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PII: S1040-6182(20)30077-X

DOI: https://doi.org/10.1016/j.quaint.2020.02.029

Reference: JQI 8161

To appear in: *Quaternary International*

Received Date: 22 March 2019

Revised Date: 10 January 2020

Accepted Date: 20 February 2020

Please cite this article as: Pérez, A.E., Batres, D.A., Rocchetta, I., Eppis, M.R., Bianchi, M.L., Luquet, C.M., Paleoenvironmental Reconstruction Using Stable Isotopes And Trace Elements From Archaeological Freshwater Bivalve Shell Fragments In Northwest Patagonia, Argentina, *Quaternary International*, https://doi.org/10.1016/j.quaint.2020.02.029.

PALEOENVIRONMENTAL RECONSTRUCTION USING STABLE ISOTOPES AND TRACE ELEMENTS FROM ARCHAEOLOGICAL FRESHWATER BIVALVE SHELL FRAGMENTS IN NORTHWEST PATAGONIA, ARGENTINA

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ABSTRACT

Stable oxygen and carbon isotopes (^{18}O and ^{13}C) and the trace elements, manganese (Mn) and strontium (Sr) were analyzed in archaeological bivalve (*Diplodon chilensis*) shell fragments recovered from Parque Diana Cave, Patagonia, Argentina, to analyze the temporal trends of human occupation of the North Patagonia forest with climatic conditions recorded at regional scale but poorly known at local scale for this site. We established a stratigraphic sequence of thirteen 10 cm thick layers spanning the period c. 2370 BP to c. 580 BP and grouped these layers into three cultural components

According to this region's climate, with rain and snow concentrated in winter and dry summers, our data suggest that these components are contemporary with three climatic periods. A dry period indicated by high values of δ^{18}Oshell, δ^{13}Cshell and Sr/Ca ratio (Mn/Ca ratio does not show any significant trend), in the Lower component is associated with brief incursions of hunter-gatherers from the eastern steppe. In the Middle component, low δ^{18}Oshell, δ^{13}Cshell and Sr/Ca ratios, suggest a humid climate with increased supply of meteoric and/or melt-water along with terrestrial plants organic matter and soil carbonates to the river. According to the archaeological evidence, in this period, hunter gatherers from the Pacific coast and forest started to colonize the area across the Andes cordillera. At the beginning of the Upper component, which is mostly contemporary with the expression of the Medieval Climatic Anomaly (MCA), the proxies are not totally coincident but a tendency to progressively drier conditions could be inferred. Except for layer 4 for δ^{18}Oshell and layer 5 for Sr/Ca ratio, δ^{18}Oshell, δ^{13}Cshell and Sr/Ca ratio show consistently high levels in the Upper than in the Middle component. In layer 5, δ^{18}Oshell and δ^{13}Cshell are elevated with respect to the Middle component while Sr/Ca ratio remains low. In layer 4, δ^{13}Cshell and Sr/Ca ratio are high while δ^{18}Oshell shows a negative peak. In layers 3 to 1, δ^{18}Oshell, δ^{13}Cshell and Sr/Ca ratio remain at high levels, indicating an arid-warm climate with high aquatic plant productivity, in coincidence with the expression of the MCA reported for this region in a partially contemporaneous period (1080 - 1250 AD). At this time, the occupation of the site by groups of the same origin as those present in the Middle component became permanent. Extensive and intensive use of local resources in this period can be inferred from the quality and quantity of artifacts recovered.

Keywords: Palaeoenvironment, Freshwater bivalves, Archaeology, Stable isotopes, Trace elements, Patagonia.

1 INTRODUCTION

This paper reports a study of palaeoenvironmental changes recorded at the archaeological site of Parque Diana Cave (PDC) Patagonia, Argentina. Our methodology is based on the analysis of isotopic ratios ($\delta^{13}C$ and $\delta^{18}O$) and trace elements, manganese (Mn) and strontium (Sr) in shell fragments from the freshwater mussel *Diplodon chilensis* (Gray 1928). The sequence of valves analyzed corresponds to archaeological ecofacts accumulated through alimentary and technological activities (Pérez and Batres 2008, 2010).

Two worldwide climatic events have been extensively described for a period which is partially coincident with the period represented in the PDC sequence, the "Warm Medieval Period" (*sensu* Lamb 1965), 800 - 1400 AD and the "Little Ice Age (1400 -1700 AD, Soon and Baliunas 2003). Several authors have proposed that these climate events have influenced cultural changes with material correlates in the archaeological record (see Arnold 1992; Jones et al. 1999; Larson and Michaelsen 1990; Larson et al. 1994; Larson *et al.* 1996). The former event, which has also been reported as "Medieval Climate Anomaly" (MCA) (Stine 1994), has been characterized as a period of increased global average temperature with intermittent and sometimes extreme droughts. The warm climate peaks of the MCA extended over several decades, showing regional and even local (less than 100 km) particularities (Bryson and Bryson 1997; Soon and Baliunas 2003). Thus, global changes could have affected distant human populations synchronically but it is necessary to know the magnitude of the changes occurred at local scale and the historical context of each population in order to propose hypotheses related to specific adaptive responses.

According to Dean et al. (1985), the impact of the climate on human societies depends on four main factors: 1) magnitude, duration and frequency of the climatic events; 2) Preexistent adaptive strategies; 3) the response of important natural resources; 4) the size and density of the human group. Halstead and O´Shea (1989) propose that human societies cope with the shortage of resources derived from environmental changes by means of a wide range of practices which they defined as "buffering mechanisms", These mechanisms can include, rules, myths alimentary taboos, alternative agricultural practices, and food storage and exchange.

In archaeological research, climate events such as the MCA allow the observation of the diverse adaptive responses of hunter-gatherer groups. For example, several works suggest deteriorated climate conditions associated with relatively rapid and dramatic cultural changes during the MCA in South West California (Larson et al. 1994; Larson et al. 1996; Raab and Larson 1997; Jones et al. 1999). The latter authors reviewed the main cultural responses for South West USA during MCA, which can be summarized as four basic strategies: 1- social complexity; 2- mobility, abandoning areas which had limited resources, e.g. those in the Mojave desert and, in colonial times, deserting of the Santa Bárbara channel by the Chumash population towards the Jesuit missions at the California channel 3- Resource intensification: a wide range of passive or active practices aimed to widen the subsistence system by exploiting a wider diversity of plants and animals and/or larger and more varied foraging areas (Halstead and O´Shea 1989). The mechanisms recorded for the MCA include increased dependence on storage (Testart 1982), production of goods for exchanging at long distances (Arnold 1992), technological innovations (Jones et al. 1999), and economic diversification (Halstead and O´Shea 1989). For example, Larson et al. (1994) proposed that long drought periods produced a stress condition related to food shortage, stimulating the population of the Santa Elena channel to intensify their diet by consuming an increasing variety of marine resources; while other authors like Arnold (1992) suggested the production of necklace beads made of mollusk shells by island groups for trading with inland groups; 4- Territorial behavior: apparently, another consequence of MCA was the competition for scarce resources, both from marine and terrestrial sources (Jones et al. 1999). The necessities to control food resources and to remain next to reliable freshwater sources seem to have further consolidated the populations territorial limits and fostered their territoriality. For example, in sites at the central coast of California, the diets were not widened and the commerce horizons were retracted, producing demographic problems, which were not solved by adaptive adjustments or population mobility (see Larson et al. 1994).

1.1 Patagonia

The climate of Austral Patagonia (Fig. 1) during the Holocene has been subject of many palaeoclimatic reconstructions. Favier Dubois (2004) reviewed the previous palaeoclimatic data, proposing a correspondence between the beginnings of the development of the palaeosol named “Pedologic Event Magallania” and the expression in Austral Patagonia of climate anomalies related to the MCA. This event has been reported to occur contemporarily in North America and in Austral Patagonia (Jones et al. 1999; Larson and Michaelsen 1990; Larson et al. 1996; Stine and Stine 1990; Stine 1994). Stine 1994 compared data from this period between California and Austral Patagonia, reporting marked changes in humidity. From these data he suggested that this was a global event and that, in the Americas, the changes in the precipitation regime were probably more important than those in temperature. In the last decades, the number and the resolution level of palaeoclimatic studies have greatly increased (Kilian and Lamy 2012). Recently, Echeverría et al. (2017) have reconstructed the palaeohydric balance variations of forest, steppe and ecotonal areas of Austral Patagonia during the Holocene by analyzing pollen data obtained from seven sites and discussing previous literature (Fig. 1). These authors have proposed a general trend for the eastern side of the Andes range, with the intensity of the southern westerly winds (SWW) and precipitations being positively correlated in the western forest areas, less positively correlated in the forest-steppe ecotone and negatively correlated in the steppe. This is coincident with data from numerous studies reviewed by Kilian and Lamy (2012), which show a high positive correlation of SWW intensity and precipitation in the west side of the Patagonian Andes, this correlation decreases towards the east, reaching slightly negative values in extra Andean Patagonia. The resulting West-East humidity gradient has varied in intensity along the Holocene due to asynchronic changes in the precipitation regimes of forest, forest-steppe and steppe environments (Echeverria et al. 2017).

