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LAST INTERGLACIAL SEA-LEVEL HIGHSTAND DEDUCED FROM NOTCHES AND INNER MARGINS OF MARINE TERRACES AT PUERTO DESEADO, SANTA CRUZ PROVINCE, ARGENTINA

Abstract: Bini M., Zanchetta G., Ribolini A., Salvatore M.C., Baroni C., Pappalardo M., Isola I., Isla F.I., Fucks E., Boretto G., Morigi C., Ragaini L., Marzaioli F. & Passariello I., *Last Interglacial sea-level highstand deduced from notches and inner margins of marine terraces at Puerto Deseado, Santa Cruz Province, Argentina. (IT ISSN 0391-9839, 2017).*

A detailed geomorphological survey was undertaken in the area of Puerto Deseado (Santa Cruz Province, Argentina) to reconstruct the Relative Sea-level (RSL) position during the Last Interglacial highstand. The presence of active and well-preserved abrasive notches and inner margins of terraces related to the MIS5e and to the Holocene, measured with DGPS, allowed to accurately estimate the RSL change from the present to the MIS5e highstand at ca. 21 m. The geomorphological and geochronological analyses support the notion of the presence of a significant regional tectonic uplift in the Atlantic Patagonia, which can be locally estimated at ca. 0.12 mm/yr.

Key Words: Abrasive notches, MIS5e, Relative Sea-level, Patagonia, Argentina

Resumen: Bini M., Zanchetta G., Ribolini A., Salvatore M.C., Baroni C., Pappalardo M., Isola I., Isla F.I., Fucks E., Boretto G., Morigi C., Ragaini L., Marzaioli F. & Passariello I., *Niveles altos del mar durante el Último Máximo Interglacial deducidos mediante muescas de abrasión y márgenes internos de terrazas marinas en Puerto Deseado, Provincia de Santa Cruz, Argentina. (IT ISSN 0391-9839, 2017).*

Se realizó un estudio geomorfológico detallado en la zona de Puerto Deseado (provincia de Santa Cruz, Argentina) para reconstruir la posición relativa del nivel (RNM) del mar durante el Último Máximo Interglacial. La presencia de muescas de abrasión activas y bien conservadas, y la posición de los márgenes internos de las terrazas relacionadas con el MIS5e y el Holoceno, medido con GPS diferencial, permitió estimar con precisión el cambio RNM desde el presente hasta la transgresión MIS5e en aproximadamente 21 m. Los análisis geomorfológicos y geocronológicos sustentan la noción de la presencia de un significativo levantamiento tectónico regional en la Patagonia Atlántica, que puede estimarse localmente en alrededor de 0,12 mm/año.

Palabras Claves: muescas de abrasión, MIS5e, nivel relativo del mar, Patagonia, Argentina

INTRODUCTION

There is a general consensus that the Last Interglacial period (LIG), dated between ca. 130 and 115 ka (e.g. Stirling & *alii*, 1998), also known as marine isotope stage MIS 5e (Railsback & *alii*, 2015), was characterized by eustatic sea-level (ESL), ranging from 4 to 9 m above m.s.l. (Stirling & *alii*, 1998; Muhs, 2002; Hearty & *alii*, 2007; Rohling & *alii*, 2008; Kopp & *alii*, 2009; Thompson & *alii*, 2011; Dutton & Lambeck, 2012; O'Leary & *alii*, 2013; Vaskogg & *alii,* 2015), and by global mean temperature that was warmer than in the pre-industrial period (e.g. Otto-Bliesner & *alii*, 2006; Clark & Huybers, 2009). The different sea-level estimations for this particularly warm interglacial can be justified by considering, among other factors, the different rates of melting of Greenland and/or the Antarctic ice sheets (e.g. Cuffey & Marshall, 2000; Dutton & Lambeck, 2012; O'Leary & *alii*, 2013).

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With these premises the Last Interglacial period serves as potential analogue to constrain future global warming scenarios (e.g. Alley & *alii*, 2005; Rohling & *alii*; 2008; Kopp & *alii*, 2009; Joughin & Alley 2011; Levermann & *alii*, 2013). In addition, the Last Interglacial highstand deposits have been used as reference levels to explore uplift rates and different tectonic behaviours at regional (e.g. Nisi & *alii*, 2003; Ferranti & *alii*, 2006) and at global scale (e.g. Pedoja & *alii*, 2014 and reference therein).

The Atlantic margin of South America preserves an almost continuous record of coastal marine deposits related to the Last Interglacial (see Pedoja & *alii*, 2014 and references therein). In particular, the Atlantic Patagonia – which is the southernmost sector of the coast – preserves an impressive succession of staircase terraces from at least MIS 11 to the Holocene (Rostami & *alii*, 2000; Schellmann & Radke, 2000; Pedoja & *alii*, 2011; Pappalardo & *alii*, 2015), which can be exploited for detailed regional to extra regional correlations (Pedoja & *alii*, 2014; Isla & Angulo, 2016). However, this rich archive of information has yielded so far a relatively poor quality of data, due to i) difficulties of precise dating of deposits (Rutter & *alii*, 1989, 1990; Rostami & *alii*, 2000; Schellmann & Radke, 2000; Pappalardo & *alii*, 2015); ii) absence of precise and accurate measurement of the geomorphological indicators (Bini & *alii*, 2017); and iii) difficulty to assign a reliable meaning to the sea-level indicators, which make it problematic to define index and limiting points for accurate reconstruction of the relative sea-level (RSL e.g. Shennan & *alii*, 2015; Roveri & *alii*, 2016).

Most of the Patagonia coast is characterized by a meso-to-macrotidal regime and therefore active beaches and past raised coastal marine deposits are dominated by successions of coarse-gravelly beach ridges (Isla & *alii*, 2005; Isla & Bujalesky, 2000, 2008), the crest of which indicate the surf and storm extension rather than the average sea-level (e.g. Tamura, 2012; Roveri & *alii*, 2016). In this reasoning, Holocene sea-level curves were proposed considering either beach-ridge crests or valley-mouth terraces (Schellmann & Radtke, 2010).

