SEPARATE PRINT

German Geographical Coastal Research

The Last Decade

Edited by
Dieter H. Kelletat

This publication was made possible by generous financial support from the
Deutsche Forschungsgemeinschaft DFG

Institute for
Scientific Co-operation
Tübingen

Committee of the
Federal Republic of Germany for the
International Geographical Union

Content

Kelletat (ed.): GERMAN GEOGRAPHICAL COASTAL RES. · The Last Decade · 1998
Institute for Scientific Co-operation, Tübingen, Federal Republic of Germany
Committee of the Federal Republic of Germany for the International Geographical Union

Coastal Development in Southern South America (Patagonia and Chile) since the Younger Middle Pleistocene – Sea-Level Changes and Neotectonics

by

GERHARD SCHELLMANN (Essen)

Abstract

In the last years a more detailed stratigraphic subdivision of elevated littoral deposits along the Patagonian Atlantic and Pacific coastline was carried out. Supported by stratigraphic field investigations and age determinations on mollusc shells (^{14}C, ESR, Th/U, AAR) these researches demonstrate that beneath several Holocene littoral deposits up to three Last Interglacial and up to three Penultimate Interglacial shorelines are preserved at different elevations. In contrast to the stronger tectonically stressed Chilean Pacific coast (active continental margin), the Patagonian Atlantic coast (passive continental margin) is characterized by a slow uplift trend in the Younger Quaternary. Probably as results of glacio-eustatic sea level fluctuations several marine terraces have been formed during the same interglacial period. Because of lacking accuracy in dating Pleistocene molluscs it is still unclear, whether these shorelines are remnants of regressive phases during interglacial transgression maximum or of more younger substages of Pleistocene sea-level highstands. Even along the more stable Patagonian Atlantic coast recent elevations of marine terraces are no significant parameter for chronostratigraphic correlation, because they are influenced of both – slow neotectonic movements and eustatic sea-level oscillations.

1. Introduction

Since the middle of the last century (DARWIN 1846) the scientifical world is aware of the emerged Quaternary beach deposits in many places along the Argentinean and Chilean coastline. Studies dealing with these marine terraces have been intensified since then, especially in the second half of this century. But even today knowledge about various items, such as age, number, distribution and composition of Quaternary beach deposits is limited and many uncertainties remain.

Due to this, misleading statements on neotectonic movements and palaeo sea-level changes are found frequently. Based on wrong stratigraphic correlations or based on the misinterpretation of the accuracy of – so called – absolute dating methods, these studies present a possible but not necessarily veritable story. For example, astonishingly there is still a strong controversy, whether along the Southern South American coastlines a so-called Mid-Wisconsin high sea-level (around 35.000 BP) exists – a statement which is due to misinterpretation of ^{14}C dates (recently discussed by SCHELLMANN and RADTKE 1997).

Results of previous researchers concerning the Chilean and Argentinean coastline have been summarized e.g. by CLAPPERTON (1993), RADTKE (1989) and PASKOFF (1989). Recent studies dealing with the Quaternary terraces in Northern Chile have been published by LEONARD and WEHMILLER (1992) and ORTLIEB et al. (1996a, 1996b, 1996c). AGUIRRE and WHATLEY (1995) and ISLA et al. (1996) present new investigations from the Pampean region (Northern Argentine), SCHELLMANN (1995, 1996, 1998) reported new results for the Atlantic coast of Patagonia (Argentine).

This paper reveals some essential results of the latest field work and geochronological studies from the Patagonian coastline with certain novelties covering the time-period from Holocene to Middle Pleistocene. These results from the passive continental margin of Patagonia are compared with studies from the active continental margin of the Chilean Pacific coast. Also general aspects and problems of neotectonic movements and sea-level changes in Southern South America during the Middle Pleistocene up to the Holocene are discussed. However, further investigations are necessary for a better insight into tuning and magnitude of eustatic palaeo sea-level changes in the higher latitudes of the Southern Hemisphere during the Quaternary period.

2. Middle and Younger Quaternary marine terraces along the Patagonian coast

Extended, pebbly beach ridge systems are emerged at varying elevations in many places along the macrotidal formed Patagonian coast. Sometimes they

spread out along the recent coastline, sometimes they are kilometres away from it. Recent beach ridges lie only a few metres (ca. 2–3m) above the highest tidewater level, the oldest one can be found up to an elevation of 100 m and more above modern sea level.

The stratigraphical framework in this area, which is valid until today, was established by FERUGLIO (1948, 1950). New chronostratigraphic researches by RADTKE (1989) and RUTTER et al. (1989, 1990) let them conclude that a detailed stratigraphic field investigation is still missing. Only by this way the new geochronological data could be interpreted correctly. Therefore extensive field investigations[1] were carried out by the author between 1992 and 1995, which gave rise to a more detailed stratification of the Middle Pleistocene, Younger Pleistocene and Holocene beach ridge sequences.

The localities investigated are shown in Fig. 1.

2.1 Methods

Based on geomorphological, palaeopedological and sedimentological field investigations, the previous stratigraphy for the Middle and Younger Quaternary marine terraces has been revised (SCHELLMANN 1996). Molluscan shells were dated by Radiocarbon (^{14}C) –, Electron Spin Resonance (ESR) –, $^{230}Thorium/^{234}Uran$ (Th/U) age determination, and for some molluscs Amino Acid Racemisation (AAR) measurements have been done[2].