In contrast with Austral Patagonia, there are few palaeoclimatic reconstructions covering the late Holocene in North Patagonia. Villalba (1990, 1994) has studied growth rings from 1120 alerce (*Fitzroya Cupressoides* (Molina) Johnston 1924) trees in the area of Río Alerce (Río Negro province, about 400 km southwards of the PDC, Fig. 1) and established the following chronology: Cold-wet, 900 - 1070 AD / Warm-dry, 1080 - 1250 AD, corresponding to MCA / Cold-wet, 1280 - 1670 AD with peaks in 1340 and 1650, related to the European Little Ice Age. This chronology is coincident with results reported for Austral Patagonia (e.g. Moy et al. 2008) but differs from others (e.g. Fey et al. 2009). Discrepancies between studies performed in North and South Patagonia could respond to climatic factors such as those explained by the atmospheric circulation model described for this period by Labraga (1997) (Favier Dubois 2004).

Alternatively, regional scale differences could be related to the ecologic factors described above, e.g. differential effects of SWW on forest and steppe environments (Echeverría et al. 2017; Fey et al. 2009; Garreaud et al. 2013; Kilian and Lamy 2012).

1.2 *Diplodon chilensis*

The long-lived freshwater mussel *Diplodon chilensis* (Hyriidae) is common and abundant in rivers and lakes of Northwest (Andean) Patagonia, Argentina (32°52’ S; 68°51’ W to 45°51’ S; 67°28’ W, Bonetto 1973) and in Southern Chile (34° 58’ S; 71° 48’ W to 46°37’ S; 74°10’ W, Parada and Peredo 2002). *D. chilensis* constitutes an abundant and predictable freshwater resource throughout the year and is the most frequently found mollusk in archaeological deposits from continental Patagonia (Pérez and Batres 2010). Valves of this species have been frequently found in archaeological sites in the western side of The Andes, from the transition between the early and middle Holocene. This includes Andean sites, such as Alero Marifilo 1 (Mera and García 2004), Pucón VI and Colicó 1 (Navarro et al 2011) and Central Valley sites, Alero Quillén 1 and Alero Quilo (Jackson and Jackson 2008). However, these valves have not been used for paleoenvironmental reconstruction so far.

1.3 Parque Diana Cave (PDC)

The PDC is a rocky shelter which allowed us to establish the temporal sequence of human occupation of the “Meliquina Archaeological Locality” (MAL). This locality includes five archaeological sites with a potential functional linkage, and is located 18.5 km South West of San Martin de los Andes city, within the Lanín National Park, (40º 19´ S 71º 19´ W), at an altitude of 970 masl (Fig. 1). This area is part of the “Andino-Patagónico Forest” phytogeographic region, which extends on the hillside of both slopes of the Andes mountain range. On the Argentine side, this region limits to the East with the Patagonian steppe, a vast semi desert-desert area, which stretches eastwards to the Atlantic coast. The climate in MAL is moderately cold and wet, typical of North Patagonian Andes. Rain and snowfalls occur mostly in winter with 1500 to 2000 mm annual average precipitation. Figure 2 shows details of the excavation and part of the PDC walls.

The sedimentary layer of PDC is presently 2 m deep (Fig. 3). Due to the site’s location, the main agents of accumulation are the natural disaggregation of mother rock and, to a lesser extent, external sources, through deposition of small wind-borne particles. Another accumulation factor is the recurrent use of the shelter by human groups and animals (Pérez et al. 2008). Our analyses derive from three assemblages of faunal remains, defined as Lower, Middle and Upper cultural components. The nearest provisioning source of *D. chilensis* to the PDC is a shallow bank of the Río Hermoso, 50 m from the site.

The Lower component (present only in PDC) comprises layers 9 to 12, 1.2 to 1.5 m from current ground level. Layer 9 and most part of layer 10 contain large blocks of mother rock, which separate them from the lower layers. The Lower component has been radiocarbon dated at layer 10 to 2370 ± 70 BP (233-762 cal. BC, LP-1704 vegetal coal, 2 sigma ^{14}C age calibration using Calib 3.0 software, Stuiver and Reimer 1993) and shows a low frequency of human activity. This occupation corresponds to a transient camp in a late exploratory stage of the area (Borrero 1994-1995), by hunter-gatherers (Pérez 2010). The diet faunal components (no cervids and few *D. chilensis* remains), the kind of lithic and animal raw materials (e.g. petrified wood, which is available in specific zones of the steppe but not in this area and guanaco bone) and the technology used suggest groups coming from contemporary steppe occupations, such as Casa de Piedra de Ortega and Epullán Grande cave, in the upper Limay River basin (Crivelli Montero 2010, Fig.1). The lack of evidence on the use of local alimentary resources or raw lithic materials along with the absence of debitage from tool manufacturing, suggest that these groups were just exploring the zone (Pérez 2010).

Between the Lower and Middle components, there is a discontinuity of about 1000 years in the artifactual or ecofactual remains, associated to detachment of mother rock from the walls. This event made PDC unsuitable for human occupation until wind-borne sediments and animal remains (rodent bones and excrements) made the surface regular again.

The Middle component, dated at layer 8 to 990 ± 60 BP (901-1206 cal. AD, LP 1720 vegetal coal) and layer 6 to 900 ± 60 BP (1018-1264 cal. AD, LP 1713 vegetal coal), shows the first evidence of contemporary open sites, which might have been functionally linked to PDC (Pérez 2010).These sites are in the form of localized accumulations or concentrations of vegetal coal, separated one from each other by up to 300 m along the banks of local streams and Lake Meliquina and suggest sporadic occupation of the area with low reoccupation rate. The lack of steppe resources and the predominance of forest and lacustrine resources among the remains, suggest that these hunter-gatherer groups had a better knowledge of the environment. These archaeological features can be attributed to a period of colonization (Borrero 1994-1995) by people who already possessed technological advantages to effectively exploit forest environments from Central-South Chile (Pérez 2010). These people were complex societies characterized by a hunting, gathering and fishing economy with, at least, access to cultivated plants or products derived from corn. They possessed pottery technologies (including patterned decoration, incised and painted by reserve technique), and used native metals such as copper, among other features (see Hayden 1981, 1995). In this component, the archaeological evidence shows a gradual replacement of artifacts manufactured with non-local raw materials by others manufactured with local rocks, e.g. obsidian characterized by the chemical groups found in the nearby area (Pérez et al. 2019) and use of local clay for pottery (Pérez 2010). This suggests a gradual increase in knowledge, interaction with and use of local resources. The faunal remains associated to these sites are predominantly, if not exclusively, from forest and freshwater environments, and include necklace beads and artifacts made from Pacific mollusks shells, which are progressively replaced by shells from local freshwater mollusks (Pérez and Batres 2010). The vegetal remains include the first record for Argentinian Patagonia of *Gevuina avellana* nuts (Pérez and Aguirre 2019) plus the most austral evidence of cultigens such as maize for pre-Hispanic America. Both vegetal resources have also been recorded in contemporaneous archaeological sites in forest areas of the Chilean Andes and Central valleys (Adán and Mera 2011; Adán et al. 2016; Pérez and Erra 2011; Pérez and Aguirre 2019).

The Upper component is dated in layer 3 to 760 ± 60 BP (1163-1388 cal. AD, LP 1697 vegetal coal) and layer 2 to 580 ± 60 BP (1289-1439 cal. AD, LP1695 vegetal coal). This component includes 300 years of artifacts and ecofacts deposition, between 0.3 and 0.8 m deep from the current ground level. This component shows the site's highest richness and variability in archaeological remains. It is characterized by the superimposition of structures related to combustion and/or the maintenance of artifacts. This is the period of most stable and recurrent occupation of MAL, with enhancement of the tendencies observed in the middle component, both in PDC and in the open sites placed on the coast of Lake Meliquina. The number of elements characteristic of the contemporary populations of the Western side of the Andes is increased, including the presence of copper artifacts. The interaction with the environment is more evident in this component, with local production of pottery elements with adequate size and shape to efficiently collect and process a great variety of vegetal and animal food items from freshwater and forest sources (Pérez 2011), including the preparation of fermented beverages (Pérez et al. 2016). This tendency is also evident in the selective use and management of the sources of lithic raw materials such as obsidian (Pérez et al. 2019), resulting in changes in the shape of extractive elements such as arrow points, among other evidences of technological specialization. The absence of steppe materials, along with the use of the forest resources, accompanied by a minor portion of Pacific coast species, shows the reoccupation of the area by the same groups that had been in this region since about 900 AD (Pérez 2010; Pérez and Batres 2010).

