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Sea-level Change during the Last Thousand Years in Chesapeake Bay

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ABSTRACT

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New basal peat dates and older published sea-level indicators for the middle Chesapeake Bay document a very slow overall rate of sea-level rise in this area during the last thousand years, around ~0.56 mm/yr. This figure is significantly lower than known rates of subsidence for the mid-Bay region (~1.6–2.0 mm/yr) and implies that most of the last millennium was characterized by a relatively flat sea-level trend punctuated by a major regression. The paleoclimatic record of the late Holocene suggests that the timing of the regression probably coincided with the Little Ice Age. Refining this picture of the recent sea-level history of the middle U.S. Atlantic Coast will require new sea-level information drawn from sources other than marsh sediments, which document regressions poorly due to slowing or cessation of vertical and lateral accretion processes when sea level falls.

ADDITIONAL INDEX WORDS: *Sea-level rise, Chesapeake Bay, Little Ice Age, radiocarbon dates, paleoclimate, shore erosion.*

INTRODUCTION

In the past decade, worldwide evidence for high rates of shore erosion (especially, of sandy beaches) and coastal wetland loss has become increasingly persuasive (*cf.* BIRD, 1993). Global sea-level rise clearly underlies such worldwide coastal phenomena, and the proposition that these shoreline changes reflect an acceleration in the global sea-level trend (probably as a consequence of greenhouse warming; TITUS and BARTH, 1984) has gained considerable attention. According to the Intergovernmental Panel on Climate Change (IPCC) world sea levels could rise by as much as 44 cm by the year 2070 (HOUGHTON *et al.,* 1990). The impacts of only a few mm per year rise in global sea level on coastal systems would be enormous (*cf.* WARRICK *et al.,* 1993), let alone a rise of this magnitude.

Though a general link between global sea level and climate is clear, our understanding of sea level/climate relationships (and the ability to predict future sea-level rise) relies mainly on analyses of relatively short tide-gauge records (*cf.* DOUGLAS, 1991, 1995). Late Holocene sea-level curves generally are of little help, as they seldom contain a sufficient number of data points to reconstruct sea-level changes at time scales shorter than several centuries to a millennium (*cf.* VAN DE PLASSCHE, 1989; FLETCHER *et al.,* 1993). The lack of fine-scale resolution in the classic sea-level records has particularly hampered deciphering sea-level/climate relations during the last thousand years. The evidence for substantial climatic changes during this period is becoming known in ever greater detail, with temperatures at times as much as 1–3 °C colder than today (*i.e.,* the Little Ice Age; LAMB, 1978). Along the U. S. Atlantic Coast, comparable detail on sea-level fluctuations over last millennium has been largely furnished by paleoecological and geochemical data. VAREKAMP *et al.* (1992) recently reconstructed a detailed sea-level record over the last fifteen hundred years for Connecticut, using changes in marsh foraminifera and metal abundances. It showed that most of the rise in sea level during this period occurred in several transgressive episodes roughly coinciding with two warm phases, whereas sea level was relatively flat during the peak of the Little Ice Age (*ca.* 1400–1700 AD). At least one of the warm episodes (T_2, *ca.* 1200–1450 AD) appears to have been characterized by rates of sea-level rise close to that of the last century (VAREKAMP *et al.,* 1992).

Nonetheless, paleoecological and similar proxy indicators from salt marsh sediments have limitations in the portrayal of past changes in sea level. Such data generally lack the less equivocal relation of basal peats to former sea-level position (VAN DE PLASSCHE, 1986), and are subject to unknown vagaries of spatial and temporal changes in marsh sedimentary environments (*cf.* KEARNEY *et al.,* 1994). Moreover, the problems of dewatering and autocompaction cannot be discounted, especially in old marsh sediments buried deeper than approximately 1 m below the present marsh surface (KEARNEY and WARD, 1986; KAYE and BARGHOORN, 1964). This paper presents the most detailed sea-level record available for the Chesapeake Bay over the last thousand years using existing published basal peat dates (and other reliable sea-level indicators) as well as new dates on basal peats from a stable marsh on Maryland's lower Eastern Shore. Since present rates of subsidence account for almost half the present sea-level trend of the region (HOLDAHL and MORRISON, 1974),

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the relationship of vertical crustal movements to the recent sea-level record of the Bay is also discussed.

