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Middle and Late Miocene stable isotope stratigraphy: Correlation to the paleomagnetic reversal record

ABSTRACT

The Late Miocene oxygen isotope stratigraphy in DSDP Site 158 can be correlated to the paleomagnetic reversal record using planktonic diatoms. Two oxygen isotope events that record, in part, the growth of the East Antarctic ice sheet are tied in this way to the lower part of Magnetic Epoch 11 and the lower part of Magnetic Epoch 10 (approximately 11 and 10 Ma [mega-annum], respectively).

INTRODUCTION

Keigwin (1979) reported on Late Cenozoic oxygen isotope stratigraphy and paleoceanography of DSDP Site 158 from the eastern equatorial Pacific. That study, which included DSDP Sites 157 and 310, called attention to isotope evidence for the growth of the East Antarctic ice sheet and further concluded that the Late Miocene was a time of climatic instability, probably associated with changes in the Antarctic ice cap. In Site 158, a number of distinct climatic events can be recognized in the oxygen isotope record. Keigwin (1979) noted a major change at approximately 280 m depth in Middle Miocene levels of Site 158, and a distinct cooling interval in the Upper Miocene at about 140 m depth, closely associated with a significant and apparently isochronous shift in benthonic ^{13}C from heavy values below to lighter values above (Bender and Keigwin, 1979).

Shackleton and Kennett (1975a, 1975b) and Savin et al. (1975) identified a major climatic event for the Middle Miocene using both oxygen isotope evidence and biotic events. According to these authors this climatic event occurred about 14 Ma and featured the development of the East Antarctic ice sheet. The build-up was essentially completed by 10–12 Ma. According to Kennett (1977), this oxygen isotope event was associated with a northward expansion of the belt of siliceous biogenic sediment (Tucholke et al., 1975) and the initiation of ice rafted debris (Margolis, 1975). Similar biotic studies indicate that the formation of the East Antarctic ice cap was accompanied by a decline in high latitude surface water temperatures (Edwards and Perch-Nielsen, 1975; Burns, 1975). In the equatorial Pacific, Van Andel et al. (1975) reported that the lysocline reached its present depth around this time. Further, Leinen (1979) noted a marked increase in biogenic silica production during the Middle Miocene in the Antarctic and for the equatorial Pacific.

The oxygen isotope event that marks the initiation of Antarctic glaciation has also been observed in Miocene sediments in the equatorial and North Pacific (Savin et al., 1975; Keigwin, 1979). Keigwin (1979) identified this event in Site 158 in the Panama Basin and Site 310 on the Hess Rise. At Site 310, late Middle Miocene sediments unconformably overlie the Oligocene. Site 158, on the other hand, appears to be reasonably complete, at least for the Middle and Late Miocene. The age of basement at this site has been estimated at 15 Ma (Van Andel et al., 1973), in comparison with the 14 Ma date given for the initiation of the Antarctic glaciation by Shackleton and Kennett (1975b).

Keigwin (1979) indicated that there is a 2.5‰ enrichment in ^{18}O of benthonic carbonate from a basal chert layer to about 140 m depth. He interprets this to reflect the combined effects of the growth of the Antarctic ice sheet and post-depositional alteration. Two shifts in the ^{18}O record are recorded (Keigwin, 1979). The oldest, at 234 m depth, involves a shift of approximately 0.7 parts per mil, while the second, at 210 m, involves a shift of approximately 0.4 parts per mil. Since our previous work on diatoms and paleomagnetic stratigraphy has largely been concerned with the equatorial Pacific (Burckle, 1972, 1977, 1979; Burckle and Opdyke, 1977; Burckle and Trainer, 1979), Site 158 seems ideal for tying these oxygen isotope shifts to the paleomagnetic record. Given a reasonably good time scale in the paleomagnetic reversal record (LaBrecque et al., 1977), such a study would further allow us to determine both the timing and duration of the ^{18}O shifts. Additionally, the position of Site 158 along the eastern boundary current allows for correlation with the Experimental Mohole Site off the coast of Mexico (Riedel, 1957; Dymond, 1966).

