Earth-Science Reviews 103 (2010) 1–30

Contents lists available at ScienceDirect

Earth-Science Reviews

journal homepage: www.elsevier.com/locate/earscirev

Timing and magnitude of Holocene sea-level changes along the middle and south Patagonian Atlantic coast derived from beach ridge systems, littoral terraces and valley-mouth terraces

Gerhard Schellmann [a,*], Ulrich Radtke [b]

[a] Universität Bamberg, Lehrstuhl für Physische Geographie, Am Kranen 1, D-96045 Bamberg, Germany
[b] Universität Duisburg-Essen, Campus Essen, D-45117 Essen, Germany

ARTICLE INFO

Article history:
Received 27 January 2009
Accepted 4 June 2010
Available online 12 June 2010

Keywords:
Patagonia
marine terraces
Holocene
sea-level change
coastal deposits
beach ridges
glacio-isostasy

ABSTRACT

Geomorphologic and chronostratigraphic investigations in various coastal localities along the middle and south Patagonian Atlantic coast, from Bahía Vera (44°S) in the north to San Julián (49°S) in the south, confirm a rich sequence of Holocene beach ridge systems and littoral and valley-mouth terraces. Beach ridges are present up to 10 m above current highest tide level (hTw) and date to the early mid-Holocene transgression maximum. Beach-ridge deposits represent high-energy, wave dominated coastal environments, whereas valley-mouth terraces and littoral terraces (elevations of 5.5–6.5 m above hTw) developed in wave-protected coastal environments.

The surface elevation of these littoral forms suggest that the middle and south Patagonian Atlantic coast is likely undergoing a slow glacio-isostatic uplift on the order of 0.3–0.4 mm/a since the mid-Holocene. The early Holocene sea-level rise reached the modern coastline by 8100 ^{14}C years ago (c. 8600 cal BP) at the latest. Sea level at that time was most likely near its present position. The Holocene transgression maximum lasted from 6900 to at least 6200 ^{14}C BP (c. 7400 to 6600 cal BP), raising relative sea level to about 2 m to a maximum of 3 m above the present level, after which sea level declined to the present level. Two significant sea-level falls of at most 1 m occurred: a) between 6200 and 6000 ^{14}C BP (c. 6600 to 6400 cal BP), and b) between 2600 and 2400 ^{14}C BP (c. 2300 to 2050 cal BP).

We assume, that both significant sea-level falls were predominantly driven by eustatic changes of ocean volume, whereas both thermo-steric changes and changes of tides may also have contributed to these relatively strong sea-level drops. Gravitational changes driven by Greenland ice growth (*sensu* Mitrovica et al., 2001) may also have amplified any eustatic portion of sea-level fall. The trend of a general sea-level decline since the mid-Holocene transgression maximum seems to be predominantly glacio-isostatically driven.

Contents

* Corresponding author. Tel.: +49 951 8632380; fax: +49 951 8635379.
E-mail addresses: gerhard.schellmann@uni-bamberg.de (G. Schellmann), u.radtke@uni-koeln.de (U. Radtke).

0012-8252/$ – see front matter
doi:10.1016/j.earscirev.2010.06.003

1. Introduction

The Patagonian Atlantic coast stretches along a relatively stable continental margin with a large shelf area, located far away from Pleistocene centres of glaciations. Tectonically, this is one of the most stable coastal areas on Earth. Some coastal areas, e.g. north of San Julián and most likely also in the area of the Península Valdés (Fig. 1), have localized tectonic activity, marked by anomalous elevations of Middle and Late Pleistocene coastal terraces (Schellmann, 1998).

Stratigraphic differentiation of Patagonian coastal terraces has been described in detail (Radtke, 1989; Clapperton, 1993; Schellmann, 1998; Rostami et al., 2000; Aguirre et al., 2006; Isla and Bujalesky, 2008). Here, we will concentrate on a short review of morpho- and chronostratigraphic differentiation of Holocene coastal terraces in this area, and we will recapitulate some central assumptions about the sources of Holocene sea-level changes along the Atlantic coast of Patagonia and Tierra del Fuego.

Coastal geomorphic research was revolutionized by the use of absolute dating methods like radiocarbon (^{14}C), Electron-Spin-Resonance (ESR) and thorium/uranium (Th/U) (e.g., Codignotto, 1983; Radtke, 1989; Radtke et al., 1989; Rutter et al., 1989; Rutter et al., 1990; Schellmann, 1998; Rostami et al., 2000). With progressively better age control came controversial discussions about the timing, magnitude and mechanisms driving relative sea-level changes. For example, Rabassa et al. (1989), Gordillo et al. (1993), and Vilas et al. (1999) suggested a considerable glacio-isostatic and neotectonic rise of Tierra del Fuego during the Holocene. Rostami et al. (2000) hypothesized a constant tectonic uplift of the Patagonian coast since the Middle Pleistocene, and suggested that the “anomalously raised” Holocene beach-deposits throughout Argentinean Patagonia may be a result of Holocene uplift and/or the high energy of this coastal environment. In contrast, Schellmann and Radtke (2003) pointed out that, superimposed upon slow epeirogenic and/or hydro-isostatic uplift, glacio-eustasy is an important reason for the different elevations of interglacial high-stand terraces formed during interglacial sea-level highstands and submaxima. Additionally, changes in tide amplitudes and wave-exposure may have also significantly contribute to the elevation of modern and Holocene littoral deposits (Schellmann and Radtke, 2003; Bujalesky, 2007; Isla and Bujalesky, 2008).

