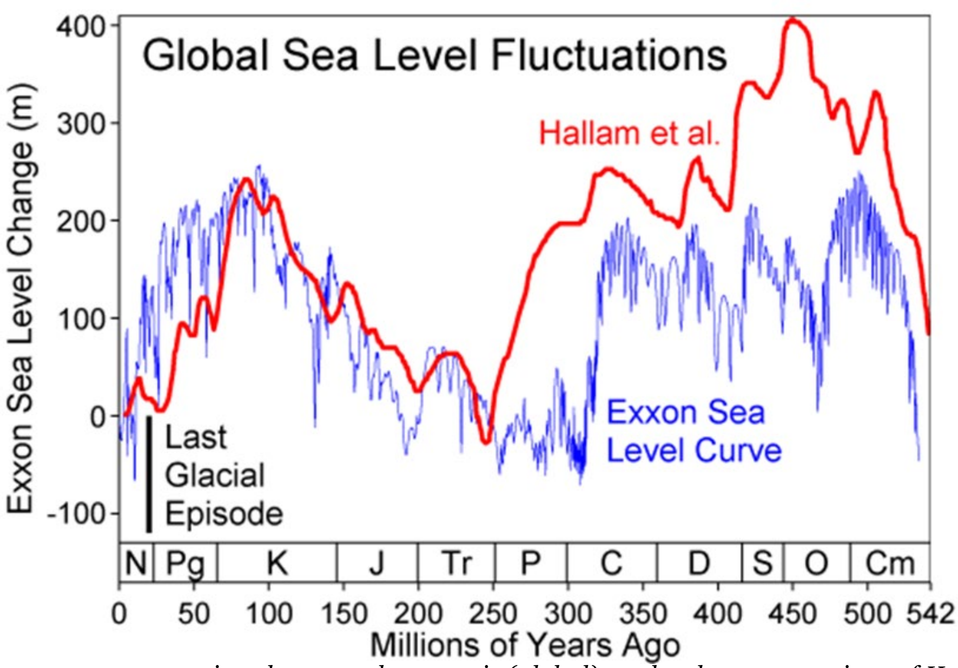
Sea Level Change

SEA LEVEL CHANGE

Understanding sea level changes, their causes, and impact is crucial in maritime archaeology. Maritime heritage sites can be found above or below the current sea level, depending on the area under investigation. But why is this the case?

To begin, this lecture will consider global climate change, as it significantly influences sea-level fluctuations. Our focus is on the Quaternary period, spanning from 2.5 million years ago to the present day.

Throughout the Quaternary, the Earth's climate has undergone substantial variations. Paleoclimate data reveals alternating warm and cold conditions. Initially, there were shorter cycles with less pronounced temperature differences, lasting about 40,000 years. Around 700,000 years ago, these shifted to more extensive 100,000-year cycles, characterized by prolonged cold periods interspersed with brief warm intervals. This means that we can observe cyclical patterns of warm and cold phases, transitioning from 41,000-year cycles to 100,000-year cycles. For most of this time, Earth experienced temperatures colder than today, with infrequent warm periods similar to our current climate.



This figure presents a comparison between the eustatic (global) sea level reconstructions of Hallam et al. (1983) and those produced by Exxon for the Phanerozoic Eon. The Exxon Sea level curve [1] is derived from multiple reconstructions published by Exxon researchers (Haq et al., 1987; Ross & Ross, 1987; Ross & Ross, 1988). Both reconstructions have been aligned with the 2004 International Commission on Stratigraphy (ICS) geologic timescale. This figure was prepared by Robert A. Rohde from publicly available data and is incorporated into the Global Warming Art project.

Evidence demonstrates a clear correlation between climate change and global sea-level fluctuations. Higher sea levels corresponded with warmer periods, while colder eras saw lower sea levels. Examining the past 500,000 years reveals only a few brief intervals when sea levels matched current heights. For most of the time, sea levels were lower, with an average of approximately -50 to -60 meters. The most extreme decrease reached between -120 to -130 meters.

SEA LEVEL CHANGE: SOME TERMINOLOGY

Here are two important definitions related to sea level.

Mean Sea-level: Average height of the ocean surface (usually between high and low **tide)**

Relative sea-level: depth/elevation of the ocean surface relative to a local datum on land (e.g. 10m relative to Ordnance Datum). This can change by vertical movement of the ocean surface or vertical movement of the land. Therefore, the datum is not fixed and has potential to move. In reality, individuals experience the effects of relative sea level rise.

DRIVERS OF SEA-LEVEL CHANGE: ICE CAPS

Ice lagoon Jökulsárlón at the foot of the Vatnajökull Glacier, Iceland. Image: DCheretovich

What is driving the changes in sea level across the globe? Glacio-eustatic changes refer to changes in ocean volume caused by the expansion or reduction of land-based ice. These fluctuations are linked to climate change, which influences the growth or melting of ice sheets. This means that when ice sheets expand, they extract water from the oceans, resulting in a decrease in sea level. Conversely, when ice sheets melt, they add water to the oceans, leading to a rise in sea level.

