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SYNOPSIS OF LEG 174A POSTCRUISE SCIENCE[1]

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INTRODUCTION

The primary goals of Ocean Drilling Program Leg 174A at the New Jersey continental margin were to date sequence boundaries of Oligocene to Pleistocene age as precisely as possible, to place constraints on amplitudes and rates of sea level change that may have been responsible for unconformity development, to assess the relationships between depositional facies and sequence architecture, and to provide a baseline for future studies. As of September 2002, postcruise activity by shipboard participants beyond the release of the Leg 174A *Initial Reports* volume in 1998 has resulted in the publication of 22 articles in the open literature (see **"Leg-Related Citations"** in the volume table of contents), along with six contributions included in this *Scientific Results* volume. The published articles deal with aspects of sequence stratigraphy and borehole geophysics, biostratigraphy and biofacies, oxygen isotope chemostratigraphy, slope failure, glauconite and other clay minerals, and geochemistry. Contributions in this volume summarize data on nannofossils, Pleistocene ichnofabrics, heavy minerals, grain size, carbon isotopes and aqueous geochemistry. The overall picture that emerges from these studies generally conforms with summaries included at the end of each of the site chapters in the Leg 174A *Initial Reports* volume, but with new details revealed by additional analysis of cores, samples, and logs, and with new perceptions about the evolution of the margin provided by the geophysical framework, modeling, and closely coordinated research in the New Jersey Coastal Plain (Miller et al., 1998). To the extent that Leg 174A shipboard scientists have now had the opportunity to publish their own perspectives in the context of their individual expertise, differences of opinion have arisen in spite of efforts at collaboration. In the summary that follows, we attempt to

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take stock of the current state of knowledge. A comprehensive synthesis of results from Leg 174A is being prepared for journal publication.

SEQUENCE STRATIGRAPHY AND BOREHOLE GEOPHYSICS

Fulthorpe and Austin (1998), Fulthorpe et al. (1999, 2000), Steckler et al. (1999), Metzger et al. (2000), and Delius et al. (2001) all focus on the sequence stratigraphic context of the Leg 174A boreholes and on the correlation of multichannel seismic (MCS) and borehole data. Pekar et al. (2001, in press b) deal with the development of Oligocene sequences best expressed beneath the New Jersey Coastal Plain and preserved only as highly condensed correlatives at slope Site 1073. These strata are geometrically similar to upper Miocene to Pleistocene sequences studied at shelf Sites 1071 and 1072 and provide insights about the manner in which sequences and their intervening boundaries have developed.

The overriding issue addressed by Fulthorpe and colleagues concerns the three-dimensional geometry of Miocene sequences and particularly the extent to which the shallow shelf was subaerially exposed during sea level lowstands. Working with abundant but low-resolution industry data acquired in the 1970s, Fulthorpe and Austin (1998) concluded that Miocene rivers generally did not discharge at clinoform breakpoints (paleoshelf edges) at any point in a sedimentary cycle because evidence for canyon breaching of shelf edges is sparse and ambiguous, in marked contrast with Pleistocene counterparts. A simple backstripping reconstruction of paleoelevations for middle to upper Miocene clinoform breakpoints compared with the eustatic curve of Haq et al. (1987) was used to argue that with the exception of a single mid- to upper Miocene sequence boundary (designated m1c), minimum paleowater depths were 80 to 100 m. Their interpretation depended critically on the amplitude estimates of Haq et al. (1987), estimates that have long been regarded as suspect (Christie-Blick et al., 1990) and that in the case of both the Oligocene and Miocene are now demonstrably too large (Kominz et al., 1998; Kominz and Pekar, 2001). In addition, changes in paleowater depth scale as ~1.48 times eustatic variation, owing to water loading and unloading as sea level rises and falls (apparent sea level change of Pekar et al., in press a). A testable corollary of the comparison with Haq et al. (1987), correcting for this loading effect, is that minimum water depths would have been in excess of 120 m. In a comprehensive two-dimensional backstripping study of the Oligocene to middle Miocene of the New Jersey margin, Steckler et al. (1999) concluded that clinoform rollovers (paleoshelf edges) at sequence boundaries correspond to paleowater depths of ~60–130 m. Only the long-term eustatic estimates of Kominz (1984) were used to obtain this result, permitting minimum paleowater depths to have been several tens of meters shallower.

