COASTAL LAGOONS

Federico Ignacio Isla
Centro de Geología de Costas y del Cuaternario, University of Mar del Plata, Argentina

Keywords: Coastal lagoons, origin, size, climatic setting, processes, tidal inlets, tidal deltas, evolution, pollution.

Contents

Summary

In recent years, coastal lagoons have received more attention and concern in regard to their increasing use for transportation, recreation and food production (aquaculture). They originated mainly along lowlands in response to the decrease in postglacial sea-level rise (or its fluctuation) and/or heavy longshore drift. They occur in every tidal regime (micro to macrotidal) and climatic regions (low latitudes to high latitudes). There are environments related to them such as tidal inlets and tidal deltas that control their present evolution. There have been many alterations of coastal lagoons; they are induced by dredging, eutrophication, pollution, hydrological imbalances and ecosystem modifications due to overfishing, introduction of species, or aquaculture.

1. Definition and importance of coastal lagoons

Coastal lagoons are defined as shallow water bodies separated from the ocean by a barrier, connected to it at least temporarily by one or more restricted inlets and usually oriented parallel to the shore. Many coastal lagoons were first described as temporarily sealed, such as Gipssland Lakes (Australia) or Mar Chiquita (Argentina). Today, these lagoons are open due to a constant human intervention. Coastal lagoons are important on account of their biological, geological, physical and chemical characteristics. Man makes them useful for transportation, food supply, mining, recreation and preservation activities. Their diversity of fauna and flora, and biomass productivity, have made them a focus of interests since the early 1970s.

1.1. Improvements of coastal lagoons knowledge

In the last 30 years, several reviews have been concerned specifically with coastal lagoons, considerably improving our knowledge about these environments. In 1967 the first symposium on coastal lagoons was held in Mexico (Ayala-Castañares and Phleger, 1969). In 1977 Robert Lankford proposed the first classification of the coastal lagoons of Mexico (1977). A seminar that took place in 1978 at Duke University Marine Laboratory at Beaufort, North Carolina was published by UNESCO in 1981. More recently (1994), Bjorn Kjerve conceived a compilation about different aspects of coastal lagoons.

2. Origin and size of coastal lagoons

Extending along 13% of the world coastline, coastal lagoons are more common in low-lying coasts. Factors that control their formation are: 1) sea-level history, 2) shoreface dyamics, and 3) tidal range. Barriers, that are genetically related to coastal lagoons, form in response to sea-level fluctuations (see *Coastal Barriers*). However, coastal lagoons can be recognised either in coasts where sea level has been rising (transgressive) or dropping (regressive). Shore parallel currents, where sediment is available in enough quantities, can create barriers from bars or spits.

Waves can transport longshore sediment provided by rivers, by coastal erosion or from submerged features, eventually to block bays by beach drift. In this sense, waves can open or seal inlets, depending on the energy delivered to barriers and the amount of sediment available on the shoreline. Coastal lagoons dominate on small tidal regimes: microtidal (less than 2 m) or mesotidal (2-4 m). On macrotidal coasts (more than 4 m), the tidal currents dominate the sediment transport minimising the beach drift, and thus not favouring development of coastal barriers. With regard to size, coastal lagoons can be small features originated within a plain of beach ridges (e.g. a deltaic plain) or environments occupying over 10 000 square km and related to shallow basins partially blocked by barrier islands (e.g. Lagoa dos Patos, Brazil).

3. Climatic setting

There is no climate restriction to formation of coastal lagoons. They occur in tropical (rainy or arid), temperate and cold coasts.

In **tropical humid areas** precipitation exceeds evaporation. Along the coast of the Gulf of Guinea, many lagoons extend for 1000 km. During the rainy season the water level rises and creates natural openings that discharge high suspended sediment loads. During the dry season, however, seawater invades lagoons and salinity can vary from 0 to 30 psu. The Mundel Lake, in Sri Lanka, reported variations from 46.5 to 5 psu in less than 4 months induced by the effects of monsoon rains. In such lagoons, distinctive features are the deltas constructed at the head of the lagoons (intra-lagoonal deltas). Different stages in the infill of coastal lagoons by intra-lagoonal deltas can be found in Mexico (Laguna San Ignacio, Laguna de Alvarado) or Brazil (Guaíba delta complex in the Patos Lagoon). Different areas of the lagoon may be influenced by the assymetry between the moment of maximum tidal height and the moment of maximum tidal currents (time-velocity assymetry); either during flood or ebb. The opposite situation can also be found on the coast of Brazil where small lagoons are common on large deltaic plains. Lagoa Feia is a coastal lagoon on the deltaic plain of the Paraíba do Sul River, and the Zacarías, Juaparaná and several other small lagoons are dispersed on the deltaic plain of the Doce River.