In the Quaternary, fluctuations between warm and cold periods led to the expansion or reduction of massive ice sheets, such as those in Greenland or Antarctica. As these ice sheets expanded, they removed water from the oceans. Conversely, when they melted, water was returned to the oceans.

The term eustatic describes changes in the amount and distribution of water. For instance, an increase in ocean water leads to higher sea levels, while shifting water to one side results in elevated sea levels on that particular side.

The immense weight of ice sheets causes the Earth's surface to sink beneath, resulting in sea-level rise in areas covered by ice. Conversely, the land at the ice's periphery is pushed upward, leading to sea-level fall in these regions. This process reverses when the ice melts. Additionally, fluctuations in water load on the continental shelf cause vertical movements. These phenomena are known as glacio-isostatic changes, which involve the uplift or subsidence of the crust due to changing ice loads.

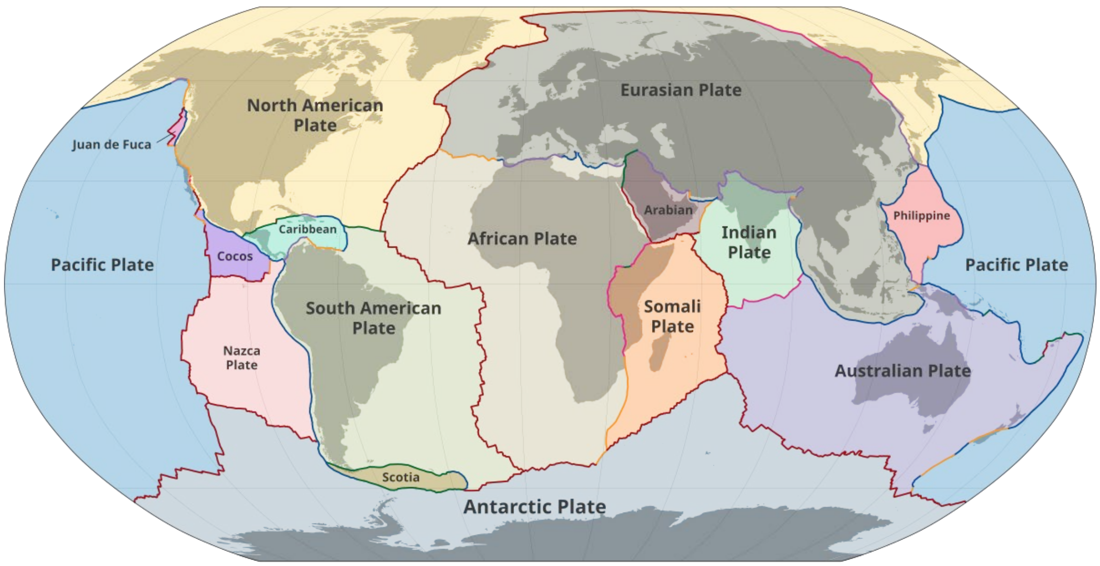
Massive ice sheets depress the underlying crust, causing sea-level rise. A forebulge forms around the ice sheet's margin, resulting in sea-level fall. When the ice load is removed, the crust rebounds over thousands of years, leading to sea-level fall at the ice centre and sea-level rise around the forebulge.

Hydro-isostatic changes refer to the uplift or subsidence of the crust driven by changing water loads. For example, an increase in ocean water volume, such as from melting ice, leads to subsidence and subsequent sea-level fall.

DRIVERS OF SEA-LEVEL CHANGE: TECTONIC CHANGES

Plate tectonics has played a significant role in shaping the global oceans over the course of the Earth's existence. The current formation of the Earth's oceans (the Pacific, Atlantic, Indian, and Arctic) was not always as it is today. The formation of these water bodies has been accompanied by substantial, gradual changes in sea level since the breaking-up of the last supercontinent, Pangea, and began approximately 250 million years ago. The resulting long-term sea level change, while significant, occurred at a pace far too slow for humans to perceive. The formation of large continents through the merging of smaller landmasses often resulted in the creation of more extensive oceanic regions between them. These vast bodies of water were later divided when super-continents broke apart, leading to the emergence of smaller oceans from what were once enormous water bodies.

Our tectonic plates are still moving today, and they can still drive sea-level fluctuations, known as tectonic changes. These include changes in the shape of the ocean basin (tectono-eustasy) and vertical land movements (uplift or subsidence) resulting from tectonic activity (coseismic). Tectonic processes can induce both rapid and gradual changes in land elevation as tectonic plates move. For instance, the devastating earthquake and tsunami on the 26th December 2004 with a moment magnitude of 9.3 lifted some areas of the Indian Ocean bed, resulting in a rise of sea level by 0.1 mm. When land rises, the relative sea level decreases. Conversely, when land sinks, the relative sea level increases.