Working with MCS data acquired aboard the *Oceanus* in 1995 (Oc270) in preparation for Leg 174A drilling, Fulthorpe et al. (1999) interpreted fluvial channels immediately landward of a number of Miocene clinoform breakpoints. On the strength of the new data, these authors concluded that the entire shallow shelf was subaerially exposed during the development of at least some of these mid- to upper Miocene sequence boundaries and that the marked progradation characterizing this interval resulted from direct fluvial delivery of sediment to the shelf edge during sea level lowstands. This significant change in perspective is consistent with the discovery in the course of Leg 174A of probable estuarine or lagoonal sediments only 3 km landward of the paleoshelf edge for upper Miocene sequence boundary m0.5(s) (Site 1071) (Austin, Christie-Blick, Malone, et al., 1998). However, Oligocene borehole data from the New Jersey Coastal Plain show that complete exposure of the shelf is not necessary to explain the observed progradation. Amplitudes of Oligocene eustatic change are estimated as 10 to 50 m for spans of 1–2 m.y. (Kominz and Pekar, 2001), a range that is comparable to the less well constrained Miocene estimate of at least 20–30 m (Kominz et al., 1998). Yet, with the exception of two lower Oligocene sequence boundaries, for which the paleoshelf edge may have become subaerially exposed, minimum paleowater depths were 20 ± 10 m (Pekar et al., 2001, in press b). Progradation and offlap development began close to eustatic maxima (water depths < 85 ± 25 m) and continued to eustatic minima without the development of onlapping lowstand systems tracts, in spite of rates of eustatic fall that at times greatly exceeded the rate of tectonic subsidence. Although ~65%–80% of the shallow shelf that had been flooded during each eustatic rise became subaerially exposed during the subsequent fall, virtually all of the offlap developed in a marine setting and primarily as a result of sediment bypassing rather than erosion (cf. erosional interpretation of Pleistocene sequence boundary pp3(s) by McCarthy et al., in press). Pekar et al. (2001, in press b) reasoned that this unexpected pattern is due to a trade-off between riverine input of terrigenous sediment and marine dispersal both along and across the flooded portion of the shelf. For comparatively low sediment fluxes, the shallow shelf is inferred to have been drowned during times of eustatic rise and sediment temporarily sequestered in the coastal environment. Sea level lowering was expressed on the shallow shelf mainly by a reduction of water depth, with the efficiency of sediment dispersal increasing as waves began to impinge upon the seafloor. These data suggest that whereas Oligocene to Pleistocene offlap surfaces at the New Jersey margin may have been modified by subaerial exposure and transgressive ravinement, particularly in the Pleistocene, they are not fundamentally due to “forced regression,” the currently popular idea for discontinuity development through seaward movement of the shoreline without sediment accumulation (Posamentier and Morris 2000; e.g., Hesselbo and Huggett, 2001; McCarthy et al., in press).

An issue highlighted by the work of Pekar and others concerns the importance of distinguishing between systems tracts as objectively recognizable stratigraphic elements within sequences and the eustatic changes that are in some cases responsible for systems tract development (see also Christie-Blick and Driscoll, 1995). Oligocene through Pleistocene sequences at the New Jersey margin are composed primarily of transgressive and highstand systems tracts. Transgressive tracts overlie sequence boundaries and are characterized by overall marine transgression (although not all of the sediments included are marine). Highstand tracts underlie sequence boundaries and are characterized by progradation with varying degrees of offlap. Lowstand systems tracts, where present, overlie sequence boundaries (with onlap), underlie transgressive deposits, and are recognizable on the basis of evidence for continued progradation and regression of the shoreline. They are also poorly developed to absent at the New Jersey continental shelf and slope. (See Metzger et al., 2000, in part summarized below, for a discussion of exceptions in the Miocene, and Pekar et al., 2001, in press b, for an explanation.) Highstand and lowstand systems tracts are specifically not stratigraphic units accumulating when sea level was either high or low. Placement of sequence boundaries between "lowstand" and transgressive systems tracts (e.g., fig. 9 of Hesselbo and Huggett, 2001; fig. 7 of Savrda et al., 2001a; fig. 3 of McCarthy et al., in press) is inconsistent with the original definitions of these terms and/or with the principle of using offlap-onlap geometry to recognize stratigraphic discontinuities (Christie-Blick and Driscoll, 1995; Pekar et al., in press b; cf. Helland-Hansen and Gjelberg, 1994; Posamentier and Morris, 2000).

