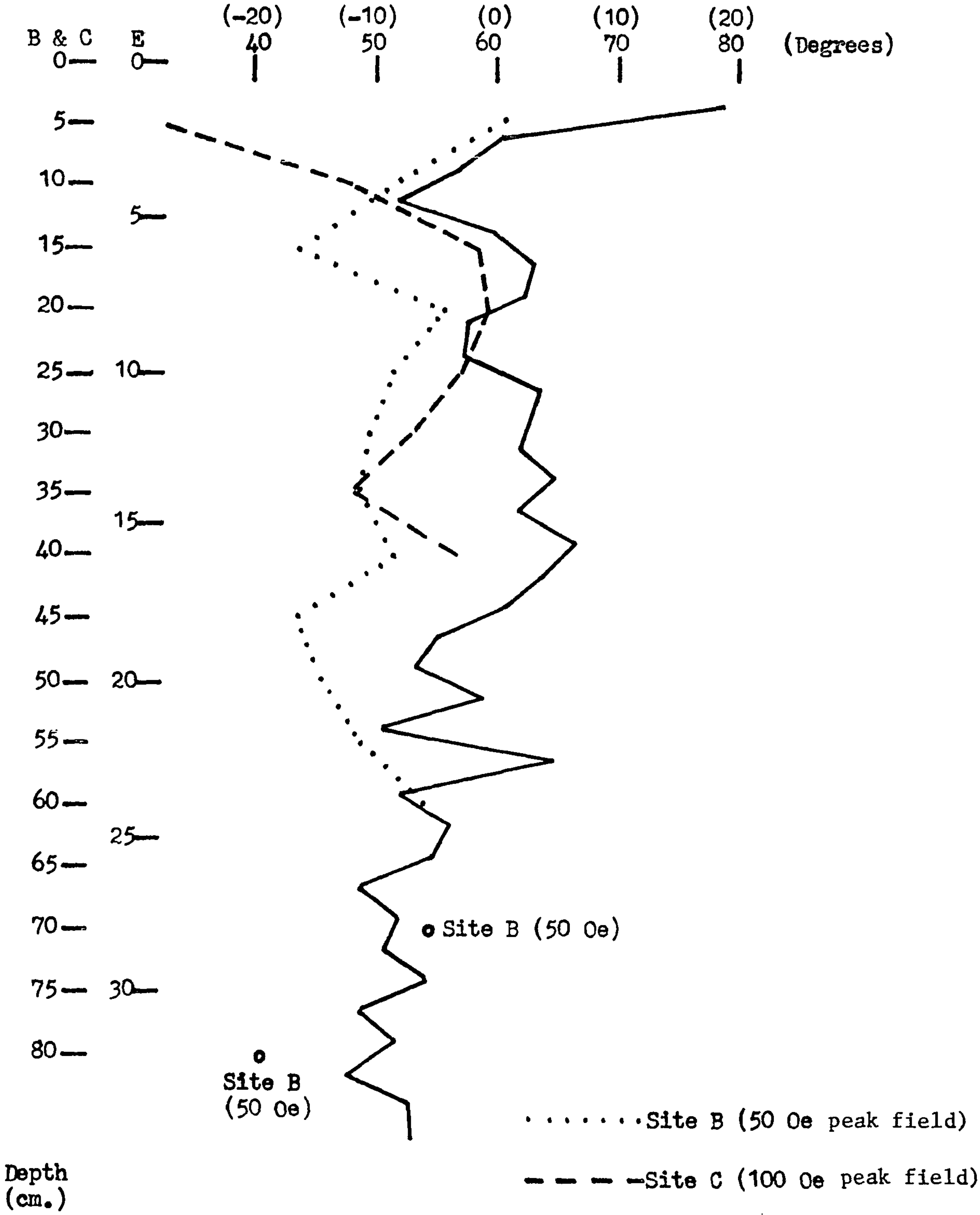


Figure 37. Inclination comparison. Angles in parentheses at top of graph are those found in the Site E specimens. No adjustment for depth Site B and Site C curves, but Site E curve depth expanded by 2.5 which assumes a slower rate of deposition at Site E. Site B - Site C correlation coefficient (r) = -0.60; n = 8. Site B - Site E r = 0.31; n = 12. Site C - Site E r = -0.51; n = 8.

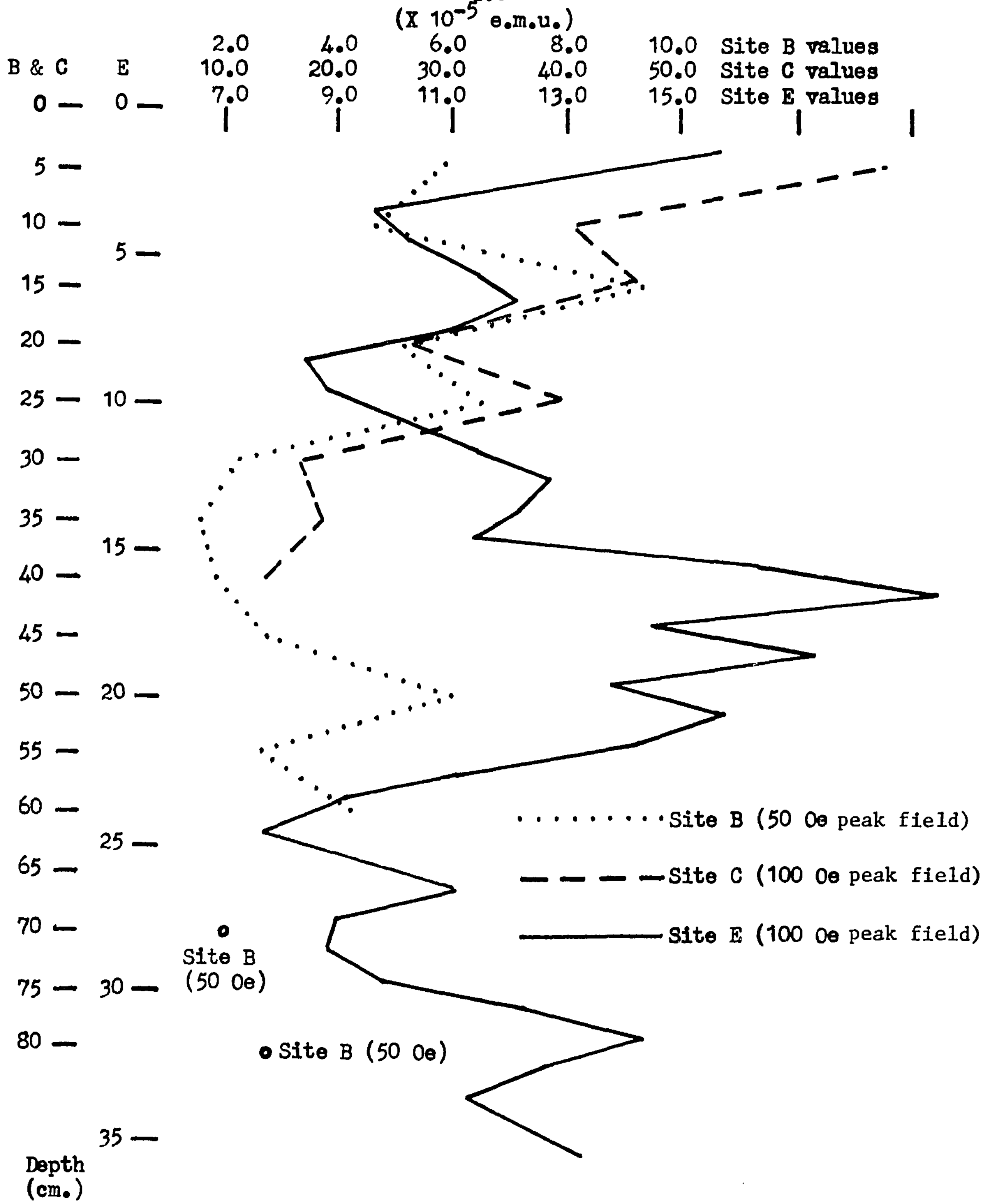


Figure 38. **Total moment per cm^3 comparison. No adjustment for depth in the Site B and Site C curves, but Site E curve expanded by 2.5 times in depth assumes a slower rate of deposition at Site E.**
Site B - Site C correlation coefficient (r) = 0.72; n = 8. Site B - Site E r = -0.24; n = 12. Site C - Site E r = 0.94; n = 8.

Comparisons with the Southwestern United States Archaeomagnetic Curves

A purpose of this investigation was to compare the declination and inclination data from playa sediments with those from the Southwestern United States archaeomagnetic data. To my knowledge there are no magnetic intensity curves derived from archaeomagnetic data for the U.S. with which to compare the magnetic intensity curves from the sediments.

Declination

Figure 39 represents the Southwestern United States declination curve as derived from the archaeomagnetic studies of R. L. DuBois (1974). The curve shows changes in declination from about 1950 A.D., at the top of the chart, to about 650 A.D., at the bottom. The curve is best defined in the period 900 to 1550 A.D. The remainder of the curve, before and after those dates, is approximated. The letters A through H to the right of the curve identify easily recognizable deflection points on the curve, and the numbers in parentheses following each letter, A-H, represent the approximate number of years before 1973 A.D. when those deflections occurred. The year 1973 was chosen as the reference year, because it was then that the playa specimens were taken, and presumably the sediments at the top of the playa lake bed were deposited at about that time.