Crucial for the presented dating results, only molluscan shells from an in situ position were studied. Contrary to most previous studies this approach gives the only security that the data can be used for stratigraphical interpretations. An in situ position of bivalves is proven, when both shells stick together ("paired mollusc shells"). As shown by RADTKE (1989: 90), the dating of single shells in a Holocene beach deposit gave ages up to Last Interglacial. Only dating of paired shells assures that they are not redeposited. The concordant radiocarbon ages of two different paired molluscs from the same sediment layer in Table 1 support this clearly.

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[1] Research was gratefully financially supported by BMFT (03PL504B) and by the Universität/GH Essen.

[2] Many thanks for ^{14}C-dating performed by Dr. B. Kromer (Institut für Umweltphysik, Universität Heidelberg), Th/U-dating by Prof. Dr. A. Mangini and A. Rostami (Umweltphysik, Universität Heidelberg) and some AAR-measurements by PROF. DR. N. RUTTER (University Alberta, Canada).

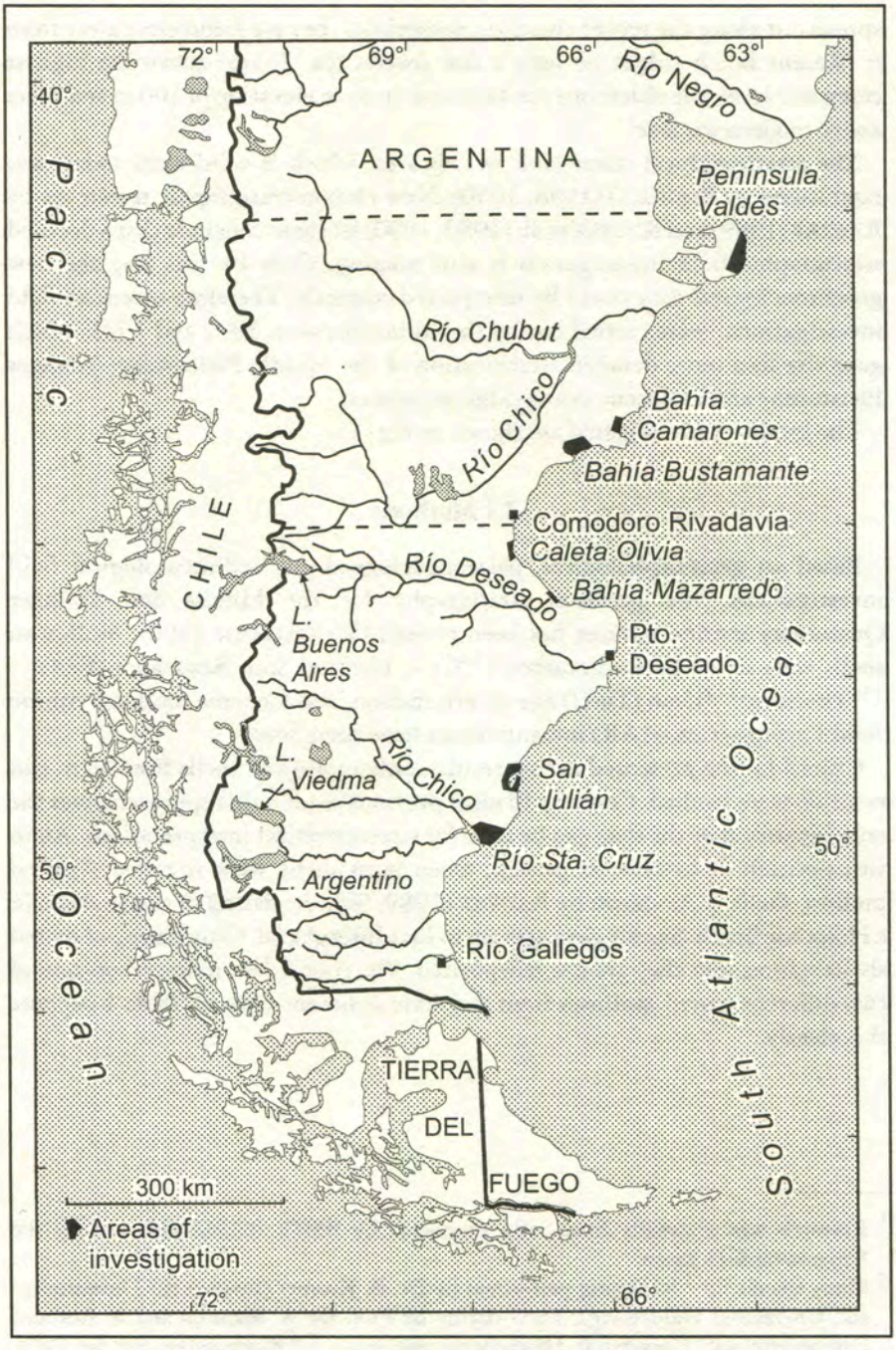

Fig. 1: Area of investigations.

Table 1: ^{14}C ages from Holocene paired mollusc shells collected along the Patagonian coast (Samples with the same field number "Pa ..*" belong to the same sediment layer).

Locality	Pa-Nr.	Stratigraphy	^{14}C age BP (uncorr.)	Hd-Nr. [1]
Camarones	Pa 33*1 Pa 33*4	T1(1) – subtidal deposits	6708 ± 46 6663 ± 59	16502 18214
Bustamante	Pa 57*3 Pa 57*4	H1 – beach ridge deposits	5424 ± 40 5380 ± 70	18213 17683
	Pa 58*3 Pa 58*4	H2 – beach ridge deposits	4473 ± 40 4420 ± 80	18397 17683
Caleta Olivia	Pa 72*1 Pa 72*3	H2 – beach deposits	5381 ± 60 5240 ± 50	16509 18473

[1] ^{14}C-dating: DR. B. KROMER (Institut für Umweltphysik, Universität Heidelberg).