In **tropical coastal lagoons in arid areas** evaporation dominates the hydrological balance. Small quantities of terrigenous sediment may be supplied as quartz sand blown from the surroundings. Most of the sediment originates locally by biochemical precipitation. Algal mats, mollusc shells, coral fragments, echinoids, ostracods and foraminifera accumulate in their bottoms. The reworking of these sediments crenates oolites or pellet muds. Coral reefs form barriers or atolls, and give origin to a special kind of coastal lagoons. High aeolian dunes can develop in relation to the availability of oolites at the tidal deltas. The intense evaporation permits the precipitation of calcium carbonate, dolomite, gypsum, anhydrite and halite. Waves and tidal currents may rework the salts into oolites. Vegetation effects and river inputs are negligible. In hyper-arid coastal lagoons, salinity is higher than the sea (54-77 psu) and temperature is subject to periodic changes. Along the gulfs of Suez and Eliat and the Arabian Sea, the prevailing winds from the NNW and N induce a longshore drift to the south. The longshore growth of spits at a rate of up to 14 m/year gives a substrate for reef growth and the formation of lagoons (Belayin lagoon is one of the most conspicuous) and sabkhas (playas). On the other coast of the Arabian Peninsula, in the vicinity of Abu Dhabi, the shallow subtidal sea and intertidal areas (sand flats, beach rock, mangroves and algal mats) display significant salinity changes, from 60-70 psu in the inner-most parts to 44 psu at the inlets. Average annual rainfall is about 34 mm/year. Groundwater in the surroundings has salinities between 70 and 356 psu.

Temperate coastal lagoons are characterised by warm temperatures and moderate precipitation. They develop on coastal plains subject to sea level fluctuations. The lagoons on the Eastern Coast of USA and southern Brazil are typical examples of coastal-plain lagoons. Sandy barriers control their marine boundary while fluvial deltas are partially infilling them from the landward margin. If the fluvial input is low these deltas are limited to the landward shore (East Coast of USA), but if the input are high, deltas could be infilling a considerable area of the lagoon (central Brazil). Winds can control their dynamics, promoting bottom resuspension or inducing septation at nodal points. Coastal lagoons with large tidal ranges can have extensive plains colonised by halophytic vegetation (see *Tidal Salt Marshes and Mangrove Swamps*) and a high biomass of benthic infauna. The strong winds of mid latitudes and large longshore drifts conspire against the stability of tidal inlets, regularly blocking the harbour entrances. The coastal lagoons of Uruguay are almost permanently blocked.