Until the early 1980s, studies along the Patagonian Atlantic coast generally lacked stratigraphic detail and concentrated on subdividing Middle and Late Pleistocene terraces. Results of these investigations (e.g. Schellmann, 1998; Schellmann and Radtke, 2000) were that (1) marine terraces of penultimate, last interglacial and Holocene ages are distributed in an elevation up to 25 m asl (above sea level) only; (2) penultimate and last interglacial, and also last interglacial and Holocene terraces could have similar elevations; (3) up to three marine terraces can be preserved from the same interglacial highstand (see Section 4). These investigations on Pleistocene terraces clearly illustrate the tectonic stability of large areas of the Patagonian Atlantic coast, with little emergence since the Middle Pleistocene (Schellmann, 1998).

Although accurate regional data about Holocene sea-level changes are of high scientific interest, there is little modern research on Holocene littoral systems along the middle and south Patagonian Atlantic coast and their morpho- and chronostratigraphic differentiation. Apart from Schellmann and Radtke (2003), recent research has focused on (a) palaeo-zoological studies about the distribution of mollusc types in Pleistocene and Holocene coastal terraces linked relevant to the palaeo-oceanography of the Falkland and Brazil currents (e.g., Aguirre, 2003; Aguirre et al., 2005, 2006, 2009), and on (b) a geophysical modelling of Holocene relative sea-level changes along the Argentine Atlantic coast (e.g., Milne et al., 2005, Rostami et al., 2000; Guilderson et al., 2000). The geophysical models assume a rapid rise of sea level in the early Holocene, reaching a maximum and relative stable mid-Holocene sea level between 8000 and 5000 cal BP, followed by a progressive decline. However, as reviewed by Milne et al. (2005), the regional Holocene sea-level data especially from the Patagonian Atlantic coast are of poor quality. The revised morpho- and chronostratigraphy of Holocene littoral deposits presented here allow reconsideration of the timing, magnitude, and main causes that driven the sea-level history for this region.

In this context, we used the term “glacio-isostatic” as a general term for climate-induced isostatic changes (including glacial- and hydro-isostatic processes) of the earth lithosphere *sensu* Milne et al. (2005), the term “eustatic” for changes in ocean volume (= changes in continental ice mass), and the term “steric” for changes of sea temperatures (thermo-steric), salinities, tides and waves.

The main object of this paper is to present further geomorphological and chronostratigraphic data of Holocene littoral forms (beach ridge systems, littoral terraces, valley-mouth terraces) along the middle and southern Patagonian Atlantic coast from field investigations between 2002 and 2005. To our mind, these data offer some new aspects about the timing, magnitude and the causes of Holocene sea-level fluctuations in this region and may give some new chronostratigraphic and sea-level data for further palaeo-oceanographic studies and geophysical modelling of Holocene sea-level changes.

1.1. Dating the littoral deposits along the Patagonian Atlantic coast

Clastic littoral deposits along the Patagonian Atlantic coast are usually coarse and contain mollusc shells, including very fragile shells of the genera *Mytilus edulis*, *Mytilus magellanicus*, *Ensis macha*, *Brachidontes purpuratus* or *Aulacomya atra* (Photo 1). Many shells are still articulated, since any reworking of the shells would have caused them to fall apart, they are without any doubt *in situ*. This has been corroborated by multiple samples with identical ^{14}C ages (e.g., Schellmann, 1998; Schellmann and Radtke, 2003, 2007a). A good example for possible age-overestimations of beach ridge deposits by dating single instead of articulated shells is given by Brückner and Schellmann (2003: Fig. 8).

Of the currently available numerical dating methods that are used to date Holocene mollusc shells, the radiocarbon (^{14}C) method is and will most likely remain the most economically efficient and the most accurate of the dating methods. In spite of all methodical improvements, dating with the ESR method remains unsatisfying (Schellmann and Radtke, 2007b; Schellmann et al., 2008), as well as Th/U dating (Schellmann, 1998).

Due to the marine ^{14}C reservoir effect, ^{14}C dating of Holocene mollusc shells can have ages several centuries too old. Little is known about spatial and temporal variations in ^{14}C reservoir effect (see also Franke et al., 2008; McGregor et al., 2008). Globally, ^{14}C reservoir effect in ocean water for the past 10,500 calendar years is about 405 years (Hughen et al., 2004). Surface water of the Falkland current has a ^{14}C reservoir value of about 560 to 600 years, corrected for