The aim of this work is to reconstruct a palaeoclimatic multiproxy sequence with adequate scale and resolution to discuss the climatic-environmental events associated to the human occupations of MAL. We hypothesize that certain parts of the North Patagonian forest-lake area were appraised during warm and/or dry episodes framed in a climatic anomaly period registered at a bigger scale but whose expression at local scale is still unknown.

The predictions for contrasting this hypothesis are: a) There is a correlation between environmental changes and human behavior in the MAL cultural sequence; b) These changes must give some advantages for human occupation to the forest environments on the East of the Andes; c) Some variables inherent to these changes, such as intensity and duration should influence cultural responses, such as mobility, technological change, economic intensification and territoriality.

2. MATERIALS AND METHODS

2.1 Sediment analysis

In order to detect possible differences among layers in the quality and quantity of the bivalve remains recovered due to taphonomic problems related to soil quality, sediment pH and the shell fragmentation index (Grayson 1984), adapted to bivalves by Batres (2008), were measured throughout the stratigraphic sequence.

2.2 Shell analysis

This study is based on 168 specimens, identified as *D. chilensis* whole shells and shell fragments, according to the number of identified specimens (NISP) defined by Grayson (1984), recovered from the PDC (Fig. 4). Samples were obtained from

10cm thick layers, which were subsequently combined into three units or components to correlate the obtained results with relevant aspects of human behavior in the frame of an ecological model of space utilization in Patagonia (Borrero 1994-1995). For stable isotopes, we analyzed one fragment per layer (10 layers containing valve fragments) plus two additional samples for each of the radiocarbon dated layers excepting layer 8, from which only one additional sample could be obtained. One fragment per layer was split in two halves. One half was used for measuring stable isotopes and the other was analyzed for Ca and trace elements (see below). We analyzed valve fragments larger than 5x5 mm; representing valve growth of 2-8 years.

Stable isotopes were analyzed with a Delta S Finnigan Mat triple collector spectrometer, at the INGEIS, Buenos Aires by the method developed by McCrea (1950) with minor modifications. Carbonate was converted to CO_2 with H_3PO_4 at 60ºC. CO_2 was purified in a vacuum line, using cryogenic traps to eliminate other volatile compounds and analyzed by mass spectrometry. $\delta^{13}C$ and $\delta^{18}O$ values were reported relative to standard V-PDB (Vienna-PeeDeeBelemnitella) (Coplen 1994), with errors of ± 0.1 and ± 0.05 ‰, respectively.

The trace elements Mn and Sr, and Ca were measured on 10 shell fragments, one half of fragment per layer. Shell fragments were washed with 5mM EDTA solution to remove externally adhered ions and then digested in a microwave oven with nitric acid and hydrogen peroxide (2:1, v/v). Organic matter was separated as an insoluble film, which accounted for ca. 5% of the sample mass. Gallium was added to these dissolutions, as internal standard. Aliquots of 10 µL were placed in a quartz reflector for analysis by total X-ray reflection fluorescence (TXRF) (Prange and Schwenke 1992). Spectrum evaluation and quantitative analysis were performed using the QXAS software package from IAEA, using least-square regression analysis and calibration curves within the range 1–20 ppm. Detection limits were 0.02 and 0.05 µg/g, for Mn and Sr, respectively, with an error of 10% (See Sabatini et al. 2009 for more detailed explanation of the method). Results were expressed as element/Ca ratio x 1000.

To compare trace element proportions, Mn, Sr, Fe and Zn were measured as described above for Mn and Sr in duplicate on valves of *D. chilensis* taken alive from Río Hermoso near the PDC and in water samples from the same site. The relevant literature to support and interpret paleoenvironmental reconstruction based on the analysis of stable isotopes and trace elements in mollusks shell remains is described in Appendix A.

2.3 Interpretation of the palaeoenvironmental data

Soldati et al. (2009; 2010) have characterized summer and winter growth bands in valves of living individuals of *D. chilensis* from about 150 km south to our study site. These authors report low δ ^{18}O in summer bands, assigning these values to higher temperatures according to previously published data (Dunca and Mutvei 2001; Dunca et al. 2005; Schöne et al. 2004). High Mn/Ca, Sr/Ca and Ba/Ca ratios have also been detected in these summer bands (Soldati et al. 2009). Low δ $^{18}O_{shell}$ in summer growth lines could be related to the effect of temperature on isotopic fractionation during shell carbonate deposition (Carré et al. 2005; Dettman et al. 1999; Epstein et al. 1953; Gordillo et al. 2015; Grossman and Ku 1986; Yoshimura et al. 2010). However, Soldati et al. (2009) have reported that the temperature cycles calculated from δ $^{18}O_{shell}$ and δ $^{18}O_{water}$ underestimate the actual summer-winter difference in their study site. Among other hypotheses, these authors have suggested that such underestimation could respond to seasonal changes in δ $^{18}O_{water}$ which, in turn, affect *D. chilensis* δ $^{18}O_{shell}$.

In the area of the present study, precipitation is concentrated in winter and stream discharge is high in winter-spring. During relatively humid years, high altitude wetlands and lakes accumulate water, and snow remains in the mountains until summer. Therefore, during such years, rivers like the Río Hermoso receive abundant ^{18}O-depleted water from lakes and streams fed by melt-water throughout the year. Under such conditions, the effect of evaporation would be small and low δ $^{18}O_{water}$ and δ$^{18}O_{shell}$ would be recorded in summer. In contrast, during arid periods, snow is already absent in spring and high-altitude reservoirs with meteoric water are reduced or even depleted in summer. This reduced input of ^{18}O-depleted water along with higher evaporation would increase δ $^{18}O_w$ in Río Hermoso with respect to humid years. Accordingly, reduced stream discharge and increased evaporation to precipitation ratio have been previously reported to reduce or even overcome the effects of temperature on δ $^{18}O_{shell}$ (Bar-Yosef Mayer et al. 2012; Gajurel et al. 2006; Kaandorp et al. 2003; Marwick and Gagan 2011; Schöll-Barna 2011; Versteegh et al. 2010; 2011). As we have analyzed the total carbonate content of shell fragments, which span several years of shell growth, our data reflect the combined effects of the hydrological and environmental parameters described above, averaged among seasons.

Kaandorp et al. (2003) have reported covariance of $\delta^{13}C_{water}$ and $\delta^{18}O_{water}$ from an Amazonian floodplain with high records of both heavy isotopes during dry periods and with $\delta^{13}C_{shell}$ and $\delta^{18}O_{shell}$ responding to water composition. These authors relate the increased $\delta^{18}O_{water}$ to a strong evaporation effect, while elevation of $\delta^{13}C_{water}$ could be responding to depletion of the light isotope due to selective uptake by aquatic plants. On the other hand, Gajurel et al. (2006) have reported that $\delta^{13}C$ of dissolved inorganic carbon in Himalayan rivers decreases downstream because of soil derived alkalinity and land plant productivity. Additionally, increased phytoplankton productivity or terrestrial plant material input to the river can stimulate mussel metabolic activity, which in term would lead to higher proportion of metabolic C being deposited in the shell and thus to lower $\delta^{13}C_{shell}$ (see McConnaughey and Gillikin 2008, for a review).

High Mn/Ca ratio has been reported as an indication of high aquatic primary productivity (Langlet et al. 2007; Carroll and Romanek 2008). Particularly for *D. chilensis*, which shows maximum growth rate in winter (Soldati et al. 2009; Rocchetta et al. 2014), Risk et al. (2010) have detected Mn peaks in winter growth lines interpreting that increased precipitations and river discharge can augment erosion, liberating soluble Mn. According to Lee and Wilson (1969), Sr/Ca ratio is expected to show positive correlation with reduced river discharge and/or with increased evaporation. However, trace element ratios are not easy to interpret and should, thus, be interpreted in combination with other proxies (Peacock and Seltzer 2008). In this regard, Sr concentration has been reported as covarying with $\delta^{18}O$ in fossil shells of *Diplodon longulus*, high values of both variables indicating dry season (Kaandorp et al. 2006).

2.4 Statistics

Consistency among the different proxies was analyzed by Spearman correlation. $\delta^{18}O_{shell}$ and $\delta^{13}C_{shell}$ values were compared between the upper and middle components through Student's t test. Results were considered significant at $P < 0.05$.