Fulthorpe et al. (2000) focused on the morphology and distribution of Miocene slope incisions and showed that many connect with shelf sequence boundaries, as is generally assumed. These authors pointed out, however, that whereas the depth of incision decreases downslope from clinoform breakpoints, it also decreases upslope from clinoform toes. They concluded that the development of canyon systems relates not only to eustasy but also to such factors as the efficiency of downslope sediment transport, sediment supply, grain size, and perhaps slope collapse related to fluid escape.

Metzger et al. (2000) integrated Oc270 MCS data, wireline logs, and core data from Sites 1071 and 1072 on the modern continental shelf. Following the scheme established by Austin, Christie-Blick, Malone, et al. (1998), they identified two sequences in the upper Miocene to Pleistocene interval, bounded by surfaces m0.5(s) (>8.6 Ma below the surface; see discussion of age below), pp4(s) (1.7 to 1.4 Ma; see Wei, **Chap. 5,** this volume, and discussion below), and pp3(s) (0.46 to 0.25 Ma). In the vicinity of the shelf drill sites, the uppermost surface, pp3(s), merges with a younger surface, pp2(s), and might better be referred to that surface in the area studied by Metzger et al. (see Katz et al., in press). The two sequences defined by the three surfaces are similar, although they represent vastly different spans of time (>8 m.y. and ~1.5 to 1 m.y., respectively). The older sequence (upper Miocene–Pliocene) for the most part deepens upward landward of the rollover in the underlying sequence boundary but is strongly progradational (upward shoaling) seaward of that rollover. The younger sequence (Pleistocene) deepens abruptly at the base, shoals upward, and then deepens again. Seismic geometry indicates that this sequence is also progradational seaward of the rollover in its underlying sequence boundary. Both sequences are clearly associated with higher-order cyclicity and variations in paleowater depth. Contrasts with older Miocene sequences, some of which contain demonstrable lowstand deposits, were ascribed by Metzger et al. (2000) to different long-term eustatic patterns upon which short-term fluctuations are superimposed. In light of the results of Pekar and colleagues (2001, in press b) in their studies of the New Jersey Oligocene and the apparent existence of many more sequence boundaries in the same Miocene to Pleistocene interval in the Bahamas (Shipboard Scientific Party, 1997), this interpretation may or may not be correct. Also unresolved is the rather different sequence stratigraphic interpretation of coeval strata in different portions of the Oc270 MCS data by Fulthorpe et al. (1999, 2000) compared with Metzger et al. (2000). Fulthorpe and colleagues mapped several additional sequence boundaries in the middle to upper Miocene.

Delius et al. (2001) used downhole logging and magnetic susceptibility data from shelf Sites 1071 and 1072, as well as slope Site 1073, to fill in gaps in core recovery, which was poor to nonexistent in sandy intervals on the shelf. Peaks in gamma ray and potassium logs were interpreted to indicate flooding surfaces; sequence boundaries are less easy to interpret from logs because their location depends on stratal geometry and not on any particular lithic character and hence log signature, either above or below a surface. Pronounced porosity variations at Site 1073 may indicate rapid burial of clay-rich sediment by turbidites at times of increased slope progradation.