Details of the ESR, Th/U and AAR dating results are discussed in SCHELLMANN (1996) and in SCHELLMANN and RADTKE (1997, 1998).

2.2 Morpho- and pedostratigraphic differentiation of marine terraces along the Atlantic coast of Patagonia

The most valuable sequence of Quaternary beach ridge systems is found in the surrounding of the Golfo de San Jorge at Bahía Bustamante and Bahía Camarones (Fig. 2).

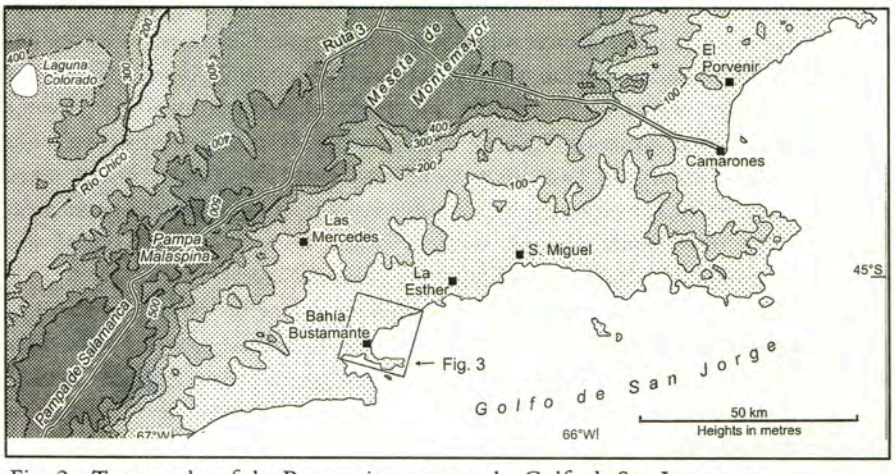

Fig. 2: Topography of the Patagonian coast at the Golfo de San Jorge area.

FERUGLIO (1950)	Altitudes (m a.s.l.)	CIONCHI (1987)	Altitudes (m a.s.l.)	RADTKE (1989)	Altitudes (m a mhT)	Levels of beach ridge systems	Altitudes (m a. mTw)	Stratigraphic units Holocene	Eem	
„*Cordón litoral interno*"	28 - 40	System I	35 - 41	Middle Pleistocene	33 - 35	T6-Komplex	35 - 43			T6
		System II	25 - 29			T5-Level	28 - 31			$T5_{(9)}$
„*Cordón litoral intermedio*"	20 - 26					T4-Level	ca. 25			$T4_{(7)}$
				Last Interglacial	18 - 20	T3-Level	18 - 21		$T3_{(5)}$	$T3_{(7)}$
						T2-Level	14 - 15		$T2_{(5)}$	$T2_{(7)}$
„*Cordón litoral reciente*"	11 - 12	System III	8 - 10	Holocene	10 - 11	T1-Level lower Holocene levels	10 - 12 9 - 10 7 - 8 < 7	$T1_{(1)}$ H1 H2 sub-recent, recent	$T1_{(5)}$	

Table 2: Stratigraphy and elevations of marine terraces in the surrounding of the Bahía Bustamante after SCHELLMANN (1996) compared with the stratigraphic systems of FERUGLIO (1950), CIONCHI (1987) and RADTKE (1989).

The main stratigraphical result of the investigations is the identification of several Holocene beach ridges, up to three Last Interglacial and at least three Penultimate Interglacial beach ridge systems (Table 2). In the hinterland there are further and more elevated beach deposits of older Pleistocene age. Fig. 3 and Fig. 4 show some geological profiles and the distribution of Middle Pleistocene beach deposits as well as younger ones from the coastal region near Bahía Bustamante.

These various stratigraphic units can be separated by geomorphological and geochronological methods (SCHELLMANN 1995, 1996). According to the age of these sediments they display different stages of pedogenesis and different kinds of covering layers (Fig. 5). Beach ridges of the maximum Holocene transgression episode in the Atlantic period are characterized by sparsely developed initial soils and calcic regosols. The latter are rarely slightly brownified. Strong pedogenic calcified horizons ("caliche") are missing. In contrast brown soils are well developed on top of Last Interglacial and older Pleistocene beach ridge systems. Generally, the older the beach ridge system, the thicker the pedocalcic horizons are developed. Marine terraces older than Last Interglacial are sometimes covered by buried fossil soils and colluvial layers.

Obviously these various beach ridge sequences cannot be found elsewhere in same diversity and richness. In some places they are eroded or never have been formed (Fig. 6). Surfaces of Holocene and Last Interglacial beach deposits, as well as those from the Last and the Penultimate Interglacial periods could have a similar altitude (Tab. 2, Fig. 4, Fig. 6). Furthermore, older marine terraces could be bordered seawards on some metres higher, but younger beach ridges (Fig. 4).

