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The Chesapeake Bay: Geologic Product of Rising Sea Level

Introduction

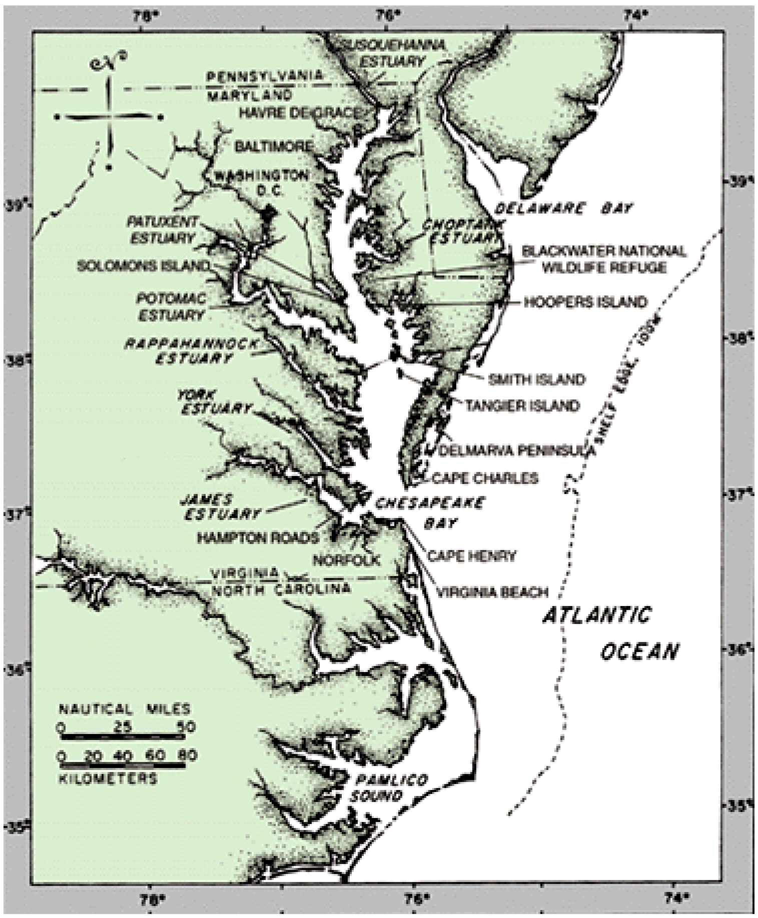


Figure 1. The Mid-Atlantic coast of the United States and the Chesapeake Bay (modified from Ellison and Nichols, 1975).

The Chesapeake Bay is the largest estuary in the United States and one of the most diverse. It covers approximately 11,400 square kilometers and stretches 332 kilometers from Virginia Beach, Va., to Havre de Grace, Md., at the mouth of the Susquehanna River (fig. 1). Its watershed drains a region of 165,800 square kilometers. The Chesapeake is the shipping artery for Norfolk, Va., and Baltimore, Md., and it is highly valued for its sea life, waterfowl, sport fishing, and recreational boating. At the same time, the bay is threatened by environmental degradation caused by man-induced pollution from a variety of sources.

There is little awareness, however, that the rapidly rising relative sea level within the bay is also having dramatic and wide-ranging effects. Islands once populated in colonial time and during the past century have disappeared due to submergence and related shore erosion. The artifacts of early European settlers and prehistoric peoples are sometimes found by watermen working over land areas now covered by the shallow waters of the bay. Sharps Island, described and mapped by John Smith in 1608, has since disappeared, although it was shown on maps and charts as recently as the beginning of the 20th century. Submerged and eroded Sharps Island (fig. 2), formerly at the mouth of the Choptank estuary, is recalled only by a prominent lighthouse erected in 1882 and is now covered by 3- to 4-meter water depths. Expanding wetlands are claiming low-lying communities on Smith Island and Tangier

Island. Settlements begun in the 18th and 19th centuries, together with their churches and cemeteries, are often surrounded by the rising water of the bay during periods of extreme high tides -- a prologue to the rising sea level (fig. 3).

