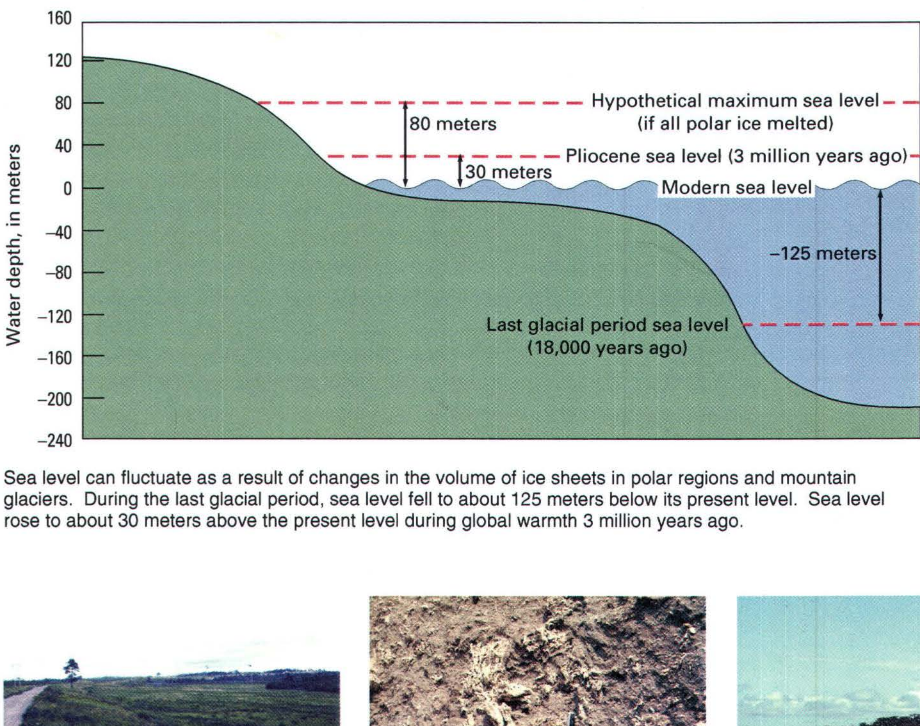
Sea Level Change: Lessons from the Geologic Record

Rising sea level is potentially one of the most serious impacts of climatic change. Even a small sea level rise would have serious economic consequences because it would cause extensive damage to the world's coastal regions. Sea level can rise in the future because the ocean surface can expand due to warming and because polar ice sheets and mountain glaciers can melt, increasing the ocean's volume of water. Today, ice caps on Antarctica and Greenland contain 91 and 8 percent of the world's ice, respectively. The world's mountain glaciers together contain only about 1 percent. Melting all this ice would raise sea level about 80 meters. Although this extreme scenario is not expected, geologists know that sea level can rise and fall rapidly due to changing volume of ice on continents. For example, during the last ice age, about 18,000 years ago, continental ice sheets contained more than double the modern volume of ice. As ice sheets melted, sea level rose 2 to 3 meters per century, and possibly faster during certain times. During periods in which global climate was very warm, polar ice was reduced and sea level was higher than today.

Sea level is expected to rise

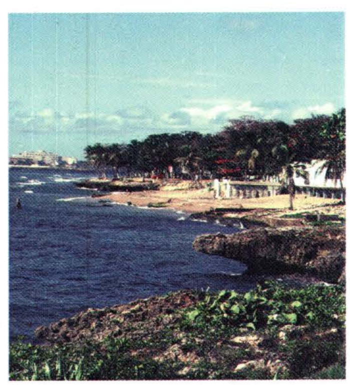
Tide gauge records from the last century show that global sea level rose about 10 to 15 centimeters (about 4 to 6 inches). At least 50 percent of this was due to thermal expansion of the ocean surface, the rest was probably due to the melting of small glaciers. In the next century, sea level is predicted to rise by between 60 and 300 centimeters, or 2 to 10 feet. But predictions of future sea levels are fraught with uncertainty because our historical record of sea level change based on tide gauges is limited to about the last 100 years and is only available from well-populated coastal areas. The next century might see an even more rapid rise than the last.



Sea level can fluctuate as a result of changes in the volume of ice sheets in polar regions and mountain glaciers. During the last glacial period, sea level fell to about 125 meters below its present level. Sea level rose to about 30 meters above the present level during global warmth 3 million years ago.

