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Criteria for the Identification of Formation Processes in Guanaco *(Lama guanicoe)* Bone Assemblages in Fluvial-Lacustrine Environments

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The aim of this paper is to present and discuss methodological criteria that may be of use in exploring the role of water in the formation of the faunal record in fluvial and lacustrine environments. As such, the dispersion potential of the bones of adult and neonate guanaco *(Lama guanicoe)* skeletons in an aquatic environment with very low hydraulic energy is evaluated through experimentation. Results of the experiments are integrated with other, complementary criteria and applied to the bone assemblage recovered at Paso Otero 1 site, situated on the margin of the ancient flood plain of the Quequén Grande River (Buenos Aires Province, Argentina). The results of this study indicate that water was the main agent responsible for guanaco bone accumulation at the site. It is proposed that some of the skeletal parts, which belong to guanaco carcasses that were processed and exploited by hunter-gatherers in areas close to the site, were added to those from animals that died naturally. This resulted in a mixture of material of both natural and anthropic origin.

Keywords: SITE FORMATION PROCESSES, GUANACO (*Lama guanicoe*), BONE DISPERSION POTENTIAL, ONTOGENETIC DEVELOPMENT, FLUVIAL AND LACUSTRINE ENVIRONMENTS, ARGENTINA.

Introduction

In the archaeological literature several bone assemblages of anthropic and natural origin have been identified that are located in lacustrine and fluvial deposits on the margins of ancient flood plains, rivers, and lakes (Salemme, 1987; Fosse, 1998; Martínez, 1999; Germonpré, 2003; Loponte & Acosta, 2003; Acosta *et al*., 2004; Bonomo & Massigoge, 2004; Bonomo, 2005; González de Bonaveri, 2005; Kahlke & Gaudzinski, 2005). One of the usual questions in this type of context concerns the origin of the bone assemblage

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and the role of water in the formation of the deposit. The effects of fluvial processes on faunal remains have been subject to various analyses (*e.g.*, Voorhies, 1969; Dodson, 1973; Behrensmeyer, 1975; Boaz & Behrensmeyer, 1976; Hanson, 1980; Schick, 1987; Trapani, 1998; Fernández-Jalvo & Andrews, 2003; Nasti, 2005). However, until now there have been no actualistic studies that have explored variations in the hydric displacement of bones that have taken the ontogenetic development of individuals into account (Kaufmann & Gutierrez, 2004).

The aim of this paper is to present and discuss methodological criteria that may be of use in exploring the role of water in the formation of the faunal record in very low energy lacustrine and fluvial environments. As such, the dispersion potential of the bones that constitute adult and neonate guanaco *(Lama guanicoe)* skeletons is evaluated in the light of experimentation in an aquatic environment with very low hydric energy. The results of these experiments are integrated with other complementary criteria and applied to the bone assemblage recovered from Paso Otero 1 site, situated on the margin of the ancient flood plain of the Quequén Grande River (Buenos Aires Province, Argentina).

To date, several experiments and observations have been carried out that explore the hydric behavior of bones belonging to different species, in both laboratories and natural environments (Voorhies, 1969; Dodson, 1973; Behrensmeyer, 1975; Boaz & Behrensmeyer, 1976; Hanson, 1980; Schick, 1987; Coard & Dennell, 1995; Coard, 1999; Trapani, 1998). Voorhies' (1969) study constituted a pioneer piece of research on the differential displacement of disarticulated sheep (*Ovis aries*) and coyote (*Canis latrans*) bones. The author defined three groups of bones that reflected different susceptibilities to fluvial transport (see Materials and Methods). Based on new experimental studies on different mammal species, Behrensmeyer (1975) established that bones' different structural properties such as size, density, and shape are related to their dispersion potential in a fluvial environment. Coard & Dennell's (1995) and Coard's (1999) approach explored the variability that bones present with regards to hydric displacement. They demonstrated that bones behave differently according to the state they are in as they contact the water; that is to say, whether they are dry or wet, articulated or disarticulated.

Guanacos are one of the two wild species of the *Lama* genus; they are currently distributed from the south of Peru, along the Chilean and Argentinean Andes to Tierra del Fuego and Navarino Island. They are also found in western Paraguay. In Argentina they occupy the entire area below 40º in latitude, from the Andes to the Atlantic Ocean (Redford & Eisenberg, 1989). This animal was a major resource for the hunter-gatherer groups that inhabited the different regions of the Southern Cone during the Late Pleistocene and Holocene. Consequently, it is common to find abundant remains of this ungulate in the archaeological sites of these regions (Madrazo, 1979; Politis, 1984; Salemme, 1987; Politis & Salemme, 1990; Miotti, 1998; Miotti & Salemme, 1999; Mengoni Goñalons, 1999; De Nigris, 2004; Martínez & Gutierrez, 2004).

The dense concentrations of guanaco bones in discrete units (*e.g.*, bone concentrations) constitute a relatively frequent trait in the archaeological sites of the Humid Pampas sub-region for the Middle Holocene (Martínez, 1999; Mazzanti & Quintana, 2001; Bonomo, 2005). Consequently, the development of methodological criteria that will enable the origins of the formation of such bone assemblages to be explored is of special interest for Argentinean archaeology.

