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Holocene coastal paleoenvironments in Atlantic Patagonia, Argentina

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Abstract

The Atlantic shoreline in Patagonia, southernmost South America, is a paraglacial coast that has undergone extensive erosion and retreat since the late Pleistocene, releasing a large volume of sand and gravel to southward littoral drift. Despite regional erosive conditions, accretionary landforms developed during the Holocene in three coastal reentrants. These are, from north to south along a 200 km long shoreline stretch: (1) the cuspate foreland that underlies Bustamante Point, in the Río Gallegos Estuary; (2) the cuspate foreland with incipient spit underlying Dungeness Point, in the eastern Strait of Magellan; (3) the San Sebastián Bay tidal flat; and (4) the El Páramo Spit, partly enclosing the San Sebastián Bay. These accretionary landforms contain a record of relative sea level changes for approximately the past 7 ka, and indicate a tectonically driven drop of about 3 m during growth of Bustamante Point and of 1–2 m in the other areas. Differential sea level fall influenced development of the landforms, with slower rates favoring spit development in the south.

1. Introduction

The Atlantic coast in southernmost South America (Fig. 1) is characterized by prominent cliffs underlain by upper Tertiary marine strata, Pleistocene glacial and glaciofluvial deposits and Holocene fluvial deposits. The cliffs are a consequence of Andean tectonic uplift since the late Tertiary (cf. Rabassa et al., 1994) and erosion by Atlantic waves that generate a strong southward littoral drift of sand and gravel. Despite a general state of erosion and coastline retreat, there exist several sites where long-term accumulation of sediment took place during the latest Quaternary (roughly the past 140 kyr), yielding cuspate forelands, spits, shoreline-attached strandplains and tidal flats. These sites occupy reentrants in the shoreline, where the sea has flooded Pleistocene glacial and fluvial valleys.

This paper describes four accretionary coastal landforms in the Patagonia region in southeasternmost Argentina, and discusses their origin and major controls on their development. The four landforms are: (a) Bustamante Point, a cuspate foreland in the Gallegos River Estuary, (b) Dungeness Point, a cuspate foreland with an incipient spit, in the eastern Strait of Magellan, (c) the San Sebastián Bay tidal flat, and (d) the El Páramo ("a desolate place") Spit, which partly encloses San Sebastián Bay (Fig. 1). Preliminary radiometric dating suggests that the oldest of these coastal landforms started to form at roughly 5–7 ka BP (Uribe and Zamora, 1981; Vilas et al., 1987a; H. O. Panarello, 1996, written communication; Ferrero, 1997). Bustamante and Dungeness points are located in southeastern Santa Cruz province and San Sebastián Bay lies in northeastern Tierra del Fuego island. Herein we mainly summarize information on

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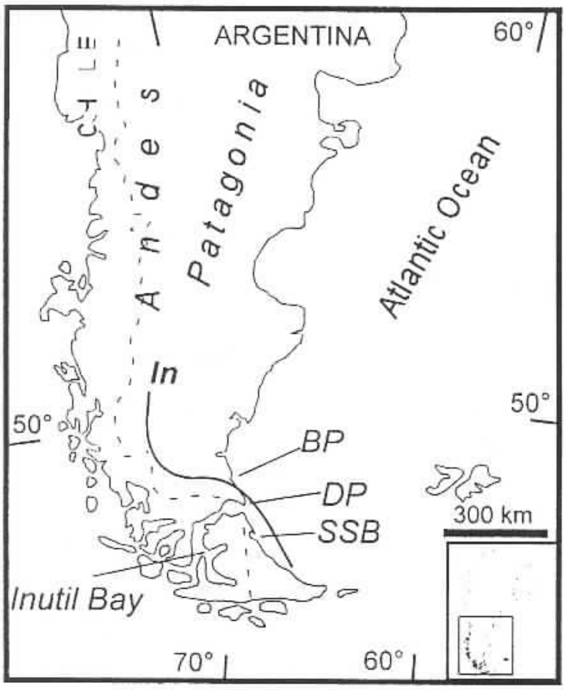

Fig. 1. General location map of southeasternmost South America. Study areas are: Bustamante Point (BP), Dungeness Point (DP) and San Sebastián Bay (SSB). The thick line shows the approximate position of the ice limit during the Pleistocene Initioglacial (In) glacial maxima of Caldenius (1932).

these four coastal landforms published by our group and other authors, providing an updated list of references on the coastal geology of Atlantic Patagonia, and we also give new, unpublished data on Bustamante and Dungeness points. Dungeness Point extends into Chile, where we have not worked; in order to provide a more complete summary we include published data for this area.