Figure 40 compares the declination curve from Site B with the archaeomagnetic declination curve. There appears to be a reasonably good agreement, although one must keep in mind that the sediment specimens were taken at each five centimeter level below the surface, therefore, changes in declination between those points do not show on the sediment

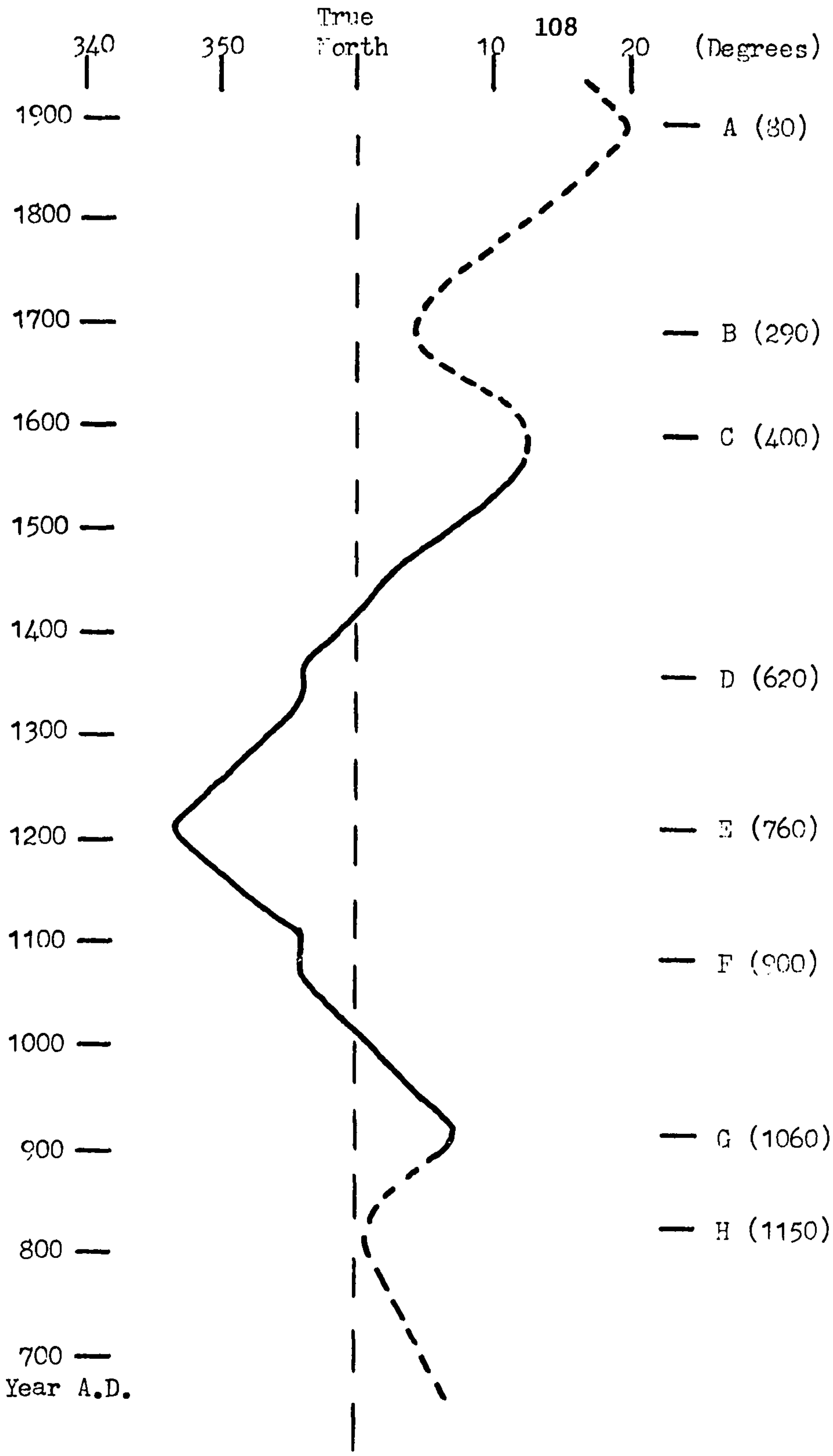


Figure 39. Southwestern United States declination curve. From archaeomagnetic data of R.L. DuBois. Letters A - H identify recognizable deflections on the curve. Numbers in parentheses are approximate number of years before 1973 when the deflections occurred. The curve is best defined in the period 900 to 1550 A.D. The remainder of the curve, before and after those dates, is approximated.

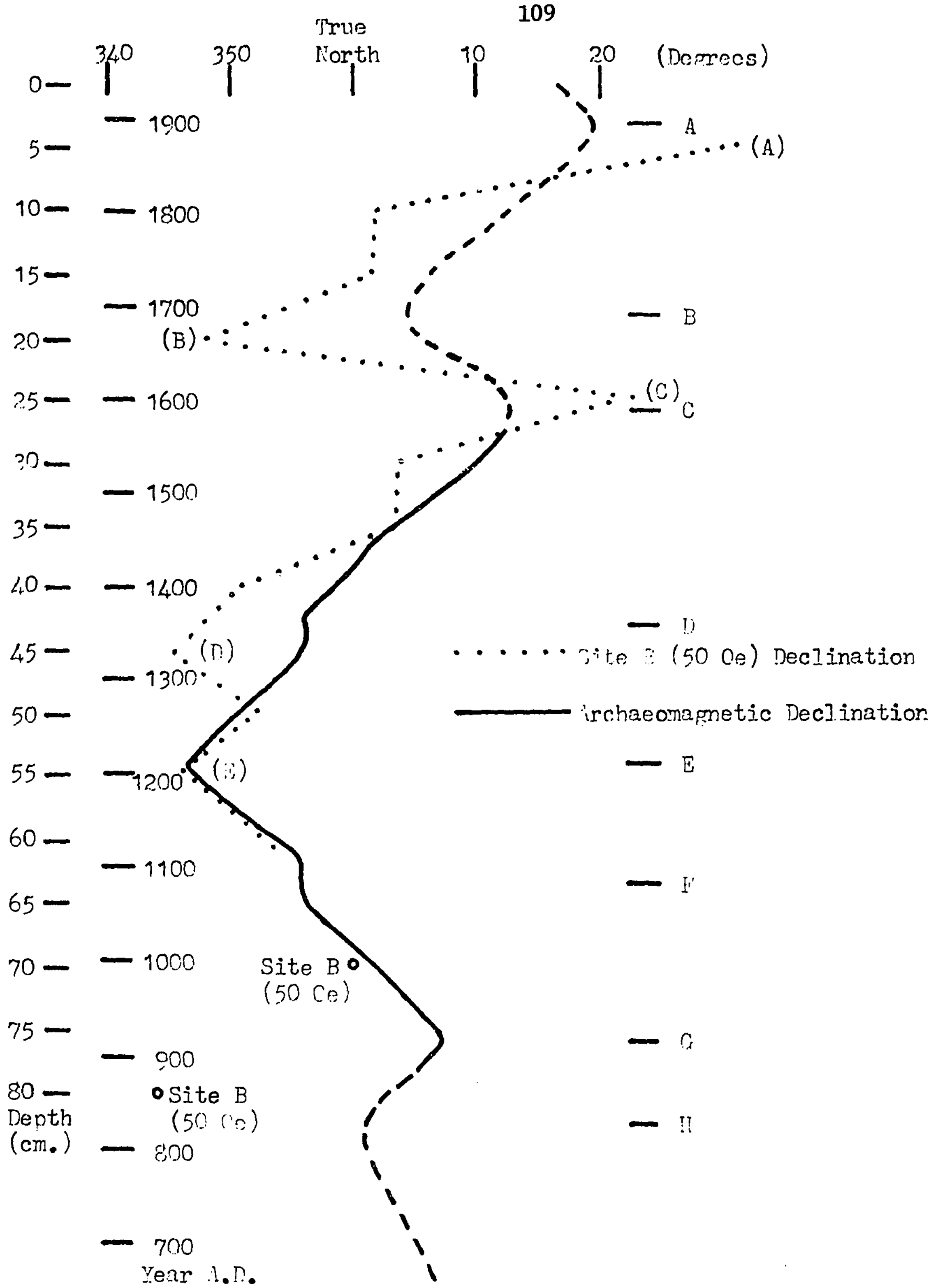


Figure 40. Comparison of Site B declination curve with Southwestern U.S. archaeomagnetic declination curve. Letters in parentheses are suggested equivalent deflection points on the Site B curve. Correlation coefficient (r) = 0.85; n = 13.

curve. The letters in parentheses adjacent to the Site B curve, (A) through (E), are thought to be deflections equivalent to the same lettered positions on the archaeomagnetic curve. The fact that all points are not directly opposite each other could be accounted for by changes in the rate of deposition in the sediments. I cannot explain why some of the deflections in the Site B curve appear exaggerated, unless it is a result of experimental errors, or the archaeomagnetic curve has been "averaged out."

Figure 41 is a comparison of the declination curve from Site C with the archaeomagnetic declination curve. Reasonable agreement was obtained by increasing the scale for depth below the surface by a factor of 1.5 times the Site B scale. This implies a slightly slower rate of deposition at this site as compared with the rate of deposition at Site B. Again, the letters in parentheses next to the Site C curve, (A) through (E), are assumed to be equivalent to the same lettered deflections on the archaeomagnetic curve. As in the case of Site B, the fact that the deflection points are not exactly aligned may be due to changes in the rate of deposition of the sediments, or failure to show any changes that might have occurred between the five centimeter sampling depths. Some of the deflections in the Site C curve appear exaggerated, which may be for the same reasons given above for Site B.