DATA SOURCES

A wide variety of dated, Holocene-age sea-level indicators has been reported for the Chesapeake Bay. The reliability of some of these materials is often questionable: sampling sites are sometimes poorly described and, more importantly, details on the type of samples dated can be sketchy. Furthermore, Bay-wide variations in rates of subsidence can affect relative age/depth relationships of equivalent-age materials across the Bay. Present subsidence rates vary by as much as 1 mm/yr across the Chesapeake region, with unusually high subsidence rates around Norfolk, Virginia largely reflecting recent land collapse from overpumping of groundwater (*cf.* HOLDAHL and MORRISON, 1974; DAVIS, 1987). Even within a period as short as a millennium, variations in average subsidence rates as low as 0.5 mm/yr can produce almost 0.5 m of difference in depth between sea-level indicators of the same age from adjacent areas of the Bay. Therefore, mixing sea-level indicators from sites across the length of the Bay can only degrade the quality of the sea-level signal. For this reason, this paper focuses on the lower middle Chesapeake Bay because the area is characterized by: (1) several sources for reliably-dated sea-level data within the last thousand years; (2) relatively uniform subsidence rates (~1.6 mm/yr); HOLDAHL and MORRISON, 1974); and (3) large marsh systems for the possible collection of new basal peat dates.

Existing Sea-Level Data

The most extensive collection of reliably dated, late Holocene sea-level indicators for the lower middle Bay area is from the Rappahannock and James Rivers (Figure 1; ELLISON and NICHOLS, 1976). Of the 16 peat dates reported for these estuaries, 6 dates are younger than a thousand years, and two are on basal peats (Table 1). The remaining dates are not from basal peats, but several are from peats shallow enough (< 0.5 m below the existing marsh surface at time of collection) that they may have experienced very little autocompaction. However, there is some question concerning the reliability of age estimates for the youngest of these shallow peats (Core 3E), which may be too recent for conventional ^{14}C dating methods.

FINKELSTEIN and HARDAWAY (1988) have reported three additional late Holocene marsh dates for the York River (Figure 1). All of the materials dated were organic-rich marsh muds, not basal peats; but one of the muds, at 94 cm below the modern marsh surface, was dated at 450 ± 80 BP (Table 1). Although the depth of this sample is greater than those of equivalent-age basal peats from the Rappahannock and James Rivers, autocompaction probably has been negligible since it was collected less than a meter below the modern marsh surface.

Other published evidence for sea-level positions in the mid-Bay region during the last millennium is available from a large, stable marsh in Monie Bay on Maryland's Eastern Shore (Figure 1). Sixteen shallow cores were collected from this marsh and dated using pollen geochronological methods, particularly the depth of a significant decline in oak to ragweed pollen ratios which marks the peak phase of colonial land clearance (KEARNEY *et al.,* 1994). This shift is dated about 1790 for the middle Chesapeake Bay (KEARNEY and WARD, 1986) and provides a time line for recent marsh sediments at this level. Marsh accretion rates can vary widely even in the same depositional environment (KEARNEY *et al.,* 1994); therefore, only the average figure for the depth of this horizon (58 cm) in the Monie Bay marshes is used here (Table 1).

New Data

The availability of only inferential data for former sea levels (like pollen horizons in marsh cores) for the Eastern Shore of the middle Bay hampers reliable reconstruction of recent sea-level trends for this area of the Chesapeake. To close this gap, basal peats were collected from a large, stable (based on comparison of historical and recent aerial photography) marsh on Deal Island on Maryland's lower Eastern Shore (Figure 1). This marsh, essentially comprising the landward side of the island, is dominated by *Spartina alterniflora* and *Spartina patens* in shoreline areas, and a mix of *Juncus* spp. and *Iva xanthafolia* in interior marsh sites which are less regularly flooded.

Selection of sites for collection of basal peat dates was determined by surveying the depth of peat across the marsh with a Davis peat corer. At the sites selected, the depth to basal peat was determined by several coring trials, and the actual sample taken by vibracoring. Sediment columns that proved to be compacted (≥5% of the drive length) by the coring process were discarded, and the site was re-cored.