2. Pleistocene glaciation and morphology

By the end of the Tertiary, the Patagonian Andes had reached considerable height and lodged Alpine-type glaciers and mountain ice caps (Rabassa and Clapperton, 1990). At approximately 1 Ma, during the Initioglacial phase of Caldenius (1932), the ice cover expanded greatly across southern Patagonia and onto the adjoining continental shelf, where submerged moraines are preserved (Isla et al., 1991). The northern boundary of this ice cap lay just south of the ancestral Gallegos River valley (Fig. 1; Caldenius, 1932; Mercer, 1976; Rabassa and Clapperton, 1990; Rabassa et al., 1992; 1994; Meglioli, 1992). Later glacial advances were progressively smaller in areal extent and by approximately 16 ka, during the youngest glacial maximum or Finiglacial phase of Caldenius (1932), glacier ice was restricted to western parts of the Strait of Magellan and to western and southwestern parts of Tierra del Fuego (Fig. 1; Caldenius, 1932; Rabassa et al., 1994). During the Holocene, glaciers persisted only in Andean heights (Rabassa and Clapperton, 1990). The coastal area of interest to this work has, however, been free of glacier ice for at least the past 120,000 years, which suggests that glacioisostatic equilibrium probably had been attained by the time the coastal landforms described in this paper began to develop (cf. Gordillo et al., 1992; Rabassa et al., 1994).

The Río Gallegos Estuary is superimposed on an ancestral glaciofluvial valley initially flooded in the late Pleistocene to earliest Holocene. At present it is a tide-dominated estuary and includes a large intertidal sand bank that partly protects the Bustamante Point from the attack of southwesterly waves. On the other hand, Pleistocene outlet glaciers carved the deep trough in eastern Strait of Magellan and the shallow trough joining the areas now occupied by Inútil Bay and San Sebastián Bay (Fig. 1; Raedeke, 1978; Rabassa et al., 1992).

3. Hydraulic setting

Westerly winds are dominant in Patagonia, with average monthly velocities commonly above 30 km/h and maxima in October (spring) reaching over 100 km/h. In contrast, Atlantic winds are much calmer except during southeasterly storms which occur with a frequency of 3%, mostly in July (winter). Tides are semi-diurnal with mean ranges of about 5 m (neap) and 9 m (spring) and a maximum range of approximately 10.5 m. Wave climate is harsh. The Atlantic shore is subject to long-period ocean swell from the northeast; waves up to 3 m high were measured during the study period. Westerly winds generate short-period waves with observed heights below 3 m; nonetheless, heights calculated by the spectrally-based method (CERC, 1992) exceed 4 m in the eastern Strait of Magellan, where the fetch is larger (*ca* 70 km) than in the Gallegos River Estuary (fetch *ca* 14 km) and San Sebastián Bay (fetch *ca* 29 km). Hydraulic conditions in the Holocene Patagonia appear to have been similar to those described, judging from sediment texture and fabric and stratification style in ancient and modern coastal deposits.

4. Sediment sources and transport

In the Pleistocene, glacier ice and meltwaters transported large amounts of sand and gravel eastward from the Andes to the Atlantic Ocean, building extensive and thick drift accumulations that unconformably overlaid Tertiary strata (Codignotto and Malumián,