It is essential that scientists use records of sea level preserved in the geologic record to determine how fast and how high sea level can rise. There are two primary ways to establish sea level history. One is through the study of ancient shoreline features such as beach ridges, coral reef terraces, wave-cut escarpments, and shallow water marine fossils. Ancient shorelines tells scientists how high sea level was at a certain time, like coral reef terraces that formed when sea level rose 6 meters above its present level during the last interglacial period, 125,000 years ago. Although an ancient shoreline can give scientists an accurate position of sea level, it often only represents a brief interval—a "snapshot"—of time when sea level was high. Scientists must therefore assume that a steady rate of sea level rise occurred between the formation of two shorelines.

Another way to measure sea level change is to estimate the volume of ice in polar regions through geochemical study of the calcium carbonate ($CaCO_3$) shells of small deep-sea microfossils. Foraminifers are one-celled organisms, and ostracodes are shelled crustaceans. Both occur as microfossils in sediment cores obtained by ships drilling the ocean floor. In contrast to shorelines, sediment cores give a fairly continuous record of ocean history and ice volume. When these animals grow, they build their shells from oxygen, carbon, calcium, magnesium, and other elements in solution in the surrounding water. The proportion of each element in the water (that is, the sea-water chemistry) is strongly influenced by evaporation, precipitation, and global climate, so the shell chemistry serves as a proxy of the ocean environment. During glacial periods, the ratio of the heavy isotope of oxygen (^{18}O) to its light isotope (^{16}O) in seawater is high because



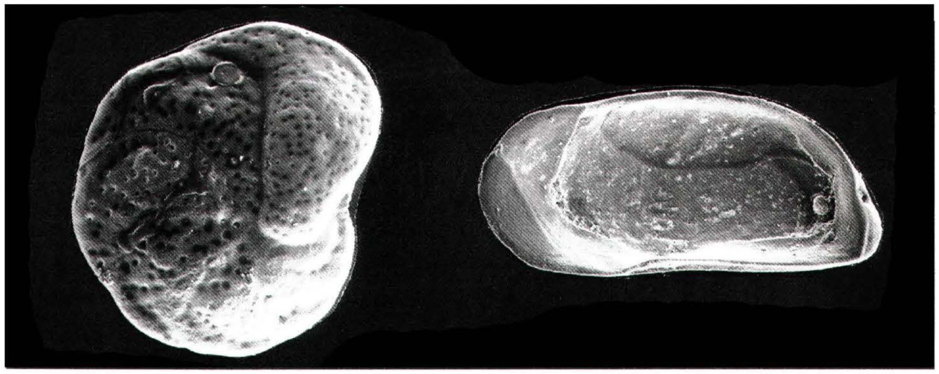
Ancient shorelines document past sea level positions in many regions.

Left—Beach ridge formed during retreat of last ice sheet, northeastern Maine.

Center—Fossil marine shells from last interglacial period, Chesapeake, Virginia.

Right—Coral reef terrace formed during last interglacial, Dominican Republic.

relatively more of the light isotope is concentrated in continental ice sheets and less in seawater. This is reflected in the shell chemistry of foraminifers. During warm periods, the opposite situation occurs, and there is a lower $^{18}O/^{16}O$ ratio in both seawater and in the shells of animals that lived during these periods. Oxygen isotope ratios are good general monitors of ice volume, but water temperature also influences the shell chemistry of microfossils. Because cold water also causes low $^{18}O/^{16}O$ ratios in foraminifer shells, it is necessary to have a "paleothermometer" to measure the history of seawater temperatures.

