# HUMAN TAPHONOMY IN SOUTHERN PATAGONIA: A VIEW FROM THE SALITROSO LAKE BASIN (SANTA CRUZ, ARGENTINA)

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## Abstract

In recent years, it has been proposed that among the main causes of the underepresentation or virtual absence of human bone remains dating from late Pleistocene to middle Holocene times in southern Patagonia, are a combination of mostly inconspicuous mortuary practices and post-depositional processes contributing to a relatively high rate of bone tissue decay associated to most of open-air depositional environments. In this paper we discuss the latter factor based on physical and chemical data collected from different types of human burials distributed in different settings on a lake basin located in north-western Santa Cruz province, Argentina. Our results suggest that bone mineral diagenesis, mediated by local hydrology under a predominant recharge regime, probably is the key factor controlling survival at this region. As long as these conditions are widespread in Southern Patagonia, it is concluded that the implementation of new, more problem-oriented and taphonomically informed sampling strategies will be necessary in order to increase the probability of recovering early human remains.

## Resumen

Recientemente, diferentes autores han propuesto que, entre las principales causas de la subrepresentación de restos óseos humanos correspondientes al Pleistoceno final y al Holoceno temprano y medio en el sur de Patagonia, se encuentra una combinación de factores vinculados con las prácticas mortuorias y con procesos conducentes a altas tasas de destrucción post-depositacional en ambientes a cielo abierto. En este trabajo, discutimos este último problema, sobre la base de datos físicos y químicos recolectados a partir del análisis de diferentes tipos de entierro registrados en la cuenca del lago Salitroso (Santa Cruz, Argentina). Los resultados obtenidos sugieren que la diagénesis de la fracción mineral del hueso, mediada por la hidrología local bajo un régimen predominante de recarga, constituye el factor clave de control de la supervivencia ósea en esta región. En la medida en que las condiciones registradas en el lago Salitroso son comunes en diferentes ambientes patagónicos, concluimos que la implementación de nuevas estrategias de muestreo que tengan en cuenta las diferencias en el potencial tafonómico de cada ambiente resultan críticas para aumentar las probabilidades de recuperación de restos humanos tempranos a escala regional.

## Introduction

Archaeological research carried out in southern Patagonia during the last seventy years has shown that most of the record of human bone remains in that region is both, relatively scarce and recent (*i.e.*, mid to late Holocene in age). The issue regarding the description and explanation of this observational fact has only been explicitly addressed in the last few years by means of systematic survey, sampling, recording, and digging-up of human burials, and the analysis of existing databases (Barrientos *et al.* 2005; Castro and Moreno 2000; Goñi and Barrientos 2000, 2004; Goñi *et al.* 2000-2002; Guichón *et al.* 2001; Reyes 2002). Recently, a number of explanatory hypotheses have been put forward in order to account for this situation. For instance, Borrero (2001: 98) and Barrientos (2002: 240) have independently proposed that mortuary practices involving the frequent abandonment of the deceased could have been a major factor, but clearly not the only one, affecting the nature of the earlier Patagonian bioarchaeological record. Barrientos (2002), in particular, has argued that the scarce and sparse nature of the late Pleistocene and early Holocene bioarchaeological record of the Americas - and hence of southern Patagonia-, can be considered the most expectable outcome of the operation of highly mobile, low dense, spatially unconstrained, and expanding human populations. According to this author, socioecological factors like high residential mobility, very low population density and high space availability due to the absence of spatial circumscription could account for a relatively high rate of body abandonment among early American populations. Alternative or rather complementary explanations have also been proposed by Dillehay (2000: 231), who discussed them in the context of the early peopling of the New World. They are: 1) methodological (sampling) biases; 2) archaeological invisibility of early burials due to geological processes; c) destructive or inconspicuous burial practices; d) sample contamination in radiocarbon dating of human bone collagen; e) any combination of the above or other factors. Although some of these hypotheses can be confidently discarded due to their scarce or null empirical support (*e.g.*, systematic radiocarbon sample contamination; Barrientos *et al.* 2005), others deserve a more in-depth evaluation in multiple contexts in order to assess their degree of probability and to estimate their differential contribution to the whole picture.

In the specific case of southern Patagonia, a potentially major contributor to the virtual absence of late Pleistocene and early Holocene human bone remains would be the high rate of bone tissue decay associated to most of the depositional environments other than caves and rock shelters (Borrero 2001: 69-75). The latter tend to preserve organic materials very well, in this region, in a way that seems to be independent of the age of the deposits. For instance, in caves located close to the eastern slopes of the Andes (*e.g.*, Cerro Casa de Piedra 5 and 7) there are excellent conditions for organic preservation, as the finding of animal bones, furs, leaves and flowers dating as much as 10,000 $^{14}$C years BP (Aschero *et al.* 1992) has attested. Despite this fact, relatively few human remains have been discovered in caves and rock shelters and none, with the sole exception of Baño Nuevo in southern Chile (Mena *et al.* 2003), has a really early date (*e.g.*, Palli-Aike and Cerro Sota skeletons, once believed to have a late Pleistocene-early Holocene age, were AMS radiocarbon dated yielding uncalibrated ages of *ca.* 7800 and 3900 $^{14}$C years BP, respectively; Hedges *et al.* 1992; Neves *et al.* 1999). As long as mortuary practices, in addition to post-depositional processes, seem to be the probable main causes of the underepresentation or virtual absence of human bone remains dating from late Pleistocene to middle Holocene times in southern Patagonia, the opportunities of survival of human bones disposed in different kinds of burials in open-air settings need to be closely inspected. In this paper physical and chemical data collected from different types of human burials distributed in different settings on a lake basin located in north-western Santa Cruz province, Argentina will be presented and discussed, as a preliminary and exploratory step aimed to achieve these goals. This data will be used to discuss the preservation potential of different depositional microenvironments and burial types; to formulate hypotheses about the taphonomic and diagenetic processes involved; and to estimate an overall rate of bone destruction valid for environmental settings that are similar, in their fundamental properties, to those discussed in this paper.