The vibracores were longitudinally sectioned in the laboratory, described, and stored at 4 °C. In four of the cores, 2 cm slices from the interior of the cores were taken at the basal peat contacts and submitted to Beta Analytic, Inc. for ^{14}C dating (Table 1).

SEA-LEVEL CHANGE IN THE CHESAPEAKE BAY SINCE 1000 BP

Overall Sea-Level Tendency

The basal peat dates and most of the other sea-level indicators document that sea levels in the Chesapeake Bay were within a meter of modern limits by 1000 BP (Table 1). Length-sedimentation rates (0.71–1.02 mm/yr, Deal Island; 1.27 mm/yr, Hunter Marsh) for the oldest (*ca.* 1000 BP) of the basal peats are much lower than present vertical accretion rates reported for marshes in this area of the Chesapeake (KEARNEY *et al.,* 1994). This disparity should be approached cautiously, given the complexities of the marsh sedimentary environment, and their influence on the reliability of marsh length-sedimentation rates as records of past sea-level trends (KEARNEY *et al.,* 1994). Nonetheless, the portrayal of a relatively flat sea-level tendency for most of the last thousand years is in keeping with Bay island land loss records which document negligible rates of shore erosion for at least three centuries prior to 1850 AD (KEARNEY and STEVENSON, 1991).

