

# Morphology, grain-size and faunistic composition of the macrotidal beaches of Tierra del Fuego

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**RESUMEN.** *Morfología, tamaño de grano y composición faunística de las playas macromareales de Tierra del Fuego.* Los modelos morfodinámicos han sido aplicados a playas macromareales basados en granulometrías unimodales y parámetros dinámicos estables como la altura de ola y período estimados en la rompiente. Las playas bimodales de grava no se consideran en estos modelos debido a que las granulometrías están sujetas a segregaciones espaciales (gravas y gránulos en los sectores superiores de la playa, y arena fina en los sectores inferiores) y variaciones temporales en la dinámica de las olas condicionadas por la marea (la playa tiene una dinámica reflectiva durante marea alta y disipativa durante marea baja). Sobreimpuestos a estas limitaciones morfodinámicas, en la costa atlántica de Tierra del Fuego se dan factores heredados que controlan la morfología costera. En costas bajas (porción de la Placa Sudamericana), la fluctuación holocena del nivel del mar permitió la construcción de planicies de cordones de playas. En las costas de alto relieve (Microplaca de Scotia), la misma fluctuación no tuvo suficiente sedimento disponible y se desarrollaron playas de bolsillo entre cabos y acumulaciones de arena en las desembocaduras de ríos. Dos áreas resultaron de interés por su contenido en minerales pesados: la planicie de cordones de playa del Río Chico y el sector comprendido entre los estuarios de los ríos Ewan y Ladrillero. En relación a la composición faunística de las playas, los moluscos que prefieren fondos rocosos son más abundantes en los cabos.

**Palabras clave:** *Playas macromareales, Morfología, Composición faunística, Tierra del Fuego*

**ABSTRACT.** *Morphodynamic models have been applied to macrotidal beaches. They are based on unimodal grain sizes and average dynamic parameters as the wave height and period at the breaker zone. Bimodal gravel beaches do not fit to these models because a) grain size is subject to spatial segregations (gravel and granules at the upper beach zones and fine sand at the lower-tide terrace), and b) wave dynamics vary temporarily during the tidal cycle: the beach has a reflective behaviour during high tide and dissipative during low tide. Superimposed to these morphodynamical constraints, along the Atlantic coast of Tierra del Fuego inherited factors control the coastal morphology. In low-lying coasts (South-American Plate portion), the Holocene sea-level fluctuation permitted the construction of beach ridge plains. On high-relief coasts (Scotia Microplate), the same fluctuation have little enough sediment available, and therefore pocket beaches developed between capes and sand accumulations at river outlets. Two areas were found of interest by their heavy mineral content: the Río Chico beach-ridge plain, and the coastline between Ewan and Ladrillero estuaries. With regard to the molluscan beach composition, rocky bottom specimens dominate at the capes.*

**Key words:** *Macrotidal beaches, Morphology, Faunistic composition, Tierra del Fuego*

## Introduction

Tierra del Fuego is known as a land of ice and moraines where glaciers arrive to the sea level as fjords, or where they flowed long distances to leave till or erratic deposits (Caldenius 1932; Coronato *et al.* 1999) merging today from the shallow continental shelf (Isla and Schnack 1995). For years, it was assumed that present Atlantic beaches composed of gravel were the result of the reworking of piedmont glaciers. Far from this reasoning, these beaches composed of rounded gravel form by the direct reworking of fossil beaches corresponding to different sea-level highstands: one related to the Last Interglacial (oxygen isotopic stage 5e, Sangamonian or locally named La Sara Formation; Codignotto and Malumián 1981), and the other

related to the maximum level that took place during the Holocene (last 7000 years).

During several summer field works along this Atlantic coastline, it was possible to distinguish that the southern beaches derived from the direct reworking of glacial deposits or Tertiary rocks (Isla 1994), and that the northern beaches are formed by the reworking of Quaternary beach-ridge plains (Isla and Bujalesky 2000).

The molluscan composition of present beaches is the consequence of the so-called «ecological effects», defined based on the mollusc content of Holocene beaches (Gordillo 1998). Present beaches of this region have not been subject to specific studies (nor the Holocene beach plains); only some areas from the Beagle Channel were analysed. Considering the coastal configuration, the «ecological characteristics» or

physical constrains of adjacent pocket beaches were very contrasting.

In the present paper, morphological and grain-size characteristics of these beaches and beach plains are described. The applicability of morphodynamic models proposed for macrotidal beaches is tested. These physical characteristics are related to the heavy-mineral concentrations and macrofauna composition of each beach in order to approximate to placer evaluations and the dominant ecological conditions within the bays.

### Geologic, climatic and oceanographic setting

The studied area comprises the southwestern boundary of the South American Plate in its border with the Scotia Microplate; this limit is assigned to the Irigoyen River Fault Zone and the Fagnano Lake (Fig. 1).

Several Tertiary formations have been described at the Eastern Grande Island. Seven formations: Strata of Río Claro, Río Turba, La Pilarica, Cabo Peña, Cabo Domingo, Cerro Águila and del Castillo were cited in the region (Doello Jurado 1922; Codignotto and Malumián 1981; Butois and Camacho 1993; Olivero *et al.* 1999). In the last years, dispersed outcrops were reinterpreted into three sedimentary cycles:

1. The Palaeocene transgression flooded the island from the west (Río Claro Formation; Butois and Camacho, 1993) and ended during the Eocene (La Despedida Formation; Doello Jurado 1922).

2. The second transgression originated from the Atlantic Ocean and is constituted by the Cabo Inés strata (informal stratigraphic unit) assumed as Oligocene and correlated to the Cabo Peña Formation (Butois and Camacho 1993).

