Palaeogeography, Palaeoclimatology, Palaeoecology 401 (2014) 166–170

Contents lists available at ScienceDirect

Palaeogeography, Palaeoclimatology, Palaeoecology

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

A reply to “Relative sea level during the Holocene in Uruguay”

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ARTICLE INFO

Article history:
Received 15 July 2013
Received in revised form 17 October 2013
Accepted 27 October 2013
Available online 9 November 2013

Keywords:
Holocene
Sea level change
Uruguay

ABSTRACT

Martínez and Rojas (2013) published a paper about the relative sea level during the Holocene in Uruguay. The paper of Martínez and Rojas could be handled as an attempt to construct a sea-level curve from data collected from different sources: open-ocean coast, the Río de la Plata coastline and the outlet of Uruguay River. In this sense, several processes were involved: storm effects at open-ocean beaches, the Holocene enclosing of coastal lagoons, storms within the funnel-shaped estuary and the floods of the Uruguay River. However, they included a series of omissions, inaccuracies, errors and critics to our work, that need to be amended, rectified and argued. In response we present a historical background about the research on this issue in Uruguay. We refute the comments about the empirical framework used to construct the first sea-level curve for Uruguay (Bracco et al., 2008, 2011b). We point out that the assumptions on which the curve proposed by Martínez and Rojas (2013) is based are mistaken. In addition, there are limitations of the performed statistical techniques, and errors — mainly systematic — within their formulation. We present evidence that the decrease in sea level from middle Holocene would not have been constant. Instead, a rapid sea level decrease would have taken place by 4300 yr BP. Finally, we not only compare our sea level curve with that proposed by Martínez and Rojas, but also we corrected the altimetry errors incurred in their formulation. We conclude that the similarity supports the validity of our curve.

1. Holocene sea level changes in Uruguay

During the 1970s and 1980s Brazilian research on Holocene sea level change was strongly linked to archeology (Fairdridge, 1976) and to Uruguayan prehistory as considered by Fairbridge (1974) in the construction of an archeological sequence of the Merín Lagoon basin (Naue, 1973; Schmitz, 1976). In agreement with this line of evidence, in the frame of paleoenvironmental and geoarcheological studies undertaken during the 1990s in the same basin, several landforms attributed to different Holocene sea levels were recognized along the Uruguayan shore. When radiocarbon ages of these landforms became first available, a remarkable consistency with the proposed chrono-altimetric sea level curves for this period (Martin and Suguio, 1989, 1992; and Suguio et al., 1984 for southern Brazil; see Bracco and Ures, 1998) was observed.

Since the year 2000 paleoenvironmental and geoarcheological research was further developed. By linking coastal lagoons and marine coastal records, the history and evolution of littoral lagoons and associated wetlands as well as the regional paleoclimatic history and the relationship with pre-historic mound-builders were reconstructed (García-Rodríguez et al., 2004a–c; Bracco et al., 2005a–b, 2011a; del Puerto et al., 2006; García-Rodríguez, 2006, 2012; Inda et al., 2006; del Puerto, 2009; Inda, 2009). A large amount of multiproxy data related to sea level oscillations was generated during this decade. The consistency and coherence of such data with regional models allowed the generation of the first relative sea level curve for the Uruguayan shore (Bracco et al., 2008). An updated version of this curve was published by Bracco et al. (2011b). This publication can be freely downloaded from http://www.csic.edu.uy/renderPage/index/pageId/1024.