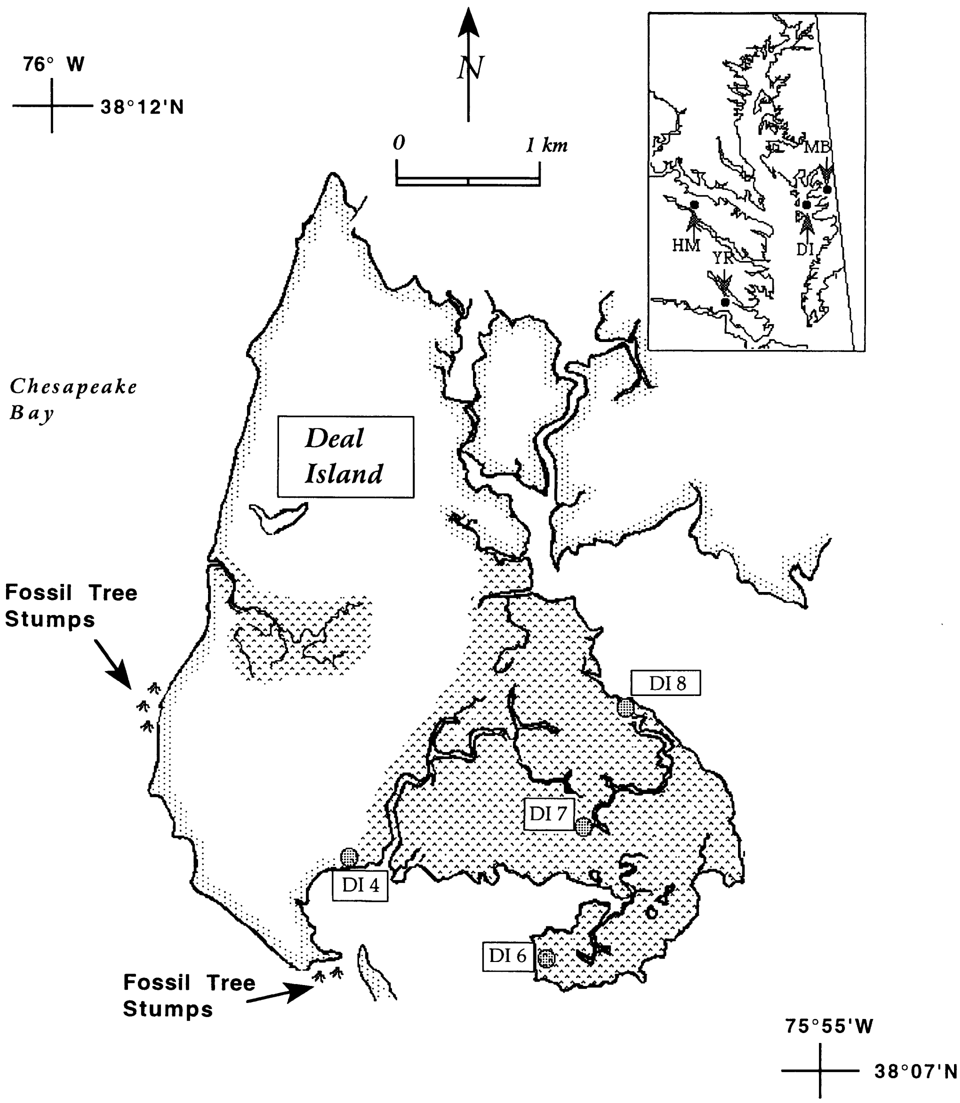

Figure 1. Location map of Deal Island, showing sites of basal peat dates. Dark shaded areas on the island indicate marsh areas. Inset map shows the general location of Deal Island in the Chesapeake Bay region as well as the sites of previously published sea-level indicators used in this paper (DI = Deal Island; HM = Hunter Marsh; MB = Monie Bay; YR = York River).

Similar interpretational problems characterize attempts to draw conclusions from the appreciably higher length-sedimentation rates (ranging from 1.3 to 2.0 mm/yr) for the younger basal peats and other sea-level indicators dating from *ca.* 300 to 500 BP. The higher figures could reflect the influence of the sharp upward trend in modern sea-level rise embedded in an average extrapolated over the last few centuries, or merely reflect differences in the amount of compaction between younger and older peats. KEARNEY and WARD (1986) showed that substantial dewatering can occur in some marsh peats buried within 0.75 m of the modern marsh surface.

A regression analysis of most of the sea-level data shown in Table 1 provides a means of suppressing within-site and between-site variations, and deriving a more regional assessment of the overall sea-level trend for the last thousand years in this area of the Bay. Excluding dates from within the last 150 years or so, the average rate of sea-level rise during the last thousand years appears to have been only about 0.56 mm/yr (Figure 2); if indicators younger than 200 BP are included, the rate changes only negligibly to 0.58 mm/yr. Both figures are low, and substantially below the long-term trend of 1.2 mm/yr reported for the Delaware Bay (KRAFT *et al.*, 1987) for the last several millennia. They are also almost an order of magnitude below tide-gauge records for modern rates of sea-level rise at Baltimore, which have varied between ~3.0 and 3.9 mm/yr since 1900 (KEARNEY and STEVENSON, 1991).

Extending this general trend into the present century requires the insertion of a sharp inflection point around 1850 AD. At present, most late Holocene sea-level curves contain

Table 1. *Dated sea-level indicators for the lower middle Chesapeake Bay.*

Sample No.	Sample Location/Depth (cm)	Age (BP)	Source
Basal Peats			
DI 4 (Beta-21803)	Deal Island/90	880 ± 100	this study
DI 6 (Beta-23318)	Deal Island/83	980 ± 70	this study
DI 7 (Beta-23319)	Deal Island/75	860 ± 90	this study
DI 8 (Beta-23320)	Deal Island/40	560 ± 60	this study
Core 1B*	Hunter Marsh/90	535 ± 95	Ellison & Nichols (1976)
Core 2C	Hunter Marsh/125	980 ± 90	Ellison & Nichols (1976)
Other Dated Peats			
Core 2C	Hunter Marsh/43	320 ± 80	Ellison & Nichols (1976)
Core 3E	Hunter Marsh/60	120 ± 75	Ellison & Nichols (1976)
Core 3E	Hunter Marsh/30	60	Ellison & Nichols (1976)
Core 3-2	York River/94	450 ± 80	Finkelstein & Hardaway (1988)
Other Sea-Level Indicators			
@18 cores	Monie Bay/58	196	Kearney *et al.* (1994)

*Laboratory numbers not given in the original publication

too few data points younger than 2000 BP to determine if this shift has correlatives elsewhere along the U. S. Atlantic Coast (*cf.* VAN DE PLASSCHE, 1990). However, the last millennium in south Florida witnessed an abrupt shift to transgressive sedimentation, paralleling sharply increased rates of sea-level rise (WANLESS, 1982; ROBERTS *et al.*, 1977), though the timing of this event remains poorly resolved.

