47.2. PALEOMAGNETIC STRATIGRAPHY

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INTRODUCTION

Measurements of the intensity and direction of remanent magnetization have been made on selected samples from the continuously cored Pleistocene and Pliocene sediment sequences of Sites 125 (Mediterranean Ridge, Ionian Basin) and 132 (Tyrrhenian Rise) in the Mediterranean Sea. The sedimentary record obtained extends back some five and one half million years and covers a time span for which the reversal sequence of the earth's magnetic field is well known.

The geomagnetic time scale to which the reversal sequence is tied, is derived from three different approaches. One consists of direct measurements of radiometrically dated lava flows (Cox *et al.*, 1963; McDougall and Wensink, 1966; and Cox, 1969). This record has been established with a high level of confidence back into the Gilbert reversed magnetic epoch of the lower Pliocene (Dalrymple *et al.*, 1967). The geomagnetic reversal sequence is also seen in the symmetrically distributed linear magnetic anomaly patterns of the crestal areas of the Mid-Oceanic Ridge (Vine, 1968 and Heirtzler *et al.*, 1968). Rapidly spreading regions not only faithfully reproduce every reversal of the field, but also aid in deciphering the relative durations of each polarity event (Pitman and Heirtzler, 1966 and Talwani *et al.*, 1971). A third record of the geomagnetic time scale is provided by uninterrupted sequences of marine sediment (Harrison and Funnell, 1964; Opdyke *et al.*, 1966; Ninkovich *et al.*, 1966; Berggren *et al.*, 1967; Glass *et al.*, 1967; Glass *et al.*, 1967; Hays and Opdyke, 1967; and Hays *et al.*, 1969).

All three of the above approaches are mutually independant, yet they can be combined for the most effective utilization. The radiometric dating gives absolute ages to a few fixed datum points. The sea floor anomaly patterns allow the entire sequence to be interpolated and extrapolated so as to deduce the relative duration of each event or epoch, and the coring permits datums to be placed at key biostratigraphic horizons of worldwide significance. The reliability of this combined approach was effectively demonstrated when drilling the sea bed on key magnetic anomalies during Legs 2, 3, 5, and 9 of the Deep Sea Drilling Project and has permitted the geomagnetic time scale to be extended to more than 70 my (Berggren, 1972).

Statement of Objectives

The magnetic measurements of the Mediterranean DSDP cores from Sites 125 and 132 are listed in Tables 1 and 2 of Chapter 19 of this volume. Also found in that chapter are discussions of the sampling and spinning procedures along with a brief description of the instrumentation used. The objectives of this present chapter are threefold:

1) To interpret the magnetic properties measured in the drill cores in terms of a recognizable magnetic reversal sequence,

2) To correlate the subsequent reversal sequence with established biostratigraphic horizons in the same cores, and

3) To assign the stratigraphic sequence a chronology using the most reliable and up-to-date geomagnetic time scale.

The conclusions arrived at come from a reconnaissance sampling of the drill cores which is consistent with the practices of JOIDES for investigations to be included in the *Initial Reports of the Deep Sea Drilling Project.* Subsequent sampling and additional measurements will have to be undertaken to verify these conclusions.

THE MEASUREMENTS

Since the cores were cut using a rotating drill stem, the direction of declination is meaningless. However, because the drill sites were situated at a fairly high north latitude, the relatively steep inclination of the earth's magnetic field lines there offer an effective method of determining whether the paleomagnetic field was normally or reversely magnetized, provided, of course, that the present fossil magnetism was acquired from the paleofield shortly after the sediment was deposited on the sea floor. This last qualification deserves some emphasis, for, as shown in Tables 1 and 2 of Chapter 19, the measured values of inclination (particularly at Site 132 where a complete column of sediment was recovered) are vastly more positive than negative even though the sediment is believed to have accumulated during a time period in which the polarity epochs were fairly evenly distributed. Consequently, we are suspicious from the beginning that, for many of the samples investigated, the direction of inclination of the natural remanent magnetization alone is not necessarily a reliable record of the ancient magnetic field.

Reliability of the Results

The lack of negative inclination values could have been produced in three ways which will be subsequently evaluated. First, the sediment could have been mechanically disturbed upon coring and remagnetized by the metal drill stem and inner core barrel during the 40 to 90 minutes between the cutting of the core and the extrusion of the plastic liner on the derrick floor. Therefore, being aware of this possibility of misorientation through physical disturbance, samples were only taken where bedding contacts could be seen which were horizontal across the core column. Furthermore, the average of the absolute values of the inclination for all 112 samples at Site 132 is only a few degrees from the theoretical inclination of the present earth's field at the latitude where the cores were taken. Because it is much more probable that mechanical disturbance would have randomized the directions of remanent magnetization, rather than align them, or that an induced field of a vertically rotating steel drill pipe would have left an imprint clearly different from that of the existing field direction, the aforementioned reasons to explain the lack of negative inclinations are discounted.