Materials and Methods

The methodological criteria proposed in this paper to evaluate the role of water in the formation of the guanaco faunal record in very low energy lacustrine and fluvial environments take the following variables into account: 1) representation of skeletal parts; 2) degree of association of the bone elements; 3) spatial distribution of the bones; 4) natural bone modification, both abrasion and polish; and 5) contextual information (*i.e.*, evidence of cultural activity). Representation of skeletal parts is measured through a) the relationship between %MAU and the hydric displacement differential probabilities proposed by Voorhies (1969); b) neonate and adult guanaco bone elements frequency, taking into account the fluvial transport potential groups for the species included in this paper; c) tooth/vertebra ratio; and d) unfused diaphysis/epiphysis proportion.

What follows is a description of the criteria that have been mentioned. It is worth indicating that a special emphasis has been placed on the description of the methodology and the results obtained from the experiments that were conducted to measure the hydric dispersion potential of the guanaco bones. This variable constitutes an original contribution towards solving the problem this paper poses. The other variables, on the contrary, constitute complementary criteria that have been established previously by others researchers and integrated into this paper.

Representation of skeletal parts

A. Bone element dispersion potential: experimentation

The individuals used to conduct the measurements and observations are guanacos that belong to the reference collection of the Archaeology Laboratory, Facultad de Ciencias Sociales (Olavarría, Argentina) that originated in the north-east region of Río Negro Province (40° 36’ SL and 65° 25’ WL; Argentina). The skeletons selected for this analysis were a neonate (IND #17, 15 days to 3 months old) with all its bone elements unfused and an adult (IND #24, 10 to 11 years old) with all the skeletal parts already fused. These skeletons were selected because they are representative of two age classes with marked fusion differences between them. Differential bone responses to hydric dispersion were expected related to size and density values.

The dry and wet global densities of the bones that make up the guanaco skeletons were estimated. The following density formula was used:

$$D = M/V$$

where: D = density; M = mass; and V = volume of the element, taking pores into account.

The measurements were taken with due consideration for the different ossification centers of the neonate bones. For example, the humerus of the adult individual was measured as one single element. In contrast, the humerus of the neonate individual was divided into the following parts: lateral tuberosity, head, distal epiphysis and diaphysis (Figure 1).

To calculate the global density of the different bone elements, each specimen was first weighed in a dry state and every 10 minutes thereafter, during which period each bone was in continuous contact with the water. Once the bone element had stopped incorporating water, its volume through water displacement was calculated. Test tubes of different grading containing tap water at 20° C and with a density of 0.966 were used. The water displacement was always recorded at the base of the meniscus. The dry global density and the wet global density of each specimen were obtained from the weight of the dry and wet bone and the volume. When the bones were measured the following were also recorded: whether the element floated, remained in suspension or sank immediately.

Figure 1. Fusion centers of the humerus according to the different age groups studied.

In the context of this paper, it is necessary to discuss some issues that arise from the methodology and the interpretation of the results obtained. Disarticulated bones with no soft tissue were used for the experimental studies. However, the variation in dispersion capacity according to the initial state of the bones as they contact the water was not ignored (Coard & Dennell, 1995; Coard, 1999). Furthermore, the variation that the density of the natural medium can undergo when compared to that recorded in this analysis (~1) should be noted. In an inundation situation, for example, the water density increases as a result of the sedimentary materials it transports, a fact that would influence, in this case, the dispersion capacity of the bone elements (Behrensmeyer, 1975). Finally, it is known that in archaeological sites long bones in general are frequently found fractured, due to cultural as well as natural agents. This situation reduces the possible applications of the model proposed in this paper. But, this is an exploratory experiment which started out examining whole bone elements in order to generate basic information which would enable the construction of a more complex theoretical model of hydric displacement that could account for various, hypothetical archaeological situations.

The results that were obtained by applying this methodology adequately answer the original question posed for this paper concerning the displacement potential of the different skeletal parts in low energy fluvial and lacustrine environments. However, the values obtained do not constitute a proper framework of reference which could solve differential preservation potential problems since they do not account for the mineral content of each bone element and, as a consequence, its survival potential (Elkin, 1995; Stahl, 1999).

Results: bone density and dispersion capacity

The results obtained from the variables, weight, volume, and density of the different skeletal elements of the two analyzed individuals, are presented in Tables 1 and 2. The density range recorded for the skeletons is ample; there are bones that float (Group I; high dispersion probability), bones that remain suspended (Group I-II; intermediate dispersion probability) and bones that do not float (Group II-III; low dispersion probability). The density range of the neonate bones when the bone is dry oscillates between 0.63 g/cm^3 (sternebra, humerus: lateral tuberosity and head) and 2.12 g/cm^3 (molars), and between 0.55 g/cm^3 (sternebra) and 2.42 g/cm^3 (molars) for the adult. In every case there was correspondence between the density of the specimen and its behavior in the water (0.966 density at 20° C); since all the bones with density values smaller than 0.999 floated, those that had values close to this remained suspended and those that exceeded this value sank.

Within the group of bones that floated, it was observed that during the first few minutes some specimens (*e.g.*, distal epiphysis of the femur) incorporated a significant quantity of water through absorption and sank rapidly. Other elements, on the contrary, incorporated small amounts of water and floated for several hours (*e.g.*, lateral tuberosity, head and distal epiphysis of the humerus) (Figure 2).

The results obtained from the adult skeleton are similar to those that have been reported for other medium-sized species (*e.g.*, *Ovis* and *Redunca* genus, Behrensmeyer, 1975). There were only some minor differences recorded possibly due to the state in which the bone samples were found and because they pertain to different species. In the case of the neonate skeleton, in contrast, the number of elements that float and remain suspended with high probabilities of hydric displacement increase significantly (Figure 3). This is basically due to the fact that most of the unfused proximal and distal epiphyses (except the distal epiphysis and the crest of the tibia) are of low density, small size, and rounded in shape. These facts would favor their displacement by flotation or suspension, even in a low energy fluvial context such as the periphery of a flood plain. Conversely, the unfused diaphysis of these same elements would not present the same predisposition to fluvial displacement given its higher density and size.