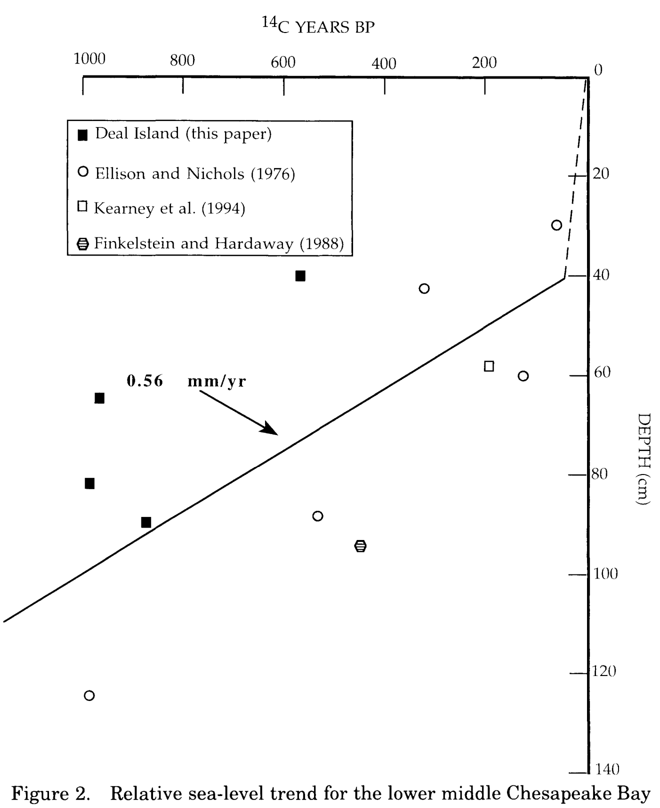

Figure 2. Relative sea-level trend for the lower middle Chesapeake Bay *ca.* 1000–150 BP based on data shown in Table 1. Dotted line indicates the apparent trend for the last century-and-a-half.

Relationship to Subsidence

Present rates of subsidence in the mid-Bay region have been estimated to range from 1.6 to 2.0 mm/yr (HOLDAHL and MORRISON, 1974), and account for more than half of the observed trend in relative sea-level rise. Modern (*i.e.,* the time frame of the last millennium) vertical crustal movements in the Bay largely result from postglacial forebulge collapse, which accounts for almost two-thirds of the present subsidence trend (~1.3 to 1.4 mm/yr; *cf.* DOUGLAS, 1991); the remaining few tenths of a millimeter difference may reflect other known mechanisms of regional downwarping, such as lithospheric flexure or errors in the geodetic leveling (CRONIN, 1981). More problematic, has been the possible impact of groundwater withdrawal in the Chesapeake region on the tidal signal. The effects of overpumping of groundwater on subsidence rates have been well documented for the Norfolk area (DAVIS, 1987), but there is little evidence to believe that the entire middle Atlantic tide gauge record has been significantly affected by this phenomenon (DOUGLAS, 1995).

Forebulge collapse is time variant in rate, and may have already peaked in the mid-Atlantic region (PARDI and NEWMAN, 1987). Therefore, rates of subsidence from forebulge collapse in Chesapeake Bay probably have been at least as high as now (*i.e.,* 4–5 times higher than the overall rate of sea-level rise suggested by the sea-level data for the last thousand years). If a sea-level "history" for the middle Bay is constructed based on present subsidence rates alone, the derived trends are significantly steeper than the one observed (Figure 3). In particular, extrapolating the subsidence trend back to *ca.* 1000 BP yields sea levels between 0.4 to 1.0 m lower than the reconstructed limits based on dated sea-level indicators. Resolving this discrepancy argues more for falling sea levels during all or part of the last millennium in the Bay, as opposed to just a flattening in rate as proposed by VAREKAMP *et al.* (1992) for the Connecticut coast.