3. The third transgression affected only the northern portion of the island and initiated as the Cerro Águila Conglomerate, continuing into the deltaic sediments of the Carmen Silva and Castillo formations (Codignotto and Malumián 1981).

There was a fourth transgression of little duration and extension (Punta Basilica Sandstone) correlated to the Filaret formation from Chile and assigned to the Upper Miocene – Lower Pliocene (Codignotto and Malumián 1981). These transgressions have similar counterparts (within the same Austral Basin) in the Santa Cruz sector (Russo *et al.* 1980; Codignotto and Malumián 1981). Pleistocene glacigenic units of different ages and environments overlay the Tertiary sediments (Bujalesky *et al.* 2001).

In most cases, the base of these beaches is an abrasion platform cut into Tertiary rocks. As these Tertiary rocks are closer to the Cordillera, they are more affected by faults. The southern beaches of Tierra del Fuego are located between capes designed by transform fault zones subject to frequent earthquakes (Fig. 2).

The climate of Tierra del Fuego is dominated by the prevailing westerly winds, with Pacific cyclones moving eastwards but not far from the Antarctic ice (Tuhkanen 1992). The Cordillera de Los Andes causes a climatic step from west to east, and from south to north (Fig. 1). Rainfall is more subject to topographic effects: while Río Grande and Ushuaia

have similar mean annual temperatures of 5–6<sup>o</sup> C, precipitation at Ushuaia sums 534.7 mm/year (it has been diminishing since 1928–1937; R. J. Iturraspe, personal communication); and in Río Grande is only 340 mm/year (Bujalesky 1998). Prevailing winds are also subject to topographic effects: in the region of the Magellan Strait they blow from the west and northwest; in Río Grande city they prevail from the west, and in Ushuaia they are from the southwest. Spring and summer are the most windy seasons (Bujalesky 1998).

At the Atlantic coastline, mean tidal range diminishes toward the southeast: 6.6 m in San Sebastián Bay, 5.7 m in Caleta La Misión, 4.16 m in Río Grande outer estuary and 4.63 m in Caleta San Pablo (Fig. 1). Maximum tidal currents are over 2 knots (either during the flood or ebb) at the inlet of San Sebastián Bay, and of 5 knots within the bay (spring tidal ranges reach 10.4 m).

Wave climate is relatively benign at the Atlantic coast due to the dominance of the strong westerly winds. Reports from the British Meteorological Office, covering a sea area from the coast to longitude 65° W and between latitudes 50° and 55° S (period 1949–1968), indicates:

(a) the frequency of wave heights higher than 3.5 m is very low;

(b) around 20% of waves were less than 1 m in height on average throughout the year;

(c) long-period waves are relatively uncommon; and wave with periods greater than 10 seconds come from the east and northeast;

(d) gales of 41–47 knots from any direction between N and ESE (with a return period of 50 years) are estimated to generate an extreme wave height of 12 m and a period of 11.5 seconds in a depth of 50 m (referred to spring tide level);

(e) this estimated extreme wave would break in a water depth of 15 m (chart depth + tidal height above chart datum + storm surge), and would be near the breaking point in 10 m depth even at spring high water.

A record of one year at Estancia Cullen (52°49'19" S, 68°13'52" W, 110 km north of the city of Río Grande) gave the following results:

(a) a maximum wave height of 5,86 m (*Compagnie de Recherches et d'Etudes Oceanographiques* and Geomatter 1985);

(b) maximum significant wave height was 3,43 m;

(c) average significant wave height was 1,02 m;

(d) maximum wave period recorded was 17,5 seconds ;

(e) maximum significant period was 12,9 seconds ;

(f) average significant period was 5,5 seconds ;

(g) waves higher than 3 m corresponded to periods of 7 to 9 seconds;

(h) the longer periods were associated with wave heights of 1,25 m;

(i) the stronger swell is associated with north and northeast winds;

(j) the estimated extreme wave height would be 5,8 m for NE to E winds and 7 m for winds from the north for a return period of 50 years.

In San Sebastián Bay, extreme winds higher than 64 knots were estimated from the SW and NW (*Compagnie de Recherches et d'Etudes Oceanographiques* and Geomatter; 1985) for recurrence periods of 50 years. These conditions

