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Marine and transitional Holocene terraces in the eastern area of the Straits of Magellan, Chile

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Abstract. Along the coasts on the east Atlantic side of the Straits of Magellan there are at least three orders of terrace, prevalently marine. They lie either on a meso–Tertiary sedimentary basement or on glacial and glaciofluvial deposits linked to the last four Quaternary glacial stages. The most ancient terrace order (I) is mainly characterised by glaciolacustrine, transitional and marine deposits and/or erosion surfaces with a maximum height ranging from 18 to 25 m above sea level (a.s.l.). Radiometric ages on macrofossil samples date this order to be of 8000-9000 years B.P., although its base could be even older. The second terrace order (II) ranges from 6 to 11 m above msl and is formed by deposits and erosion surfaces mostly related to the marine and intertidal environments. Its age can be estimated at ca. 6000-7000 years B.P. The third terrace order (III) ranges from 3 to 5 m a.s.l. It also belongs to the marine intertidal environment and its age can be estimated at ca. 4000-5000 years B.P. Younger terraces are also present, dated 1200-2500 years B.P. Due to problems of horizontal scale, they are not examined and mapped in this work. The first–order terraces evolved in the environments of the first phase of the last deglaciation. The other two orders are connected to the subsequent stages of the last deglaciation. The influence of tectonics in their evolution cannot be excluded. In this paper, we have reproduced the cartography of the marine terraces mentioned above, with the aim of verifying their lateral continuity. The analysis of detailed lithostratigraphic examples contributes to a redifinition of the Holocene palaeogeographical evolution of the Straits of Magellan coasts.

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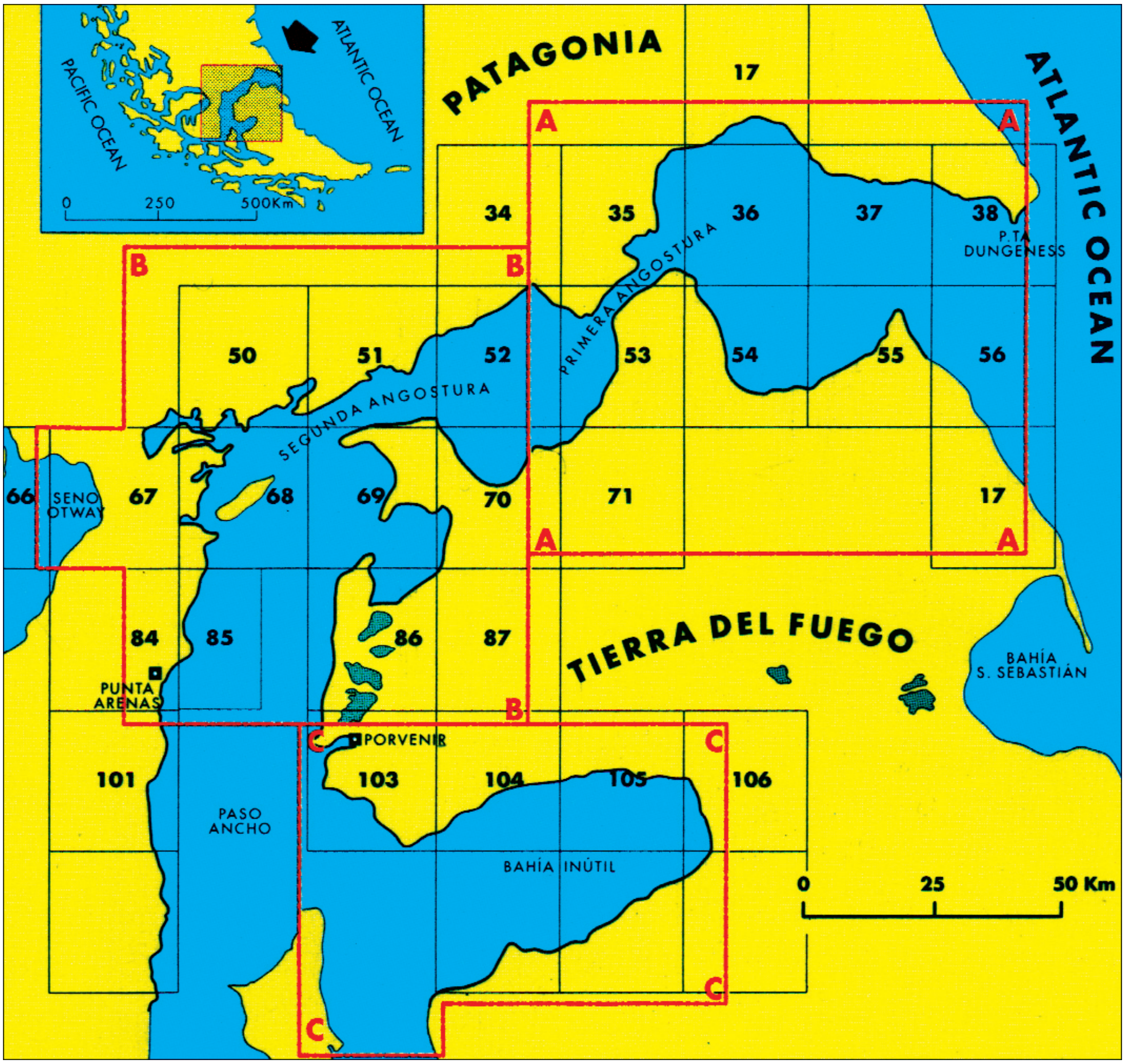

Fig. 1 - Location of the study area in the 1991 and 1994 expeditions; only the coastal stretches were surveyed. The small squares refer to maps on a scale of 1:50 000 of the Chilean I.G.M. (17, 34, 35, 36, 37, 38, 50, 51, 52, 53, 54, 55, 56, 67, 68, 69, 70, 71, 84, 85, 86, 87, 101, 103, 104, 105, 106), their geomorphological elaboration is in process; the large squares, identified with the letters A, B, C in the corners, show the three geomorphological maps attached separately to the text.

1. Introduction

In 1988 an interdisciplinary research project in the Straits of Magellan was promoted by the italian P.N.R.A. (Programma Nazionale Ricerche in Antartide). It was mainly based on three campaigns (1988, 1989, 1991). Sedimentological surveys were initially carried out at sea on a large scale, in order to obtain an overall view. The whole of the Straits of Magellan was involved, and in particular the areas facing the Pacific and Atlantic entrances, as well as the Magdalena, Cockburn, Ballenero and Beagle Channels.

In order to support the marine survey, the first campaign shorewards along the coastal belt was programmed and carried out in 1991. This led to the presentation of the preliminary results in two 1:100 000 geomorphological maps at the third International Conference of Geomorphology in Hamilton (Canada) in 1993 (Brambati et al., 1993a, 1993b). In 1994, after almost three years of processing the collected geomorphological data, another land campaign was organised to check the results obtained. Three new 1:200 000 geomorphological maps (Fig. 1 - A, B, C) were produced.

The main objective of the research was to map the marine terraces present along the eastern Magellan coasts, with the focus on verifying both the evidence of the terraces unit in the area and the reliability of these terraces as regional geomorphologic-stratigraphic markers for the late Quaternary and Holocene. Despite the lack of general references, the existence of marine terraces within the Magellan area is broadly described in local scientific reports (Gordillo et al., 1992; Clapperton et al., 1995). Their presence has often led various authors to make regional palaeogeographic deductions starting from local data, and correlations whose physical continuity has never been clearly verified.

The final aim of the campaign was a wide–ranging geomorphological and sedimentological survey of the north–eastern areas of the Straits of Magellan (Fig. 1). The southern and western parts were not studied due to the lack of suitable access. This investigation was carried out in two phases: firstly the stretch from Punta Arenas to Punta Dungeness (Patagonia) was examined; then, the coastal belt of Tierra del Fuego between Cameron (Bahía Inutíl) and Punta Catalina was investigated.

To the South of Punta Arenas, outside the area shown in the attached tables, the survey was extended to the coast beyond Río Leñadura up to Puerto del Hambre. With respect to the late Quaternary and Holocene, a geological and geomorphological sketch of the area was drawn, starting with available data from inland surveys (1991 campaign) and supplemented by the study and interpretation of aerial photographs in order to complete the preliminary mapping of the coastal belt. In some areas, only the limited information available from the literature was used, when consistent aerial cover and proper cartography were lacking.

The attached cartography on a 1:200 000 scale provides an aerial view of the entire Atlantic entrance to the Straits, both in the Patagonia and Tierra del Fuego areas. A 1:50 000 geomorphological Atlas, resulting from the mapping of all data from the Austral spring campaigns of 1991 and 1994 (Fig. 1), is at the moment in preparation. Aerial photographs from the S.A.F. (Aerophotogrammetrical Service Fuerza Aerea de Chile) were analysed on a scale of 1:40 000.

This work consisted of a first phase of geological and geomorphological cartography of the area, with collection of samples, a second phase of integration and correlation of mapped areas by means of aerial photographs and MSS Landsat Images, a third phase of sample analysis, and a final phase of data processing and checking the results obtained.

2. Geological–structural setting

On the basis of the geological and structural characteristics, three different sectors can be seen in the area of the Straits of Magellan. The first one is the western pacific area, which mainly consists of Meso–Cenozoic tonalites and granites (Andean Intrusive Complex) and of sediments belonging to the Upper Palaeozoic. The second and central section, located between Isla Carlos III and Punta Arenas, crosses the Meso–Cenozoic Magellan Basin. The last part mostly extends over glacial and glaciofluvial and paralic Plio–Quaternary deposits.

The Straits of Magellan are situated on the southernmost part of South–American Plate, adjacent to the Antarctic and Scottish Plates, i.e., on a recent collision zone of high intensity (Cordoval, 1981; Ramos, 1989). On the whole, it goes through a Palaeozoic–Quaternary sequence of surface–lengthened sedimentary magmatic and metamorphic terrains in conformity with the Andean Chain (E.N.A.P., 1978; S.N.G.M., 1982).

In the Pacific stretch there is a prevalence of tonalites, diorites and granites dating back to the Upper Mesozoic which outcrop westwards. As far as Isla Dawson, Palaeozoic metamorphites, volcanites of the upper Jurassic–lower Cretaceous and marine sediments of the Cretaceous outcrops. In the outward Atlantic stretch, Quaternary glacial and glaciofluvial deposits prevail, whereas the inward area (Punta Arenas–Bahía Inutíl) is characterised by Tertiary transitional and continental sediments.

In particular, the section between Isla Dawson and Punta Arenas crosses folded beds or terrain variably faulted, striking NNE-SSW; argillic, arenaceous, conglomerate sediments of the Cretaceous–Eocene are present. Around Punta Arenas, clays from the Middle–Upper Eocene and Oligocene sandstones outcrop. From Punta Arenas to the Atlantic, the same wide Quaternary glacial and glaciofluvial cover as in Tierra del Fuego and Patagonia extends to the surface: the only exception is the area around Bahía Pecket, where sandstones, conglomerates and continental clays of the Middle–Upper Miocene prevail.

In accordance with Forsyther (1982), Dott et al. (1982), Biddle et al. (1986), the most relevant stages of the geological evolution of the Straits of Magellan are the following:

1) In the Permian–Carboniferous, transgression with marine sedimentation and initiation (within the Permian stage) of the Magellan Basin, formed by a mainly Palaeozoic basement of sedimentary origin, subsequently metamorphosed;
2) The Magellan geosyncline was formed during the Upper Jurassic and produced an intense final magmatic activity which lasted until the Miocene, and a marked local instability in the crust;
3) In the late Jurassic, there was a transgression and initiation of a new sedimentary basin, stretching from North to South and characterised by greater instability westwards;
4) In the Lower and Mid Cretaceous, great subsidence;
5) In the Mid, and locally in the Upper Cretaceous, basic intrusions followed by accentuated foldings in the western part of the basin;
6) In the Cretaceous (Maastrichtian), end of the Mesozoic sedimentary cycle with formation of molasse deposits;
7) In the Paleocene, beginning of a new sedimentary cycle, which lasted until the Upper Miocene–Pliocene.