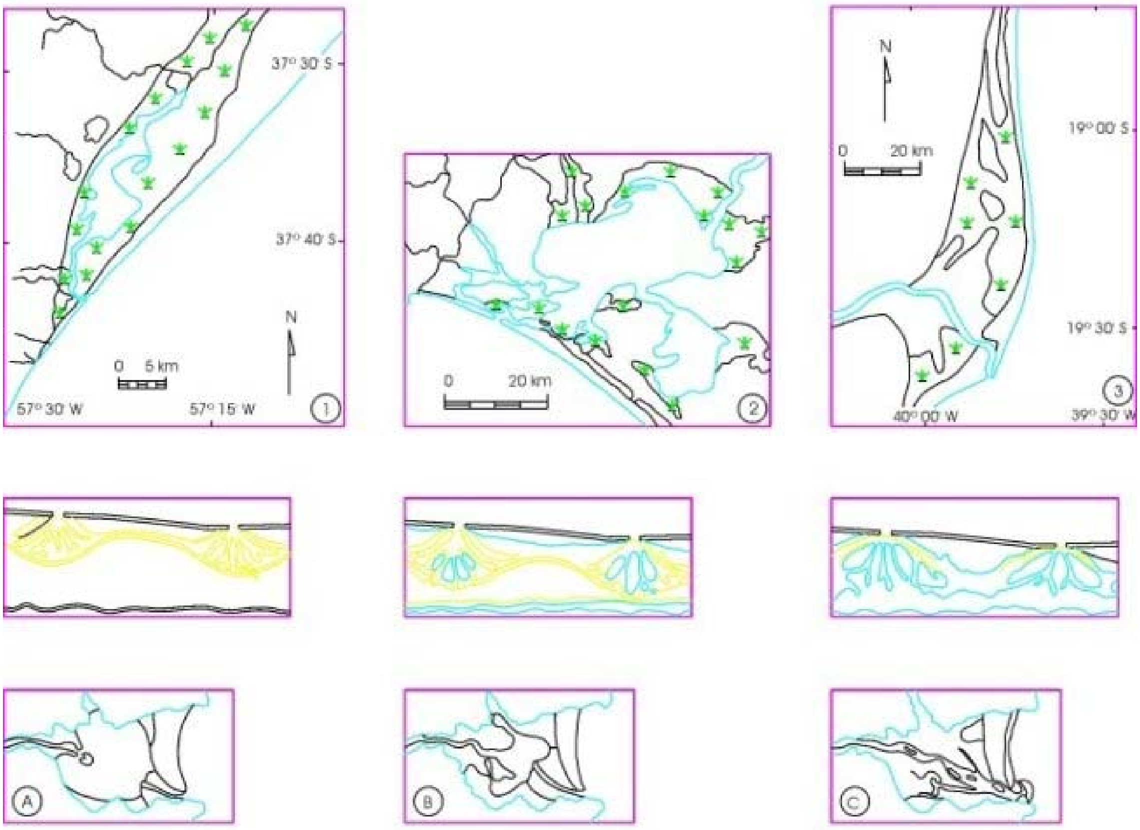

Figure 1. Different stages of infilling of temperate coastal lagoons. A) Mar Chiquita, Argentina. B) Murray-mouth lagoons, Australia. C) Doce River intra-lagoonal delta, Brazil. D-E-F) Roy´s model of fluvial delta infill. G-H-I) Lucke´s model of tidal delta infilling.

High-latitude coastal lagoons are controlled by freeze and thaw processes. Freeze preserves the coastal lagoon from morphological changes during winter. During the summer, they could be subject to ice rafting, waves, tides and wind actions. The Bahía San Sebastián, on the eastern coast of Tierra del Fuego, with tidal ranges of more than 9 m, is a good example of these processes. Vegetation can become dominant in certain places (tidal marshes) and salt can precipitate on tidal flats of windy regions. Significant amount of sediment can be transported by icebergs that ground at low tide, incorporate sediment when they freeze during the night, and are put into motion again in response to tidal outflow.

4. Grain size and sedimentation rates

Three types of grain-size distributions can be discriminated in relation to dominant processes:

- In coastal lagoons dominated by fluvial inflow, the coarsest sediments are deposited as bedload on the landward margin, and finer sediments settle from suspension at the deeper portions of the basin. The Roy´s model of fluvial delta infilling should be applied (D-E-F of Figure 1)

- On tide-dominated coastal lagoons (leaky in the sense of Kjerve), the deceleration of the flow is towards the mainland. Coarser sediments are deposited in the deeper parts whereas mixed and mud flats dominate the shallower portions. Lucke´s model would be applicable.
- On microtidal coasts, lagoons can be wave-dominated with restricted inlets.

Flood tidal deltas are distinctive features that distribute sand coming from the sea. In some lagoons, such as the Langebaan Lagoon, South Africa, the sediment distribution within the intertidal deposits is a mixture between two different source populations. In recent years significant attention has been focused on the effects of flocs (micro and macroflocs) in coastal lagoons. Microflocs are less than 125 microns in size and are composed of mineral particles and organic matter. Macroflocs are larger (up to 3 to 4 mm depending on turbulence) and are aggregates of microflocs and mineral particles. They were studied in detailed in several coastal areas such as the estuaries of Gironde, Ems, and Rhine, in Europe, and Saint Margaret's Bay, in Canada. It was suggested to study them *in situ* using plankton camera photography. Morten Pejrup proposed a hydrodynamic classification of estuarine sediments based on the percentage of the flocculated grain-size population in the mud fraction.