Another possibility to be considered is that the only sediments sampled are those deposited predominantly during periods of normal field polarity. It takes a slightly circular argument to discard this alternative explanation if we use the reversal sequence arrived at in Figure 1 to demonstrate that the recovered cores span a continuous interval of time from the Late Miocene to Recent. However, we can also base a rebuttal to the alternate explanation on biostratigraphic arguments alone (see Chapters 13, 46, and 47, Part I). We can show that the relative durations of the various foraminiferal and nannofossil zones are consistent in many of the Mediterranean drill holes, and particularly that the nannofossil zones of Site 132 have relative durations directly proportional to those derived from Pacific Ocean sequences which were also continuously cored. Since samples for magnetic measurement were taken from every core of Site 132, and practically from every core section as well, we would have to consider it highly improbable that only normal polarity epochs were sampled.

In fact, the only really plausible explanation we can offer is that the remanent magnetic field measured in the samples is not that of the paleofield at the time the sediment was deposited, but instead, the long normal polarity of the Brunhes epoch of the last 690,000 years has effectively remagnetized older sediment and given it an overprint of positive inclination.

Exactly how a new magnetization is acquired and whether this is a viscous type of remanent magnetization

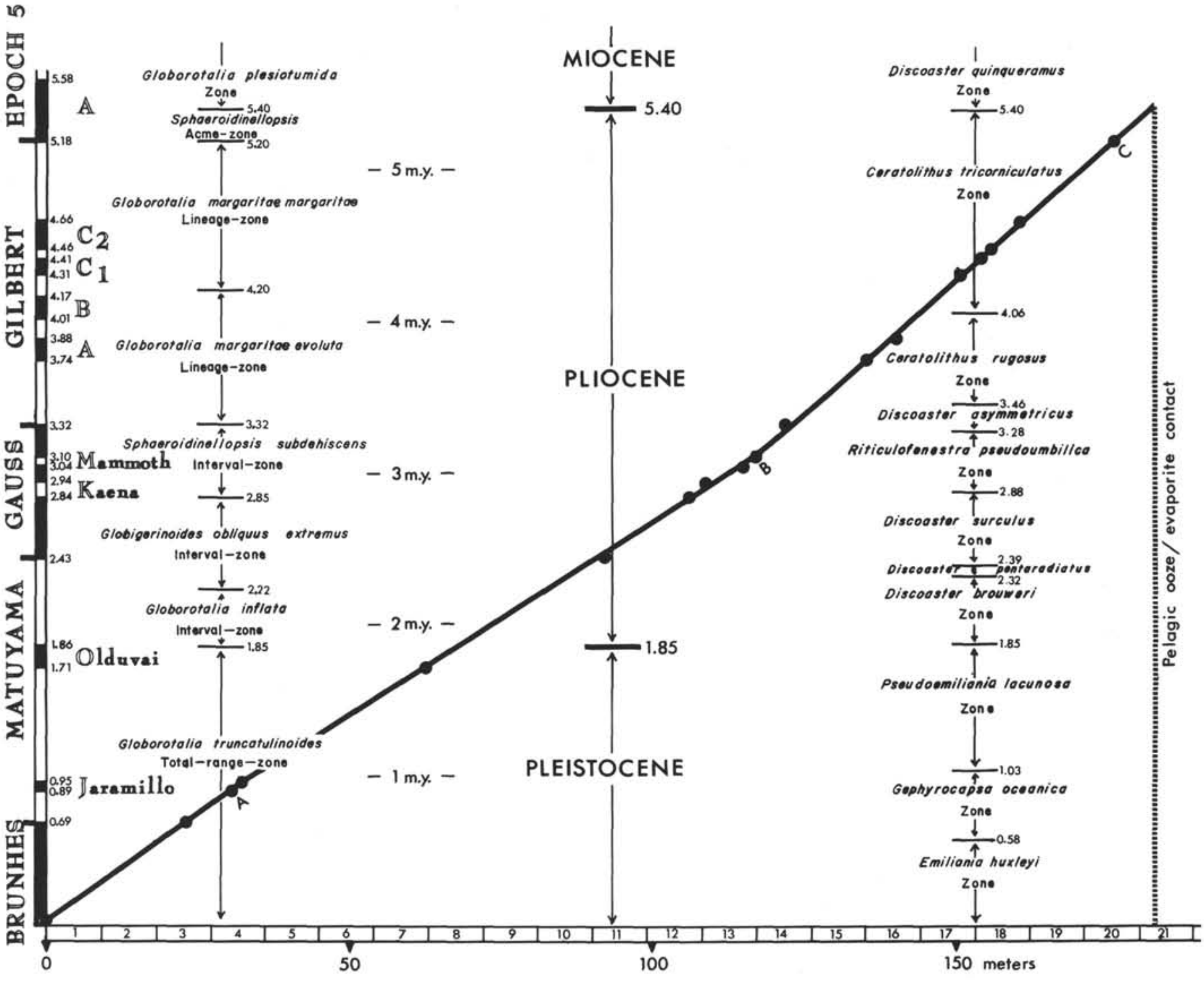

Figure 1. *The interpreted sequence of paleomagnetic reversal boundaries in Hole 132 - Tyrrhenian Basin. The horizontal axis shows the depths of the successive cores which were cut back to back. Dots on the heavy line locate selected boundaries which could be interpreted from the measurements of intensity of magnetization and the direction of inclination and position them relative to the geomagnetic time scale on the vertical axis from Talwani* et al *(1971). Straight segments from the origin to "A", "B", and "C" on the line indicate intervals of uniform sedimentation. The age of the various foraminiferal and nannofossil zonal boundaries are interpolated from the heavy line based on their respective levels in the cores and are considered provisional pending further investigations.*

(Irving, 1964) is not known. What is known is that upon partially demagnetizing many of the samples in alternating fields of 60 cycles of successively higher strengths, the intensity of magnetization was often observed to increase as if a field of opposite polarity were being progressively removed (see for example Figure 1 of Chapter 19) allowing the strength of a previously acquired magnetization to "shine through." Unfortunately, because of the excessive time required to progressively demagnetize each sample, most were not treated in this fashion, although all of them were measured first without demagnetization and then again after a brief immersion in a 100 oe demagnetizing field.

Method of Interpretation

The plots of the direction of inclination of the natural remanent magnetization (NRM) and remanent magnetization after demagnetization (100 oersted) for Holes 132, 125 and 125A are shown in Figures 2 and 3 of Chapter 19. These illustrate that for certain segments of the sediment column the demagnetization process has changed the sample polarity and has produced less scatter around the mean of + 60°, where for other segments of the cores it has produced a greater deviation. Note, in particular the changes in the first three cores of Hole 132 down to a depth of 23 meters and the observation that below there most of the few measurements of negative inclination remain negative after washing even up to fields of 400 oe.