In this paper we report on the use of abrasive notches and inner margins of marine terraces to establish the position of the RSL during the Last Interglacial in the area of Puerto Deseado (Santa a Cruz Province, Argentina, (fig. 1). This study benefits from recent investigations on modern analogues and inactive Holocene abrasive notches that have a very different genesis and meaning compared to tidal notches, commonly used in the reconstruction of past sea-levels (Bini & *alii*, 2013, 2014; Zanchetta & *alii*, 2014).

SITE DESCRIPTION

The study area is located on the left bank of the mouth of the Deseado River (fig. 1). Local climate is characterized by a mean annual precipitation around 200 mm and an average annual air temperature of 8.2 °C (Servicio Meteorológico Nacional-Argentina, http://www.smn.gov.ar). The coastal area experiences a macrotidal regime (Isla & *alii*, 2004; Isla & Bujalesky, 2008), with a tide range usually fluctuating between 2.5 and 5.5 m (http://www.hidro.gov.ar/Oceanografia/Tmareas/Form_Tmareas.asp). The lunar and solar cycles produce a mixed tidal type yielding unequal low and high tides (Bini & *alii*, 2014). Geologically, the Puerto Deseado area is located on the so-called Deseado Massif (Ramos & Ghiglione, 2008), a structural high, which is superficially composed by middle-upper Jurassic welded rhyolitic pyroclastic density current deposits, and by volcanoclastic rocks of the Chon-Aike Formation of Bahía Laura Group (Guido & *alii*, 2004; Sruoga & alii, 2004).

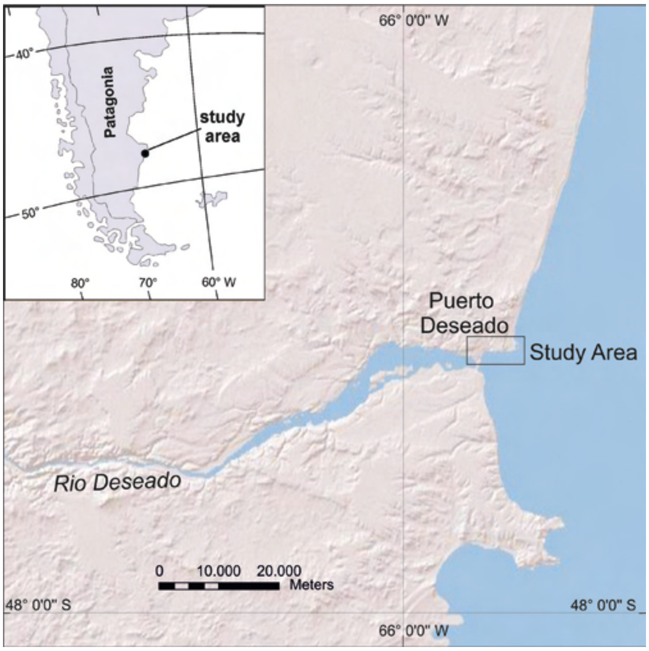

FIG. 1 - Location map of the studied area.

Isla & *alii* (2004) illustrated the morphology and sedimentology of the Deseado River and interpreted the river embayment as a “Rias”. The Deseado area is morphologically characterized by a succession of paleosurfaces developed on the welded volcanic rocks, covered by marine and fluvial deposits of different ages (e.g. Feruglio, 1950; Codignotto & *alii*, 1988), from *ca.* 8-10 m up to *ca.* 180 m a.s.l. (above sea-level). Rutter & *alii* (1989, 1990) reported some chronological constrains for the lower terraced units by using electron spin resonance (ESR) dating and aminostratigraphy. According to Rutter & *alii* (1989), the lower terrace (*ca.* 8-10 m a.s.l., called System VI by Feruglio, 1950, terminology later followed also by Rutter & *alii*, 1989, 1990) is Holocene in age. In agreement with aminostratigraphy, the terrace at *ca.* 20-25 m a.s.l. (System V) has been initially related to MIS5e (Rutter & *alii*, 1989). Later on, ESR data did not confirm this interpretation yielding ages older than MIS5e (two ESR determinations yielded both ages ≥400 kyr). Similarly, ESR dating of the terrace comprised between *ca.* 30 and 35 m a.s.l. yielded ages ≥242 kyr (System IV; Rutter & *alii*, 1990). However, Zanchetta & *alii* (2014) argued on the stratigraphic consideration that the terrace between ca. 20-25 m a.s.l. should be correlated to the MIS 5, as also implicitly assumed by Ribolini & *alii* (2014).

Field work surveys and radiocarbon dating performed by Shellmann (1998), Schellmann & Radke (2010), Zanchetta & *alii*, (2014), and Bini & *alii*, (2014), delimited more precisely the lower terrace (System VI), entirely correlated to the Holocene, ranging in age from the present to ca. 5 ka BP, mostly comprising a succession of gravelly beach ridge deposits. As described in detail by Zanchetta & *alii* (2014) and Ribolini & *alii* (2014), the marine deposits of terrace V (although the authors did not follow this labelling and indicated System V with Tp5 labelling) are eroded and covered by Holocene deposits (System VI) toward the coast. At its top, System V is characteristically covered by a complex succession of loess, and by colluviated and pedogenised deposits with ground-wedge pedogenic structures. Ribolini & *alii* (2014) interpreted these structures as periglacial features. Radiocarbon dating on a Bk horizon of this succession at the top of system V yielded an age of ca. 25 ka, where as an OSL measurement on a loess layer yielded an age of ca. 14 ka (Ribolini & *alii*, 2014).

METHODS

For stratigraphic and geomorphological investigations we followed the same approach already used in previous studies performed on the Patagonian coast (Ribolini & alii, 2011; Isola & alii, 2011; Zanchetta & alii, 2012, 2014). The widest geomorphological features were digitally drawn in GIS environment from high resolution Quick Bird images (acquisition date, 2004), supported, in case of cloudily cover, by LANDSAT 7 images (acquisition dates, 1999-2001) and by shaded images derived from the SRTM digital elevation model (www.jpl.nasa.gov/srtm).