3 RESULTS AND DISCUSSION

3.1 Sediment analyses

Sediment pH ranged from 7.3 to 7.9 (Table 1). This slightly alkaline soil favored the preservation of archaeological materials, especially $CaCO_3$ containing shells, as was previously reported for similar environments in North Patagonia (see Pérez et al. 2008 and citations therein). The fragmentation index (Grayson 1984, modified by Batres 2008) showed that, various taphonomic processes acted in the Lower component. The high rates of sample fragmentation found in layers 9 and 10 coincide with the lowest NISP for the site. In the Middle and Upper components, pH was almost constant. NISP values, in the Middle component are higher than in the Lower one. A trend to increased bivalve collection by human groups is evident, although NISP remains low. The Upper component shows the largest number of *D. chilensis* shell remains. The fragmentation index remains constant between the Middle and Upper components, which indicates that the larger number of items recovered in the Upper component is not due to lower taphonomic factors but to increased bivalve collection activity (Table 1).

3.2 Trace elements in modern shells and water samples

Mn, Sr and Fe were present in shells and in water at similar proportions. Table 2 shows Ca and trace element concentrations in Río Hermoso water and in valves taken from live mussels collected from the same site.

3.3 Stratigraphic analyses

Due to sample limitation, trace elements were measured in one valve fragment per layer while stable isotopes were measured in three fragments from layers 2, 3, 6, and 10, two fragments from layer 8 and one fragment from layers 1, 4, 5, 7, and 9. Therefore, we interpreted our results taking into account that results from only one fragment should be analyzed with care. Spearman analysis showed significant correlation between $\delta^{18}O_{shell}$ and $\delta^{13}C_{shell}$ only after excluding data from layer 9, which showed an extremely high $\delta^{18}O_{shell}$ value (P = 0.037, R = 0.71). Similarly, $\delta^{18}O_{shell}$ shows good correlation with Sr/Ca ratio if layer 9 is excluded (P = 0.024, R= 0.75). $\delta^{13}C_{shell}$ and Sr/Ca ratio are also correlated (P = 0.0154, R = 0.83) only if data from layers 5 and 7 are excluded. These correlations are consistent with the results reported by Risk et al. (2010), who have found similar peaks of $\delta\ ^{18}O$ and Sr/Ca and Ba/Ca ratios in the same species in Chile in summer growth lines, considering that summer is the dry season in both Chilean an Argentine Patagonia. In our study, the Mn/Ca ratio was not considered for the analysis because it does not show any significant trend along the sequence and is not correlated with the other proxies. All the data excluded from the correlation analyses correspond to layers in which only one shell fragment was used.

The Lower component shows high $\delta^{18}O_{shell}$ and $\delta^{13}C_{shell}$ along with high Sr/Ca ratio in layer 10 (Fig. 5), suggesting arid conditions according to Kaandorp et al. (2006). Similarly, Echeverría et al. (2017) have reported negative palaeohydric balance for several forest environments of Southern Patagonia during a period which includes the corresponding to this component. The $\delta^{18}O_{shell}$ value recorded in layer 9 is extremely high compared to the rest of the sequence while $\delta^{13}C_{shell}$ and the Sr/Ca ratio decrease in this layer pointing to less arid conditions. However, these data correspond to a single fragment from a layer with a small archaeological sample, typical of a transient camp used for specific activities. Hence, we discuss the palaeoclimatic information from this component mostly based on layer 10 data.

It could be interpreted that small groups of hunter-gatherers from the eastern steppe used rocky shelters like PDC in the area of LAM as temporal camps, possibly logistically integrated from base camps described by other researchers to the eastern steppe (Crivelli Montero 2010), including transitional sectors of cypress forests in Valle Encantado (Hajduk and Albornoz 1999; Hajduk et al. 2011) and some occupations of forested sites in the Traful area (Silveira 1996, 1999). This would have been favored by arid conditions that had changed part of the forest area and related wetlands into grasslands suitable for grazing by steppe herbivores, especially guanacos, which do not tolerate wet soils. Additionally, these incursions could have also been related to the gathering of obsidian from sources located in the forest area near the MAL. This is supported by the presence of obsidian characterized by the same chemical groups and tools with similar laminarity as those found in PDC in steppe sites (Pérez et al. 2019). This occupation may have not persisted as a result of climate changes not recorded because of the absence of shell remains in the hiatus between the Lower and Middle components and/or because the rock detachment from the cave's walls made this site not suitable for human use.

In the Middle component, the three analyzed proxies are mostly coincident. $\delta^{18}O_{shell}$ shows low values with a negative peak in layer 7 (Fig. 5), which could indicate a long humid period (lower effect of evaporation on $\delta^{18}O_{water}$). Sr/Ca ratio is also low in layers 6 and 7, with the negative peak in the same layer as $\delta^{18}O_{shell}$, reinforcing the idea of a wet period with high river discharge, at least in layers 6 and 7. Records of $\delta^{13}C_{shell}$ are slightly lower in this component than in the others in layer 8 and show a marked negative peak in layer 6, suggesting higher input of forest-derived organic matter and soil alkalinity due to increased runoff. Terrestrial plant material can provide low $\delta^{13}C$ organic compounds, which would be reflected in $\delta^{13}C_{shell}$ through deposition of metabolic C in shell carbonate (Gajurel et al. 2006; see McConnaughy and Gillikin 2008, for a review). In turn, soil derived alkalinity contributes with low $\delta^{13}C$ HCO_3^-, which is the main source of shell carbonate (e.g. Leng and Marshall 2004). Taken together, the three analyzed proxies reflect high humidity and high river discharge in the middle component (990-1050 AD), especially in layers 6 and 7. The fact that the amplitude of the changes in $\delta^{18}O_{shell}$ is lower than that of the other proxies could indicate that this period was also cold, since $\delta^{18}O_{shell}$ in *D. chilensis* increases as temperature decreases (Soldati et al. 2009), which would partially counteract the effect of the humid conditions. Villalba (1990, 1994) has previously reported a cold humid period (900 - 1070 AD) in the same region based on alerce tree rings, while Moy et al. (2008) have interpreted positive moisture balance between 850 and 1100 AD from $\delta^{18}O$ records on *Pisidum sp*. valves and on the fine fraction of Lago Guanaco sediments in the Southern Chilean Patagonia.

At the time corresponding to the Middle component of PDC, hunter-gatherer populations from South-Central Chile, which possessed a complex economy, including pottery, fishing, incipient agriculture, and common burial grounds (Aldunate 1989; Dillehay 1990; Adán et al. 2016; Campbell et al. 2018) began to colonize this area, possibly as a result of the temporary segmentation of large groups, including a more recurrent occupation of the eastern side of the Andes (Aldunate 1989; Pérez 2010. The increased precipitation rate suggested by the proxies analyzed above is contemporaneous with an increase in the intensity of SWW that was reported to occur in several areas of Southern Patagonia (e.g. Echeverría et al. 2017). The climatic models for Patagonia predict a strong positive effect of SWW on precipitations on the West side of the Andes, which becomes weaker on the East side forest area and neutral to negative in the forest-steppe ecotone and in the steppe, respectively (Kilian and Lamy 2012; Garreaud et al. 2013). Thus, these human groups from the western side of the Andes could have increased their residential mobility towards the Eastern forest and the neighbor ecotone during the time of precipitation peaks. This geographic expansion could also be partly related to brief abrupt climate changes, accompanied by volcanic episodes and forest fires, which have been reported for the west side of the Andes range during this period (Pérez 2010). In general, the precipitation peaks, volcanic activity episodes and fires were short duration catastrophic events, which were recurrent in this period and favored the fragmentation of large groups and their mobilization to more benign areas as an adaptive response (Jones et al. 1999). These were short-term responses and the groups returned to their original location when the extreme events were over. Accordingly, Torrence (2002) has proposed a response to volcanic episodes of short duration in New Guinea, with human groups migrating to unaffected areas and returning to the original area when conditions were favorable again.

The archaeological evidence in the Middle component suggests the recurrent occupation of MAL by people with forest adaptations in the form of short-term camps both, under rocky shelters and in open sites. These groups interacted with the local environment and made intensive use of the local resources, as is detailed in 1.3, but no changes in their way of life or technology are evident from the quality of the artifacts recovered, which does not change throughout the record of this component (Pérez 2010; Pérez et al. 2017).