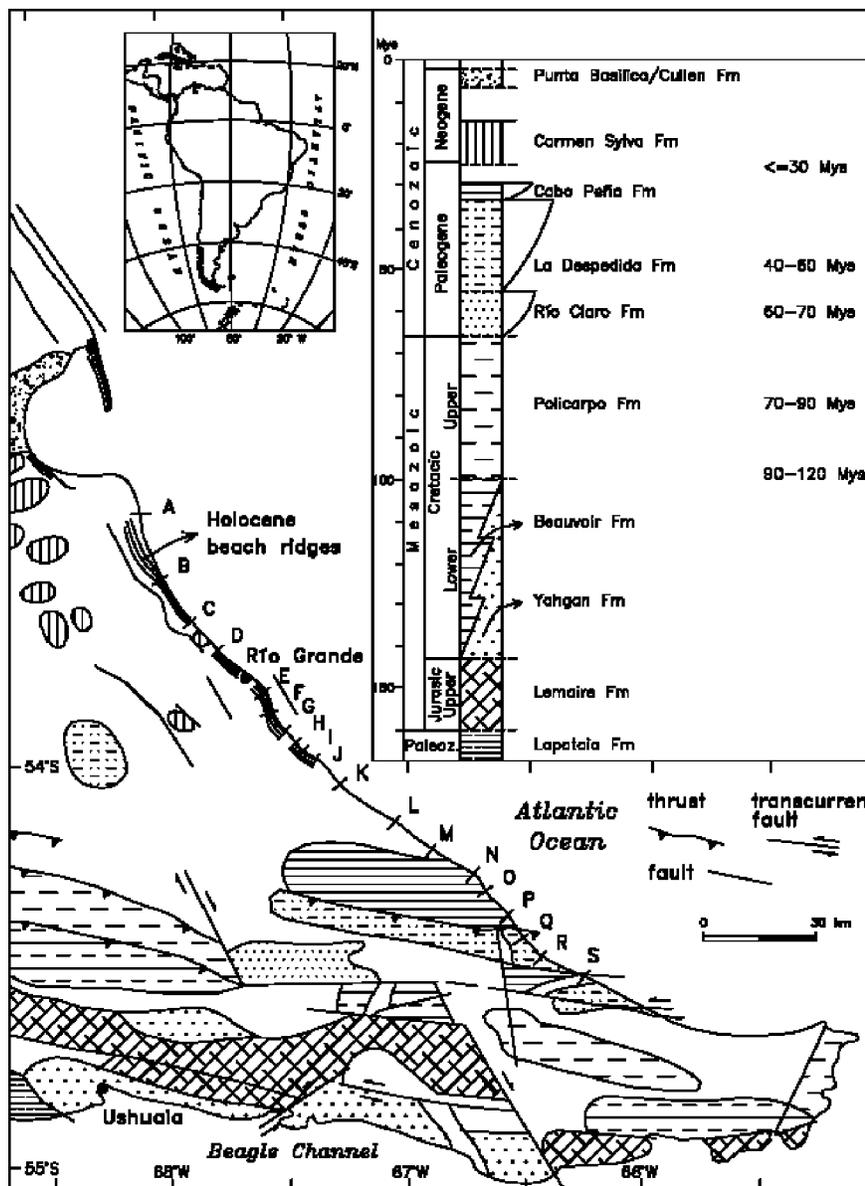


Figure 1: Location map of the studied beaches of Tierra del Fuego (Letters correspond to the geographic coordinates of table 1). Geological sketch and stratigraphic column modified from Olivero *et al.* (1999).

would produce maximum significant waves of 2,74 m originated within the bay.

### Sediment sources and beach drift

In northern Tierra del Fuego, beach gravel is provided from the reworking of glacial, glacialfluvial or former coastal deposits (Bujalesky 1998; Bujalesky *et al.* 2001). In some places the source of sediments are ancient moraines today submerged (Isla and Schnack 1995). Sand is provided by fluvial or eolian processes, by the reworking of beach plains (Isla and Bujalesky 2000) or coastal erosion from Tertiary cliffs.

The bimodal beaches of Tierra del Fuego are directly or

indirectly related to glaciogenic sources. Different glaciations affected the area (Rabassa *et al.* 1992); the oldestmost is of Upper Pliocene age (Drift Río Grande; *sensu* Meglioli *et al.* 1990) and the most recent (Bahía Inútil Glaciation) was limited to the southern flank of the Carmen Sylva hills, and has a Wisconsinan age (isotopic stage 5e) with some ice advances (see Mc Culloch and Bentley 1998). Two glacialfluvial delta systems were recognised. The oldest one is Pleistocene and located between 10 and 50 m over MSL (the lowermost). The most recent is settled at a higher altitude (50-100 m) and limited to the western area of northern Tierra del Fuego (Bujalesky *et al.* 2001).

A regional longshore drift has been reported from north to south in regard to coastal features and sediment transport experiments (Codignotto and Malumián 1981; Isla *et al.* 1991).



**Figura 2:** The coast at the Ladrillero estuary is a pocket beach between two capes rounded by the Pleistocene glaciations. The river meanders on a plain dominated by *Sphagnum* peat. The outlet is permanently blocked by an accumulation of gravel and sand. The river seeps at the upper beach (about 40 m width) during low tide. The Cabo San Pablo lighthouse became tilted on the earthquake of 1949.

However, beach heavy minerals suggest that present longshore transport is from south to north (Gomez Peral and Martinez 1997). Based on ancient aerial photographs, Bujalesky (1997) described the evolution of the recurring Popper Spit (Rio Grande Inlet) in response to a local drift from south to north. Refraction diagrams explained how this local drift is caused by the refraction of waves induced by rocky reefs (Gusano and Exterior reefs; Isla and Bujalesky 2000).

### Morphodynamics of sand and gravel beaches

Although the stability field of bedforms composed by sand is rather well known, some gravel steep bedforms are reported with doubts whether they form by lower or upper regimes (Carling 1999). Sandy macrotidal beaches often have concave-upward profiles (Masselink and Hegge 1995). Gravel beaches are concave-upward, but the upper beach is convex-upward due to the development of berm crests at the high-tide level. Bluck (1967) studied the distribution of sediments on a beach composed mainly of gravel and discriminated four facies: the zone of large discs (transported to the higher altitudes by storms), the imbricate zone (smaller clasts dipping to the sea), the infill zone and the outer frame zone (dominated by spherical clasts). Eolian processes can dominate the upper beach during low tide or neap tides (Masselink and Hegge 1995). The upper part of gravel beaches is only modified during spring high tides or storms. Overtopping is an episodic

process commonly recognised in gravel beaches (Orford *et al.* 1995). Seepage could induce the capture of eolian sand (at the low-tide terraces and/or on the foreshore) in sandy beaches. In gravel beaches, the seepage could be an important process (Carter *et al.* 1984), causing gravel transport down the beach profile and deposition as seepage deltas (Isla *et al.* 1991). During neap tides, the retreating erosion of the seepage portion causes a sediment transport down the beach, and thinning the body of the barrier. During spring tides, waves transport gravel towards the beach crest, due to the reflective behaviour of the beach, reconstituting the dynamic profile.