The Pleistocene sequence between surfaces pp4(s) and pp3(s) is particularly interesting because elements of this interval are well developed at all three sites and they offer the prospect of correlating specific features in logs and magnetic susceptibility data. However, the scheme offered by Delius et al. (2001) is inconsistent with shipboard seismic reflection geometry, biostratigraphy, and magnetostratigraphy (Austin, Christie-Blick, Malone, et al., 1998). Sediments above surface pp4(s) at Site 1073 on the slope are younger than 1.6 Ma (see Wei, **Chap. 5**, this volume; McCarthy and Gostlin, 2000) and, with the possible exception of a 5-m interval of unstable magnetic inclination immediately above surface pp4(s) (519.8–515 meters below seafloor [mbsf]), are entirely within the Bruhnes Chron (younger than 0.78 Ma) (Austin, Christie-Blick, Malone, et al., 1998). In contrast, the Bruhnes/Matuyama boundary (0.78 Ma) is located immediately below surface pp3(s) at both shelf Sites 1071 and 1072. Therefore, the portion of the intervening sequence on the shelf is for the most part and perhaps entirely older than the portion preserved on the slope; the correlation scheme of Delius et al. (2001, fig. 7) requires the opposite to be true.

BIOSTRATIGRAPHY AND BIOFACIES

Papers by McCarthy and Gostlin (2000), McCarthy et al. (2000, in press), Katz et al. (in press), and Savrda et al. (2001a, 2001b) extend shipboard work on palynology, benthic foraminiferal biofacies, and ichnofabrics. McCarthy and Gostlin (2000) and McCarthy et al. (in press) studied Pleistocene palynomorphs (pollen and dinocysts) from Sites 1072 and 1073 as a means for determining ages in shelf sediments lacking nannofossils and as a proxy for environmental change. Cluster analysis shows that the highest degree of dissimilarity in terrestrial and marine palynomorph records in Hole 1072A is around 90 mbsf, and the second highest degree of dissimilarity is above ~127 mbsf. This allowed the identification of three palynomorph zones informally labeled, from youngest to oldest, P1, P2, and P3. Surface pp4(s) is found within Zone P3 at Site 1072 and between zones P2 and P3 at Site 1073, consistent with a hiatus of up to 0.8 m.y. at Site 1073 and with evidence for the relative ages of shelf and slope sections of the overlying sequence. Surface pp3(s) lies within Zone P1, but uncertainty in its location and, hence, age at Site 1073 can be considered with reference to palynological data. The surface has been traced with seismic data to the interval between 243 and 325 mbsf at Site 1073, an uncertainty that reflects complexities in physical stratigraphy on the slope. Its age, based on nannofossils, depends critically on whether it is located above or below 324.86 mbsf (younger or older than 0.46 Ma). A marked change in palynological character at 285 mbsf at Site 1073 led McCarthy and Gostlin (2000) to interpret surface pp3(s) at that level. The high ratio of terrestrial to marine palynomorphs observed at that horizon is consistent with downslope transport of neritic sediments from a subaerially exposed continental shelf.

McCarthy et al. (in press) formulated a general model for how palynological records may relate to sequence development and sea level change at a siliciclastic-dominated passive margin. During times of falling sea level and progradation, recycling of palynomorphs is expected to produce a taphonomically altered and ecologically mixed palynological assemblage, an increase in the ratio of terrestrial to marine palynomorphs, and a lowering of palynomorph concentration. During times of marine transgression, the opposite trends are anticipated, with pollen assemblages dominated by bisaccate pollen adapted for long-distance transport at interglacial sea level highstands. The main uncertainty in this reasoning concerns whether observed palynological changes reflect the timing of particular sequence boundaries such as surface pp3(s) directly or only indirectly. The horizon interpreted by McCarthy and Gostlin (2000) as surface pp3(s) is close to an oxygen isotopic minimum, a time of relatively warm climate and, hence, elevated global sea level (see McHugh and Olson, 2002). The marked palynological change may therefore indicate a threshold in the long-term progradation of the margin or perhaps in its climatic history. Sedimentological evidence of glaciation in maritime Canada and New England dates back to oxygen isotope Stage 14 (~550 ka) (Fullerton, 1986).