As regards the interpretation of the data, it can be established that in theory in an archaeofaunal assemblage the frequencies of differential distribution of the elements with different dispersion probabilities due to flotation or suspension would indicate that a hydric modification or displacement could have taken place at the site. An example of this would be the scarce presence of bone elements with high or intermediate dispersion probabilities caused by flotation or suspension and, consequently, of low density. These profiles should not necessarily be interpreted initially as resulting from hydric displacement; that is to say, as a bone assemblage produced by selection by aquatic transport. The reason for the low representation of these elements could be linked to attritional processes (*e.g.*, weathering) or to carnivore activity (Behrensmeyer, 1978; Gifford-Gonzalez, 1989). Similarly, as occurs with other species (*e.g.*, bison, Kreutzer, 1992), some of the guanaco bone elements that present a high fluvial displacement probability, such as ribs and sternebrae, are also part of the bone elements ranked as of high economical value (Borrero, 1990). All the possibilities

Table 1. Distribution of the results obtained for the variables weight, volume and density of the different bone elements of a neonate guanaco. Bones are ordered according to their density values in a dry state.

Neonate Skeleton	Dry weight	Volume	Density in dry state
GROUP I			
Humerus. Head	7.52	12.00	0.63
Sternebra	3.46	5.50	0.63
Humerus. Lateral tub.	3.76	6.00	0.63
Axis. Odontoid apophysis	1.97	2.80	0.70
Humerus. Distal epiphysis	8.27	11.00	0.75
Patella	2.84	3.40	0.83
Pelvis. Pubis	4.38	5.20	0.84
Femur. Distal epiphysis	24.45	29.00	0.84
Radius. Distal epiphysis	8.16	9.50	0.85
Scapula. Tuberosity	2.07	2.40	0.86
Metapodial. Condyle	2.59	3.00	0.86
Femur. Head	5.33	6.00	0.89
Ulna. Olecranon	2.07	2.30	0.90
Sacrum	9.05	10.00	0.91
Femur. Main trochanter	2.57	2.80	0.92
Tibia. Proximal epiphysis	12.15	13.00	0.93
Thoracic vertebra	7.02	8.00	0.94
Calcaneum. Proximal ep.	1.71	1.80	0.95
Atlas. Ventral arch	1.92	2.00	0.95
Pelvis. Ileum	21.83	22.79	0.96
Phalanx 2	1.83	1.90	0.96
Caudal vertebra	0.29	0.30	0.98
Radio. Proximal epiphysis	3.96	4.00	0.99
Scapula	34.10	34.19	1.00
GROUP I-II			
Axis. Body	15.08	15.00	1.01
Ulna. Distal epiphysis	2.05	2.00	1.03
Calcaneum. Body	14.61	14.00	1.04
Cervical vertebra	18.23	17.50	1.04
Phalanx 1	5.45	5.20	1.05
Pelvis. Ischium	17.26	16.50	1.05
Lumbar vertebra	7.56	8.00	1.08
GROUP II-III			
Rib	4.38	4.00	1.10
Tibia. Crest	2.20	2.00	1.10
Atlas. Dorsal arch	5.69	5.10	1.12
Tibia. Distal epiphysis	5.37	4.80	1.12
Hemimandible	51.51	45.58	1.13
Tibia. Diaphysis	80.37	69.00	1.17
Humerus. Diaphysis	59.43	50.00	1.19
Femur. Diaphysis	75.86	63.00	1.20
Ulna. Diaphysis	15.66	13.00	1.21
Metatarsal. Diaphysis	49.13	40.00	1.23
Radious. Diaphysis	55.02	42.00	1.31
Metacarpal. Diaphysis	55.02	42.00	1.34
Molar	4.24	2.00	2.12

Table 2. Distribution of the results obtained for the variables weight, volume and density of the different bone elements of an adult guanaco. Bones are ordered according to their density values in a dry state.

Adult skeleton	Dry weight	Volume	Density in dry state
GROUP I			
Sternebra	7.91	13	0.55
Thoracic vertebra	25.97	30	0.87
Caudal vertebra	3.63	4	0.91
Patella	20.76	20.7	1.00
GROUP I-II			
Femur	244.75	240	1.02
Sacrum	94.24	90	1.05
Lumbar vertebra	37.25	34.5	1.08
GROUP II-III			
Humerus	224.57	200	1.12
Cervical vertebra	71.37	61	1.17
Scapula	130.70	111.15	1.18
Cranium	364.64	259.35	1.20
Phalanx 2	5.68	4.6	1.23
Tibia	246.36	200	1.23
Axis	50.84	40	1.27
Rib	15.33	12	1.28
Pelvis	382.00	296.4	1.29
Phalanx 1	16.10	12	1.34
Radius-ulna	226.17	160	1.41
Calcaneum	36.54	26	1.41
Atlas	34.42	24	1.43
Metatarsal	124.36	80	1.55
Metacarpal	133.02	85	1.57
Mandible	220.21	133.38	1.65
Molar	8.47	5.00	2.42