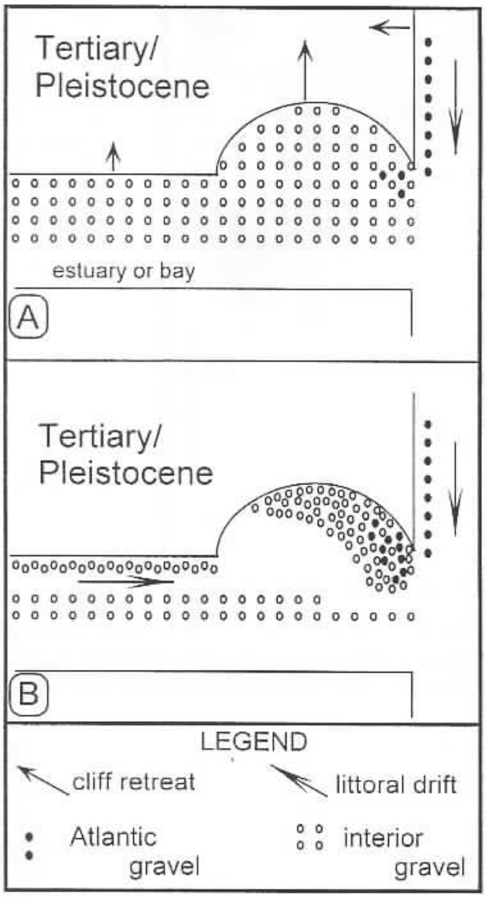

Fig. 2. Schematic representation of gravel sources for cuspate forelands in Atlantic Patagonia. (A) Atlantic gravel is contributed through the littoral drift and enters the estuary of the bay transported by refracted waves and southeasterly storms (black circles). In turn, within the reentrant, the cliff retreat leaves behind a mantle of gravel (rings). (B) A cuspate foreland grows with contributions of Atlantic and internal gravel; the latter is favored by the relative sea level fall exposing a larger area of the estuary or bay to wave attack.

1981; Rabassa and Clapperton, 1990). These deposits are exposed in erosionally active and inactive coastal cliffs. Active cliffs face the Atlantic Ocean and are presently undergoing erosion, whereas inactive cliffs, or paleocliffs, occur within the coastal reentrants and show an east–west orientation. Paleocliffs were carved in the late Pleistocene to early Holocene and were later protected from marine erosion by the accretion of marshlands and the accretionary landforms described herein. Cliff erosion presently is the major source of sand and gravel to the littoral transport system. The sediment regionally moves southward following two divergent paths. One path carries it offshore where it accumulates as subtidal banks. The other path parallels the shoreline until a reentrant is met, upon which Atlantic wave refraction moves the sediment westward into the estuary or embayment. Prominent wave-cut platforms, exposed at low tide, project oceanward from the cliffed shoreline (Fig. 1). The seaward edge of the platforms mark the position of the shoreline in the early Holocene and suggests 1–3 km of cliff retreat. Consequently, cliff erosion probably was the major source of sediment to Patagonian accretionary landforms in the Holocene. Two additional sediment sources are of subordinate importance. One results from cannibalization of the accretionary landforms along their Atlantic flanks; this sediment mixes in with cliff-derived detritus. The other source lies within the reentrants, where Pleistocene glaciers and rivers and Holocene cliff erosion at an early stage of flooding, deposited a mantle of gravel that, in shallow areas, is at present swept toward the accretionary landform by westerly waves. Fig. 2 schematically characterizes these alternative sediment sources.

5. Coastal landforms

5.1. Bustamante Point

Bustamante Point is a cuspate foreland 4.5 km long and 1.5 km wide attached to a 30 m-high paleocliff (Fig. 3). Preliminary radiocarbon ages have been obtained from shelly fauna; the oldest age is 6300 yr BP (Fig. 3; H.O. Panarello, 1996, written communication). The strandplain comprises approximately 100 ridges built from foreshore and berm gravel and subordinate interstitial sand and mud. The intermediate (b-axis) diameter of the gravel ranges from 2–5 cm. Fossil foreshore layers dip about 5 to the south and south–southwest, indicating accretion of beach ridges by storm waves generated within the estuary. During the Holocene, southwesterly waves swept relict gravel from the estuary and fed it to the foreland. In plan view, sets of gently curved, subparallel ridges are separated from adjoining sets by abrupt changes in ridge orientation. The angular discordances cannot be attributed to exceptional storms alone but are thought to reflect major hydraulic reorganizations. The height of the strandplain falls by about 3 m from north to south, that is from older to younger ridges, indicating an equivalent fall in the relative sea level. This fall surely was tectonically driven and may involve reactivation of deep-seated east–west faults mapped offshore the Río Gallegos Estuary (cf. Mapa Geológico de la República Argentina, 1982).

Atlantic waves contribute overwash sand and subordinate gravel to the cuspate foreland. Overwash sedimentation dominates over beach ridge formation in the southeastern sector of the point (Fig. 3B). The proportion of overwash deposits diminishes northeastwards, however. The present shoreline cuts older ridges at positions progressively more distant from the ancient shoreline.