McCarthy et al. (2000) showed that changes in Pleistocene palynomorphs from the New Jersey margin (Site 1072) are approximately synchronous with similar changes observed at the Iberian margin (ODP Leg 149, Site 898) (Sawyer, Whitmarsh, Klaus, et al., 1994). Sediments older than ~1.4 Ma contain relatively few terrestrial palynomorphs and a dinocyst flora rich in *Operculodinium israelianum* and other taxa characteristic of relatively warm surface water. Pollen-rich sediments with a cooler-water "modern" dinocyst flora rich in *Operculodinium centrocarpum, Bitectatodinium tepikiense, Spiniferites* spp., and *Brigantedinium* spp. are found in sediments younger than ~1.15 Ma. The change was attributed by McCarthy et al. to a climate-driven intensification of the subtropical gyre in response to global cooling.

Katz et al. (in press) evaluated late Miocene to Pleistocene benthic foraminiferal biofacies and planktonic foraminiferal abundances at shelf Sites 1071 and 1072 in the context of an interpretation of borehole lithology and the seismically defined sequence stratigraphic framework. Providing more detail with respect to the preliminary benthic foraminiferal interpretation quoted by Metzger et al. (2000), Katz et al. interpreted paleowater depths ranging from near zero to >100 m. The most obvious feature of these tantalizing data is the very considerable within-sequence variability. This makes it difficult to interpret systems tracts, especially because the assignments suggested by Katz et al. (in press) are without specific reference to internal sequence geometry. None of the lowstand designations can be defended conceptually for backstepping stratigraphic elements overlying prominent offlap surfaces in a shallow shelf setting, nor repetitions of transgressive and highstand systems tracts within a single sequence.

In a review of stratigraphic age constraints, Katz et al. (in press) used an assessment of sedimentation rates between dated horizons to estimate the ages of two sequence boundaries. Surface pp4(s) is said to be ~1.8 Ma, an age that is slightly older than the range quoted by Metzger et al. (2000) (1.7 to 1.4 Ma) or inferred here on the basis of nannofossils (see Wei, Chap. 5, this volume, and below) (1.6–1.4 Ma). The age of surface m0.5(s) was interpreted by Katz et al. (in press) as ~8.6 to ~7.6 Ma, a range that is within the uncertainty of the more conservative interpretations of Austin, Christie-Blick, Malone, et al. (1998) and Metzger et al. (2000). The greatest difficulty in dating this sequence boundary relates to uncertainty in its location in boreholes owing to poor recovery of sands. Austin, Christie-Blick, Malone, et al. (1998) argued that its age is >7.4 Ma and probably >8.6 Ma.

Papers by Savrda et al. (2001a, 2001b) deal, respectively, with Eocene to Pliocene and Pleistocene deepwater ichnofabrics at Site 1073. Sixteen erosional surfaces are recognized in the 144-m-thick highly condensed section of Eocene–Pliocene age (Savrda et al., 2001a). Most of these correspond, at least approximately, to stratigraphic discontinuities inferred on the basis of nannofossil and strontium isotope data. These age data are generally consistent, although with some notable exceptions in the Oligocene to lower Miocene. All of the discontinuities separate clay or biogenic muds below from authigenic glauconitic sandy muds and sands above, and they define the bases of upward-fining successions. The entire interval studied is thoroughly bioturbated and dominated by ichnotaxa representing softground conditions. In contrast, most of the discontinuities are marked by firmground *Thalassinoides,* burrow systems that penetrate up to 2 m into underlying clays and are characterized by extremely sharp walls. According to Savrda et al. (2001a), many of the surfaces correlate with sequence boundaries on the shelf. However, available seismic data lack the resolution and reflection continuity needed for critical evaluation of this possibility, and specific discontinuities may relate instead to sediment starvation or to marine erosion unrelated to sequence boundary development.

The upper Pleistocene section at Site 1073 is characterized by two texturally defined sedimentary facies (Savrda et al., 2001b). Clay-rich sediments are inferred to have been deposited rapidly from turbidity currents and suspended plumes during times of cooler climate and lowered sea level. The low-diversity *Cruziana* ichnofacies is dominated by deposit-feeding worms. Sand-rich sediments are interpreted to represent overall slower sedimentation by off-shelf spillover and winnowing during times of warmer climate and higher sea level (cf. McHugh and Olson, 2002). Biogenic disruption is greatest in sandy sediments, predominantly *Thalassinoides* (crustacean burrows in firmground substrates).