## The Salitroso Lake Basin

The Salitroso basin (47° 25' S, 71° 29' W) is a low-altitude lacustrine basin situated between 100 and 300 m.a.s.l. It covers an area of about 200 km² surrounded by mountains (*e.g.*, Sierra Colorada, Cerro Negro) and plateaus or *mesetas* (del Águila and del Lago Buenos Aires). It is about 30 km west of the eastern slopes of the Andes, in the province of Santa Cruz in south-western Argentina (Figure 1). The basin is of glacial origin, and was filled up by an extensive postglacial lake (Giacosa *et al.* 1997), possibly until late mid-Holocene times. Currently, the prevailing vegetation is a shrubby steppe, with low-lying bushes (*e.g.*, Rosaceae, Asteraceae and Solanaceae) and some species of grasses (*e.g.*, Poaceae and Cyperaceae). In southern Patagonia, the soils are generally sandy and rocky, and very poor in organic matter. The temperature regimes of such soils are mesic and cryic, and the main moisture regime is ustic (Del Valle *et al.* 2002). In the study area, the formation of soils is extremely restricted. They are predominantly arid soils formed on landforms like broad depressions, dunes, and hill slopes (Del Valle *et al.* 2002). The parent materials are glacial, fluvio-

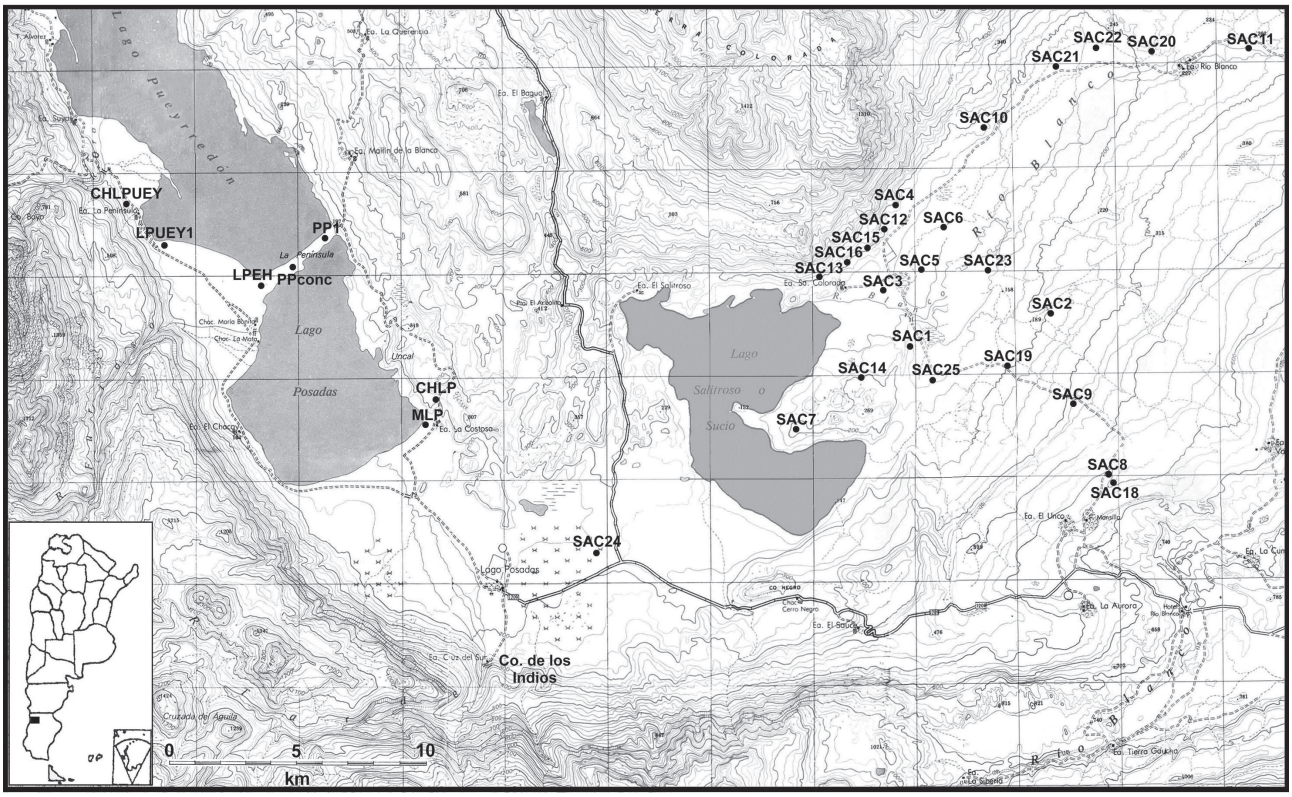


**Figure 1.** Spatial distribution of archaeological sites in the Salitroso lake basin.

glacial, alluvial, lacustrine and aeolian. These soils belong to the ustic natrargids and ustic paleargids edafic domains (*sensu* USDA's Soil Survey Staff 1999) (Del Valle *et al.* 2002), and they are susceptible to rather moderate hydric and aeolian erosion (Lapido and Pereyra 2002).

## The Bioarchaeological Record

To this moment, several *loci* with human burials have been recorded at the Salitroso basin (Figure 1). The human burials are of two basic kinds: *chenques* (typical and atypical) and niches. The *chenques* or cairns are intentionally-made stone structures with an irregular albeit near-elliptic contour, 3 to 5 m of diameter, and 0.5 m of maximum height. Inside them, the skeletons usually lay directly on the ground surface or, least often, on a shallow depression. The stones used to build the cairns are generally available in the immediate surrounding area. Most of the *chenques* are located on low hills, and other similar elevated landforms (*e.g.*, plateau's edges or *bardas*). These burials are usually arranged in clusters of variable size, though isolated *chenques* have also been recorded. Some of the structures show evidence of long-term use, like SAC1-1, which presents a difference of about 300 $^{14}$C years between the deepest interred individual and the one deposited at the top (Goñi and Barrientos 2000; Goñi *et al.* 2000-2002). Some *chenques* are not totally artificially made structures (atypical *chenques*). They were constructed using some pre-existent landscape feature like an erratic boulder or the edge of some dislocated stratum, as one of the sides of the funerary structure. The niches are natural hollows or rocky crevices where the bodies were deposited. At least six niches have been found in the north-western slope of a low hill (SAC 4), along an extension of about 200 m. They are usually single interments, although there is a multiple burial of at least four individuals.

A total number of 32 burials have been completely excavated up to this moment: 24 typical *chenques*, 3 atypical *chenques*, and 5 niches. From these structures, a minimal number of 79 individuals have been recovered. According to 19 AMS radiocarbon dates (human bone collagen), the chronology of the typical *chenques* ranges from 352 ± 40 to 1147 ± 40 $^{14}$C years BP, and that of niches and atypical *chenques* ranges from 2274 ± 40 to 2607 ± 40 $^{14}$C years BP (Goñi and Barrientos 2004; Goñi *et al.* 2000-2002).

## Human Bone Modification in the Salitroso Lake Basin: Some Expectations Based on Burial Types and Depositional Environments

A number of specific studies have been performed in order to account for human bone modification under different conditions (Bell 1990; El-Kammar *et al.* 1989; Gordon and Buikstra 1981; Greenlee 1996; Henderson 1987; Waldron 1987). The degree of post-burial bone modification has been determined to depend on factors that are both extrinsic and intrinsic to the bone (Henderson 1987; Linse 1992; Von Endt and Ortner 1984). Extrinsic factors are those related to the environment of bone deposition (*e.g.*, sediment pH, temperature, moisture content, macrobial and microbial organisms, soil chemistry, hydrological regimes of soils) while intrinsic factors are a function of the bone material itself (*e.g.*, porosity, density, shape, size, age, bone chemistry) (Beisaw 1998). Intrinsic factors may act to accelerate or to buffer the effects of the extrinsic factors (Lyman 1994). In this section the main extrinsic factors operating on the human bone remains from the Salitroso basin will be identified, discussing their probable differential impact on each type of burial.