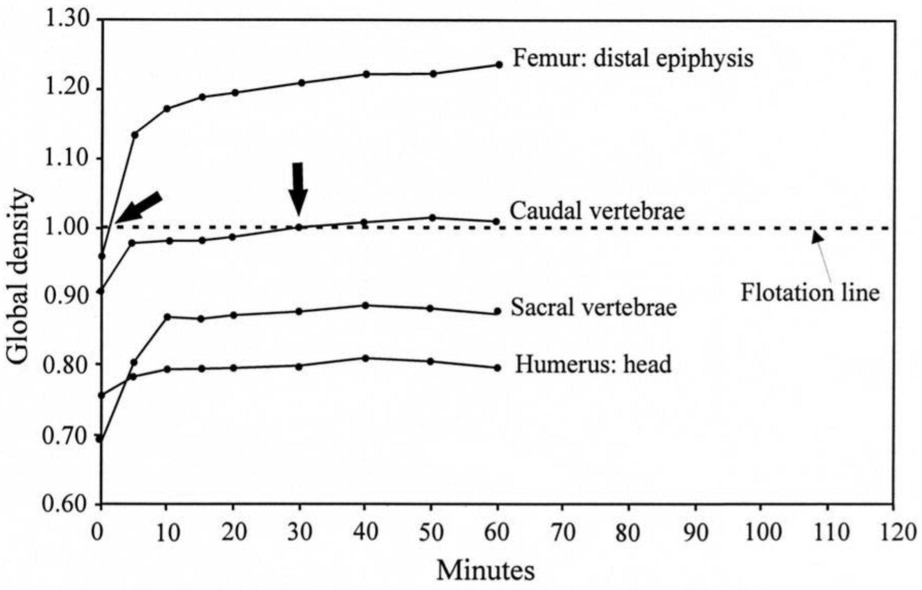

Figure 2. Examples of increase in density due to water absorption. The arrows indicate the moment in which the bones exceeded the density of the water and sunk.

that have been mentioned so far constitute examples of equifinality between fluvial displacement and other taphonomic processes. Therefore, complementary evaluative criteria would provide integral information to interpret, in an adequate way, the taphonomic history of a bone assemblage.

B. Voorhies' groups

Voorhies (1969) conducted experiments on disarticulated sheep (*Ovis aries*) and coyote (*Canis latrans*) bones in artificial channels, controlling the speed of the current. He defined three groups of bones that reflect different susceptibilities to fluvial transport. Group I includes bones that are immediately transported by saltation or floating: ribs, vertebrae, sacrum and sternebrae. Group II includes bones that are gradually removed by traction: femur, tibia, humerus, metapodial, pelvis, and radius. In an intermediate condition between groups I and II are the scapula, the phalanxes and the ulna. Finally, group III includes the cranium and the mandible; both elements resist transport and remain as delayed elements. These groups have traditionally been used to infer the degree of transport and fluvial selection that a bone assemblage has undergone throughout its formation (Shipman, 1981).

C. Tooth/vertebra ratio

Behrensmeyer (1975) proposed the tooth/vertebra ratio as a fluvial selection index. In a mammal skeleton, the tooth/vertebra ratio is usually close to 1.0. Teeth are the densest elements while vertebrae are among the least dense elements and consequently among those that can be more easily transported by currents (Voorhies, 1969; Behrensmeyer, 1975; Badgley, 1986).

D. Unfused diaphysis/epiphysis proportion

As in the previous case, it is suggested that the proportion of unfused long bone diaphysis to epiphysis constitutes another line of evidence that enables an evaluation of the integrity of a bone assemblage found in a fluvial-lacustrine environment. Most of the unfused proximal and distal epiphyses have low densities; they are of small size and rounded in shape, a fact that favors their displacement by floating or suspension. In contrast, the unfused diaphyses of the same elements would not present the same displacement predisposition due to their higher density and size. According to the hydric displacement differential capacity of epiphyses and diaphysis it is expected that primary deposited bone assemblages affected by water selection would present a higher proportion of unfused diaphyses in comparison to unfused ephiphyses. Contrary, transported bone assemblages would have a higher representation of unfused ephiphyses than unfused diaphyses. Thus, the biased values in these proportions would imply low integrity of the bone assemblage, suggesting that water was one of the possible transport agents. However, transport or destruction by carnivores and weathering could also generate bone assemblages with low representation of ephiphyses. The analysis of the entire bone deposit will yield information on the role of these processes at the site. It is argued that the epiphyses may not have been the only ones affected. Consequently, this isolated variable also presents equifinality problems with other taphonomic processes.

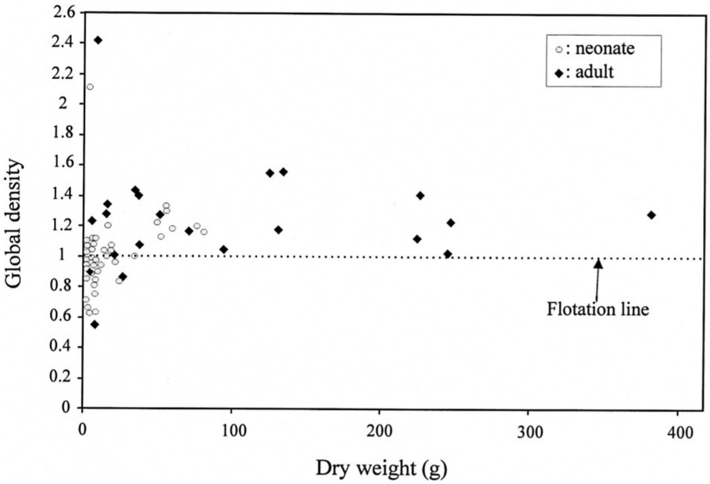

Figure 3. Global density of the bones in dry state *versus* the weight of the bone elements belonging to the neonate and adult individuals.