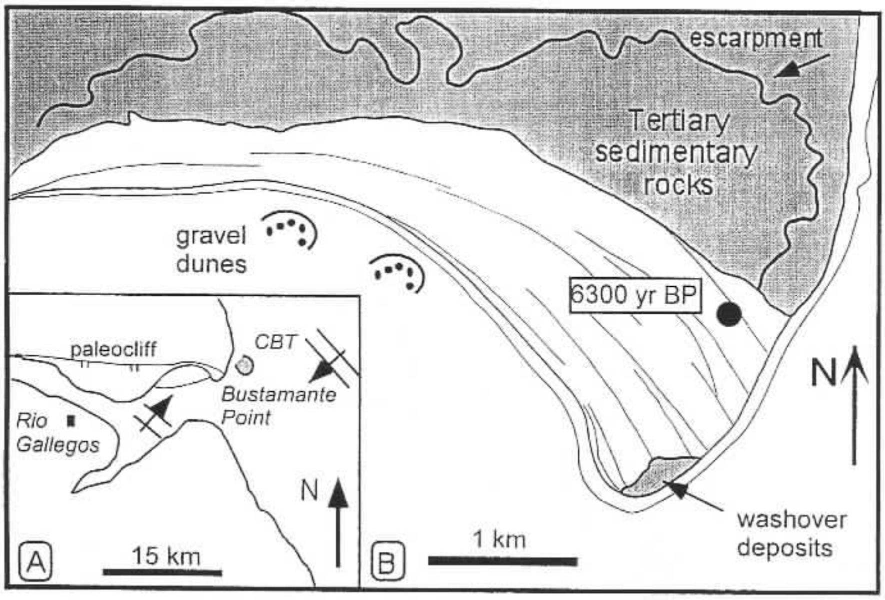

Fig. 3. (A) Inset shows the outer part of the Gallegos River Estuary, with the Bustamante Point and Cape Buen Tiempo (CBT). Dominant wave approaches are indicated. The dark gray area is a wave-cut platform and the light gray area is an intertidal sand bank. The edge of the paleocliff is indicated. (B) Map of Bustamante Point. Gravel ridges are shown schematically. Position of radiocarbon age is marked by black dot.

5.2. Dungeness Point

Dungeness Point is a triangle-shaped cuspate foreland that projects 7 km into the strait and measures 8 km at the base, attached to a 50 m-high marine paleocliff (Fig. 4). Radiocarbon ages are available only for the youngest strandplain, lying entirely in Chile; the oldest age reported is 900 yr BP (Fig. 4B; Uribe and Zamora, 1981). The Dungeness foreland is made up of three contrasting deposits: (a) gravel beach ridges in narrow strandplains with a north–northwest orientation; these strandplains attain the highest elevations and are herein identified as "high-level gravel", (b) back-barrier marsh muds and loess deposits infilling depressed areas that separate the gravel strandplains, and (c) subordinate gravel accumulations

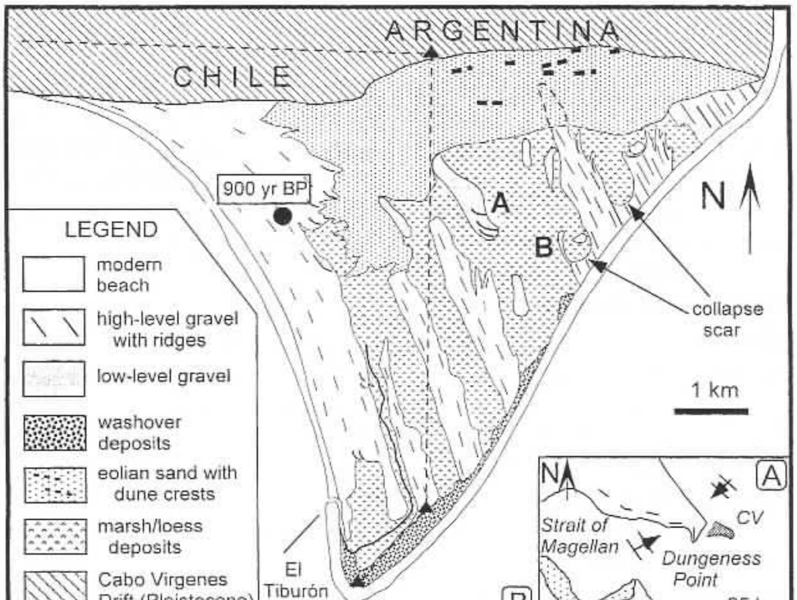

Fig. 4. (A) Inset shows the eastern portion of the Strait of Magellan, with the Dungeness Point and Cape Virgenes (CV). Dominant wave approaches are indicated. The dark gray area is a wave-cut platform and the stippled area is a sand bank. (B) Morphologic map of Dungeness Point (modified after Uribe and Zamora, 1981).