Unimodal beaches can be modelled by uniform parameters (Short 1979; Wright *et al.* 1982; Wright and Short 1984; Masselink and Short, 1993) that depend on breaker height (Hb), wave period (T) and settling velocity of the particles (Ws). The W parameter ( $Hb/Ws \cdot T$ ) and the Relative Tidal Range ( $RTR = MSR/Hb$ ) define the beach morphodynamics (MSR: mean spring tidal range). Beach slopes are related to the grain size and to wave action. Sunamura (1984) proposed an approximation for microtidal beach slopes ( $\tan B$ )

$$\tan B = 0,12 (Hb/g^{0,5} T \cdot d^{0,5})^{0,5}$$

where g is the acceleration due to gravity, and d is the grain size.

For bimodal beaches, the relationship between slope and grain size is not clear (Mc Lean and Kirk 1968). Their sediment transport prediction depends on the understanding of inter-related factors (Mason and Coates 2001). For meso and macrotidal beaches, and considering them composed of

fine to medium sand, the relationships are less easy; some characteristics can be explained in relation to dominant processes in the different beach zones:

- the upper intertidal zone is dominated by swash and aeolian processes,
- the mid-intertidal zone is dominated by swash and surf,
- the lower intertidal zone is controlled by surf and shoaling wave processes, and
- the subtidal zone is subject to shoaling processes (Masselink and Hegge 1995).

Many beaches of England are presently and preferably being nourished with gravel as it is more resistant to erosion. However, many doubts arise about their stability as:

- there is no ideal profile assigned for mixed beaches,
- no onshore or offshore losses can be predicted,
- uncertainty about their behaviour in relation to coastal structures, and
- seepage effects (Mason and Coates 2001).

## Methods

Gravel beach plains were recognised by the mean of aerial photographs and Landsat TM images, and surveyed with teodolite. Beach profiles were executed using teodolite and ruler during low tide. At the field, beaches and beach plains were positioned by a hand-held GPS equipment Ensign Trimble XL (Table 1 and 2). Grain size samplings were conducted according to morphodynamic criteria. Foreshore samples were tested for heavy mineral concentrations. The 3-3,5 phi intervals were submerged into a heavy liquid (Carbon tetrachlorine) in order to separate and evaluate (by weights) the heavy and light minerals fractions (Table 2).

Molluscs were collected from the tidal and storm berms of the southern beaches (Table 3) where beach drift effects are lower (pocket beaches). Mollusc taxonomy were determined according to Castellanos (1989, 1992 a and b, 1993) and Castellanos and Landoni (1988, 1989, 1992 a and b).

## Results

### Beach-ridge plain topography

Beaches from the northern portion of the island derived from the reworking of beach-ridge plains of Holocene age.

From north to south, several beach-ridge plains were analysed (Isla and Bujalesky 2000), some are related to river plains: San Sebastián (Río San Martín), Río Chico, Cabo Peñas, Ensenada de la Colonia, Río Fuego, and Río Ewan (Fig. 3). From NW to SE, beach ridge plains are shorter and narrower (see Table 1). This is explained by the landscape morphology: the northern area has less hills with plains developed by the former action of piedmont glaciers. In the southern area, the relief is higher (hills higher than 50 m) and river valleys are narrower.

### Beach morphology and morphodynamics

At some beaches related to beach plains and subject to wind action, low coastal dunes can be recognised (Cabo Peñas, Ensenada de la Colonia). From Punta María (G in fig. 1) to the south, the beaches are at the foot of high cliffs. Some beaches are related to spits blocking estuaries (Río Fuego, Ladrillero, Río Irigoyen). Along these beaches longshore drift selection of different sizes can be expected.

Beach profiles (Figs. 4 to 6) indicate two different zones: the foreshore and the low-tide terrace. These profiles do not fit into the three classes of sandy macrotidal beaches described by Short (1991). The foreshores have very uniform slopes higher than 6%. The low-tide terraces have slopes of less than 2% (Fig. 7). Some beaches show convex-upward profiles due to the development of crest berms. Three crests can be distinguished in these beaches: the storm berm, the spring-tide berm and the present tidal berm (subject to changes in relation to the present-day dynamics). Different relationships exist between the slopes of the upper beaches and their grain sizes (Fig. 7): north of profile L (Ewan river estuary) beaches are the response of the reworking of gravel beach plains. On the other hand, southern beaches are located between capes composed of Tertiary rocks with glacial deposits on top of coastal cliffs.

As on gravel beaches  $H_b$  varies during the tide (up to 100%), the relationship  $W/RTR$  cannot be applied. Gravel beaches have a reflective behaviour at high tide and dissipative at low tide. These processes were already noted by Wright and Short (1984).

### Grain size

The storm berms are dominated by oblate or tabular pebbles usually larger than 4 mm (Table 2). Upper foreshores are composed dominantly of pebbles, granules or coarse sand

**Table 1:** Morphological parameters of Holocene beach-ridge plains (modified from Isla and Bujalesky, 2000). moms: meters over mean sea level. D: mean grain size at the foreshore. Sublittoral slope is measured at the inner shelf.

Parameters	San Sebastián	Río Chico	Cabo Peñas	Ensenada de la Colonia	Río Fuego	Río Ewan
Latitude S	52° 58'	53° 39'	53° 50'	53° 56'	53° 58'	54° 07'
Longitude W	62° 12'	67° 54'	67° 35'	67° 31'	67° 29'	67° 09'
Length (km)	17	33	10	11	5	1
Max. Width (km)	1,5	1,6	0,7	2	1	0,15
Altitude (moms)	9,5	9	8	5	6	6
Beach slope (%)	7-9	7-9	11	7,5	9	19
D (mm)	40	0,6	0,3	0,36	-	0,255
Sublit. slope (%)	0,31	0,5	0,55	0,60	0,30	0,22

**Table 2:** Location and grain-size of the studied beaches (see Fig. 1). Grain size in phi units. (1) Percentage of heavy minerals in the 3-3,5 phi interval at the foreshore.

