



*PROGETTO ATENO 2007*

*University of Pisa*

*Department of Earth Science*

“Reconstruction of sea-level changes and climate during the last and present interglacials over Patagonian coast (Argentina). An essay of evaluation for futures climatic scenarios”.

FINAL REPORT 2010

“The end of the beginning”

*(Leader Dr Giovanni Zanchetta)*

## Abstract of the “Progetto Ateneo 2007”

The Patagonia is the only continental landmass emerging along the mid to low-latitudes in the Southern Hemisphere, and this makes it a unique region of the world. This represents a key area for understanding the role of the southern hemisphere in regulating climate during the last hundredth of thousand years. From the Andes to Atlantic coast Patagonia preserves an impressive geological record of the glacial events and sea-level oscillations. The Quaternary coastal deposits, often organised in spectacular successions of raised-beaches-ridges deposits contain an almost unexplored archives of past climate. These natural archives can offer precious information on local relative sea-level changes, tectonic and glacial isostasy component, and fundamental information on past surface ocean conditions and, through the study of the continental deposit related to beach-ridge systems, information also on terrestrial climate. This project intends to explore these paleoclimate archives through a multidisciplinary approach as detailed stratigraphy, morphological, paleontological and geochemical analyses of a target area. The target area, the northern part of Gulf S. Jorge (Chubut, Argentina) has been selected collecting and collating remote sensing and literature data and has recently been a subject of a preliminary field work. Concisely, the main aims of the project are: i) to construct a local relative-sea level curve; useful for estimating local deviation to the eustatic component due to glacial isostasy and tectonic activity; ii) to reconstruct local sea surface condition through geochemical studies; iii) evaluate the biological changes associated to different sets of beach-ridges through the paleobiological studies of fossil shells; iv) to study the general evolution of coastal area in relation of evolution of continental deposit related to the beach ridges; v) in a more restricted area, selected on the basis of previous points, sea level rise due to the progressive global warming will be modelled the using IPCC current predictions, in order to produce scenarios for understanding the potential changes occurring in the area during the current climatic change.

This project will provide to the international community new data for understand climate system in this strategically located region of the world. The expected results are important since the patagonian coast is an environment of high natural values (however, it is threatened by oil exploitation, mining and increasing tourism) and represent a natural heritage that need to be preserved for future generations as reserve of marine and terrestrial biodiversity. This project intends to produce and disseminate data also for supporting form of tourism based on care and responsibility and selecting some area to be further preserved as “geosites”. All the data will be

organised in a Geographical Information System, which will be available, under request, to all the national and international institutions.

This is an ambitious project, which will project an Italian team in one of the “hot” areas for the study on past climate and where the sign of current climatic warming are clear. It also represents the opportunity for developing international scientific collaborations, in a first instance between two countries (Italy and Argentina) linked by strong cultural and scientific relationships.

### Abstract of the activity 2009-2010

The project has followed its marching list and the final main targets of the project was reasonably achieved. Of particular relevance was the capacity to obtain further financial support from the PRIN 2008 (ca 50,000 E) project. This is an important success, which allow a further two years of research and further looking for funding. This unequivocally demonstrated that Ateneo funding for research can produce important opportunity for attracting funding and promoting science.

During the second year of the project a further field campaign was performed (January-February 2010). During this campaign some localities was re-visited for stratigraphic and sampling refinement and new ones were visited in order to complete the work on the Gulf S. Jorge (down to Puerto Deseado, see Fig. 1). New sections were measured and sampled. Part of the analytical work is still in progress as part of the project of a PhD student. Within this project a care use of funding allowed to partially support (part of the economical support was make available by hosting Institutions) a visit of two students at the University of Newcastle and University of Melbourne (Australia) in a frame of collaborative project with the intent to study the isotopic response of different type of carbonate (including samples from Patagonia) during Quaternary to climatic changes.

Analytical data definitively demonstrate the suitability of *Prototacha antiqua* as potential proxy for paleoclimatic studies. Preliminary selection of *P. antiqua* samples prepared in a completely new manner suggests that this mollusc can be used for dating using U/Th methods (usually difficult to apply for marine shells). If this new preparation methods will be confirmed by further U/Th dating this will give a very powerful tool for accurately dating these successions. Preliminary geochemical data suggest that U content could be a further tool for selecting shells for dating. Other geochemical proxies (e.g. Ba/Ca, Sr/Ca molar ratio) seems indicate that they can be used as paleoproxies for paleoceanographic reconstructions. Stable isotope data ( $^{13}\text{C}/^{12}\text{C}$  and  $^{18}\text{O}/^{16}\text{O}$  ratios) indicate very large variability of modern condition in the gulf but that in the past systematic differences between old beach ridges sets existed, which can be interpreted as substantial different paleoceanographic

conditions. Paleontological and geochemical data indicate that the last interglacial (MIS5) and MIS7 appears consistently different from the current interglacial. In particular they seem to contain molluscs indicating a more stronger influence of the cold and less saline Malvinas current. Although, it is not surprising for the MIS 7, which is usually considered a “colder” interglacial (e.g. Bard et al., 2002), this finding seems, if confirmed, particularly relevant for the MIS5.

Geomorphological investigation have been virtually completed for two selected localities (for others, the work is actually in progress) and a certain number of radiocarbon and U/Th dating have allowed some chronological constraints. Two separated manuscripts are now in progress (see list) and the final drafting and submission is foreseen for the end of June (further manuscript are foreseen for the end of the year). These two manuscripts illustrated as new geomorphological approaches for the area have been attempted to overcome the current methodological difficulties in obtaining accurate estimation of relative sea level in the area. The new field campaign has allowed to select new localities in which these approaches can be tested.

For the area selected as geosite (see report 2008-2009), the Bahia Bustamante, a preliminary project (summarised in a bilingual poster – Spanish and English, see enclosure 1) have been submitted to the local owner.

After intense and complex discussion with the Argentinean team involved in the project, we hope to formalize a scientific agreement between the University of La Plata and the University of Pisa within this summer which can be used as basis for further collaboration/projects. The approval of the PRIN2008 will give a better opportunity to exploit all the data collected so far, enlarge the studied area, and to have time for submitting further project.