Map of Earth's principal tectonic plates. Plate boundary types: Divergent: — Spreading center — Extension zone Convergent: — Subduction zone — Collision zone Transform: — Dextral transform — Sinistral transform

Image: M.Bitton,

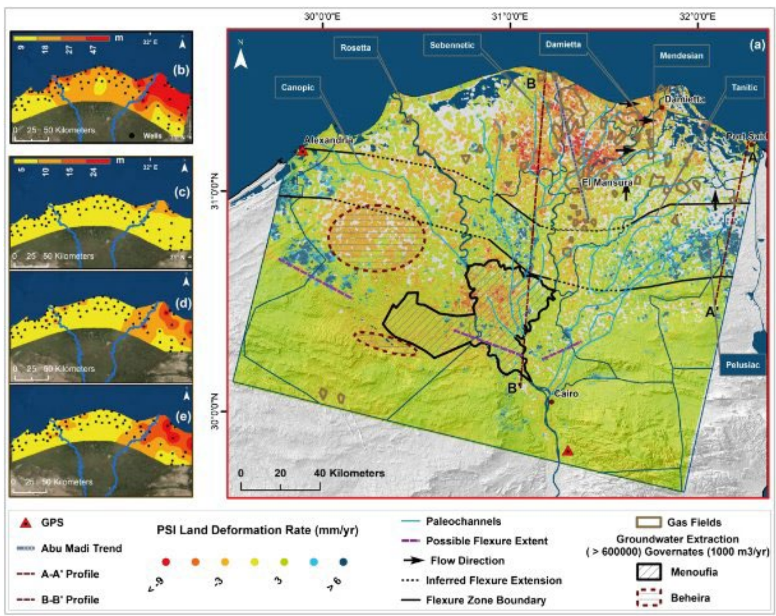
DRIVERS OF SEA-LEVEL CHANGE: WATER DENSITY

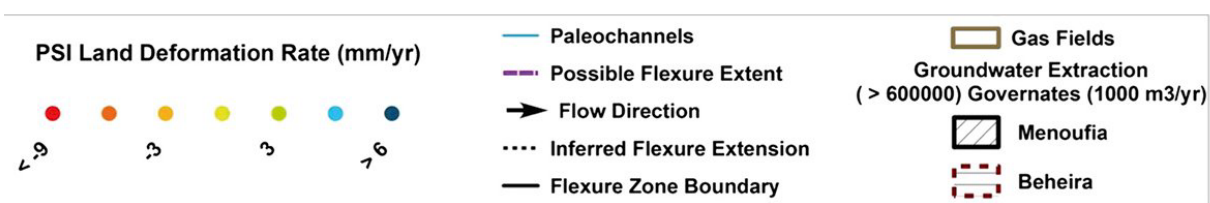
The phenomenon known as Steric causes changes in ocean volume due to variations in water density. As the temperature of water rises or falls, its density changes, leading to expansion or contraction. When temperatures increase, the volume of water expands through thermal expansion. Conversely, cooler temperatures cause the volume of ocean water to decrease. A rise of 1°C in the overall ocean temperature is associated with roughly 50cm of sea-level increase. While these subtle changes are difficult to identify in paleoclimate records, they are crucial factors in projecting future sea-level rise.

DRIVERS OF SEA-LEVEL CHANGE: COASTAL SEDIMENT CHANGE

Changes in coastal sediments can also play a significant role in relative sea-level fluctuations. The buildup of sediment can cause the land to rise, resulting in an apparent relative sea-level decrease, while sediment erosion or compression can lead to an increase in relative sea-level. This issue is particularly pronounced in delta regions, where substantial sediment accumulation occurs, followed by gradual compaction over time.

The removals of sediments such as through uncontrolled sand mining combined with the loss of soil holding mangroves, the extraction of groundwater or hydrocarbons from beneath the sediment layer, or the disruption of sediment supply can drive the drive relative sea-level rise. These challenges are currently evident in areas such as the Nile delta, where subsidence is indicated by red-orange zones, and in coastal urban centres like Jakarta.





Modern deformation of the Nile Delta (from Gebremichael et al. 2018)

DRIVERS OF SEA-LEVEL CHANGE: LOCAL AND GLOBAL IMPACTS

The impact of these driving factors for sea level change varies geographically, resulting in diverse changes across different regions. Some areas have experienced a decrease in relative sea level since the last glacial period, while others have seen rapid increases or fluctuations. In the Middle East and North Africa (MENA) region, for instance, the influence of isostasy is minimal due to its distance from ice sheets. Instead, glacio-eustasy and local tectonic activity play more significant roles. In fact, tectonic forces have led to highly complex sea-level changes throughout the MENA region, with substantial variations between different areas.

- Glacio-eustasy (global)
- Glacio-isostasy (regional)
- Hydro-isostasy (regional)
- Tectonics (regional-local)
- Sedimentary (local)

To summarize, throughout the Quaternary period, the primary indicator of climate change is the alternating growth and melting of ice, which leads to global sea-level fluctuations. However, at smaller scales ranging from regional to local, the worldwide pattern is altered by isostatic, tectonic, and sedimentary factors. As a result, geological and geomorphological evidence of historical sea levels, coastlines, and coastal regions can be discovered both above and below the current sea level.

Disclaimer: The materials and information presented in these lectures have been compiled from a range of academic sources, which are listed in the Bibliography and Further Reading section of this course.