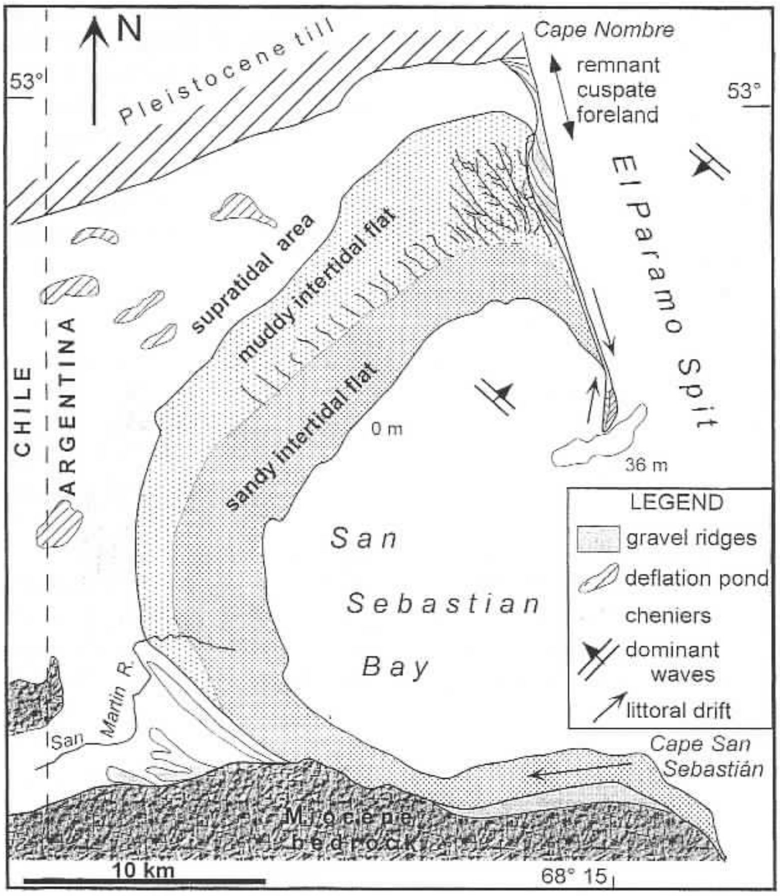

Fig. 5. San Sebastián Bay and El Páramo Spit. Dominant wave approaches are indicated. Prominent wave-cut platforms (not shown) face Cape Nombre and Cape San Sebastián. Reference depth is average of lowest tides. Note remnant of cuspate foreland in northern portion of El Páramo Spit.

at elevations intermediate between the strandplains and the marsh deposits, and herein identified as "low-level gravel". The high-level gravel strandplains show recurved ridges that indicate transport of Atlantic gravel toward the northwest under the influence of southwesterly to south–southwesterly waves. The northern sector of the youngest strandplain shows, however, curved ridges indicating southeastward transport of gravel (Fig. 4B), that is from a source within the strait. The older strandplains show circular collapse scars at several sites (Fig. 4B).

The low-level gravel gives amorphous bodies in central parts of collapsed areas and forms at least two spits. The larger spit (A, Fig. 4B) grew in a southeastward direction fed with gravel from the interior of the strait, whereas the smaller spit (B, Fig. 4B) is anchored to a collapse scar and elongated toward the northwest. The surfaces of the low-level gravel bodies lie approximately 2 m below that of the high-level strandplains, suggesting their formation under depressed wave setup conditions.

The northern sector of Dungeness foreland is mantled by eolian deposits that partly hide proximal parts of the strandplains. The older, densely vegetated marsh areas show traces of former tidal channels; the modern marsh, in Chile, is drained by the El Tiburón Creek. Topographic leveling showed that elevation of the high-level strandplains in the Argentine Dungeness Point decreases on the order of 1 m from north–north-

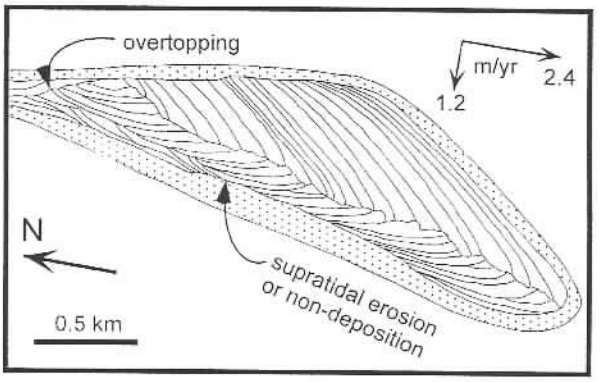

Fig. 6. Enlargement of the southern strandplain in the El Páramo Spit. Approximate long term rates of westward migration and southward elongation are indicated in the upper right corner.

east to south–southwest, suggesting an equivalent fall in relative sea level.