Figure 42 compares the declination curve from Site E with the archaeomagnetic declination curve. There are deflections in the Site E curve which do not show on the archaeomagnetic curve. This may be due to averaging of the archaeomagnetic data. What appears to be a reasonable fit between the two curves was obtained by increasing the Site E

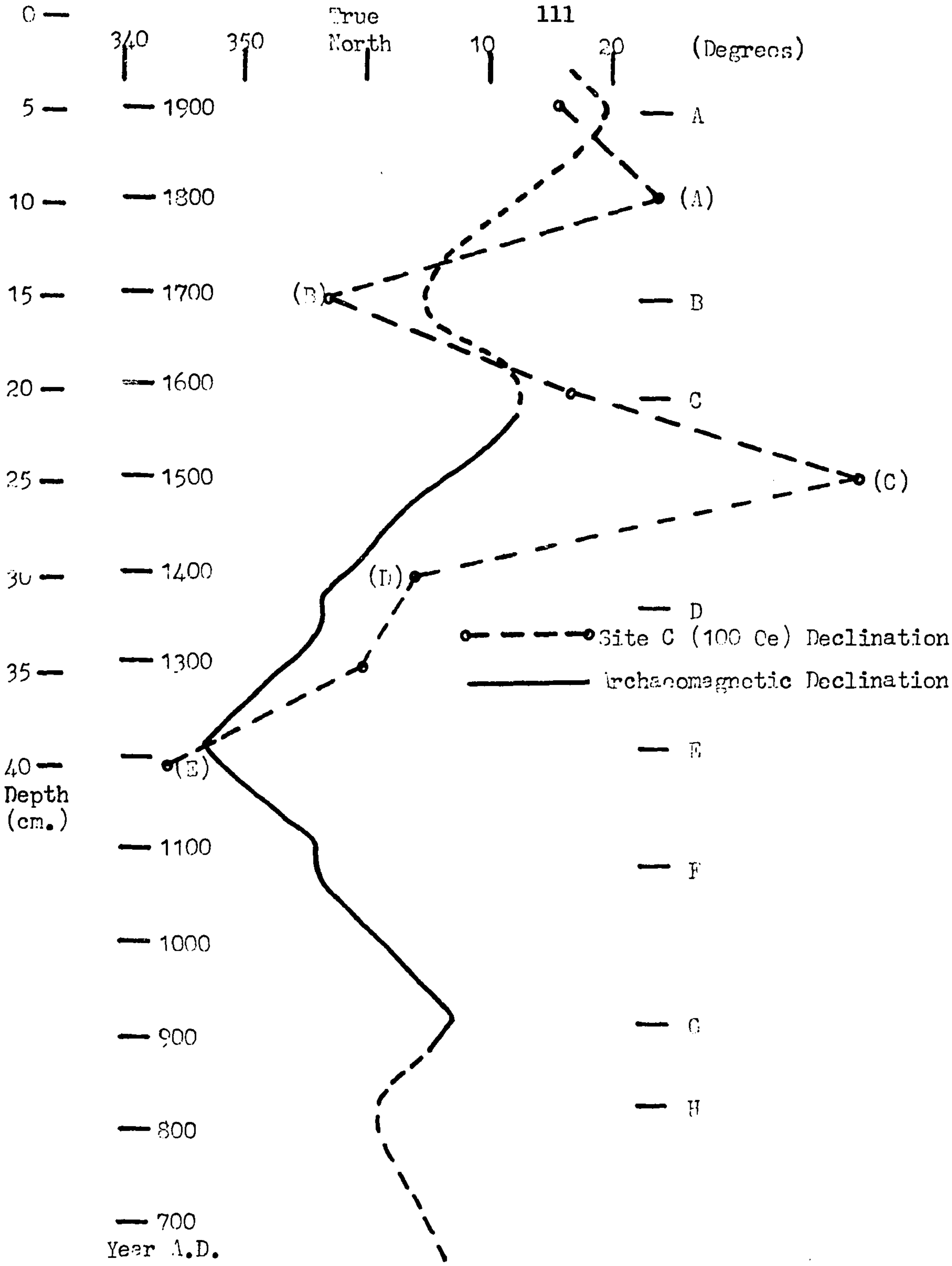


Figure 41. Comparison of Site C declination curve with Southwestern U.S. archaeomagnetic declination curve. Letters in parentheses are suggested equivalent deflection points on the Site C curve. Correlation coefficient (r) = 0.65; n = 8.

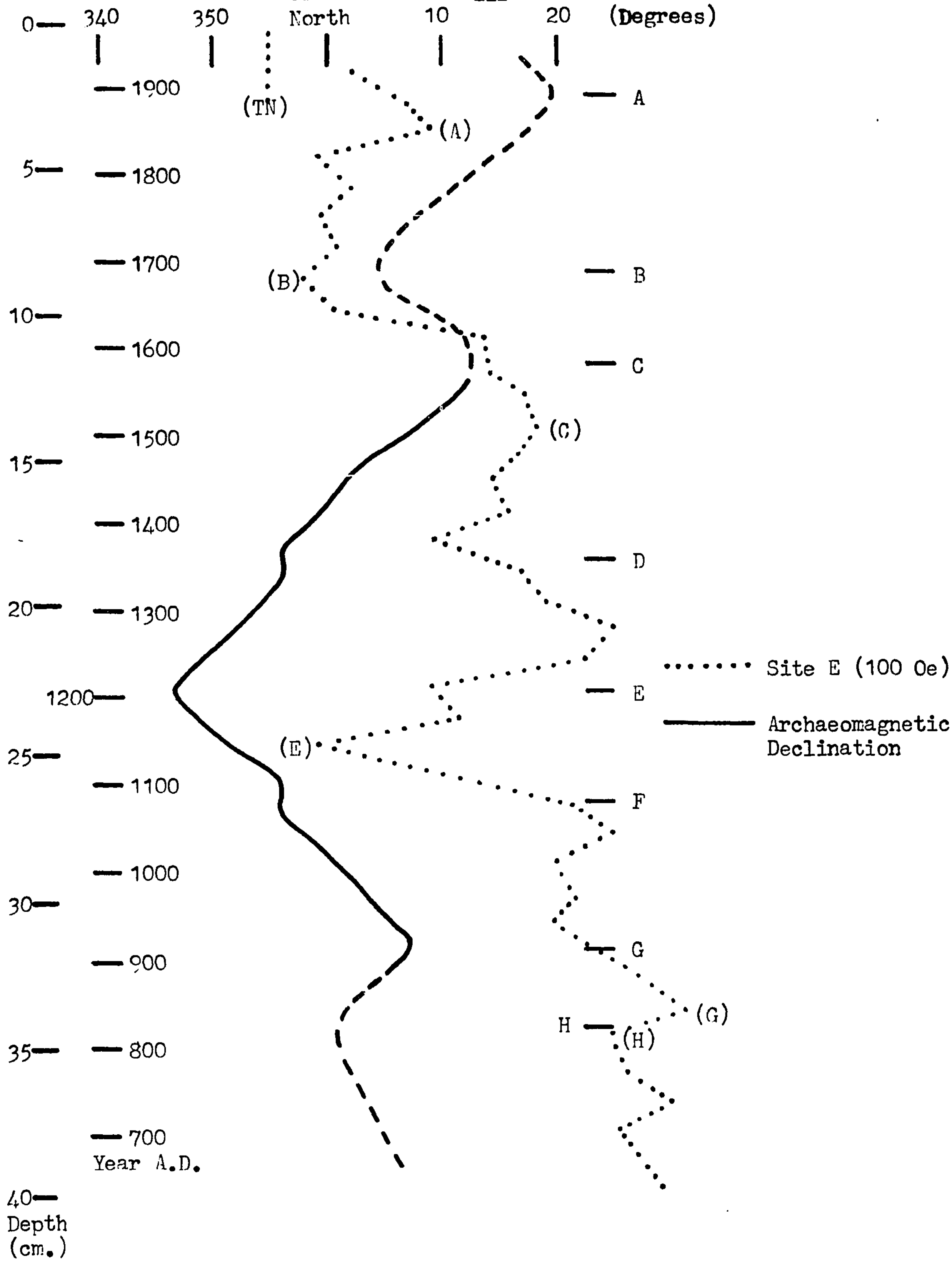


Figure 42. Comparison of Site E declination curve with Southwestern U.S. archaeomagnetic declination curve. Letters in parentheses are suggested equivalent deflection points on the Site E curve. Correlation coefficient (r) = -0.27; n = 37.

scale for depth by a factor of 2.5 times the Site B scale. This implies a rate of deposition of the Nevada sediments only two-fifths that of the Willcox sediments. The letters in parentheses adjacent to the Site E curve, (A) through (H), are assumed to be equivalent to the same lettered points on the archaeomagnetic curve.

Inclination

Figure 43 is a representation of the Southwestern United States inclination curve, derived from R. L. DuBois' (1974) archaeomagnetic studies. Like the archaeomagnetic declination curve, it shows changes in inclination from around 1950 A.D. at the top to around 650 A.D. at the bottom. The curve is best defined in the period 900 to 1550 A.D. The remainder of the curve, before and after those dates, is approximated. The letters N through U to the right of the curve identify recognizable deflection points, and the numbers in parentheses following each letter, N-U, are the approximate number of years before 1973 when these deflections occurred.

A comparison of the archaeomagnetic inclination curve and the Site B inclination curve is made in Figure 44. The Site B inclination curve was plotted in the same relative position as the Site B declination curve with respect to scale in depth and year A.D. The agreement between these two curves, if any, is more difficult to see than is that of the declination curves; however, what are thought to be comparable deflection points have been identified with letters in parentheses, (N) through (T), adjacent to the Site B curve.