We can happily conclude that the most important target proposed in the “Progetto Ateneo” was achieved. This is particularly relevant since the potentiality of the selected area was only tested using remote sensed analyses and bibliographic researches. The active collaboration of the University of La Plata (in particular of Dr M. Aguirre and E. Fucks) has made the project possible especially for the field work in remote area which has required a lot of technical organization (especially with limited funding).

## **Introduction**

The main characteristic of the study area and scientific issues of the project were extensively discussed in the 2008-2009 report. In this final report we will discuss mainly the activity and some of the most relevant results of the project and future development (especially in the frame of the PRIN 2008 -*Reconstruction of relative Sea-level, palaeoenvironments and palaeoclimate during the*

last 500 ka over a selected areas of the Patagonian coast (Argentina): a contribution to evaluate future climatic scenarios- Leader G. Zanchetta).

### The 2010 field trip

The second field trip started on January 24 from Pisa. After three days of technical organization in La Plata, a team of 8 people moved toward Patagonia, using a minibus equipped with a wagon. The team was composed of 3 Argentines of the University of La Plata (biologists and geologists), four geologists of the University of Pisa and one local driver.

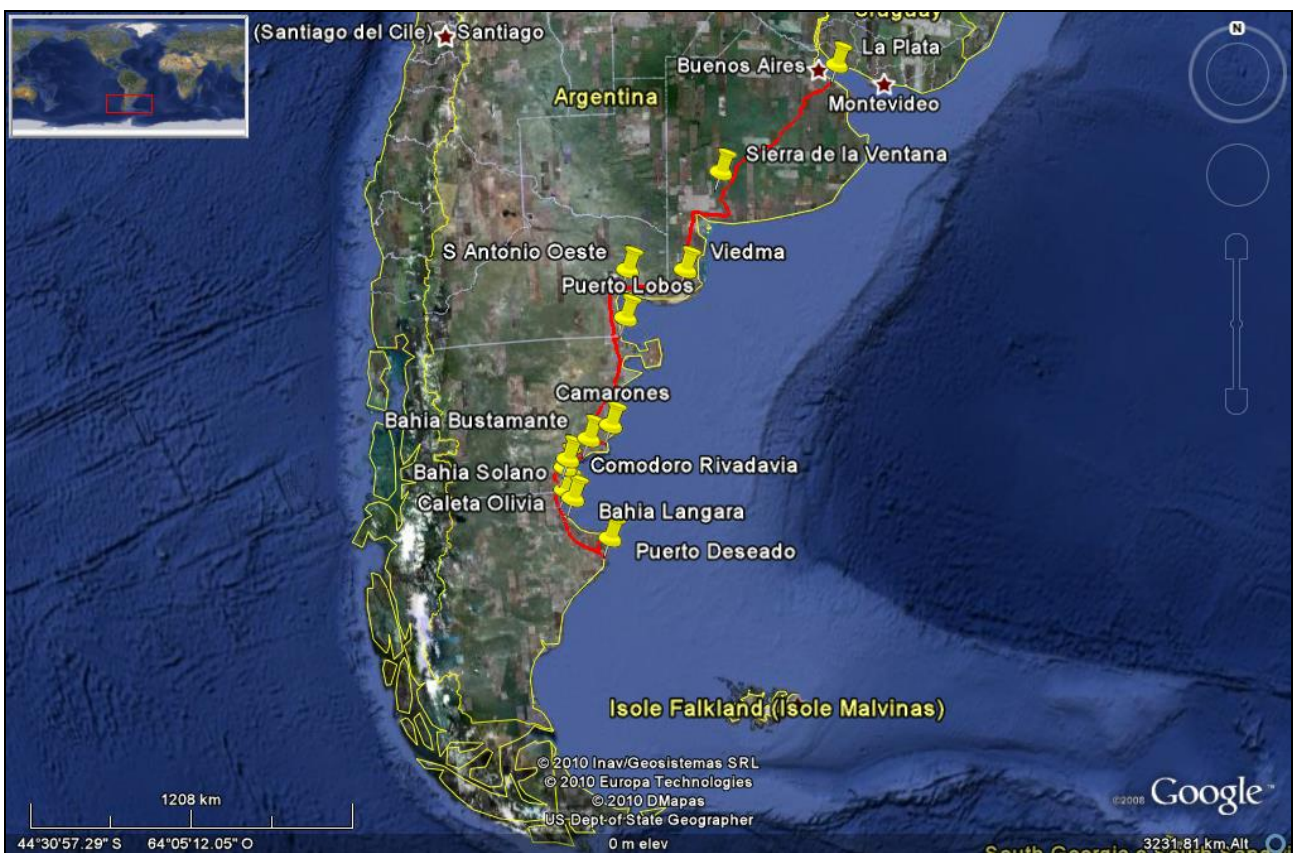


Fig. 1 - Trip path (in red). The most important visited localities are highlighted.

The main stops were the areas of Puerto Deseado, Caleta Olivia, Bahia Solano, Bahia Bustamante and Camarones (Fig. 1). These places allowed to visit and collect samples of the most important successions described in the older and recent literature (especially those sections containing robust chronological control). As regards the former trip, both new (e.g. Caleta Olivia) and already studied successions were visited. Unfortunately two days of sand storms obliged us to renounce to visit some sections in remote areas (Cabo Blanco, Cabo Tres Puntas). Particularly fruitful was the work

at Puerto Deseado, which was the subject of a rapid visit during the first campaign owing to a technical problem to the Van wagon.

During the field trip about 140 samples of fossils and sediment were collected for different analyses (geochemical, OSL,  $^{14}\text{C}$ , U/Th, sedimentological). The field trip ended on February 24, with the two last days spent in La Plata preparing samples for the final expedition.