METHODS AND SOURCES OF DATA

Permanent diatom slides were prepared using the procedure described by Burckle et al. (1978). Oxygen isotopic analyses were performed on specimens of the benthonic foraminifera *Uvigerina* sp. and *Globocassidulina subglobosa* (Brady) following standard procedures (Keigwin, 1979). These foraminifera are thought to secrete their calcite tests in isotopic equilibrium with the ^{18}O defined by

$$\delta^{18}O = \left(\frac{^{18}O/^{16}O \text{ sample}}{^{18}O/^{16}O \text{ reference}} - 1\right)$$

10^3 of ambient seawater (Shackleton, 1973; Shackleton and Opdyke, 1977) and analysis of these specimens from the same sample gives equivalent $\delta^{18}O$ results at DSDP Site 158 (Keigwin, 1979).

Table 1 gives the location, length and water depth of the six deep sea sites that were examined for this study. Of these, four are piston cores with a paleomagnetic reversal record. As text-figure 1 shows, our objective is to use diatoms to tie the four paleomagnetically dated piston cores to the fifth core, that of DSDP 158. This site, finally, is correlated to the Experimental Mohole Site. Most of the piston cores have already been partly described (Opdyke and Foster, 1970; Opdyke, 1972; Burckle, 1972), but we have selected additional diatom datum levels which permit us a higher degree of resolution. The diatoms in Site 158 have been described by Bukry and Foster (1973) and Burckle and Opdyke (1977), while those of the Experimental Mohole Site have been described by Kanaya (1971) and Schrader (1974). In each case we re-examined the diatoms with results that, in some cases, modify previously published ranges. The time-scale for paleomagnetic reversals used here is taken from LaBrecque et al. (1977); the K-Ar ages obtained by Dymond (1966) from ash layers in the Experimental Mohole are included in text-figure 1 for reference only, and are not used to calibrate our results.

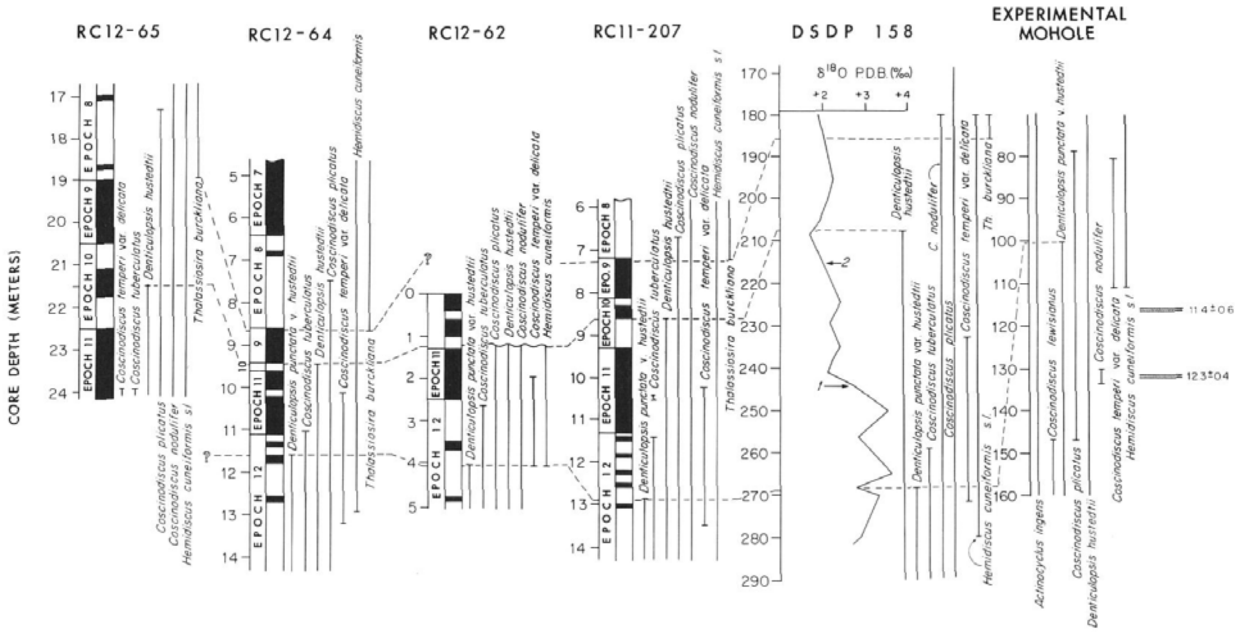
TABLE 1
DSDP sites and pistons measured in this study.