The Upper component (layers 5-1) is partially contemporaneous with a warm and dry period between 1080 and 1250 AD, reported by Villalba (1990; 1994) as an expression of the MCA in the area of Los Alerces National Park, North-West Patagonia (Figs. 1,5) and with a period of high evaporation in Lago Guanaco (Moy et al. 2008). In this component, $\delta^{18}O_{shell}$ starts to rise in layer 5 and is high throughout the component except for a negative peak in layer 4, which does not correlate with the values of the other proxies. If this negative peak is excluded, pooled $\delta^{18}O_{shell}$ in this component is significantly higher than in the Middle component (Student's t test, $p < 0.05$). Similarly, $\delta^{13}C_{shell}$ is significantly higher in the upper than in the middle component, considering all the layers (Student's t test, $p < 0.05$), and the Sr/Ca ratio is consistently high between layers 4 and 1. Although Sr/Ca ratio remains low as in the middle component in layer 5, this value is not correlated with the other two proxies.

In layer 3, which coincides with the highest level of occupation of the MAL, all the three proxies considered in this discussion are consistent at maximum values, pointing to a dry-warm climate with high aquatic plants productivity. This result is in agreement with the conditions described by Villalba (1990; 1994) for the same period (Fig. 5). From the archaeological analysis, this layer seems to be an occupation floor, in which the maximum human activity for this site can be inferred from a high artifact deposition rate (Pérez 2011). According to the artifactual evidence, at this time, the PDC occupants remained in the site for several decades (Pérez 2010, Pérez et al. 2019). Layer 2 is contemporary with a cold period thought by Villalba (1990; 1994) to be a local expression of the Little Ice Age. Although we have recorded slight changes in $\delta^{13}C_{shell}$ and in Sr/Ca ratio with respect to layer 3, $\delta^{18}O_{shell}$ does not change. Thus, no clear evidence pointing to the expression of the Little Ice Age in the area of MAL can be observed in the sequence studied in this work.

The Upper component shows a new colonization event after a period of no or scarce occupation of the area. The reoccupation of the MAL included potentially articulated camps in open sites and rocky shelters made by the same populations which had temporarily expanded their mobility during the Middle component. In this component, the increment in residential mobility occurred in the context of a new stage of colonization (Borrero 1994-1995). At variance with the Middle component, this mobility was not correlated with environmental instability but with increasing aridity.

This climatic event persisted for many decades, enabling the effective occupation of the territory (Borrero 1994-1995). The relatively stable environmental conditions recorded between layers 5 and 1 have probably favored the intensification, in this case, related to an evident increase in the interaction with the local resources, with predominant use of local raw materials, such as obsidian and clay. This would have also stimulated changes in the organization of various cultural aspects (Jones et al. 1999), including the production of large combustion structures related to the local production of pottery described by Pérez (2011) and technological innovations, such as lithic sinkers for fishing lines and new shapes in the projectile points (Pérez et al. 2017).

The resulting capacity to exploit local resources may have allowed these groups to cope with the increasing aridity recorded from layer 5, with peak in layer 3 by taking advantage of the increased aquatic productivity. For this period, previous papers describe an active exchange of resources and technology among populations of the Pacific coast, the Central valleys of Chile and the Argentine side of the Andes Range (Aldunate 1989; Pérez 2010; Campbell et al. 2018), similar to the described by Arnold (1992) for island and inland populations of California and Santa Barbara channel, in the Northern hemisphere.

4 CONCLUSIONS

We have reconstructed a palaeoclimatic multiproxy sequence based on stable isotopes and trace metals measured in archaeological *D. chilensis* shell remains, which allows to correlate the sequence of human occupations of the MAL with environmental changes at a resolution scale with no antecedents for this region. We have detected climatic change pulses and the local expression of climatic events, such as the MCA, which have previously been registered for only one site in North Patagonia, which covers an area with a radius of 100 km. (Villalba, 1990, 1994). Our results allow to extend the geographic area in which the expression of the MCA is evident in North Patagonia by ca. 300 km to the North and could contribute to the development of regional interpretations. Since *D. chilensis* is one of the most abundant species in the archaeofauna of a wide region comprising North-West Patagonia, Argentina and South-Central Chile, this multi-proxy approach is a promising tool for the interpretation of landscapes and climates in which human populations migrated into and developed in the past.

Goñi et al. (2019) proposed that in Austral Patagonia, the climatic fluctuations occurred along the last 2500 years, especially the MCA and other events caused the reduction of the residential mobility of hunter-gatherer groups of the Center-West of Santa Cruz province (Fig. 1). In contrast, we have identified palaeoenvironmental trends, which can be associated with changes in mobility, technology and use of natural resources in the MAL by human populations with different ways of life and territoriality. The occupations of the area occur when it becomes comparatively advantageous relative to the areas occupied by different human populations. For example, the archaeological remains found in the Lower component of PDC suggest exploratory incursions from the Eastern steppe, mostly related with the gathering of lithic raw materials and favored by arid conditions in the forest area, which extended the steppe herbivores distribution range towards the forest-steppe ecotone, ca. 2.300 BP.

In the last millennium, when the MAL became advantageous relative to the West side of the Andes, it was colonized and effectively occupied by populations from South-Central Chile, which possessed an efficient technology for exploiting forest and freshwater resources. The first colonization by these groups, with recurrent short-term occupations, took place during a humid period with high precipitation rates and environmental instability (ca.990-1080 A.D) related to increased intensity in the SWW. This effect was milder in the Eastern slopes of the Andes, where the influence of the SWW is less important than in the Western side. The second, and more permanent occupation by the same groups was contemporary with the local expression of the MCA (ca. 1080 and 1250 AD), and was probably favored by increased productivity of the rivers and lakes. Besides, the effective occupation with increasing degree of interaction with the local resources from the lower to the upper component was stimulated by the longer duration of the favorable environmental conditions.

Finally, the MAL record allows us to propose that the different models that suggest social complexity, mobility, resource intensification and territorial behavior during moments of environmental instability associated to the MCA are probably not monothetic and / or contradictory, but rather they can be complementary and / or concurrent.

Acknowledgements

We thank Héctor Panarello, Christian Favier Dubois, Sebastián Sabatini and Gabriela Batres for their kind help and valuable suggestions. This work was supported by grants: ANPCYT PICT 1293 to IR and UBA- FFL 840162, to AEP and CONICET PIP 0529 to CML. We also thank two anonymous Reviewers, who made very helpful comments for improving this work.

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Captions to the figures

Figure 1. Meliquina Archaeological Locality (MAL, 1) including the Parque Diana Cave (PDC) and associated open (Meliquina Lake) sites, and related steppe sites (3, 4), in North-West Patagonia, Argentina. The location of MAL (1) and reference sites for paleoclimatic reconstruction in North-West (2) and Austral (5) Patagonia are shown in a regional map. SWW, South Westerly Winds.

Figure 2. A- Excavation in Parque Diana Cave showing part of the cave's wall. B- South profile and layer 10 (Lower component) C- Planimetry of the three components showing the distribution of the archaeological remains.

Fig.3. Stratigraphic sequence at the Parque Diana Cave consisting of thirteen 10 cm thick layers pooled into three cultural components. Left, East profile of the cave; center, percentage of recovered *Diplodon chilensis* shells per layer; right, ^{14}C chronology.

Fig.4. *Diplodon chilensis* shells collected from the different layers of Parque Diana Cave.

Figure 5. Stable isotope ratios (V-PDB ‰, right y axis) and element/Ca ratios (mg/g, left y axis) recorded in shell carbonates of *Diplodon chilensis* from the stratigraphic sequence of Parque Diana Cave. δ^{18}O (open triangles) and δ^{13}C (closed triangles) data are plotted as mean, n = 3 for layers 2, 3, 6 and 10, n = 2 for layer 8 and n = 1 for layers 1, 4, 5, 7 and 9. Sr/Ca and Mn/Ca ratios are represented by open and closed circles, respectively, n = 1.The human activities interpreted from the archaeological record of the Parque Diana Cave are shown below the graph. The arrow indicates the expression of the Medieval Climatic Anomaly (MCA) in the same region, according to Villalba (1990; 1994).

Table 1. pH, Number of identified specimens (NISP) and fragmentation index (F.I.) in the 10 layers of the site Parque Diana cave which contained *Diplodon chilensis* shell remains.

Layer	pH	NISP	F.I
1	7.58	10	0.20
2	7.69	52	0.30
3	7.32	77	0.26
4	7.91	10	0.36
5	7.71	4	0.25
6	7.78	3	0.33
7	7.73	5	0.20
8	7.56	4	0.25
9	7.64	1	0.00
10	7.29	2	0.50

Table 2. Element concentrations measured by TXRF in Río Hermoso water and in the shells of living *Diplodon chilensis*.

	Ca	Mn	Sr	Fe	Zn
Water (µg/mL)	5.695	0.012	0.031	0.113	0.044
Shell (mg/g)	216.3	0.168	1.144	1.308	0.428

APPENDIX A

Antecedents of paleoenvironmental reconstruction using stable isotopes and trace elements, with emphasis on freshwater bivalves' shells.