After this preliminary phase, field surveys were carried out in February 2009, 2010, and 2011 (Bini & *alii*, 2014; Zanchetta & *alii*, 2014). A further field survey was conducted in January 2016 and dedicated to the precise and accurate measurement of sea-level indicators. The elevations of each indicator were measured by using a Trimble R10 DGPS (Differential Global Position System). The data were acquired by the WGS84 Geographic Coordinate System (maximum error in elevation of acquired points was 10 cm) and post-processed and referred to the current global geoid model EGM2008 (Pavlis & *alii*, 2012) (4 cm planimetric error and 9 cm elevation error). In this paper elevation measurements indicated as "a.s.l." (above sea-level) are referred to the EGM2008 vertical datum.

Geomorphological features are reported in figure 2 following the legend for coastal areas recently proposed by Mastronuzzi & *alii* (2017).

Well-preserved articulated valves for radiocarbon dating were preferentially selected to reduce the possibility of reworking from older levels (Schellmann & Radke, 2010; Tamura, 2012; Zanchetta & *alii*, 2012, 2014). However, this was not the case for the two new radiocarbon measurements presented in this work (tab. 1). The samples for radiocarbon dating were cleaned in ultrasonic bath with the addition of oxygen peroxide and then gently etched with diluted HCl. Radiocarbon measurements were performed at the CIRCE Laboratory of Caserta, Italy (Terrasi & *alii*, 2007, 2008). Radiocarbon ages were calibrated by using the Marine13 curve in Calib 7.10 (Reimer & *alii*, 2015). It is important to underline that the reservoir effect values for the Southern Atlantic Ocean and, in particular, for coastal Patagonia, are not well constrained and specific studies suggest that for different localities of the Patagonian coast between *c.* 42°S and 50°S the reservoir effect can vary between 180 and 530 years (Cordero & *alii*, 2003; Butzin & *alii*, 2005; Schellmann & Radtke, 2010).

RESULTS

Figure 2 shows a simplified geological and geomorphological map of the Puerto Deseado village area, while figure 3 shows some schematic geomorphological sections

TABLE 1 - Radiocarbon dates obtained for the deposits of the studied area (from this work and Zanchetta & *alii* (2014). Radiocarbon ages were calibrated using the Marine13 curve in Calib 7.10 (Reimer & *alii*, 2015).

Sample	Field code	^{14}C yr BP (±2σ)	^{14}C cal yr BP (±2σ)	Elevation (m. a.s.l)	Species
DSH1966*	WP385(1)	41,600±1200	42,683 - 46758	10	*Brachidontes purpuratus*
DSH2160*	WP385(2)	45,880±2060	45,235 -≥ 50000	10	*Brachidontes purpuratus*
DSH1963**	WP323	710±30	283 - 430	5.5	*Aulacomya atra*
DSH4028**	PDP1	5850±40	6181 - 6364	9	*Mytilus edulis*
DSH4031**	PDP2	4260±90	4091 - 4618	8	*Mytilus edulis*
DSHI961**	WP383(I)	3520±25	3334 - 3475	9.5	*Nacella (Patinigera) deaurata*
DSH2732**	WPi 038	2225±60	1677 - 1982	7	*Alaucomia atra*
DSH 1959**	WP344	880±30	449 - 542	3.8	*Nacella (Patinigera) deaurata*
DSH2735**	WPi 039	480±60	449 - 542	3.5	*Alaucomia atra*
DSH 1968**	WP381	2080±25	1990 - 2124	7	*Nacella (Patinigera) deaurata*

* From this work; ** After Zanchetta & *alii*, 2014

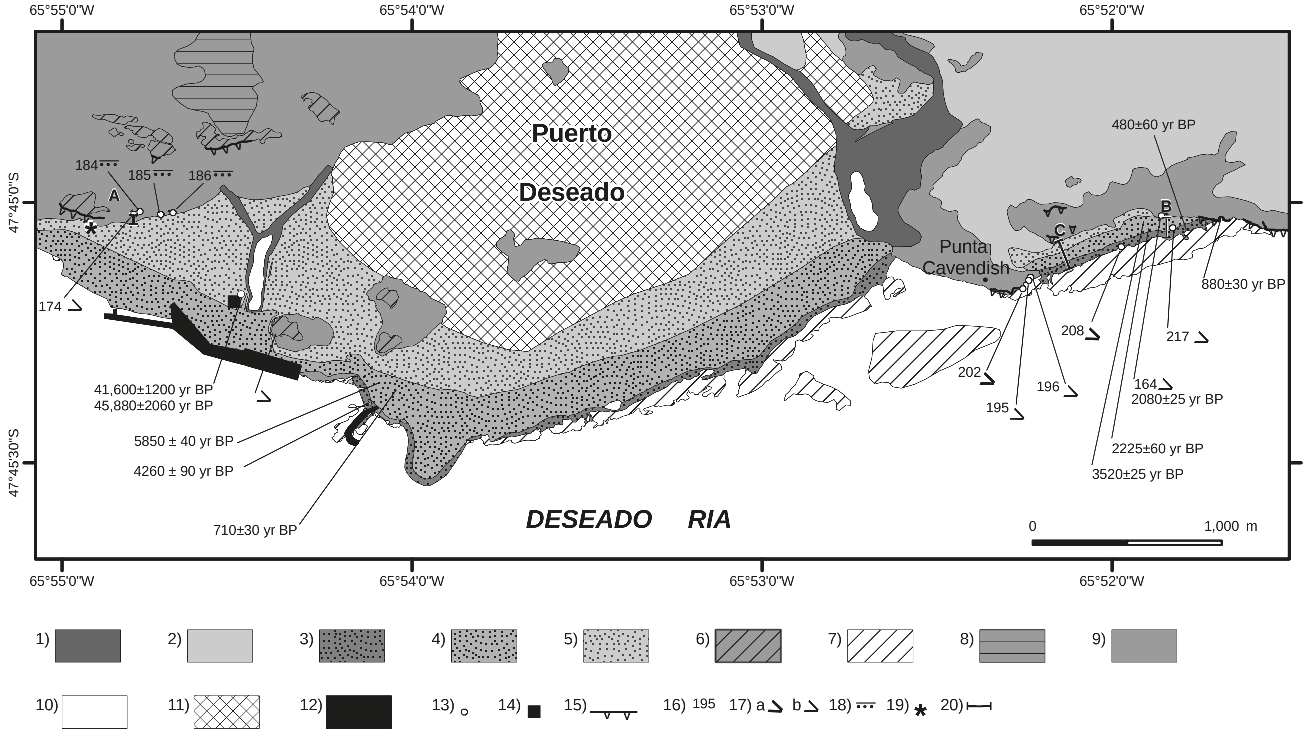

FIG. 2 - Geomorphologic sketch map of the studied area.

