COASTAL ZONE AND ESTUARIES

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Summary

Coastal systems are complex and fragile. They are important as the link of water, sediment, and nutrients between continents and oceans. There are some doubts about their role as sources or sinks of greenhouse gases. The present behavior of sea level, ice sheets, and coral reefs is still a matter of controversy and concern. Coastal experiences learned in developed countries should be used to improve coastal policies in developing regions. Within the Global Change Programme, it is recognized that the earth system is characterized by critical limits and abrupt changes. The coastal systems are particularly sensitive to these changes and there they can occur more abruptly.

1. The Coastal Zone

Coastal systems are recognized by their complexity and fragility. The different processes that operate in the present behavior of coastal features, and those that are inherited from the past, lead to complexity. Fragility is a lesson about how humanity is damaging the place it depends on and in which it prefers to live.

In terms of the coastal project of the International Geosphere-Biosphere Programme (LOICZ), the coastal zone extends from the coastal plains to the outer edge of the continental shelves, approximately matching the region that has been alternately flooded and exposed during the sea level fluctuations of the Late Quaternary period. The coastal zone therefore covers about 8 percent of the planet surface while accounting for 25 percent of biological production.

1.1. Climate Change

Climate changes have profound effects on the coast. Precipitation and temperature changes affect the degree of weathering on the basins and therefore the amount of sediment transported to the continental shelves. Variations in ocean circulation, ice-shelf dynamics, and upwelling phenomena affect the processes that operate in coastal systems. Biological processes also respond to these changes, and they may be triggered by variations in temperature, nutrient supply, and light penetration.

1.2. Sea Level and Sea Ice Fluctuations

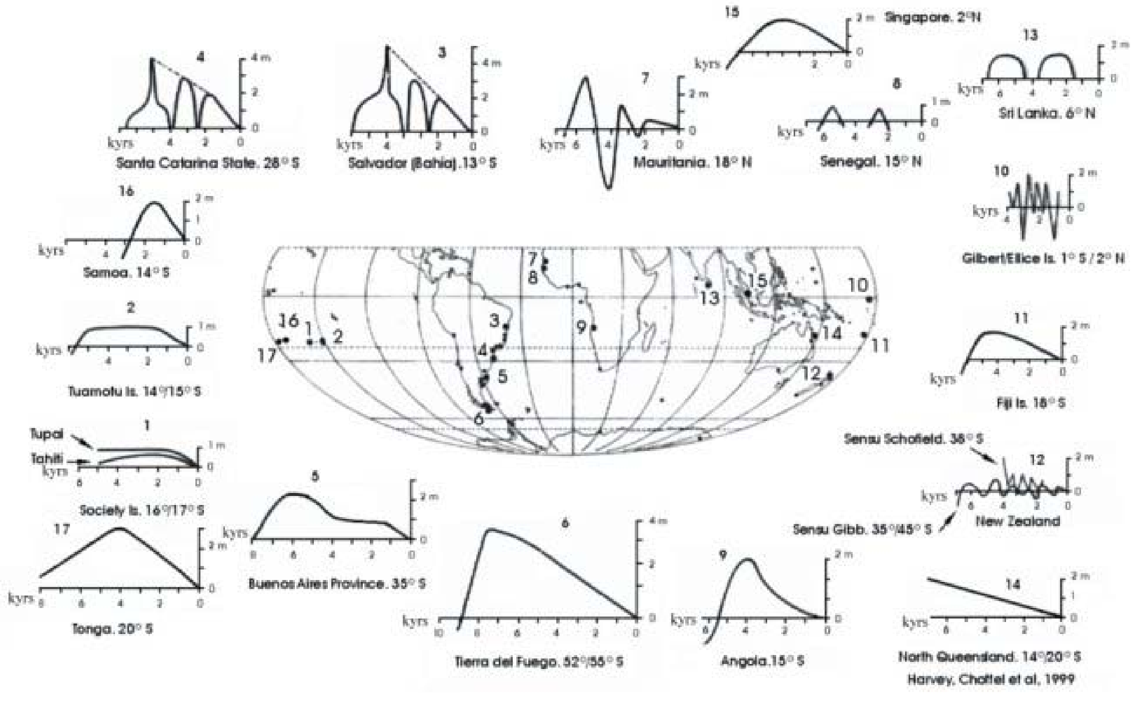

Figure 1. Holocene sea-level fluctuations from the Southern Hemisphere
Source: Isla, 1989. The Southern Hemisphere Sea Level Fluctuation. *Quaternary Science Reviews*, No. 8, pp. 359–68.