Stable isotopes

Stable isotopes, especially those of oxygen (18O) and carbon (13C), have been widely used as proxies for palaeoclimate reconstruction since the early works by McCrea (1950) and Epstein et al. (1953). For this purpose, isotopic ratios, e.g. 18O/16O, are expressed in delta notation (e.g. δ18O) relative to internationally accepted standards. δ18O palaeothermometry is based on the principle that if carbonates (or phosphates) precipitate in equilibrium with the surrounding water, the isotopic ratio in the mineral depends only on water isotopic ratio and precipitation temperature. Thus, if water δ18O is known, temperature can be estimated from the carbonate δ18O (reviewed in Grossman 2012).

Stable isotopes have been recorded in samples from great variety of biogenic materials, such as carbonates from foraminifers and limpet shells (e.g. Barker et al. 2005; Ferguson et al. 2011), carbonates or phosphates from fossil groups like branchiopods, belemnites and conodonts (Grossman 2012), phosphates and collagen from extinct mammals (e.g. González Guarda et al. 2017), and cellulose from tree rings (Lavergne et al. 2017).

Bivalve mollusks are especially good candidates for palaeoclimate reconstruction since they deposit carbonate in equilibrium with ambient water, their shells present conspicuous annual growth lines, and are relatively well preserved through time.

Particularly, δ18Oshell is closely related to the host water isotopic composition and temperature (Carre et al. 2005; Dettman et al. 1999; Epstein et al. 1953; Ferguson et al. 2011; Gordillo et al. 2015; Grossman and Ku 1986; Grossman 2012; McCrea 1950; Yan et al. 2009; Yoshimura et al. 2010.

Valve growth, structure, mineralogy, and isotopic and chemical fractionation, can be affected by variations in environmental parameters, such as water isotopic composition, temperature, food supply, type of substrate, salinity, dissolved oxygen concentration or oxygen/carbon ratio. Thus, shell isotopic patterns or signs can serve as archives of environmental history (Dettman et al. 1999; Gajurel et al. 2006; Goodwin et al. 2003; Kaandorp et al. 2003; Schöne et al. 2007).

Freshwater bivalves

Hydrological and climate conditions such as river discharge and the balance between precipitation and evaporation can also be principal factors affecting δ18Owater and thus δ18Oshell. (Gajurel et al. 2006; Kaandorp et al. 2003; 2006; Marwick and Gagan 2011; Ricken et al. 2003; Rodrigues et al. 2000; Schöll-Barna 2011; Versteegh et al. 2010; 2011). Carbon isotopic ratio (δ13Cshell) can covariate with δ18Oshell and has also been discussed in previous papers as an isotopic proxy for reconstruction of marine palaeoenvironments (e.g. Surge and Walker 2006). In freshwater environments, δ13Cshell can be affected by biological factors, which modify the proportion of metabolic C deposited in the shell and by many environmental factors such as temperature, evaporation, soil derived dissolved carbon and the kind and productivity of the dominant plants (or phytoplankton) (Geist et al. 2005; Gillikin et al. 2009; Goewert et al. 2007; Goodwin et al. 2012; Kaandorp et al. 2003; Keller et al. 2002; Klein et al. 1996; Krantz et al. 1987; Leng and Marshall 2004; Lorrain et al. 2004; McConnaughey and Gillikin 2008; Moy et al. 2008; Surge and Walker 2006).

Trace elements

Since different divalent cations can substitute for calcium in biogenic carbonates, their presence in carbonate deposits or in the shells of aquatic species has been widely studied as proxies for environmental reconstruction. According to Barker et al. (2005), trace element ratios can be analyzed in parallel with δ18O measured in the same sample for obtaining more robust temperature estimations. For marine mollusks, Ferguson et al. (2011) report that both Mg/Ca ratio and δ18O in modern shells of limpets (Patella spp.) reflect the seasonal regime of surface seawater temperature (SST) of the western Mediterranean. In contrast, Füllenbach et al. (2015) argue that the incorporation of Sr and Mg is often strongly controlled by physiological factors, and thus Sr/Ca and Mg/Ca ratios are not reliable as palaeothermometers.

Besides their relative suitability for palaeothermometry, trace elements can supply information about past environmental conditions, since shell element/Ca ratios reflect the concentration of elements, such as Mn and Sr in the ambient water at the time of calcification (Carroll and Romanek 2008; Jeffree et al. 1995). Peacock and Seltzer (2008) have recorded increased Sr/Ca ratio in bivalve shells from the late Holocene and discussed such results in terms of aridity, while Kaandorp et al. (2006) have correlated Sr concentration in bivalve shells with precipitation-evaporation cycles in Amazonian freshwaters. Besides water chemistry, temperature, soil erosion, primary productivity and processes associated with growth exert strong controls on the incorporation of trace elements, together with other physiological factors which can vary among different species (Carré et al. 2006; Carroll and Romanek 2008; Freitas et al. 2006; Füllenbach et al. 2015; Klein et al. 1996; Langlet et al. 2007; Lazaret et al. 2003; Takesue and van Geen 2004; Tynan et al. 2006).