OXYGEN ISOTOPE CHEMOSTRATIGRAPHY

McHugh and Olson (2002) have constructed an oxygen isotope record for the Pleistocene at Site 1073 and by comparison with the SPECMAP oxygen isotope timescale have significantly improved the age calibration of this important section. Four sequence boundaries are recognized in the section on the basis of seismic stratigraphic correlation from the shelf: pp4 at 520 mbsf, pp3 at 325 mbsf (cf. McCarthy et al., in press), pp2 at 145 mbsf, and pp1 at 79.5 mbsf. Oxygen isotope values range from 3.3‰ to 1.5‰. These are lower than those observed at North Atlantic deep sea sites, owing to proximity to the shelf and a continental ice sheet. The data are noisy, owing to disequilibrium effects in the planktonic foraminifers used to construct the record as well as the high-resolution sampling. Nannofossil datums are the base of the *Emiliania huxleyi* acme zone around 70 mbsf (~85 ka), the first appearance of *Emiliania huxleyi* at 120 mbsf (260 ka), and the last occurrence of *Pseudoemiliania lacunosa* at 330 mbsf (460 ka). (See Wei, **Chap. 5,** this volume, for slightly modified datums.) Surface pp1 is correlated by McHugh and Olson (2002) with an inferred hiatus between oxygen isotope Stages (OISs) 8 and 5; surface pp2 is correlated with the transition between OIS 9 and 8; pp3 is correlated with a hiatus between OIS 12 and 11. Although not the interpretation of McHugh and Olson (2002), these data and uncertainty in the distribution and duration of hiatuses permit the hypothesis that the surfaces correlate at least approximately with prominent glacial intervals and corresponding oxygen isotopic maxima: pp1 with OIS 6 (~150 ka), pp2 with OIS 8 (~300 ka), and pp3 with OIS 12 (~450 ka). Glacially modulated changes in sediment supply strongly influenced sedimentation at the continental slope, with rates of accumulation greatest during interglacial intervals (cf. Savrda et al., 2001b; McCarthy et al., in press). During glacial times, sediment was effectively trapped behind terminal moraines or captured at canyon heads and delivered to the continental rise.

SLOPE FAILURE

McHugh et al. (2002) studied mass-transport deposits sampled at Leg 150 Sites 902–906. These consist predominantly of muddy slumps and debris flows and, to a lesser extent, sandy mass flows. In the Pleistocene and upper Miocene, mass-wasting deposits are thought to rest preferentially on sequence boundaries of the middle to upper paleocontinental slope. In older Oligocene and Miocene strata, they are inferred to overlie sequence boundaries mainly on the mid- to lower slope.

Dugan and Flemings (2000) recognized that Pleistocene sediments of the continental slope (Site 1073) are undercompacted (40%–65% porosity) to depths as great as 640 mbsf. They interpreted these data to imply that fluid pressures reach 95% of the lithostatic stress. Such excess pressures may account for slope failure during both interglacial and glacial intervals (McHugh and Olson, 2002) and cold seeps.

Dugan and Flemings (2002) used a hydrodynamic analysis of Site 1073 porosities to demonstrate the interplay of sedimentation and fluid migration on the distribution, timing, and size of sedimentary failures. They hypothesized that portions of the New Jersey slope were unstable at ~500 ka, owing to rapid sediment loading during a Pleistocene lowstand combined with flow-focusing in underlying permeable Miocene strata. Their modeling suggests that stability on this slope has increased since 300 ka.

GLAUCONITE AND OTHER CLAY MINERALS

Glauconite at the New Jersey margin was studied by Harris and Whiting (2000) and by Hesselbo and Huggett (2001). Glauconite is generally inferred to correspond to shelf to upper slope settings characterized by low rates of sediment accumulation and times of marine flooding. This is borne out by Leg 174A data, although glauconization ceased in the Pliocene–Pleistocene at slope Site 1973 (Harris and Whiting, 2000). In deepwater settings, the concentration of glauconite pellets in burrows indicates in situ formation (Hesselbo and Huggett, 2001). Glauconite is associated with quartz sand only in proximal deepwater strata. The high degree of fragmentation and presence of ooidal glauconite around mature pellets or pellet fragments in shallow-water settings suggests reworking or transportation after deposition. The relative roles of physical and biogenic processes in this reworking is unknown.

