Quaternary and Environmental Geosciences (2017) 07(1):1-9
Revisão e atualização

Coastal barriers from Argentina: Buenos Aires, Patagonia and Tierra del Fuego

Federico Ignacio Isla

Instituto de Ciencias Marinas y Costeras, Instituto de Geología de Costas y del Cuaternario, CONICET-UNMDP
fisla@mdp.edu.ar

Abstract

Barriers, barrier islands and spits characterise low-lying coasts. However, they can grow along erosive coasts where there is a constant supply of sand, gravel, or both. At the Argentine coast, sandy barriers characterise the template coast of Buenos Aires. The availability of gravel at the Patagonian and Tierra del Fuego coasts induces the formation beach-ridge plains that can derived into coarse-grained spits. The morphology of these spits obeys to the basin depth and the availability of sediment. Recurved spits signify that the beach drift is locally modified by the action of waves or sediment-supply shortages. Some spits are today subject to local erosion (cannibalisation) that compensates these sediment deficits. Barriers and spits are ideal to locate harbours, marinas or touristic (resort) villages. However, the freshwater volumes inside their bodies are limited, even in areas where rain-fed aquifers have plenty of capacity. In this sense, resort villages are limited in their urban sprawl and planners should foresee these resource-based limitations.

Keywords: gravel spits; coastal evolution; land-use changes; sediment availability; dune-vegetation processes

1. Introduction

Barriers and barrier islands are very ubiquitous around the planet, particularly at low-lying coasts. Inheritance, meaning both tectonics and sea-level history, plays a crucial role in their morphology (Stutz and Pilkey 2011, Lentz and Hapke 2011). During the XX century, several coastal barriers were described in detail (Fitzgerald and Buynevich 2006), and discussions merged in regard to their origin. While some authors propose that the sea-level rise was responsible for their origin (Hoyt 1967), others proposed the growing of complex spits (Fisher 1968). A multiple causality is today accepted (Schwartz 1971, Short 1979), and at different tectonic settings (Glaeser 1978). Regarding sediment availability, temperate barriers are dominantly composed by sand. Gravel and rock fragments are more abundant at high-latitude coasts (Hayes 1980). While in sand barriers the reworking (cannibalisation) is difficult to recognize, in gravel barriers these processes can be more easily described in regard that they are not subject to aeolian reworking or dense forestations. In an attempt to classify gravel beaches the proportions and distribution of sand and gravel were discriminated into 5 types: sand and gravel mixed, sand with gravel segregated, gravel with sand mixed, gravel with sand segregated, and gravel beaches (Aragonés et al. 2015)

In the present review, a comparative analysis and the evolutionary trends of the barriers of Argentina were described. Although some barriers located in touristic areas of Buenos Aires were subject to detailed descriptions, other barriers composed dominantly by gravel from Patagonia and Tierra del Fuego (figure 1**)** are fairly known. In this sense, these high-latitude barriers are originated by a sea-level fluctuation where the macrotidal regimes permit to discern the segregation of processes.

2. Tidal regime, climate, tectonics and sediment availability

Barriers are more common in microtidal coasts, but also occur in mesotidal ones (Boothroyd 1985). The growth of sand dunes depends on the availability of sand, also related to wind dynamics. In this sense, wider barriers occur in temperate climates where there is a significant supply of sand. In general terms, the coast of Argentina has a microtidal regime at the north and macrotidal regime at the south. In regard to long-term tectonics, an uplift rate of 8-9 cm/kyr has been applied to sea-level analysis (Guilderson et al. 2000). The coast of Tierra del Fuego is assumed to be subject to tsunami events (Bujalesky 2012) although their frequency was not yet known.

Mar Chiquita barrier (Buenos Aires Province; figure 1) is located in a temperate subhumid to humid region (figure 2). As average rains sum 790 mm/yr and evapotranspiration about 713 mm/yr, there is an excess in the water balance of 77 mm/yr (Fasano et al. 1982). However, and due to the very low slope, runoff is only 1% of the total precipitation, indicating the importance of the groundwater flow (Glok Galli et al. 2014). The discharge of the watershed of Mar Chiquita coastal lagoon induces a transition of fresh to saltwater along a choked inlet (in the sense of Kjerve 1994). However, during some dry summers the marine substrate can provoke salinity concentrations at the lagoon as high as 52 psu (Fasano et al. 1982).

Figure 1: Location of Argentine barriers.

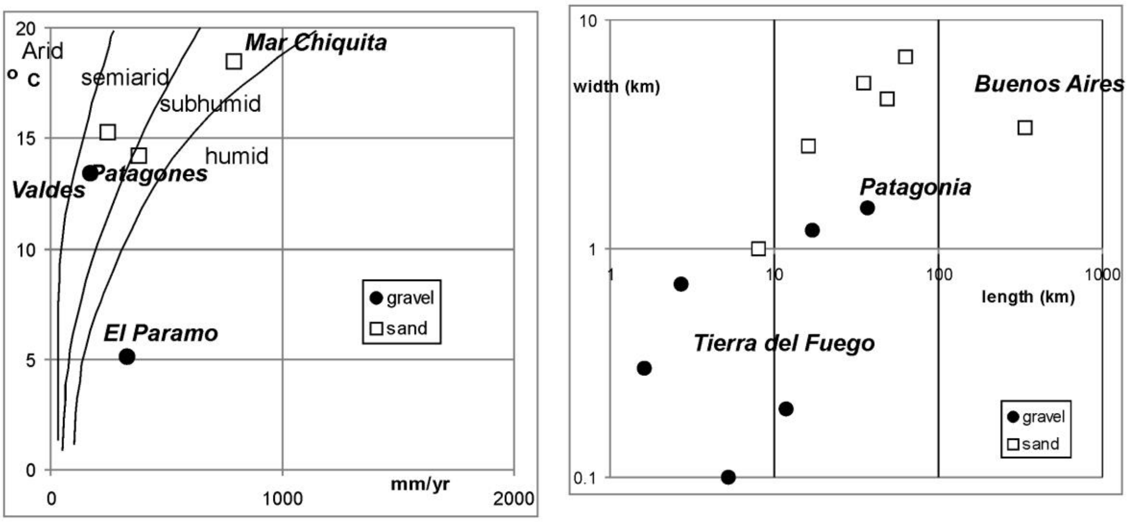

Figure 2: A) Temperature and Precipitation conditionings of Argentine barriers. B) Morphological dimensions (length and width in km) of Argentine barriers.