2. On the construction of our sea level curve

Martínez and Rojas (2013) have reported that our research related to sea level changes has been restricted to just a few points. Nevertheless, Fig. 1 shows the sites surveyed by us along the fluvial, estuarine and marine coast of Uruguay, corresponding to multiple indicators,

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http://dx.doi.org/10.1016/j.palaeo.2013.10.012

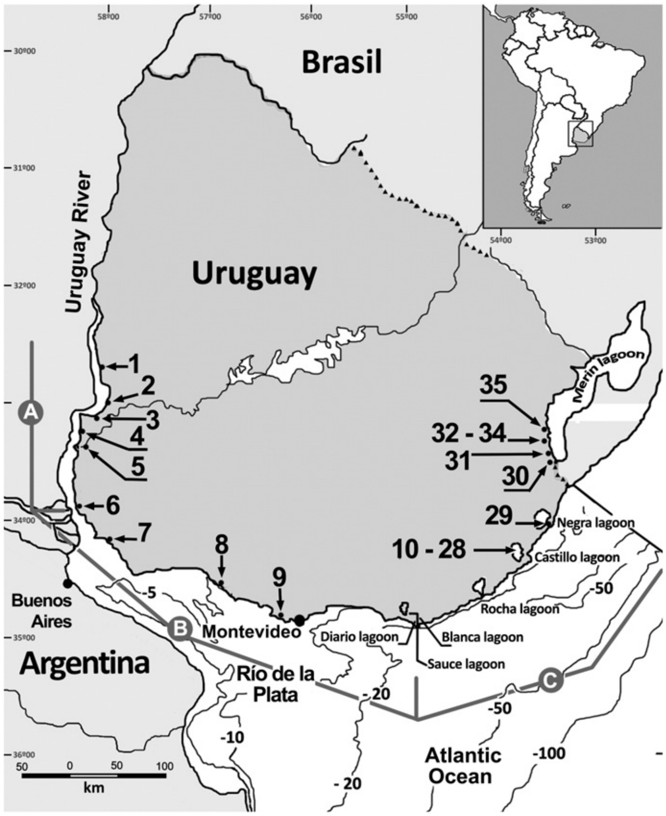

Fig. 1. Location of surveyed sites. Section A: lower reaches of Uruguay River, section B: Río de la Plata Estuary and section C: Atlantic coast.

i.e., beach ridges, sand barriers, tidal plains, intertidal deposits, lagoon bottom cores, erosion terraces and archeological sites.

Samples represent different dates from 6000 to 1200 yr BP. The number of dated samples totals 35, from which 19 correspond to Castillos Lagoon (Bracco et al., 2008, 2011a) (Fig. 1). Martínez and Rojas (2013: Table 1) in turn reported just 15 additional sampling points and 8 new radiocarbon ages for localities previously sampled by us. No single disagreement in radiocarbon age reported by the above-mentioned authors was observed.

Martínez and Rojas (2013) stated that they used "coastline deposits generated by storm and not further eroded: 'permanent berm' as sea level proxies". They reported that "beach ridge" is commonly used in the available literature to define deposits such as those they analyzed, and reported following Hesp (2006), that "beach ridge" is a rather ambiguous term (see Otvos, 2000 and Hesp et al., 2005, among others, for a discussion on the topic). Martínez and Rojas (2013) omitted part of Hesp et al.'s (2005) explanation and, also misinterpreted it to some extent. Hesp (1999) redefined beach ridges as swash aligned, swash and storm wave built deposits or ridges formed primarily of sand, pebbles, cobbles (gravel) or boulders, or a combination of these sediments. In addition, Hesp et al. (2005) reported that the critical difference between a berm and a beach ridge is that berms are generally not persistent forming part of the intertidal to slightly above high tidal active swept prism.

Secondly, Martínez and Rojas (2013) misinterpreted the nature and origin of deposits. The vast majority of the deposits that were sampled and dated by us — which were redefined by Martínez and Rojas (2013) as storm deposits or permanent berms — were recognized as beach ridges (Bracco and Ures, 1998: Table 1; Bracco et al., 2011a: Table 1). According to Hesp et al. (2005) such deposits are sand beach ridges on some modality of low beach (open coast, lagoon or estuary). Moreover, Hesp et al. (2005) also presented an explanation about the frequency of such deposits in the Lower Uruguay River, Rio de la Plata Estuary and littoral lagoons, which describes them as sand beach ridges