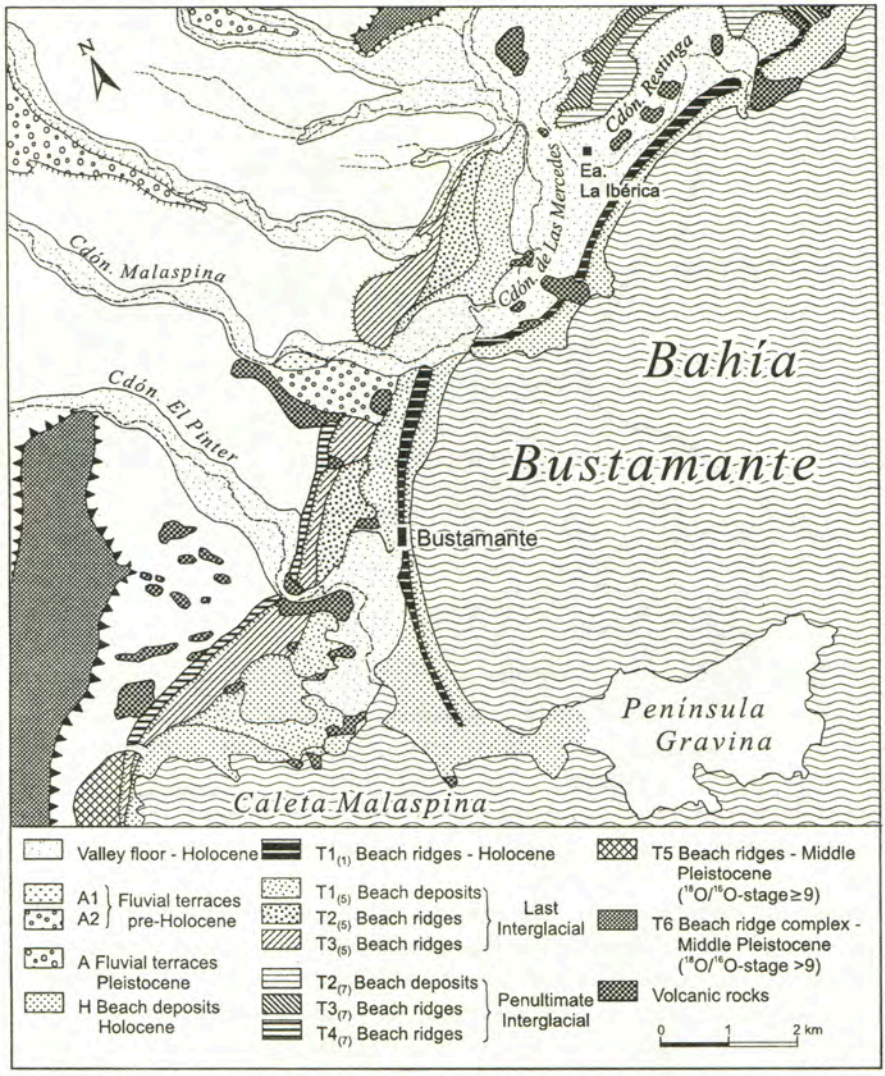

Fig. 3: Geological map of the coastal area in the surrounding of the Bahía Bustamente.

So, by no way elevation is a significant parameter for chronostratigraphic correlation of marine terraces, as performed by previous researchers.

2.2 Chronostratigraphic results

To obtain a chronostratigraphy of the various beach deposits, a lot of buried fossil shells were dated by ^{14}C- and ESR measurements (Fig. 7, Fig. 8). The inaccuracy of dating unpaired shells is demonstrated by the age results in Fig. 7.

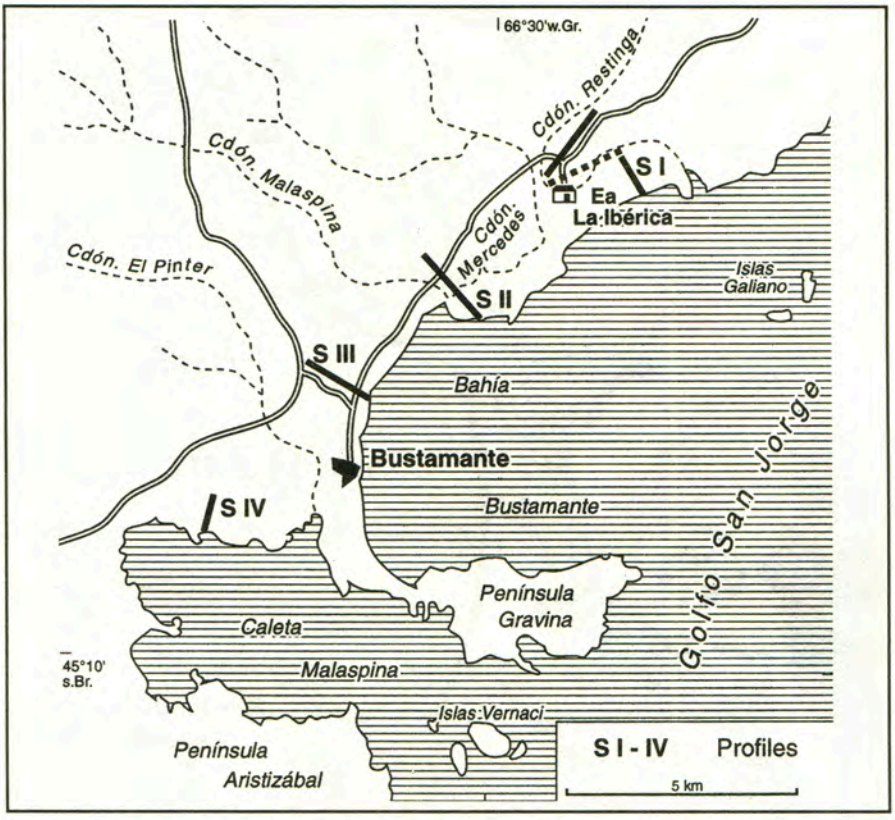

Fig. 4: Location and geological profiles S I to S IV near Bahía Bustamente.

Despite the scattering of the ESR ages in one horizon, four groups of Holocene, Last Interglacial and Penultimate Interglacial and older ages are obvious.