1: fluvial deposits (Holocene); 2: fluvial deposits (Pleistocene); 3: active beach deposits; 4: Holocene marine deposits, system VI by Feruglio (1950 undifferentiated); 5: Pleistocene marine deposits, System V by Feruglio (1950 - MIS5e); 6: relict wave-cut platform; 7: wave cut platform; 8: relict surface; 9: bedrock; 10: lake/sea; 11: urban area; 12: harbour area; 13: DGPS way point position (WP); 14: Prefectura Naval; 15: marine cliff edge; 16: way-point number; 17 a) active and b) inactive abrasive notch; 18: inner margin ; 19: sand wedge polygons; A) B) and C) cross sections. The position of radiocarbon ages is reported.

of the study area. The separation of Systems VI and V was undertaken following morphological and stratigraphic evidences, soil development and radiocarbon dating. System VI is characterized by an alternation of well-rounded gravel with low-angle seaward prograding foresets. At least three different sub-units within System VI can be distinguished, even if the discontinuity of the outcrops and the presence of the villages did not allow their mapping in figure 2. The younger unit is basically active and the basal marine abrasive surface developed on the volcanic rocky substrate seawards. The second sub-unit is characterized by a very thin 20-30 cm soil cover, locally dated at 4260±90 yr BP (tab. 1; Zanchetta & *alii*, 2014). The older unit is covered by 50-60 cm of pedogenised sand (probably of aeolian origin), with a well-developed A horizon, and with an accumulation of pedogenic carbonate at the base. This was locally dated at 5850 ± 40 yr BP (Zanchetta & *alii*, 2014). A shellmidden accumulation within the upper A horizon of the soil was dated at 710±30 yr BP (Zanchetta & *alii*, 2014). Just below the building of the "Prefectura Naval" (fig. 2) this older sub-unit lies on the erosive surface of the System VI deposits prograding with an angle over System V (fig. 4a) and it can be considered the pinch-out on land of the Holocene deposits of System VI. However, two samples of badly preserved shells of *Brachidontes purpuratus* (Lamarck) were collected from this outcrop yielding very old ages close to the limit of the radiocarbon method (tab. 1). *B. purpuratus* is a euhaline marine inhabitant of supralittoral, intertidal and sublittoral environments with an epifaunal life habit. This bivalve is an epibyssate suspension-feeder related to hard bottoms, i.e. rocky or coarse sands with pebbles. A high percentage of *B. purpuratus* may indicate cool sea surface temperature (Aguirre, 2003; Aguirre & *alii*, 2006).

System V deposits show low-angle prograding structures similar to System VI (fig. 4 a,c), resting on an erosive surface over the welded volcanic rocks (fig. 4d). The deposits are characterized by well-rounded coarse polygenic gravels with rare, abraded and fragmented marine shells. The top is marked by the succession of continental deposits and truncated paleosoil horizons (fig. 4b) described in detail by Ribolini & *alii* (2014), which makes these units easily recognizable, with higher elevation compared to System VI.

The limit on the land of System V is often marked by a succession of relatively well-preserved vertical erosive cliffs sealed at the base by coastal deposits or showing directly the inner margin of the terraces with the shore platform (figs. 2 and 5), and in some cases preserving erosive notches (figs. 2 and 6 a,b). Table 2 reports the altitude of the most important sea-level indicators surveyed in the area.