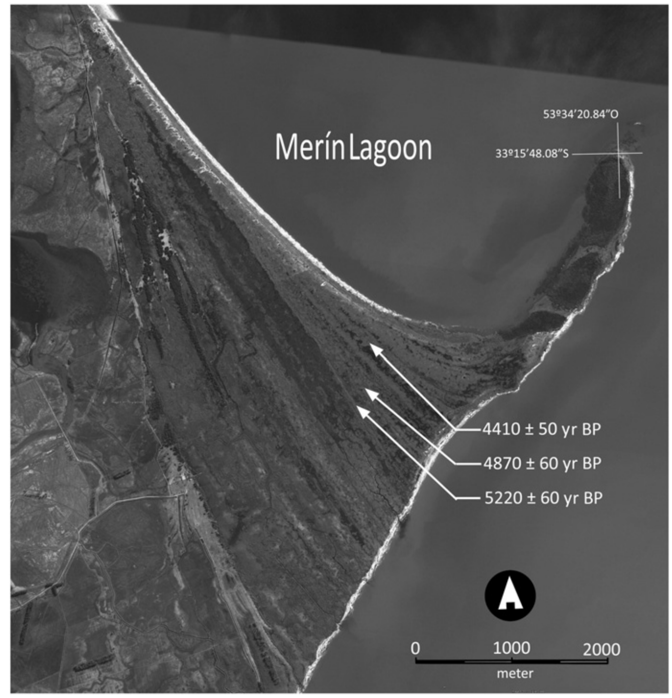

Fig. 2. Satellite image of beach ridge system on the Merín Lagoon coast and radiocarbon dates.

with coarse to fine sand on some modally low energy beaches (open coast, lagoon or estuary) (Fig. 2).

The reason why Martínez and Rojas (2013) assigned all deposits to storm deposits in their sea level curve, is based on the need to link the height of the landforms to sea level at the time of formation. Thus, they made the assumption that storm deposit heights were placed somewhere between average and exceptional sea level for the Rio de la Plata Estuary, calculated from historical series: around 1 to 1.5 m (Martínez and Rojas, 2013: 124). Regrettably, such an assumption did not consider the fact that these values are related to the "zero level" at Montevideo Harbor (i.e., the former Zero Wharton) (SOHMA, 2012). Such "zero level" is placed 0.91 m below the topographic "official zero" and thus the height assigned by Martínez and Rojas (2013) to the deposits has been underestimated (i.e., by 0.91 m). In addition to such systematic error in height assignment, and the lack of empirical evidence to support the assumption of storm deposits for the entire set of landforms, other shortcomings must be highlighted, when the mean storm sea level is used for sea level estimation. Firstly, the fact that highest sea levels reached at severe storm events were not considered and, at the time scale of the entire Holocene, the frequency of such events is far from insignificant and cannot be neglected (see Fig. 3). In addition, they did not consider neither the wave height variation due to different beach profiles and orientation, nor the existence of subaquatic structural control in the inner estuary. They also assumed that the Rio de la Plata historical storm averages were representative for the entire Holocene for the whole Uruguayan coast, i.e., from the Rio Uruguay mouth to the Atlantic shore, including littoral lagoons. The risk of such an extremely actualistic assumption became apparent when the incidence of the aeolian variable over regional sea levels was considered (Laborde, 1997; Nagy et al., 1997). Significant climatic variations have been inferred for the region throughout the Holocene (del Puerto, 2009). Such oscillations were related to atmospheric circulation variations (see, for example, Muhs and Zárate, 2001; Zárate, 2003; Piovano et al., 2009). Second, it must be pointed out that they did not consider the possibility of differential continent ascents or descents due to neotectonic movements in some sectors of the coast, nor the incidence of the Paraná and Uruguay River flows in the height reached in the inner estuary.

According to Martínez and Rojas (2013: 127) "Bracco et al. (2011b: 85) constructed by hand a curve of relative sea level in Uruguay based