#### *Periglacial condition during the last glacial*

During field work it was possible, for the first time for most of the area investigated, to collect evidences of the past extension of periglacial environment in the area during (presumably) the Last Glacial Maximum (Fig. 2). The most clear evidence are represented by fossil “sand wedge” individuate at the top of marine terraced successions related (preliminarily) to MIS5 and on upper, older “fluvial” surfaces (e.g. Pampa de Salamanca). The review of literature data confirm not only the absence of these finding in the studied area but the substantial absence of chronological constrains of these “periglacial relicts”. These finding indicate very harsh condition during glacial in the area. The collection of appropriate samples for OSL dating method can allow in the near future to obtain important data for reconstruction climate condition during the last glacial maximum.



*Figure 2. “Sand wedge” at Puerto Deseado.*

*Puerto Deseado: the cornerstone for the relative sea level curve in Patagonia?*

Puerto Deseado area preserves some of the most intriguing evidence of sea level changes encountered in Patagonia. In this area typical beach ridge deposits alternate or coexist with erosional features (erosional notches, marine cave with erosional notches, inner terrace margin) giving the unique opportunity to accurately measure the relative sea level at least for the last two interglacial (Fig. 3). A selection of ca 10 radiocarbon samples will give soon the first result for constraining the maximum sea level during the Holocene and further research will allow a detailed estimation of past sea level at time of the last interglacial with an accuracy never reached in the previous studies. This represents the possibility to quantitatively estimate geophysical model of the isostatic rebound and estimate the existence of differential uplift in the Patagonian coast.



*Figure 3. Cabo Raso: marine cave in volcanic rocks showing a perfect erosional notch. Erosional notches in this area seem to be a perfect indicators of high tide conditions.*

*Cabo Raso: the first systematic use of accurate indicator of past sea level in the Patagonia area.*

In the Patagonia coast estimation of relative sea level curve was virtually based on the estimation of the height of depositional form (terraces surface, beach ridges crest ect, Rostami et al., 2000; Schellmand and Radke, 2000) and not on erosional forms. It is well known that the latter (especially in an environment dominated by energetic high tides) are more accurate estimation of past sea level than the former. However, to determine the exact nature and chronology of erosive form require an accurate field work and proved experience.

Fig. 4 and Figure 5 illustrate the geomorphological situation in the are of Cabo Raso, for which radiocarbon dating have allowed to precisely constrain the inner position of marine terraces during

the Holocene (facilitate by the presence of quoted points in the area). These data indicate that the quote of the maximum transgression today is displaced at ca 7 m asl (ca 6 ka BP), and taking into account the global estimate on eustatic sea level at that time this coastline has been uplifted of ca 8 m. The data also indicate a phase of local stationing at ca 4 ka BP, whereas (with some doubts) the high stand during MIS5e is now uplifted at ca 12 m asl. Further details on the area are reported in the previous report

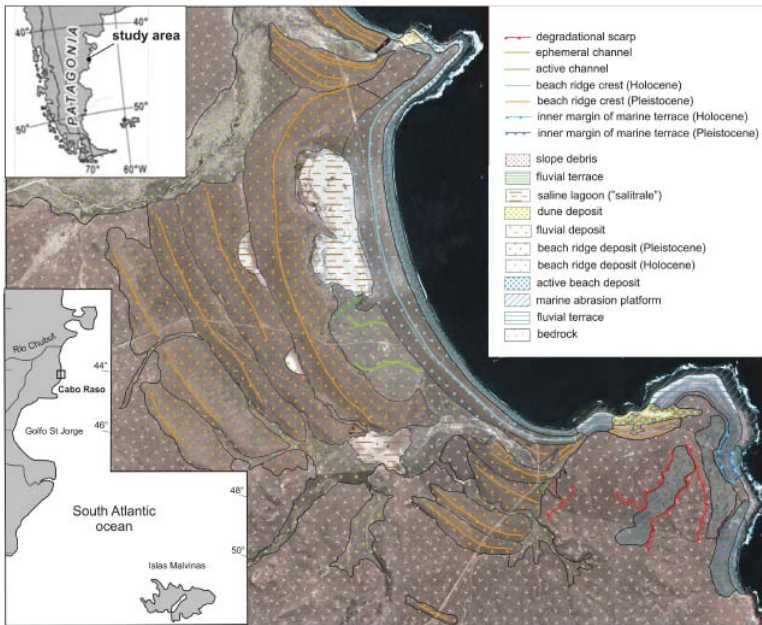


Figure 4. Geomorphological map of the Cabo Raso area (after Ribolini et al., in progress)

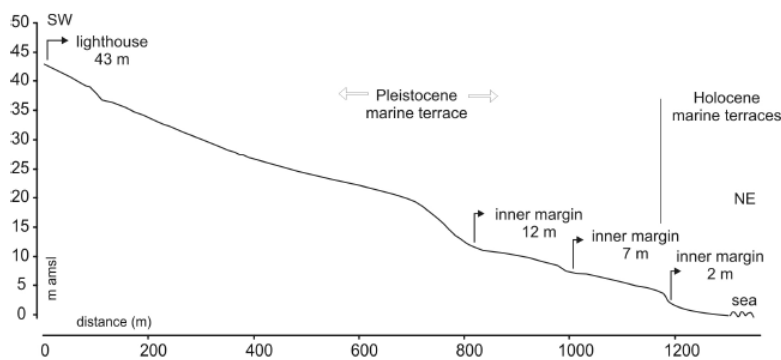


Figure 5. Morphological section along the Capo Raso. Note three well defined inner scarps which are correlated to different sea level high stand during Holocene and Pleistocene (after Ribolini et al., in progress)

Camarones Nord: the prove of differential uplift in the Patagonian coast?



The area of Camarones nord was one of the areas previously studied by Shellman and Radke (2000 and reference therein), which, in particular, supplied fundamental chronological constrains for the beach ridges related to MIS 5. A new accurate survey allowed the identification and dating of the Holocene basal transgression and accurately estimate its current height asl (Fig. 6). The radiocarbon age is ca corresponding to those determined for Cabo Raso and other Patagonian localities indicating that the maximum transgression in the Patagonian cost is substantial coeval and occurring at ca 6000-7000 yr BP. However, the new detailed survey indicate that the quote at Camarones Nord is significantly lower than those estimated (ca + 2 m asl), for instance at Cabo Raso (ca. + 7 m asl), and more close to the eustatic level proposed for this phase (not far from present sea level). This surprising results (which needs to be verified in detail in nearby sections) open the possibility that in the Gulf S. Jorge there are sectors with different behaviour in relation to the isostatic rebound. For the area details are also supplied in the previous report.