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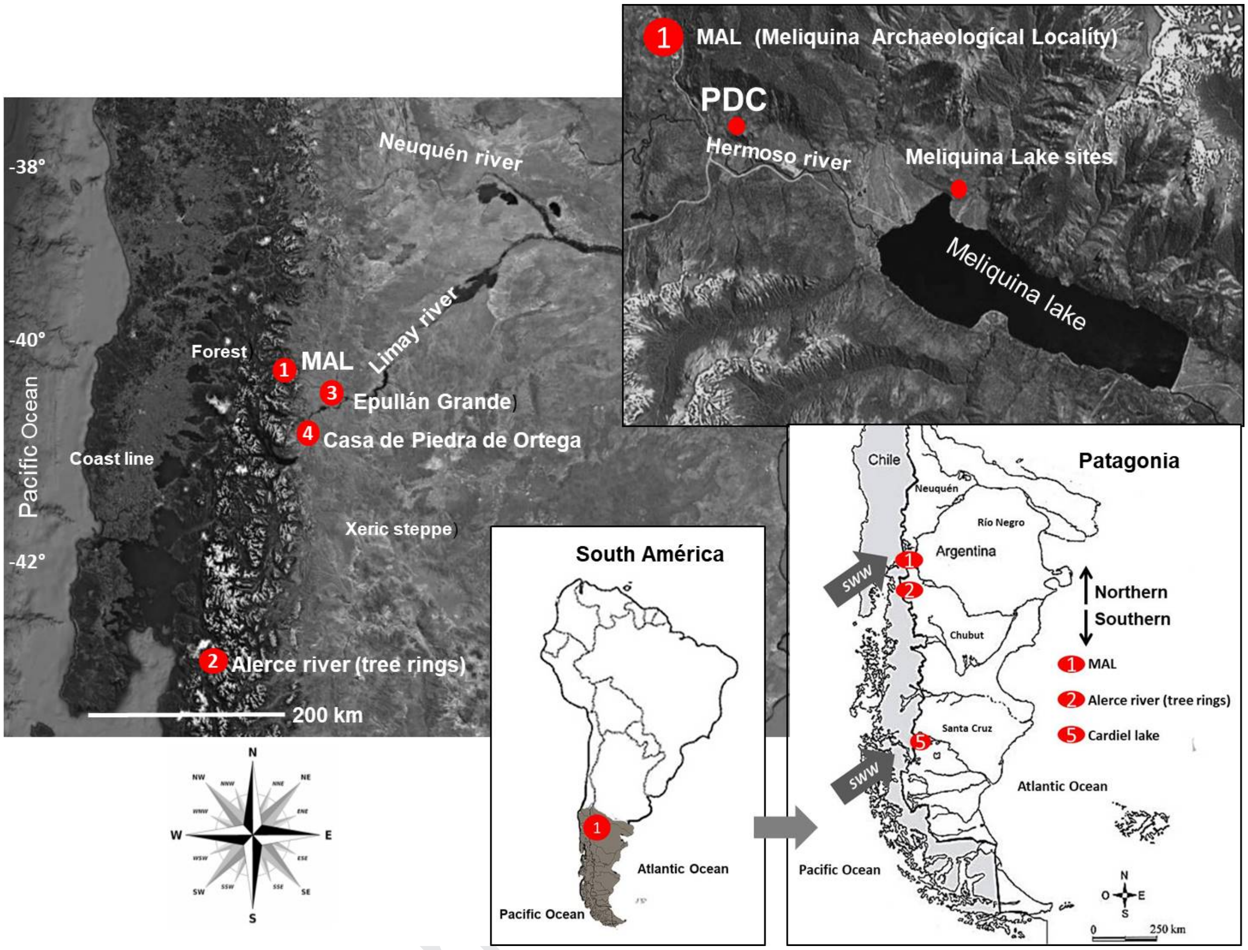
1 MAL (Meliquina Archaeologícal Locality)
PDC
Hermoso river
Meliquina Lake sites
Meliquina lake
Neuquén river
-38°
-40°
-42°
Pacific Ocean
Forest
1 MAL
Limay river
3 Epullán Grande
4 Casa de Piedra de Ortega
Coast line
Xeric steppe
2 Alerce river (tree rings)
200 km
N
NNW
NNE
NW
NE
WNW
ENE
W
E
WSW
ESE
SW
SE
SSW
SSE
S
South América
1
Atlantic Ocean
Pacific Ocean
Chile
Patagonia
Neuquén
Río Negro
Argentina
SWW
1
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Northern
Southern
Chubut
1 MAL
2 Alerce river (tree rings)
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Santa Cruz
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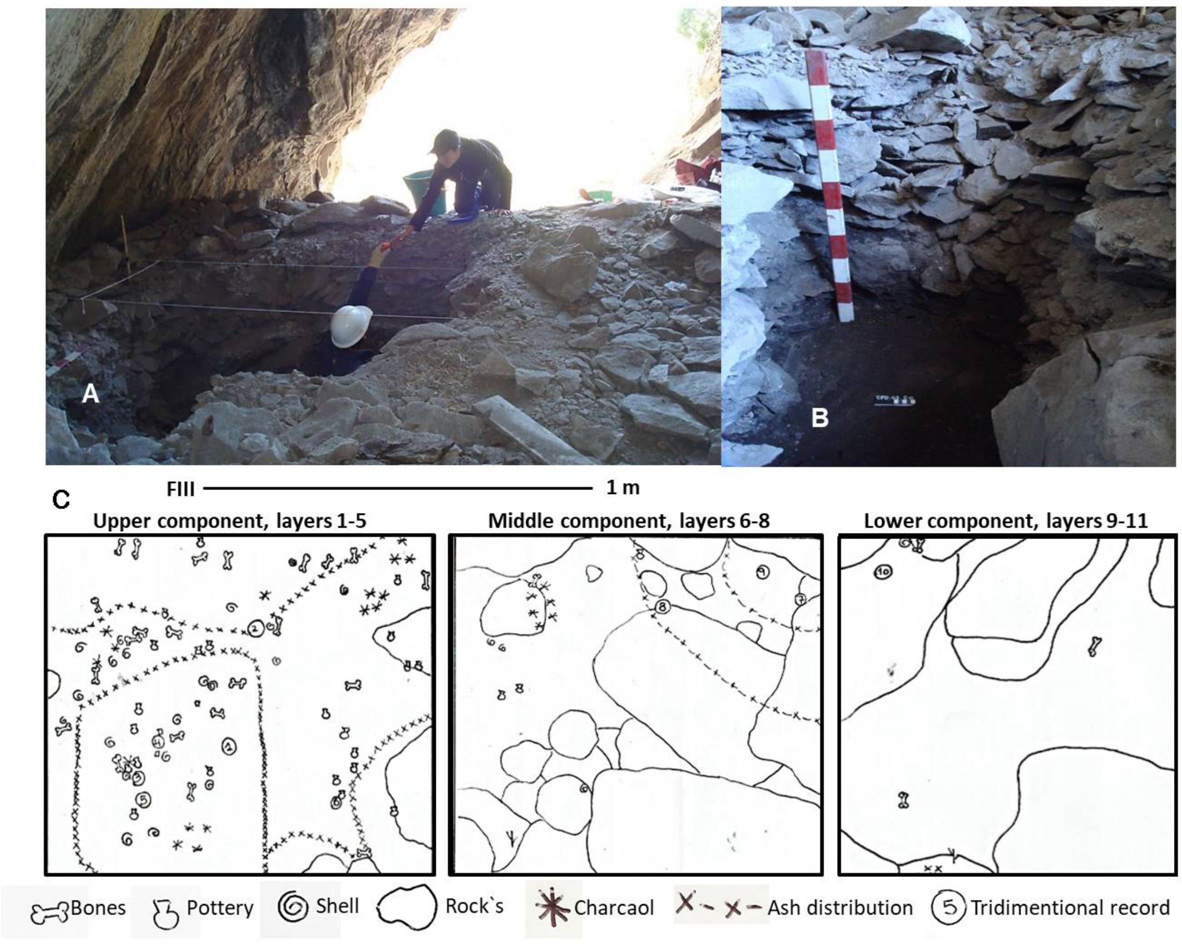
A
B
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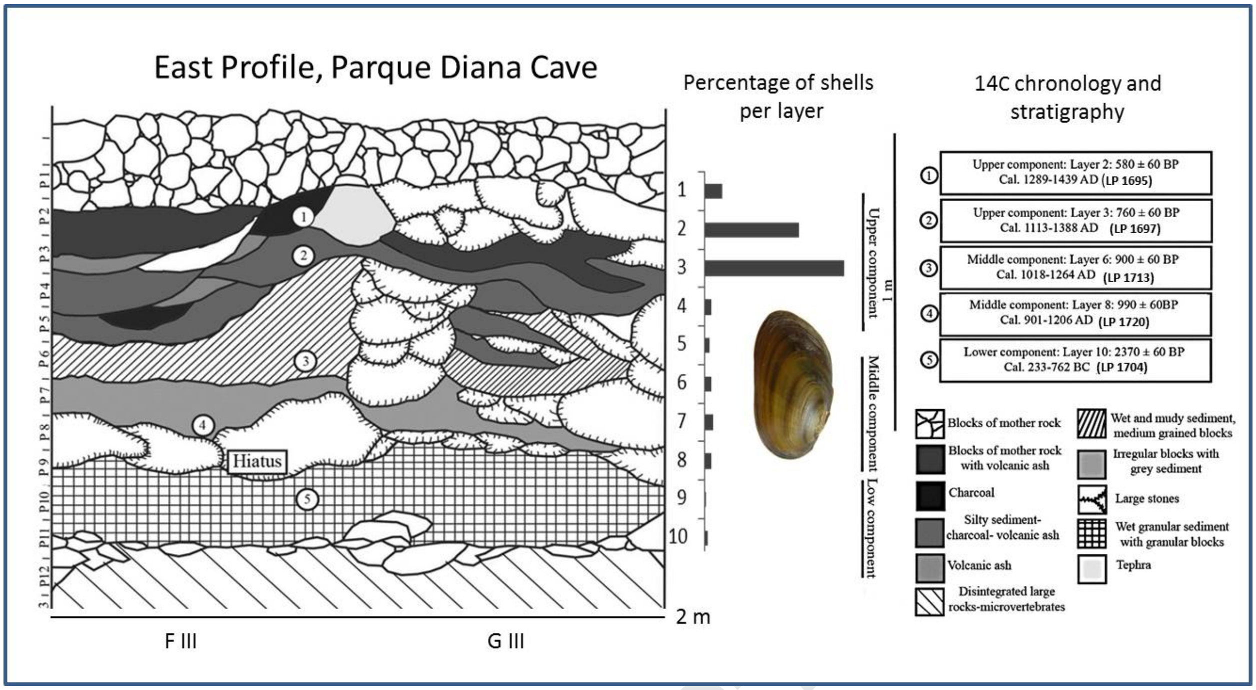
1 m
Upper component, layers 1-5
Middle component, layers 6-8
Lower component, layers 9-11
Bones
Pottery
Shell
Rock`s
Charcaol
Ash distribution
Tridimentional record


