Correlating Miocene sequences in onshore New Jersey boreholes (ODP Leg 150X) with global $\delta^{18}$O and Maryland outcrops

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ABSTRACT

Recent onshore New Jersey drilling (Ocean Drilling Program Leg 150X) provided excellent recovery of lower to middle Miocene sequences that we dated with Sr isotopic stratigraphy. Sequence boundaries correlate with deep-sea $\delta^{18}$O increases (inferred glacioeustatic lowerings), indicating a primary control by global sea-level change. Maryland Miocene outcrops appear to correlate with New Jersey sequences and the $\delta^{18}$O record, although diagenesis and intense bioturbation limit Sr isotopic age resolution in Maryland. The early Miocene is not well represented in Maryland due to regional tectonics; in contrast, early Miocene accommodation in New Jersey was provided by flexural effects due to sediment loading.

INTRODUCTION

The Oligocene-Holocene is an interval suitable for evaluating the relation between glacioeustasy inferred from $\delta^{18}$O studies (e.g., Miller et al., 1991; Wright and Miller, 1992) and the deposition of sequences on passive margins. The U.S. Middle Atlantic Coastal Plain (Fig. 1) provides an excellent record of shallow-marine sequences, particularly in Miocene outcrops in Maryland and Virginia and the New Jersey subsurface. However, previous studies of the Miocene outcrops were limited by poor age correlations due to the absence of index fossils. Initial efforts to date Miocene sequences in New Jersey with Sr isotopes suggested a possible correlation between sequences and $\delta^{18}$O changes (Sugarman et al., 1993), although the study was limited by discontinuous sampling of boreholes. As part of the New Jersey Sea Level Transect, Leg 150X (a collaboration of Continental Scientific Drilling and the Ocean Drilling Program) drilled three continuously cored boreholes at Island Beach, Atlantic City, and Cape May, New Jersey (Miller et al., 1994, 1995; Fig. 1). We provide detailed Sr isotopic age estimates for the Miocene sequences at the Atlantic City and Cape May boreholes and compare them to Maryland outcrops (Fig. 1).

The Miocene strata of Maryland and Virginia (Calvert and Choptank Formations) have provided an informal standard for shallow-water sequences because of the extensive studies of outcrops along Chesapeake Bay (the Calvert Cliffs, Fig. 1; e.g., Shattuck, 1904; Gibson, 1971; Andrews, 1988; Kidwell, 1984; Ward, 1992). The age correlations of the outcrops are not known with certainty because they lack good plankton biostatigraphic control. The primary means of dating the outcrops has been through provincial mollusk (Ward, 1992) and diatom zonations (Andrews, 1988) that are poorly correlated to the time scale.

Sr isotopic stratigraphy allows the calibration of Oligocene shallow-marine sequences to the time scale with age resolution of $\pm 0.4$ m.y. for the early Miocene and $\pm 0.9$ m.y. for the middle Miocene (e.g., Oslick et al., 1994). We synthesized published (Sugarman et al., 1993; Miller et al., 1994, 1995) and new Sr isotopic results from the New Jersey boreholes (Fig. 1) with new Sr isotopic results from Maryland outcrops (Table 1). Sr isotopic data were generated on shells using standard techniques (Sugarman et al., 1993; Oslick et al., 1994) and are reported using the Berggren et al. (1985) and Cande and Kent (1992) time scales (Table 1).

NEW JERSEY MICOCENE KIRKWOOD FORMATION

Ages of the lower-middle Miocene Kirkwood Formation are determined primarily from subsurface data because outcrop samples are virtually barren of calcareous material. Sugarman et al. (1993) used Sr isotopic stratigraphy and Andrew’s (1988) diatom biostratigraphy to define four Kirkwood sequences in the subsurface: Kw1 (22.6–19.2 Ma), Kw2a (17.4–17.0 Ma), Kw2b (16.0–15.5 Ma), and Kw3 (13.6–12.2 Ma). Although Sugarman et al.’s (1993) study provided the first precise ages for the Kirkwood sequences, they relied primarily on updip boreholes where the sections are thinner and less complete. Continuous coring downdip at Atlantic City and Cape May provided longer, more continuous lower to middle Miocene sections than were previously available, and contained numerous shells suitable for Sr isotopic age estimates.