Figure 45 compares the inclination curve from Site C with the archaeomagnetic curve. The Site C curve was positioned in depth and time

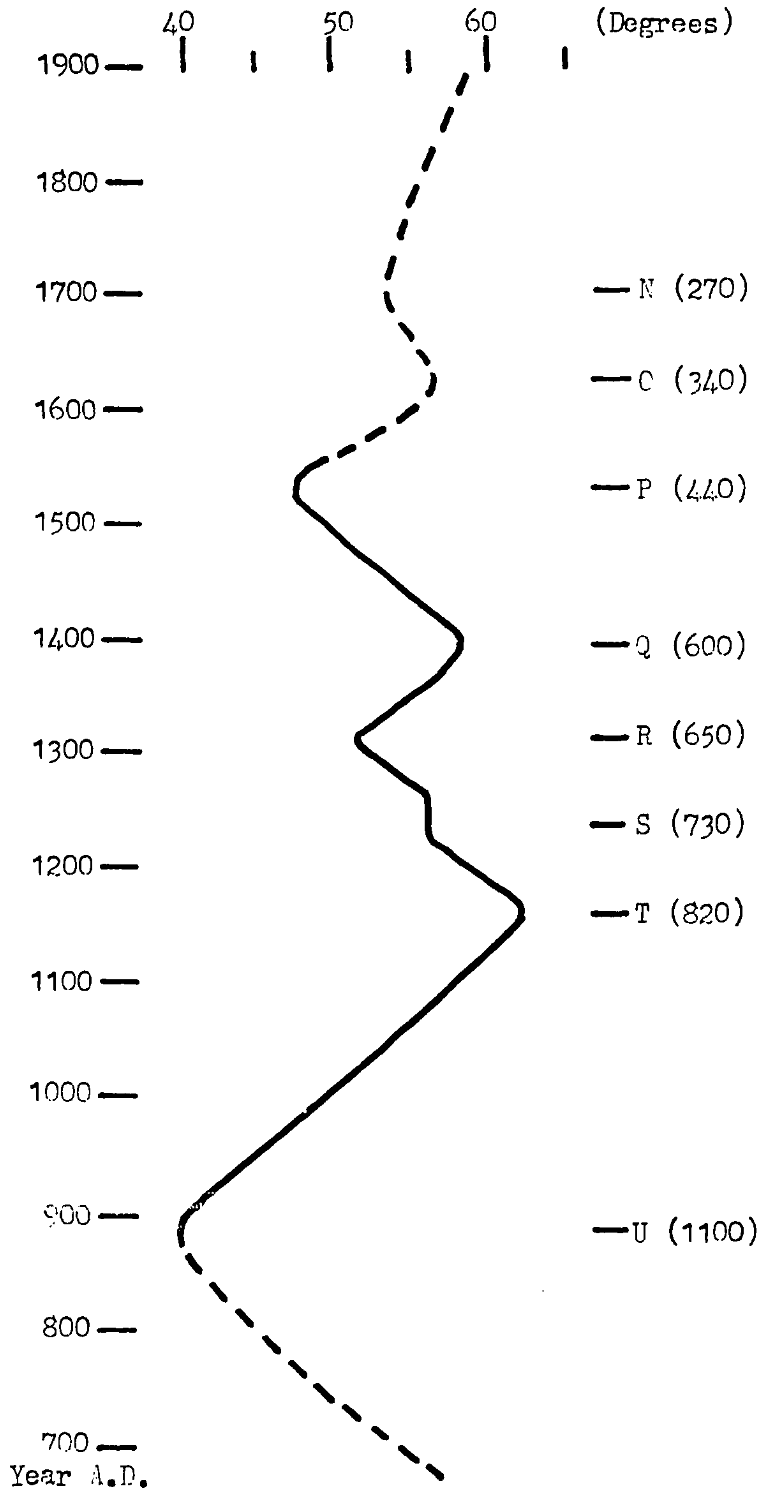


Figure 43. Southwestern United States inclination curve. From archaeomagnetic data of R.L. DuBois. Letters N - U identify recognizable deflections on the curve. Numbers in parentheses are approximate number of years before 1973 when the deflections occurred. The curve is best defined in the period 900 to 1550 A.D. The remainder of the curve, before and after those dates, is approximated.

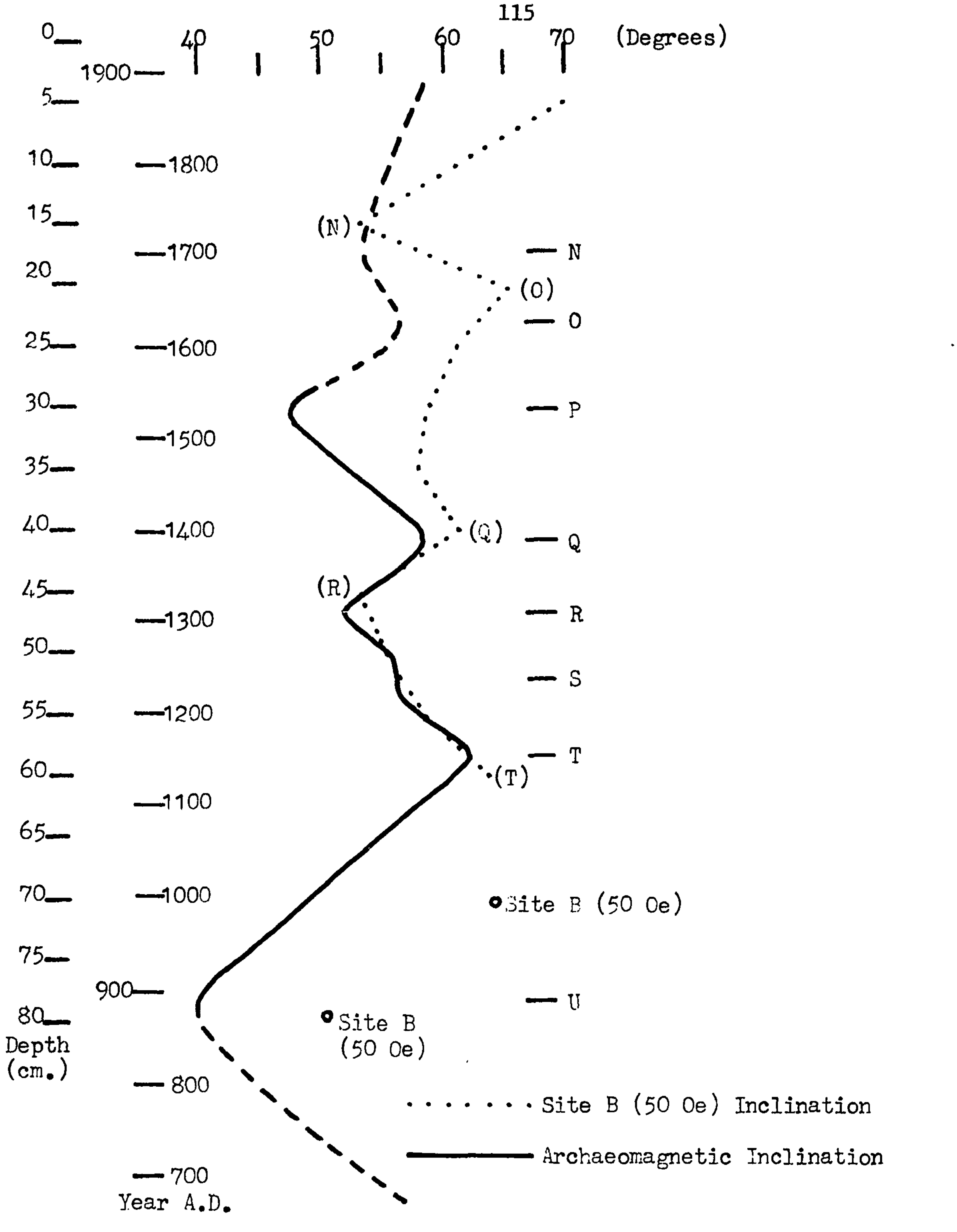


Figure 44. Comparison of Site B inclination curve with Southwestern U.S. archaeomagnetic inclination curve. Letters in parentheses are suggested equivalent deflection points on the Site B curve. Correlation coefficient (r) = 0.54; n = 14.

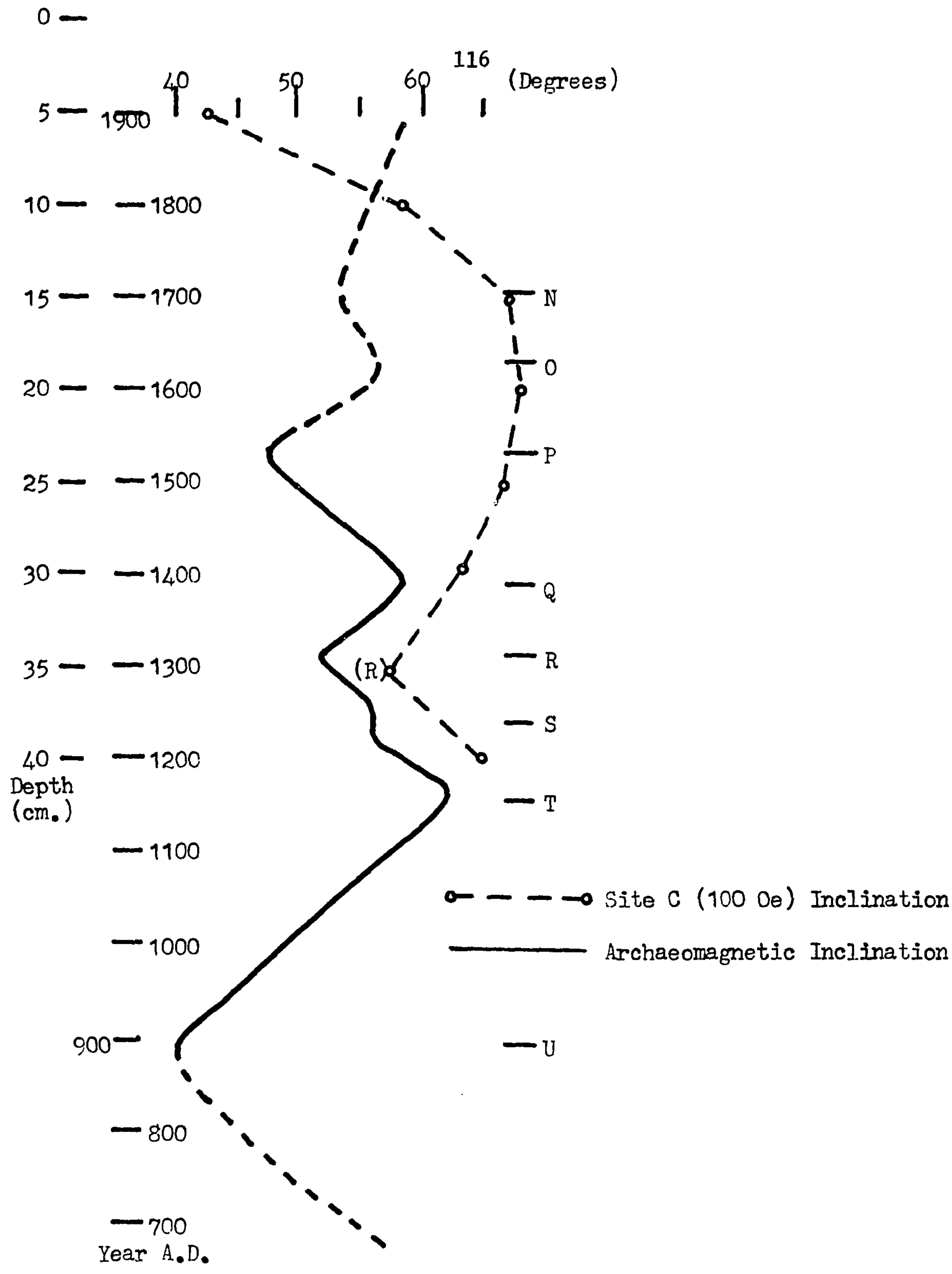


Figure 45. Comparison of Site C inclination curve with Southwestern U.S. archaeomagnetic inclination curve. Letters in parentheses are suggested equivalent deflection points on the Site C curve, which has been positioned in depth and scale to agree with Site C declination curve in depth and scale.
Correlation coefficient (r) = -0.44; n = 8.