The geologic sequence was modified by several collisions, of various types over the ages, causing numerous series of foldings, faults and overthrusts (Olea and Davis, 1977; Cande and

Leslie, 1986; Ramos, 1989).

During the Quaternary, the area of the Straits of Magellan was affected by various glaciations, consequently creating the moraine barrier which nowadays broadly occupies the eastern area. According to Caldenius (1932), Feruglio (1933) and Auer (1970), there is glacial evidence also for part of the Pliocene.

The recent geological–structural setting of the Straits of Magellan is extensively affected by the tectonic evolution of the Andean Chain (Ridge) on its western side (Pacific coast). The eastern area basically shows traces of the Quaternary glacial morphoclimatic evolution influenced by the local interaction of glacio–isostatic, tectonic and volcanic components.

The last phase of glacial expansion is defined by the large moraine front, lined upon the axis Isla Isabel–Península Juan Mazía, where Segunda Angostura is situated on the deposits of the previous glacial phases. Successively, eustatic episodes are to be observed, associated with impressive isostatic movements. Together they define the marine and transitional terraces described in this study.

3. Quaternary glaciations within the Straits of Magellan

From a geological and morphological point of view, the Straits of Magellan show on a regional scale, a close genetic and evolutive link with the Quaternary glaciations of the Patagonic-Magellanic area. This interdependence was previously demonstrated by Caldenius (1932), Feruglio (1993) and Auer (1956).

This close connection is deduced by comparing the glacial Andean dominance with the recent morphology of the Magellanic coasts. In this area the various fjords form the natural seaward continuation of the ice lobes, and represent the morphogenetic result of the different phases of glacial expansion. In the investigated area, the geomorphological records of the last phase clearly show the extension of glacier fronts in some inlets (Seno Skyring, Seno Otway, Bahía Inutíl, etc.).

Pleistocene glaciers terminated in the sea in wide ice lobes branching along the present inlets of the Straits of Magellan (Heusser and Rabassa, 1987). Due to climatic and possibly tectonic factors (Rabassa, 1987) during the Holocene Age, they decreased progressively. During the Quaternary, the area was affected by several glaciations (Caldenius, 1932; Auer, 1956, 1970). The Atlantic side of the Straits of Magellan cuts through several groups of moraine (terminal, recessional, etc.) according to Feruglio (1933) and Bruggen (1950); the widest and oldest of these moraine arcs is located near the Atlantic entrance, whereas the inward ones are set at the same level as the narrows (Angosturas); Auer (1970) also recognized three glaciations in the Magellanic area.

However, according to Marangunic (1974), Rabassa and Clapperton (1990), and Clapperton (1992), there were four main Late Quaternary glacial stages; up–to–date scientific reports seem to agree with this hypothesis, although several authors indicate possible alternatives (Meglioli et al., 1990; Rabassa et al., 1992). The associated glacial deposits, rich with erratics and glacial palaeolandforms in Tierra del Fuego, are very well represented throughout the Magellanic area,

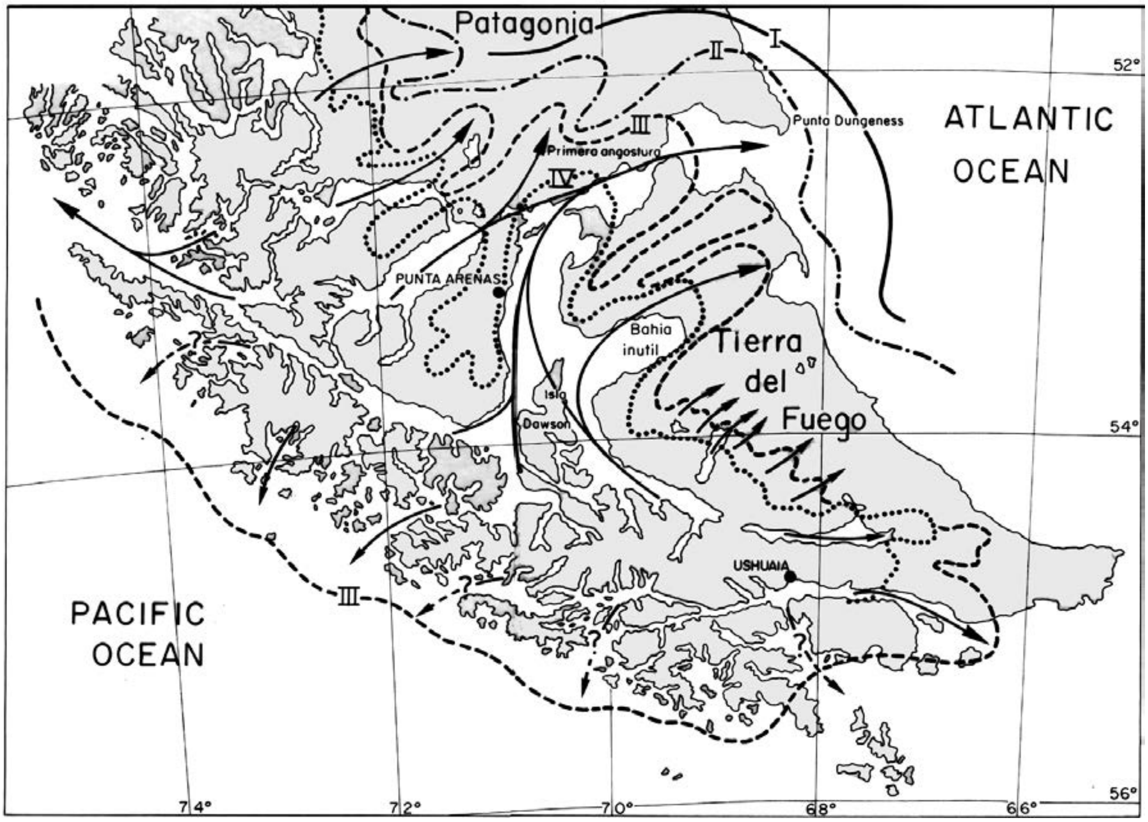

Fig. 2 - Caldenius (1932), plotted the position of most major moraine system, and attempted to date these using glacial lake varves linked to the Swedish chronology (de Geer, 1927, 1929) and believed they corresponded to the Initioglacial (I), Daniglacial (II), Gotiglacial (III) and Finiglacial (IV) late-glacial stages of the last glaciation in Scandinavia. However, palaeomagnetic studies at equivalent moraine belts in Argentina have shown that in Tierra del Fuego-Patagonia, the Gotiglacial and Finiglacial moraines are of Bruhnes age, and that the Bruhnes-Matuyama magnetic reversal (ca. 780 000 yr B.P.) lies within the Daniglacial system (Morner and Sylwan, 1989). Thus, some moraine belts along Magellan Strait are much older than the last glaciation and could date to the middle and early Quaternary. The arrows show the main directions of the Quaternary glaciers according to Raedeke (1978).

and sometimes present intercalated interglacial levels (Auer, 1956).

According to Caldenius (1932), who plotted the position of most of the major moraine system (Fig. 2), and attempted to date these using glacial lake varves linked to the Swedish chronology (de Geer, 1927, 1929) and believed they corresponded to the Daniglacial, Gotiglacial and Finiglacial late-glacial stages of the last glaciation in Scandinavia, with whom most researchers agree, the first of the four Late Quaternary glaciations belong to the Initioglacial stage, and its largest expanding front is located a few kilometres towards the outside of the eastern area of the Straits of Magellan. The second glaciation, (maximum age of 16 500 years), is represented by moraines at Cabo Virgenes, has a more inner expanding front, and is dated back to the Daniglacial. The third glaciation (16 500-9770 years), from the Gotiglacial stage, is represented by the moraines at Primera Angostura, whereas those of Segunda Angostura belong to the Finiglacial and represent the last glaciation (9770-8700 years). Caldenius (1932) also refers to moraines linked to a "post–Finiglacial" period.

Therefore, the establishment of all four glaciations occurred prevalently from the Upper Pleistocene until the Lower Holocene. According to Marangunic (1974), the Dani–Gotiglacial limit dates back 15 000 years, the Goti–Finiglacial from 10 200 to 8900 years and the Fini–Postglacial from 9000 to 8900 years.

In recent reports, the ages have been increased (Gordillo et al., 1992). It can be suggested that the last glaciation reached its maximum at 18 000-20 000 years and started its deglaciation at 14 700 years (Rabassa et al., 1992). Mercer (1976) established for the examined area a period of deglaciation dating at least from 12 500 years against the 15 880 proposed by Porter et al. (1985) and averaged by Rabassa et al. (1992) at 14 700 years. At Lago Blanco, the deglaciation itself is indicated at 13 500 years.

Palaeomagnetic studies of similar moraine belts in Argentina have shown that in Tierra del Fuego-Patagonia, the Gotiglacial and Finiglacial moraines are of Bruhnes age, and that the Bruhnes-Matuyama magnetic reversal (ca. 780 000 yr B.P.) lies within the Daniglacial system (Morner and Sylwan, 1989). Thus, some moraine belts along the Magellan Straits are much older than the last glaciation and could be dated between Middle and Early Quaternary, as suggested by Meglioli (1992).

In accordance with its glacial origin and the climatic and structural evolution, the opening of the Straits of Magellan occurred gradually, contemporarily with the withdrawal stages of the different glaciations. The Atlantic entrance was set up just after the first Pleistocene glaciation, whereas communication between the Atlantic and Pacific oceans occurred after the last glaciation. Indeed, the predominance of the last glaciation on the central area of the Straits of Magellan (Fig. 3) is clear and acknowledged in recent studies (Rabassa et al., 1986; Clapperton, 1992; Clapperton et al. 1995). In the quite inner area of Puerto del Hambre, south of Punta Arenas, Porter et al. (1984) calculated, that the deglaciation period dated back to 15.880 years, whereas on the Chilean coast of the Beagle Channel they recognized that the withdrawal of the glaciers had already occurred around 12 730 years B.P.

Prieto (1988a, 1988b), in agreement with Caldenius (1932) and Marangunic (1974), assigns to the last glaciation the glacial and glaciofluvial deposits capped by marine terraces below ten metres above msl in the area of Punta Arenas–Cabo Negro. Besides, at Cabo Negro, the first author observes a first glacial phase with partial meltwater related to a pause, and a second phase of further advance with glaciotectonisation of the first phase deposits. A similar aspect, characterised by two cold phases of the last glaciation, had already been noticed by Rabassa et al. (1992) within the Argentine Tierra del Fuego, and by Clapperton (1990) in the southern hemisphere in general.

Clapperton et al. (1995), revise and refine previous hypothesi for the last glaciation in the central part of the Magellan Straits (Fig. 3), highlighting a more complex sequence of glacial events than originally identified distinguishing five glacier advances.