Recognizing that a simple polarity interpretation for most of the core column could not be based on the absolute value of inclination alone, and not wanting to discard the measurements as meaningless and hence useless for stratigraphic purposes, a technique of *subjective interpretation* was devised which places most of its emphasis on the magnetic behavior of the samples during demagnetization. This technique is new, untested, and it rests with the reader whether or not he is convinced there is any reliability to it.

The original aim of the present investigation was to arrive at a magnetic stratigraphy independent of biostratigraphic data, and then subsequently test the validity of the reversal sequence by comparing certain reversal boundaries in the Mediterranean cores which coincided with faunal extinctions with the same boundaries in previously investigated deep-sea cores from the Pacific and Indian oceans where extinctions of the identical species had also been recorded. However, it was not possible to find sufficiently *objective* criteria for an independent interpretation of the magnetic reversal boundaries alone. Consequently, the final interpretation presented in Figure 1 employs several lines of reasoning including both biostratigraphic paleoclimatological, as well as the magnetic data. Listed below are the magnetic criteria used in identifying some of the major reversal boundaries in the sediment sequences of Holes 125, 125A, and 132.

1) Samples of sediment which show an initial increase in intensity of magnetization upon demagnetization in successively stronger induced fields are interpreted to have originally been deposited during a period of reversed polarity.

2) Samples which show a negative inclination before demagnetization and which keep this negative remanent magnetization in alternating fields up to 100 oe are interpreted to have been originally deposited during a period of reversed polarity.

3) Samples which gain negative inclinations after demagnetization are interpreted to have originally been deposited during a period of reversed polarity.

4) Samples which originally had a negative NRM inclination but which revert to a positive inclination after demagnetization in fields up to 100 oe are interpreted to have originally been deposited during a period of normal polarity.

5) Reversal boundaries are characteristically accompanied by low values of magnetic intensity, particularly if the paleofield reversal occurs after a relatively long period of constant polarity.

6) Reversal boundaries are identifiable by marked changes in inclination, even though this does not always involve a flip from negative to positive or vice-versa.

7) Intervals of cores which develop a greater scatter of inclination readings after demagnetization are possibly indicative that the sediment was originally deposited during a period of opposite polarity, though this criterion is not widely applied.

8) More or less uniform rates of sedimentation are assumed for Hole 132 based on the identification of a complete and intact sequence of nannofossil and foraminiferal zones, documented in Chapters 13 and 40. No hiatuses or stretched sections were expected which requires that when the subbottom depths of inferred reversal boundaries are plotted against age, three or more consecutive datum points should fall on a straight line.

9) After an inferred reversal sequence is arrived at, it must conform to the established reversal sequence of the Late Neogene (Foster and Opdyke, 1970). This must be in terms of the relative duration and length of magnetic events and epochs, and extinction horizons of marine fauna in the Mediterranean cores must be more or less time synchronous with equivalent horizons as identified in other cores in the Atlantic, Pacific, and Indian oceans where an independent magnetic stratigraphy is available.