Degree of association of the bone elements

The anatomical refitting of bone assemblages is an appropriate tool to evaluate the degree of association of the skeletal elements, principally when the bone beds are very dense and the presence of articulated bones is not clear. The relationship among bones from the same carcass or conjoining pieces of the same bones may indicate horizontal and vertical dispersion from the original source (Behrensmeyer, 1991). It is possible to determine the natural and cultural processes that have affected the distribution and dispersion of the faunistic remains in a site from the degree of association of the bone elements. In this way, the integrity and resolution of the faunal assemblages can be determined (Hofman, 1992; Todd & Frison, 1992; Messineo & Kaufmann, 2001). The anatomical refitting that is habitually implemented in these types of studies includes bilateral refits, intermembral refits, and mechanical refitting of bone elements. In this paper the mechanical refitting of unfused diaphyses and epiphyses of young elements is also included.

Spatial distribution of the bones

Orientation analysis of the bones may reflect taphonomic processes such as the action of water currents and trampling. Experiments indicate that the long axis of a bone element tends to align parallelly or perpendicularly to the direction of the fluvial current, if it is intense enough (Toots, 1965; Voorhies, 1969; Shipman, 1981). However, in the case of mass transport the preferable orientation tends to be unclear or non-existent (Fernández-Jalvo & Andrews, 2003).

Natural bone modifications: abrasion and polish

Bone modifications caused by sedimentary abrasion provide important information on the depositional history of the bone assemblage (Fernández-Jalvo & Andrews, 2003). Fluvial activity may cause abrasion in bones during transport or *in situ* by contact with the sedimentary particles that are found suspended in the water. Three abrasion and polish stages are defined in this paper that, together with other taphonomic attributes, can be linked to sedimentary abrasion *in situ* and fluvial transport:

Stage 1: presence of sheen or gloss and smooth texture.

Stage 2: presence of blunt borders (gloss and smooth texture may also be present).

Stage 3: external tissue removal and possibly exposed trabecular tissue in those bones that have it (*i.e.*, vertebrae, and epiphysis)

Stage 2-3 has been included for diaphysis fragments because there is no attribute to distinguish between the stages as they are only comprised of compact tissue.

Contextual information: evidence of cultural activity

The idea that human action is at least partially responsible for the formation of a bone assemblage would be supported by the record of cut marks or fractures produced by anthropic processing, as well as by the presence of lithic artifacts. However, the mere presence of human traces on some bones and the instruments recovered at a site would not be sufficient evidence to sustain a cultural origin for a bone assemblage found among sediments of fluvial origin. It is important to take into account the rest of the variables that are considered in this paper that, when combined, will provide information on the origin and formation processes of the bone beds found in fluvial contexts.

Applying the results to a case study: Paso Otero 1

Site background

Paso Otero 1 is part of the archaeological locality Paso Otero (Politis *et al.*, 1991; Martínez, 1999, 2007; Gutierrez, 2007), which is located on the banks of Quequén Grande River, Necochea District, Buenos Aires Province, at 38° 34' SL and 58° 42' WL, within the Interserrana Bonaerense Area (Figure 4). The archaeofaunistic assemblage recovered at the site consists of approximately 3500 determinable bones in a total excavated area of 22 m^2 (Politis *et al.*, 1991). Except for a few small rodent bones, all the bone remains belong to guanacos (*Lama guanicoe*).

The site's stratigraphic sequence is similar to that of the fluvial valleys of the Pampas plains (Fidalgo *et al.*, 1973; Fidalgo & Tonni, 1978, 1981). The bone assemblage analyzed is from the Río Salado Member of the Luján Formation (Figure 4). This member is a stratified fluvial deposit that at the site presents three stable surfaces of the landscape that are represented by the A horizons of the buried soils (Johnson *et al.*, 1998; Holliday *et al.*, 2003). These places are interpreted as wet meadows (*charcas*) and their typical vegetation would have been grasses and rushes.

The guanaco bone remains are spatially distributed in at least five bone concentrations, described as discrete bone accumulations with defined limits in which bones are juxtaposed at a depth of 20 cm and with a relative inclination. One of these accumulations comes from the upper stable landscape (bone concentration 4) and the others from the middle stable landscape (bone concentrations 1-3 and 5) (Gutierrez, 1998). The stratigraphic position of the findings indicates that there were two different depositional events, which is supported by the radiocarbon dating (Johnson *et al.*, 1997, 1998). For the purposes of this paper, only the bone material coming from the middle stable landscape has been analyzed. Five small flakes (< 4 cm) and a bipolar artifact (coastal pebble) were recovered in close spatial association within the faunistic assemblage context of the middle stable surface. The minimal number of guanacos identified is 30. All the materials from the site come from an approximately 20 cm-thick level.

The chronology of the site is known through radiocarbon dates obtained from organic soil matter from the different stable landscapes and from a bone recovered in the deposit studied in this paper. The lower stable surface of the landscape gave an age of *ca.* 9950 years BP, the middle one *ca.* 4900 years BP and the upper one *ca.* 2900 years BP (Johnson *et al.*, 1998). Recently, a radiocarbon date from a guanaco molar from the middle stable surface yielded an age of 3056 ± 42 years BP (AA-72844; δC^{13} –19 ‰), indicating a different chronologies for the pedogenetic process and the depositional event (Favier Dubois, 2006; Martínez, 2007; Gutierrez, 2007).