Eastwards, there is an upper chronological boundary related to the creation of the Straits, which could be the age of Punta Dungeness. This cuspate foreland was formed, according to

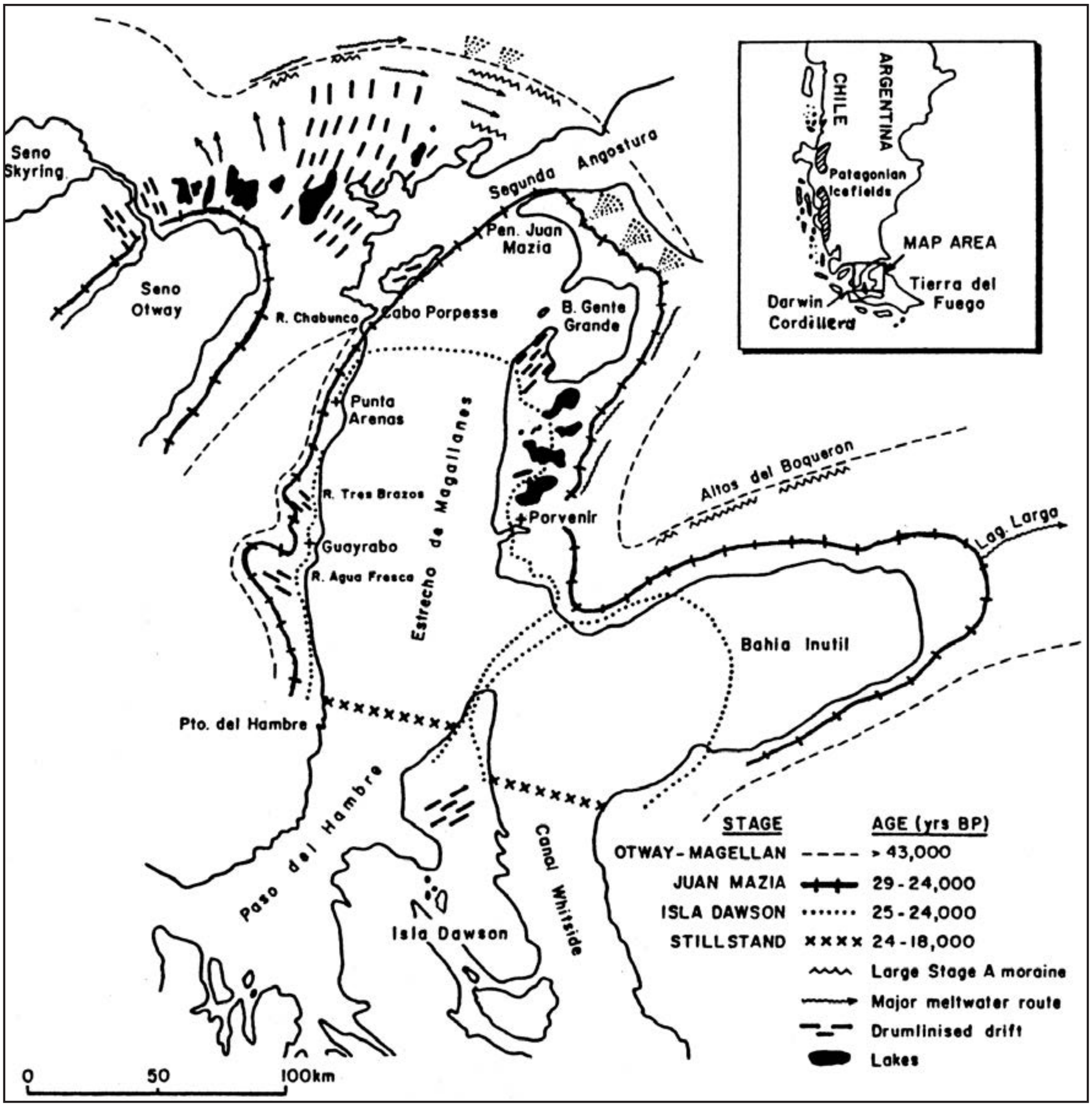

Fig. 3 - Expansion fronts of the Magellanic Glaciers during the late phase of last glaciation, after an original diagram in Clapperton (1992).

Uribe and Zamora (1981), at most 4200 years B.P. The latter, therefore, must have already had an oceanographic setting similar to the present one (cuspate foreland). The presence of a second–order marine terrace on the adjacent Península northwards, where bars, cliff, scarp and beach ridges (Fig. 23 and enclosed maps) are perfectly preserved, suggests that even in the past, its geo–morpho–sedimentological role was similar to the present. The same consideration is probably true for the area of Punta Catalina.

The present configuration of the Straits of Magellan was reached gradually. It was produced by the interconnection of a series of deep bays along the Atlantic and Pacific coasts, prevalently located on residual erosive and/or glacial depositional morphologies. Canal Beagle was probably flooded by the sea at several stages; originally at 9400 years B.P., its eastern stretch was a glacial lake flooded by the sea 8200 years B.P. and fully occupied just 300 years later, although the direction (eastwards or westwards) is not yet known (Rabassa et al., 1986).

Shackleton (1987), believed that when the global sea level fell below 40 m during the interval ca. 70 000-11 000 years ago, seawater from the Atlantic was excluded from the Magellan Straits. Since Pacific seawater (Clapperton et al., 1995) could not enter the Magellan Straits when glaciers advanced into its southern end, marine incursions from the south were only possible when ice withdrew into fjords when the land was isostatically depressed.

4. Outline of Holocene mainly marine terraces

With the exception of some localities where the Mesozoic–Tertiary basement outcrops (Punta Arenas, Seno Otway, Bahía Inutíl, etc.), the Straits of Magellan area consists mostly of glacial, glaciofluvial and alluvial deposits. The dominant morphologies are characterised by areas of drumlin fields, terminal, medial, lateral, interlobate, recessional and ground moraines, and the association of typical glacial and periglacial landforms with erratics, kettle holes, glacial striations, eskers, etc.

Interfluves are mainly occupied by flat and/or slightly mounded areas, sometimes with bog, lakes, swamps or marshes, locally called "lagunas". Leaving aside mountain areas with valleys and palaeovalleys these flat morphologies mainly occupy elevated areas above 25 to 30 metres a.s.l. These have been referred to in the past as glacial (Halle, 1910; Caldenius, 1932) or marine (Nordenskiold, 1898; Feruglio, 1933) terraces for the investigated area.

Along the coasts of the Straits, huge flat surfaces extend at various altitudes, and are formed by pelite, arenite and rudite deposits (Fig. 4), mostly of marine origin, sometimes evolving landwards into a transitional or continental environment; this occurs especially in areas where the fluvial valleys flow into the Straits. In places, the terraces are represented by clear erosive surfaces, stratigraphically and altimetrically connected to deposits, located either on mainly Quaternary glacial deposits or on Mesozoic–Tertiary bedrock.

These terraces occupy narrow belts which run parallel to the coast; depending on palaeogeographic conditions, they are usually wide in the inlets (Bahía Gente Grande, Bahía Felipe, Bahía Inutíl, Seno Otway, west of Banco Direction, Bahía Santiago, Bahía Gregorio, Ensenada Oazy, Bahía Pecket, Bahía Shoal, Bahía Laredo, etc.) and narrow in marine cliff and scarp areas close to Primera and Segunda Angostura, between Punta Dungeness and Bahía Posesion and between Punta Arenas and Forte Bulness.

For the Patagonic–Magellanic area and in Tierra del Fuego, the bibliography (Feruglio, 1933; Auer, 1956, 1970) is rich with reports of terraced marine deposits below 30 metres of elevation. In the eastern part of the Straits of Magellan, they have been continuously reported since Darwin's times (1846). Their presence has been subsequently noted by (among others) Nordenskjold (1898) at Porvenir (10-15 m a.s.l.), Hagg (1910) south of Punta Arenas (10-15 m

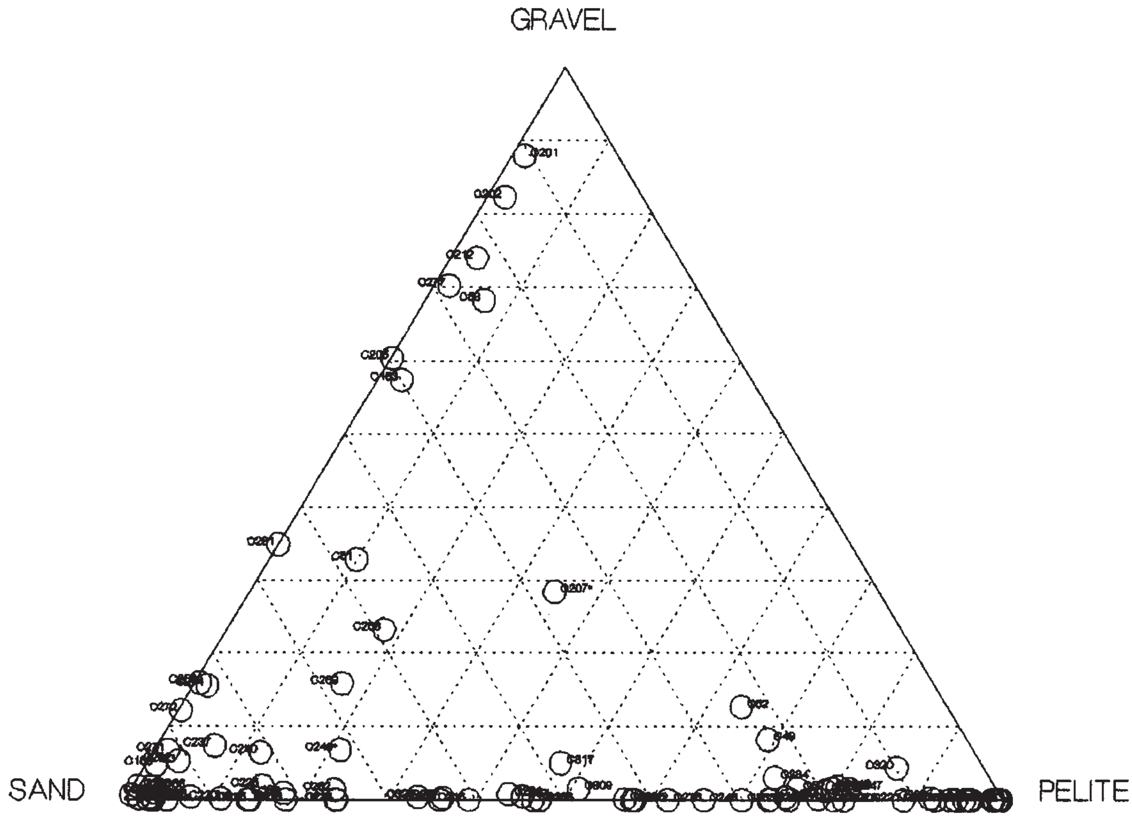

Fig. 4 - Textural distribution of samples collected from deposits of the I, II, III order terraces.

above msl), Caldenius (1932) (4 m a.s.l.) at Rio Pescado, Rio Tres Brazos, Rio Santa Maria, Rio Amarillo and Cecioni (1957) at Cabo Boqueron (30 m a.s.l.).

Just outside the area, both Caldenius (1932) and Feruglio (1933) report the 6 m high terrace which, physiographically, links Seno Otway with Seno Skyring through Canal Fiz Roy.

The above reports are mainly local and poorly documented, or not supported by sufficient cartography to provide a reliable overall regional view. The monographies of Caldenius (1932), Feruglio (1933) and Auer (1956, 1970) are significant. However, in spite of the accurate bibliography and personal observations, they do not reach regional effectiveness due to the lack of cartography technically consistent, with modern requirements, and reliable enough for a regional palaeogeographic verification.

We prefer there for to give wide space in this work to the cartography of marine and transitional terraces, in addition to the detailed lithostratigraphic observations carried out, both on field and in the laboratory. The aim is to verify the lateral continuity of the terrace and, consequently, the reliability of the reconstructed palaeogeographical evolution. Palaeogeographical deductions based solely on the altimetric placement of terraces would probably be unreliable, unless their planimetric connection is certain and can be verified along all extended stretches of coastline.

In this work, which is aimed at a palaeogeographic reconstruction of the coastlines of the Straits of Magellan, only Holocene marine and transitional palaeosurfaces (or so presumed) have been taken into consideration. They can be attributed to a first order (more ancient) from 18-25 m a.s.l., a second (intermediate) order, from 6-11 m a.s.l. and a third (more recent) order from 3-5 m a.s.l. Locally, there are small outcrops of marine terraces which are not shown on the already published and attached maps, due to scale problems, and which can be attributed to a fourth order from 1-2 m a.s.l.

A similar marine sequence, dating back to the Holocene, had already been observed by Feruglio (1932) in Patagonia at heights between 15-30 m, 8-12 m and 5-6 m a.s.l. respectively, whereas at Isla Gable the three orders are at 18, 10 and 5 m a.s.l.