The Southern Barrier of Buenos Aires is located on top of former cliffs, extending along 300 km, from General Alvarado to Coronel Rosales counties (figure 1). Climate is temperate and humid with rains about 760 mm/yr (figure 2) increasing over 900 mm/yr in the last years (Cortizo and Isla 2007).

The Patagones barrier is located in the semiarid coast of Northern Patagonia (figure 1), with rains of only 390 mm/yr (Cortizo and Isla 2012), and therefore dominated by evapotranspiration. Winds prevail from NW and N, although the strongest are from the S and SW. The sand barriers enclosing the San Antonio Bay (Villarino and Reparo) are in a similar semiarid area (248 mm/yr) with a mean temperature of 15.3°C (figure 2a).

Valdés barrier (Chubut) is a complex spit dominated by gravel, and enclosing a saline coastal lagoon. It is located at an arid/semiarid region where rains sum only 173 mm/yr and mean temperature is 13.4°C (figure 2a).

El Páramo Spit (Tierra del Fuego; figure 1) is another long barrier composed of gravel although sand is available below a certain depth (Isla 1993). Rains sum 330 mm/yr while mean temperature is only 5.1°C.

3. Comparative geometry of sand barriers and gravel spits

Sand barriers reach higher altitudes in regard to the availability of sand to construct dunes, and they are wider in relation to the degree of backbarrier (mostly aeolian) and washover processes (figure 2b).

Regarding gravel barriers, sediment availability is more restricted for longshore transport and in that sense they are narrower (figure 2b**).** However, gravel-composed beach ridge plains of widths of about 1.3 km (Valdés barrier, El Páramo Spit) can be cannibalised to permit the growing of narrow flying spits (Isla and Bujalesky 2000). On the other hand, at gravel barriers accumulation and erosion processes are more evident from remote sensing devices as the vegetation covers are very restricted. The discrimination of drift-aligned, cannibalised and swash-aligned barriers (figure 3) was achieved in relation to inferences of longshore gravel availability (Orford et al. 2002).

4. Barriers of Buenos Aires

Several sandy barriers have grown along the coast of Buenos Aires. The Cabo San Antonio barrier is a complex barrier that grew from Punta Médanos towards the north in response to the attaching of recurving beach ridges. According to shells dated by the radiocarbon method there was a constant beach drift for the last 5800 years (Codignotto and Aguirre 1993). The main resource of these barriers of Buenos Aires is the availability of groundwater to feed touristic villages and to permit their forestation with ornamental trees (Bértola et al. 2002, Turno Orellano and Isla 2004). In the last years (1964 to 2009) the Punta Rasa complex spit would have been retreating about 560 m (Dragani et al. 2013).

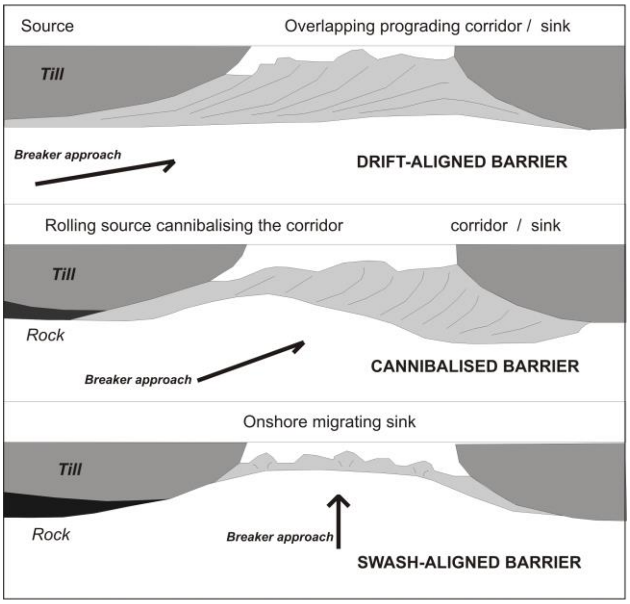

Figure 3: Classification of coarse-grained barriers (drift-aligned, cannibalised and swash-aligned) in relation to the longshore supply of sediment (modified after Orford et al. 2002).

Mar Chiquita barrier grew from north to south, from a former cape constructed by sandy silts in Villa Gesell (Violante 1993). An open bay became progressively isolated from the sea as the barrier continued growing. Mar Chiquita costal lagoon was assumed to establish approximately 2800 years ago (Fasano et al. 1982) when the tidal flats were colonised by salt-tolerant plants and aeolian processes constructed backbarrier deposits (figure 4). A reversal in the beach drift was proposed (Fasano et al. 1982) as the present spit of the outlet of Mar Chiquita coastal lagoon grows from south to north (Isla 1997).

The Southern Barrier of Buenos Aires is composed dominantly of transverse and barchanoid dunes. Parabolic dunes are located to the continent where sand is less available. As the coast is under significant erosion, cliff-top dunes are common. The age of the barrier was estimated as very modern (less than 500 years BP) as in some places it is covering estuarine sequences related to the regression facies of the Late Holocene sea-level fluctuation (Cortizo and Isla 2007). At the western extreme of this barrier, a spit evolved as a recurved one enclosing the tidal flats of the eastern Bahía Blanca embayment (Spagnuolo 2004).