In the funerary structures, either *chenques* or niches, the skeletons are very close to the surface, covered by a very thin layer of sediment (*i.e.*, not more than 20 cm thick) mainly deposited by natural agents. In *chenques*, the deposit was probably formed by the entrapping of dust particles carried by the wind. Those particles progressively filled-up the interstices between the rocks that formed the *chenque*, and were then fixed by vegetation [*e.g.*, by shrubs like *mata torcida* (*Nardophyllum obtusifolium*) and *duraznillo* (*Colliguaja integerrima*), which very often grow on the structures]. In niches, the indurate sediment that covered the skeletons was probably formed through a process characterised by the deposition of dust particles carried by the wind, and the later incorporation of carbonates and other minerals leached from the rocky walls of the hollows.

The near-surface position of the bodies could have influenced their post-depositional fate in many different ways. In the first place, it could facilitate the access of scavengers to the body. In southern Patagonia, grey foxes (*Dusicyon griseus*) are the most active scavengers (Martin 2002), producing both a limited destruction of bone and some loss of anatomical integrity of carcasses. The intensity of the damage and the dispersion of the bones caused by these agents is seemingly dependent on the location of the body in relation to their activity areas (*i.e.*, lower in dens and higher in open-air spots) (Martin 2002: 143). In the second place, it is known that the depth of the burial controls the temperature of the immediate environment of the corpse. In general terms, the shallower the burial, the warmer it will be, directly influencing the rate of chemical reaction which, in turn, relates to the rate of soft tissue decomposition (Gill-King 1997). This is an important issue since the rate of soft tissue decomposition may act as a major factor controlling the attractiveness for scavengers of a decaying body. In the Salitroso basin, bodies deposited in niches and *chenques* probably had slightly different skeletonisation rates because the degree of exposure of the bodies deposited in niches was probably higher in the early stages of their post-depositional history, prior to any significant covering of the remains with aeolian sediments. At this locality the temperature of the near-surface sediments varies mainly seasonally. From May to August (*i.e.*, from fall's last third to winter's last third), the bottom of the basin is occasionally covered by snow, which probably gives a constant cold temperature to the external layers of the deposits. In summer the diurnal temperatures raise typically up to 25-30ºC (mean summer temperature of about 13.4ºC; San Martino and Manavella 2004), with relatively low thermal amplitude (about 10 to 15ºC). Under these conditions, the expected decomposition pattern is one in which different rates of tissue decay alternate on a seasonal basis. The whole skeletonisation process takes no less than 144 days [calculated with the formula $y= 1285/x$ (Vass 2001: 191), where $y$ is the number of days a body takes to become skeletonised and $x$ is the average temperature in ºC during the decomposition process]. In fact, due to local conditions, the skeletonisation period may have been much more extended, as it is shown by the Cerro Johnny skeleton discovered in Palli-Aike lava field (around 45 km north of the Magellan Strait coast), which was in a semi-exposed position in a rocky hollow very similar to the niches described herein. This individual, dated between 480 ± 70 and 350 ± 90 $^{14}$C years BP, presented mummified soft tissues in the hands and spinal column (Martin 2002: 134), a very exceptional condition in southern Patagonia. Relatively slow rates of soft tissue decay imply that the total period in which the corpses presented some attractiveness for scavengers may have been prolonged in relation to other environments. A previous study carried out on the human remains from the Salitroso basin (Zangrando *et al.* 2004) shows that 17% of the analysed individuals (n = 30) exhibited damages produced by carnivores or scavengers. The most affected area of the skeleton was the periabdominal one, including the anterior iliac crests, the proximal third of the femora, and the caudal end of the sacrum. Damages on scapulas, ribs, vertebras and metatarsals were also identified. The form and distributional pattern of the recorded bone modifications are compatible with the kind of bone destruction produced by canids. The restricted location of the damages as well as the low frequency of marks on individual skeletons indicates that foxes were the most probable agents implied. In *chenques* (n = 26) only the 0.2% of the elements exhibited damages produced by carnivores, whereas in niches (n = 4) 6.4% of the elements were affected. This clearly indicates that niches offered both, a lesser protection and a greater attractiveness for scavenger activity relative to *chenques*, the latter probably due to a longer persistence of soft tissue remains attached to bones.

The decay of the body via putrefaction, decomposition and/ or consumption by scavengers progressively leaves bones bare of its surrounding tissues and periosteum. In this situation, bone is subjected to diagenesis, *i.e.*, the alterations in the physical and chemical composition of bone following its deposition in the geological environment. Bone is a composite of mineral (bone apatite) and organics (mainly collagen) and its survival is governed by the diagenesis of both components (Nielsen-Marsh *et al.* 2000). Once the stability of either the mineral or protein is compromised, the other becomes vulnerable to rapid deterioration. Actually, bone diagenesis seems to proceed via three alternative pathways: a) chemical deterioration of the organic phase, b) chemical deterioration of the mineral phase, or c) biodegradation (*i.e.*, utilization of the bone components as an energy source by micro-organisms) (Nielsen-Marsh 2002: 12). These three pathways are not mutually exclusive, and the predominance of any of them seems to depend on the burial environment. Due to the intimate association of the organic fraction with mineral, which prevents microbial decomposition (*i.e.*, collagen hydrolysis by proteolytic enzymes), demineralisation seems to be a necessary forerunner for biodeterioration. Such mineral dissolution, which may be biologically mediated, is usually controlled by site hydrology and geochemistry (Hedges and Millard 1995, Nielsen-Marsh and Hedges 2000, Pate and Hutton 1988; see also Trueman *et al.* 2004 for exposed bones). Hedges and Millard (1995) outlined the relationships between hydrological regimes of burial contexts and diagenetic changes in bone. Those hydrological regimes are diffusion (still water conditions), recharge (a wet-dry cycle) and flow (continuous water movement). Under a diffusive regime, the dissolution rate is related to the surface area of the bone, and it is largely linear. The recharge dissolution model shows an accelerating dissolution rate, although recent calculations by Pike *et al.* (2001) suggest recharge is unlikely to be a significant dissolution mechanism. The flow model shows a sudden and rapid dissolution of the bone after a long period of apparent stability. In burial conditions, however, the volume of water available for flow may limit such behaviour (Hedges and Millard 1995; Pike *et al.* 2001). In the specific case of the Salitroso basin the prevalent hydrological regime currently is, and probably was during much of the late Holocene, recharge. The supply of water to the sediments is mainly given by the rainfalls, which are concentrated in summer (particularly in January) and in winter (the mean annual precipitation is about 100 to 200 mm), and by the snow melting in late winter and early spring. In general, the rather coarse sediments that surround the skeletons retain a very low content of moisture, which only increases close to the roots of the shrubs that frequently grow onto the funerary structures. The loss of moisture by the near-surface sediments is primarily controlled by evaporation, whose rate is accelerated by the westerly winds that are especially intense during austral summer (*i.e.*, October-February; Prohaska 1976). This situation promotes a predominantly wet-dry cycle affecting the bones, which might contribute to bone diagenesis and biodeterioration through increased demineralisation (Hedges and Millard 1995; *cf.* Pike *et al.* 2001).