Although the methodological error of the ESR ages is supposed to be less than 15%, the distribution of ESR ages from the studied paired mollusc shells – which undoubtly have the same age – often display a greater interval. For this reason it is impossible to divide between different interglacial substages, e.g. the Last Interglacial stages 5a, 5c or 5e. Some shells have also been dated by Th/U age determination and AAR as well. These results do not compare adequately with their stratigraphic background (SCHELLMANN 1996).

3. Middle and Younger Quaternary marine terraces along the Chilean Pacific coast

Strong neotectonic activities along the Chilean Pacific coast, caused by subduction of the Eastern Pacific ocean crust beneath the South American

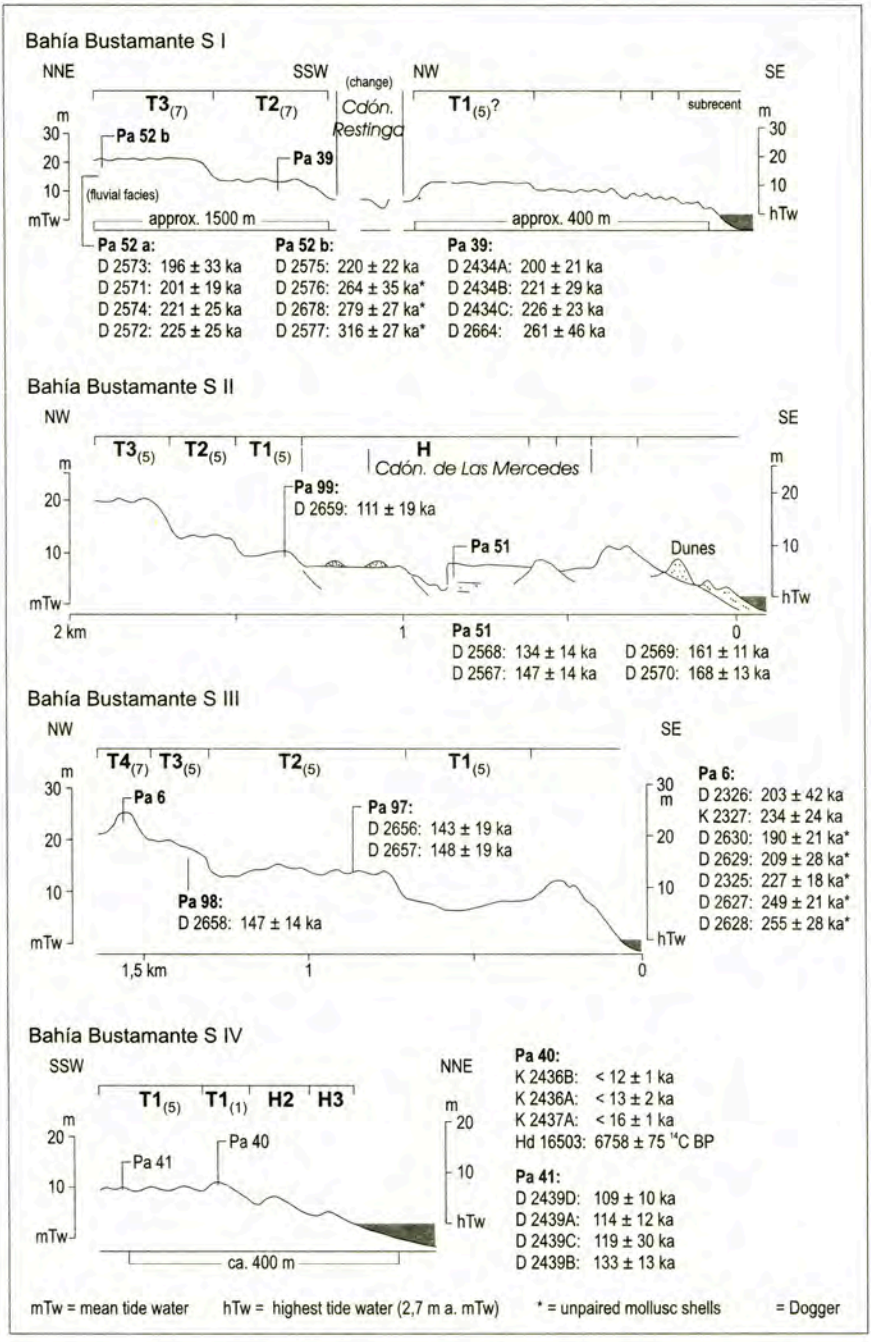

Fig. 4: continued

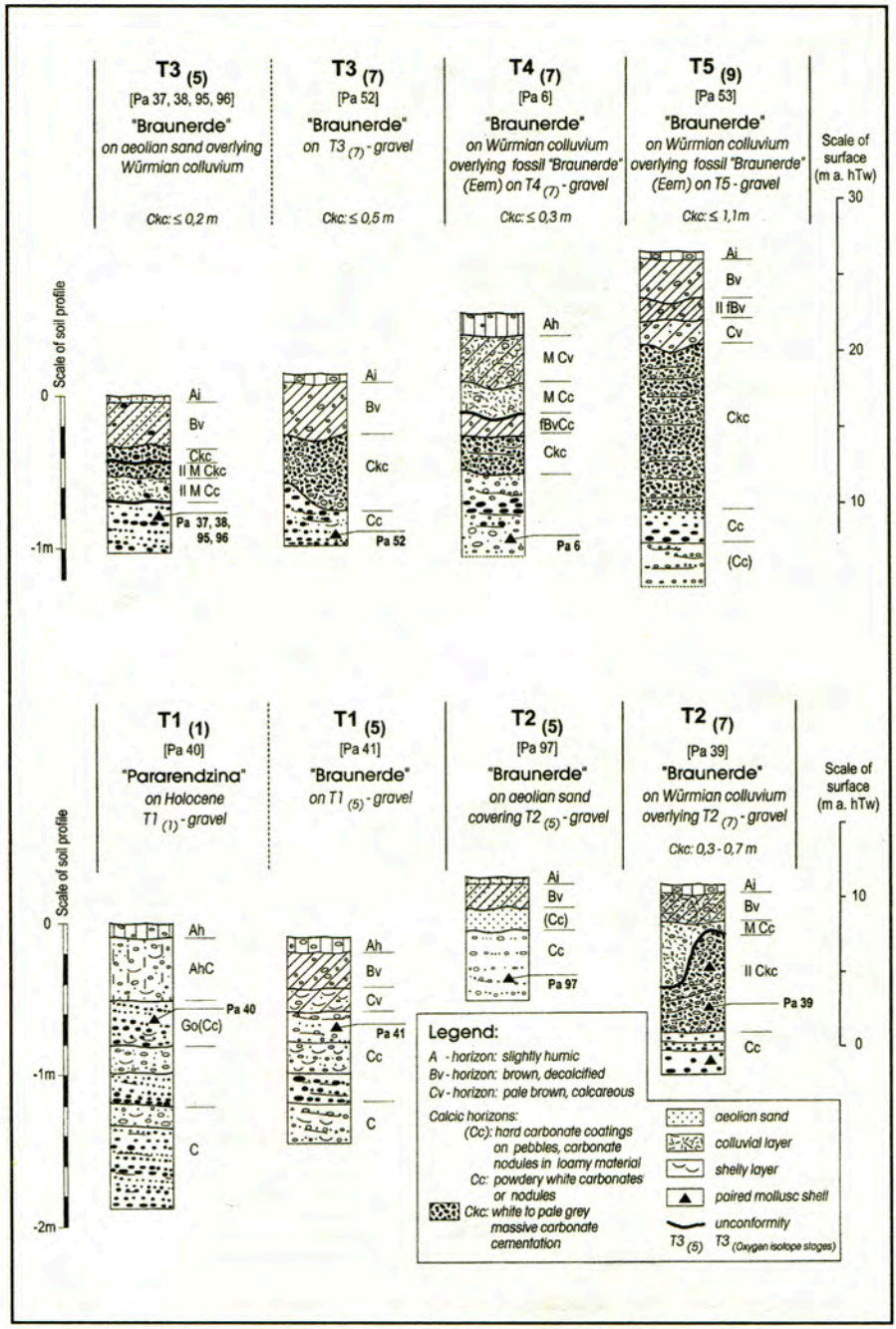

Fig. 5: Soil development and colluvial layers on Middle and Younger Quaternary beach ridges in the Bahía Bustamente area.

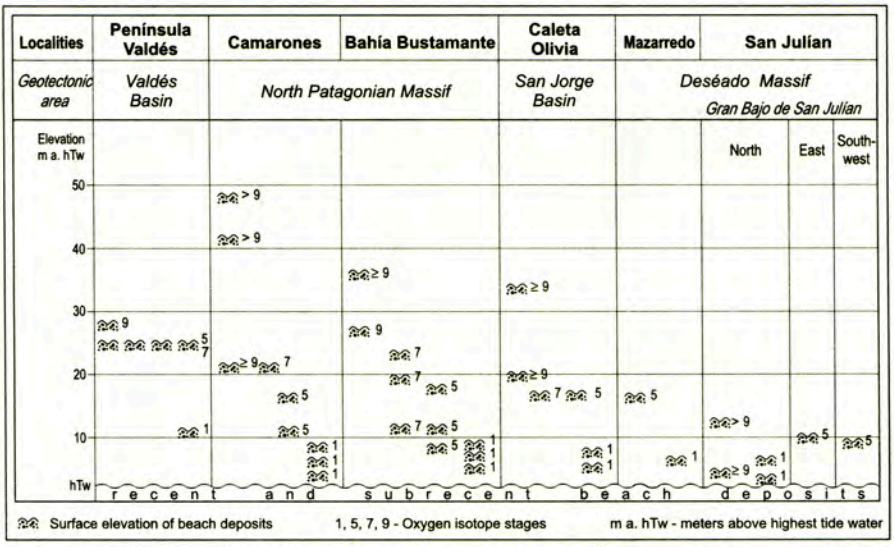

Fig. 6: Elevation of Middle Pleistocene, Younger Pleistocene and Holocene beach ridges along the Patagonian atlantic coast.

continental plate, reject any chronological subdivision of the various elevated or subsided marine terraces by interregional altimetric correlations. Because of the paucity of fossils in Pleistocene terraces in central and southern Chile geochronological investigations have been concentrated on Middle and Younger Pleistocene shorelines along the northern Chilean Pacific coast.

Supported by numerous ESR- and Th/U ages of shells RADTKE (1987; 1989) could demonstrate that the northern Chilean coast has experienced variable degrees of neotectonic movements, which caused different elevations of Pleistocene shorelines. For example, in the coastal region between Tongoy (30°S) and Iquique (20°S) the present surface of the highest Last Interglacial terrace is situated between 10 and 40 m a.s.l. Further north along the coast of southern Peru Last Interglacial beach deposits have been elevated at heights of 100 m and more above modern sea-level. In single bays however, as at La Serrena/Coquimbo (30°S), marine terraces could have been elevated by different amounts and possibly at different rates. At the classical site near the Bay of Herradura (30°S) RADTKE (1989:56f.) stated, that the marine Herradurra II terrace (5–15m a.s.l) contains shells from the last two interglaciations (Oxygen isotope stage 5 and 7), implying for this coastal area a longer period of relatively slow uplift.