DISCUSSION

New details have begun to fill in gaps in the picture of sea-level changes since 1000 BP for the U. S. Atlantic Coast. His-

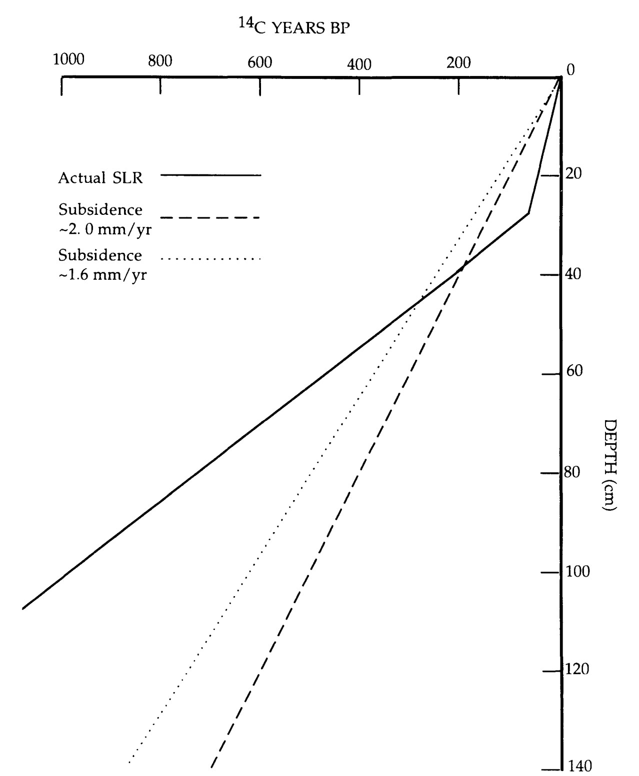

Figure 3. Relative sea-level rise in the Chesapeake Bay during the last thousand years compared to apparent sea-level trends for the area based on present rates of subsidence alone.

torical evidence from several areas indicates that sea levels stood within a meter of modern limits along this coast by early colonial times (NATIONAL ACADEMY OF SCIENCES, 1987). The data presented here for Chesapeake Bay suggest that sea levels may have attained this level by as much as a thousand years earlier, rising by <0.5 m during most of the last millennium. This interpretation is supported by historical land loss records for Bay islands which show very low rates of shore erosion (implying equally low rates of sea-level rise) from the middle 17th century until about 1850 AD (KEARNEY and STEVENSON, 1991). The portrayal of an almost flat sea-level tendency in the Chesapeake Bay until only a century or so ago (less than half the overall late Holocene rate for the area (KRAFT *et al.,* 1987)) is also similar to the one described by VAREKAMP *et al.* (1992) for Connecticut. In the Severn Estuary of southern Britain, archaeological and historical sources for the construction of sea defenses indicate almost a doubling in the rate of relative sea-level rise since the early 19th century (ALLEN and RAE, 1988).

The apparent acceleration in the rate of sea-level rise since 1920 found by BRAATZ and AUBREY (1987) in tide-gauge records for the Chesapeake Bay and elsewhere along U. S. Atlantic Coast draws mixed support from analyses of other long tidal records. Using tide-gauge records from sites worldwide, GORNITZ and LEBEDEFF (1987) calculated that the global rate of sea-level rise increased by 0.6 mm/yr between 1932–1982 compared to the previous half-century (1880–1932). On the other hand, WOODWORTH (1990) found little evidence of a significant acceleration in MSL in long tidal records from northern Europe, where the mean rate of sea-level rise for the last several centuries appears to have been only 0.4 mm/yr. DOUGLAS (1991), in examining other recent global sea-level records, reached similar conclusions. In fact, several European tidal records indicate a weak deceleration in MSL since *ca.* 1800 AD, a phenomenon also noted by GORNITZ and LEBEDEFF (1987). These disparities between regional and global sea-level trends described for long tidal records possibly reflect differences in the quality and length of data sources and, in addition, differences in accounting for crustal movement inputs in regression models (*cf.* DOUGLAS, 1991).

Though a very slow rise in sea level in the Chesapeake Bay for most of the last thousand years is consistent with climatic history, it still sheds little light on the numerous ambiguities in relations between more short-range climatic changes and sea-level variation. As noted, if it is assumed long-term rates of subsidence in the middle Bay region have averaged at least as high as present rates (1.6 to 2.0 mm/yr), achieving a net sea-level rise of 0.56 mm/yr for most of the last thousand years requires a continual fall in global sea levels of between 1.04 and 1.44 mm/yr. However, there is little reason to believe that this occurred. Only part of the last millennium was punctuated by the general (if not continuous) decline in global temperatures associated with the Little Ice Age (GOUDIE, 1992); other periods, like the Little Climatic Optimum, were considerably warmer. Presumably, global sea levels during these warm intervals rose at rates comparable to the degree of climatic amelioration. The geochemical and microfossil records for Clinton Marsh in Connecticut hint at some of the complexities of this sea-level record absent in the Chesapeake data, showing at least one transgressive episode between 1200–1450 AD, lagging somewhat behind the Little Climatic Optimum.