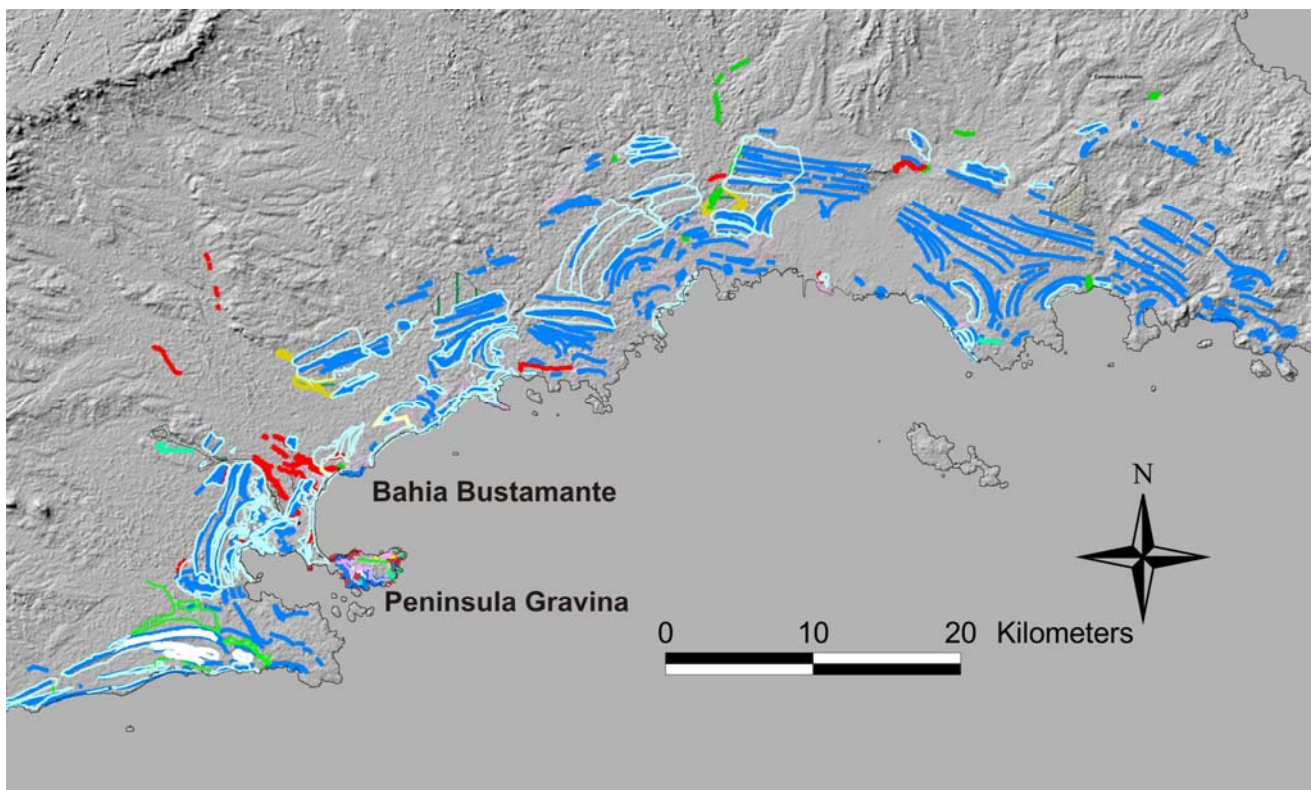
*Figure 6. Deposits of the maximum Holocene transgression at Camarones Nort.*

**Bahia Bustamante: the area with the longest record (up to MIS 13?).**

Bahia Bustamante area is particularly relevant for geological evidences of sea level oscillations, specially for the great number and the dimensions of beach ridges. Preliminary data suggest that there is a record comprising at least MIS 11 but it can preserve older beach ridges (MIS 13?). To prepare field surveys remote sensing analysis was performed using:

- Landsat 7 ETM+ images (seven spectral bands and one panchromatic band);
- ASTER digital elevation model;
- High-resolution Spot images 2002/2009 (QB02 sensor Band Info Pan\_MS1)

Data from remote sense analysis were checked and increased during two field surveys obtaining a preliminary map (Fig. 8)



*Figure 8. Schematic geomorphological map of Bahia Bustamante . In blue beach ridges.*

With the aim to improve the topographic and altimetry information 300 points were taken with a GPS (barometric altimeter) and several topographic sections were made.

Thanks to the great geomorphological paleoclimatic and naturalistic values this area is worthy of particular attentions, having all the characters to be a Geosite (see enclosure 1).

### **Geochemistry and chronology**

So far we have analysed more than 80 specimens of Upper Pleistocene, Holocene and modern *Protothaca antiqua* (King, 1832) Bivalve shells coming from S. Jorge Gulf and a minor number of individuals of other species. *P. antiqua* represents the dominant molluscan species in these deposits (fig. 8). Articulated shells were preferred for the analyses (fig. 8) to decrease the possibility to collect reworked shells from older beds. One to six whole and well preserved shells were analyzed for each layer.



*Figure 8. Protothaca antiqua within a Pleistocene beach ridge.*

The shells were rinsed several times with deionised water and cleaned in an ultrasonic bath. The shells remained dirty were cleaned manually with a drill. Shells were then dried in an oven at 60°C. Each valve was sectioned along the axis of maximum growth using a saw and then a half valve was powdered.