The clay fraction of shelf sediments at Sites 1071 and 1072 is composed of variable proportions of chlorite, smectite, kaolinite, vermiculite, and mixed-layer clays (Vanderaveroet, 2000). Miocene and Pliocene climates permitted the development of vermiculite and kaolinite, whereas Pleistocene clays are characterized by abundant chlorite and illite from glacial erosion of crystalline crustal rocks at least during the past 550 k.y.

GEOCHEMISTRY

Malone et al. (in press) used the ionic and stable isotopic composition of interstitial waters and the petrology, mineralogy, and stable isotopic composition of authigenic carbonates (Sites 1071 and 1072) to constrain the origin of the carbonates and the evolution of methane on the outer New Jersey shelf. The pore fluids of the New Jersey continental shelf are characterized by (1) a freshwater to brackish water plume and (2) organic matter degradation reactions, which proceed through sulfate reduction. However, only minor methanogenesis occurs today. In contrast, the carbon isotopic composition of authigenic siderites and calcites document an active methanogenic zone during their formation. Siderite $\delta^{13}C$ values range from –17.67‰ to 16.4‰ Peedee Belemnite (PDB) but are largely positive (mean = 2.8‰) and are interpreted to have formed throughout the zone of methanogenesis. Calcite $\delta^{13}C$ values are highly negative (as low as –41.7‰) and must have formed from waters with a large component of dissolved inorganic carbon derived from methane oxidation. This methane may have been either oxidized or vented from shelf sediments, perhaps during sea level fluctuations. Malone et al. (in press) suggested that if this unaccounted and variable methane flux is an areally important process during Neogene sea level fluctuations, then it likely plays an important role in long-term carbon cycling on passive continental margins.

CONTRIBUTIONS IN THIS VOLUME

Wei (**Chap. 5,** this volume) presents new nannofossil data from all three sites. Data from Sites 1071 and 1072 do not result in any change in the estimated ages of interpreted sequence boundaries. This is due to the rarity of fossils at these shelf sites and to the very significant regional offlap that results in large hiatuses. At Site 1073, the first appearance of *Emiliania huxleyi* at 120 mbsf marks the base of Zone CN15 (260 ka), slightly lower than specified in the Leg 174A *Initial Reports* volume. *E. huxleyi* increases abruptly in abundance around 70 mbsf at the base of the *E. huxleyi* acme zone (~85 ka). The recognition of *Helicosphaera sellii* in Sample 174A-1073A-57X-4, 54–55 cm, below the interpreted location of surface pp4(s) at 519.8 mbsf, suggests an age for that surface of <1.3 Ma. However, the presence of *Calcidiscus macintyrei* in Section 174A-1073A-57X-6 indicates an age >1.6 Ma. Since surface pp4(s) is known to be older than 1.4 Ma at the shelf sites, it is likely that the stratigraphically highest occurrence of *Helicosphaera sellii* is only an apparent top beneath the interpreted sequence boundary where it has been traced to the upper slope. In that case, surface pp4(s) is best dated as 1.6–1.4 Ma.

Savrda and Krawinkel (**Chap. 3,** this volume) provide a comprehensive summary of Pleistocene ichnofabrics at Site 1073, data that underpin the article by Savrda et al. (2001b). Thoroughly bioturbated intervals dominate the section and exhibit variable fabrics. Some are monochromatic and homogeneous; others are characterized by homogeneous background fabrics overprinted by diffuse burrow mottles.

Krawinkel (**Chap. 6,** this volume) summarizes the heavy mineral content of sandy intervals at each site. The bulk of the samples analyzed were obtained from shelf sites because sediments at slope Site 1073 are predominantly fine grained. Eight distinct mineral associations are recognized. In the interval overlying surface pp3(s), amphiboles and pyroxenes dominate, with generally high but variable proportions of garnet and low proportions of zircon, tourmaline, and rutile (ZTR). Below surface pp3(s) but above surface pp4(s), the proportions of ZTR increase at the expense of the other minerals in the overlying assemblage. Between surfaces pp4(s) and m0.5(s), heavy mineral assemblages are highly variable, with a distinct downsection decrease in the proportion of ZTR and an increase in the proportion of amphiboles and pyroxenes.