to put it in the same relative position as the Site C declination curve depth and time. There is only one deflection point on this 100 Oersted curve which shows any agreement, (R)-R. However, the 400 and 800 Oersted demagnetization curves for Site C show two other deflection points which more nearly agree with the archaeomagnetic curve. The 800 Oersted comparison curve is Figure 46. Points (P), (Q), and (R) on the 800 Oersted Site C curve now apparently agree with points P, Q, and R on the archaeomagnetic curve. The 800 Oersted inclination comparison made it necessary to compare the 800 Oersted declination curve from Site C against the archaeomagnetic declination curve to determine whether or not there were significant changes from the 100 Oe curve. The comparison is shown in Figure 47. There was a repositioning upward of point (C) from its location on the 100 Oe curve.

Figure 48 is a comparison of the Site E and archaeomagnetic inclination curves. Just as in the case of the declination curve from Site E, there are deflections on the inclination curve which do not show on the archaeomagnetic curve. Positioning in depth and time of the Site E inclination curve has placed it in the same relative position as the Site E declination curve. Those deflection points which are thought to be equivalent on the two curves have been identified (N) through (U).

The above visual, or graphic, "fits" between sediment D and I curves and the archaeomagnetic D and I curves are speculative. Following are other methods for comparing the separately derived curves, which attempt to determine more conclusively whether or not the fit between them is real.

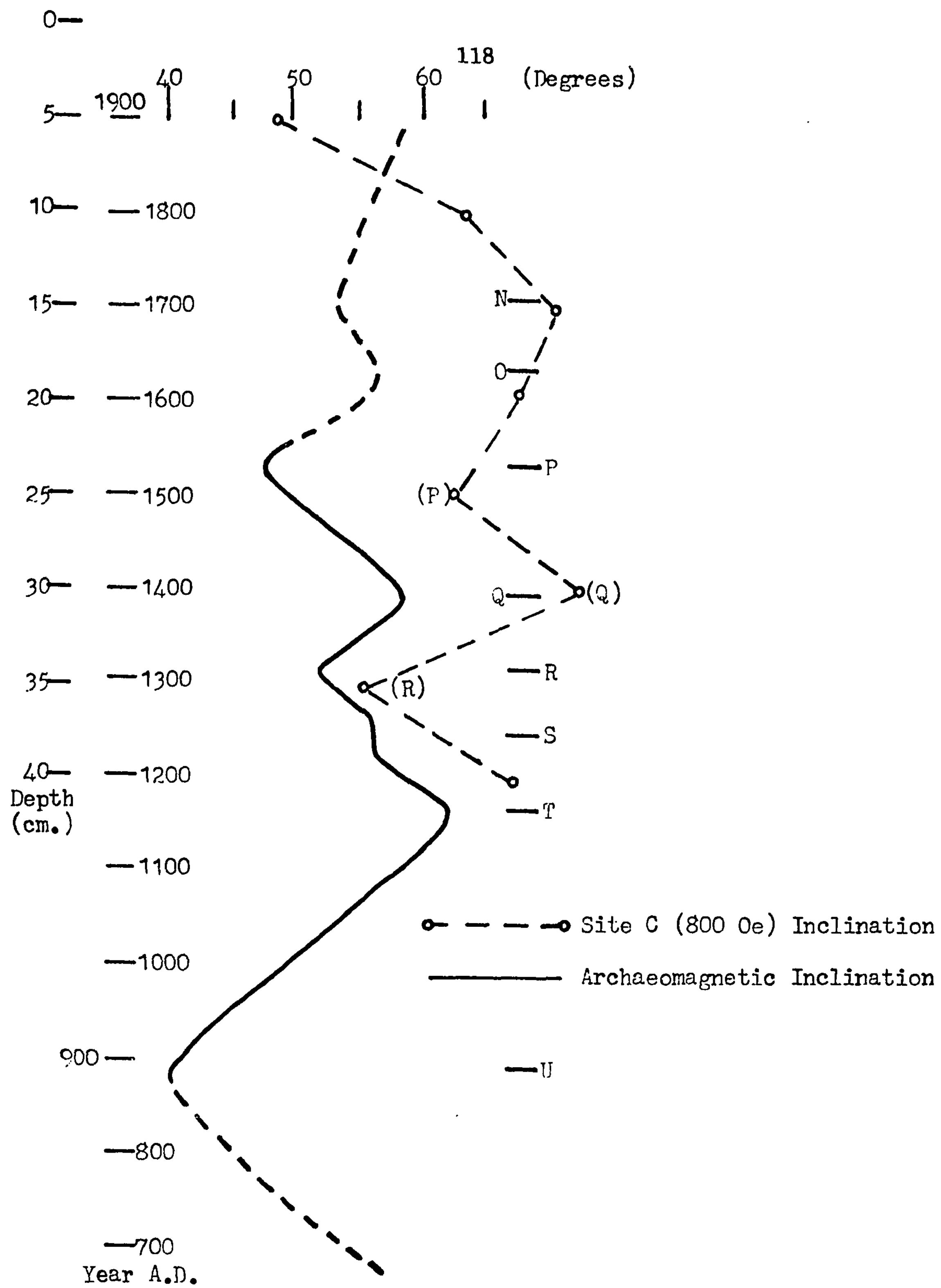


Figure 46. Comparison of Site C inclination curve with Southwestern U.S. archaeomagnetic inclination curve. Letters in parentheses are suggested equivalent deflection points on the Site C curve. Correlation coefficient (r) = -0.06; n = 8.

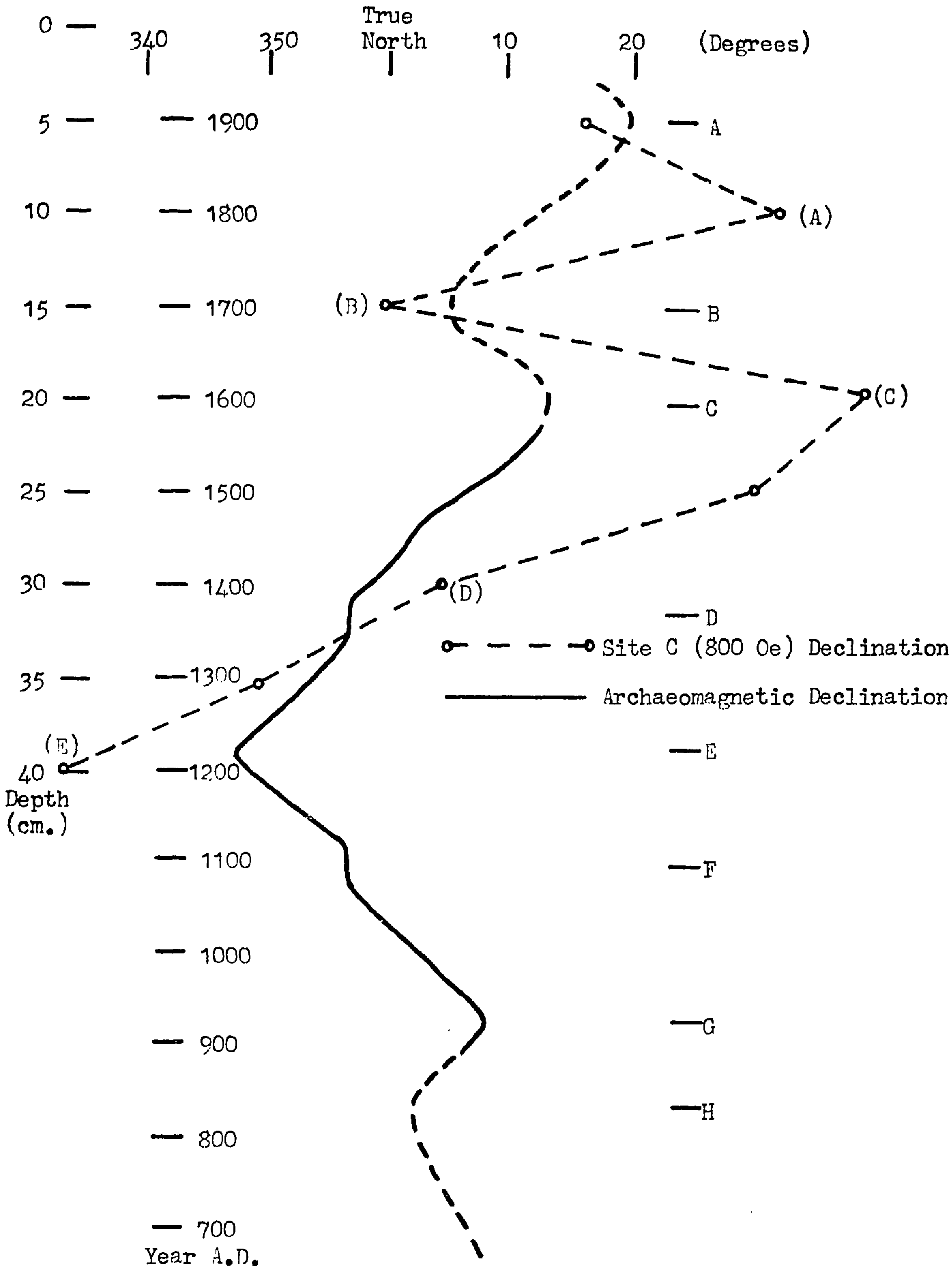


Figure 47. Comparison of Site C declination curve with Southwestern U.S. archaeomagnetic declination curve. Letters in parentheses are suggested equivalent deflection points on the Site C curve. Correlation coefficient (r) = 0.84; n = 8.