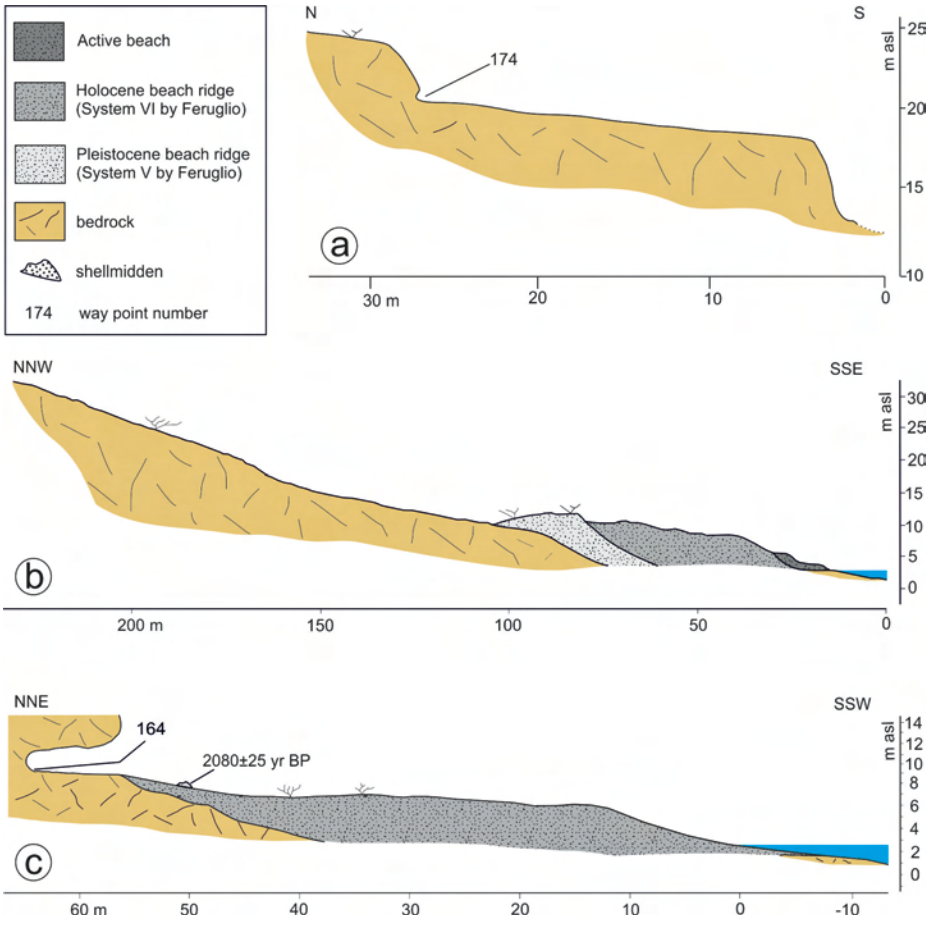

FIG. 3 - Geomorphological sections of the study area (see location in figure 2): a) section NS oriented passing from 174 WP. This WP whit an elevation of 21.4 m a.s.l. represents the inner margin in this area. In this point a notch is well visible; b) section NNW-SSE oriented passing from 164 WP. This section shows the stratigraphic relation between an abrasive notches located at 9.15 m a.s.l. and the Holocene marine deposit (system VI by Feruglio 1950); c) section NNE-SSW oriented showing the stratigraphic relation between Holocene marine deposits (System VI by Feruglio, 1950) and Pleistocene deposits (System V by Feruglio, 1950); b and c are after Zanchetta & *alii* (2014, modified).

DISCUSSION

Stratigraphy and chronology

According to Rutter & *alii* (1989, 1990) Electron Spin Resonance (ESR) dating and aminostratigraphy proposed for System V could be controversial, although their original age assignment was probably the most correct. Field observations indicate that System V is characterized by rare and poorly preserved marine shells, which have probably limited the selection of samples for dating (Rutter & *alii,* 1989, 1990; Schellmann & Radke, 1997, 2003). However, there is little doubt that System V is the youngest unit sealed by Holocene coastal deposits (Zanchetta & *alii,* 2014) and is directly covered by a continental succession developed during the Last Glacial – late Glacial (Ribolini & *alii,* 2014). Thus, it appears consistent to confidently assign System V to the Last Interglacial phase. Moreover, regional considerations on elevation indicate that System V should be reasonably correlated to MIS5 (Rutter & *alii,* 1989, 1990; Schellmann & Radke, 1997, 2000; Rostami & *alii*, 2000; Pappalardo & *alii*, 2015), and in particular to the MIS 5e highstand. The deposits outcropping close to the "Prefectura Naval" yielding very old ages (table 1) are stratigraphically coherent in representing the on-land termination of Holocene marine units. There are other examples of radiocarbon ages on marine samples at the limit of the methods obtained in Patagonia in the past (e.g. Codignotto & *alii*, 1988; Zanchetta & *alii*, 2011) and generically indicating MIS2-3 chronology. These radiocarbon data are now reviewed as having been obtained on weathered and/or reworked material and are usually referred to the MIS5 interglacial, rather than to the MIS2-3 (Rutter & *alii*, 1990). We have to admit that our samples are probably the result of reworking from the System V deposits. This indicates, once again, that badly preserved shells in systems characterised by high energy, like those discussed in this paper, cannot be confidently used for chronological purposes. Moreover, this may suggest that some of the ages obtained for System V by Rutter & *alii* (1990) are the results of reworked older material.

Geomorphological Indicators and Relative Sea-level

For a long time, notches developing in non-carbonatic rock by a predominantly abrasive action have generally been considered unreliable sea-level indicators, their meaning mostly depending on the availability of abrasive sediments and wave energy (e.g. Pirazzoli, 1986; Kellatat, 2005). However, recent works have highlighted that pro-

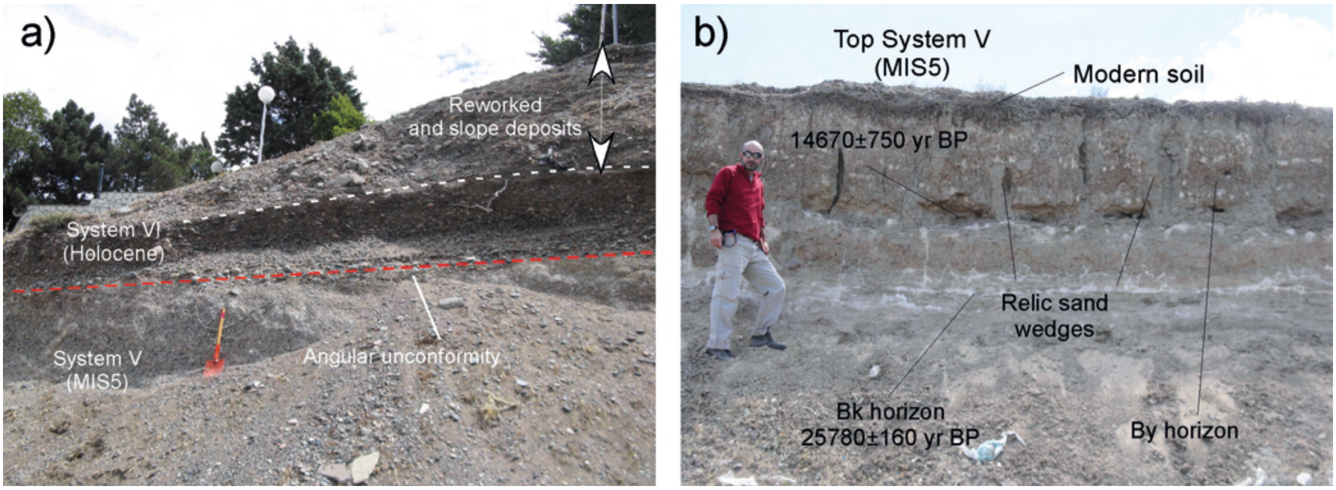

FIG. 4 - a) Contact between System V and VI; b) Succession of continental deposits on top of System V. Detailed description of dating in Ribolini & *alii* (2014): c) Low angle prograding structures in the System V deposits; d) Basal erosive contact of the System V on the weleded volcanic rocks.