Hoyanagi and Omura (**Chap. 4,** this volume) report on the results of grain-size analysis. They provide a series of histograms for Sites 1071 and 1073 and plots of average grain size as a function of depth for all three sites. These data elaborate on the qualitative shipboard descriptions of cores.

Claypool et al. (**Chap. 1,** this volume) focus on microbially mediated redox diagenetic processes. Oxidation of organic matter results in dissolved CO_2 with about the same $\delta^{13}C$ value as the starting organic matter. Subsequent reduction of CO_2 to form CH_4 leads to significant ^{13}C depletion in the CH_4 and to ^{13}C enrichment of the residual CO_2 in pore water samples. These processes are well displayed in data from Sites 1071, 1072, and 1073. The $\delta^{13}C$ values for CO_2 from shelf Sites 1071 and 1072 vary downsection but are in the range of –12‰ to –27‰ (with respect to the PDB standard). At slope Site 1073, $\delta^{13}C$ values for CH_4 are highly depleted (–62‰ to –84‰); corresponding $\delta^{13}C$ values for CO_2 tend to be positive (<9.9‰), with negative values restricted mainly to the upper 20 mbsf.

Malone and Martin (**Chap. 2,** this volume) provide isotopic data ($\delta^{18}O$, δD, and $^{87}Sr/^{86}Sr$) for interstitial water samples from all three sites. Two well-developed Cl^- and $\delta^{18}O$ minima are observed at Site 1071, at the approximate level of upper Pleistocene surface pp3(s) and close to upper Miocene surface m0.5(s). Similar minima are observed also at Site 1072 near surface pp3(s), but samples were not recovered at that site from the level of surface m0.5(s). The authors suggest that the observed freshening may indicate relict water. However, no obvious freshening is observed at the level of the intervening sequence boundary pp4(s). At Site 1073 on the continental slope, both $\delta^{18}O$ and δD values decrease downward to a depth of ~300 mbsf (by ~2‰ for $\delta^{18}O$ and by ~12‰ for δD), below which they change little to a depth of >600 mbsf.

WHERE DO WE GO FROM HERE?

Significant progress has been made at the New Jersey margin in the documentation and calibration of sequence formation and in developing some quantitative understanding of how patterns of sedimentation relate to both eustatic change and noneustatic phenomena. However, much of the Miocene remains to be sampled adequately, particularly in the mid- to inner continental shelf where depocenters of this age are best developed. Cores are needed also from the Cretaceous of the

Coastal Plain to evaluate the potential role of eustasy in a tectonically simple setting during an interval in which continental ice sheets were small to absent. One of the enduring puzzles of the New Jersey margin is why the numerous glacial–interglacial cycles of the Pleistocene are represented by so few geometrically expressed sequences, in spite of the presence of abundant sediment of appropriate age. Also to be resolved are stratigraphic details of the past 125 k.y. and the role of ice sheet loading and unloading of the margin in influencing patterns of sedimentation and erosion since 550 ka. The eustatic paradigm has strongly influenced stratigraphic research over the past quarter-century. General issues of current interest relate to questions of phase in the sedimentary response to sea level change and to the range of phenomena other than eustasy that play a significant role in governing sedimentation.

The Ocean Drilling Program will end in 2003, but another scientific drilling program entitled IODP, or the Integrated Ocean Drilling Program, is likely to take its place. So-called "mission-specific" drilling platforms (i.e., jack-ups, semisubmersibles, and so on) are expected to be part of the technology deployed for IODP. With such technology, core recovery and logging of sand-rich sections on thickly sedimented inner continental shelves for science will become a reality. As of this writing, proposed drilling for early Neogene and Paleogene "sea level" objectives on the New Jersey inner shelf is highly ranked by the international scientific community and will be considered for drilling by a "mission-specific" platform as part of IODP in 2004.

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