	Latitude South	Longitude West	Storm berm	Foreshore	Toe of beach	Low-tide terrace	% heavy minerals (1)
A. Punta Sinaia	53 24,714	68 04,613	-2,33	-0,60	0,40	2,68	
B. La Cholga	53 35,880	67 58,513	-3,36	-1,53	-0,80	0,33	31-47
C. Las Violetas	53 39,249	67 54,623	-2,97	-3,73	-1,00	2,00	44
D. La Misión	53 43,025	67 47,916	0,16	-1,16	0,12	3,08	15
E. Cabo Peñas	53 49,914	67 35,090	-3,03	0,70	-0,60	---	
F. Ens. de la Colonia	53 53,176	67 34,417	-2,13	1,46	-0,50	3,13	4
G. Punta María	53 56,437	67 30,261	-4,00	-4,00	-2,03	-1,27	6
H. Río Fuego	53 57,857	67 27,732	-2,90	-1,35	-2,77	1,90	
I. Norte de Auricosta	54 00,339	67 21,819	-3,66	-2,35	-2,48	3,33	1.6
J. Río de los Mineros	54 02,188	67 20,172	-2,13	0,73	3,03	3,42	
K. Cabo Viamonte	54 04,663	67 15,429	-3,36	-0,93	-2,16	3,46	2-7
L. Estancia La Inés	54 10,186	66 59,294	2,27	1,70	0,85	2,13	2
M. Estancia Pirinaica	54 13,379	66 52,436	-4,85	-3,94	-3,88	3,33	33-60
N. Río Ladrillero	54 16,739	66 43,677	-4,05	-1,35	1,70	1,03	62-73
O. Cabo San Pablo	54 18,413	66 41,836	-3,50	-0,01	1,20	3,03	
P. Ea. La Fueguina	54 23,007	66 35,824	-4,24	1,40	-1,30	3,06	2-5
Q. Cabo Irigoyen	54 24,888	66 33,425	1,50	0,53	-1,93	3,30	
R. Punta Torcida	54 28,841	66 27,247	-3,68	-3,32	-3,83	3,16	18-29
S. Río Irigoyen	54 30,846	66 17,258	-4,25	-0,96	-2,46	2,93	5

(Fig. 7). Where the availability of different materials is significant there is a grain-size selection into sand runs, gravel segregations or even shell accumulations. The lower foreshore and the toe of the beach are also composed of pebbles, granules or coarse sand. The low-tide terraces are dominated by fine to very fine sand. Only on few beaches, abrasion platforms were recognised (Río Irigoyen).

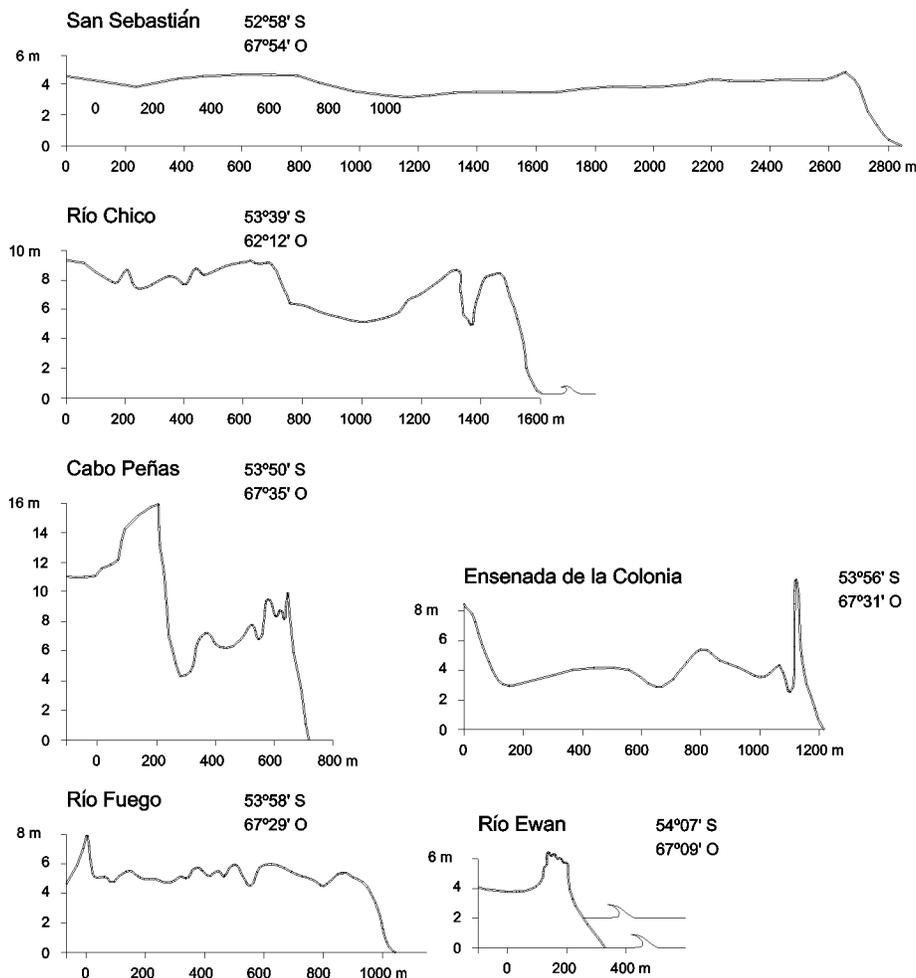
Plotting grain size (in phi units) versus beach slope (%), we

can distinguish a significant linear correlation for the data obtained from the upper foreshores (Fig. 7). The differences for the foreshore grain sizes between the northern and southern beaches were attributed to inherited conditions as the degree of reworking and sorting. At the low tide terraces composed of fine sand, there is no relation to their gentle slopes. These results confirm the conclusions of Mc Lean and Kirk (1968) for New Zealand beaches, that there are no