The geoarchaeological studies carried out recently (2001-2003) by Favier Dubois (2006) yielded new evidence for understanding the formation processes of the site. This author proposes the presence

Table 3. Summary of the results obtained in each one of the variables analyzed in this paper. TA = total assemblage, BC = bone concentration.

Taphonomic Variables	**TA**	**BC1**	**BC2**	**BC3**	**BC5**
1A. Kaufmann and Gutierrez's (2004) groups	G I: 32% (N=10); G I-II: 12% (N=193); G II-III: 56% (N=897)	G I: 13% (N=45); G I-II: 12% (N=39); G II-III: 75% (N=251);	G I: 13% (N=47); G I-II: 8% (N=27); G II-III: 79% (N=281)	G I: 34% (N=171); G I-II: 17% (N=87); G II-III: 49% (N=248)	G I: 61% (N=247); G I-II: 10% (N=40); G II-III: 29% (N=117)
1B. Voorhies's (1969) groups	Group I partially under represented	Groups II and III prevail	Groups II and III prevail	All the groups are present	Groups I-II and I prevail
1C. Tooth/ vertebra ratio	1.18	1.35	2.75	0.51	0.16
1D. Unfused diaphysis/ epiphysis proportion	50 epiphyses surplus	44 epiphyses shortage	18 epiphyses shortage	2 epiphyses surplus	110 epiphyses surplus
2. Bone elements degree of association	*Articulation:* scarce (<1%) *Intra bone concentration refitting*: 1. Bilateral: 25; 2. Intermemberal: 17, 3. Mechanical: 9 *Inter bone concentration refitting*: Mechanical: 14				
3. Association degree of the bone elements	Absence of preferred orientation. Grouped into discrete assemblages of 20 cm deep.				
4. Abrasion and polish		21% (N=355)	27% (N=404)	8% (N=574)	3% (N=865)
5. Contextual information: a. Cut marks b. Anthropic fractures c. Lithic artifacts	a. 5% (N=1103) b. 2% (N=1277) c. 5 small flakes; 1 bipolar artifact	a. 3% (N=289) b. 2% (N=418)	a. 9% (N=404) b. 3% (N=442)	a. 2% (N=410) b. 0% (N=417)	a. Absent b. Absent