Sea level changes are related to Quaternary climate changes but also to the configuration of the geoid, the rate of plate tectonics (tectonoeustasy), or the dynamics of wind patterns and ocean currents. In the last 10,000 years humanity has lived in a period 2 °C warmer than before, known as the Holocene interglacial. This also means that the sea level is about 100 m higher than it was 18,000 years ago. During the Last Glacial era, rivers discharged sediments to the borders of the continents. The present continental shelves were extensive plains and many of the present closed seas were freshwater lakes. Deglaciation produced a rapid sea level rise that slowed down over the last 6,000 years. However, along certain coasts the sea level has actually been dropping over the last 6,000 years. This has happened in most of the Southern Hemisphere (see Figure 1) and at high-latitude coasts where the weight of the former ice sheets induced an isostatic land recovery (uplifting of the coast and the consequent relative sea level fall).

Many coasts are threatened by predictions of a rise of 1–2 mm/year in mean sea level as a consequence of natural (ocean thermal expansion, mountain glacier and polar icecap wastage) and land-based anthropogenic causes (reservoir impoundment, groundwater extraction, and so on). The scenarios forecast by the Intergovernmental Panel for Climate Change (IPCC) range from an increase of 0.3 to 1.0 m for the year 2100. In order to assess the vulnerability of each coast, a common methodology was proposed, considering not only coastal erosion but also salinization of aquifers and loss of habitats, species, and heritage sites. Many cities and countries should take notice of present sea level trends and modify their infrastructure appropriately (roads, bridges, sewage outfalls, docks, navigation facilities). Another issue stressed concerns about the increased danger to people and properties as a result of storm surges, hurricanes, and typhoons. The UNESCO report of 1990 was very cautious in regard to the doomsday predictions about accelerated rises triggered by rapid melting of ice sheets. An increase in precipitation would cause the growing of the ice sheets, making it uncertain whether there would be a net rise or fall of global sea level. In many parts of the world the relative mean sea level is falling rather than rising, and may continue to do so despite greenhouse warming.

Various coastal areas suffer from a complex of problems associated with sea level movements. Many deltas of the world are subject to sediment compaction. Other coastal areas have subsided in response to groundwater extraction (for example, the Dutch coast, the San Francisco Bay area). Many cities such as Venice, Shanghai, Bangkok, and Taipei have carefully measured their subsidence processes, but in other Third World cities, such as Jakarta, Hanoi, and Manila, this process is not well documented. The freshwater Everglades in Florida, USA, are subsiding in response to drainage and oxidation of peat soils. The restoration of the Everglades wetlands, which today occupy only 50 percent of the area originally covered, is complicated because it threatens the future of agriculture in the area.

Sea-ice formation involves the cooling of seawater below –1.8 °C and the freezing of the initial frazil ice. It covers 7 percent of the world’s ocean. Once formed, it varies considerably in its physical properties, spatially and temporally. According to the World Meteorological Organization, sea ice less than 0.1 m thick is called Nilas or Pancakes. Young ice is the name given for rafts (0.1–0.15 m thick, also called “gray ice”) or ridges (0.15–0.3 m thick, also known as “gray-white ice”). Thin first-year ice (FYI) is between 0.3 and 0.7 m thick, and medium/thick FYI is thicker than 0.7 m. Most Antarctic sea-ice moves northwards as it melts during its first year. However, in the Weddell, Ross and

Bellingshausen Seas there are important amounts of thicker multi-year ice. Sea-ice shelf dynamics depend on sea-surface temperature and ice thickness. Ice compression makes it thicker (ridging) while winds and coastal currents make it move as rafts (rafting). Around Antarctica, the total area of sea-ice varies between averages of 3.5 x 10^6 km^2 for February to 19 x 10^6 km^2 for September. However, there is great inter-annual variability in the order of 10 x 10^6 km^2 that was attributed to El Niño–Southern Oscillation (ENSO) effects in the Antarctic Cyclone Belt or Southern Circumpolar Trough. Interpretation of data from the Nimbus and DMSP satellites indicates that the Weddell Sea is increasing its sea-ice extension while it is declining in East Antarctica and the Ross Sea coasts. This inter-annual variability or noise in the sea-ice records, coinciding with the spatial variability of retreating-prograding trends, makes it very difficult to predict the behavior of sea-ice in a global warming scenario.

1.3. Coastal Processes

Coasts are subject to changes induced by near-shore dynamics. Where the tidal range is small, the principle physical impact on the coast is produced by waves, while storms can episodically cause severe erosion. On those shorelines where the vertical changes induced by the gravity of the Moon and the Sun are most significant, the energy is delivered mainly by tidal action. Cliffs and abrasion platforms (see Plate 1) are typical features indicating erosion on consolidated coasts, while scarps of dunes or berms are temporary erosive features of accreting coasts.