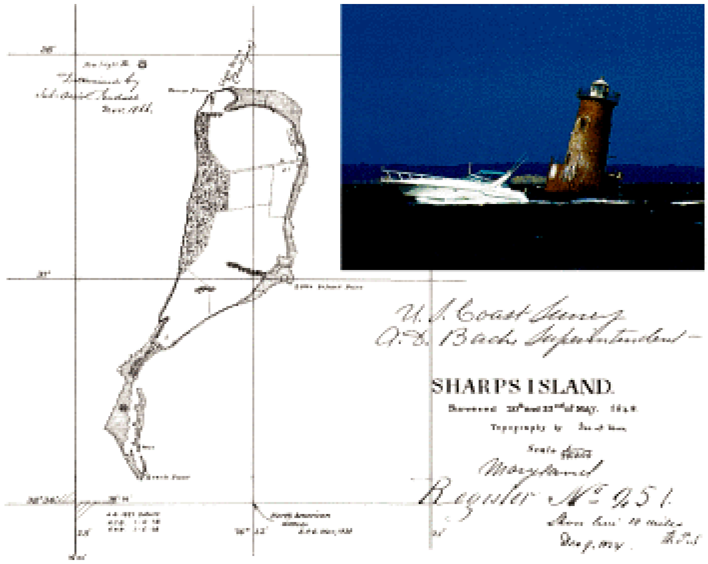


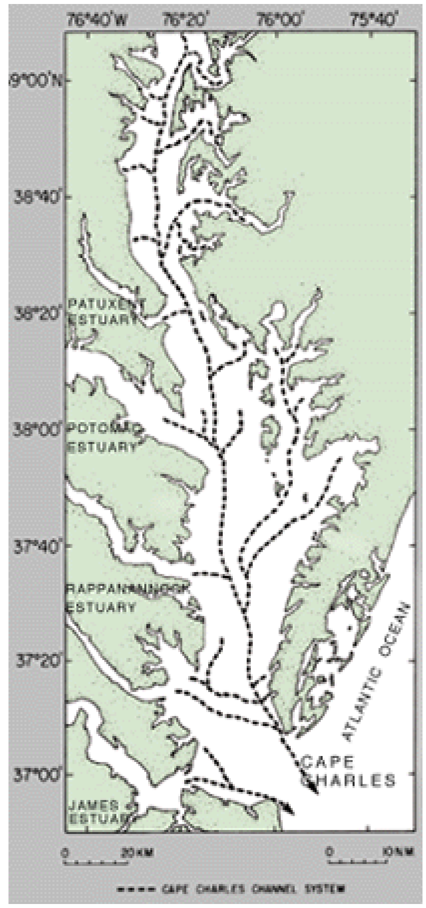
Figure 2. Map of Sharps Island, showing extent of land mass in 1848 (U.S. Coast Survey, 1848). Inset shows Sharps Island lighthouse, which was built in 1882 (photograph from Vojtech (1997); used with permission from Tidewater Publishers). The former Sharps Island is now submerged, and the lighthouse is surrounded by water 3 to 4 meters deep.

Figure 3. Extreme high tide, March 1, 1998, Hoopers Island, Eastern Shore, Md. Photograph by J. Williams.

The Blackwater National Wildlife Refuge, situated on Maryland's Eastern Shore, is unique in its coastal marshland waterfowl habitat. The refuge is being widely affected as steadily rising sea level converts vegetated marshlands into shallow ponds and changes important shallow-water marsh habitat into deeper water plant and animal communities. In short, the bay is changing and changing rapidly, even in human timeframes. With the potential for climate warming in the near future, relative sea-level change could accelerate and bring about even more dramatic change for the bay in the next century.

Sea-Level Change

The Chesapeake Bay is the drowned, ancestral valley of the Susquehanna River; the bay is fed by runoff from tributaries of the Potomac, Patuxent, Rappahannock, and James Rivers (fig. 4). About 18,000 years ago, the Susquehanna riverbed extended beyond present Cape Henry and Cape Charles and continued to the shoreline of the Atlantic Ocean, at that time at the edge of the continental shelf. During the last glaciation, ice sheets covered most of Canada and extended southward into the Midwestern United States and eastward into northern New Jersey and along Long Island. Water, once contained in the ocean basins, fell as snow onto the continents, where it was stored as glacier ice. Worldwide sea level fell as glaciers expanded.