**Table 3:** List of molluscs collected at the berms of the southern beaches.

	G	H	I	J	K	L	M	N	O	P	Q	R	S
<b>Gastropoda</b>													
Acanthina monodon (Solander)							2		4			2	
Adelomelon ancilla (Solander)	4											2	2
Buccinanops sp.	4	8	4	4	2	4	4		6			6	4
Calyptreaa costellata Philippi	2												
Calyptreaa pileolus d Orbigny	2				2								
Falsilunatia limbata (d Orbigny)	4	4		2							2		
Fissurella oriens Sowerby	8					4	4		2				2
Margarella violacea (King yBroderip)										2	4		
Nacella magellanica (Gmelin)		8	6	8	6	6	6	4	6	2	6	8	6
Nacella deaurata (Gmelin)	6	8	6	8	6	6	6	4	6	2	6	8	6
Odonthocymbiola magellanica (Gmelin)	4	4	2	6	2		4	2	2	4	4	6	
Pareuthria plumbea (Philippi)	4	4		2	2	6	6		6		4		4
Siphonaria lessoni (Blainville)		6			4	2							4
Tegula atra (Lesson)	2	2				4			2		2		
Tegula patagonica (d Orbigny)							2				2		
Trophon geversianus (Pallas)	8	8	6	6	4	6	8	6	6	4	4	8	4
Xymenopsis muriciformis (King)		4		4	2			2			4		
<b>Bivalvia</b>													
Aulacomya atra (Molina)	6	6			4	4	6	4	6	4	6	6	
Darina solenoides (King)	4	4			6				4		4		
Hiatella solida (Sowerby)					2		2					2	6
Malletia cumingii (Hanley)							2	2					
Mulinia edulis (King)	6						2						
Mytilus edulis chilensis (Hupé)	8	8	6	8	8	6	8	4	8	4	6	8	6
Perumytilus purpuratus (Lamarck)	2	4	4			4						4	
Sphaenia hatcheri Pilsbry										2			

2: rare; 4: scarce; 6: abundant; 8: very abundant



**Figura 3:** Topographic profiles from beach ridge plains: San Sebastián, Río Chico, Cabo Peñas, Ensenada de la Colonia, Río Fuego and Río Ewan (locations in Fig. 1).

clear relationships between beach slope and mean grain size in bimodal beaches.

#### Heavy-mineral distribution

The heavy mineral content in the 3-3,5 phi interval ranged between 2 and 73%. Two areas were distinguished as of interest by their values: The first one is the area between La Cholga and Las Violetas sampling stations (percentages between 31 and 47%). It belongs to the Río Chico beach ridge plain, and was already tested for placers (Gómez Peral and Martínez 1997). Another area of interest was recognised at the coastline between Estancia Pirinaica and the Río Ladrillero estuary, with values between 33 and 73% (Table 2).

#### Mollusc distribution

In present beaches no trend was analysed in relation to the different mollusc species found. *Nacella magellanica*, *Nacella deaurata*, *Trophon geversianus*, *Mytilus edulis chilensis*, *Aulacomya atra* were the most abundant species; *Tegula atra*, *Tegula patagonica*, *Hiatella solida* were found

in lower percentages (Table 3). Considering the preferences of these mollusc assemblages to rocky- or soft-bottom substrates, it is concluded that more specimens related to rocky bottoms were found at capes: Punta María, Viamonte, Santa Inés, San Pablo and Irigoyen capes (Fig. 8).

#### Discussion

Little is known about macrotidal bimodal or «mixed» beaches (Mason and Coates 2001). Their dynamics is complicated by processes acting in different ways along space and time (i.e. during high or low tide). Sediment composition is subject to many different processes: overtopping, gravel armouring, sand sieving, water seeping and size and shape segregations. The upper foreshore slope is conditioned by gravel size; the grain size of low-tide terraces seems to be controlled by inherited factors. This causes a dissipative behaviour at low tide changing abruptly to reflective at mid- or high tide (Wright and Short 1984; Mason and Coates 2001).