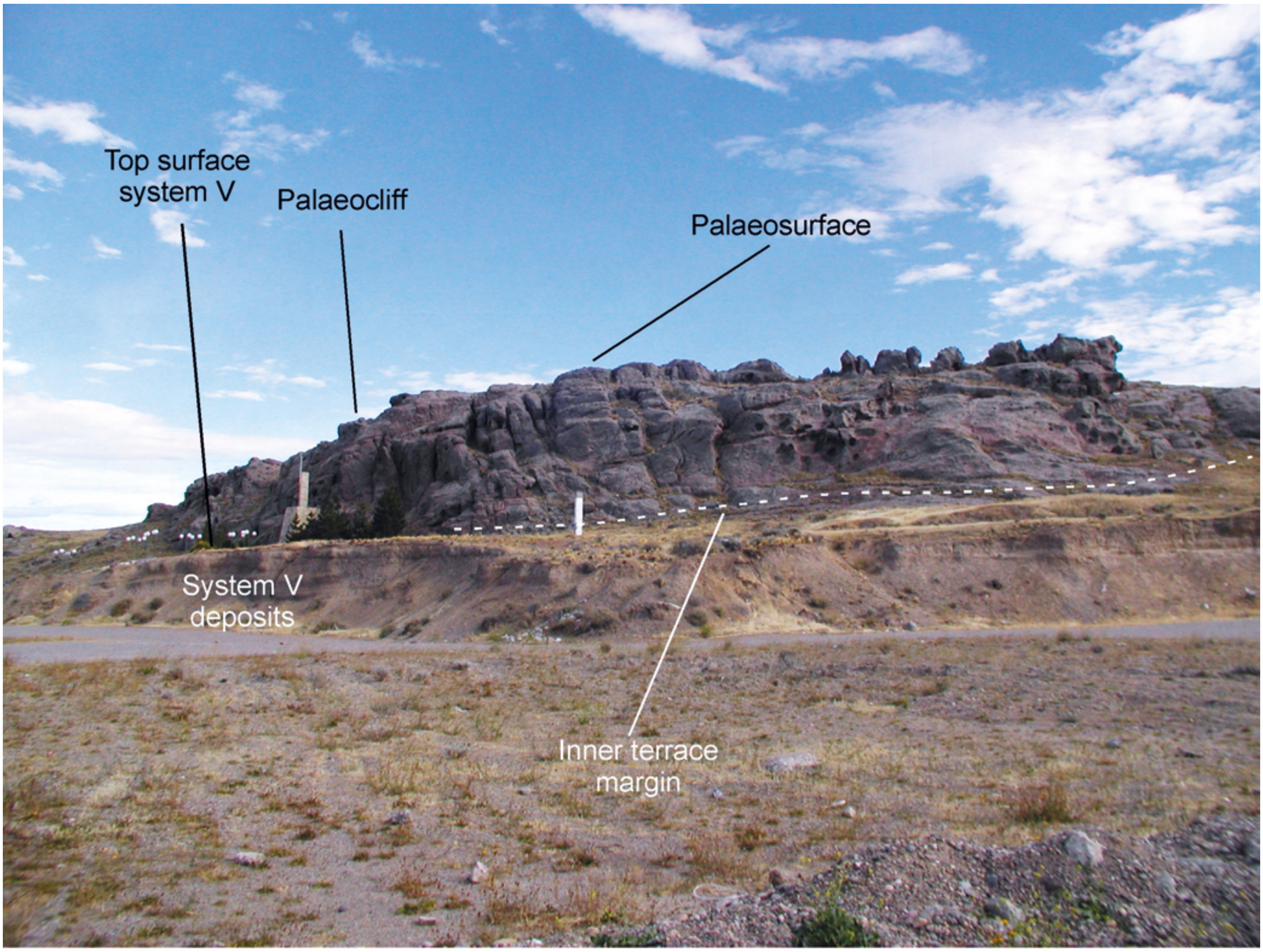

FIG. 5 - Overview of the main morphological elements characterizing the System V described in the text.

TABLE 2 - Elevation (m a.s.l.) of the main indicators used in this work for RSL reconstructions. Radiocarbon dating are discussed in the text. Way point locations are shown in fig. 2. Abrasive notches and inner margin mark the upper limit of high tide level, taking into account tidal range (4 m), the mean sea-level is located about 2 m below the elevation of these geomorphological indicators.

Point	Altitude (m. a.s.l.)	Age (yr cal BP)	Geomorphological Indicator
164	9.15	3367-6305	Abrasive notch
174	21.40	MIS 5e	Abrasive notch
184	23.36	MIS 5e	Inner margin
185	22.82	MIS 5e	Inner margin
186	22.99	MIS 5e	Inner margin
195	5.30	476-1697	Abrasive notch
196	5.00	476-1697	Abrasive notch
202	2.96	modern	Abrasive notch
208	2.65	modern	Abrasive notch
217	4.97	476-1697	Abrasive notch

cesses forming abrasive notches can be more confidently related to average sea-level stands, and that they can represent important sea-level indicators in macrotidal areas, when their formation processes are well understood (Trenhaile, 2015). Trenhaile & *alii* (1998) observed that the retreat point of abrasive notches on the Canadian coast was located a short distance below the mean high tide level. Similarly, Dickinson (2000) in the Pacific Islands observed that the retreat point is located close to the high tide level, while Irion & *alii* (2012) related the floor of the notches to the spring high tide on the Brazilian coast. Therefore, abrasive notches are now also used to obtain information on RSL on the Last Interglacial (Sisma-Ventura & *alii*, 2017).

Specifically for the area of Puerto Deseado Bini & *alii* (2014) observed that the retreat points of several active notches and the inner margins of shore platforms developed in the welded volcanic units close to the average of high tide. In the same area other inactive abrasive notches were observed and used as indicators of Holocene RSL (Bini & *alii*, 2014; Zanchetta & *alii 2014*).