These samples were used for bulk carbonate stable isotopic analyses ( $\delta^{18}\text{O}$  and  $\delta^{13}\text{C}$ ). The samples were analyzed partly at S.U.E.R.C. (East Kilbride, Scotland) with the AP2003 mass spectrometer equipped with a separate acid injector system, after reaction with 105%  $\text{H}_3\text{PO}_4$  under He

atmosphere at 70°C and partly at I.G.G. – C.N.R. (Pisa) with manual CO<sub>2</sub> extraction after purification with cryogenic traps. Isotopic results were reported using the conventional δ‰ notation relative to V-PDB.

Aragonite, forming the shell of these Bivalves, is the least-stable calcium carbonate phase at the Earth's surface and is diagenetically transformed into low-Mg calcite (Land, 1967; Brand and Veizer, 1980; Takesue and Van Geen, 2004). For this reason several shells mineralogy was determined by qualitative X-Ray Diffraction (XRD) to indicate whether diagenetic mineral transformation had occurred. Inductively coupled plasma mass spectrometry (ICP-MS) was used for high resolution trace element measurements on more than 40 *Protothaca antiqua* specimens.

Moreover, the radiocarbon ages of 6 fossil specimens, collected from Holocene and modern shells coming from Cabo Raso and Camarones North to improving the stratigraphy of Holocene beach-ridges successions, were determined at the Keck Carbon Cycle Accelerator Mass Spectrometry laboratory of the University of California, Irvine (USA), using a compact Accelerator mass spectrometry (AMS) unit (NEC 0.5MV 1.5SDH-1). Radiocarbon data are reported as Fraction Modern (FM), the ratio <sup>14</sup>C/<sup>12</sup>C in the sample, corrected for isotopic fractionation, with respect to a “Modern” sample defined as the 95% activity (in AD 1950) of NBS Oxalic Acid I normalized to δ<sup>13</sup>C = -19 ‰ PDB (Olsson, 1970) (Table 1). Further 10 samples are under dating and result will be available within the next weeks.

A small chunk of solid and pristine shell material were extracted from a *Protothaca antiqua* specimen coming from an already dated outcrop (Schellmann and Radke, 2000 and refs therein) in order to apply the <sup>230</sup>Th/<sup>234</sup>U dating method at the university of Melbourne (Australia). The radiometric age obtained (132 ± 2 ka) is in agreement with the previous data and indicate proposed preparation of the samples is probably the most useful for obtaining samples suitable for this methods. New samples are now in Australia (thanks two students now working for their thesis there) for confirming the quality of the approach.

Mineralogical results from X-ray diffraction (XRD) indicate that the pristine aragonite composition was preserved for all the samples analyzed, without any calcite alteration. Manganese content in fossil shells corresponds to the modern specimens concentrations (fig. 9), suggesting any meteoric water alteration (Brand and Veizer, 1980).

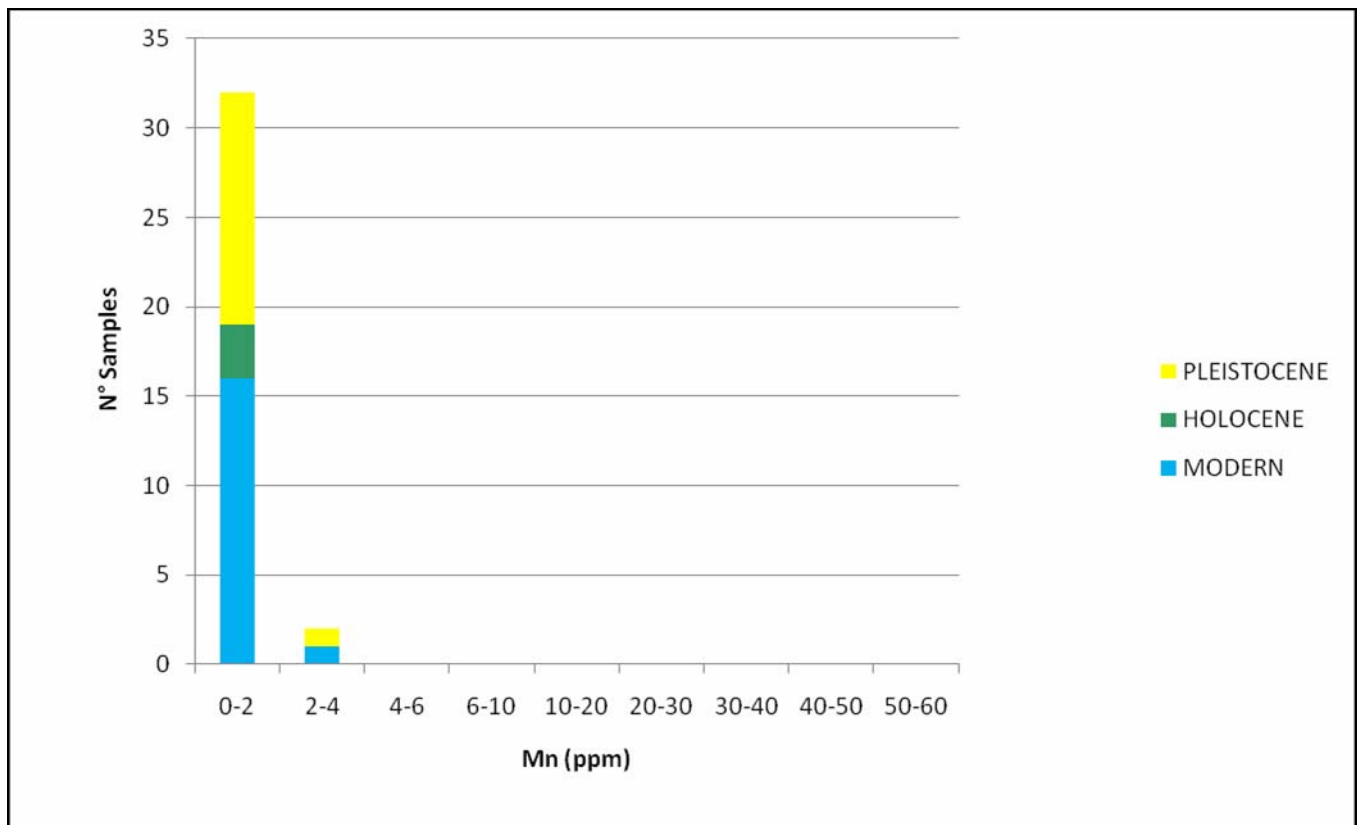


Fig. 9 – Manganese content on *Protothaca antiqua* shells.