Microbial (*i.e.*, fungal and bacterial) attack is an important contributor to bone deterioration. A recent study by Jans *et al.* 2004 shows that animal and human bones from complete burials are more likely to be affected by bacterial than by fungal attack. Bacterial degradation is linked to putrefaction, which occurs during the early stages of decomposition involving endogenous bacteria, most of them coming from the bowel and respiratory tract (*e.g.*, *Staphylococcus*, *Candida*, *Malasseria*, *Bacillus*, *Streptococcus* sp.) (Vass 2001). Bones from the thoracic and, particularly, abdominal areas are then expected to be more affected by microbial attack, being near to the intestines where bacterial putrefaction starts (Child 1995). Under this condition the position of the body inside the grave would be a controlling factor since an extended position keeps most of the bones apart from the abdominal and thoracic areas whereas in highly flexed or bundled burials most of the bones become close to these areas, increasing the chances of endogenous bacterial attack on them. In the Salitroso basin, the predominant position is the extended one (dorsal and ventral), particularly in *chenques*. In niches, probably due to reduced space availability, the burials are mostly flexed. These differences in the position of the bodies inside each kind of grave may introduce concomitant differences in the overall preservation state of the skeletons. However since the *chenques* are generally multiple burials composed by not well aligned (both longitudinally and transversally), asynchronous, and very often superimposed burials, the proximity of the bones of either individual to the abdominal or thoracic areas of any one other was highly probable in most situations. This factor could compensate for any advantage of *chenques* relative to niches in terms of bone preservation potential introduced by the position of the bodies inside the grave.

Another potential source of bacterial aggression on skeletal tissues is soil. Graveyards or burial grounds may have dormant populations of bacteria that are well adapted to attack human bone because they are able to use collagen as a growth substrate (Balzer *et al.* 1997; Janaway 1987). The existence of such quiescent bacterial populations is more probable in multiple burials than in single ones and in frequently used graveyards than in those scarcely used ones. In the Salitroso basin the *chenques* tend to be multiple burials whereas the niches are usually single burials. On the basis of this single factor, a better preservation potential can be expected in niches in relation to *chenques*. However, there are some clues that bones from single burials and scarcely used graveyards, where dormant populations of bacteria would not be expected to exist, do not show a significantly better preservation (Mant 1987). This may indicate that the effect of soil bacteria on bone is almost negligible, while the condition of the body and the burial circumstances has more impact on bone preservation (Jans *et al.* 2004).

It is known that the presence of heavy metals like copper (Cu) and zinc (Zn) can inhibit bacterial activity (Saeki *et al.* 2002). In the Salitroso basin, the presence of copper artefacts (*e.g.*, beads and plates) has only been recorded in association to very few *chenques*. So, it can be said that at least some *chenques* provided a somewhat worse environment for this kind of micro-organism in relation to niches if this factor had any influence on bacterial activity.

Diagenetic processes can be interrupted by events leading to the re-exposition of bones to those aerial or sub-aerial conditions that promote weathering (Behrensmeyer 1978). One major controlling factor is the structural stability of the grave, which influences the probability that any single skeletal element become exposed to weathering in the short, medium or long term. In our case study, both *chenques* and niches seem to be very stable on the short and medium term. However, on the long run niches are prone to collapse, thus creating the conditions for bone physical damage (*e.g.*, crushing) and weathering. In the case of *chenques*, the major agents for aerial exposure of bones are modern human activities like vandalism and looting which are very frequent in southern Patagonia (Castro and Moreno 2000; Goñi and Barrientos 2000).

In summary, it can be said that there are no clear differences in the expected preservation potential of *chenques* and niches on the basis of the factors discussed above (Figure 2) with the sole exception, probably, of scavenger activity, which could have been much higher in niches (Zangrando *et al.* 2004). Under these conditions any demonstrable difference in bone preservation and skeletal integrity between assemblages may be, mainly but not exclusively, a function of time (see Gutiérrez 2001). If such an assumption is true, the general expectation is that human skeletal remains from niches and atypical *chenques* will be, on average, worse preserved than those from typical *chenques* on the basis, mainly, of their greater antiquity, allowing the estimation of a general bone destruction rate.

## Materials and Methods

A total sample of 31 individuals recovered in typical (n = 21) and atypical (n = 6) *chenques* and niches (n = 4) were selected for examination, although the actual number of individuals included in each particular analysis differed in some cases. The comparative analyses were performed taking into account two temporally differentiated groups: a) the Early Assemblage (EA) composed by cases whose radiocarbon age is >2200 $^{14}$C years BP, and the Late Assemblage (LA) composed by cases whose radiocarbon age is <1200 $^{14}$C years BP.