THE INTERPRETED RECORD OF REVERSALS

The interpreted intervals of normal and reversed polarity of the paleomagnetic field for Sites 125 and 132 are shown in Figures 2 and 3 of Chapter 19 where dark shading represents times of normal polarity. The interpretation for Hole 132 is represented in Figure 1 of the present chapter where the subbottom depths of eighteen reversal boundaries are plotted against their age according to the adopted geomagnetic time scale of Talwani *et al*., (1971). Levels of the boundaries which could be identified are discussed in chronological order below along with the criteria used.

Brunhes-Matuyama Boundary

The Brunhes-Matuyama boundary is located at 23 meters below bottom in Hole 132 between Samples 3-3, 27 cm and 3-4, 91 cm based on an abrupt change of the 100 oe inclination curve from positive above to negative below according to criterion (2). The positive polarity of the

Brunhes sediment is attested to by the lack of scatter after demagnetization and the fact that originally negative samples were demagnetized to positive (criteria (7) and (4), respectively).

The Brunhes-Matuyama geomagnetic reversal boundary cannot be recognized in Hole 125 because of poor core recovery and excessive mechanical distrubance of the sediment in Core 2.

Jaramillo Event

The Jaramillo event is represented only in Hole 132 and there by a single sample (4-3, 131 cm) showing a pronounced positive spike with an inclination of +74.9 degrees (NRM). The upper boundary of the Jaramillo event is recognized at 30.5 meters by a change from negative inclination after demagnetization above to positive in the event as per criterion (3). The lower boundary at 32 meters displays a markedly low value of intensity which often characterizes changes of polarity in deep-sea cores (Ninkovich, *et al.*, 1966 and Opdyke, 1972) as discussed for criterion (5), though the sediment immediately below has positive inclinations. The negative inclination spike at 49.5 meters in Sample 6-4-4 cm is not considered an event because it reverts to a positive value upon A-C demagnetization according to criterion (4). As was the case for the Brunhes-Matuyama boundary, the Jaramillo event could not be determined in Hole 125 due to disturbed sediments in Core 2.

Olduvai Event

The Olduvai event is not clearly revealed in the inclination plots of Holes 132 and 125. However, in both sequences the inferred location is bracketed by marked changes in the inclination directions (though they remain positive after demagnetization) and low values of intensity of magnetization per criteria (3), (6), and (5), respectively. In Hole 132, it is the top of the Olduvai event which is most clearly suggested, at 62.5 meters, in the NRM plot, as in Hole 125 where the top of the event occurs at 26 meters. Sample 125-3-6, 132 just above the Olduvai event, although it remained positive, demagnetized to a lower value of inclination and displayed an initial increase in intensity in fields up to 75 oe beyond that measured before demagnetization (criterion 1) to suggest that it was formerly deposited during a period of reversed polarity.

Matuyama-Gauss Boundary

The Matuyama-Gauss boundary shows a change from reversed polarity above to normal polarity below at 92 meters in Hole 132 and at 41 meters in Hole 125A. The sediment recovered below Core 4 in Hole 125 was too scant and disturbed to allow its identification as well as that of any other older magnetic boundary there. Both Samples 132-11-2, 21 cm and 125A-2-2, 49 cm just above the Matuyama-Gauss epoch boundary remained negative after washing, satisfying criterion (2), and the former sample gave a higher intensity at 75 oe than at NRM in accordance with criterion No. 1.

Kaena and mammoth Events

Within the Gauss normal epoch two short reversed events are recognizable in Hole 132. The uppermost appears in two samples, i.e., 12-6, 14 cm and 12-6, 79 cm, between 106 and 107.5 meters, and is believed to be the Kaena event. The other is revealed in only one sample (13-6, 100 cm) at 116.5 meters, and is correlated with the Mammoth event. All three samples remain negative and reveal higher intensities over their NRM values in demagnetization fields up to 100 oe.

The lower boundary of the Gauss epoch is also revealed by an abrupt change from positive to negative inclinations with Sample 132-14-3, 138 cm independently satisfying criteria (1), (2), and (6), thus supporting the proposition that the sediment below was formerly deposited during a period of reversed polarity. Sample 132-14-2m 66 cm immediately above the boundary shows a minimum in its intensity of magnetization as per criterion (5).

Since only three sections of sediment were recovered in Core 14, we cannot be sure whether the Gauss-Gilbert epoch boundary actually occurs at 121.5 meters or deeper, down to 126 meters, where coring was terminated.

Events A, B, C_1 and C_2 of the Gilbert Epoch

The Gilbert epoch is characterized by predominantly reversed polarity with three short normal events, the oldest split by a brief interval of reversed polarity. Nevertheless, it turns out that the inclination values of Holes 132 and 125A for the part of the sediment column corresponding to this epoch are mostly positive, although they exhibit an appreciable scatter of values after demagnetization in an alternating field of 100 oe (e.g., Figure 3 of Chapter 19).