Plate 1. Cliffs and abrasion platforms characterize the Patagonian coast. Caleta Córdova is a village oriented to petroleum production close to Comodoro Rivadavia city, Chubut. Coastal facilities, such as jetties and pipelines, affect coastal dynamics and cause more erosion.

Wind causes waves in the open ocean and then further affects them when they reach the coast, either increasing or decreasing their heights. The behavior of waves in relation to shallower depths modifies the bedforms and therefore has a big influence on sediment dynamics and transport (see Figure 2). When waves arrive on a beach at a certain angle they induce currents between the breaker and the shoreline that are called long-shore currents. These currents are responsible for the littoral transport of sediment along beaches. Man has tried to control the effects of these long-shore currents by the construction of groynes or breakwaters, and has caused many erosion problems.

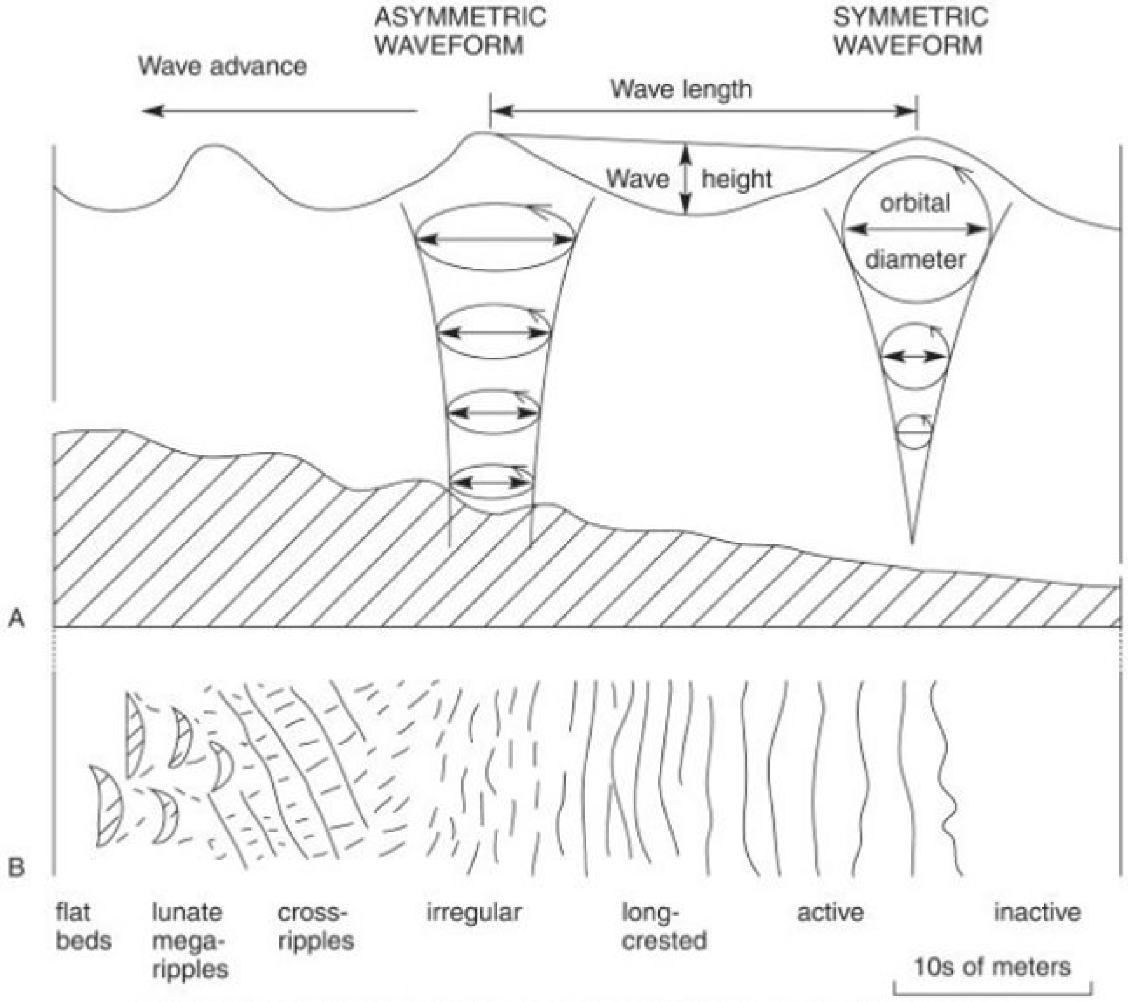

Figure 2. Different stable bedforms related to the action of waves approaching the coast
Source: Clifton (1976). Wave-formed Sedimentary Structures. A Conceptual Model. In: Davis and Ethington (eds.), *Beach and Near Shore Sedimentation,* SEPM, Special Publication No. 24, pp. 126–48.