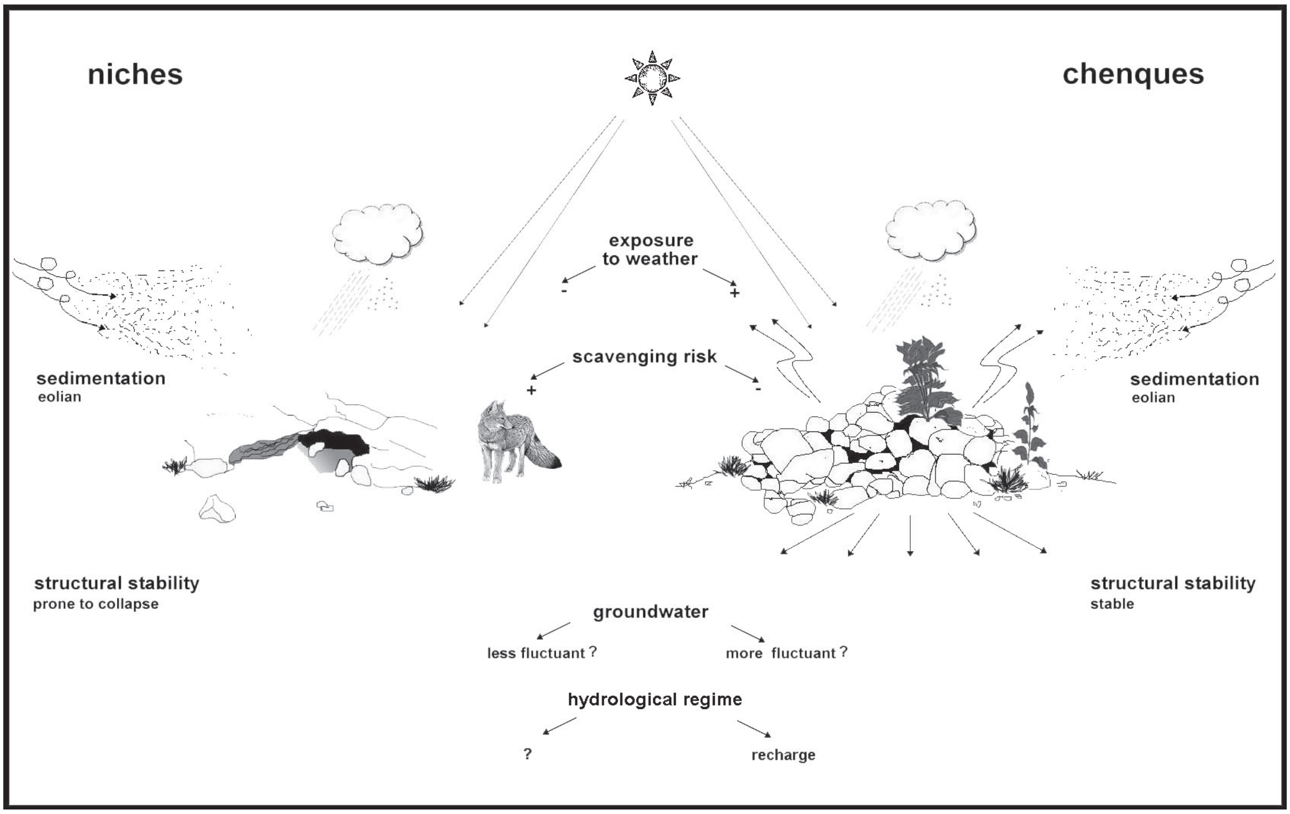


**Figure 2.** Main extrinsic factors impinging differentially upon niches and chenques at the Salitroso lake basin.

As an overall measure of skeletal preservation and integrity on an individual basis, the total number of analysable elements per individual (TNAE) was counted (*i.e.*, the total number of elements from each individual that could be reliably examined in search of bone modification evidence). This index may differ slightly from the total number of recorded elements, which may be considered a more straightforward measure of skeletal integrity. However, it was preferred to quantify TNAE because it is not only informative about the quantity but also about the quality of the preserved material. The differences between temporal groups was assessed by means of the Kolmogorov-Smirnov two-sample test, which is sensitive to differences in the general shapes of the distributions in the two samples (*i.e.*, differences in dispersion, skewness, etc.). Due to the exploratory nature of this research, the alpha level for this and for other statistical analyses was set at 0.05.

The percentage of survivorship (% survivorship), which measures the relative abundance of skeletal parts in an assemblage (Brain 1981; see discussion in Lyman 1994), was used in order to assess the degree of skeletal preservation on an elemental basis. In this study this percentage was obtained by dividing the observed frequency of each anatomical element multiplied by 100, by the expected frequency resulting from multiplying the total sample size (actually not a MNI value as it is frequently used in zooarchaeological analyses) by the *n* times each element is represented in a complete skeleton. It is expected that in a progressively diagenetic-altered bone assemblage, the % survivorship will be strongly correlated with the bone mineral density value of each skeletal part (Lyman 1994: 249). The % survivorship of 18 elements consisting of the proximal, medial, and distal thirds of six appendicular long bones (*i.e.*, humerus, radius, ulna, femur, tibia, and fibula) of adult individuals with the corresponding values of bone mineral density by circumference (BMDc) was compared (Galloway *et al.* 1997). It has been demonstrated that in human assemblages BMDc is strongly correlated with bone survival, and that it is a more efficient descriptor of density relative to other measures, like bone mineral density (BMD) and volume density (VD) (Willey *et al.* 1997). In order to adequate the information provided by Galloway *et al.* (1997: Tables 2 and 3) to our data, some processing of such information was necessary. First, an average value for each third of every bone (left and right, male and female) was calculated using the values of all scan locations between the distal extreme and the 20% for the distal portion, between 20% and 80% for the medial portion, and between 80% and the proximal end for the proximal portion. Second, the values corresponding to each third of both sides and, finally, the values corresponding to both sexes were averaged. This final value of BMDc was used for comparison with the % survivorship of each third of bone. The relationship between these two variables was tested by Spearman Rank Order Correlation analysis.

On each suitable element of 26 individuals (17 from typical *chenques*, 5 from atypical *chenques* and 4 from niches), nine modifications were recorded which are informative about a number of post-depositional processes affecting the bone in its depositional microenvironment. These modifications are:

*Rodent gnawing*: The gnawing action of rodents, this behaviour is generally aimed to provide attrition to their continuously growing incisors, and produces a characteristic pattern of scores and furrows on bone surfaces. Rodent gnawing tends to focus on the densest skeletal parts (Lyman 1994), particularly on the edges. In this study, only the position of the marks was recorded, with no attempt to estimate the extension or to describe the morphology of the bone modification.

*Manganese dioxide ($MnO_2$) staining:* It usually appears as small, dark and rounded spots that may coalesce forming more extensive patches on the bone surface. Manganese dioxide staining is probably produced by microbial activity during early diagenesis (Daniels 1981; Ecker 1989). Water-insoluble manganese oxides are favoured under high pH and oxidizing conditions. However, redox reactions of manganese ($Mn^{2+}$) in many environments have been linked to microbial metabolism (Bratina *et al.* 1998), which convert manganese that is ubiquitously present in the soil to $MnO_2$, and leave it as a surface residue when the microbes dies (Daniels 1981). Thus, $MnO_2$ staining would be considered a general indicator of the microenvironmental conditions (*e.g.*, availability of oxygen, water, a balance of air -and water-filled pore space, near neutral pH values, adequate supplies of inorganic nutrients like nitrogen and phosphorus, and abundant organic substrates) that surrounded the bone, particularly during its early post-depositional history. In this study, the presence of $MnO_2$ was determined by means of naked eye and low magnification (£ 20X) examination of the entire surface of each anatomical element. In the positive cases, the extension of the stained areas was estimated using a percentile scale with four intervals (*i.e.*, 1-25%; 26-50%; 51-75%; 76-100%).

*Root etching*: It usually takes the form of dendritic patterns of shallows grooves on bone surfaces, although in many cases a significant part of the cortical layers of bone may be completely removed (Andrews 1990). Root etching can be interpreted as the result of the dissolution by acids, either excreted by plant roots (Lyman 1994), or associated with the growth and decay of roots or fungi in direct contact with bone surfaces (Behrensmeyer 1978). Vegetation roots very often play an important role in the state of preservation of bone assemblages as they contribute, by applying mechanical force, to fragmentation and destruction of the cancellous bone as they penetrate the interior throughout existing cortical desiccation cracks (Gutiérrez 2001). In the present study, the extension of the etched areas was estimated using a percentile scale with four intervals (*i.e.*, 1-25%; 26-50%; 51-75%; 76-100%).

*Fractures*: A fracture is a transverse, oblique, and more rarely longitudinal break that develops because of repeated or prolonged forces against the bone. If more pressure is put on a bone than it can stand, it will split or break. Bone resistance to fracturing forces will be a function of its biomechanical properties and its degree of structural preservation, which is expected to change through time at a site-specific rate. In a burial environment, compression forces induced by overburden weight constitute a major factor responsible for the fragmentation of bones in an assemblage, as they become progressively dry. According to Villa and Mahieu (1991), a post-burial fractured assemblage is characterised by *in situ* bone breakage in such a way that conjoining fragments usually lay adjacent to one another, incomplete fractures and cracks are frequent, and breakage tends to occur in bones resting on concave or convex surfaces. In this study the position and the form of each fracture were recorded following Johnson (1985) and Davis (1985).