The top of event A which is picked in Hole 132 at 135 meters, just below Sample 15-6, 138 cm, satisfies criteria (1), (2), (3), and (5). Neither boundary of event B is discernable, whereas those of events C_1 and C_2 satisfy criteria (1), (5), and (6). The small reversed interval between C_1 and C_2 is revealed by a single sample which goes to -60.7 degrees in inclination after washing in an 100 oe field.

A single normal event in the Gilbert epoch is identified in Core 5 of Hole 125A at 66.5 meters (Sample 5-4, 100 cm), although we cannot be sure which of the multiple events it is.

The identification of events A, B, C_1 and C_2 in the Gilbert epoch is very tentative since the criteria used are not very strong. The best judge of these inferred reversals is the fact that when the boundaries are plotted against age in Figure 1 they give six points on a straight line as recognized by criterion (8).

Event A of Epoch 5

Epoch 5 (Hays and Opdyke, 1967) is split into two relatively long intervals of normal polarity known as events A (younger) and B (older), separated by a period of reversed polarity. The top of event A in Hole 132 is inferred to be at 175.5 meters below bottom; Sample 20-4, 24 cm, just above the boundary, gives a pronounced minimum of intensity of magnetization (criterion 5), and demagnetizes in a field of 100 oe to an inclination value lower than NRM. As with the normal polarity events of the Gilbert epoch, event A of epoch 5 can only be identified tentatively although its upper boundary falls on the straight line referred to above. Epoch 5 was not seen at Site 125, because of a hiatus of more than one million years between the Pliocene and Late Miocene evaporites.

CORRELATION OF THE REVERSAL SEQUENCE WITH BIOSTRATIGRAPHIC EVENTS

The most powerful test of the inferred paleomagnetic reversal sequence for the Mediterranean drill holes is that biostratigraphic horizons falling at or near a particular magnetic boundary in the recovered cores should be expected to occur also at or near the identical boundary in sedimentary sequences from other regions of the world's ocean populated by similar assemblages of fauna. In one of the most stimulating papers published in the last few years, Hays, Saito, Opdyke and Burckle (1969) have correlated the biostratigraphy of various fossil groups with a clearly defined paleomagnetic stratigraphy of piston cores from the equatorial Pacific and Indian oceans. Levels of evolutionary change and species extinction were demonstrated to be remarkably synchronous over great distances. Assuming *a priori* that the synchroneity of several key datums established by Hays *et al.*, (1969) also applies to the Mediterranean region, we propose, below, to calibrate the inferred Mediterranean reversal sequence to that already established and accounted for elsewhere. Four principal bio-horizons are considered for the time period represented by the Pleistocene and Pliocene sedimentary successions.

First Evolutionary Appearance of *Globorotalia truncatulinoides*

As discussed in Chapters 47.1 and 46, the first evolutionary appearance of *Globorotalia truncatulinoides* evolving from *G. tosaensis*, is considered a reliable biostratigraphic event for recognizing the Pliocene/Pleistocene boundary in marine sediments (Hays and Berggren, 1971). At Site 125 on the Mediterranean Ridge, this event occurs only a meter or so below the extinction horizon of *Discoaster brouweri* which is, itself, very well marked in the Mediterranean drill cores. Paleomagnetic investigations on piston cores from the Atlantic, Pacific, and Indian oceans (Berggren *et al.*, 1967; Berggren, 1968; Glass *et al.*, 1967), have invariably located this evolutionary appearance within or near the base of the Olduvai event, at an age presently estimated to be 1.85 my (Opdyke, 1972).

The first evolutionary appearance of *Globorotalia truncatulinoides*, referred to as Datum IV by Hays *et al.*, (1969), also takes place within the Olduvai event in the Mediterranean cores, where, in particular, it has been noted at 33.5 meters below bottom in Section 5, Core 4 of Hole 125. Although the initial occurrence of this taxon cannot be precisely defined in Hole 132 due to scattered occurrences with very few specimens, its established synchrony with the extinction of *Discoaster brouweri* allows us to place Datum IV at ≈ 70 meters below bottom in the Tyrrhenian Basin at a level just 0.5 meters above the inferred base of this same magnetic event.

We are given additional assurance that the aforementioned correlation is probably close to being correct because the boundaries of the Olduvai and Jaramillo events and the Brunhes-Matuyama epochs, as identified in Hole 132 and plotted against age, fall on a straight line and permit a reasonably accurate interpolation of the Pliocene/Pleistocene boundary at 1.85 my.

Extinction Horizon of *Sphaeroidinellopsis*

The level of extinction of representatives of the genus *Sphaeroidinellopsis* was first noted by Glass *et al.*, (1967) to fall near the top of an event of reversed polarity recognized in Pacific Ocean cores and inferred to lie within the Gauss normal epoch. At that time only a single event, called the Mammoth, was recognized in this epoch. Hays *et al.*, (1969) also recognized this extinction horizon in an Indian Ocean core (their Datum V) where they again assign it to the top of the Mammoth event.