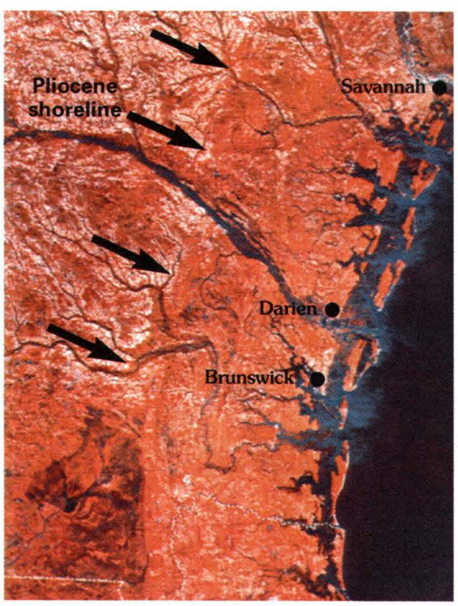


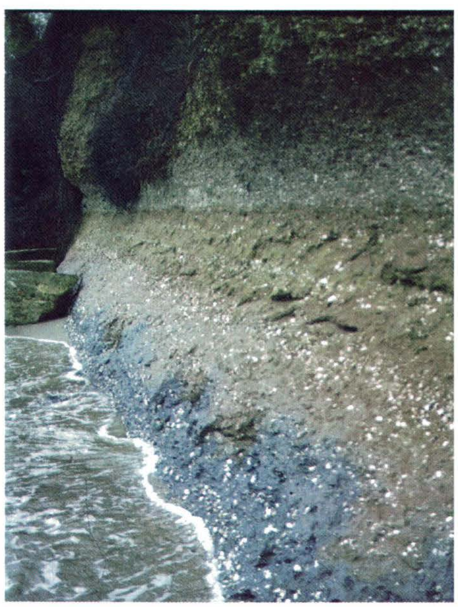
Geochemistry of deep-sea microfossils holds clues to changes in global ice volume. A. The ratio of heavy to light oxygen ($^{18}O/^{16}O$ ratio) of the deep-sea benthic foraminifera *Cibicidoides*, tell ice volume history; B. Magnesium/calcium ratios in the ostracode *Krithe* tell bottom water temperature and dissolution history.

Researchers try to estimate rates of sea level rise

USGS researchers are working to develop improved methods to estimate how high and how fast sea level can rise. In collaboration with scientists at Duke University, the Massachusetts Institute of Technology, Woods Hole Oceanographic Institution, The University of Basque Country (Spain), and Shizuoka and Kanazawa Universities (Japan), scientists are investigating how the proportions of magnesium and calcium in ostracode shells are controlled by water temperature and shell dissolution. By improving methods to estimate bottom water temperatures, a more accurate estimate of ice volume can be obtained from the $^{18}O/^{16}O$ ratios. By comparing the ice volume estimated from deep-sea microfossil chemistry with the elevation of ancient shorelines along the eastern United States, researchers can use two independent methods to crosscheck how high sea level rose during past periods of global warming.

Results show that sea level can reach levels many meters above present sea level during periods of warm global climate. For example, sea level rose to as much as 30 meters above present sea level during a time of global warmth about 3 million years ago. Researchers hypothesize that this rise was due to reduced continental ice on Antarctica and Greenland, which implies that the Antarctic ice sheet was more dynamic than previously thought. These studies also provide evidence that substantial changes occurred in deep-sea bottom water temperatures and in levels of shell dissolution during glacial and interglacial cycles. These changes are due in part to the effects of changing polar ice volume on the temperature and salinity of the world's oceans. Understanding the linkage between oceanic circulation history, ice volume and sea level is a prerequisite for testing computer models designed to determine the ocean's role in the global biogeochemical carbon cycle and the potential impact of high atmospheric carbon dioxide on future climate and sea level.





Evidence for high sea level is common along the east coast of the U.S. Left—Shoreline formed about 3 million years ago during period of global warmth highlights this Landsat photograph of the Georgia Coastal Plain. Right—The fossiliferous shelly sands of the Yorktown Formation, exposed along the York River, southeastern Virginia, records a period of high sea level and warm climate.

Implications for coastal regions

One implication of sea-level research is that coastal regions are vulnerable to shoreline movement over different timescales. Current research is aimed at providing a detailed record of sea level change on timescales of decades to centuries that can be obtained from high-sedimentation-rate cores along continental margins and in the deep sea. This research involves developing an understanding of complex biological and hydrological systems, including the factors that influence the chemistry of foraminifers and ostracode shells, as well as the tectonic factors that can alter the original position of ancient shorelines. An integrated research program, carried out in partnership with other institutions, is essential if scientists are to unravel the mysteries of sea level and ice volume and apply them to improved modeling, prediction, and coastal resource management. Without accurate estimates of the rate of future sea level rise, it will be difficult for policy makers to determine the economic and social consequences of future climate change.

For more information:

Dr. Thomas M. Cronin
U.S. Geological Survey
Reston, VA 22092
Tel: (703) 648–6363, Fax: (703) 648–5420
Internet: tcronin@geochange.er.usgs.gov