Sea Level Change

Donald R Prothero, *Occidental College, Los Angeles, California, USA*

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The level of the oceans has risen and fallen many times in the geological past.

Introduction

For centuries humans have recognized that the level of the sea is not constant, but has risen and fallen in the geological past. The presence of ancient marine fossils and rocks in the centres of continents, thousands of kilometres from modern shorelines, suggests that at times the sea has risen to drown large areas of the continents. In other regions, ancient marine shoreline features now high above modern sea level suggest that relative sea level has sometimes dropped as well. In the past century, the methods for estimating the true change in sea level have improved greatly, so there is considerable agreement about the past history of sea level change. Understanding sea level change has many important implications. Most of the world's sedimentary rocks (and with them, most of the world's oil, gas, and coal) formed as marine sedimentary environments advanced and retreated with changes in sea level. In addition, the human-induced greenhouse warming could melt the polar ice caps, causing a sea level rise of 70 m (230 feet), which could drown most of the coastal regions of the world (and their cities and farmlands), and have a profound impact on human civilization.

Local and Eustatic Changes

In the 1750s, the Swedish biologist Linnaeus noted the raised shorelines around Scandinavia and argued that sea level had receded, while the German geologist von Buch suggested that Scandinavia had risen instead (we now know that von Buch was right). This dispute captures the essence of the longstanding problem of deciphering sea level change. In any given region, the relative change of sea level could be due to global (eustatic) sea level changes, or to local rise and fall of the land (isostatic changes, due to tectonic uplift or subsidence). In many parts of the world, it is easy to show that offshore marine deposits have progressively covered the land (transgression), while in other parts, there is evidence that the sea has retreated relative to the land (regression). But transgression could be due to global rise of sea level, or to local land subsidence (which also causes drowning of coastlines), or a combination of both. Likewise, regression could be due to a global fall of sea level, or to local tectonic uplift, which causes shorelines to retreat, or to the outward building of sediments deposited at the mouths of river deltas (progradation).

How do we decide whether the relative change in sea level is due to local uplift or subsidence, or to global changes in sea level? The best method is to compare the relative sea level curves of different regions around the world. Where they agree, it is reasonable to assume that they have a common, global eustatic cause; where they disagree, local tectonic effects clearly predominate. However, the practical problems are much more complex than this. In every region, there has been a complex mixture of both tectonic and eustatic effects, so that some have argued that the true change in eustatic sea level can never be truly known. Despite these limitations, most geologists agree that the approximate history of relative sea level can be determined with a level of precision appropriate to most geological problems.

How to Measure

A number of different techniques have been used to determine relative change of sea level. For relatively recent (archaeological scale) changes in sea level, raised shorelines can be used to determine how much relative sea level has dropped. In the longer term (geological scale), maps of the real distribution of marine deposits through time can be used to determine how much the seas have advanced or retreated from one time to the next. However, both of these methods give only a few data points with which to construct sea level history. The best method is to examine thick sections of stratified sedimentary rocks, which give a near-continuous record of deposition in one particular place. If finer-grained, more offshore deposits such as shales and limestones lie above nearshore sandstones, then sea level has transgressed; if coarser-grained, more onshore sandstones overlie offshore shales and limestones, then sea level has regressed. In addition to giving a near-continuous sea level curve, such rocks also yield biostratigraphically important fossils, so the age of each sea level episode can be dated.

These methods work best for sea levels that are higher than present, but are difficult to use for times when sea level has dropped below its present level. In some cases, dredges have recovered shallow marine or terrestrial rocks in deep waters at the edge of the continental shelf, showing that sea level was as low as 125 m below present level as recently as 17 000 years ago. Cores have been drilled in the deep-sea floor which record the sedimentary history of the ocean basins. These yield evidence of sediments formed in much shallower waters, showing that episodes of significant sea level drop have occurred, and placing sea level much lower than it is at present.

The most recent development of sea level analysis has come from seismic reflection profiles of the continental margins. Known as sequence stratigraphy, this method uses seismic reflections to detect how much the sedimentary deposits have onlapped or offlapped the continental margin in the deeply buried records of the past. From this, numerous versions of an onlap–offlap curve (sometimes erroneously equated with a true sea level curve) have been published. However, there are numerous criticisms of this method. The biggest problem is that many of the data are confidential oil company records, and cannot be checked by independent geologists. In addition, the sequence stratigraphic curve shows far more 'sea level events' than can be accounted for by other sources of data, and posits multiple million-year 'eustatic cycles' which have no known mechanism. If the sequence stratigraphic curve is valid, however, it would give by far the most detailed record of sea level change for the last 200 million years.