Lowermost Miocene Sequences Kw0 and Kw1a

The lower Miocene sections at Atlantic City and Cape May contain at least four sequences, Kw0, Kw1a, Kw1b, and Kw2a: the latter three are typical New Jersey sequences that have shoaling-upward lithofacies (Sugarman et al., 1993).

The basal Miocene sequence (Kw0) is dominated by shelf glauconite (similar to Oligocene sequences in New Jersey), is best represented at Cape May, and is dated as $\sim$22.7–22.6 Ma (Fig. 1). At Atlantic City, repetition of three thick (>0.5 m) shell beds and glauconite sands (286–282 m) spanning the Oligocene-Miocene boundary (Sr ages of 26–21.9 Ma; Fig. 1) may represent three thin, truncated sequences (Miller et al., 1994), including one (23.8–21.9 Ma) that correlates to Kw0 at Cape May (Fig. 1). The earliest Miocene transition from Kw0 to Kw1 marks a fundamental change in depositional regime from shelf to deltaic and nearshore, although offshore seismic stratigraphic studies indicate that local deltaic deposition may have begun in the Oligocene (Greenlee et al., 1988). Kw1a is the most pervasive sequence in the New Jersey subsurface (Sugarman et al., 1993, Fig. 3B). Shell beds (~1 m thick) and glauconitic sands mark the base of Kw1a at both boreholes. At Atlantic City, the Kw1a sequence (56 m thick) shallows upward; shelf and prodelta silty clays are in the base and delta front sands are at the top. At Cape May, the Kw1a sequence (49 m) represents shelf environments that grade upward from middle to inner neritic. Kw1a was deposited between 20.9 and 20.4 Ma (Fig. 1).

Lower Miocene Sequence Kw1b

At Atlantic City, the Kw1b sequence is 23 m thick, and 20.4–20.2 Ma; at Cape May, the coeval (20.1 Ma) sequence is ~27 m thick (Fig. 1). Sr isotopes cannot be used to resolve a hiatus between Kw1a and Kw1b at either borehole, although a major disconformity is indicated by gamma logs, facies shifts, and an irregular surface at the contact.
The Kw1b sequence contains two coarsening-upward sections at Atlantic City. At Cape May, the Kw1b sequence coarsens upward from 259 to 216 m. The section from 259 to 216 m at Cape May appears to be younger (19.5–18.6 Ma) than the Kw1b sequence at Atlantic City; it may represent a previously unsampled sequence or an expanded upper Kw1b.

Upper-Lower (Kw2a) and Lower-Middle (Kw2b) Miocene Sequences

At Cape May, there appears to be a middle-middle Miocene unnamed sequence that is not present at Atlantic City (Fig. 1). The sequence is a shelf quartz sand with a single Sr isotopic age of 14.8 Ma. At Avalon Manor (Fig. 1), a Sr isotopic age estimate of 14.6 Ma (Sugarman et al., 1993) indicates that this sequence may be present only in the Cape May peninsula.

A major unconformity separates the unnamed and Kw3 sequences. The Kw3 sequence is 13.6–13.3 Ma (Fig. 1) at Atlantic City, although Sugarman et al. (1993) reported younger (up to 12.2 Ma) ages for this sequence in other boreholes (shales in Fig. 2). Paleoenvironments in Kw3 are dominantly inner neritic and nearshore.

Another middle Miocene sequence is present at Cape May and is dated as 11.9–11.2 Ma. A possible correlative section at Atlantic City (Fig. 1) lacks shells for Sr isotopic analyses. At Cape May, the sequence is dominated by shell quartz sands (inner neritic) and lesser amounts of laminated micaceous clay-silt and fine sand. We are uncertain whether this unit correlates with the middle Miocene Kirkwood Formation or the poorly dated Cohansey Formation (Owens et al., 1988), and we call it the Kirkwood-Cohansey sequence.
and CT1 surfaces of Kidwell, 1984) for interregional comparison (Table 1).

S isotopic age estimates from the base of the Calvert Formation (beds 3–9; Shattuck, 1904) yielded an average of 17.8 ± 0.4 Ma (Table 1), and no discernible hiatus associated with the Fairhaven–Plum Point contact (PP0). The lower Calvert correlates with the Kw2 sequence (Fig. 2); the Kw1 and Kw0 sequences correlate with a hiatus in the Maryland outcrops (older than 18 Ma; Fig. 2).