Isotopic composition of modern shells (fig. 10) may suggest very large variability, probably driven by changes in salinity and dissolved inorganic carbon isotopic composition, which can complicate simple interpretation of fossil material. However, samples of different age collected in different places, suggest different trends in isotopic composition (e.g. MIS 5 and MIS 7 fossils, fig. 11).

Uranium contents suggest for some specimens subtle diagenesis (fig. 12) , which nevertheless does not affect the isotopic composition. Mg/Ca vs  $\delta^{18}\text{O}$  preliminary results may indicate different geochemical behaviors for different selected periods (fig. 13) possibly related to different set of temperatures.

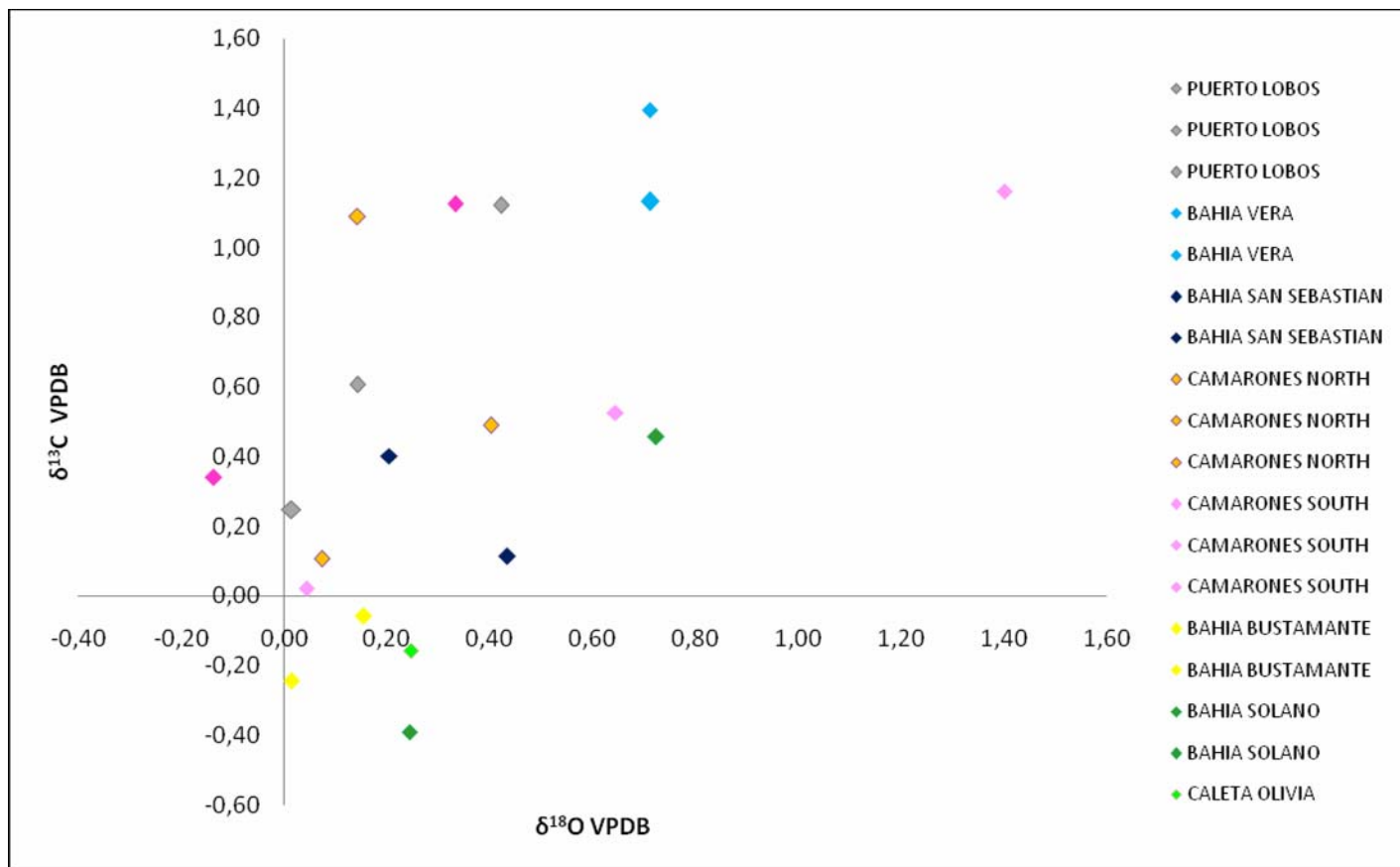


Fig. 10 - Stable isotopes of modern *Prothotaca antiqua* shells from different Patagonian areas.