Sea Level Change Through Time

By combining these different methods of analysis, geologists have arrived at a general consensus about sea level history for the past 600 million years (Figure 1). The curve has many complex details, but there are several prominent trends. First of all, it is apparent that there were two long-term episodes of globally high sea levels, in the early Palaeozoic (500–300 million years ago) and in the Cretaceous–early Cenozoic (150–50 million years ago), when sea levels were typically 200 to 400 m above present. Both of these episodes are thought to represent periods of global 'greenhouse' climates which were much warmer than present. All the polar ice caps were melted, so their water returned to the ocean basins. In addition, the early Palaeozoic and mid-Mesozoic were periods of the break-up of supercontinents, which have multiple effects that cause global transgression. As the continents break up, their margins sink as they pull away from the subsiding mid-ocean ridge, causing the drowning of the passive margin region. As mid-ocean ridges grow and accelerate their rate of spreading, they produce much more ridge volume on the ocean floors, which displaces water from the ocean basins onto land. In the mid-Cretaceous, there were extraordinary volumes of submarine lavas erupted from mantle plumes, which further decreased the volume of ocean basins and displaced the waters onto the land.

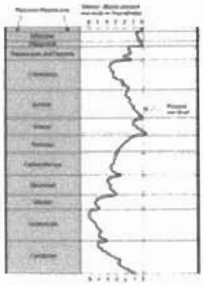

Figure 1
Eustatic curve for the past 600 million years (modified from Hallam, 1992).

By contrast, the late Palaeozoic–Triassic and the late Cenozoic have been periods of relatively lower sea level. Through most of these periods, sea level was still higher than present, although there were global regressions in the late Permian, late Triassic, the middle Oligocene, and especially during the last 3 million years of ice ages, when global sea level apparently dropped below present level. These periods are well known as 'icehouse' phases in global climate, when large ice caps occurred on one or both poles, advancing and retreating with global changes in solar radiation caused by variations in the earth's orbit around the sun. When these ice caps formed, and especially when they expanded, they withdrew large volumes of sea water from the ocean basins and caused global regression. In addition, the late Palaeozoic and late Cenozoic have been periods of the coalescence of continents. When two continents collide (such as when India slammed into Asia to form the Himalayas), it causes the entire region to rise up and form high plateaus and mountain ranges, which causes global regression of seas from the rising continents. This effect was particularly pronounced in the late Palaeozoic, when all the continents coalesced to form one supercontinent, Pangaea ('all land'), which was relatively high in elevation and rarely covered by marine sediments.

Within this long-term sea level history, there have been many complex, shorter cycles of sea level. For example, the lowest sea level ever recorded occurs in the middle Oligocene, when seismic records show a gigantic offlap event. Originally, it was estimated that sea level had dropped as far as 400 m below present level, but more recent estimates place it at about 150 m below present level. During the Pleistocene ice ages of the last 2 million years, sea levels rose and fell globally with each major advance and retreat of the ice sheets. During warm interglacials, sea levels were a few tens to as much as a hundred metres above present level, drowning the world's coastal regions and leaving elevated marine terraces and marine fossils high above the shoreline. During the cold glacials, sea level dropped as low as 125 m below present, exposing the continental shelves of the world to subaerial erosion and deposition of nonmarine sediments, which have still not been completely reworked and redeposited, even though they have been under hundreds of metres of sea water for over 17 000 years.

The last lowstand of sea level occurred around 20 000 years ago, when glaciers were at their last maximum. Since then, sea level has been rising steadily to its present level as ice caps have retreated during our current interglacial. If the present interglacial ends in the next few thousand years (as expected from the ice age climate cycles), then sea level should drop again, and eventually reach its glacial lows. However, humans are causing global warming by burning fossils fuels to produce greenhouse gases, causing the ice caps to melt at a rapid rate. Some scientists estimate that sea level will be rising 2–3 m in the next few decades, which will cause severe flooding in many coastal cities. If all the ice caps melted, sea level would rise by 70 m, which would drown most of the inhabited coastal regions of the world, and cause massive disruption to human civilization as most of the world's cities were drowned, and most of the world's farmlands were flooded by the ocean. However, such a global sea level rise would not even begin to approach the record high sea levels of the early Palaeozoic and Cretaceous, when continents were nearly completely drowned, and sea level was as much as 400 m above present.

Ironically, the source of much of the human-induced greenhouse gases is fossil coals formed from the trees and vegetation that were buried in the earth's crust during the Carboniferous, about 300 million years ago. These coals are a tremendous reservoir of carbon, which was withdrawn from the 'greenhouse' atmosphere of the middle Palaeozoic by these ancient plants and then locked into the crust, triggering the late Palaeozoic 'icehouse' climates. By burning this coal, humans are now re-releasing these ancient greenhouse gases to the atmosphere, and triggering a new global greenhouse.

Further Reading

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Embryonic ELS

Brunel Road, Houndmills, Basingstoke, Hampshire, RG21 6XS, England