*Cracks*: A crack or fissure is defined here as any breakage without separation of parts, generally longitudinal or parallel to the main axis of bone. The depth and length of each crack can be variable; being any increase of these attributes a probable function of time, and the correspondent rate of change, strictly site-specific. The cracking of the bone tissue is one of the macroscopic changes involved in bone weathering, along with flaking, splitting and fragmentation (Behrensmeyer 1978, 1990).

*Bone loss*: By bone loss it exclusively means here the post-depositional destruction and disappearance of parts of a bone without any reference to *in vivo* processes like osteopenia and osteoporosis. While the underlying cause may remain undetermined in most cases, bone loss may be a useful measure of the intensity of post-burial dynamics. In each specimen, this feature was recorded taking into account both the position and the extension of the modification.

*Crushing*: In this particular context, crushing refers to the *in situ* breakage and collapse of bone walls mainly due to rock overburden weight. It often appears as rounded or elliptical depressed areas on the bone surface with radial fractures. Concentric fractures associated to the radial ones are rare or absent. These crushed areas are usually located in zones of thinned walls and low mineral density like metaphyses or epiphyses. Like most of the post-depositional breakage of bones, the crushing effect is probably more intense on diagenetically altered (*i.e.*, weakened) elements. This feature was recorded following the same criteria made explicit for bone loss.

*Deformation*: It refers to the plastic (*i.e.*, irreversible) distortion of a skeletal element. In this kind of post-depositional bone modification, two or more anatomical points on a single element change their relative spatial locations (Lyman 1994). The deformation of a bone can take different forms (*e.g.*, homogeneous deformation, bending; Shipman 1981; Lyman 1994), depending on several factors, including its original morphology, modulus of elasticity, orientation, and nature and timing of diagenetic factors affecting the tensile and compressive strengths and modulus of elasticity (*e.g.*, mineralization and leaching) (Henderson 1987; Lyman 1994; Turner-Walker and Parry 1995). In this study, the presence of deformation was assessed by means of macroscopic examination of all skeletal elements and comparison with undeformed bones.

To allow the comparison between groups it was first calculated, on the basis of presence/absence of data, the percentage of bones (relative to the individual TNAE) with positive cases of each kind of bone modification. After this, in order to estimate the mean percentual value of each group, only the individuals with TNAE of equal order of magnitude (two digits) were considered. To compute the significance level (two-sided) for the difference between the mean percentages of both groups, the mean TNAE of each group was introduced as sample size.

In addition to bone modifications soil pH was analysed, which is a measure of the acidity or alkalinity of the soil. Linse (1992) pointed out that the three primary factors that affect the preservation or destruction of buried bones are pH, temperature, and moisture content. Temperature and moisture content, however, influence the pH of a deposit. The importance of pH in bone preservation results from the enzyme most commonly involved in the breakdown of collagen, collagenase, which is produced by only a few microscopic organisms and is active only within a fixed pH range (Beisaw 1998). In the specific case of human burials, Gordon and Buikstra (1981) found that soil pH correlated inversely with bone deterioration, and that some age-associated preservation biases are expectable in any assemblage subjected to acidic environments due to differences in bone mineral density. Bone hydroxiapatite is most stable around pH 7.8 and has low solubility in alkaline aqueous systems (pH <7.5), while in an acidic environment (pH £6.0), its solubility is relatively high (White and Hannus 1983; Nielsen-Marsh *et al.* 2000). In this study, the pH was measured at both in the field and in the lab using a 50ml/50ml solution of soil and distilled water. The samples (n = 38) were collected inside and outside burials. The pH values were converted to hydrogen ion concentrations before averaging them, and then reconverted to pH.

## Results and Discussion

The averaged TNAE of both assemblages is significantly different (Kolmogorov-Smirnov two-sample test; $p < 0.05$). The mean TNAE value calculated for the EA is 15.7 ± 5.4, and for the LA is 28.7 ± 10.2, which indicates that the individuals of the LA tend to be better represented than those of the EA in terms of skeletal parts suitable for analysis. The comparative analysis of the % survivorship of the adult individuals of both groups (Figure 3) shows that for almost all skeletal parts, the values of this index in the EA are lower than those expected under the assumption of a perfect identity between the two groups (*i.e.*, they are at the left of the dashed line which represents the perfect agreement between both samples). The cases for which such a deviation is probably higher than that expected by chance (*i.e.*, on the left of the upper 99% confidence band around the empirically calculated regression line) are the proximal tibia, and the distal and proximal fibula. The comparison between the % survivorship of both assemblages with BMDc indicates that there is a non-significant correlation between these two variables in the LA ($R = 0.36$; $p = 0.14$), but a relatively high and significant positive correlation in the EA ($R = 0.61$; $p = 0.01$) (Figure 4). These results suggest that taphonomic and post-depositional processes mediated by the structural density of the skeletal parts affected the pattern of survivorship in the EA but not in the LA. Soil pH does not explain the observed differences in preservation and integrity between both assemblages since there are no statistical differences between burials or sites. The mean pH inside the burials (n = 26) is 8.08 ± 0.97, which indicates nearly neutral to slightly basic conditions.

The comparison between groups of the mean percentages of presence of the other kinds of bone modification (Figure 5) shows that the fractures (EA = 93%, LA = 57%) and cracks (EA = 97%, LA = 72%) are the only variables for which there are significant statistical differences between both assemblages (two sided test of difference between two percentages; $p < 0.05$; mean TNAE EA = 16, mean TNAE LA = 29). The bones of the EA tend to be more fragmented than those of the LA, although there are no significant differences in bone loss (EA = 90%, LA = 71%). This suggests either some loss of structural strength in the bones of the EA relative to those of the LA, or the existence of a more stressing microenvironment in terms of loads