At the full extent of the last glaciation, sea level was approximately 100 meters lower than at present, and as a result continental shelves were exposed throughout the world. At the end of the last glacial epoch, sea level rose relatively rapidly as continental glaciers melted. By 15,000 years ago, the outer continental shelves had been submerged, and by 10,000 years ago, the main channel of the ancient Susquehanna River valley was flooded and became a narrow estuary. Between 6,000 and 7,000 years ago, the rate of submergence began to slow, and the Chesapeake Bay took on its characteristic "drowned river valley" shoreline pattern. Sea level at that time stood approximately 9 meters lower than the present level. Since then, the rate of sea-level rise over much of the last 6,000 years has been an almost-imperceptible 1.4 millimeters per year (about 6 inches per century). The present general shoreline configuration was attained by the time the first European and colonial maps were prepared (fig. 5), but as tide gauges and the continued inundation of low-lying areas indicate, relative sea level in the bay is still rising.

Figure 4. Ancestral channel of the Susquehanna River and its tributaries 18,000 years ago at the peak of the last glaciation (modified from Colman and Mixon, 1988). Sea level was about 100 meters below the present level. The Chesapeake Bay is the drowned ancestral valley of the Susquehanna River. NM, nautical miles.

Figure 5. Early colonial map of Maryland and Virginia (from Ogilby, 1671). The map is oriented with north on the right, reflecting its original purpose as a port-finding chart for ship captains approaching the entrance of the Chesapeake Bay.

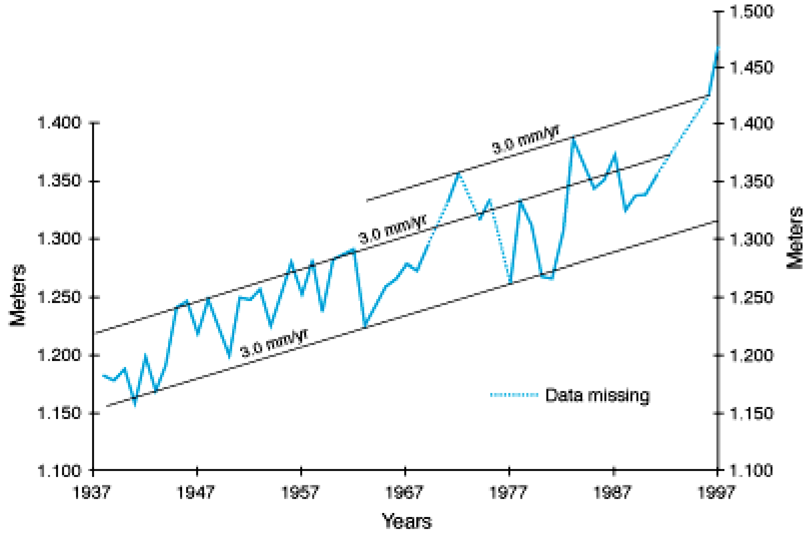
Relative Sea Level

Sea-level change during the past 10,000 years has varied from place to place and region to region. Sea level is measured relative to datums on land, but the altitude of the land changes as well, due to imperceptible natural subsidence and uplift of the Earth's crust. If the land surface is subsiding at the same time that ocean volumes are increasing, then the rate of submergence will be greater than it would be due to changes in ocean volume alone. If the land area is rising relative to the sea, apparent sea level may fall. Human changes such as ground-water extraction and fluid withdrawal from petroleum reservoirs can induce subsidence and influence relative sea-level change. Monitoring altitudinal changes in the Earth's crust is a difficult task, although satellite measurement with global positioning systems promises to give more accurate results than were formerly possible. To complicate the picture further, changes in ocean volumes due to natural or man-induced climate changes can cause relatively short-term fluctuations in sea level, by changing the thermal expansion of the ocean.