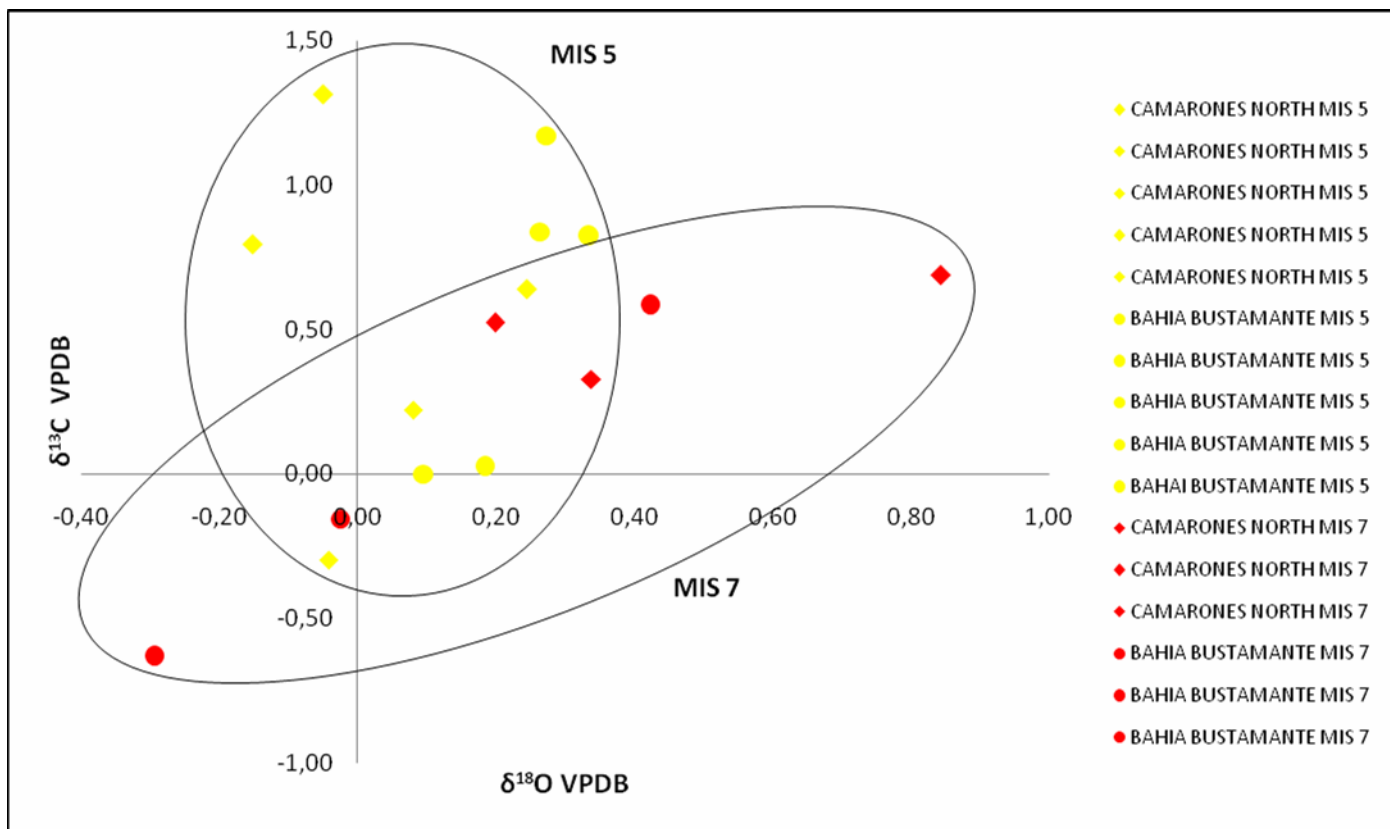


Fig. 11- Stable isotopes of *Prothotaca antiqua* shells collected within MIS 5 and MIS 7 beach ridges.

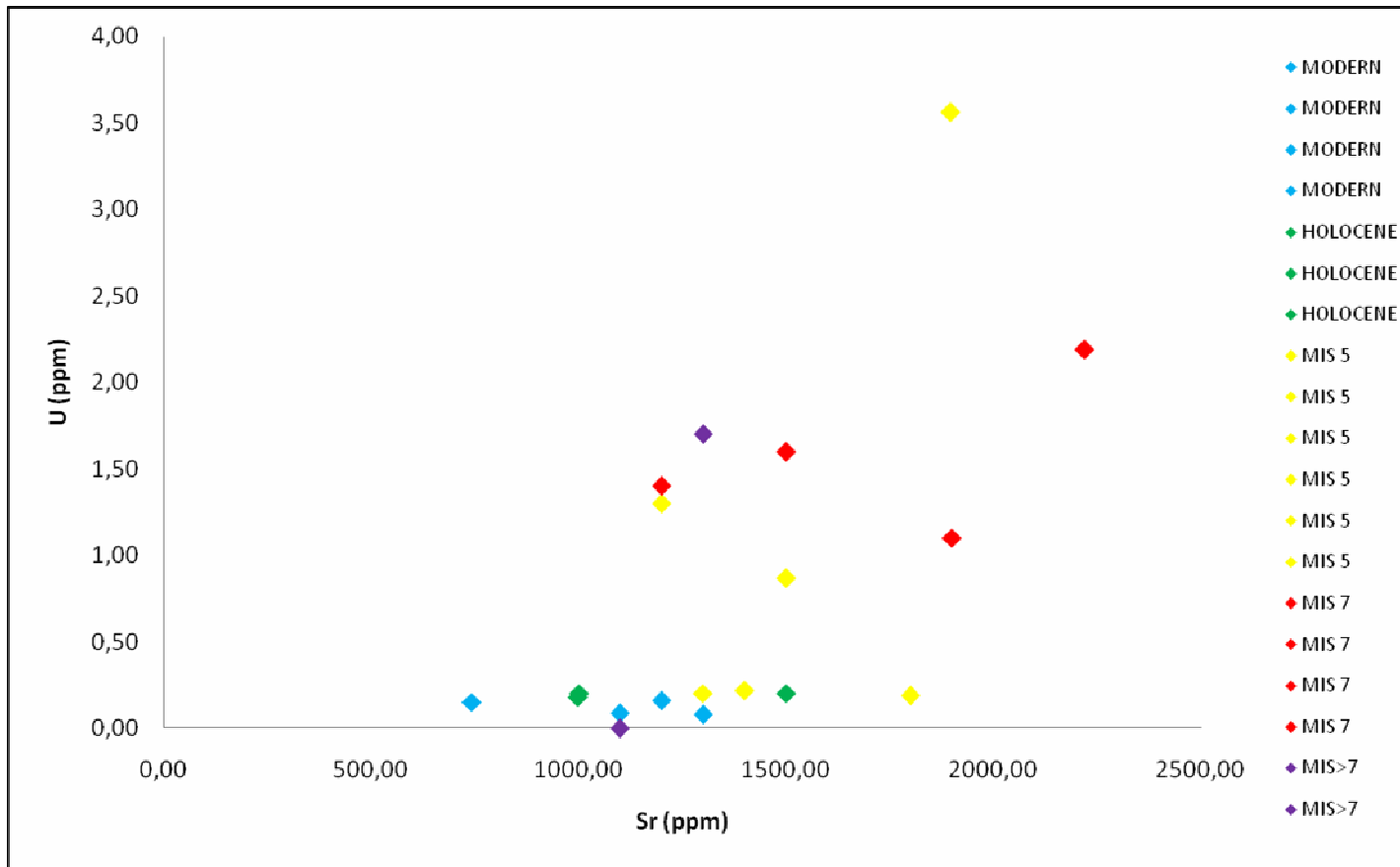


Fig. 12 - Plots of Sr vs U in Bivalve shells.