The comparison of the above mentioned terraces with the sequence of marine terraces from 1.5-10 m of Beagle Channel–Tierra del Fuego (Gordillo et al., 1992; Rabassa et al., 1992; Gordillo, 1993) seems accurate, with the exception of the older terraces dated over 7000 years B.P.

Porter et al. (1984) report the presence, on–site, of Holocene marine terraces at Puerto del Hambre, Bahía S. Gregorio and Bahía Gente Grande.

Clapperton et al. (1995) point out the presence of marine shorelines (6 - 7 m a.s.l.) south of Punta Arenas, at Isla Dawson and at the Peninsula Juan Mazia.

Both continental and marine conditions are shown in these terraces following an evolutive sequence. The palaeolandforms comprise erosion benches backed by relict cliffs and conspicuous shingle deposits commonly containing fossil shells, probably formed during the middle Holocene marine transgression.

Considering the facies and the faunal content, this mixing of transition from a continental to marine environment seems to be recurrent in all terraced orders, with clear indication of an intertidal environment, especially in palaeogeographical inlets.

The altimetric figures given in this work are taken from official Chilean cartography (I.G.M.C.), and confirmed by topographic control surveys carried out in test areas (Seno Otway, Laguna Cabeza de Mar, Punta Zegers, Caleta Clarencia, Bahía Felipe). Apart from the areas checked, we can not exclude that the marine and transitional terraces themselves may have an altimetric disposition differing by even several metres from the stated range.

At places, limited intermediate terraced surfaces are inserted in the sequence, and disappear laterally in the field. They are very often detremined to sedimentary structures of a coastal environment such as bars (midbay bar, cuspate bar etc.), beach ridges, storm berms, etc. (see Figs. 23-25).

It should be noted that, in general, any lateral altimetric inconsistency of several metres in terraces may be linked not only to glacio–isostatic or tectonic factors but also to the shape and exposure of palaeobasins, to soil thickness and/or to the fraction of terraced deposits now eroded.

The geological and geomorphological features of the specified units are described below, starting from the oldest terrace (first order). The three orders appear almost always in a rigid morphostratigraphic sequence.

Disregardind macrostratigraphic lithology, the stratigraphic order of the sediments and micro

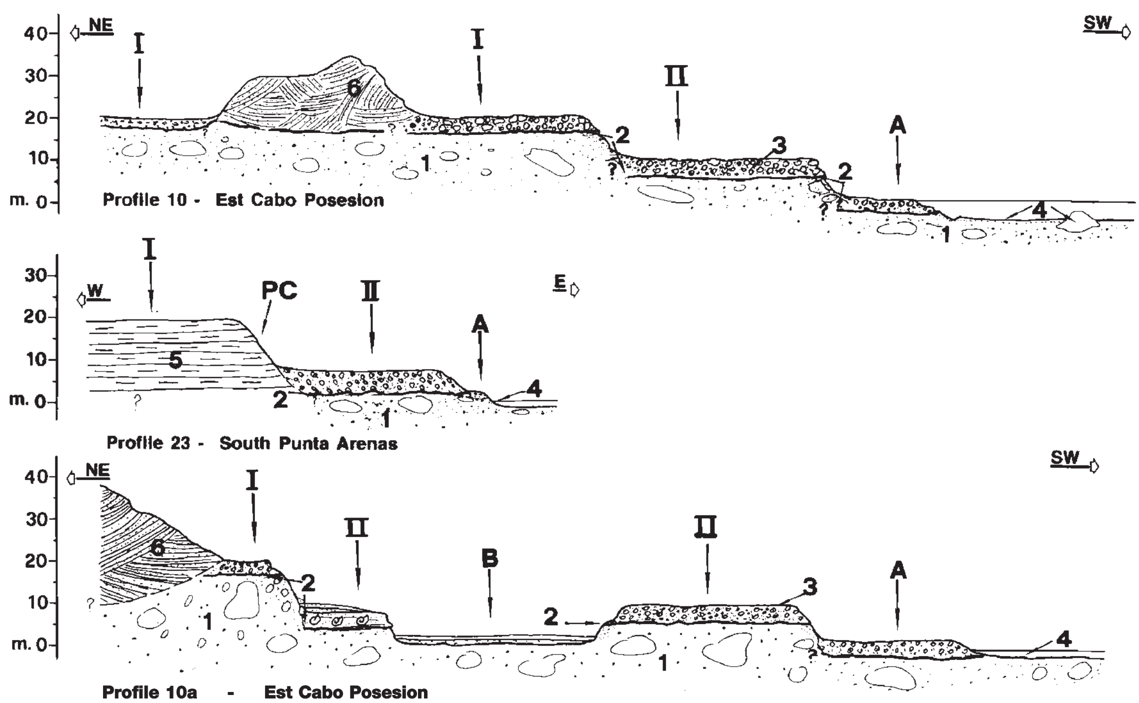

Fig. 5 - Schematic profiles of the various orders of terraces in the neighbourhood of Cabo Posesion (Patagonia) and Rio Agua Fresca (South Punta Arenas – Patagonia), which are identified in Fig. 6 by numbers 10, 10a and 23. A: modern beach; I: First–order terrace; II: Second–order terrace; B: Backshore; PC: palaeocliff; 1) Glacial deposit; 2) Erosion surface; 3) Deposit of palaeobeach pebbles, sometimes fossiliferous. 4) Tidal flat (gravels, sands, pelites) sometimes with erratics; 5) Pelites; 6) Aeolian deposits characterised by cross bedding.

and macro-faunal contents of all three orders of terraces have to be considered, since they are always disposed with a regular geometry, conforming exclusively to the present coastline. All the elements, as previously stated, suggest the hypothesis of a mainly intertidal environment.

It cannot be excluded, especially for the first–order terrace, that further detailed analysis of the sediments (still in progress) may indicate moments of higher transitional, lacustrine and/or continental affinity, depending on local or temporary palaeogeographic conditions, as observed elsewhere in Tierra del Fuego (Rabassa et al., 1986).

5. First Order Terrace (18-25 m a.s.l.)

The first order terrace is formed over an altimetric range extends between 18 and 25 m a.s.l. It is typically found at around 20 m and is characterised by a variety of narrow benches running roughly parallel to the coast. Single outcrops often show a marked geomorphological identity; sometimes, especially within the terminal part landwards, this first order terrace disappears gradually, either in outwash plains (sandur) or in transitional erosive surfaces on moraines. The pro-

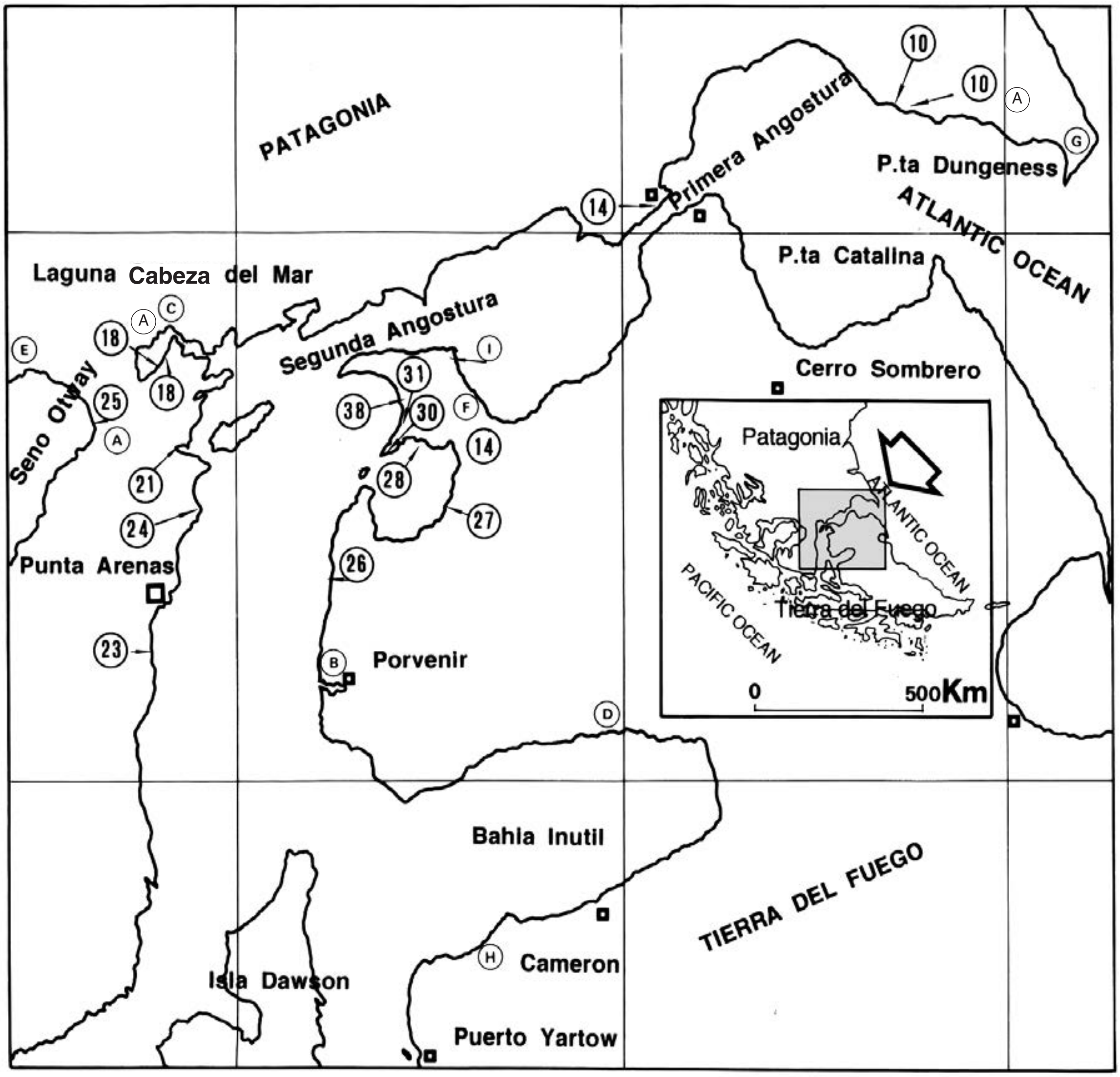

Fig. 6 - Geographic location of stratigraphic sections, geomorphologic processes and photos taken during the 1991 and 1994 campaigns. Their profiles and sections are marked with numbers; the photos are marked with letters.

cess can be observed on the attached maps (A, B, C), especially by comparing the present morphology with the first–order margins within mapped braided areas. These braided areas, which are certainly older than first order terrace, were presumably bound in their origins to this first order and connected spatially and altrimetrically to it as the base of ancient proglacial outwash plains. Marine transgression would have sometimes affected these plains, subsequently going through lacustrine and transitional stages after the last glaciation. The landward margin of this morphological unit is sometimes characterised by palaeocliffs and paloeoscarp. Its seaward boundary is always marked by a convex nick point in the upper section belonging to the first