Dating indicators like abrasive or tidal notches is not so straightforward. The currently active notches and inner margins in the Puerto Deseado areas range from ca. 2.5 to 3.0 m a.s.l., whereas a set of inactive notches has been identified at 5-5.30 m a.s.l.. These notches are morphologically more recent than a beach ridge dated at 2225±60 yr BP, and also younger than a shellmidden dated at 2080±25 yr BP, and sealed by beach deposits dated at 880±30 yr BP and by deposits covered by archeological levels dated at

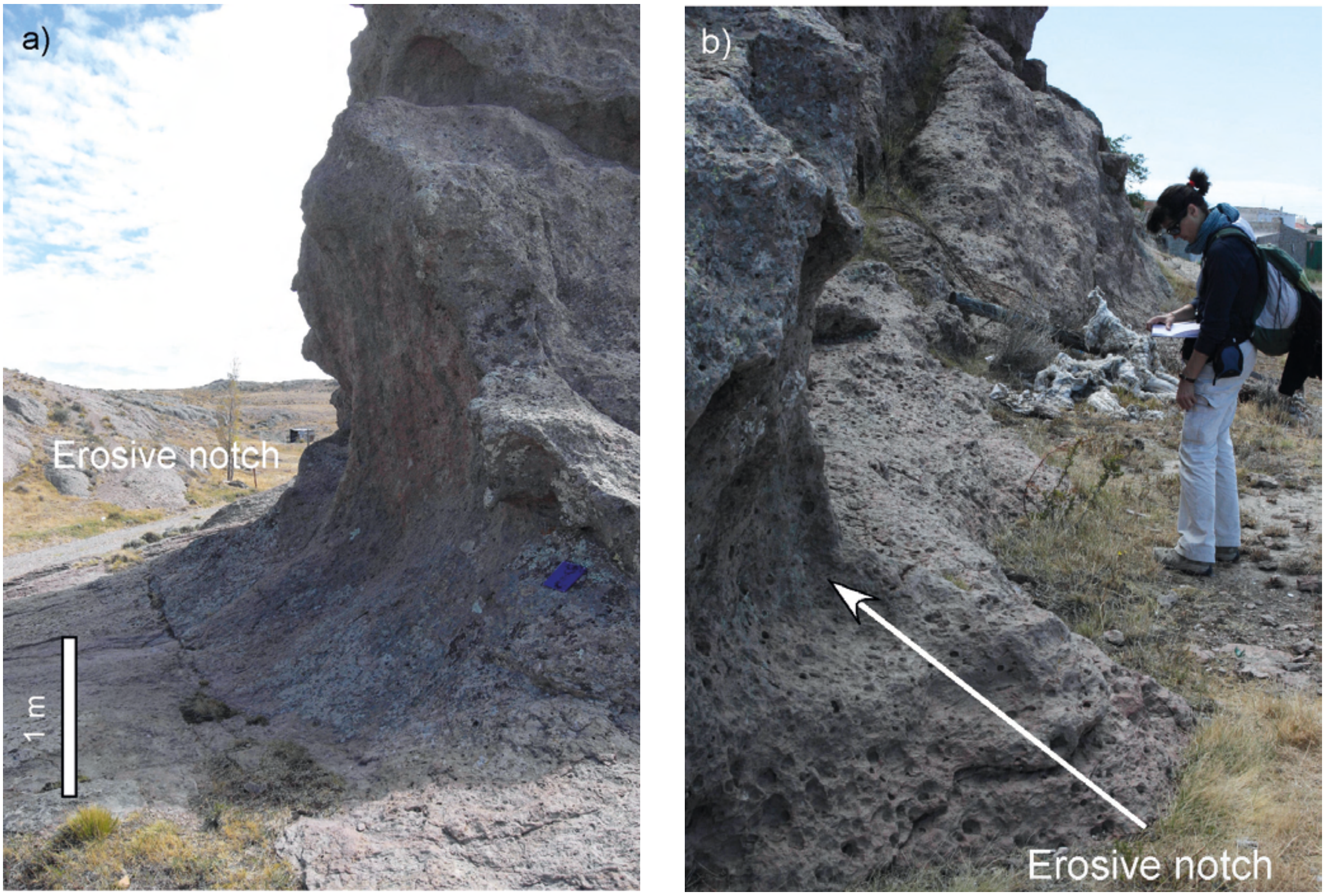

FIG. 6 - a) and b) examples of abrasive notches surveyed in the area of Puerto Deseado village, in the correspondence of inner margin of the terraces formed by System V.

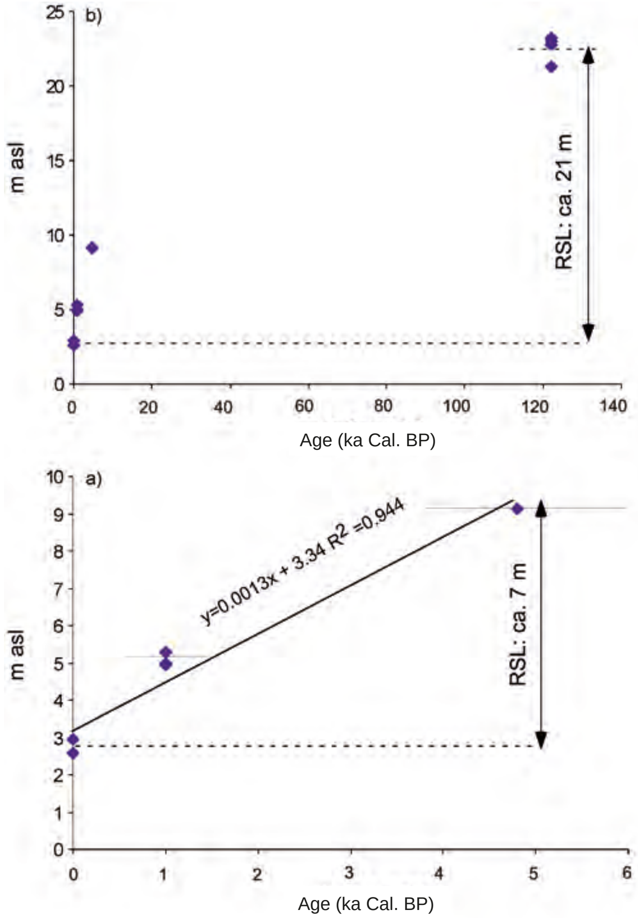

FIG. 7 - RSL changes reconstructed for the Holocene and MIS5 highstands. A) Holocene data; B) Comparison between Holocene and MIS5e. Having a good set of sea-level indicators with the same meaning close each other their vertical differences give directly the RSL change (Shennan, 2015). Table 2 reports the data from which the figure was obtained.