Coastal defense is a problem which extends to many coastlines. During the 1970s many countries implemented national plans against coastal erosion. During the 1990s some problems were solved but many became worse. The Intergovernmental Panel on Climate Change proposed two apparently simple alternatives: do nothing or do something.

Within the last alternative, there are three possibilities:

- to plan a retreat (building setbacks)
- to accommodate (raise buildings or pile above the flooding level)
- to protect (construction of seawalls, groyne fields, or beach nourishment).

In the Netherlands, the coastal defense policy proposed zoning three regions (Delta, Holland and Wadden), considering four alternatives:

- coastal retreat
- selective erosion control
- full erosion control
- seaward expansion in some locations.

It was recommended to integrate the traditional method of sea defense with more nature-oriented dune management.

Many coastlines of the world suffer the effects of particular energetic processes. They occur infrequently, but their consequences had a major effect on the behavior of humans and their relation to coastal ecosystems.

Some coasts are periodically affected by extra-tropical storm surges or tropical hurricanes. Other coasts of the world can suffer episodic tsunami events originated from the opposite side of the ocean. Several alarm systems based on satellite imagery have been implemented to prevent loss of life from these events.

1.4. Sediment Delivery

In a very general way, climate controls the radiation, evaporation, and sediment availability on every coast (see Figure 3). However, every continent discharges different amounts of water. Basin configurations facilitate the relative discharge of sediment in some continents while offering sediment traps in others.

South America is effectively discharging water while Asia and Oceania are effectively discharging sediment (see Figure 4). Milliman and Meade calculated that 70 percent of the sediment discharged to the global ocean annually occurs in Southeast Asia. Due to varying latitude conditions the sediment contributions of the continents depend on the dominance of chemical (weathering) or physical processes.

In Asia, North America, Oceania, and Europe, the annual inputs of particulate organic carbon (POC) dominate; in South America the dissolved organic carbon (DOC) input is more effective. Worldwide POC contributions to the ocean is estimated at about 0.42–0.57 billion tons of C/year, while DOC is estimated in 0.11–0.25 billion tons of C/year. South America is especially subject to inter-annual variations due to ENSO effects.