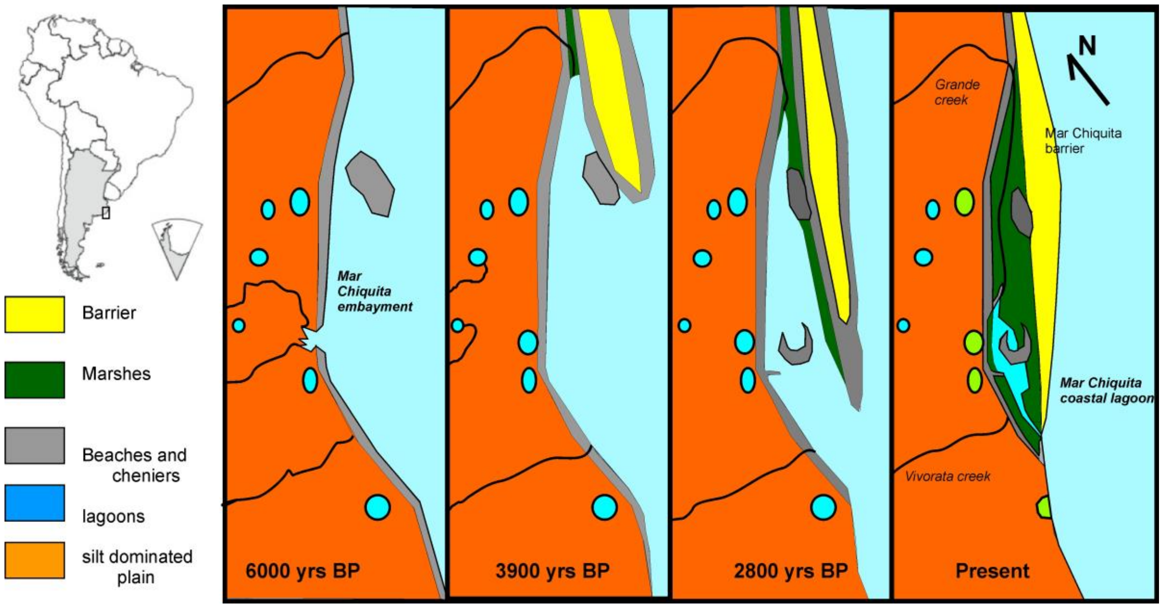

Figure 4: Evolution of the Mar Chiquita sandy barrier (modified from Fasano et al. 1982,Violante 1993).

5. Barriers of Patagonia

The Patagones Barrier (Buenos Aires, Patagonia) is located on top of former cliffs composed of Pliocene sandstones. Parabolic dunes dominate where sand is scarce or has been naturally fixed by grass. Transverse and brachanoid dunes dominate to the NE of the barrier, where there is more availability of sand (Cortizo and Isla 2012). North of this barrier, the Colorado River delta prograded interfingered to gravel beaches between 6630 and 1300 years BP (Weiler 1983).

The Valdés barrier is enclosing the Caleta Valdés coastal lagoon (figure 1). In surface, it is composed exclusively of gravel derived from the original Tehuelche Gravel formation. However, sand is sieved between pebbles larger than 4 cm (Isla 1993). During the eighties this spit was growing at a rate of 25 m/yr (Codignotto and Kokot 1988) and increased to 167 m/yr to the end of the XX century (figure 5). Although the closure was forecasted, it never happened. In the last 28 years the gravel transport was estimated in 5 millions of tons (Kokot et al. 2005).

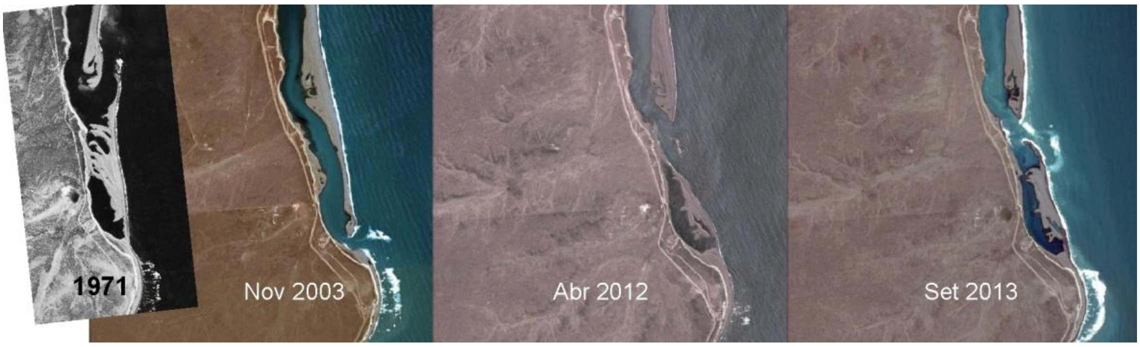

Figure 5: Recent evolution of the Caleta Valdés tidal inlet.

In Chubut Province, drift-aligned barriers evolved into swash-aligned barriers as soon as they completely enclosed former depressions. The Playa Union barrier grew from north to south leading the migration of the Chubut River. The growing of these complex spits occurred between 4987 and 1009 radiocarbon years BP (Monti 2000**;** figure 6**).**

In a same way, a succession of beach ridges and spits growing from north to south enclosed the Bahía Solano. (Codignotto et al. 1987). Three systems were recognised: the first one spanning 6500 and 5200 years BP; the second between 5200 and 3800 years BP), and the last one between 2700 and 1700 years BP. Two ancient coastal lagoon developed between the three systems (Codignotto et al. 1990). The case of Ensenada Ferrer is completely different: a former bay changed into a coastal lagoon when a sea-level drop induced a spit to grow anchored on former volcanic rocks (Medina et al. 2014).

6. Barriers of Tierra del Fuego

The barriers of the Magellan region evolved during the same sea-level fluctuation, but within a macrotidal coast with a significant availability of coarse sediments transported to the Atlantic plains by former glaciations

(Coronato et al. 1999). Where the availability is restricted, only cuspate forelands constructed, reworking Pleistocene tills (figure 7**).** These are the cases of the Gallegos River inlet (González Bonorino et al. 1999, Ercolano 2010) and the Magellan Strait Atlantic inlet (Uribe and Zamora 1981).

Where the sediment availability was enough the littoral drift permitted the construction of gravel-composed flying spits as the El Páramo Spit, that has been progressively restricting the San Sebastián Bay, Tierra del Fuego (Bujalesky 1998). El Páramo Spit implies therefore a succession of coastal landforms, from a cuspate spit to a flying spit (figure 8), and to a cannibalised complex spit (Isla and Bujalesky 2000, 2008). The spit has an asymmetric transverse profile composed of pebbles of 4-6 cm decreasing towards the bay and towards the sea (Isla and Bujalesky 1993). Pebbles can be supplied either from moraines (Isla and Schnack 1995), glaciofluvial deposits (Bujalesky et al. 2001) or deposits of former highstands (Codignotto and Malumián 1982; Ercolano 2010; figure 7). One of the amazing characteristic of this spit is that, due to the dominant westerly winds, waves formed within the bay are higher than those breaking at the open-ocean beach (Isla et al. 1992). The end of the spit reflects the combination of an open-ocean beach drift with a large supply of gravel and sand, and a gravel drift produced by the waves generated within the bay. The longshore growing of the spit was estimated about 2.4 m/yr while the cross-shore transport about 1.2 m/yr (González Bonorino et al.1999; figure 8b**).** The flying spit grew from a supply of gravel and sand that progressively diminished leading to the cannibalisation of its own beach deposits. The availability of gravel at the bay beach was supplied by gravel-dominated washover fans located at the narrower portion of the spit.