480±60 yr BP (Zanchetta & *alii,* 2014). There is also a set of inactive notches at ca. 9 m a.s.l., enclosed by beach ridges dated at 3520±25 yr BP and 5850±40 yr BP. Considering the calibrated ages (tab. 1), we can infer that the lower inactive notches formed between 449 and 1990 cal yr BP, while the uppermost notch developed between 3520-6364 cal yr BP (tab. 1, 2 and fig. 6a).

As already stated, there are no confident direct radiometric ages from the Puerto Deseado area for System V, and the radiometric ages for MIS5 deposits in the Patagonian coast are generally characterized by low precision estimations (Rostami & *alii*, 2000; Schellman & Radke, 2000; Pappalardo & *alii,* 2015); consequently, it is still problematic to assign an age to the MIS 5e highstand. In general, the most accepted ages for the MIS 5e highstand are those obtained using the U/Th technique from coral collected in stable tectonic settings with an age of 128-116 ka (122±6 ka, Stirling & *alii,* 1998; Muhs, 2002). Direct comparison of indicators of different ages and altitudes with the same meaning in a specific area provides a direct estimation of the RSL change (Shennan, 2015).

Figure 6 shows the RSL change obtained by means of indicators ranging in age from the Holocene to the MIS 5e. At ca. 5 cal kyr BP RSL was ca. 7 m higher than the present sea-level (fig. 7). This value is ca. 2 higher than the predicted total RSL change minus the eustatic model component for a time-window extending from 6 cal ka to the present-day obtained from global models (Milne & Mitrovica, 2008). For ca. 5 kyr, our data indicate an average rate of RSL fall of ca. 1.3 mm/yr (fig. 7).

Interestingly, Purkey & *alii* (2014) evaluate a regional Sea-level Rise (SLR) of 3.3 mm/yr caused by global warming between 1996 and 2006, using full-depth *in situ* ocean data and satellite altimetry. In the awareness that a comparison of short-period and long-period data could introduce some errors, it is important to observe that the net effect of estimated RSL fall (1.3 mm/yr) and regional SLR (3.3 mm/yr) is ca. 2 mm/yr for the Puerto Deseado area.

Figure 6b shows that MIS 5e shorelines are likely to rise 21 m from the present-day sea-level. The points related to the MIS 5e highstand (fig. 6b) are not located on the same linear trend previously described for the Holocene (fig. 6a). This deviation is the result of different components like: i) higher eustatic sea-level during the MIS5e; ii) potential tectonic effect on the passive margin; iii) current glacio isostatic adjustment (GIA). By applying a crude correction of ca 6 m for the eustatic component (e.g. Esat & *alii*, 1999; Nisi & *alii 2003;* Hearty & *alii, 2007;* Muhs & *alii*, 2012), an uplift of ca. 0.12 mm/yr is accepted, in agreement with previous regional estimations (Pedoja & *alii,* 2011). The eustatic component set at ca. 6 m is a matter of debate, and is now considered a lower boundary for the MIS5e highstand, with maximum values reaching 9 m during a later stage of the highstand (Creveling & *alii*, 2015 and reference therein). We obtain a rate of uplift of ca. 0.10 mm/yr by using the maximum values of 9 m. However, a more correct approach should consider the combined effect of eustasy and GIA specific to the location considered (Hay & *alii*, 2014; Creveling & *alii*, 2015). Glacial isostatic adjustment encompasses the full deformational, gravitational, and rotational perturbation in the sea-level driven by the redistribution of ice and ocean mass, introducing significant geographic variability (i.e. departures from eustasy) into the correction. Different model experiments performed by Creveling & *alii* (2015) introduce corrections for coastal Patagonia which can be up to 4 m of departure from the eustatic component. This may reduce the uplift rate to values as low as 0.06 mm/yr.

However, the presence of an important tectonic component for a passive margin, initially suggested by Codignotto & *alii* (1992), was also supported by other authors (Pedoja & *alii,* 2011*;* Isla & Angulo, 2016) on a very large scale set of observations. The author interpreted the Quaternary raised terraces of the Atlantic coast of Patagonia to be the result of the uplift induced by the subduction of the Chile Ridge, and also related to the presence of a Quaternary extra-Andean plateau lava volcanic field.

Despite the complications arising from the departure from eustatic components of the regional sea-level, simulations suggest that most of the Patagonian coast has the same range of correction (Creveling & *alii*, 2015). This may suggest that accurate measurements in different sectors could be very precious to define differential uplift and/or subsidence rates.

CONCLUSIONS

The Deseado area is peculiar within the context of the Patagonian coast because it is an uplifted massif, according to the classical geological literature. It is therefore reasonable to think that the uplift rates in this area are higher than elsewhere along the Patagonian coast. In this work new evidence is presented supporting this general view.

The data obtained from terrace inner margins and notches related to the MIS 5e highstand in the area of Puerto Deseado allowed to estimate the RSL change ca. 21 m with respect to the current sea-level. This implies a significant component of tectonic uplift, roughly estimated to be ca. 0.12 mm/yr, in agreement with previous papers. These values can be halved considering the regional GIA corrections.

The data presented are the result of precise and accurate DGPS measurement of sea-level indicators for which the indicative meaning is well understood. This approach is mandatory to obtain the best estimation of uplift rate for this portion of the Patagonian coast. Previous authors calculated the tectonic uplift by measuring the geomorphological indicators directly at the Argentinian network elevation or by using a barometric altimeter, producing data affected by a large error.

Our data indicate that the ongoing uplift at Deseado can compensate the effect of the SLR related to ocean mass and steric changes induced by modern global changes.

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