If transgressive phases marked warm periods of the last millennium, the Little Ice Age would be a likely candidate for a period of sharp regression. Gathering evidence, especially paleoecological records, suggests that the Little Ice Age was as cold as any period of the late Holocene (GROVE, 1988). High-latitude and alpine glaciers advanced worldwide and, in North America, both alpine and arctic timberlines retreated to their lowest elevations since the end of the Hypsithermal warm period (GROVE, 1988; KEARNEY and LUCKMAN, 1983; NICHOLS, 1974). Reconstructed changes in tidal positions at several sites in northern Europe for the late 18th century onward imply the termination of an apparent regression around 1800 AD (MORNER, 1973; HORNER, 1972). However, climatic conditions varied considerably during the Little Ice Age, and the severe cold that characterized parts of this period was not continuous. The first thermometer records from Britain (LAMB, 1978) show that the late 17th and early 18th centuries were characterized by decades when temperatures ameliorated, and were probably close to modern normals (GOUDIE, 1992). In fact, MORNER'S (1973) analyses of the historical tidal archives from the Baltic, the oldest dating from 1683 AD, document significant fluctuations in mean sea-level position throughout the late Little Ice Age (*ca.* 1680–1840 AD).

Inferring the magnitude, or even the duration, of a possible Little Ice Age regression is not feasible with the present sea-level position data. However, paleobotanical indicators from Deal Island suggest that the fall in relative sea level in the Chesapeake Bay was pronounced. In 1988, large (0.75 to 1.0 m in diameter), subfossil pine stumps, with attached root stocks, were found partially submerged in the surf 5–10 m from present MHW at several sites around the island (Figure 1). The stumps, apparently *in situ,* appear to comprise the remnants of a pine forest characterized by trees far larger than the generally small, often stunted, loblolly pines found on the island today. Present groundwater levels on the island are generally too high (and brackish) to allow growth of large loblolly pine, with their relatively deep and extensive root systems. Thus, the occurrence in the surf of these fossil stumps probably records a period when water tables were much lower and shorelines considerably seaward of modern limits, as the result of a drop in local sea level of possibly as much as a meter (?). Pith wood from one of the better-preserved stumps yielded a ^{14}C date of 790 ± 100 BP (Beta-21802). However, the tree obviously survived well beyond this date, for at least 200 years, as estimated from dbh (diameter breast height) measurements and a limited ring count. This places the tree growing well within the early Little Ice Age.

The absence of an unequivocal indication of a Little Ice Age regression (if it occurred) in the conventional sea-level indicators for the Chesapeake Bay is puzzling, but it is not an isolated phenomenon. The detailed late Holocene sea-level record of VAREKAMP *et al.* (1992) for the Connecticut coast portrays only a flattening in the sea-level trend at this time. Refining the picture of sea-level variations during the last millennium (especially the Little Ice Age) may require additional sources of information on paleo-sea levels beyond the traditional reliance on coastal marshes. Conventional sea-level curves, based on marsh basal peats, may not be capable of fully detecting short-range variations in sea level, especially regressions. The basal peats from the Deal Island marsh cover a thousand years across a spatial distance of 1 km of marsh, but are compressed in depth changes to only 40 cm. It is not clear that a closer interval sampling would yield more information, given the irregularities in marsh surface elevations (*cf.* KEARNEY *et al.,* 1994) and the normal inaccuracies associated with the collection of basal peats. Moreover, basal peat curves are probably predisposed to show only rising trends, or at best, no change: if sea levels fall, lateral accretion ceases, and does not begin again until sea levels rise once more. Similarly, vertical accretion also slows or stops, and if the regression is sharp enough, existing marsh substrates can oxidize and degrade, producing gaps in the paleoenvironmental record that may be difficult to detect. In the end, new ways of examining historical evidence for sea-level variations or other indicators for past changes in sea-level position may prove the best means for obtaining detailed information on recent sea-level history.

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