The former single event was subsequently shown to be two short events separated by a brief period of normal polarity lasting less than 100,000 years. In the cores from Hole 132 in the Mediterranean the extinction of representatives of the genus *Sphaeroidinellopsis* occurs in Section 5 of Core 12 at 107 meters below bottom, which, from the inferred magnetic stratigraphy, places it in the younger of the two reversed events. This younger event, called the Kaena event has an interpolated age of 2.85 my in Hole 132. Although this level does not agree precisely with the interpretation of Glass *et al.*, (1967) or Hays *et al.*, (1969), the former investigators did not recognize a split in their relatively large single reversed event and the latter investigators only measured a 10 centimeter gap between the bottom of the Kaena event and the top of the Mammoth event in their Pacific Ocean core V24-59. In a personal communication to the author, B. Glass expressed no particular concern that the Mediterranean finding placed the datum in the Kaena, rather than in the Mammoth event, and he said that he felt the interpolated age of 2.85 my for the extinction horizon in Hole 132 agreed sufficiently well with his earlier inference of 3.0 my so as not to doubt the validity of the interpretation of the reversal sequence there.

The Kaena event was not recognized in Holes 125 or 125A, but the extinction level of the genus *Sphaeroidinellopsis* in Core 2 of Hole 125A agrees with the inferred placement of the Matuyama-Gauss epoch boundary, between Samples 2-2, 49 cm and 2-2, 122 cm at 41.5 meters below bottom.

Extinction Horizon of *Globorotalia margaritae*

Another level of correlation is provided by the widely recognized extinction horizon of *Globorotalia margaritae* (group) which has been noted to occur in Pacific and Indian ocean cores invariably at the Gauss-Gilbert epoch boundary (Datum VI of Hays *et al.*, 1969).

In the interpreted reversal sequence for Hole 132, the level of this extinction, just above the core catcher of Core 14 at 121.5 meters, precisely matches the assignment of this paleomagnetic boundary. Although no magnetic measurements were made on sediments from Holes 125 and 125A in the vicinity of this horizon, the perfect correlation at Hole 132 lends significant support to the reversal interpretation at least from the top of the hole back to 3.32 my.

Evolution of *Sphaeroidinella* from *Sphaeroidinellopsis*

The first evolutionary appearance of *Sphaeroidinella* has been known for some time to have taken place in the lowermost part of the Pliocene of the Mediterranean region. Blow (1969) recorded this "*Sphaeroidinella* datum" very close to the bottom of the Trubi formation of Sicily (defining his N.18/N.19 boundary), and we have found it near the top of epoch 5 in the upper part of the *Sphaeroidinellopsis* Acme-zone, less than 9 meters above the top of the evaporites in Hole 132 (see Chapter 47.6).

Despite the fact that the piston cores from the Pacific and Indian oceans investigated by Hays *et al.*, (1969) do not extend into epoch 5, the presence of *Sphaeroidinella* in the bottom of Core V 24-59 below event C of the Gilbert epoch certainly suggests that this bio-horizon is at least older than 4.7 my. The reversal sequence of Figure 1 places it at 5.2 my.

Though there is a good possibility that the reversal boundaries picked in the Gilbert epoch in Hole 132 are in error and the presented correlations make the Lower Pliocene too old, this cannot be diagnosed at present. We note an inflection of the age-depth curve of Figure 1 at the letter "B", resulting in lower rates of sediment accumulation for the basal Pliocene, yet we also have nine datum points on a straight line there.

Our inferred age of the Miocene/Pliocene boundary at the top of the evaporites in Section 2 of Core 21 is ≃ 5.4 my. This corresponds reasonably well to an age of 5.2 my recently assigned by van Couvering and Miller (1971) in their radiometrically dated late Miocene marine and nonmarine time scale of the Neogene.

DISCUSSION OF THE INTERPRETED RECORD

As mentioned previously, the criteria used for interpretation of the reversal boundaries in Holes 125, 125A, and 132 are new and untested, and thus should be considered controversial at best. However, the sequence of reversals arrived at by following the proposed criteria is markedly similar to that established from several other independent lines of evidence. Furthermore, when the depths of the several boundaries continuously cored in Hole 132 are plotted against the most recent assessment of their ages (Talwani *et al.,* 1971), we find an excellent clustering of data points to three straight line segments.

Discrete points on the line segments are themselves independently tied to four biostratigraphic datums whose level in the several sequences has already been established and whose ocean-wide synchroneity has been proved. Furthermore, the lowermost Pliocene pelagic sediments, which lie directly above the Mediterranean evaporite (see Chapter 43) in Section 2 of Core 21, have an extrapolated age only a few hundred thousand years older than that which has just recently been assigned to the Miocene/Pliocene boundary.