	Lat./Long.	Water Depth (m)	Length (cm)
DSDP Site 158	06°37'N, 85°14'W	1953	3231
Experimental Mohole Site	28°59'N, 117°30'W	948	—
RC11-207	07°24'N, 139°56'W	5081	1440
RC12-62	06°44'N, 141°22'W	5073	1303
RC12-64	05°42'N, 143°10'W	4857	1435
RC12-65	04°39'N, 144°58'W	4868	2426

RESULTS

Three of the piston cores that were studied (RC11-207, RC12-62, RC12-64) have a paleomagnetic stratigraphy that extends into the lower part of Magnetic Epoch 12. Our data (Burckle, 1978; Theyer and Burckle, in preparation) indicate that Magnetic Epoch 13 should be just below the base of all these cores. The earliest datum level in these sections is *Coscinodiscus temperi* var. *delicata* Barron, which appears in the middle part of Magnetic Epoch 12. Just above this datum is the first occurrence of *Hemidiscus cuneiformis* Wallich s.l. In this paper, we have chosen to recognize this species in the broader sense. Other workers (for example, Hanna and Grant, 1926; Schrader, 1974) have divided this form into *H. simplicissimus* Hanna and Grant and *H. cuneiformis*. However, since both forms are relatively uncommon in Middle Miocene sediments of the equatorial Pacific we feel that combining them will give us more reliable stratigraphic control. In the Experimental Mohole Site, *C. temperi* var. *delicata* and *H. cuneiformis* s.l. both appear at the same level (110 m) suggesting a hiatus at this level.

The last appearance of *Denticulopsis punctata* var. *hustedtii* Schrader occurs just above the *Hemidiscus cuneiformis* datum in the middle part of Magnetic Epoch 12. The uppermost part of this Epoch is easily recognized by the last occurrence of *Coscinodiscus tuberculatus* Kolbe, although in some cores this species ranges up into the basal part of Magnetic Epoch 11. It is apparently restricted to low latitudes, since it is not recorded in the Experimental Mohole Site (Kanaya, 1971; Schrader, 1974). This species reappears in the middle part of Epoch 11 in the Central Pacific. How-



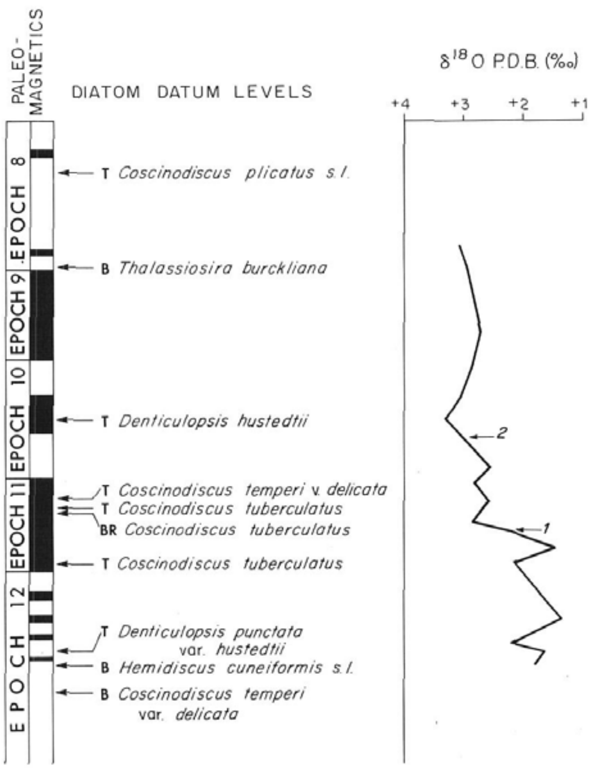
TEXT-FIGURE 1
Paleomagnetic and diatom stratigraphy and oxygen isotope record for cores used in this study. Dotted lines indicate proposed correlations between sites. The oxygen isotope record on DSDP Site 158 is from Keigwin (1979) and the K-Ar dates on the ash layers in the Experimental Mohole are from Dymond (1966).

ever, we do not record this re-occurrence in DSDP Site 158 or the Experimental Mohole Site.