East Profile, Parque Diana Cave
Percentage of shells per layer
14C chronology and stratigraphy
P1
P2
P3
P4
P5
P6
P7
P8
P9
P10
P11
P12
① ② ③ ④ ⑤
Hiatus
1
2
3
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6
7
8
9
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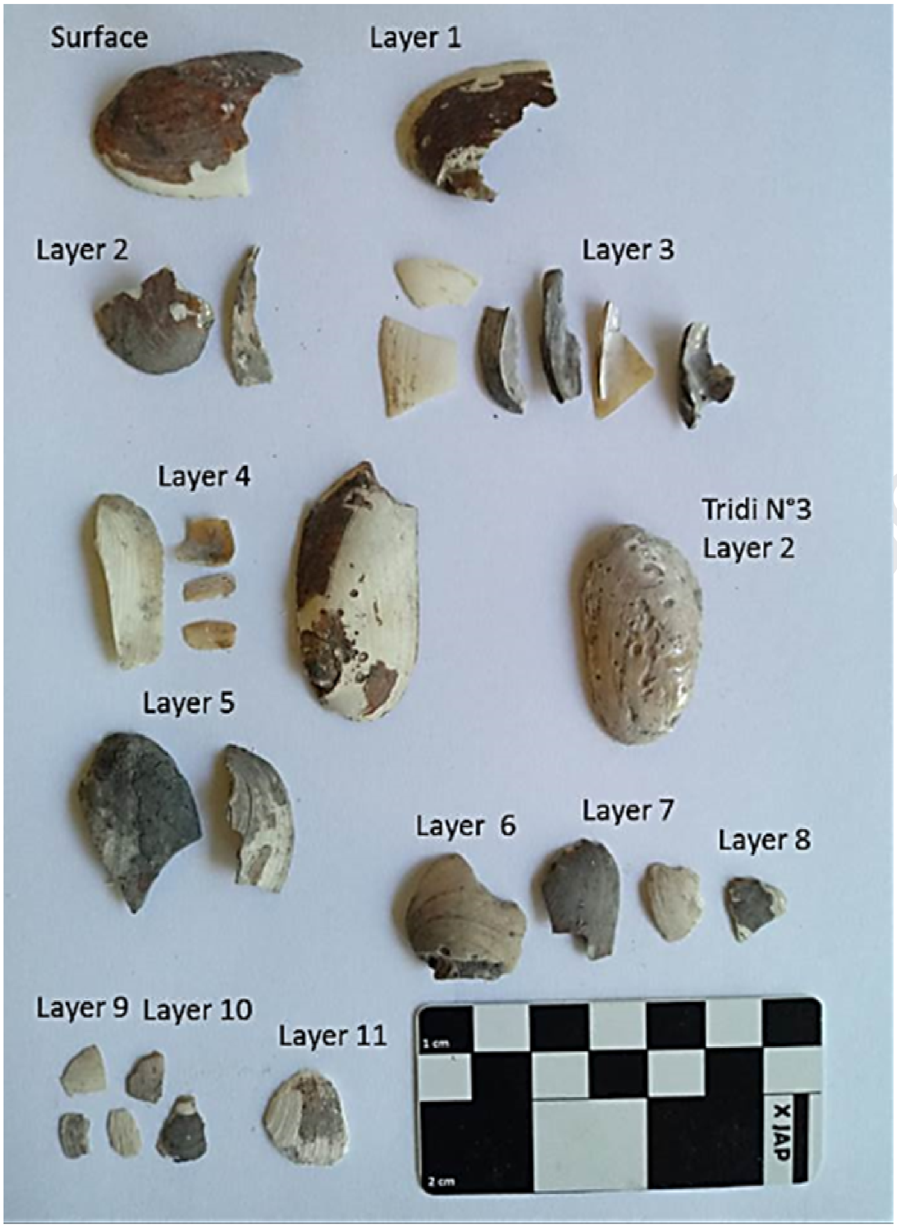
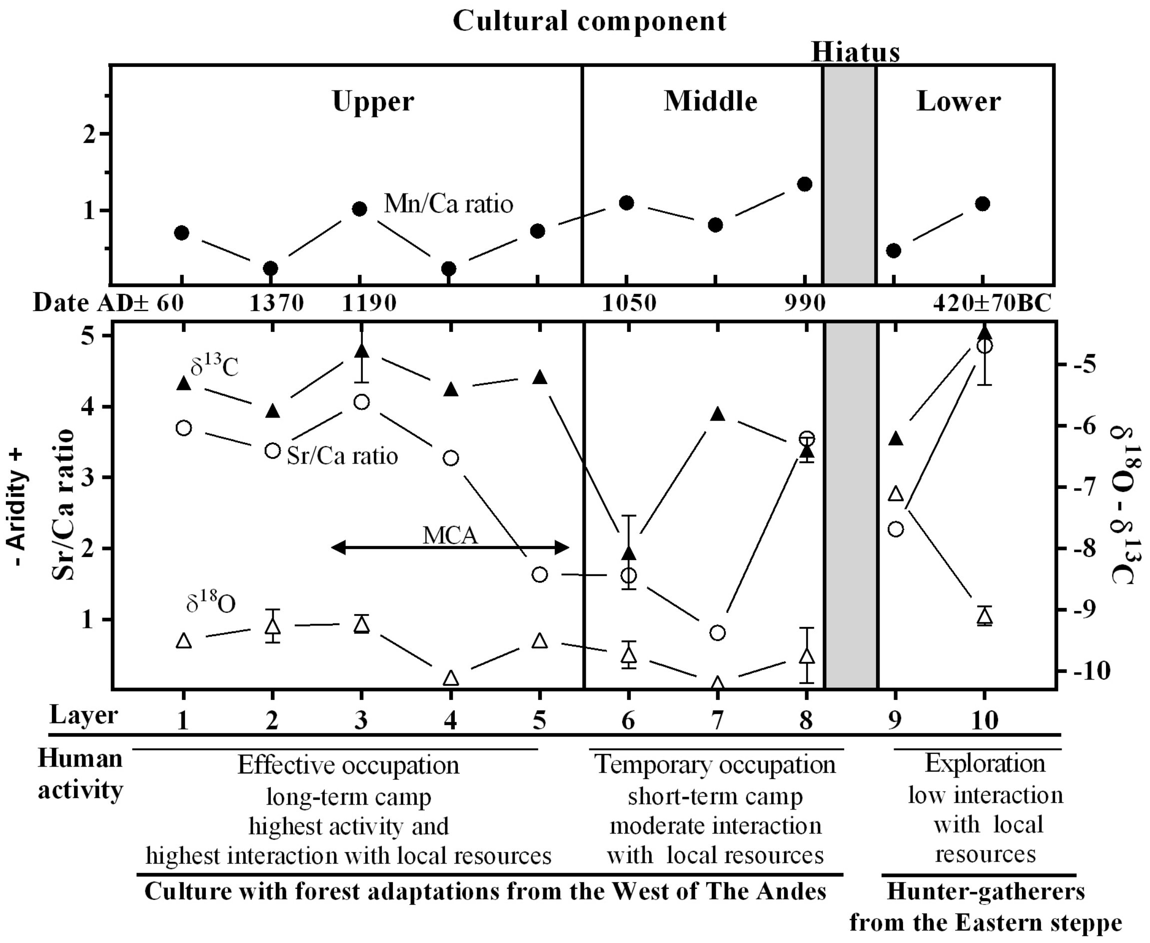
2 m
1 m
F III
G III
Upper component
Middle component
Low component
① Upper component: Layer 2: 580 ± 60 BP Cal. 1289-1439 AD (LP 1695)
② Upper component: Layer 3: 760 ± 60 BP Cal. 1113-1388 AD (LP 1697)
③ Middle component: Layer 6: 900 ± 60 BP Cal. 1018-1264 AD (LP 1713)
④ Middle component: Layer 8: 990 ± 60BP Cal. 901-1206 AD (LP 1720)
⑤ Lower component: Layer 10: 2370 ± 60 BP Cal. 233-762 BC (LP 1704)
Blocks of mother rock
Blocks of mother rock with volcanic ash
Charcoal
Silty sediment-charcoal- volcanic ash
Volcanic ash
Disintegrated large rocks-microvertebrates
Wet and mudy sediment, medium grained blocks
Irregular blocks with grey sediment
Large stones
Wet granular sediment with granular blocks
Tephra


Surface
Layer 1
Layer 2
Layer 3
Layer 4
Tridi N°3
Layer 2
Layer 5
Layer 6
Layer 7
Layer 8
Layer 9
Layer 10
Layer 11
1 cm
2 cm
X IAP


Cultural component
Hiatus
Upper
Middle
Lower
Mn/Ca ratio
2
1
Date AD± 60
1370
1190
1050
990
420±70BC
5
4
3
2
1
- Aridity +
Sr/Ca ratio
δ13C
Sr/Ca ratio
MCA
δ18O
-5
-6
-7
-8
-9
-10
δ18O - δ13C
Layer
1
2
3
4
5
6
7
8
9
10
Human activity
Effective occupation
long-term camp
highest activity and
highest interaction with local resources
Temporary occupation
short-term camp
moderate interaction
with local resources
Exploration
low interaction
with local
resources
Culture with forest adaptations from the West of The Andes
Hunter-gatherers
from the Eastern steppe

UNIVERSIDAD CATOLICA
DE TEMUCO

Temuco, Chile, January 10th 2020

Dr. Thijs van Kolfschoten
Editor Quaternary International

Dear Dr. Kolfschoten,

None of the authors have any conflicts of interest to declare.

Kind regards

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