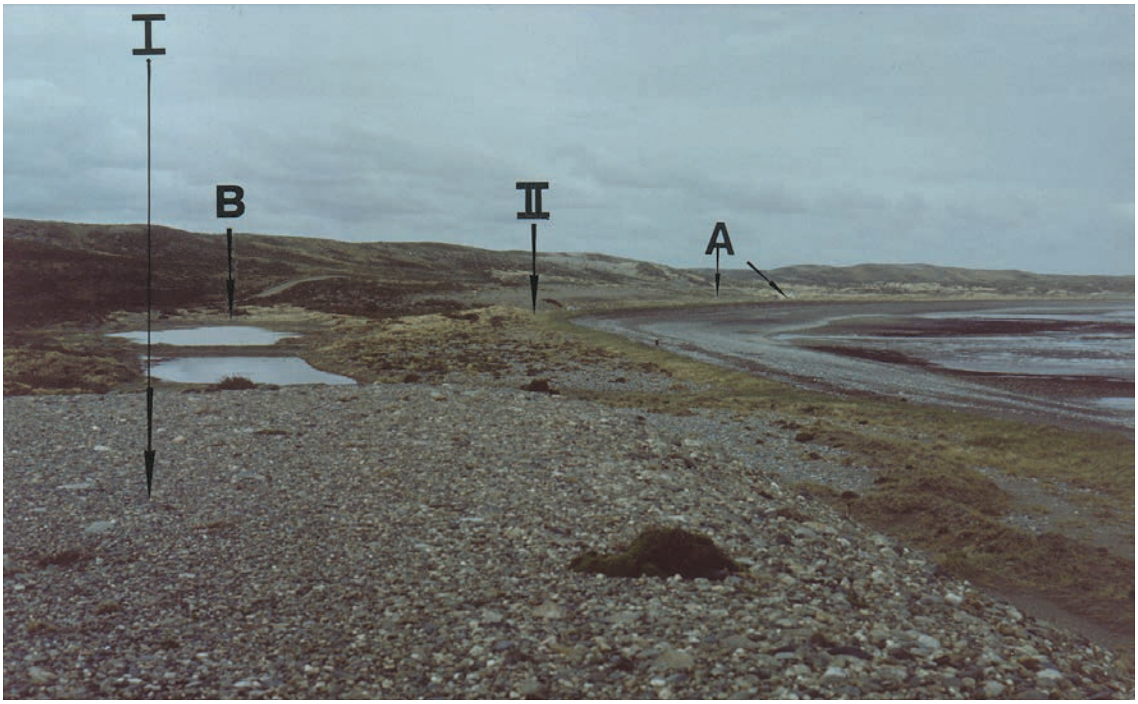

Fig. 7 - East Cabo Posesion (Patagonia) – 10 and 10a profiles. A: Modern beach, bar and tidal flat (low); B: palaeo-backshore basin located on the second–order terrace (II); I: Surface with beach pebbles of first–order terrace; II: Second–order terrace.

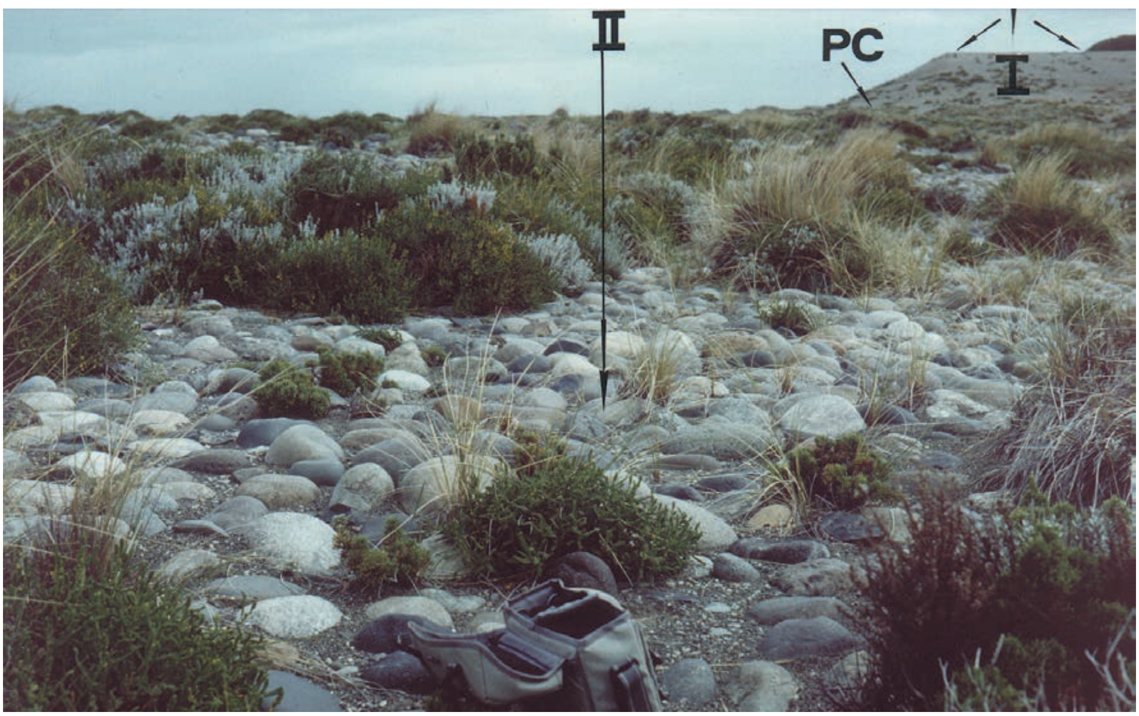

Fig. 8 - East Cabo Posesion (Patagonia). In the background, first–order terrace profile (I); second–order palaeocliff (PC); II: palaeobeach belonging to the second–order terrace.

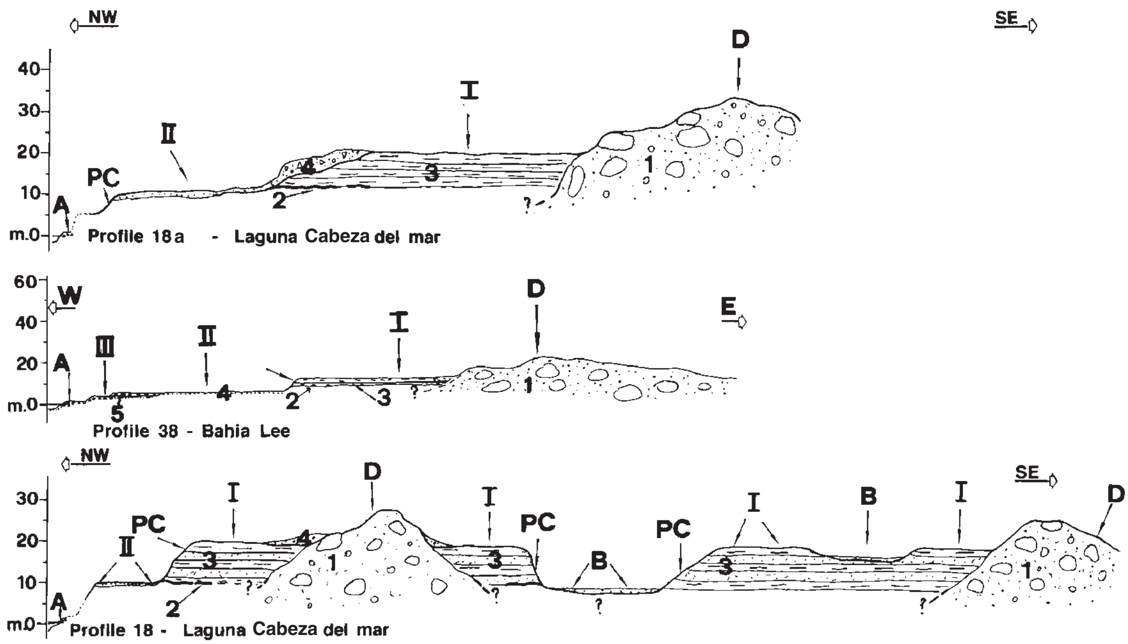

Fig. 9 - Schematic profiles in the vicinity of Laguna Cabeza del Mar (Patagonia) and Bahía Lee (Tierra del Fuego), identified in Fig.6 by numbers 18, 18a and 38. A: modern beach; I: First–order terrace; II: Second–order terrace, III: Third–order terrace; B: Lakes; D: Drumlins; PC: palaeoscarp; 1) glacial drift; 2) erosion surface; 3) pelites with different laminations, sometimes bioturbated; 4) colluvial deposits and/or soils; 5) gravels and palaeobeach sands.

order, and concave in the lower area which belongs to the second order.

The numerous references to local marine terraces mainly concern younger units. Comments on the present order can be found in Caldenius (1932), Feruglio (1933), Auer (1970), Clapperton (1990) and Clapperton et al. (1995). In the Falkland Islands, marine terraces have been noted for a long time; they are located 20 m a.s.l. or even much higher (Clapperton and Roberts, 1987).

Porvenir terrace, cited by Nordenskiord (1898) and Auer (1970), is probably of this order, as well as the one near Punta Arenas, considered to be marine by Prieto (1988b).

This morphological unit, which sometimes contains intermediate stages, is represented either by deposits or simple abrasion surfaces. In some occasions, it lies over ancient alluvial fans, now suspended, and connected to a different base level. The deposits, when present, are made up of poorly cemented gravels, sands, marls, clays and silt.

In profiles 10 and 10a in Figs. 5 to 8, relative to the surroundings of Cabo Posesion, and in profile 23 (South of Punta Arenas–Patagonia), the two orders of terraces are easily seen (I and II), and are separated by a marked palaeocliff (see Fig. 6 for the location of the profiles). The first–order terrace shows a distinct palaeocliff formed at the expense of the glacial drift in the area; the second–order terrace partially erodes the first and sets its palaeocliff upon it.

In Figs. 9 to 20 (profiles 18, 18a, 38, and sections 18, 21, 24, 27), some aspects of the first–order terrace are shown for the areas of Laguna Cabeza del Mar, Bahía Laredo, Rio Pescado, Seno Otway, Bahía Gente Grande and Bahía Lee.

The basement consists almost invariably of glacial deposits, as shown in Fig. 15 at Rio Verde

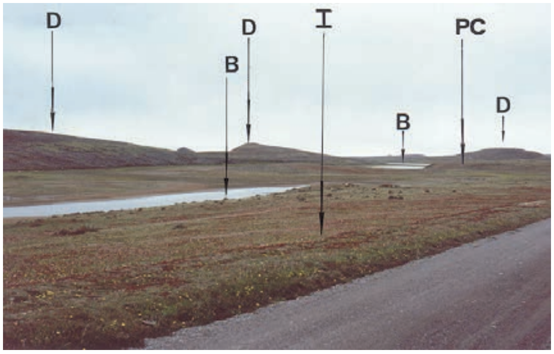

Fig. 10 - From Laguna Cabeza del Mar towards Brazo Recto (Patagonia) – Profile 18 and 18a. The situation outlined in profiles 18 and 18a is partly noticeable. B: Lakes; D: Drumlins; PC: palaeoscarp; I: First–order terrace.

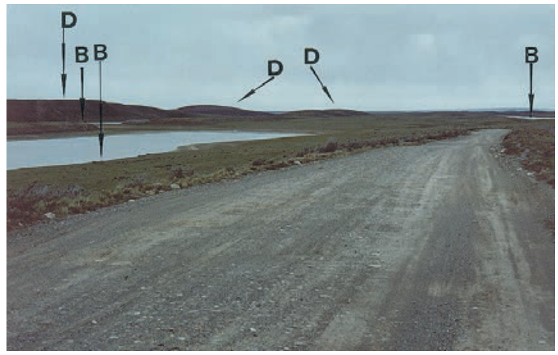

Fig. 11 - General view and other features of Fig. 10 – Profiles 18 and 18a. In the background, the Straits of Magellan to the north of Isla Isabel. D: Drumlins; B: inter drumlin lakes.

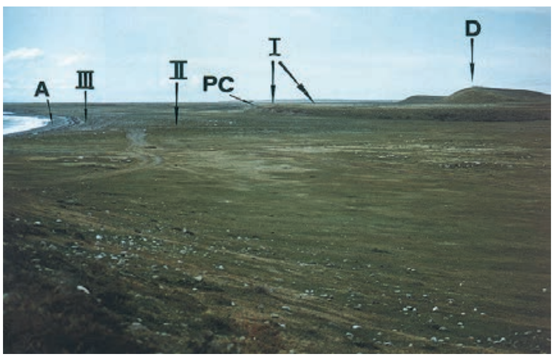

Fig. 12 - From Porto Percy towards Punta S. Vincente (Bahía Lee – Tierra del Fuego) – Profile 38. General view of the sequence of terraces. A: modern beach; D: Drumlins; I: First–order terrace; II: Second–order terrace; III: Third–order terrace; PC: palaeoscarp.