Just above the last appearance of *C. tuberculatus* in the middle of Epoch 11 is the final occurrence of *C. temperi* var. *delicata*. Although Barron (personal communication) reports this species recurring higher up in this section, its last Middle Miocene occurrence in the equatorial Pacific appears to be consistently tied to the middle part of Magnetic Epoch 11. The same point cannot be made for the next datum level, *Denticulopsis hustedtii* Simonsen and Kanaya. This form disappears in the middle of Magnetic Epoch 10 in low latitude Pacific cores but ranges up into the latest Miocene (Magnetic Epoch 6) in the North Pacific (Harper, 1977; Koizumi, 1977) and into the lower part of the Gilbert in the South Pacific (McCollum, 1975; Burckle and Opdyke, 1977). This point is illustrated in the Experimental Mohole Site where *D. hustedtii* ranges well above the next youngest datum and is certainly not isochronous with the low latitude last occurrences in the central Pacific and the eastern equatorial Pacific. However, our data (text-fig. 1) suggest that its last occurrence in the equatorial Pacific is isochronous. Similarly, the last occurrence of *Thalassiosira burckliana* Schrader appears to be isochronous in low latitudes of the Pacific at the top of Magnetic Epoch 9. Its presence in DSDP Site 173, off the north coast of California, and its absence from the Experimental Mohole Site suggest that a part of the middle Late Miocene may be missing from the latter.

Finally, we have the last appearance of *Coscinodiscus yabei* Kanaya in the middle of Epoch 8. There is some suggestion that the last appearance of this form may be diachronous into the higher latitude North Pacific but we have no direct evidence to substantiate this. Our data indicate that the last occurrence of this species is isochronous to at least 30°N.

Text-figure 2 is a composite of the paleomagnetic and diatom stratigraphy for the four piston cores studied in this report. We have utilized the diatom stratigraphy to make an approximate tie between the oxygen isotope record in Site 158 and the paleomagnetic reversal record. This correlation places the oldest oxygen isotopic increase in the lower part of Magnetic Epoch 11 and the younger event in the lower part of Magnetic Epoch 10, using the calibration of LaBrecque et al. (1977). Epoch 10 is 10.45 to 10.91 Ma at its top and bottom, respectively, while Magnetic Epoch 11 is 11.4 Ma at its base. These ages imply that the oldest event began around 11.3 Ma and was completed in less than 200,000 years. Similarly, the next youngest event, in the lower part of Epoch 10, occurred over an interval of about 250,000 years. The isotopic event associated with the ^{13}C shift has previously been shown by Bender and Keigwin (1979) to occur in Magnetic Epoch 6 (see also Haq et al., 1980).



TEXT-FIGURE 2
Composite showing the proposed correlation between the paleomagnetic reversal stratigraphy and the oxygen isotope record. Diatom datum levels were used to tie several piston cores from the central Pacific to DSDP Site 158. Symbols: T, Top; B, Base; BR, Base recurring species.

DISCUSSION

Oxygen isotope evidence for the growth of the East Antarctic ice sheet has previously been noted by Shackleton and Kennett (1975a, 1975b) and Savin et al. (1975). It seems apparent, however, that Site 158 did not penetrate through the entire Middle Miocene. Therefore, the earliest stages in the growth of the ice sheet are not recorded at this site although the isotopic data record considerable Middle and Late Miocene climatic instability. Three stages in climatic deterioration during this period are noted—the latest Middle Miocene, early Late Miocene, and late Late Miocene—and some, if not all, of these stages are accompanied by concurrent paleoceanographic and/or biotic events.