The Chico River spit originated as a simple flying split. In this sense, its original evolution was very similar to the El Páramo Spit but under higher sedimentation rates supplied by the river and a shallower basin (Montes 2015). A morphological and sedimentological study applying different techniques (Ground Precision Radar and resistivity soundings) permit to discern several stages including drift reversals (Bujalesky 2012, Montes 2015).

There are other barriers at the Eastern coast of Isla Grande of Tierra del Fuego (Mitre Peninsula) that are enclosing embayments, coastal lagoons (Caleta Falsa; Isla and Bujalesky 1995) or partially-blocked estuaries (Bueno River; Montes 2015).

Figure 6: A. Playa Union complex of spits enclosing the Chubut River estuary. B. Bahía Solano barrier.

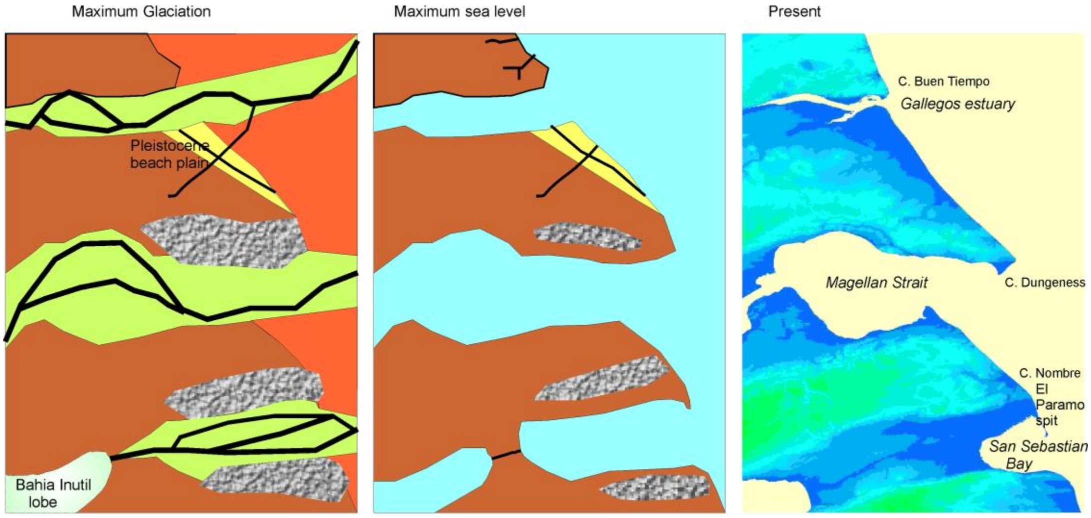

Figure 7: Evolution of the Magellan barriers (Punta Bustamante, Punta Dungeness and Punta El Páramo). A) Maximum glaciation, b) Mid-Holocene Maximum highstand, c) Present. (modified from Bujalesky 1998, González Bonorino et al. 1999, Ercolano 2010).

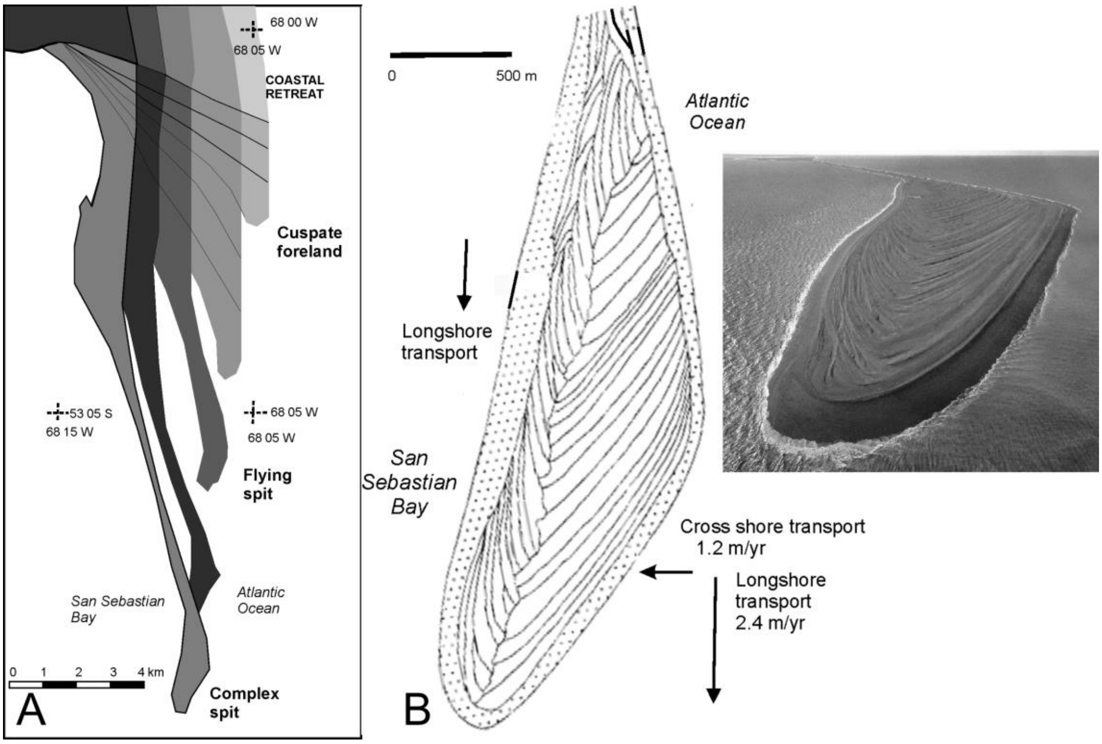

Figure 8: A. Evolution of the El Páramo Spit (modified from Bujalesky 1998). B. Two different beach drifts at each side of the point (Modified from González Bonorino et al. 1999).

7. Evolution of barriers and spits

Either at Mar Chiquita, Caleta Valdés and Chico River plain, there are evidences of drift reversals. Mar Chiquita barrier grew from north to south, while present beach drift is undoubtedly from south to north (Fasano et al. 1982). Although the Valdés Barrier has grown towards the south in the last 5000 years (Codignotto and Kokot 1988), some overlaps at the inlet were suggesting reversals of the drift (figure 5). Although the main spit is composed mostly of gravel, there are smaller cuspate spits indicating septation processes (Codignotto and Kokot 1988). The evolution of the gravel-dominated spits of the Magallanes region (Gallegos River outlet, Magellan Strait and San Sebastián Bay) is related to the availability of sediment eroded from glacial deposits, and the reworking from coastal terraces constructed during Quaternary highstands (figure 7).