Particle size can be modified once sediments enters the coastal lagoon. The shallowness of these environments can favour the settlement of fine particles during slack waters. On the other hand, wind action can easily resuspend fine sediments from the bottom. Biological action can also help to induce sedimentation or to favour erosion. Those organisms that produce mucus or organic films can help to bind inorganic particles into flocs. On the other hand, many organisms bioturbate the bottom and help the entrainment of particles. Animal tracks, burrows or pellet formation are examples of the action of organisms to induce sediment entrainment. Some organisms can act as engineers modifying the conditions of the bottom. In Mar Chiquita coastal lagoon, the introduced polychaete *Ficopomatus enigmaticus* which constructs reefs, altered the sediment dynamics and is accelerating the infilling rate. The depth to where benthic organisms can generate bioerosion depends on the redox (reduction-oxidation) potential depth in the sediments. Lagoons are predominantly sinks of sediments on scales of 100 to 1000 years, where the sedimentation rate balances or exceeds submergence. However, the sedimentation rate is not always continuous; storms or floods can cause episodic erosional effects. For example, the erosion of the floor of Venice Lagoon, Italy, is supposed to be in response to submergence and changes in the water circulation. In Lagoa dos Patos, Toldo and collaborators estimated an infilling rate of 0.52 to 0.75 mm/yr during the last 8000 years, from ^{14}C datings. These sedimentation rates increase to 3.5 to 8.3 mm/yr in the last 150 years (estimated by determinations of ^{210}Pb) due to the deforestation that occurred after the European settlement in southern Brazil. Eric Bird described similar changes in the sedimentation rates of coastal lagoons in the Western Pacific. Deforestation and agricultural improvements in the watershed increased the sedimentation rate of Segara Anakan Lagoon, Java (Indonesia). River dams, on the other hand, can very significantly reduce the sediment input of coastal lagoons.

-
-
-

TO ACCESS ALL THE **19 PAGES** OF THIS CHAPTER,
Visit: http://www.eolss.net/Eolss-sampleAllChapter.aspx

Bibliography

Ayala-Castañares, A. and Phleger, F.B. (1969). *Lagunas costeras, un simposio*. UNAM-UNESCO, Mexico, 221-236. [The first symposium on coastal lagoons].

Boothroyd, I. C. (1978). Mesotidal inlets and estuaries. In Davis, R. A. (ed.) *Coastal sedimentary environments*, Ch. 6. [An analysis of bedforms and dynamics of tidal inlets].

Fairbridge, R. W. (1980). The estuary: its definition and geodynamic cycle. Chem*istry and biogeochemistry of estuaries* (Olausson E. and Cato, I. eds.) Wiley, NY, 1-35. [A geomorphological classification of estuaries].

Isla, F. I. (1995). Coastal lagoons. *Morphology and sedimentology of estuaries (*Perillo, G.M.E. ed.) Ch. 9, Developments in sedimentology 53, Elsevier Science Publishers, 241-272. [A review about the morphology and sedimentology of coastal lagoons].

Kjerve, B. (1994). *Coastal lagoon processes*. Elsevier Oceanography Series 60, 577 pp. [A modern approach to coastal lagoon research].

Kjerve, B. and Magill, K. E. (1989). Geographic and hydrodynamic characteristics of shallow coastal lagoons. *Marine Geology*, 88, 187-199 [A hydrodynamic classification of coastal lagoons].

Lankford, R.R. (1977). Coastal lagoons of Mexico: their origin and classification. *Estuarine processes* (Wiley, M. Ed.) Academic Press Inc., volume II, 182-215 pp. [An inventory of the coastal lagoons of Mexico].

Nichols, F.H., Cloern, J.E., Luoma, S.M. and Peterson, D.H. (1986). The modification of an estuary. *Science*, 231, 567-573 [An excellent compilation of the environmental problems of San Francisco Bay].

UNESCO (1981). *Coastal lagoon research: present and future*. UNESCO technical papers in marine science 33, 348 pp. [A very useful compilation of different subjects on coastal lagoons].

Biographical Sketch

Federico Isla was born in La Plata, Argentina. He obtained his PhD from the University of La Plata (Museum of Natural Sciences) in 1986. Since 1979, he has been working at the Coastal Geology and Quaternary Research Center (University of Mar del Plata). He is a member of the career board for scientific researchers 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 in 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, and International Quaternary Shorelines Commission).