5.3. El Páramo Spit

El Páramo Spit is attached to the remnants of a cuspate foreland which, in turn, abuts the paleocliff (Fig. 5). The spit is 20 km long and only 50 m wide, at high tide, in its narrow central tract. The cuspate foreland and the spit are built from open work gravel (intermediate axes range from 1 to 6 cm) with subordinate interstitial sand. The spit terminus shows two sets of intertwined ridges (Fig. 6) instead of a recurved end. This morphology is a direct consequence of westerly waves picking up gravel brought into the bay from the Atlantic through wave refraction, and moving it toward the north along the internal (western) flank of the spit. Northward transport of gravel from the spit terminus, coupled with washover in the narrow central tract of the spit, allowed long-term westward migration of the spit without breaching (Bujalesky and González Bonorino, 1991). Topographic leveling did not show a significant change in elevation along the spit and thus there is no evidence for relative sea level change.

5.4. San Sebastián Bay tidal flat

The San Sebastián Bay tidal flat accreted to bedrock exposed in the glacial trough; its growth started at least 5270 yr BP (radiocarbon age in shells in a chenier ridge; Fig. 5; Ferrero, 1997). The supratidal area, which extends into Chile, is mantled by eolian deposits and, locally, sediments trapped in deflation ponds. The intertidal flat is 10 km wide in the north and narrows to 2 km in the south. It shows lower, sandy, and upper, muddy divisions; the latter widens from southwest to northeast due to sheltering by El Páramo Spit and a clockwise circulation of the tidal flow within the bay (Isla et al., 1991). The tidal signature is strongest in the northern sector of the intertidal flat, where a well-developed tidal drainage system can be observed (Ferrero and Vilas, 1988; Vilas et al., 1987b); in the south storm processes dominate.

Southern and southwestern sectors of the San Sebastián supratidal area are covered by Holocene gravel ridges attached to Miocene bedrock and by cheniers rich in shelly remains (Fig. 5). Older cheniers extend farther north than younger ones, reflecting progressive elongation of El Páramo Spit and the narrowing of the gap for wave fronts entering the bay. Supratidal cheniers and gravelly beach ridges record shoreline regression at an exponentially diminishing rate varying from 2.6 to 0.6 m/yr in the past 5300 years (Ferrero, 1997). Growth of the gravel beach ridges, coupled with regression, has forced the course of the San Martín River northward (Fig. 5). The elevation of the supratidal surface falls by approximately 1.8 m along a 6 km-long traverse representing approximately 5300 years of tidal flat accretion. This fall is attributed to tectonic uplift (Ferrero, 1997) and to diminishing wave setup due to growth of the El Páramo Spit (Bujalesky, 1990; Bujalesky and González Bonorino, 1991; Gordillo et al., 1992).

6. Discussion and conclusions

Although Bustamante Point, Dungeness Point and El Páramo Spit developed under similar hydraulic conditions they differ considerably in their constitution. All three landforms originated as cuspate forelands in the mid-Holocene. Bustamante and Dungeness points continued to grow as cuspate forelands until the present, with a significant contribution of gravel from sources within the Río Gallegos Estuary and the Strait of Magellan. The El Páramo cuspate foreland has ceased to accrete and is being cannibalized by the Atlantic littoral drift, providing gravel to the El Páramo spit. This spit is an extremely slender form that has undergone considerable elongation and westward migration without breaching.

Changes in relative sea level probably played a central role in the contrasting development of these landforms. The transgressive nature of the El Páramo Spit suggests that it developed under a stable or slightly rising relative sea level. Quite likely, however, the spit represents only the younger fraction of the 5300 years recorded in the supratidal deposits, the older terms having been eroded away. Spit development requires an abundant supply of sediment by littoral drift, which is favored by a stable sea level (e.g., Roy et al., 1994). Such conditions appear to have prevailed in the area of San Sebastián Bay. At the other extreme, relative sea level fall was large in the area of Bustamante Point; rapid uplift would have hindered spit development. In turn, Dungeness Point records an intermediate fall in the relative sea level and the incipient spit may reflect this situation.

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