As it occurred along most of the South American coast, barriers and spits evolved in relation to the Mid-Holocene sea-level fluctuation (Isla 1989, Isla and Angulo 2016). However, In Southern Patatagonia the macrotidal effects produced differences between estuaries and open-ocean sequences (Schellmann and Radtke 2010). In Tierra del Fuego, the Andean tectonics was quite different to the north and south of the Cordillera (Isla and Bujalesky 2008, Isla and Angulo 2015). The Holocene beach ridges of the Beagle Channel (Gordillo et al. 1992) are higher than those of similar age extending as a beach-chenier plain of San Sebastián Bay (Vilas et al. 1999).

8. Sand-vegetation processes at barriers

The Holocene fluctuation of the sea level induced the emergence of extended coastal plains at the trailing-edge coast of South America. During this 6000 years-spanned interval, littoral drift persisted constructing flying spits. Sandy barriers were built when there was availability of sand subject to aeolian processes. The magnitude of the sand transport can be estimated according to the longshore segregation of grain sizes in relation to the stability of some minerals. Considering that mafic minerals (opaques and piroxenes) derived from Andean rocks, their percentages diminution along the Eastern Barrier of Buenos Aires is indicating present beach-drift trends (figure 9**).**

Several sandy barriers formed and became progressively subject to wind processes and colonisation by vegetation where the water table is not very deep (Seeliger 2003). According to the availability of sand, different dune patterns are distributed along and across coastal barriers. The succession from parabolic to transverse and barchan dunes was recognised either at Mar Chiquita, Rio Grande do Sul (Isla and Tomazelli 1999) and Patagones barriers (Cortizo and Isla 2012). The natural colonisation of dunes by psamophyllous plants (*Panicum racemosum*, *Poa lanuginosa*, *Senecio crassiflorus*, *Hydrocotyle bonariensis*) produced significant changes in dune morphology. In this sense, transverse dunes can be reduced in their sand availability to become parabolic dunes (figure 10). At the Southern Barrier of Buenos Aires, 72% of the area covered by dunes become colonised by grass inducing morphological changes to the dune fields (Cortizo and Isla 2007, Monserrat 2010).

Dunes fixed by ornamental trees have been a constant effort for colons of these temperate sand barriers (Bravo Almonacid 2010). Several administrative departments of Buenos Aires Province were originated by the afforestation of dune fields during the first half of the XX century (Juárez and Mantobani 2006). If the water table is not very deep, pine trees can grow in less than 50 years in order to transform sand-covered dunes into forested barriers (Turno Orellano and Isla 2004), and inducing the growing of coastal cities from the original residential villages devoted to the "sun and beach" tourism (Bravo Almonacid 2010). Therefore, the second step is the urbanisation techniques for the forested barrier.

9. Land-use changes

Due to the urbanisation pressure at coastal areas, mobile dunes were rapidly converted into semifixed and fixed dune fields. These temperate barriers enclose lens of fresh water that can feed vegetation and human populations. However, the water-pumping availability should be analysed previously in order to prevent the intrusion of salt or brackish water (figure 11). In Villa Gesell, the fixation of foredunes (mainly by *Carpobrotus edulis* and *Tamarix gallica*) led to an increase in their altitudes but to a decrease in beach widths as the sand trapped on foredunes induce the narrowing of beach berms. These processes of fixation of foredunes by artificial berms (scraping) have also caused the diminution of beach widths at the barrier island of Fire Island (Kratzmann and Hapke 2012).).

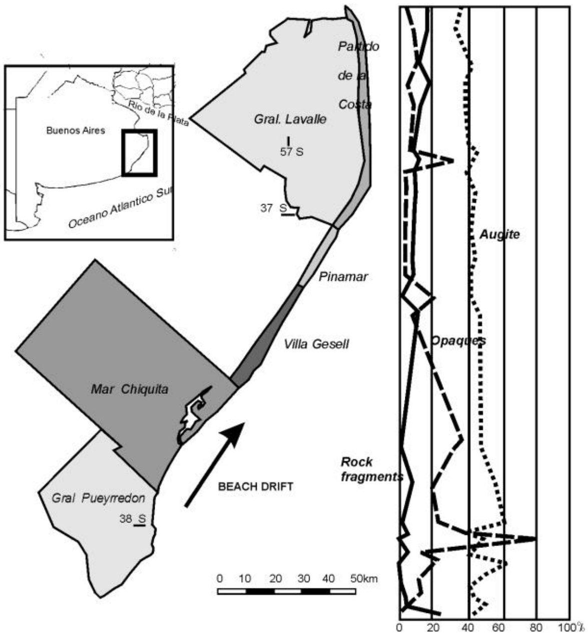

Figure 9: Alongshore variations of heavy minerals content (88-125 microns interval) along the Eastern Barrier of Buenos Aires (modified after Mazzoni 1977, Isla 1991).

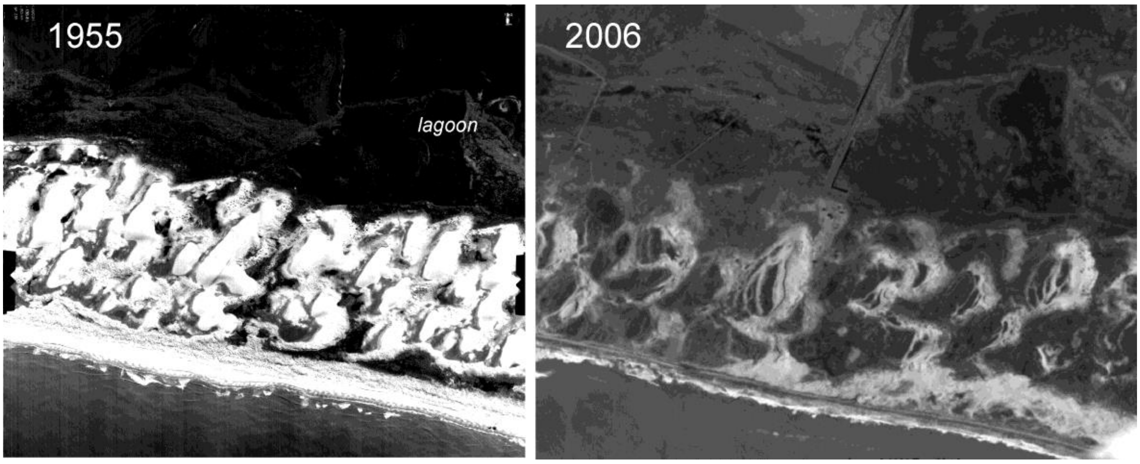

Figure 10: Morphological changes of dunes (transverse to parabolic) due to the natural colonisation by grass (Mar Chiquita barrier).