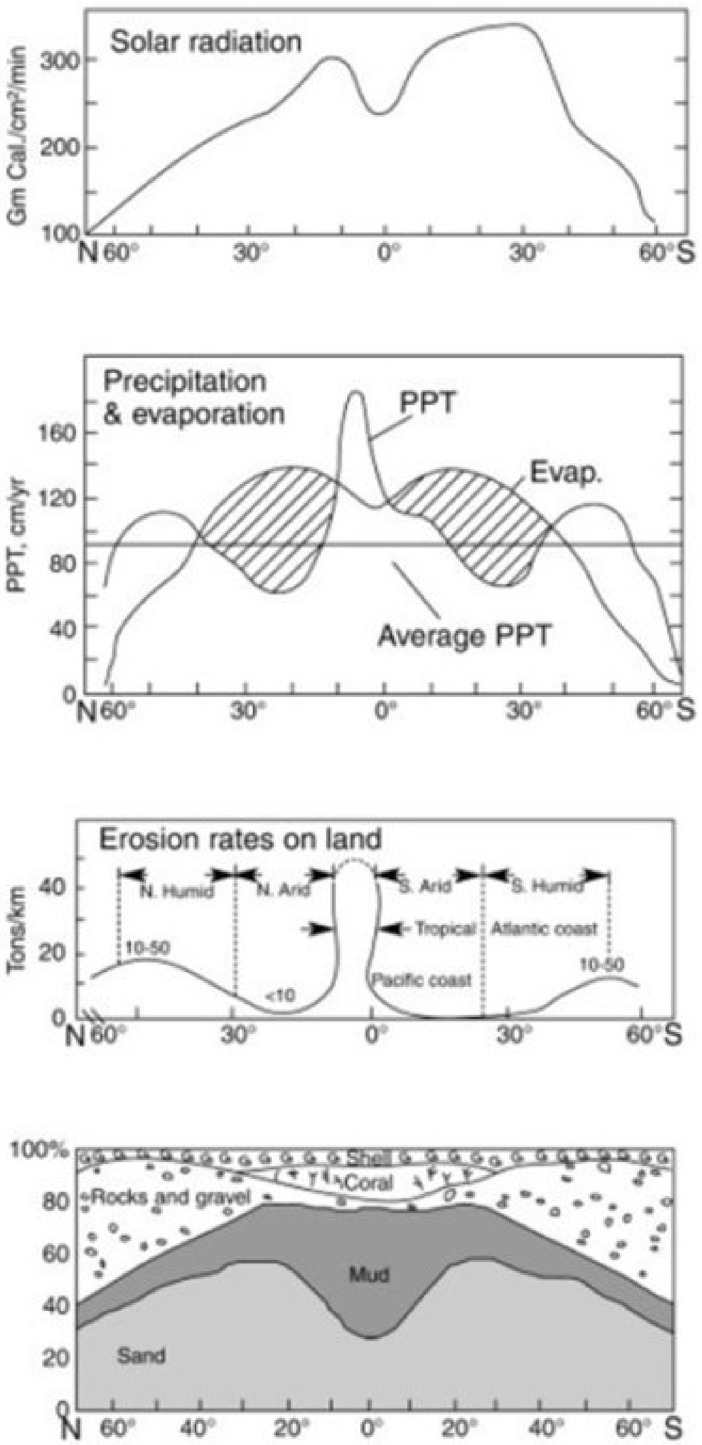

Figure 3. Global variation of solar radiation, precipitation, evaporation, erosion rates, and sediment availability
Source: Nichols and Allen, 1981. Sedimentary Processes in Coastal Lagoons. Proceedings of the UNESCO-IABO Seminar Coastal lagoon research, present and future. *Technical Papers in Marine Science* No. 33, pp. 27–80.

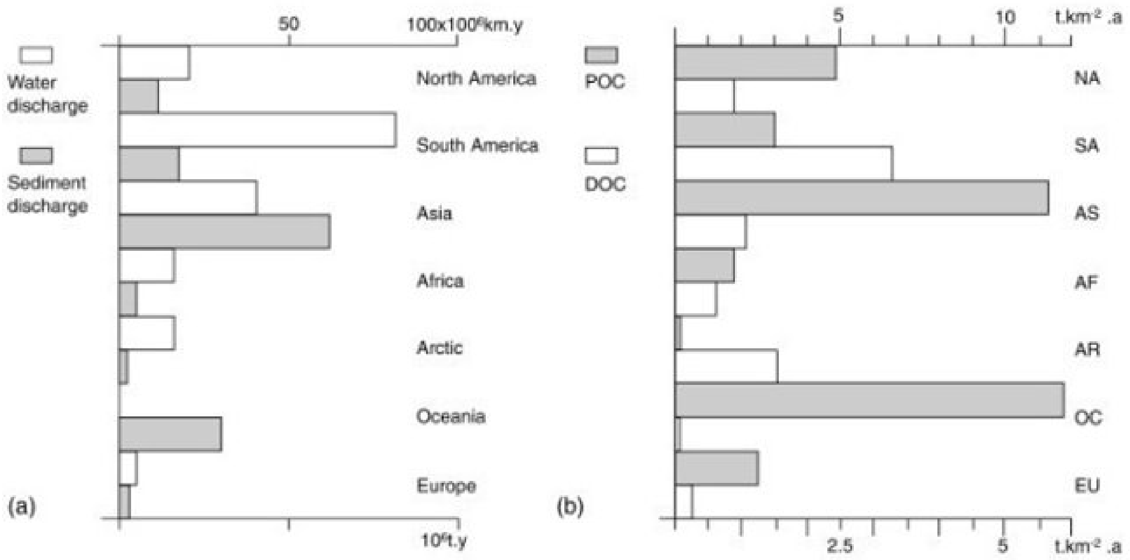

Figure 4. (a) Relative water and sediment discharge from the continents via rivers.
(b) Annual inputs of organic carbon from the continents via rivers
Source: Degens and Ittekkot, 1985. *Relative Organic Carbon: An Overview*. Mitt. Geol. Palaont. Inst., Univ. Hamburg, SCOPE-UNEP Sonderband, pp. 7–27.

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Biographical Sketch

Federico Ignacio Isla was born in La Plata, Argentina, in 1955. He obtained his Ph.D. from the University of La Plata (Museum of Natural Sciences) in 1986. Since 1979, he has worked at the Coastal

Geology and Quaternary Research Center (University of Mar del Plata). He is member of the career of scientific researcher of the Argentina Research Council (CONICET) and Professor of Geological Oceanography and Remote Sensing at the University of Mar del Plata. In recent years he has become involved with several international projects devoted to the coast and the sea (IGCP 200-274-367, Ocean Science related to Non-Living Resources, Land-Ocean Interactions in the Coastal Zone, International Quaternary Shorelines Commission).