Recently ORTLIEB et al. (1996a) confirmed again the spatially differentiated tectonic uplift history along the northern Chilean coast. Based on AAR and Th/U ages of mollusc shells they mentioned that in the coastal area near Hornitos (23°S) terrace remnants of two sea-level fluctuations within the Last Interglacial

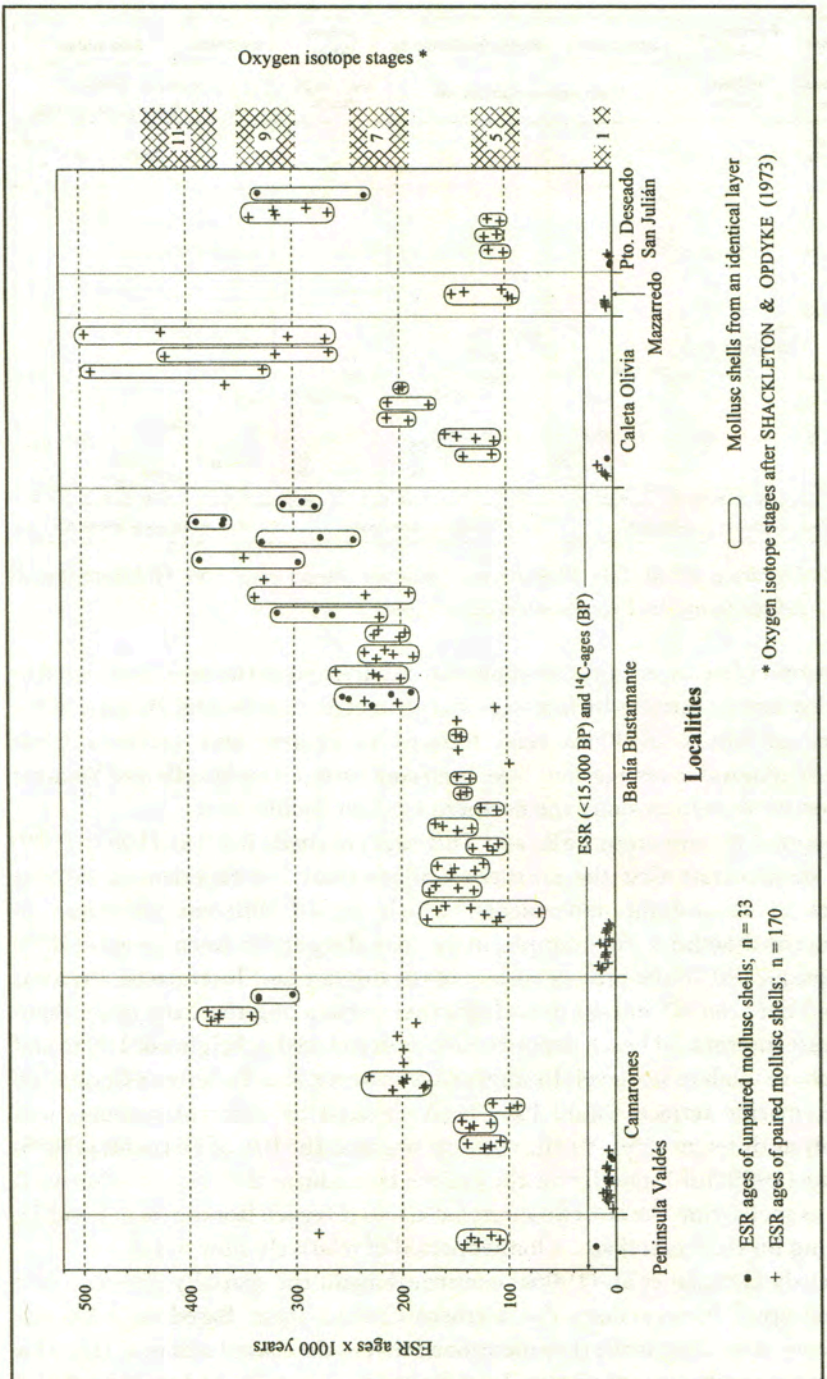

Fig. 7: ESR and ^{14}C ages of mollusc shells from different locations along the Patagonian Atlantic coast. Shells from one stratigraphic horizon are framed with a line.

coeval with the Oxygen isotope substages 5e and 5c would have been preserved. But it should be kept in mind that until today the accuracy of these both dating methods performed on mollusc shells cannot give any reliable chronostratigraphic differentiation between the Last Interglacial substages 5e and 5c.

4. Neotectonics and palaeo sea-level changes in Southern South America since the Middle Pleistocene – some general implications

For the first time it was possible to demonstrate that not only in areas of elevated coral reef islands (e.g. Barbados, Huon Península), but also in higher extratropical latitudes as the Atlantic coast of Southern Patagonia up to three Last Interglacial and up to three Penultimate Interglacial shorelines (Fig. 6) besides several Holocene beach deposits (Fig. 8) are preserved. Along the north-central Chilean Pacific coast ORTLIEB et al. (1996a) propose a subdivision of Last Interglacial depositional remnants in perhaps two different units.