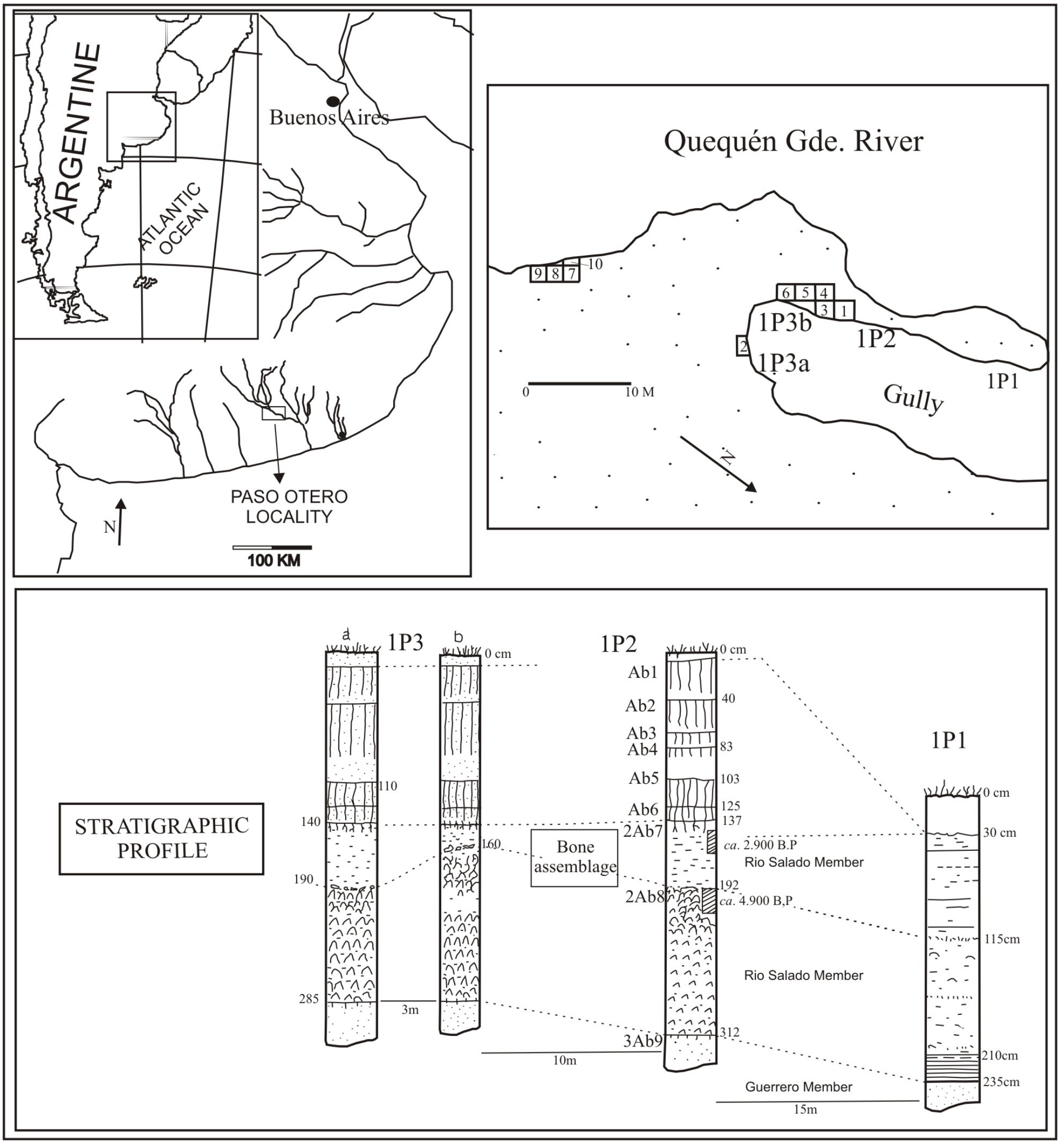

Figure 4. Paso Otero archaeological locality position. Detail of the excavation of the site and the stratigraphic profile. The stratigraphic sequence was taken from Favier Dubois (2006).

of two erosive unconformities. The first affects the middle stable landscape: it is channel-shaped and more than 40 cm deep), which implies the development of a spatially limited turbulent flow. After the channel was excavated (a high energy event) the prior conditions were likely restored: the quiet waters and slow sedimentation that are predominant in the unit that contains the unconformity, the Río Salado Member of the Luján Formation (Favier Dubois, 2006). The second erosive unconformity was identified within what was originally defined as the upper stable landscape. This is a horizontal discordance that has a lateral continuity and represents an important change in fluvial dynamics during the Late Holocene. Its origin may be linked to a flooding event of a larger scale and less turbulence than the one previously mentioned. From the stratigraphic analysis of the site, and taking the recorded erosive unconformities into account, Favier Dubois (2006) suggests that the deposition of both bone assemblages is related to erosive flows that differentially affected two of the main soils identified in the profile of the site. As discussed below, these results are consistent with both those obtained by Kaufmann & Gutierrez (2004) and those presented in this paper.

The frequency distribution of skeletal parts among bone concentrations are statistically significant indicating a differential representation of bone elements in each assemblage (Gutierrez, 1998). In general, short bones are best represented in bone concentration 3, long bones in bone concentrations 1 and 2, and a combination of short and long bones in bone concentration 5. The variability of the skeletal part profiles can not be explained using either bone mineral density or the food utility index frame of references (Gutierrez, 1998). Pre-burial processes were not severe at the site, suggesting a relatively rapid burial of the bone assemblages. The frequency distribution of the taphonomic effects differs significantly between bone concentrations in the following variables: solution pitting, geological abrasion, root etching, trampling, manganese staining, fracture patterns, and cut marks. Carnivore-damaged bones are scarce in the assemblage (1%) and are recorded only in bone concentration 1. Although bone fragmentation is high in the studied sample (*ca*. 60%), the fracture patterns are mainly characteristic of post-burial processes indicating that the majority of the bones were complete at burial (Gutierrez, 1998).

The anthropic or natural origin of the site has always been discussed and debated; it remained a problem to solve from the start of research. The main doubts generated concerned the scarcity of lithic materials or other human traces associated with the abundant faunistic bone remains, the spatial bone distribution, and site functionality (Politis *et al*., 1991; Johnson *et al*., 1997; Gutierrez, 1998, 2007; Kaufmann & Gutierrez, 2004).

Results

Representation of skeletal parts

A. Dispersion groups of guanaco bones in low energy environments (Kaufmann and Gutierrez's groups)

The juvenile and adult guanaco bone elements frequency for each bone concentration was estimated, taking into account the potential fluvial transport groups for this species that are presented in this paper (Table 3 and Figure 5). It is observed that bone concentrations 1 and 2 include large quantities of long bones from adult individuals and unfused diaphyses from juvenile individuals (75% and 79%, groups II and III, respectively) that have low relative probabilities of being transported by water. These proportions are the opposite of those found in bone concentration 3, where the frequency of bone elements from group I (34%) increases. Finally, bone concentration 5 includes 61% of bone elements that are easily transported by flotation or suspension (group I), even in a low energy fluvial environment (Kaufmann & Gutierrez, 2004) (Table 3 and Figure 5). Among these, the prominent elements are phalanxes, caudal vertebrae, patellae and unfused long bone epiphyses.

B. Voorhies' groups

The results for the %MAU of adult individuals indicate that all the bone elements are present at the site. However, the bones that are immediately transported by flotation or saltation (Voorhies group I) are represented by low %MAU values (less than 40%). Group I-II is very well represented by second and third phalanxes with %MAU values of 70%, while the bone elements that are resistant to hydric transport (Voorhies groups II and III) are represented by %MAU values higher than 50% (Figure 6). In general, the recovered bone remains in part present the characteristics of a group that has undergone hydric selection (Voorhies, 1969), where the bone elements that are easily transported (*i.e.*, vertebrae, ribs, sternebrae) could have been displaced outside the excavated area. On analyzing the bone concentrations individually, the %MAU values of each assemblage present differential characteristics in their percentages. Bone concentrations 1 and 2 include a large number of bone elements that resist transport; concentration 3 presents balanced values for the different Voorhies' groups; and bone concentration 5 presents the characteristics of a transported group with elements from Voorhies groups I and I-II, especially a large number of caudal and lumbar vertebrae and phalanxes (Table 3).