The Modern Setting

Continuous tide gauge records around the Chesapeake Bay show that the rate of sea-level rise during the 20th century has not been constant and that modern rates are more rapid than those determined by geologic studies conducted two decades ago. The current rate of sea-level rise at the mouth of the Chesapeake is about 4 millimeters per year (about 1.3 feet per century) and decreases northward. Tide gauges with longer periods of record, like that at Solomons Island, Md., midway along the length of the bay, record mean sea level since 1937 and illustrate a 3-millimeter-per-year rate of rise (about 1 foot per century) (fig. 6). Areas described as marsh in colonial times have given way to shallow creeks. Dead trees farther up tributary creeks characterize areas only recently submerged to become marsh. Tree stumps of former forests can be found beneath the sediments of tributary creeks. Sea-level rise continues.

Figure 6. Annual mean relative sea level recorded at the Solomons Island, Md., tide gauge 193797 (National Oceanic and Atmospheric Administration, written commun., 1998).



The Chesapeake Bay Today

Tide gauges for the Chesapeake Bay and the Mid-Atlantic coast show rates of sea-level rise twice that of the worldwide average. Scientists disagree on the cause of the recent increase in the rate of rise. Is the increase caused by land subsidence, or is it related to a changing climate and ocean volume? Anthropogenic (man-induced) causes are often sought to account for anomalies in the short historical records of environmental change. Sediment compaction resulting from extraction of ground water is another popular explanation used today to account for land subsidence. On a much broader scale, a zone of subsidence along the entire Mid-Atlantic coast has been attributed to crustal adjustment still taking place following the removal of vast thicknesses of glacier ice to the north thousands of years ago (isostatic adjustment).

The Chesapeake Bay has also been identified as one of four anomalous areas along the U.S. East Coast that appear tectonically active. A zone of crustal downwarping and sediment accumulation known as the Salisbury embayment has long been recognized beneath the Delmarva Peninsula. It is clearly possible for vertical movement to occur along such zones. Another geologic factor that might account for anomalous rates of sea-level change, at least for the mouth of the bay, is possible subsidence related to compaction of the fill of a large buried impact crater that underlies much of the Norfolk, Hampton Roads, and Cape Charles area. For the Chesapeake Bay, the rate of sea-level rise has certainly accelerated, but just as certainly, rising sea level is the norm in the region rather than the exception. The applied scientific issues in this area revolve around understanding, coping with, and more importantly, planning for an ongoing dynamic Earth process like sea-level change.

The USGS Role in Sea-Level Research in the Chesapeake Bay

The U.S. Geological Survey (USGS) role in sea-level research is national in scope and ranges from remote sensing and geologic mapping of wetlands to studies of coastal erosion and evidence of older shorelines in the geologic record. Both short- and long-term environmental records are taken in account. One goal is to be able to determine the rate of sea-level change on century to thousand-year time scales in order to compare consistency and agreement (or lack thereof) with the decadal and annual records of the tide gauges. In the Chesapeake Bay, the USGS is conducting research to reconstruct the detailed pattern of relative sea-level change during the last 6,000 to 8,000 years. Few modern data are available from which to establish baselines to compare with the ongoing rate of sea-level rise. Current research efforts focus on the central region of the Chesapeake Bay. For example, coring studies of marshes and tributary creeks in the Patuxent River basin are providing sedimentary and biological records of rising sea level.

One aspect of USGS research is to place in perspective the role of sea-level rise as a natural ongoing process that continues to modify the bay and its resources. Another aspect is to demonstrate the effects of sea level on past and present settlement, as well as environmental change. The Patuxent River was a center of 17th and 18th century settlement and so is a key study site from which to obtain geologic information that can be applied to a variety of societal and scientific problems. Data from sediment cores obtained to document the sea-level history can also furnish records of sedimentation rates, temperature and salinity changes, and water chemistry and can be used to measure human impacts on the natural systems from pre-European settlement times to the modern industrial world. Understanding the history of sea-level rise and associated changes in sedimentation and salinity will help resource managers better formulate and refine restoration strategies for the bay and its resources.

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For more information, please contact:
Curtis E. Larsen
U.S. Geological Survey
955 National Center Telephone: (703) 6486342
Reston, VA 20192 E-mail: clarsen@usgs.gov

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