In the North Pacific, Keller (in press) has recognized three cold pulses in the Middle and early Late Miocene. The earliest pulse comes in Blow's (1969) zones N14 and N15 and may correlate, in part, with our earliest oxygen isotope event in Site 158. The second pulse occurs in the middle of Zone N16 and appears to be correlative with a cool event that we record in magnetic Epoch 10 of Site 188. The final event is easily correlated to Magnetic Epoch 6 since it occurs in association with the isochronous ^{13}C shift (Bender and Keigwin, 1979; Loutit and Kennett, 1979).

Leinen (1979) has recorded a significant increase in the accumulation of biogenic opal at about 11 Ma for Pacific sediments. Brewster (1980), on the other hand, recorded an enormous increase in silica accumulation in the Antarctic during the latest Miocene at a time when equatorial Pacific silica accumulation was declining (Leinen, 1979). Both of these authors suggested that the global silica budget was altered as a result of Neogene climatic changes.

Some evidence of that may be seen in a detailed examination of DSDP Site 158. Accompanying the oxygen isotope event in Magnetic Epoch 11 in Site 158 is a marked change in the diatom flora. Below this event, the diatoms are associated with manganese micro-nodules and are characterized by highly solution-resistant forms such as the genus *Denticulopsis* and more thickly silicified representatives of the genus *Coscinodiscus*. A complete change takes place at 234 m depth. Great masses of *Thalassionema nitzschioides* (Grunow) and varieties come in accompanied by a marked change in sediment character. This change can be interpreted in the light of evidence that we have accumulated on diatoms in surface sediments of this region. In present-day sediments of the equatorial Pacific, Cooke-Poferl et al. (1975) have identified four distinct diatom assemblages. Three of these are major assemblages and are associated with the Peru-Chile current, the north and south equatorial current and the North Pacific counter current. The Peru-Chile current is characterized by *Thalassionema nitzschioides* and T. *nitzschioides* var. *parva* Heid. In species composition and abundance the diatoms in DSDP Site 158 just above the 234-m level is most similar to the present-day Peru-Chile current assemblage. Further, it should be pointed out that this site can be backtracked to a lower latitude eastern equatorial Pacific position for the late Middle Miocene.

Since diatoms are at the base of the food chain, this may have forced some biotic changes at higher trophic levels. Specifically, we suggest that sea bird diversity and/or abundance may have been affected by this change. Similarly, marine mammals may also have been affected. Lipps and Mitchell (1976), have suggested that periodic increases in upwelling during the Cenozoic may account for the development, distribution, and extinction recorded for sea mammals during this period. They point out that the pinnipeds (seals, sea lions, walruses) have a scant record in the Early Miocene of California (Wilson, 1935; Mitchell and Tedford, 1973) but are fairly diverse by Middle Miocene times (Mitchell, 1966; Barnes, 1972).

SUMMARY

Two oxygen isotope events in DSDP Site 158 record, in part, the growth of the east Antarctic ice sheet. These events have been correlated to the paleomagnetic reversal record and have been dated at 11 and 10 Ma (late Middle Miocene and early Late Miocene), respectively. Our preliminary data based upon a study of other equatorial Pacific DSDP sites and piston cores suggest that there is a third, unique, oxygen isotope event which occurs near the Magnetic Epoch 14/15 boundary (early Middle Miocene). Thus, our data are not in disagreement with the original contention of Shackleton and Kennett (1975b) that the east Antarctic ice sheet was initiated about 14 Ma and reached full growth about 10 Ma. Rather, we show that the ice sheet grew in several distinct stages, two of which are recorded in DSDP Site 158.

ACKNOWLEDGMENTS

We thank Constance Sancetta and Peter Thompson for critically reviewing the manuscript and offering many helpful suggestions. Piston cores used in this study were obtained and curated under National Science Foundation Grant OCE78-25448 and Office of Naval Research Grant N00014-75-C-0210 Scope E. Material from Site 158 of the Experimental Mohole were provided by the Deep Sea Drilling Program and W. R. Riedel of Scripps Institute of Oceanography. Research was supported by National Science Foundation Grants OCE78-20885 and OCE79-19092. This is Lamont-Doherty Geological Observatory of Columbia University Contribution No. 3374.

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Manuscript received May 26, 1981.
Revised manuscript accepted August 18, 1981.