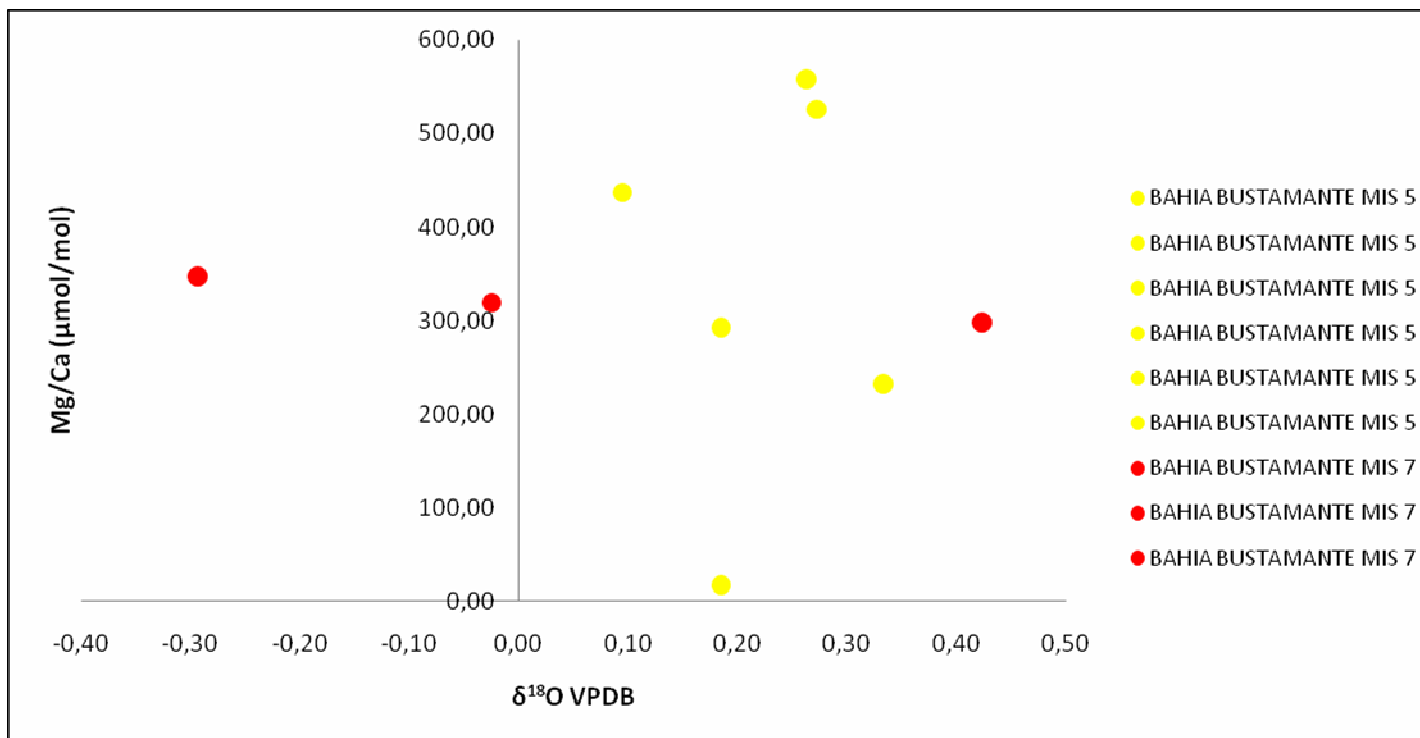


Fig. 13 -  $\delta^{18}\text{O}$  vs Mg/Ca of shells collected within MIS 5 and MIS 7 beach ridges.

Sample name	Fraction	± sd	<sup>14</sup> C age	± sd
	Modern		(BP)	
WP39(1)	0,4707	0,0010	6055	20
WP41(2)	0,5710	0,0012	4500	20
WP60A(2)	0,8923	0,0019	915	20
WP60B(2)	1,0504	0,0022	-390	20
WP63A(1)	0,0388	0,0004	26110	100
WP63B(3)	0,4527	0,0010	6365	20

*Tab. 1 - Radiocarbon data measured for shells reported as Fraction Modern and Radiocarbon age (not calibrated). Data are not corrected for reservoir effect.*

## **Main conclusions**

Data collected so far indicate that in the next months it will be possible:

- To have a first general relative sea level curve to be compared with the previous studies obtained in the same area and to be compared with other curve in the south Hemisphere (e.g. Bonaerense region, Antartica, Tierra del Fuego) in a way to estimate differential uplift at local and regional scale;
- To have important information on extreme condition during glacial (presumably during MIS 2 and 4);
- To have some new chronological data on deposits never dated so far;
- Important information on paleoceanographic changes during different phases of high stands useful for testing hypothesis on paleocurrent changes in the past and exploring potential future changes.
- To transfer these information in an accessible way to local institution through the production of simple development project in the area (like support geosites).



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### **In progress manuscript**

Ribolini et al., Holocene Beach Ridges and coastal evolution in the Cabo Raso Bay (Atlantic Patagonian Coast, Argentina). In progress for Journal of Coastal Geomorphology

Pappalardo et al. Landscape evolution, geodynamics and climate change: a study case form Central Patagonia (Argentina). In progress for Journal of Coastal Geomorphology

Fucks et al., Dèpositos litorales en la region Norte del Golfo San Jorge, en los arleadores de las Estancia La Iberica y San Miguel, provincial de Chubut, Patagonia, Argentina. In progress for Revista Geologica Argentina.