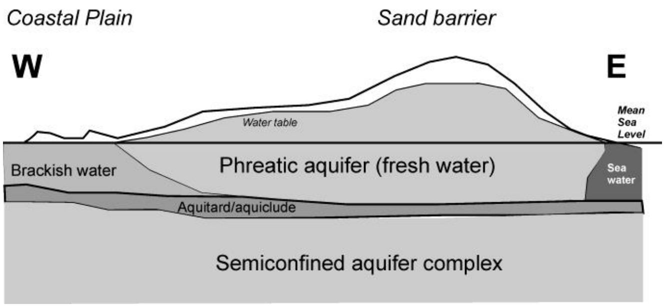

Figure 11: Schematic hydrogeologic profile of Northern Buenos Aires Barrier (modified from Carretero et al. 2014).

In a first attempt the urbanisation strategy focuses alongshore as bathers give priorities to beach proximity. In a second step the resort villages need services and they are usually installed towards the continent (figure 12). Villa Gesell (Buenos Aires) grew alongshore; today the city occupy the entire width of the 3 km wide barrier.

In Northern Buenos Aires barrier, from an area of 187 km^2 the recharge of the water table diminished 10% between 1973 and 2010 due to land-use changes. Considering the urbanisation rates groundwater annual recharges diminished 17.5% in San Clemente del Tuyú-Las Toninas, and 25% in San Bernardo-Mar de

Ajó (Carretero et al. 2014). These processes reinforced conservation policies of hydrogeologic reserves.

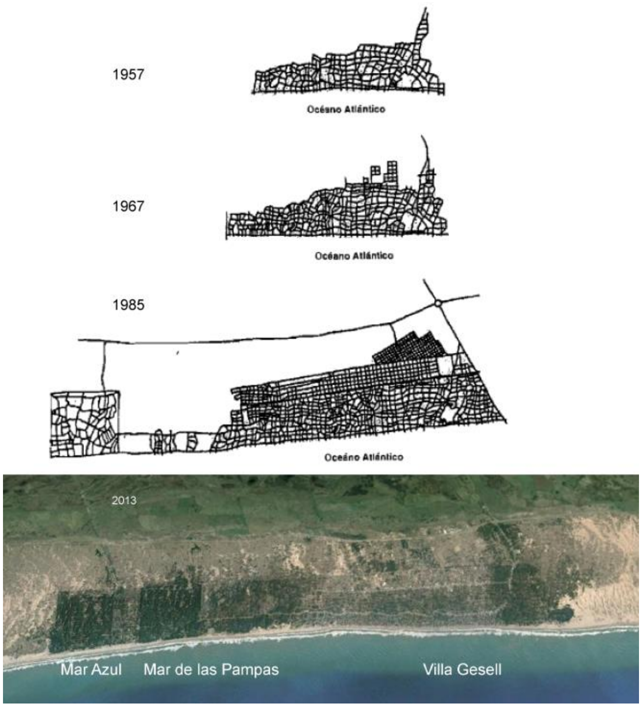

Figure 12: Urban growth of Villa Gesell city from 1957 to 2013 (modified after Juarez and Isla 2000).

10. Conclusions

Different kind of barriers settled at the Argentine coastline. In temperate areas barriers extended in relation to the availability of sand. Where gravel dominates -either derived from the Tehuelche Gravels or from former glacigenic deposits-, spits grew alongshore from capes.

Coastal lagoons were related to barriers where there is a support of fresh-water supply.

At the gravel spits of southern Patagonia and Tierra del Fuego, cuspate spits evolve into flying spits and afterwards into complex spits in relation to the depth increments.

References

Aragonés L., López I., Villacampa Y., Serra J.C., Saval J.M. 2015. New methodology for the classification of gravel beaches: Adjusted on Alicante (Spain), *Journal of Coastal Research* 31, 4, 1023-1034.

Bértola G., Isla F., Cortizo L., Turno H., Farenga M., 2002. Modelo sedimentario de la barrera medanosa al norte de Villa Gesell (Prov. de Buenos Aires) de aplicación hidrogeológica. *Revista AAS*, 9, 2, 109-126.

Boothroyd J. 1985. Tidal inlets and tidal deltas. In Davis, R. A. (ed.) Coastal sedimentary environments. Springer-Verlag, New York, 445-532.

Bravo Almonacid R. 2010. El proceso de urbanización del Partido de Pinamar: Desafíos hacia un desarrollo sostenible. In Isla F. I. and Lasta C. A. (eds.). Manual de manejo de barreras medanosas de la Provincia de Buenos Aires. EUDEM, Mar del Plata, 49-87.

Bujalesky G.G. 1998. Holocene coastal evolution of Tierra del Fuego. Quaternary of South America & Antarctic Peninsula, A. A. Balkema Publishers, 11, 247-242.

Bujalesky G.G. 2012. Tsunami overtopping fan and erosive scarps at Atlantic coast of Tierra del Fuego. *Journal of Coastal Research* 28, 2, 442-456.

Bujalesky G., Coronato A., Isla F. 2001. Ambientes glacifluviales y litorales cuaternarios de la región de Río Chico, Tierra del Fuego, Argentina. *Revista, Asociación Geológica Argentina*, 56, 1, 73-90.

Carretero S., Braga F., Kruse E., Tosi L. 2014. Temporal analysis of the changes in the sand-dune barrier in the Buenos Aires Province, Argentina, and their relationship with the water resources. *Applied Geography* 54, 169-181.

Castro A., Moreno J.E., Izeta A. 1999. Descripción del material lítico del sitio Cabo Blanco 1. XII Congreso Nacional de Arqueología Argentina. In: Actas del XII Congreso Nacional de Arqueología Argentina. Universidad Nacional de La Plata, 7-15.

Codignotto J.O., Aguirre M.L. 1993. Coastal evolution, changes in sea level and molluscan fauna in northeastern Argentina during the late Quaternary. *Marine Geology* 110, 163-175.

Codignotto J.O., Beros C.A., Trebino L.G. 1987. Morfocronología secuencial evolutiva holocena, en Bahía Solano, Chubut. Revista Asociación Geológica Argentina 45:205-212, Buenos Aires.