The middle Plum Point Member of the Calvert Formation (beds 10 and 11; between PP1 and PP2) has an average age of 16.5 ± 0.4 Ma (range 17.0–16.0 Ma). The PP1 surface at the base of this section is a conformity with a ~0.5–1.0 m.y. hiatus (~17.5–17.0 Ma). Thus, it correlates with the Kw2b sequence (~16.3–15.9 Ma), although it may be slightly older (Fig. 2).

The upper Plum Point Member (beds 12 and 13; between PP2 and PP3) has an average age of 13.7 ± 0.9 Ma. The upper sequence (13.7 ± 0.9 Ma) is a conformity with the PP3 surface (beds 14 and 15; between PP3 and CT0 surfaces). Sr isotopes and diatom biostratigraphy (Andrews, 1988) indicate a possible hiatus (~0.6 m.y.) at the PP3 disconformity. Thus, it correlates with the Kw3 sequence (Fig. 2).

DISCUSSION AND CONCLUSIONS

Although deposition was punctuated by hiatuses associated with at least two well-dated sequence boundaries (the bases of Kw0, Kw1a, Kw1b, and Kw2a), the New Jersey subsurface provides a relatively complete early Miocene record of shallow-marine sequences (Fig. 2). The major sequence boundaries in New Jersey (Kw0, Kw1a, Kw2a, Kw3, and Kw–Cohansey) show an excellent correspondence to δ18O increases associated with Mi1, Mi1a, Mi1b, Mi2, Mi3, and Mi5 oxygen isotope zones (Fig. 2). This correlation indicates a glacioeustatic influence on the New Jersey sequences because these δ18O increases reflect global ice-volume increases (Miller et al., 1991). Hiatuses are associated with δ18O increases. In addition, the bases of the New Jersey sequences generally correlate with the δ18O maxima used to define the Mi zones (Fig. 2). This indicates that unconformities were cut during the most rapid eustatic falls, but that deposition resumed during the eustatic lowstands as subsidence outpaced the rate of sea-level fall. Kw1b is the only sequence without a corresponding δ18O increase (Fig. 2); it could correlate with an ~20 Ma δ18O increase that is poorly defined at present (indicated by ? in Fig. 2; Wright and Miller, 1992).

Comparison of the New Jersey and Maryland Miocene records shows similarities and distinct differences (Fig. 2), although we are less certain of the precise ages assigned to the Maryland sections. For example, the PP1 sequence appears to be slightly older than Kw2b, and the Mi2 δ18O maximum (~16.2 Ma) appears to fall in the middle of the sequence (Fig. 2). We attribute this apparent difference to the 1 m.y. scatter on ages in the Maryland sections. The PP1–PP3, CT0, CT1, and CT2 surfaces are the surfaces of Kidwell (1984). HB = Herring Bay; samples 15, 22, 14, 6, 7, 5, and 37 are localities in Kidwell (1984).

*Values suspected to be altered by diagenesis.
Figure 2. Comparison of deposition in New Jersey and Maryland (derived from Table 1) with benthic foraminifer (Cibicidoides) δ18O record from Site 747 (Miller et al., 1991; Wright and Miller, 1992). Arrows indicate times of maximum δ18O values that form bases of δ18O zones (e.g., M1, M1a) and are inferred maximum glacioeustatic lowstands. Shaded boxes indicate time represented by deposition. Diagonal-rule boxes indicate ages not known with certainty.

ACKNOWLEDGMENTS

Supported by National Science Foundation grants OCE-89-11810, OCE-92-03282, and EAR-92-18210. Cores were obtained by the New Jersey Coastal Plain Drilling Project, supported by the Continental Dynamics and Ocean Drilling Programs. We thank T. Gibson, S. Kidwell, L. McCartan, and J. Owens for samples and discussions; S. Kidwell for field guidance; M. Feigenson for Sr isotopic analyses; C. Padover for field and laboratory assistance; C. Liu for discussions; and T. Cronin, L. de Verteuil, D. Jones, M. Katz, and S. Kidwell for reviews. Lamont-Doherty Earth Observatory contribution 5351.

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Manuscript received December 19, 1994 Revised manuscript received May 8, 1995 Manuscript accepted May 15, 1995