In contrary to the generally stronger tectonically stressed Chilean Pacific coast along the passive continental margin of the Southern Patagonian Atlantic coast a relative slow uplift (<0.12m/ka) has predominated the period since the Middle Pleistocene. Aside from small areas of young subsidence (Fig. 6: San Julián North) or of relative stable tectonic conditions during the Middle and older Younger Pleistocene period (Fig. 6: Península Valdés), the generally slow uplift tendency for the most coastal localities is underlined by slightly higher elevations of Holocene, Last Interglacial and Middle Quaternary beach ridge formations with increasing age (a few meters, Fig. 6) – as long as they were remnants of an interglacial transgression maximum. However, along the Patagonian coast any relationships between Quaternary neotectonic movements and the distribution of Mesozoic and Tertiary sedimentary basins (Fig. 6) cannot be recognized – as postulated by CODIGNOTTO et al. (1992). Coastal areas lying over such old structural depressions like the San Jorge Basin as well as positive areas like the Deseado Massif are both characterized by a slow uplift since the Middle Pleistocene. Other areas like the north of San Julián, which lie over the Deseado Massif, have been subsided relatively during the same time period (SCHELLMANN 1995, 1996).

Beach sediments have been deposited not only during relatively short periods of maximum interglacial sea-level highstands. In many locations along the Patagonian coast also lower elevated remnants of regressive phases exist, probably as results of glacio-eustatic sea-level changes (Fig. 6, Fig. 8). As shown in Fig. 8 beneath the highest beach deposits and beach ridge systems of the early Atlantic transgression maximum around 6600–8100 ^{14}C BP (uncorrected ^{14}C ages) further younger terraces in different altitudes above modern sea-level are preserved. The radiocarbon ages of embedded paired mollusc shells (uncorrected

^{14}C ages) suggest, that these younger beach ridge formations have been mainly developed between 5400–5900 ^{14}C BP, around 4400 ^{14}C BP and in the older Subatlantic period.

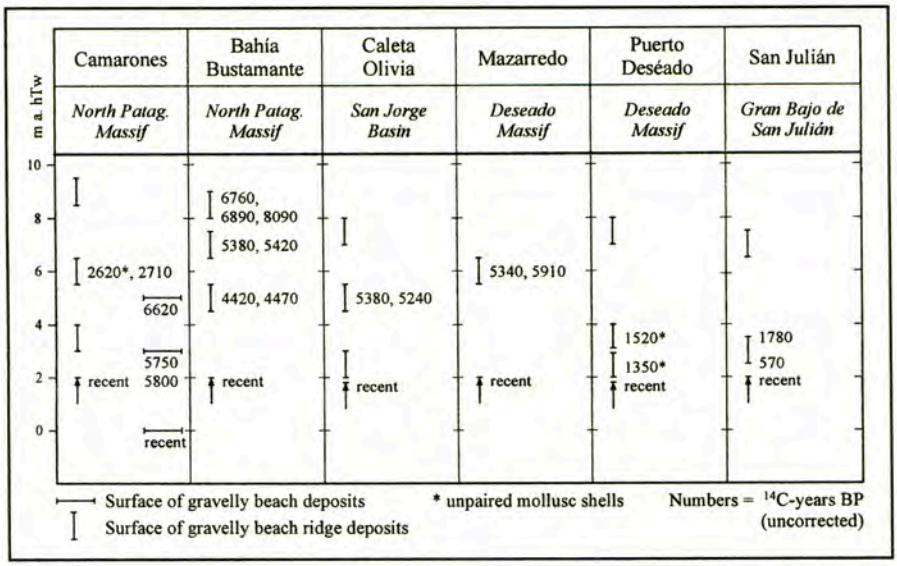

Fig. 8: ^{14}C ages and elevations of Holocene beach ridges along the Patagonian Atlantic coast.

Because dating of Pleistocene molluscs is not sufficiently accurate enough to separate between substages of Pleistocene sea-level highstands of one interglacial, therefore, it is unclear, whether the less elevated regressive beach deposits of the Last Interglacial and Penultimate Interglacial sea-level highstands along the Patagonian Atlantic coast (Fig. 6) are – similar to the various Holocene beach deposits – a result of sea-level regressions shortly after the interglacial transgression maximum or whether they are remnants of secondary high seastands during younger interglacial substages.

In recent years a lot of papers are dealing with Holocene sea-level changes along the Patagonian Atlantic coast (e.g. AGUIRRE and WHATLEY 1995; GONZALES and WEILER 1994, ISLA et al. 1996; PORTER et al. 1984; SCHNACK 1993). Radiocarbon ages of paired mollusc shells (SCHELLMANN 1996) indicate, that the oldest and most elevated Holocene beach deposits and beach ridges have been accumulated during the older Atlantic period (ca. 6600–8100 ^{14}C BP). This implies, that Holocene transgression has reached its maximum level some hundred years earlier as recently stated. Afterwards sea-level declines discontinually with phases of stagnation around 5300–5900, 4400 (?), 1300–1800 ^{14}C BP (uncorrected ^{14}C ages). If beach ridges with an elevation of ca. 6 m a. hTw in the

coastal area of Camarones (Fig. 8) may not be looked upon as only a local phenomenon, than they have to be a result of strong relative sea-level rise in the older Subatlantic period (around 2700 ^{14}C BP). An important incline of younger Holocene sea-levels around 3600 and around 2500 ^{14}C BP has also been described by MARTIN et al. (1987) along the Brazilian Atlantic coast. Nevertheless, this general picture of relative sea-level fluctuations along the Patagonian Atlantic coast during the Holocene is surely still incomplete, without regarding further ancient shorelines having been drowned by modern sea-level rise.

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Edited on behalf of the Committee
of the Federal Republic of Germany
for the International Geographical Union
by Prof. Dr. Dieter H. Kelletat.

INSTITUT FÜR WISSENSCHAFTLICHE ZUSAMMENARBEIT
Olgastrasse 8
D-72074 Tübingen

ISBN 3-922362-20-6

Herstellung: Druckerei Deile, Tübingen