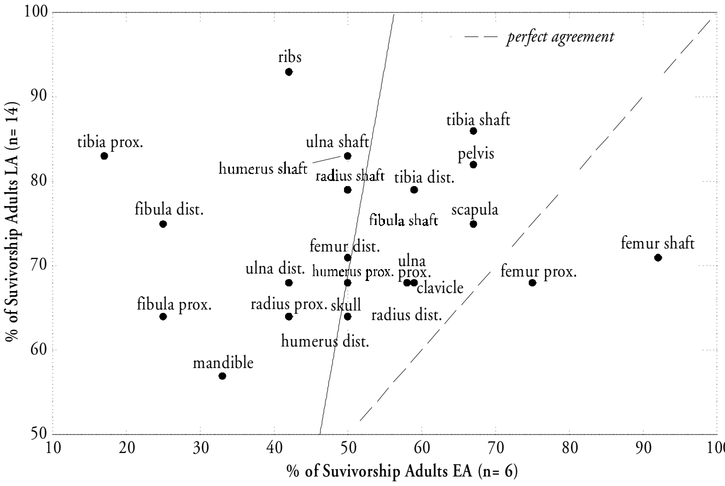


**Figure 3.** Scatterplot of % survivorship of the Early and Late Assemblages.

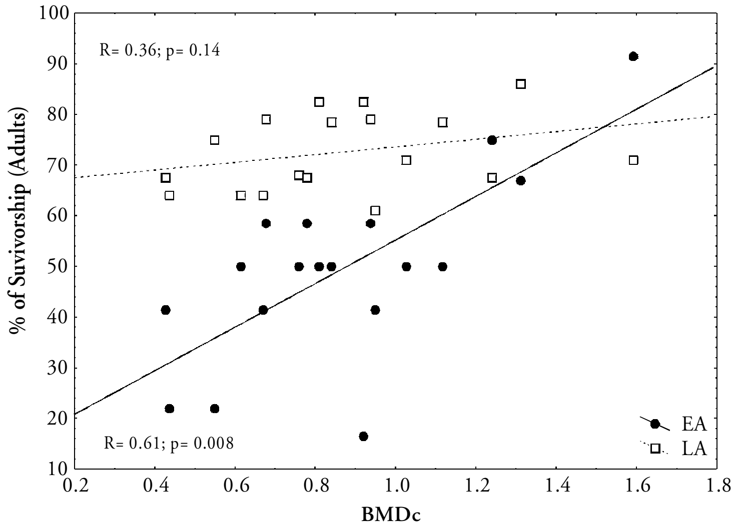


**Figure 4.** Scatterplot of the % survivorship of the Early and Late Assemblages against bone mineral density by circumference (BMDc).

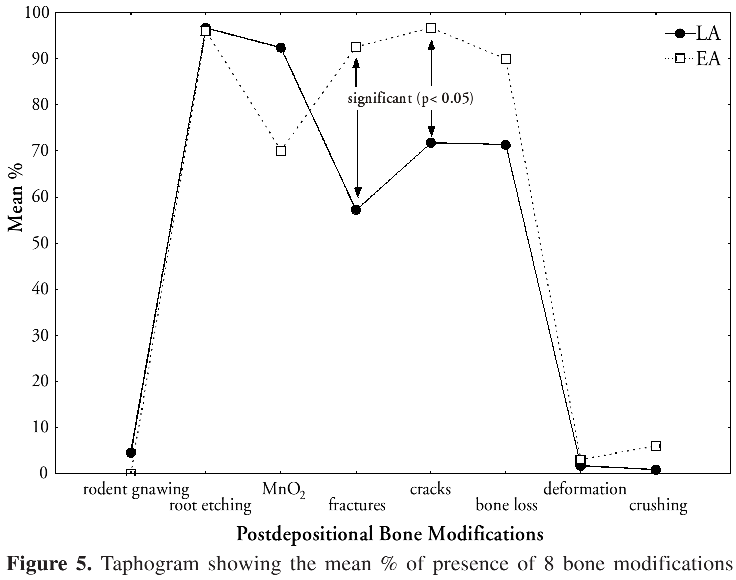


**Figure 5.** Taphogram showing the mean % of presence of 8 bone modifications on bones of de Early and Late assemblages.

or forces impacting bones in this group. The similar low percentages of deformation (EA = 3%, LA = 2%) and crushing (EA = 6%, LA = 1%) in both assemblages suggest, however, that there were no significant differences in the overburden weight to which the bones were exposed. This probably indicates the existence of diagenetic processes differentially affecting the bones of the EA, either related to the local condition of the depositional environment or to time. The statistically undifferentiated percentages of rodent gnawing marks (EA = 0%, LA = 5%), root etching (EA = 96%; LA = 97%), and $MnO_2$ staining (EA = 70%, LA = 90%), indicate a remarkable similarity in different properties of the depositional environment of both assemblages.

Summarising, it can be said that there are differences in the degree of preservation and integrity of individual skeletons between both diachronic assemblages. There are proofs of increasing bone destruction and loss (*i.e.*, diminishing TNAE) in the EA relative to the LA, probably caused by higher levels of fragmentation *via* fracturing and cracking. Such destruction follows the expected pattern related to intra-skeletal differences in bone mineral density as measured by BMDc. All this suggests that there was a temporal progression in bone susceptibility to experiment physical damage, which was probably related to an increasing diagenetic alteration of the assemblage.
Was the apparent increased fragility of bones in the EA relative to the LA mainly due to bone apatite dissolution? As long as the proteinaceus content seems to be predominantly high, as indicated by the fact that every sample selected for radiocarbon analyses (n = 19) yielded more than 5 wt % of «collagen», and that the %N measured on the whole bone powder of 14 samples using a Carlo Erba EA 1108 CHNS-O Analyzer (e = ± 0.5%) (INQUIMAE, University of Buenos Aires) ranged between 3.1 and 4.8, such a possibility seems unlikely. In fact, high protein content is usually accompanied by good mineral preservation (Nielsen-Marsh 2002). However, if the high values for %N are a result of significant contamination occurring concurrently with loss of bone collagen, then this would indicate that the mineral phase was indeed undergoing diagenetic alteration (*i.e.*, to some extent dissolution and/or recrystallisation). At the current stage of our research, particularly in the absence of supporting data about contamination (*e.g.*, C:N ratio from the collagen fraction), is still not possible to accept or to reject either possibility.

Notwithstanding the above mentioned fact, some considerations based on the properties of the depositional environment can be advanced in order to preliminarily discuss this problem. According to Nielsen-Marsh *et al.* (2000), the key environmental parameters controlling bone apatite dissolution are a) soil pH, b) saturation of water with respect to $Ca^{2+}$ and $PO_4^{3-}$ ions, and c) the rate of groundwater movement. Since no major differences in soil pH across the entire locality was found, and that the measured pH values were nearly neutral to alkaline, a condition under which the apatite is expected to be stable (White and Hannus 1983) it is reasonable to think that bone apatite dissolution, if it occurred at any significant degree, was mediated by soil phosphate content and, more probably, local hydrology. Our observations support the idea about the existence of very fluctuant conditions in the moisture content of the depositional environment. The probable hydrological regime may have been, in almost every location, recharge. The unsaturated (in terms of $Ca^{2+}$ and $PO_4^{3-}$ ions) and oscillating nature of the hydrological environment could create sufficient conditions to promote a rather accelerated rate of mineral dissolution which, in turn, could increased the mechanical fragility of bones making them prone to physical damage and, in ultimate instance, to destruction and loss. Further increase in sample size, the carrying out of controlled experiments and observations, as well as the measurement of mineralogical and organic diagenetic parameters (*e.g.*, histological integrity, porosity, crystallinity, %N and C:N ratio from the collagen fraction; see, among others, Ambrose 1993; DeNiro 1985; Hedges *et al.* 1995; Müldner and Richards 2005; Stafford *et al.* 1988; Van Klinken 1999), are urgently needed in order to address this issue properly.