Consequently, we believe that until further measurements can be made on the drill cores, hopefully employing thermal demagnetization techniques, there is good reason to accept the correlations proposed here and to use them to interpolate absolute ages of various biostratigraphic events by means of the geomagnetic time scale.

Ages and Durations of the Various Faunal Zones

Since Hole 132 was continuously cored and apparently contains an uninterrupted sequence of more or less uniform sedimentation, the ages of numerous biostratigraphic events can be interpolated with considerable relative accuracy from the age-depth relationship of Figure 1. The Pliocene and Pleistocene sequence in the Tyrrhenian Basin comprises seven foraminiferal zones and ten nannofossil zones.

Criteria to identify the boundaries of the different zones are presented in Chapters 13, 40, and 47.1. The precision of the boundaries depends in part on the shipboard sampling intervals and the fact that only an optical microscope has been used in identifying the discoasters and coccoliths. The interpolated ages appear in Figure 1 and require no further discussion here. One can see that except for the *Globorotalia truncatulinoides* Total-range-zone of the Pleistocene, the Pliocene foraminiferal zones are more or less of equivalent duration. The *Discoaster pentaradiatus* nannofossil zone is extremely short (≃ 0.07 my years) and the *Ceratolithus tricorniculatus* Zone rather long (≃ 1.34 my). The age of the base of the *Emiliania huxleyi* Zone at 0.58 my is only an estimate since this taxon is extremely small and very difficult to identify with certainty when using an optical microscope.

Because there are seventeen paleomagnetic reversal boundaries and as many biostratigraphic boundaries recognized in Hole 132, the last 5.4 my of Mediterranean history can be subdivided with an appreciable relative precision for beyond that of the average duration of individual late Neogene climatic cycles (see Chapter 47.3). This means that event for event the stratigraphic and lithologic record of Hole 132 becomes a very significant meter stick on which we can mark out a detailed chronology of geologic happenings in the Mediterranean Basins. It is anticipated by the authors of this chapter that subsequent studies on these important cores will take full advantage of this relative time scale and lead us into new avenues of research on cyclic geological phenomena.

Correlations Between the Ionian and Tyrrhenian Basins Based on the Magnetic Properties of the Sediments

The ratio of the intensity of the natural remanent magnetization in selected samples to the specific susceptibility affords a measure of the inherent magnetic properties of the sediment independent of the particular sample orientation. For instance, we might expect that a sediment rich in volcanic components (tephra) or certain ferro-magnetic minerals would show different readings than sediments containing primarily biogenic skeletal debris.

Figure 2 shows variations in this ratio of magnetic intensity to specific susceptibility for the sediment columns of Sites 132 and 125 where the data from each site have been plotted on a linear time scale against the established reversal sequence of Talwani *et al.*, (1971). The age assignments for the various samples from Hole 132 have been derived directly from the interpreted reversal sequence by linear interpolation between the inflection points "A", "B", and "C" in Figure 1. The age assignments for the samples from Holes 125 and 125A are from a combination of sources including interpolations of recognized magnetic reversal boundaries, the age of assignments of faunal boundaries shown in Figure 1, and by detailed correlations of certain discrete beds to Hole 132 as discussed in Chapter 46.

A certain repetition of low and high intensity/susceptibility ratios appears in both the Tyrrhenian and Ionian basin sequences which seems to suggest that changes