Fig. 13 - Seno Otway (Patagonia). General view on the second–order terrace (II) and related palaeocliff (PC) inserted in the first–order terrace (I). In the vicinity of the present beach is the third–order terrace (III). Area marked in Fig. 6 with the letter A.

(Tierra del Fuego). The erosion surface on the glacial drift, shows a strong truncation, above which firstly gravels and sands and subsequently transitional marly sands (Fig. 14, section 27), pelites and peats are deposited in stratigraphical progression.

Collected data on this terrace, in spite of its certain disposition along the edges of the Straits, and therefore its older age, do not clarify the palaeogeographical setting of the first stage of its formation. It cannot be excluded that the beginning of withdrawal of the last expanding glacial fronts could have caused palaeogeographical conditions in which this geomorphological unit was the local expression of lacustrine and/or glaciofluvial conditions as well as marine and transitional.

If this palaeogeographic hypothesis is applied to the initial phase of the last deglaciation, at least as far as the base levels of this terrace are concerned, its age is considered to be slightly less than 14 700 years B.P., in accordance with Rabassa et al. (1992).

Nevertheless, it should not be overloded that in Rio Verde (Tierra del Fuego) the top levels

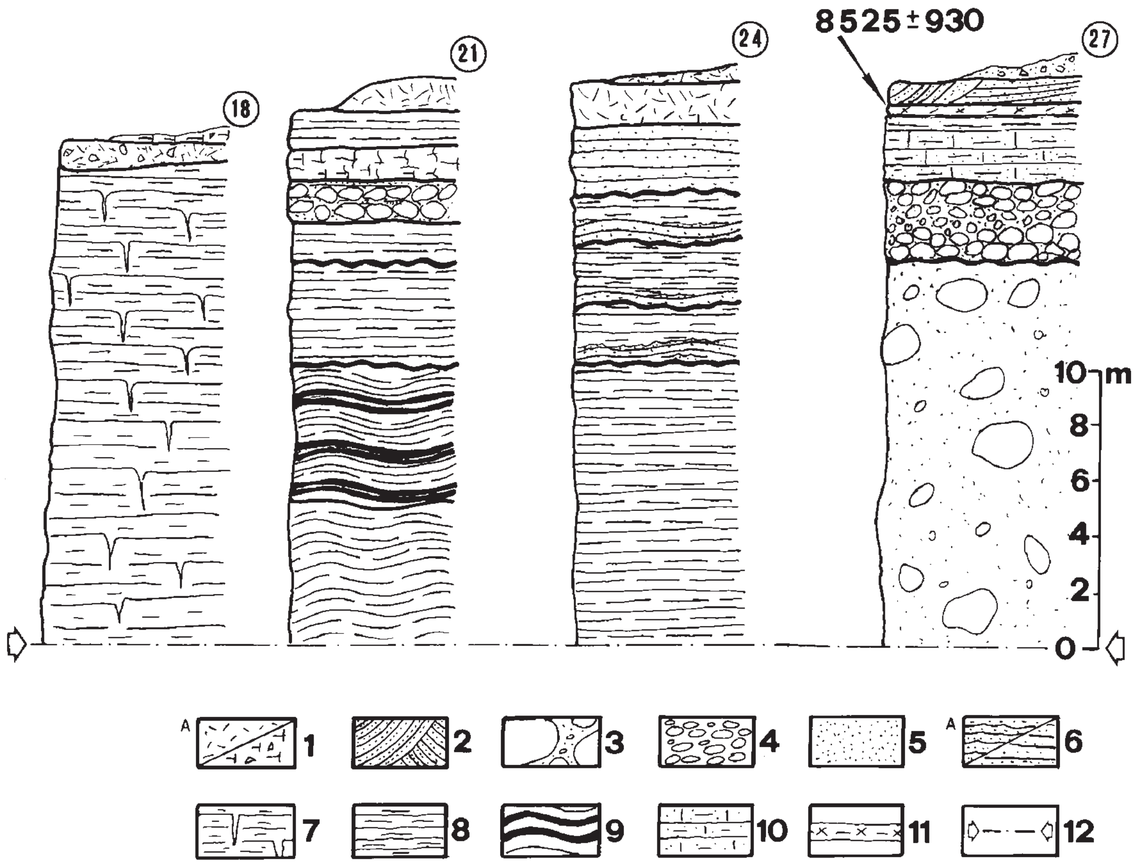

Fig. 14 - Schematic stratigraphic sections in the sediments of the first–order terrace cliffs. Section 18 (Laguna Cabeza del Mar – Patagonia), section 21 near the mouth of Rio Pescado – Patagonia), section 24 (South Bahía Laredo – Patagonia). The sample corresponding to the arrows in section 27 (Rio Verde – Tierra del Fuego) has a 14C radiometric age (uncorected) of 8525+930 years B.P. (see also Fig. 15). 1) colluvial and talus deposits (A), soils and palaeosoils; 2) aeolian deposits, 3) glacial deposits; 4) gravels with rounded, poligenetic pebbles; 5) sands; 6) ripple sands (A), laminated sands; 7) bioturbations; 8) pelites and pelitic sands disposed in parallel and ripple lamination; 9) varves; 10) sandy marls; 11) peats; 12) modern msl.

of this terrace date it back to 8525 years B.P., and the few metres of deposit (Fig. 14, section 27) express a local shoaling upward evolution from high–energy shore to mud flat, and then backshore. Hypothesizing a thousand years (without excluding as little as a hundred years) for that evolution, it is valid to propose for Rio Verde terrace an age ranging from 8000 to 9000 years B.P.

On the whole, considering the quoted references, this terrace can be back mostly dated to the lower Holocene, without excluding that its base may fall within the uppermost Pleistocene.

The outcrops of this order sometimes have a different disposition to the present coastline, thus showing a probable passageway for the related marine ingression, differing from the present configuration of the Straits of Magellan. These conditions occur north–east of Bahía Santiago, north of Segunda Agostura, west of Bahía Pecket which is connected, through the area of Seno

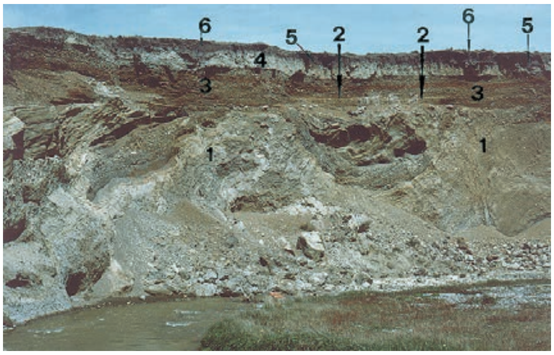

Fig. 15 - Rio Verde (Tierra del Fuego) – Section 27. Sediments belonging to first–order terraces discordantly superimposed on tectonized glacial deposits. Starting from the bottom, an environment from continental to transitional.; 1) glacial deposits; 2) erosional truncation; 3) gravels and sands; 4) marly arenaceous transitional deposit; 5) peats (radiocarbon age uncorected); 6) aeolian cover slightly pedogenisized.

Fig. 16 - From Porvenir towards Punta Gente. (II): Second–order terrace (on the left); PC: palaeocliff created upon the first–order terrace (on the right). I: First–order terrace. Area marked in Fig. 6 with the letter B.

Fig. 17 - General view of the first–order terrace to the north of Laguna Cabeza del Mar (Patagonia). At the bottom of the figure, in the background the II order terrace is also visible. It is marked in Fig. 6 with the letter C.

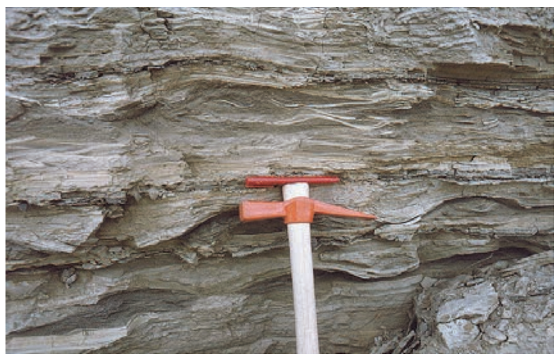

Fig. 18 - Detail of the lithotypes which characterize the first–order terrace in the former figure (17). Area marked in Fig. 6 with the letter C.

Tortuoso, with the Laguna Cabeza del Mar area, located to the south of Bahía Felipe, and Caletta Clarencia, between the western edge of Bahía Felipe and Bahía Lee.

To the south of Bahía Gente Grande, an alternative hypothesis involves an old passageway of the Straits through the areas of Laguna Deseada, Lago Serrano, Laguna Verde and Lago de los Cisnes up to north of Porvenir.

All this altimetric, morphologic, stratigraphic and geometric evidence is clear at Bahía Inutíl, where the disposition of this terrace is very regular. Landwards, there is an extensive connection between the ancient alluvial fans and this terrace. In the north–eastern sector of Bahía Inutíl (around Puerto Nuevo–Tierra del Fuego) this terrace cuts through the underlying moraine belt and drumlin field. Analogous geometric regularity is observed at Bahía Porvenir. Sometimes fluvial denudation begins to destroy the terrace, and it may also undergo partial burial under allu-

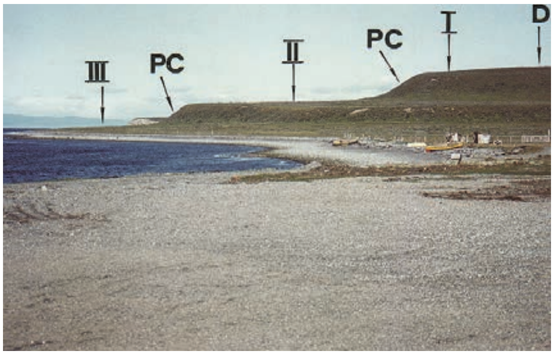

Fig. 19 - Bahía Inutíl (Tierra del Fuego) near Puerto Nuevo. General view of first (I), second (II) and third–order (III) terraces, of the related palaeocliffs (PC) and of the contact with glacial morphologies (D). Area marked in figure 6 with the letter D.

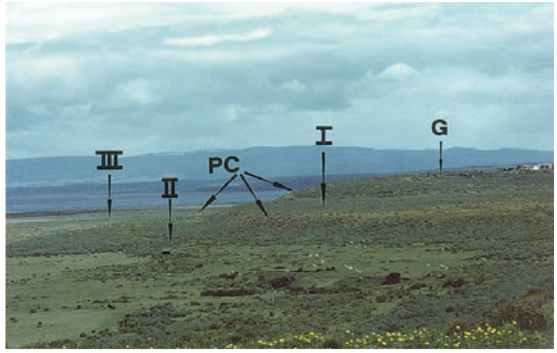

Fig. 20 - Seno Otway (Patagonia). General view of the three orders of terraces. G: Glacial deposits; PC: palaeo-cliffs; I:First order; II: Second order; III: Third order. Area marked in Fig. 6 with the letter E.

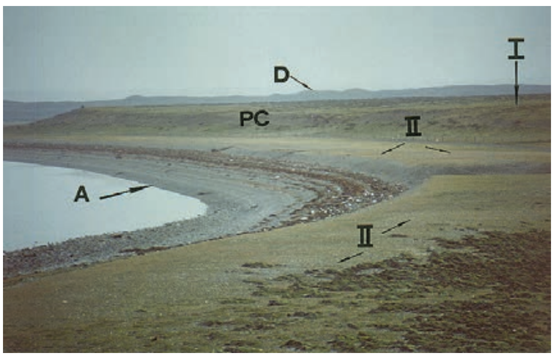

Fig. 21 - Bahía Gente Grande. Modern beach (A) and cliff placed on the second–order terrace (II), whose palaeocliff (PC) is visible eroded to the first–order terrace (I). In the background, glacial morphology (D). Area located in Fig. 6, section 38.