The origin of beach ridge plains is not precisely

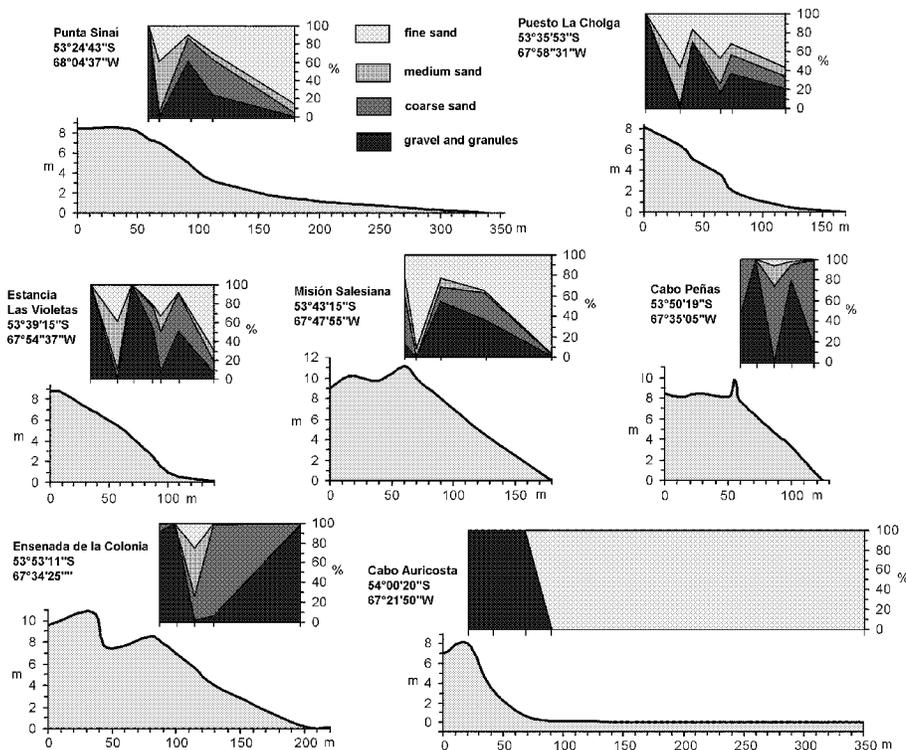


Figura 4: Beach profiles and grain-size distributions at the northern sector of the studied area (profiles A to I of figure 1).

understood: some authors assigned them to fair-weather conditions while those composed of coarse sediments are assumed formed by storms (Taylor and Stone 1996). Tropical beach-ridge plains are clearly related to significant inputs from big rivers (Anthony 1995). The sea level should remain stable or dropping (Short 1987; Anthony 1995; Hesp and Short

1999). In the coast of New Zealand, the glacioeustatic evolution and the availability of sand and gravel permit the development of gravel beach plains (Schulmeister and Kirk 1993; Soons *et al.* 1997) similar to these of Tierra del Fuego.

Heavy mineral studies pretended to analyse the origin of the gold placers exploited at the beginning of the XX century

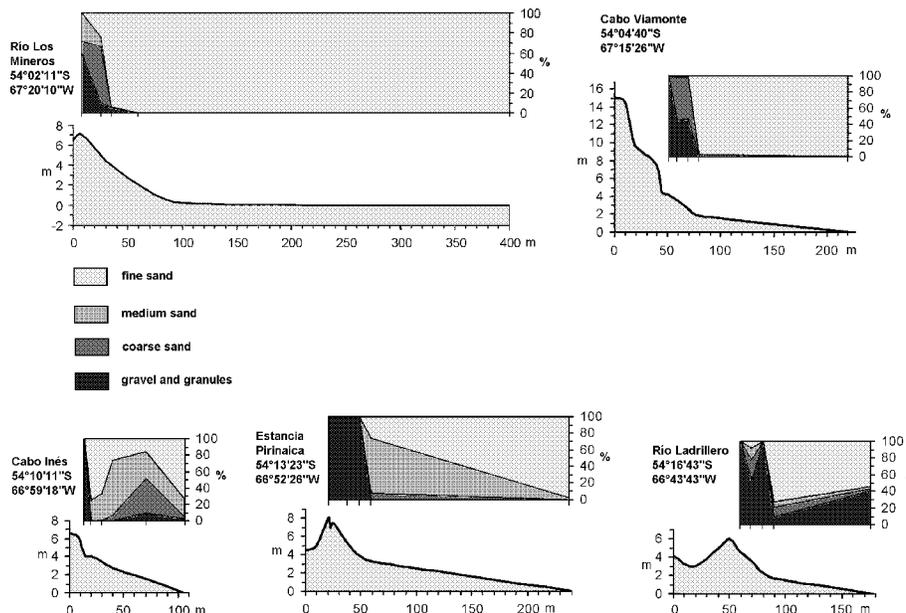


Figura 5: Beach profiles and grain-size distributions at the central sector of the studied area (profiles J to N).

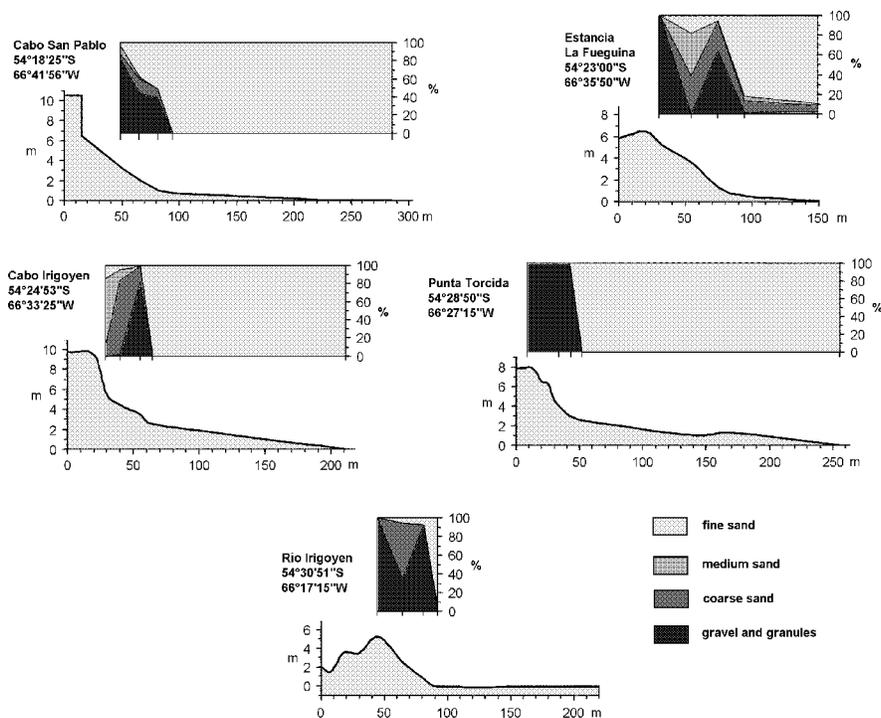


Figura 6: Beach profiles and grain-size distributions at the southern sector of the studied area (profiles O to S).