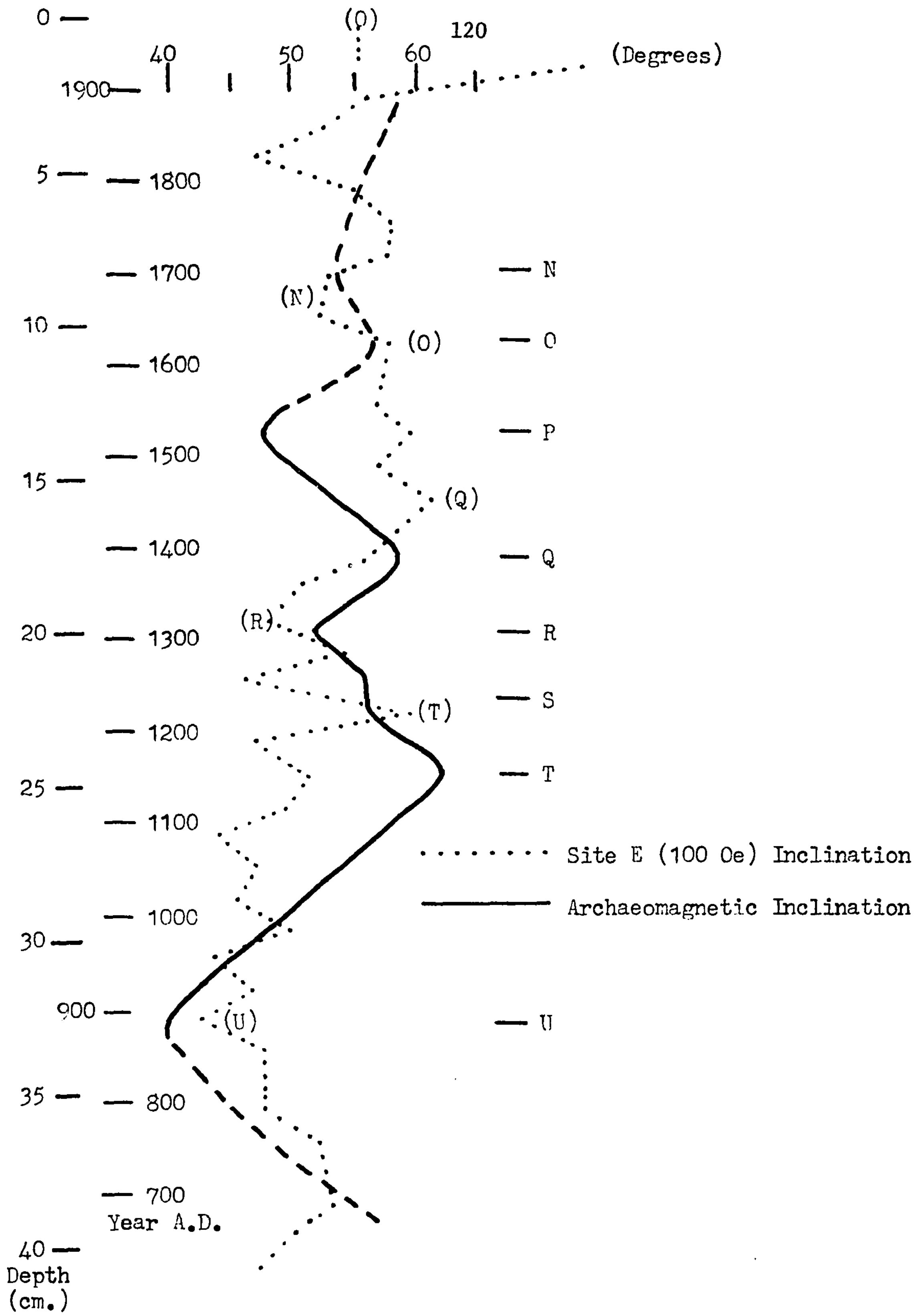


Figure 48. Comparison of Site E inclination curve with Southwestern U.S. archaeomagnetic inclination curve. Letters in parentheses are suggested equivalent deflection points on the Site E curve. Correlation coefficient (r) = 0.31; n = 37.

Rates of Sedimentation

Another way of looking at the fit of the curves is to calculate sedimentation rates using deflection points from the separate D and I curves. If the rates for declination curves are found to be the same as the sedimentation rates for the inclination curves at each site (it is not expected that they would be the same between sites), it is evidence that the playa data are in agreement with the archaeomagnetic curves. As a further test, if it can be shown that sedimentation rates calculated from the paleomagnetic data agree with sedimentation rates calculated from an independent source, such as Carbon-14 dating, the validity of the playa data would be further established.

By using points on a curve derived from the dry lake sediments, which give a measure of depth below the present playa surface, and matching them with similar points on the archaeomagnetic curve, which give a measure of time in years before the present, it is possible to calculate sedimentation rates for the playas. Following are tables of data taken from the archaeomagnetic-playa sediment comparison curves showing the sedimentation rates calculated from them.

The sedimentation rates in Tables 18 through 25 show some agreement between the declination and inclination comparisons for each site. The use of sedimentation rates as evidence for agreement between curves might have more meaning quantitatively if the actual curves produced rates which closely approximated rates derived from a theoretical "perfect match" between the archaeomagnetic and playa sediment data. In other words, if we assume a perfect agreement between archaeomagnetic curves and playa sediment curves, "standard sedimentation rates could be

TABLE 18

SEDIMENTATION RATES FROM SITE B[a]
ARCHAEOMAGNETIC DECLINATION COMPARISON

Equivalent Points	Depth (cm.)	Years (B. 1973)	Sed. Rate: Cumulative Average (cm/year)	Depth Between Points (cm.)	Time Between Points (years)	Sed. Rate Between Points (cm/year)
	0	0				
(A) - A	5	80	0.062	5	80	0.062
(B) - B	20	290	0.069	15	210	0.071
(C) - C	25	400	0.062	5	110	0.045
(D) - D	45	620	0.073	20	220	0.091
(E) - E	55	760	0.072	10	140	0.071

[a]See Figure 40.

Note: Average rate of sedimentation for 760 years = 0.072 cm/yr.
Average of sedimentation rates between points = 0.068 cm/yr.

TABLE 19

SEDIMENTATION RATES FROM SITE B[a]
ARCHAEOMAGNETIC INCLINATION COMPARISON

Equivalent Points	Depth (cm.)	Years (B. 1973)	Sed. Rate: Cumulative Average (cm/year)	Depth Between Points (cm.)	Time Between Points (years)	Sed Rate: Between Points (cm/year)
	0	0				
(N) - N	15	270	0.056	15	270	0.056
(O) - O	20	340	0.059	5	70	0.071
(Q) - Q	40	600	0.067	20	260	0.077
(R) - R	45	650	0.069	5	50	0.100
(T) - T	60	820	0.073	15	170	0.088

[a]See Figure 44.

Note: Average sedimentation rate for 820 years = 0.073 cm/year.
Average of sedimentation rates between points = 0.078 cm/year.

TABLE 20

SEDIMENTATION RATES FROM SITE C (100 Oe)[a]-
ARCHAEOMAGNETIC DECLINATION COMPARISON

Equivalent Points	Depth (cm.)	Years (B. 1973)	Sed. Rate: Cumulative Average (cm/year)	Depth Between Points (cm.)	Time Between Points (years)	Sed. Rate: Between Points (cm/year)
	0	0				
(A) - A	10	80	0.125	10	80	0.125
(B) - B	15	290	0.052	5	210	0.024
(C) - C	25	400	0.062	10	110	0.091
(D) - d	30	620	0.048	5	220	0.023
(E) - E	40	760	0.053	10	140	0.071

[a]See Figure 41.

Note: Average sedimentation rate for 760 years = 0.053 cm/year.
Average of sedimentation rates between points = 0.067 cm/year.

TABLE 21

SEDIMENTATION RATES FROM SITE C (100 Oe)[a] -
ARCHAEOMAGNETIC INCLINATION COMPARISON

Equivalent Points	Depth (cm.)	Years (B. 1973)	Sedimentation Rate (cm. per year)
(R) - R	35	650	0.054

[a]See Figure 45.

Note: Rate of sedimentation based upon only one point = 0.054 cm/year.

TABLE 22

SEDIMENTATION RATES FROM SITE C (800 Oe)[a]--
ARCHAEOMAGNETIC DECLINATION COMPARISON

Equivalent Points	Depth (cm.)	Years (B. 1973	Sed. Rate: Cumulative Average (cm/year)	Depth Between Points (cm.)	Time Between Points (years)	Sed. Rate: Between Points (cm/year)
	0	0				
				10	80	0.125
(A) - A	10	80	0.125			
				5	210	0.024
(B) - B	15	290	0.052			
				5	110	0.045
(C) - C	20	400	0.050			
				10	220	0.045
(D) - D	30	620	0.048			
				10	140	0.071
(E) - E	40	760	0.053			

[a]See Figure 47.

Note: Average sedimentation rate for 760 years = 0.053 cm/year.
Average of sedimentation rates between points = 0.062 cm/year.

TABLE 23

SEDIMENTATION RATES FROM SITE C (800 Oe)[a]--
ARCHAEOMAGNETIC INCLINATION COMPARISON

Equivalent Points	Depth (cm.)	Years (B. 1973)	Sed. Rate: Cumulative Average (cm/year)	Depth Between Points (cm.)	Time Between Points (years)	Sed. Rate: Between Points (cm/year)
	0	0				
				25	440	0.057
(P) - P	25	440	0.057			
				5	160	0.031
(Q) - Q	30	600	0.050			
				5	50	0.100
(R) - R	35	650	0.054			

[a]See Figure 46.