Codignotto J., Cesari O., Beros C.A. 1990. Morfocronología secuencial evolutiva holocena en Bahía Solano, Chubut. Revista de la Asociación Geológica Argentina, 45 (3-4): 205-212, Buenos Aires.

Codignotto J.O., Kokot R.R. 1988. Evolución holocena en Caleta Valdés, Chubut. *Revista de la Asociación Geológica Argentina* 43(4): 474-481.

Codignotto J.O., Malumián N. 1981. Geología de la región al norte del paralelo 54° Sur de la Isla Grande de la Tierra del Fuego. *Revista de la Asociación Geológica Argentina* 36 (1), 44-88. Buenos Aires.

Coronato A., Salemme M., Rabassa J. 1999. Palaeoenvironmental conditions during the early peopling of Southernmost South America (Late glacial-Early Holocene, 14-8 ka B.P.). *Quaternary International* 53/54, 77-92 .

Coronato A.M.J., Coronato F., Mazzoni E., Vázquez M. 2008. The Physical Geography of Patagonia and Tierra del Fuego. *Quaternary Sciences*, 11: 13-55.

Cortizo L.C., Isla F.I. 2007. Evolución y dinámica de la barrera medanosa de San Cayetano y Tres Arroyos, Buenos Aires. *Revista de la Asociación Geológica Argentina* 62, 1, 3-12.

Cortizo L.C., Isla F.I. 2012. Dinámica de la barrera medanosa e islas de barrera de Patagones (Buenos Aires, Argentina). *Latin American Journal of Sedimentology and Basin Analysis* 19, 1, 47-63.

Dragani W.C., Martin P.B., Alonso G., Codignotto J.O., Prario B.E., Bacino G. 2013. Wind wave climate change: Impacts on the littoral processes at the Northern Buenos Aires coast, Argentina. Climatic Change 121, 649-660.

Ercolano B. 2010. Evolución de la costa comprendida entre el Río Gallegos y Chorrillo de los Frailes. Tesis inédita, UBA, Buenos Aires, 243 pp.

Fasano J.L., Hernández M.A., Isla F.I., Schnack E.J. 1982. Aspectos evolutivos y ambientales de la laguna Mar Chiquita (Provincia de Buenos Aires). *Oceanologica Acta*, N SP: 285-292.

FitzGerald D.M., Buynevich I. V. 2006. Coastal Barriers. In Isla F. I. (ed.) Coastal Zone and Estuaries, Encyclopedia of Life Support Systems (EOLSS), Eolss Publishers, Oxford, UK, 35 pp. [http://www.eolss.net].

Fisher J.J. 1968. Barrier island formation discussion. Geol. Soc. Am. Bull. 79, 1421-1426.

Glaeser J.D. 1978. Global distribution of barrier islands in terms of tectonic setting. *Journal of Geology* 86, 283-297.

Glok Galli M., Martínez D. E.,Kruse E. E. 2014. The carbon budget of a large catchment in the Argentine pampa plain through hydrochemical modeling. Science of the Total Environment 493, 649-655.

González Bonorino G., Bujalesky G., Colombo F., Ferrero M. 1999. Holocene coastal paleoenvironments in Atlantic Patagonia, Argentina. *Journal of South American Earth Sciences* 12, 325-331.

Gordillo S., Bujalesky G.G., Pirazzoli P.A., Rabassa J.O., Saliege J.F. 1992. Holocene raised beaches along northern coast of the Beagle Channel, Tierra del Fuego, Argentina. *Palaeogeography, Palaeoclimatology Palaeoecology*, 99, 41-54.

Guilderson T. P., Burckle L., Hemming S., Peltier W. R. 2000. Late Pleistocene sea level variations derived from the Argentine Shelf. *Geochemistry, Geophysics, Geosystems* 1, 2000G000098.

Hayes M. O. 1980. General morphology and sediment patterns in tidal inlets. *Sedimentary Geology* 26, 139-156.

Hoyt J.H. 1967. Barrier island formation. *Geological Society of America Bulletin* 78(9), 1125–1135.

Iantanos N. 2004. Dinámica sedimentaria de la Río de Puerto Deseado, Provincia de Santa Cruz. Universidad de la Patagonia San Juan Bosco, Comodoro Rivadavia. Unpublished Thesis, Comodoro Rivadavia.

Iantanos N., Moreno E., Andolfo M., Isla F., Castro A. 2009. Características y Evolución del Tómbolo Cabo Blanco, Provincia de Santa Cruz, Argentina. *Naturalia Patagónica* 4, 2, 33-45.

Isla F. I. 1989. The Southern Hemisphere sea level fluctuation. *Quaternary Science Reviews*, 8, 359-368.

Isla F. I. 1991. Spatial and temporal distribution of beach heavy minerals: Mar Chiquita, Argentina. *Ocean and Shoreline Management*, 16, 161-173.

Isla F. I. 1993. Overpassing and armouring phenomena on gravel beaches. *Marine Geology* 110, 369-376.

Isla F. I. 1997. Seasonal behaviour of Mar Chiquita tidal inlet in relation to adjacent beaches, Argentina. *Journal of Coastal Research* 13, 4, 1221-1232.

Isla F. I., Angulo R. J., 2016. Tectonic processes along the South America coastline derived from Quaternary marine terraces. *Journal of Coastal Research*, 32, 40, 840-852.

Isla F. I., Bujalesky G. G. 1993. Saltation on gravel beaches, Tierra del Fuego, Argentina. *Marine Geology* 115, 263-270.

Isla F. I., Bujalesky G. G. 1995. Tendencias evolutivas y disponibilidad de sedimento en la interpretación de formas costeras: Casos de estudio de la costa argentina. *Revista Asociación Argentina de Sedimentología*, 1-2, 75-89.

Isla F. I., Bujalesky G.G., 2000. Cannibalisation of Holocene gravel beach plains, northern Tierra del Fuego, Argentina. *Marine Geology,* 170, 1-2, 105-122.

Isla F. I., Bujalesky G. G. 2008. Coastal Geology and morphology of Patagonia and Fueguian Archipielago. *Developments in Quaternary Science* 11, 10, 227-240.

Isla F. I., Tomazelli J. L. 1999. Eolian sand dispersals and modern erosion processes in Holocene coastal barriers: comparison between Mar Chiquita and Patos barriers (Argentina and Brazil). *Revista Thalassas*, 15, 2, 75-88.

Juárez V. I., Mantobani J. M. 2006. La costa bonaerense: un territorio particular. In Isla, F. I and Lasta, C. A. (eds.) Manual de Manejo costero para la Provincia de Buenos Aires, EUDEM, Mar del Plata, 41-69.