by Julius Popper. Modern studies carried out along the coastline of the Río Chico beach plain proposed a fluvial origin for the beach heavy mineral concentrations (Gómez Peral and Martínez 1997). However, the El Páramo and Río Chico barriers, composed by sand and gravel, clearly derived from the glacial deposits outcropping at the coast (Cabo Nombre, Punta Sinaia) and at the shallow inner shelf (Isla *et al.* 1991; Isla *et al.* 1995). At the coast of Alaska (Seward Peninsula), the nearshore deposits in front of the village of

Nome (between the Snake and Nome rivers) contained gold placers. The surface sediments with the highest gold content were the relict lag gravel that veneers glacial drift at the depth of less than 10 m. The largest particles (several mm in diameter) were therefore related to relict gravel over the submerged drift (Nelson and Hopkins 1972).

Macrofaunal species richness in beaches is controlled by their dynamics, increasing from reflective to dissipative conditions, and in response to the maximum tidal range (Mc

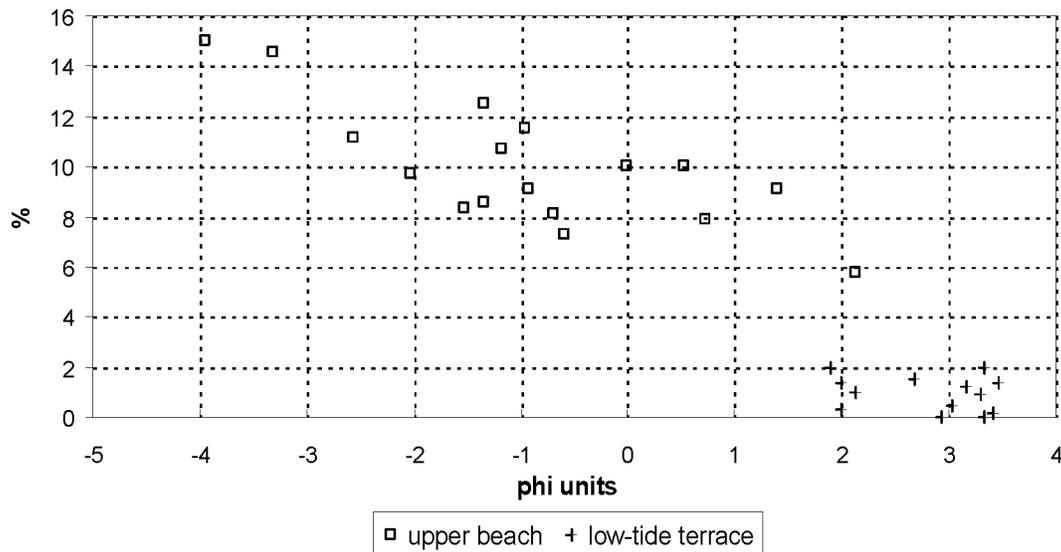
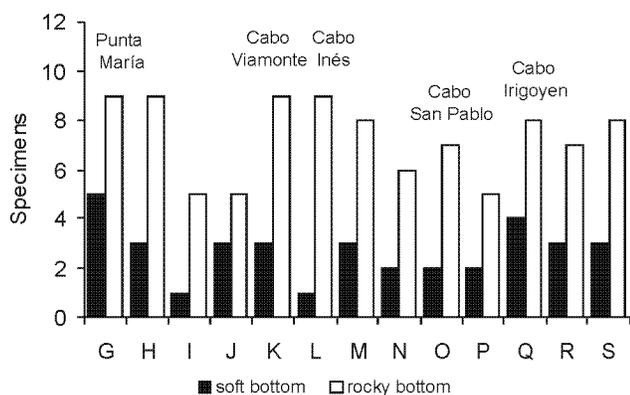


Figura 7: Relationships between mean grain size (phi units) and intertidal slopes (%). There is a significant relationship at the foreshore, while there is no relation within the low-tide terrace.



**Figura 8:** Abundance of mollusc specimens collected at the berms (beaches coded by the letters of table 1).

Lachlan 1990). More precisely, swash climate has been assigned as the crucial effect. Dissipative swash conditions require minimal faunal adaptations while reflective beaches are more hostile, demand more specializations and exclude more species (Short and Hesp 1999).

## Conclusions

1. In Eastern Tierra del Fuego, southern portion of the South American Plate, inherited factors related to tectonics permit the development of beach ridge plains in the north in response to the Holocene sea level fluctuation. This fluctuation eroded cliffs at the southern coast of the island (Scotia Microplate domain), but there was not enough sediment in order to construct wide plains during the last 6000 years.

2. In macrotidal bimodal (gravel and sand) beaches, it is clear that the slope of the foreshore is controlled by the gravel size. The grain size of the low-tide terrace is conditioned by an inherited factor, i.e. the availability of sand.

3. Spits denote the effects of beach drift at the northern coast. The southern coast is characterised by pocket beaches and sand accumulation at river outlets.

4. On the northern beaches the availability of sediment is directly related to the reworking of beach ridge plains. South of the Cabo Irigoyen, the availability of sand is conditioned to the erodability of the different Tertiary units or provided by Quaternary piedmont glaciers.

5. Two segments of the coast were recognised as relatively rich in beach heavy minerals: La Cholga - Las Violetas and Estancia Pirinaica - Ladrillero estuary.

6. Considering the mollusc composition of these beaches, rocky-bottom specimens dominate at the beaches between capes.

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