Fig. 22 - Palaeoberm (A) on the second–order terrace (II) to the south–east of Punta S. Isidro (Bahía Felipe – Tierra del Fuego). Area marked in Fig. 6 with the letter F.

vial fan deposits.

In accordance with Clapperton et al. (1995), we believe that the palaeoshorelines were formed at the margin of proglacial lakes and originally were lacustrine-transitional and they became marine when moraine barrier was breached by the following deglaciation.

6. Second order terrace (6-11 m a.s.l.)

This ranges from 6 to 11 m a.s.l., it is prevalently distribuited around 10m. It is the most important palaeogeographic element in the present study, since, unlike the previous order, it shows a surprising regularity and continuity throughout the Magellanic coastal stretch.

Its outcrops lie along depositional surfaces. Its distinct morphological clarity is exceptional and allows to observe, often in their entirety, the relative marine palaeoforms (Figs. 21 to 25) of

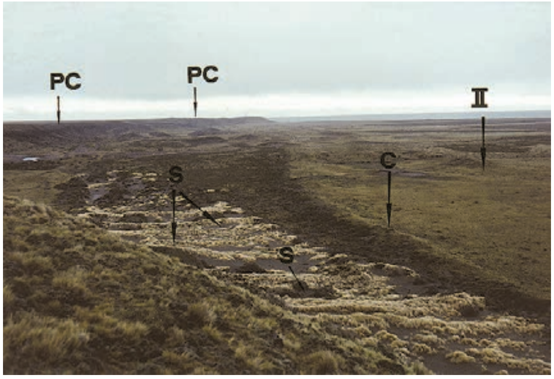

Fig. 23 - Punta Dungeness. palaeocliff (PC) of second–order terrace (II) and palaeobar (C) with aeolian coverings and sand–wave interdune (S). Area marked in Fig. 6 with the letter G.

Fig. 24 - Second–order terrace to the south of Bahía Inutíl (Tierra del Fuego) and shingle ridges (B) on pebbly palaeobeach. Area marked in Fig. 6 with the letter H.

Fig. 25 - Beach ridges on Punta S. Isidro cuspate foreland, within Península Juan Mazía (Tierra del Fuego). Area which can be located in Fig. 6 with the letter I.

coastal and transitional environment, like scarps, cliffs, abrasion platforms, berms, bars, troughs, tidal flats, spits, salt–marshes, swales and beach ridges.

Following the same trend as the most ancient terrace, the terrace becomes more evident within inlets, and its location strengthens the hypothesis discussed in the previous section according to which the nearby Straits of Magellan an outline different from the present one was active. In fact, between the northern part of Primera Angostura and Punta Tandy, this terrace marks with regularity an arm of the sea which probably, westwards, goes around the moraine front to the west of Punta Satellite and reconnects with the Straits of Magellan at Bahía Santiago.

Likewise, to the west of Bahía Gregorio, it again defines a palaeogeographic condition by a branch of the sea which penetrates westwards, whose inland disposition is not fully defined yet. At Bahía Pecket, the second order terrace provides evidence of an arm of the Straits, which in the past, used to connect this area with Laguna Cabeza del Mar through Laguna Baja as already noted for the most ancient order. This bay may in fact to represent a residual stretch of sea entrapped by the terrace before the uplift.

Between Punta Catalina and Cabo Orange, at Bahía Lomas, this terrace shows a slow progressive uplift that exhibits some analogies between the relative palaeocliff and the modern coast. Currently isolated marine areas are also present in this area. The slow uplift is proved by the superimposition and regular adjustment of the hydrographic network from the most ancient to this terrace order (Fig. 21). Also the tract south of Punta Bahía demonstrates a slow and regular uplift with raised shorelines parallel to the present ones.

At Bahía Inutíl this terrace had a larger inlet depth in the past which probably extended several km eastwards. Arms of the sea isolated at the time of this terrace uplift are present at Bahía Laredo and south of Porvenir, in addition to those mentioned before.

This terrace is quite frequently mentioned in scientific reports. Hagg (1910) points to its presence to the south of Punta Arenas, between Punta Carrera and Puerto Femina. Some deposits, related to this terrace are dated back to 5400 years B.P. at Bahía Golondrina and are considered of recent age at Isla Gable, where they lie on moraine of 9380 years B.P. (Urien, 1966).

Sometimes this terrace reveals intermediate raised shorelines, as a prove of local and temporary stand of the sea presumably connected with isostatic rebounds. Meaningful examples, are those of Punta Gente, south of Cerro Direction, the south–western point of Península Juan Mazia, south of La Fortuna, north–west of Silvana Maria, north of Banco Direction and west of Laguna Deseada.

From the lithological point of view, the deposits are similar as those of the older terrace, with the exception of a greater diffusion of rudites and fossiliferous levels.

Fig. 26 illustrates some of the most important stratigraphical sections for the localities to the south of Punta Delgada (section 14) and Puerto Percy (section 28). Figs. 27 to 30 show other features of this terrace to the north of Punta Zegers (section 31) and south of Punta Gente (section 26).

Samples from the marine deposits of the cited above areas, gives ages of 6501 (+65), 6190 (+65), 7174 (+60) and 6750 (+65) years B.P. For the same areas a slightly older period has to be considered for the oldest terrace, since the samples examined come from the medium–high part of the section.

7. Third order terrace (3-5 m a.s.l.)

Unlike the previous terraces orders and despite being clearly present in the whole area, the third order terrace occupies a rather narrow belt, which runs strictly parallel to the present coast. It evidently corresponds to a brief depositional phase and for the Straits of Magellan, shows a configuration, almost identical to the present one.

South of Caleta Municiones, up to Primera Angostura, south–west of Cabo d'Orange, near Punta Tandy, at Seno Otway, at Bahía Inutíl near Laguna Emma and Rio Pantanos, analogous to the previous morphological units, the uplifting of this terrace has produced the isolation of salt marshes and bars.

The marine deposits of Puerto del Hambre, Bahía S. Gregorio and Bahía Gente Grande, analyzed by Porter et al. (1984), and the outcrops of Rio Chabunco, observed by Prieto (1988b),

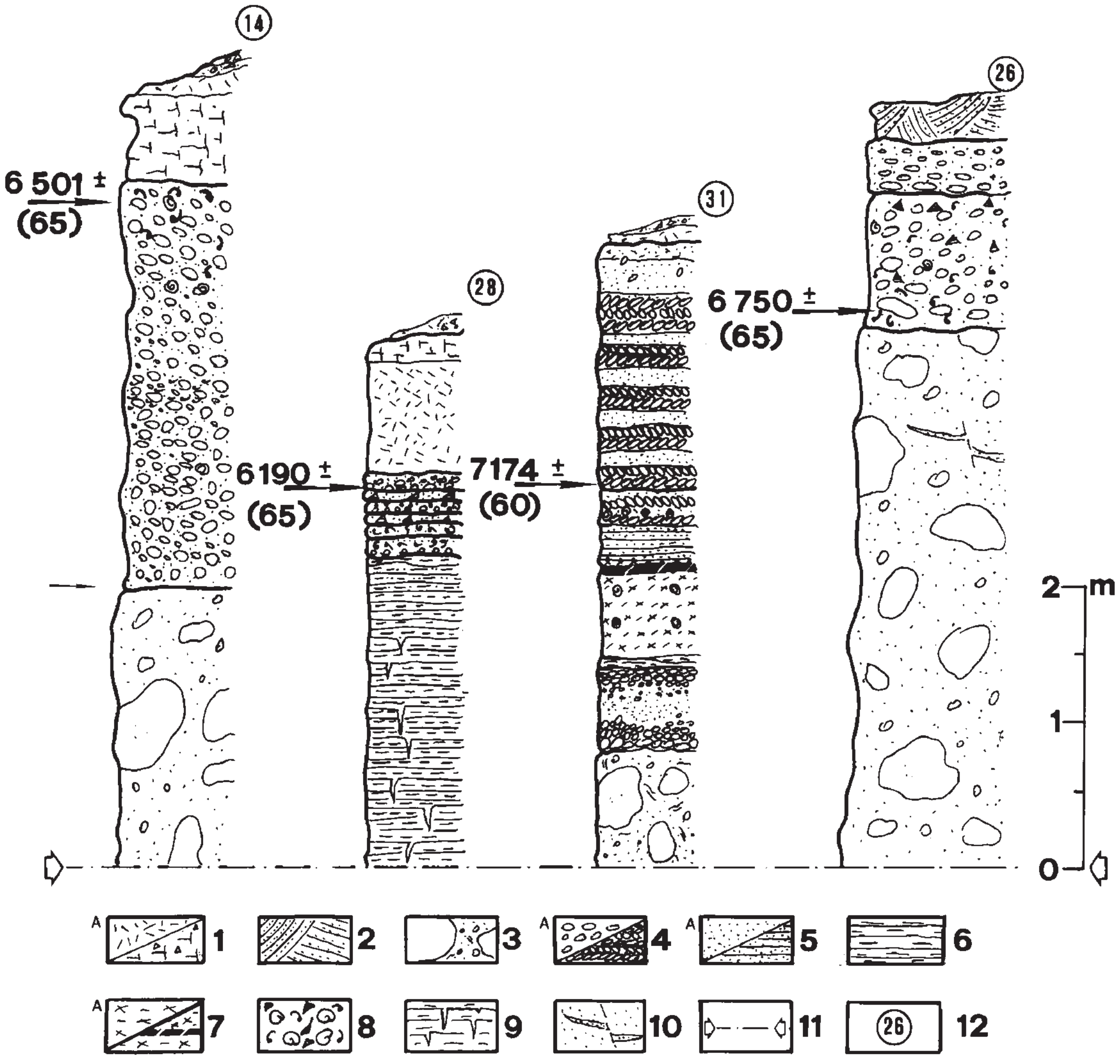

Fig. 26 - The most significative stratigraphic sections relative to deposits of second–order terraces in Patagonia and Tierra del Fuego. The arrows indicate the location of samples dated with ^{14}C (radiocarbon ages uncorected). All the samples date back to the Holocene. South of Punta Delgada (section 14), Puerto Percy (section 28), north of Punta Zegers (section 31) and south of Punta Gente (section 26); 1) colluvial and talus deposits (A), soils/palaeosoils; 2) aeolian deposits; 3) glacial deposits sometimes with vegetable frustules; 4) gravels (A), imbricated gravels; 5) sands (A), laminated sands; 6) pelites; 7) peats (A), carbonaceous peats; 8) fossiliferous deposits; 9) bioturbations, vegetable frustules; 10) sedimentary sills; 11) modern msl; 12) number of the stratigraphic section.

may be included in this third order terrace where remains of marine mammals can be faund. Outside the area, this order is characterised by terraces at 3-4 and 5-7 metres a.s.l. (Caldenius, 1910), at Seno Skyring, Seno Otway and along Canal Fitz Roy. Some other terraces at Bahía Lepataia (Rabassa et al., 1986), and in particular the one at Rio Ovando dating back 4425 years B.P., have also been observed.

Fig. 27 - Puerto Percy – Tierra del Fuego – section 28. Second–order terraced deposits (section 28, Fig. 26). One notes a pedogenesized upper range, another, intermedium, is gravelly, sandy and fossiliferous with bivalves and gasteropods and a lower one, with bioturbated pelites.

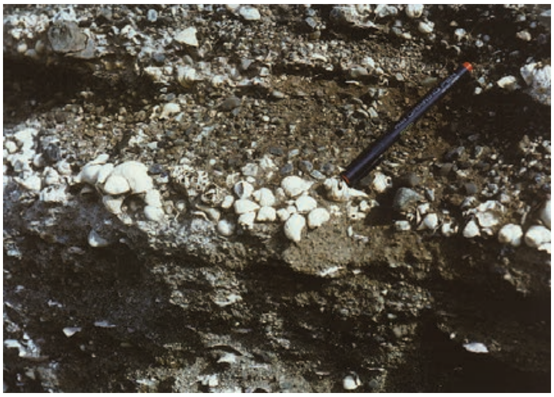

Fig. 28 - Detail of the fossiliferous level in Fig. 27.