Kjerve B. 1994. Coastal lagoons. En Kjerve, B. (ed.) Coastal lagoon processes. Elsevier Oceanographic series 60, 1-8.

Kokot R. R. 2010. Espigas indicadoras de proveniencia de olas en la costa Argentina. *Revista de la Asociación Geológica Argentina* 67(1): 19-26.

Kokot R.R., Monti A.A.J., Codignotto J.O. 2005. Morphology and short-term changes of the Caleta Valdes harrier spit. Argentina. *Journal of Coastal Research* 21(5), 1021-1030.

Kratzmann M. G., Hapke Ch. J. 2012. Quantifying anthropogenically driven morphologic changes on a barrier island: Fire Island National Seashore, New York. *Journal of Coastal Research* 28(1), 76-88.

Lentz E. E., Hapke Ch. J. 2011. Geologic framework influences on the geomorphology of an anthropogenically modified barrier island: Assessment of dune/beach changes at Fire Island, New York. *Geomorphology* 126, 82-96.

Mazzoni M. M. 1977. Características composicionales de la fracción pesados de arenas de playa frontal del litoral atlántico bonaerense. Revista AMPS 8, 3-4, 73-91.

Medina R. A., Aguirre M. L., Codignotto J. O., Richiano S. M., Mormeneo L. 2014. Geoformas, malacofauna y evolución costera durante el Holoceno en Ensenada Ferrer (Santa Cruz, Patagonia, Argentina). Revista de la Asociación Geológica Argentina 71 (1), 69-81.

Monserrat A. L. 2010. Conservación en médanos: la vegetación de la costa bonaerense en Coronel Dorrego, Monte Hermoso y Coronel Rsales. In Isla, F. I. and Lasta, C. (eds). Manual de Manejo de Barreras medanosas. EUDEM, Mar del Plata, 197-216.

Monti A. J. A. 2000. Edades 14C y ciclicidad de la acreción en depósitos costeros elevados, Bahía Engaño, Chubut. Revista de la Asociación Geológica Argentina 55, 4, pp. 403-406. Buenos Aires.

Orford J. D., Forbes D. L., Jennings S. C. 2002. Organisational controls, typologies and time scales of paraglacial gravel-dominated coastal systems. *Geomorphology* 48, 51-85.

Pedoja K., Regard V., Husson L., Martinod J., Guillaume B., Fuks E., Iglesias M., Weil P. 2011. Uplif to for Quaternary shorelines in Eastern Patagonia: Darwin revisited. *Geomorphology* 127, 121-142.

Rabassa J., Gordillo S., Ocampo C., Rivas Hurtado P. 2008. The southernmost evidence for an interglacial transgression (Sangamon?) in South America. First record of upraised Pleistocene marine deposits in Isla Navarino (Beagle Channel, Southern Chile). *Geologica Acta* 6, 3, 251-258.

Rutter N., Schnack E. J., Fasano J. L., Isla F. I.., Del Río L, Radtke U. 1989. Correlation and dating of Quaternary littoral zones along the Patagonian coast, Argentina. *Quaternary Science Reviews* 8, 213-234.

Schellmann G. 1998b. *Coastal development in Southern South America (Patagonia and Chile) since the Younger Middle Pleistocene. Sea level changes and tectonics.* In Kelletat, D. H. (ed.) German Geographical Coastal Research.The last decade. Institue for scientific cooperation, Tübingen, 289-304.

Schellmann G., Radtke U. 2000. ESR dating stratigraphically well-constrained marine terraces along the Patagonian Atlantic coast (Argentina). *Quaternary International* 68-71, 261-273.

Schellmann G., Radtke U. 2003. Coastal terraces and Holocene sea level changes along the Patagonian Atlantic coast. *Journal of Coastal Research* 19, 4, 983–996.

Schellmann G., Radtke U. 2010. Timing and magnitude of Holocene sea-level changes along the middle and south Patagonian Atlantic coast derived from beach ridge systems, littoral terraces and valley-mouth terraces. *Earth-Science Reviews* 103, 1-30.

Schwartz M. L. 1971. The multiple causality of barrier islands. Journal of Geology 79, 91-94.

Seeliger U. 2003. Response of southern Brazilian costal foredunes to natural and human-induced disturbance. *Journal of Coastal Research* SI35, 51-55.

Short A. D. 1979. Barrier island development along the Alaskan-Yukon coastal plains: summary. *Bull. Geological Society of America* 90, 3-5.

Spagnuolo J. O. 2004. Evolución geológica de la región costera-marina de Punta Alta, Provincia de Buenos Aires. Unpublished Ph. D. thesis, UNS, Bahía Blanca, 269 pp.

Stutz M.L., Pilkey O.H. 2011. Open-ocean barrier islands: global influence of climatic, oceanographic, and depositional settings. *Journal of Coastal Research* 27(2), 207-222.

Turno Orellano H., Isla F. I. 2004. Developing sinks for CO_2 through forestation of temperate coastal barriers: an environmental business. *Regional Environmental Change*, 4, 1, 70-76.

Uribe P., Zamora E. 1981. Origen y geomorfología de la Punta Dungeness, Patagonia. Anales del Instituto de la Patagonia 12, 143-158, Punta Arenas, Chile.

Vilas F., Arche A., Ferrero M., Isla F. 1999. Subantarctic macrotidal flats, cheniers and beaches in San Sebastián Bay, Tierra del Fuego, Argentina. *Marine Geology*, 160, 301-326.

Violante R. A. 1993. Ambientes sedimentarios asociados a un sistema de barrera litoral del Holoceno en la llanura costera al sur de Villa Gesell, Provincia de Buenos Aires. *Revista de la Asociación Geológica Argentina* 43, 529-543.

Weiler N. 1983. Rasgos morfológicos evolutivos del sector costanero comprendido entre bahía Verde e Isla Gaviota, Provincia de Buenos Aires. Revista de la Asociación Geológica Argentina 38, 3-4, 392-404.

Zanchetta G., Consolini I., Isola I., Papalardo M., Aguirre M., Fucks E., Baneschi I., Bini M., Ragaini L., Terrasi F. Boretto G. 2012. New insights on the Holocene marine transgression in the Bahía Camarones (Chubut, Argentina). *Italian Journal of Geosciences (Boll. Soc. Geol. It.)* 131, 1, 19-31. [i]

Recebido 02 de novembro de 2015
Aceito 22 de março de 2017