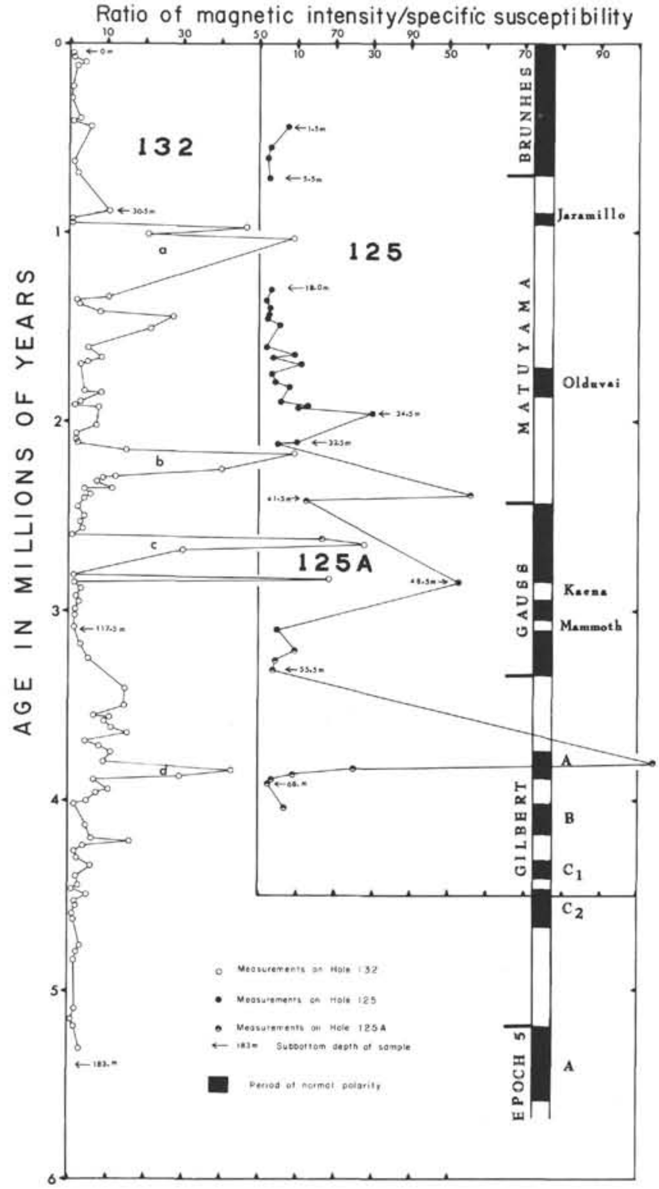

Figure 2. *Ratios of magnetic intensity to specific susceptibility for the three drill holes, where the individual samples have been plotted against the geomagnetic time scale according to their interpolated ages (see text for discussion). The rough coincidence of peaks suggests synchronous variations in the Tyrrhenian and Ionian basins in the accumulation of sediment with different properties of magnetization, since neither of the two parameters is dependent on sample orientation.*

in the sediments which affect the magnetic properties are synchronous over large distances in the Mediterranean. The variations might perhaps be partially controlled by the oxidation-reduction levels of the sea floor environment, which have been shown to fluctuate with repeated changes in the regional climate (see Chapters 47.3 and 47.4), or they might reflect the influx of certain mineral components. Layers of sapropelitic mud which accumulated during periods of basin-wide stagnation (Olausson, 1965) apparently possess very weak intensities of magnetization (Ryan, 1971; Opdyke *et al.*, 1972).

The matching of the two curves in Figure 2 provides some slight support for the stratigraphic correlations between the two basins worked out independently with biostratigraphic and climatic criteria. It is interesting to note that the Lower Pliocene is characterized by very low ratios consistent with a high level of oxidation observed in the recovered oozes, particularly the red colored hues in Cores 19, 20, and 21.

CONCLUSIONS

A sequence of magnetic reversal boundaries has been interpreted from measurements of intensity and direction of inclination of magnetization on selected samples from two continuously cored sites in the Mediterranean. The reversal sequence closely resembles that derived from the pattern of sea floor magnetic anomalies in the crestal areas of the mid-ocean ridge and extends back into epoch 5.

Four horizons, representing faunal extinctions and first appearances, have been located in the interpreted reversal sequence. Their position relative to the geomagnetic time scale is identical to that which has previously been established in Pacific, Indian, and Atlantic Ocean piston cores.

The Pliocene/Pleistocene boundary in the Mediterranean, based on the extinction of *Discoaster brouweri* and the first evolutionary appearance of *Globorotalia truncatulinoides*, occurs in the Olduvai event of the Matuyama epoch at an interpolated age of 1.85 my. The Miocene/Pliocene boundary, marking the first occurrence of deep-water marine sediments following the "crises of salinity" during which evaporites were deposited, has an extrapolated age of ≈ 5.4 my and lies with event A of epoch 5.

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47.3. PALEONTOLOGICAL EVIDENCE OF CHANGES IN THE PLIOCENE CLIMATES

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INTRODUCTION

During the shipboard investigations of the Pliocene sections continuously cored at Sites 132 (Tyrrhenian Basin) and 125/125A (Mediterranean Ridge, Ionian Basin), changes in the foraminiferal associations were noticed. It was suspected that fluctuations in assemblages at various stratigraphic horizons had been influenced by a combination of then unknown paleoenvironmental factors, notwithstanding the ever present interaction of biological evolution.

The purpose of the present study was to examine in some detail the populations of foraminifera in the Pliocene sedimentary sequences from these two sites in an attempt to learn something about ecological responses of the fauna which can be attributed particularly to changes in the Pliocene climate of the Mediterranean region.

It was anticipated early in the cruise that what we thought were fluctuations in faunal diversity would reflect past environmental variations in the Mediterranean. Caution was required at first because initial observations showed that in the Pliocene sediments diversity, as measured by the number of taxa in any single association, is not highly variable and is far less variable than in the Glacial Quaternary, where changes from less than ten to more than twenty taxa have been observed within one core section (1.5 m of sediment), during a time period when distinct climatic changes were known to have occurred (see Chapter 46). The number of taxa recorded in the Pliocene sediments ranges from fifteen to twenty-five, with fluctuations amounting to mostly less than twenty-five per cent.

The Possibility of Using Certain Genera

The number of species belonging to the genera *Globigerina, Globigerinoides,* and *Globorotalia* is highly vari-