Fig. 29 - South of Punta Gente (Tierra del Fuego) – section 26. Modern cliff, located on glacial drift surmounted by second–order terraced deposits. From the bottom to the top A) modern beach; B) marine cliff cut on glacial drift; C) erosion surface (palaeo abrasion platform); D) fossiliferous beach deposit; E) pedogenisized aeolian deposit.

Fig. 30 - The same terrace as in Fig. 29. Note the border of the cliff on the second–order terrace, the flat morphology of the upper part of the terrace and its slight pedogenesis.

Locally, this terrace also shows little evidence of rised shorelines with secondary terracing, as the same type as those found by Rabassa et al. (1986) in the terrace of Estancia Tunel, dating back 4870 years B.P.

From a lithological point of view, it shows a marked prevalence of gravels, although limes, pelites and sands are present, thus demonstrating a certain energetic variability.

All terraces altimetrically attributable to the third order have been dated by Porter et al. (1984) between 7980 and 3970 years B.P. in Puerto del Hambre, at least 3860 B.P. in Bahía S. Gregorio, and 5860-4860 years B.P. in Bahía Gente Grande. The remarkable age differences within this group of outcrops are probably due to the fact that the first dating (Puerto del Hambre)

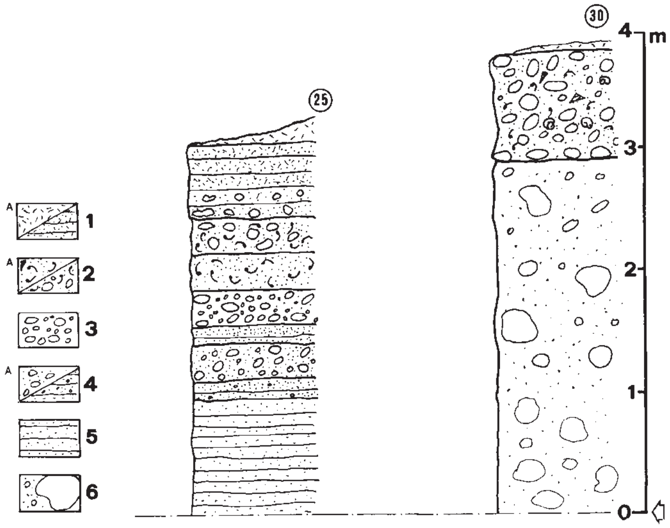

Fig. 31 - Schematic stratigraphical sections 25 and 30 in the third–order terrace deposits, in Seno Otway (Patagonia) and in Punta Zegers (Tierra del Fuego) respectively. 1) soils (A), pedogenesized aeolian sands; 2) sands with fossiliferous levels (A), pebbles with fossiliferous levels; 3) poligenetic well–rounded pebbles; 4) pebbles with sands (A), sands with pebbles; 5) slightly laminated sands; 6) glacial deposits.

was for deeper levels of the terraced sediment. According to those authors, the sea corresponding this terrace reached its highest level between 5000 and 6000 years B.P. Figs. 31 to 35 relative to Punta Zengara (section 30–Tierra del Fuego) and Seno Otway (section 25–Patagonia) illustrate some features of this terrace.

8. Chronostratigraphical aspects

Despite several attempts of analysis of various sections and numerous samples, the micro and macrofossiliferous content of the terraced deposits was found insufficient for the stratigraphical investigation. The reason of this was found in the lack and modernity of the fauna, as noticed by Feruglio (1933) and, recently, by Gordillo (1993). Therefore the content is not useful for the purposes of chronostratigraphy with traditional ^{14}C radiometric ages (unfortunately at the present stage of research, accelerated mass spectrometry measurements are not available due to scarsity of funds). The most consistent fossiliferous levels were found in the youngest terrace (III order) and, lesser, in the second one (II order). In first–order sediments, the fossiliferous content is practically zero according to their prevalently lacustrine and transitional origin.

The macrofauna is highly specialized with a few fragile shelled. The Genera Patinigera, Mytilus, Trophon, Balanus, Adomelodon, Chiane e Mulinia are well represented.

On the contrary, valid relative ages were achieved dating the glacial deposits cut from terraces. In this case, the all three orders are younger than the last glaciation, and belong to the Upper Pleistocene or to the Lower Holocene, according to Marangunic (1974), to Gordillo et al. (1992) and Clapperton et al. (1995).

Fig. 32 - Third–order terrace at Punta Zegers (Tierra del Fuego) – section 30.

Fig. 33 - Detail of the previous figure.

Fig. 34 - General view of the second (II) and third–order (III) terraces in Seno Otway (Patagonia) – section 25.

Fig. 35 - Third–order terraced deposits in Seno Otway (Patagonia).

There are some doubts about the original significance of the first order of terraces originally. It is not clear if it was everywhere a proglacial lake shorelines located upon the moraine front of the last glaciation. It means it was frequently floodeed by marine transgression. In this case, already mentioned, the dating of its basal levels could, be slightly younger than the beginning of the last deglaciation, to 14 700 years B.P. as average (Rabassa et al., 1992) or 16 590 yr B.P. and 14 260 yr B.P. (Clapperton et al., 1995).

The studied terraces could be chronostratigraphilly inserted in a (upper Pleistocene–Holocene) very brief stratigraphical period. Thus, considering these biostratigraphic difficulties, the chronology of the examined terraced marine and transitional deposits, reported in the bibliography, is mainly based on ^{14}C radiometric ages inferred from shell or from ashes and lavaflows. Good results have also been obtained from the calculations of varve and the analysis of pollen. Regarding glacial deposits, Caldenius (1932), by means of the varve method, deduced the moraine chronology, which can be still considered reliable with certain reservations.

Overall, for the purposes of this work, the following observation should be borne in mind (Urien, 1966; Rabassa et al., 1986):

- At Punta Pinguinos, there is a marine terrace at 8 m a.s.l., and dated 8000 years B.P.;

- At Isla Gable, a terrace at 10 m a.s.l., has an age of less than 9380 years B.P.;
- At Bahía Lepataia a terrace, at 6 m dates back to 4425 years, and the one at 8 metres a.s.l. is 4400 years B.P.
- At Estancia Tunel (Ushuaia) a terrace at 4.5 m a.s.l. is, at least, 4870 years B.P.;
- At Bahía Golondrina the terrace at 8.5 m a.s.l. is 5400 years B.P. and is located on glacial till dating back to 7095 years B.P.

Altogether, the marine terraced sequence of the Beagle Channel, at less than 10 m a.s.l. (Gordillo, 1993), is attributed to a post–glacial stage from 6000 to 3000 years B.P., and another terrace at 1.5 m a.s.l. is even younger.

In the central part of the Straits, invaded by the last glaciation, Porter et al. (1984) date the glacial deposits to 15 800 years B.P. The same authors establish, at Puerto del Hambre, for the base and the top of a third–order terrace, ages of 7980 and 3970 years B.P. respectively. They date the top of the marine terraced deposits at Bahía S. Gregorio and Bahía Gente Grande back to 3860 years B.P., and the base from 5860 to 4600 years B.P. They highlight the fact that the sea reached the highest level from 6000 to 5000 years B.P.

By means of tephrachronology, Auer (1970) identifies three groups of tuffs (Tephra, I, II, III) from 10 330 to 2500 years B.P., produced by local eruptive activity.

Stern (1990) clarifies that the tuffs in the Magellanic area could only have been caused by the activity of Mount Burney and the Reclus volcano, and is dubious about the stratigraphical sequence of tuffs proposed by Auer. The chronology and research into these pyroclasts is not dealt with in this work.

Clapperton (1990) and Meglioli et al. (1990) consider dates based on the presence of lava-flows within in tills.

At the present stage of research, the examined data regarding radiometric chronology show, for the three orders of terraces described in this work, a younger age than that reported in the literature.

9. Conclusions

On the basis of this geomorphologic and chronostratigraphic research and by comparison of the results with the data taken from the bibliography, the series of marine and transitional terraces described can be placed prevalently in the lower Holocene and partly in the Upper Pleistocene.

By comparing palaeogeographic data of the last deglaciations in the Magellanic area, which mainly occurred in the upper Pleistocene–lower Holocene, with the disposition of mapped terraces, the following conclusions can be drawn:

1) The communication between the Atlantic and Pacific Oceans through the Straits of Magellan opened after the last glaciation and before 4200 years B.P. (Age of Punta Dungeness), according to Uribe and Zamora (1981). The presence of the three orders of mainly marine terraces only along its borders, and especially in its inlets, justifies this hypothesis. Moreover, considering the absence of the youngest terrace both at Punta Dungeness and at Punta Catalina, the

global age of at least the two oldest orders described in this work can be placed in the same chronological period;

2) Whereas morphology and disposition of the two youngest terraces are clear in field, the same cannot be said for the first–order terrace. It appears rather eroded, sometimes losing wholeness, in the sense that its presence, which is evident when in contact with the second order, often loses consistency along the coast when it is in near contact with the Quaternary glacial or pre-Quaternary basement. There are no doubts about its parallel continuity along the Magellanic coast. Its formation, therefore occurred after the opening of the Straits, at least in the investigated area. It cannot be excluded that originally, it may have lain on a retromoraine and proglacial lacustrine morphology; in this case its age sometimes would be, at least initially, slightly erlier than the beginning of the last deglaciation (14 200 for Clapperton et al., 1995). Nevertheless, the dated sample gives an ages for its high levels of ca. 8525 years B.P., at least as far as the northern area of Tierra del Fuego is concerned. We believe that the first order terraces in origin were formed in lacustrine environment, become transitional and marine when moraine barrier was breached following deglaciation;

3) The existence of three orders of mainly marine terraces after the last deglaciation shows that the postglacial uplift is not bound to a single and continuous positive isostatic and/or eustatic movement. It is due to more complex dynamics with alternating vertical pulsations, where marine or transitional terraces, starting from the first order, correspond to moments of marine ingression connected with the lasting stationary phase. The problem of the regional meaning of these Holocene marine ingressions (connected with both positive eustatic and isostatic movements) and how they can be fit in to the contest of local palaeoclimatic evolution is still open and will be the object of our subsequent reports;

4) The problem of the morphological evolution of the Straits of Magellan is still open. Its present conformation is probably different from the one during the formation of the three orders of terraces. This is inferred from the shift of the old coastlines, as shown by the terraces themselves in the attached cartography. The disposition especially of the first and second–order terraces, suggests a configuration with ramifications and arms of the sea which allowed a link between the Atlantic and Pacific Oceans through passages different than those at present;

5) On the base of the in–field information we do believe that for the various terraces the sedimentation was suddenly interrupted, hence, the uplifts which caused the terracing might be due not only to deglaciation and isostasy, but also to Quaternary tectonics, which were active in the Holocene (Winslow and Prieto, 1991);

6) The sequence of terraces examined is related to the immediately local marine palaeogeographical evolution, starting from the beginning of the last deglaciation. The most ancient order (I), which reaches 18-25 m above msl, is connected to the morphological situation resulting from the first withdrawal of ice after the last glacial period; it can be dated back to 8000-10 000 years B.P.; its base could be even older. The two other orders of terrace depend on subsequent stages of the last deglaciation, without excluding the influence of tectonics on their evolution. The second order (II) reaches 6-11 m above msl; it is represented by deposits and erosive surfaces mostly related to a marine and intertidal environment ranging from 6000-7000 years B.P. The third order (III) outcrops between 3-5 m, and it also belongs to a marine

and intertidal environment, ranging from 4000-5000 years B.P.;

7) Finally, there are other younger terrace orders not mapped in the attached maps, due to scale difficulties; they are dated back to 1200-2500 years B.P., indicating continued uplift during the late Holocene.

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