Note: Average sedimentation rate for 650 years = 0.054 cm/year.
Average of sedimentation rates between points = 0.063 cm/year.

TABLE 24

SEDIMENTATION RATES FROM SITE E[a]--
ARCHAEOMAGNETIC DECLINATION COMPARISON

Equivalent Points	Depth (cm.)	Years (B.	Sed. Rate: Cumulative Average (cm/year)	Depth Between Points (cm.)	Time Between Points (years)	Sed. Rate: Between Points (cm/year)
	0	0		3.5	80	0.044
(A) - A	3.5	80	0.044			
				5.0	210	0.024
(B) - B	8.5	290	0.029			
				5.0	110	0.045
(C) - C	13.5	400	0.034			
				11.0	360	0.031
(E) - E	24.5	760	0.032			
				9.0	300	0.030
(G) - G	33.5	1060	0.032			
				1.0	90	0.011
(H) - H	34.5	1150	0.030			

[a]See Figure 42.

Note: Average sedimentation rate for 1150 years = 0.030 cm/year.
Average of sedimentation rates between points = 0.031 cm/year.

TABLE 25

SEDIMENTATION RATES FROM SITE E[a]--
ARCHAEOMAGNETIC INCLINATION COMPARISON

Equivalent Points	Depth (cm.)	Years (B. 1973)	Sed. Rate: Cumulative Average (cm/year)	Depth Between Points (cm.)	Time Between Points (years)	Sed. Rate: Between Points (cm/year)
	0	0				
				8.5	270	0.031
(N) - N	8.5	270	0.031			
				2	70	0.029
(O) - O	10.5	340	0.031			
				5	260	0.019
(Q) - Q	15.5	600	0.026			
				4	50	0.080
(R) - R	19.5	650	0.030			
				3	170	0.018
(T) - T	22.5	820	0.027			
				10	280	0.036
(U) - U	32.5	1100	0.030			

[a]See Figure 48.

Note: Average sedimentation rate for 1100 years = 0.030 cm/year.
Average of sedimentation rates between points = 0.036 cm/year.

calculated from this hypothetical "perfect fit." Then sedimentation rates calculated from comparison of the actual curves might be compared to this "standard." These standard rates may be derived by determining at what depth below the playa surface the major deflections in the archaeomagnetic declination and inclination curves (A through H, and N through U) would occur on Figures 40, 41, 42, 44, 45, and 48 without regard to the actual playa sediment curves, as the playa curves are assumed to overlie the archaeomagnetic curves exactly for this purpose. The "perfect match" assumes a constant rate of deposition throughout the column, because the time scale and depth scale remain constant for each site. For alingment of depth and time scales for this "perfect fit," zero depth (the sediment surface) is assumed to occur at 1973 A.D.

The "standard" sedimentation rates derived from a hypothetical "perfect match" at each site are:

Site B (Declination) for 1150 years = 0.075 cm/year.
(Inclination) for 1100 years = 0.075 cm/year.
Site C (Declination) for 1150 years = 0.051 cm/year.
(Inclination) for 1100 years = 0.051 cm/year.
Site E (Declination) for 1150 years = 0.030 cm/year.
(Inclination) for 1100 years = 0.030 cm/year.

These "standard" rates compare with the actual sedimentation rates from Tables 18 through 25 as follows:

Site B Declination (Table 18)
Perfect match = 0.075 cm/year
Actual rate for 760 years = 0.072 cm/year (-4.0%)
Actual average of rates between points =
0.068 cm/year (-9.3%)

Site B Inclination (Table 19)

Perfect Match = 0.075 cm/year

Actual rate for 820 years = 0.073 cm/year (-2.7%)

Actual average of rates between points =

0.078 c/year (+4.0%)

Site C Declination (Table 22)

Perfect match = 0.051 cm/year

Actual rate for 760 years = 0.053 cm/year (+3.9%)

Actual average of rates between points =

0.062 cm/year (+21.6%)

Site C Inclination (Table 23)

Perfect match = 0.051 cm/year

Actual rate for 650 years = 0.054 cm/year (+5.9%)

Actual average of rates between points =

0.063 cm/year (+23.5%)

Site E Declination (Table 24)

Perfect match = 0.030 cm/year

Actual rate for 1150 years = 0.030 cm/year ($\pm$ 0)

Actual average of rates between points = 0.031 cm/year (+3.3%)

Site E Inclination (Table 25)

Perfect match = 0.030 cm/year

Actual rate for 1100 years = 0.030 cm/year ($\pm$ 0)

Actual average of rates between points =

0.036 cm/year (+20.0%)

In addition to any experimental errors involved, the deviations of "actual" from "standard" rates, and the differences in percent of deviation between declination derived rates and inclination derived rates at the same site, are probably a result of non-uniform rates of deposition throughout the column.

While the above sedimentation rate comparisons are not absolute evidence that the playa data are in close agreement with the archaeomagnetic data, the values for each site are similar enough to suggest that some positive relationship does exist.

Checking playa sedimentation rates derived from paleomagnetic data against playa sedimentation rates derived from other methods was more difficult. The difficulty was in finding playa sedimentation rates calculated by other means. Neal (1965) briefly mentioned two instances. In one case a twig was found buried seven feet beneath the surface of China Lake, California. The radio-carbon age of the twig was determined to be 3500 years. When seven feet is converted to centimeters (213.4) and divided by 3500 years, the rate at which the sediments accumulated above the twig is equal to 0.061 centimeters per year, which is close to the paleomagnetically derived sedimentation rates for the two Arizona playas. The second instance Neal mentioned was in the Wah Wah Valley Hardpan in Utah. Here one marker horizon, which appeared to represent the youngest Pleistocene lake level of Ancient Lake Bonneville, was 15 feet beneath the surface of the playa center. Neal gave no age for the marker horizon, but I assumed it to be approximately 10,000 years old, the figure often associated with the last retreat of the Pleistocene ice sheet. Similarly, when 15 feet is converted to centimeters (457.2) and divided by 10,000 years, the rate at which the sediments accumulated above the buried lake level is 0.046 centimeters per year. This value lies between the average sedimentation rates calculated from paleomagnetic data from Site C and Site E.

Schreiber et al. (1972) published a table of radiocarbon dates obtained by others from sediments in and around Willcox Playa, Arizona. From this table, I calculated sedimentation rates that ranged from 0.004 to 0.012 centimeters per year. The average of these rates is less than the paleomagnetically derived sedimentation rates for Willcox Playa by a factor of nine. However, Schreiber suggested that the radiocarbon dates listed in the table may not have been reliable because of low organic content, modern contamination, and mixing due to groundwater movement in the area. For these reasons, I shall not reject my paleomagnetic sedimentation rates for Willcox Playa as being inaccurate. I found no other references to playa sedimentation rates in the literature.

Dr. Leonard R. Wilson, a palynologist at The University of Oklahoma, was unable to detect pollen in the material taken from the playa sediments which I provided him, so we were unable to attempt dating of the specimens at the various levels by that method.

Correlation Coefficients

Correlation coefficients were calculated for the relevant sets of data in order to better determine the relationship between the curves. The method used to calculate the correlation coefficients is briefly explained in the Appendix and fully discussed in Till (1974).

A summary of the results is listed below. The symbol r is the correlation coefficient, and n is the number of points compared between the two curves. The symbol SW refers to the Southwestern U.S. archaeomagnetic curve. Correlation coefficients greater than 0.5 are acceptable as indicators of correlation, and 0.8 or greater indicates a very good correlation. Negative values indicate an antipathy between the curves.

Figure 33.	Site B - Site C Declination	r = 0.55; n = 8
	Site B - Site E Declination	r = -0.83; n = 9
	Site C - Site E Declination	r = -0.76; n = 8
Figure 34.	Site B - Site C Inclination	r = -0.60; n = 8
	Site B - Site E Inclination	r = -0.41; n = 9
	Site C - Site E Inclination	r = 0.09; n = 8
Figure 35.	Site B - Site C Total Moment	r = 0.72; n = 8
	Site B - Site E Total Moment	r = 0.20; n = 9
	Site C - Site E Total Moment	r = -0.27; n = 8
Figure 36.	Site B - Site E Declination	r = -0.24; n =12
	Site C - Site E Declination	r = -0.45; n = 8
Figure 37.	Site B - Site E Inclination	r = 0.31; n =12
	Site C - Site E Inclination	r = -0.51; n = 8
Figure 38.	Site B - Site E Total Moment	r = -0.24; n =12
	Site C - Site E Total Moment	r = 0.94; n = 8
Figure 40.	Site B - SW Declination	r = 0.85; n =13
Figure 41.	Site C (100 Oe) - SW Declination	r = 0.65; n = 8
Figure 42.	Site E - SW Declination	r = -0.27; n =37
Figure 44.	Site B - SW Inclination	r = 0.54; n =14
Figure 45.	Site C (100 Oe) - SW Inclination	r = -0.44; n = 8

Figure 46.	Site C (800 Oe) - SW Inclination	r = -0.06; n = 8
Figure 47.	Site C (800 Oe) - SW Declination	r = 0.84; n = 8
Figure 48.	Site E - SW Inclination	r = 0.31; n =37

The best correlations are between the Site B - Site C total moment curves (r = 0.72), the Site B - SW archaeomagnetic declination curves (r = 0.85), the Site C (800 Oe) - SW archaeomagnetic declination curves (r = 0.84), and the Site C - Site E total moment curves (r = 0.94).

Acceptable correlations exist between the Site B - Site C declination curves (r = 0.55), the Site C - SW archaeomagnetic declination curves (r = 0.65), and the Site B - SW archaeomagnetic inclination curves (r = 0.54).

In general, Site B and Site C declination correlations are acceptable, while Site E declination correlations are not. Only one inclination correlation is acceptable (Site B - SW archaeomagnetic inclination). All other inclination correlation coefficients are less than 0.5.