Despite our still rather limited and imperfect knowledge about the clear-cut causes of bone destruction, it is feasible to explore its relationships with time in a more detailed way. Figure 6 is a scatterplot of the individual TNAE against $^{14}C$ age. It shows that there is a significant negative correlation

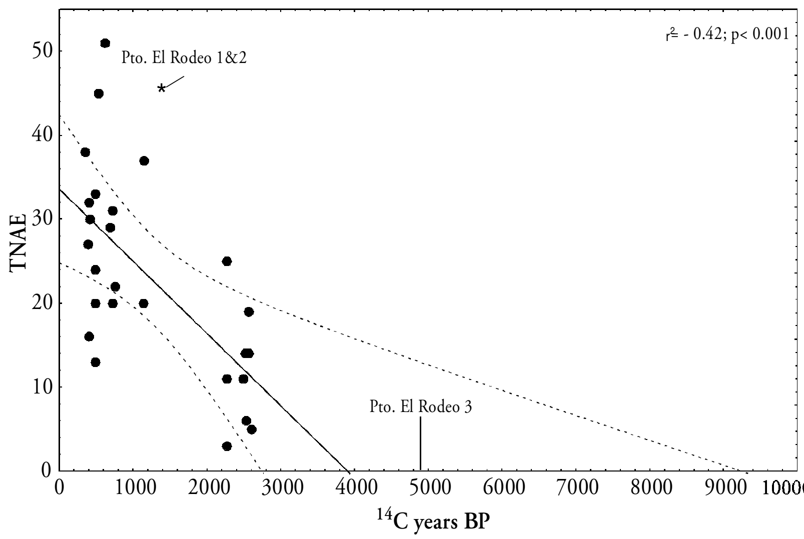


**Figure 6.** Scatterplot of the TNAE values of each individual (black circles) against its radiocarbon date. The dashed lines represent the 99% confidence bands around the regression line (solid line). Superimposed are the individuals recovered at Puesto el Rodeo.

between these two variables (r = -0.65; p< 0.001). The dispersion of values around the regression line ($r^2 = 0.42$), however, indicates that a good predictive model (*i.e.*, to accurately derivate the expected TNAE value on the basis of the $^{14}$C age) cannot be constructed with these data. Notwithstanding this fact, this relationship can be used to calculate approximate rates of bone destruction and to set the limit beyond which the chances of skeletal preservation and, consequently, of burial recognition are extremely low. The 99% confidence bands around the fitted line to set that limit were used. As it is shown in Figure 6, the upper band cuts the x-axis at 9210 $^{14}$C years BP indicating that this is, under the assumption of a linear relationship between the $^{14}$C age and the individual TNAE, the expected end limit of skeletal preservation at this locality. The rate of bone destruction estimated from the final slope of this band is 3 elements/1000 $^{14}$C years. However, the final slope of the lower band indicates that such a rate can be as fast as 12.8 elements/1000 $^{14}$C years, leading to a total skeletal destruction at an early date of 2758 $^{14}$C years BP. At the present time, there are neither quantitatively or qualitatively comparable data in southern Patagonia outside the Salitroso basin that could be used to test the general applicability of this model. However the *chenque* excavated at Puesto El Rodeo, some 60-km north-east of the Salitroso basin (Gradin and Aguerre 1994), provided useful information to provisionally evaluate its predictive value. This *chenque* was a multiple burial composed by three individuals. A bed of shrub twigs separated the uppers two (PER1 and PER2) from each other. The third individual (PER3) was directly laying on the rocky floor of the funerary structure, separated from the other two by a 15 cm thick layer of sterile sediments. A sample of vegetal remains extracted from the bed of twigs separating PER1 and PER2, and a fragment of vegetal charcoal recovered close to the lumbar vertebrae of PER3 yielded ages of 1380 ± 90 $^{14}$C years BP and 4860 ± 150 $^{14}$C years BP, respectively (Gradin and Aguerre 1994: 268-271). PER1 and PER2 exhibited a high degree of skeletal integrity; comparable to that of the skeletons included in the LA of the Salitroso basin, along with a very good bone preservation state. PER3 was, instead, very badly preserved to the extent that virtually no bones were recovered in a suitable state to perform different analyses (*e.g.*, morphometric, paleopathologic, paleodietary). This data seem to fit very well into the model of bone destruction presented here, suggesting that there is some room to believe that it might be generalised to environmental settings that are similar, in their fundamental properties, to the Salitroso basin.

The results discussed in this paper have serious implications for the bioarchaeological study of the early peopling of southern Patagonia. They clearly indicate that the probability of obtaining samples of human bone remains buried or deposited in open-air settings is extremely low. The post-depositional processes operating on skeletal assemblages, mainly those probably related to the properties of the hydrological environments (*i.e.*, unsaturation of $Ca^{2+}$ and $PO_4^{3-}$ ions and oscillation in groundwater content) promote relatively high rates of bone destruction, which severely diminish the chances of skeletal preservation and survival through time. Insofar as there seems to be no significant differences in preservation potential between the two main forms of disposal (*i.e.*, *chenques*, both typical and atypical, and niches), the general expectation is that irrespective of this factor, very few -if any- recognisable burials of early Holocene or late Pleistocene age might be recovered in environmental settings similar to those sampled in this study. Since these kinds of environment have a widespread distribution at the regional scale, the search for evidence of early human burial needs to be reoriented to geographically more restricted places with better preservation potential. Such a potential, mainly given by stable environmental conditions -either dry or waterlogged-, is found in southern Patagonian settings like caves, wetlands or marshes (*mallines)*, bogs, and floodplains. Remarkably, the last three constitute places that are rarely taken into account in archaeological sampling design at the regional level.

## Concluding Remarks

The research described in this paper has been exploratory in the sense that it was intended to proportionate a limited set of answers as well as a broader set of questions referred to the chances of bone survival in open-air settings in southern Patagonia. On the one hand, our results indicate that bone mineral diagenesis, mediated by local hydrology, probably is the key factor controlling survival at this and other similar locations in this region. It seems that wherever microenvironmental conditions allow dissolution of bone apatite in unsaturated media, relatively high rates of skeletal destruction should be expected. At the present time, however, the exact nature of the diagenetic alteration remains unknown and needs to be addressed by means of more specific analyses. On the other hand, it becomes evident that the high rates of post-depositional bone destruction inferred for open-air settings are among the most probable co-occurring causes of the under representation of human skeletal remains of late Pleistocene to early Holocene age in southern Patagonia. A combination of largely destructive taphonomic and post-depositional processes and of inconspicuous practices of body disposal (Dillehay 2000), which may include abandonment (Barrientos 2002; Borrero 2001) and the deposition of corpses in niches or shallow burials with different degree of exposure, could all contribute to obliterate a significant part of the early bioarchaeological record at the regional level. The implementation of new, more problem-oriented and taphonomically informed sampling strategies will be necessary in order to be able to recover the elusive and vanishing remains of the early inhabitants of the southernmost tip of South America.

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