Other comparisons, such as visual comparisons between the curves and sedimentation rates, should not be rejected on the basis of low correlation coefficients. Variable rates of sedimentation undoubtedly occurred at each playa, as suggested by the different locations of the deflection points on the sediment curves when compared to the archaeomagnetic curves. Because the variable sedimentation rates for each playa were not accurately known, they could not be taken into account when calculating correlation coefficients. If the playa sediment curves could have been adjusted to compensate for known changes in sedimentation rates, there might have been a better correlation between more of the archaeomagnetic and playa sediment curves. The correlation coefficients are a useful quantitative tool, but they are only one means for interpreting the data.

INTERPRETATIONS

With the acknowledged limitations on the reliability of the data, there are still enough indications of agreement between the archaeomagnetic curves derived from baked clays and the paleomagnetic curves derived from playa sediments to suggest some interpretations.

Geophysically, the comparisons made in the previous section confirm earlier results from other methods of investigation that the earth's magnetic field does, through time, change in declination, inclination, and intensity at any given location on the earth's surface. Different methods give essentially the same, or comparable, results.

The comparisons of the previous section indicate that a record of the temporal changes in the geomagnetic field is retained by baked clays containing magnetic minerals and lake sediments of the type found in modern playas. When the baked clays and playa sediments are from the same geographic area of the continent, their paleomagnetic records are sufficiently similar that a correlation between the two can be made. The time variation characteristics of the baked clay curves were confirmed by the results obtained from the playa sediments, and no new "excursions" of the field were found.

Geologically, the comparisons provide a means for calculating sedimentation rates of playas and other sedimentary environments that might preserve an accurate record of temporal changes in the geomagnetic field. It is necessary to determine the age of these changes (in absolute years before the present) by such means as the archaeomagnetic curve before sedimentation rates can be calculated. However, once an accurate paleomagnetic curve has been established from the sediments in a particular feature, such as a playa, it might serve as the "standard" for other depositional rates being investigated in the area. In those instances where a known geomagnetic field-reversal is found at a measureable depth beneath the surface of the sediments, it could serve as a time line. The signatures of the paleomagnetic curves, when compared between sites, offers a new means of stratigraphic correlation.

CONCLUSIONS

The conclusions reached in this section are tempered with the knowledge that many more specimens of playa sediments must be measured magnetically before a thoroughly reliable information is obtained.

One conclusion is that the damp sediment specimens apparently contain a more reliable record of changes in the geomagnetic field than the dry sediment specimens. The dry specimens seem least reliable with regard to inclination. This may be explained by Kerr and Langer's (1965) observation that "fine-grained playas are composed of at least 50 percent clay and possess an exceptionally high colloidal content. Upon dehydration these surfaces undergo marked shrinkage and compaction, and they appear to collapse into a dense, well-bonded structure that is remarkably coherent and stable." It is such shrinkage and compaction that might account for the large inclination errors found in the dry sediments from Smith Creek Valley Playa, Nevada.

A second conclusion is that there does appear to be a record in the sediments of relative changes in the geomagnetic field strength. Before starting this investigation, I was of the opinion that any changes in magnetic intensity found in the sediments would be due entirely to the concentration of magnetic minerals, and would be quite unrelated to the ambient field strength at the time of deposition. However, a comparison of the field-intensity curves for the three playas shows some agreement in the locations of the strong and weak deflections in the curves (see Figure 38).

A third conclusion is that there is a reasonable agreement among the declination and inclination curves of the three playa lakes and the archaeomagnetic declination and inclination curves for Southwestern United States.

Playa specimens more closely spaced in depth are needed to fill the gaps that occur between levels tested in this investigation, and more horizontal rows of specimens are needed to provide additional statistically reliable data (alpha-95's). However, the methods of investigation used here appear to be basically sound, and the implications for both theoretical and practical applications in geology and geophysics warrant continued research in this area.

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APPENDIX

Types of Remanent Magnetization

The following are the most widely used meanings of the terms as they are defined in glossaries or textbooks on the subject of paleomagnetism.

Anhysteritic Remanent Magnetism (ARM)

Remanence produced by the simultaneous application of a constant magnetic field, such as the geomagnetic field, and an initially stronger alternating magnetic field whose amplitude decays to zero. Lightning strikes are thought to produce these conditions in a rock or sediments.

Chemical Remanent Magnetization (CRM)

A stable remanent magnetization produced when magnetic material is formed chemically in rocks or sediments below the Curie temperature. It is caused by the slow growth of magnetically ordered mineral grains in the presence of a magnetic field. The grain size is critical, and above a certain limit the prevailing magnetic field direction is permanently retained by the grains. This magnetization occurs during such chemical processes as oxidation, reduction, and exsolution.

Detrital Remanent Magnetization (DRM)

The magnetization produced in sediments and sedimentary rocks when the magnetic mineral grains are mechanically oriented along the direction of the ambient field during sedimentation, that is, while settling through water. The inclination of the particles is generally less than that of the ambient field, due to the manner in which the elongate grains settle on the bottom surface.

Isothermal Remanent Magnetization (IRM)

The remanent magnetization at zero external field after the rock or sediment specimen has been subjected to a cyclic magnetic field without change of temperature of the specimen.

Natural Remanent Magnetization (NRM)

The permanent magnetization produced in rocks or sediments by natural processes. It can be any one, or a combination, of the various types of remanent magnetization.

Post Depositional Remanent Magnetization (PDRM)

Magnetization produced during consolidation of the sediments after initial deposition, when packing and compression cause realignment of the direction of the magnetic grains.

Piezo (or pressure) Remanent Magnetization (PRM)

The magnetization produced by the simultaneous application of pressure and a magnetic field.

Thermo-Remanent Magnetization (TRM)

The magnetization acquired as a rock cools through the Curie temperatures of its constituent minerals in the presence of an external magnetic field. It is stable, and parallel to the ambient field at the time of cooling.

Viscous Remanent Magnetization (VRM)

The magnetization acquired by the rock or sediment specimen after being subjected to an applied field, such as the geomagnetic field, for a long period of time.

Remanent Magnetization

The component of a rock's (or sediment's) magnetization which has a fixed direction within the rock or sediment and is independent of moderate external applied fields, such as the geomagnetic field.

Primary Magnetization

The component of NRM acquired when the rock was formed. This may represent all, part, or none of the total NRM.

Secondary Magnetization

Subsequent magnetization added by a number of processes to the primary magnetization.

Temporary Magnetization

A special class of secondary magnetization acquired between collection in the field and measurement in the laboratory.

Alternating Field Demagnetization

This brief explanation of the principle of alternating field (a.f.) demagnetization is summarized from Strangway (1970). For a more thorough discussion, one should read the section on Laboratory Tests beginning on page 77 of Strangway's book.

The removal of unstable secondary components of magnetization from rock or sediment specimens is commonly done by means of the a.f. demagnetization technique, which permits detection of the more stable fraction of the natural remanent magnetization. The techniques involve exposing the specimen to peak alternating fields of various strengths. A rock, or sediment, probably will have many different types of minerals in which NRM is present. The NRM will not have a single magnetic field which corresponds to the coercive force, rather the remanence can be divided into parts with different coercive forces. There will be a spectrum of coercive forces. By subjecting a specimen to increasing magnetic fields, some of the lower coercive forces are exceeded and those remanences are removed leaving only the most stable fractions of the NRM in the specimen. For the removal of secondary components the lowest peak field value is chosen which gives the best results, as successively higher fields will eventually weaken or eliminate even the stable NRM.

Statistical Analysis of Magnetic Vectors

Fisher (1953) developed a statistical method for analyzing directions found in paleomagnetic studies which has become the standard among workers in the field. Fisher's method is summarized here, but his paper is recommended for a more complete explanation.

Paleomagnetic researchers generally use a 95-percent confidence level and calculate two statistical parameters (Strangway, 1970). One parameter, alpha-95, is the radius of a cone about a mean direction such that there is a 95 percent probability the true mean direction will lie within this cone.

$$\text{alpha-95} = \frac{140}{\sqrt{kN}}$$

where N is the number of specimens in the sample, and k is the precision parameter.

The other parameter, the precision parameter k, is a measure of the scatter or dispersion of the magnetic directions. If k = 0, the set of directions is completely random. When the grouping of directions is good, k will acquire large values, sometimes values of several hundred.

$$k = \frac{N - 1}{N - R}$$

where N is the number of specimens in the sample and R is the sum of the individual vectors in the mean direction.

Another of Fisher's statistical parameters used in my research is theta-95, the radius of a cone about the mean direction which will contain 95 percent of the direction vectors.

$$\text{theta-95} = \frac{140}{\sqrt{k}}$$

where k is the precision parameter $\frac{(N - 1)}{(N - R)}$ and R is the sum of the individual vectors in the mean direction.

Correlation Coefficients

Following is a brief explanation, adapted from Till (1974), of the method used to calculate those correlation coefficients found in the Discussion of Data section of this thesis. For a more complete explanation of the method, the reader is referred to Chapter 5 of Till's book.

The correlation coefficient r is given by

$$r = \frac{\text{covariance } (x,y)}{\sqrt{[\text{variance } (x) \ \ X \ \ \text{variance } (y)]}}$$

where n values of x and y were obtained. This may be expressed in a form which is simple to compute as

$$r = \frac{\text{CSCP}}{\sqrt{(\text{CSSX} \cdot \text{CSSY})}}$$

where CSCP (corrected sum of cross products) = $\sum xy - \sum x \cdot \sum y/n$

and CSSX (corrected sum of squares of x) = $\sum x^2 - \sum x \cdot \sum x/n$

and CSSY (corrected sum of squares of y) = $\sum y^2 - \sum y \cdot \sum y/n$

Values of r, which is dimensionless, can vary between +1 and -1. If r = +1, x and y have a perfect linear relationship and covary together. If r = -1, there is a perfect antipathy between x and y, and r = 0 means that there is no relationship between x and y.