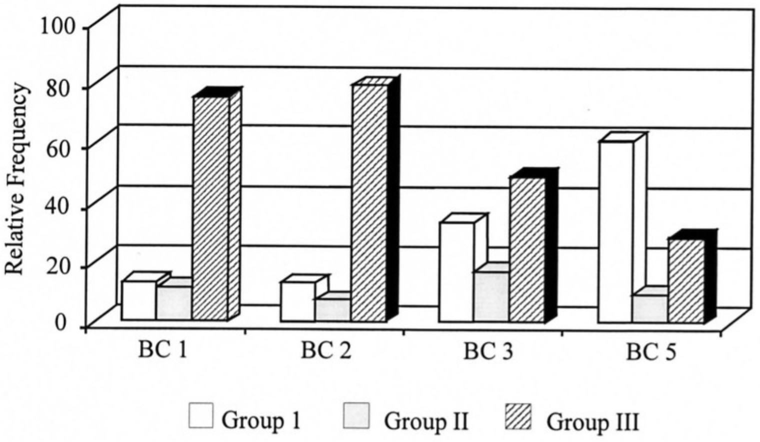

Figure 5. Relative frequency of the adult and neonate bone elements taking into account the hydric displacement potential groups established by Kaufmann & Gutierrez (2004).

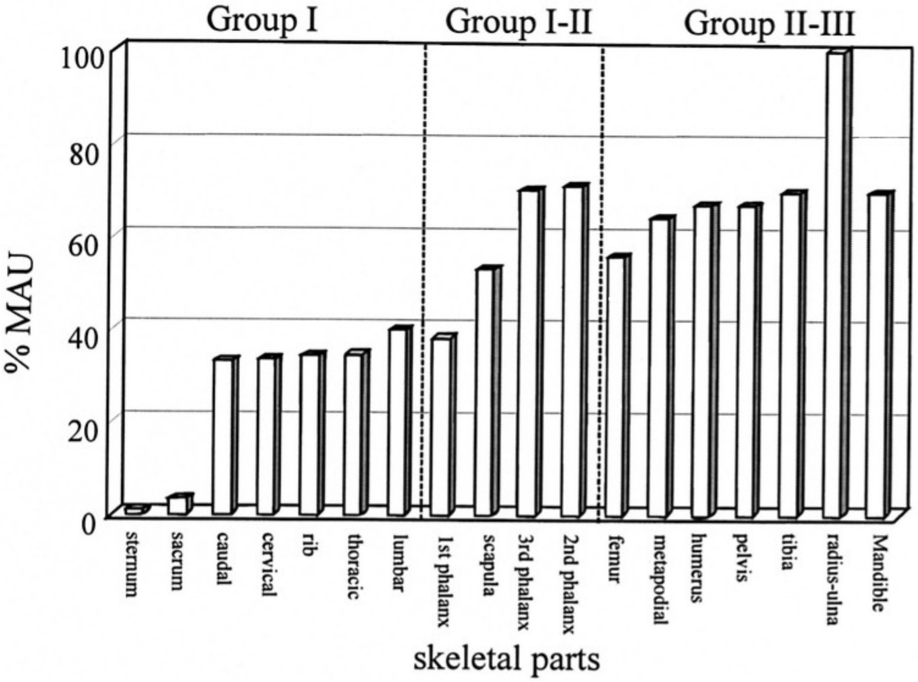

Figure 6. %MAU of adult individual grouped according to Voorhies's (1969) groups.

C. Tooth/vertebra ratio

The values of the tooth/vertebra ratio are similar in bone concentrations 1 and 3 (1.35 and 2.75, respectively), indicating a decrease in the number of vertebrae. Bone concentrations 4 and 5, on the contrary, present values of 0.16 and 0.51, respectively, yielding evidence of an accumulation of vertebrae as a consequence of fluvial transport (Table 3).

D. Unfused diaphysis/epiphysis proportion

According to the unfused diaphysis record it is observed that in bone concentrations 1 and 2 water must have selected the epiphyses, displacing them to other areas (Table 3). Water also transported the epiphyses to other areas in bone concentration 3 but, unlike the previous case, it received epiphyses from other sources based on the presence of unfused diaphyses that do not have their corresponding epiphyses and, moreover, on the fact that some unfused epiphyses do not have their corresponding diaphyses (Table 3). Finally, bone concentration 5 can be distinguished by the great number of unfused epiphyses, such as metapodial condyles, femur heads and tibia tuberosities, among others (Table 3). According to the stratigraphic profiles, this concentration is located in an area of the landscape where the water body was shallower, a fact that probably helped trap several epiphyses originating in other areas in this sector (*i.e.*, by hydrophic vegetation).

Degree of association of the bone elements

Messineo (1999) and Messineo & Kaufmann (2001) analyzed the anatomical refitting, identifying a total of fifty-one (Table 3). These results suggest that even though no articulate bone elements were found, there was a significant quantity of bones close to others with which they articulated within each bone concentration, separated by a 24.22 cm mean distance (Messineo & Kaufmann, 2001).

Fourteen mechanical refittings were added in this study. They involved unfused diaphyses and epiphyses that were found in different bone concentrations separated by a 297.6 cm mean distance (Table 3). In most cases (N=10) the unions were established between unfused diaphyses that were found in bone concentrations 1 and 2 with epiphyses from concentrations 3 and 5 (Figure 7). This information establishes synchronicity for many of the bones that make up the different assemblages. Hydric action is the agent that most probably re-ordered the bones once they had little soft tissue left and a NW-SE direction is suggested for the hydric action in this area of the excavation.

Spatial distribution of the bones

The orientation of the bones in the deposit was measured to estimate the possible influence water had in the formation of the site. The data on orientation comes from

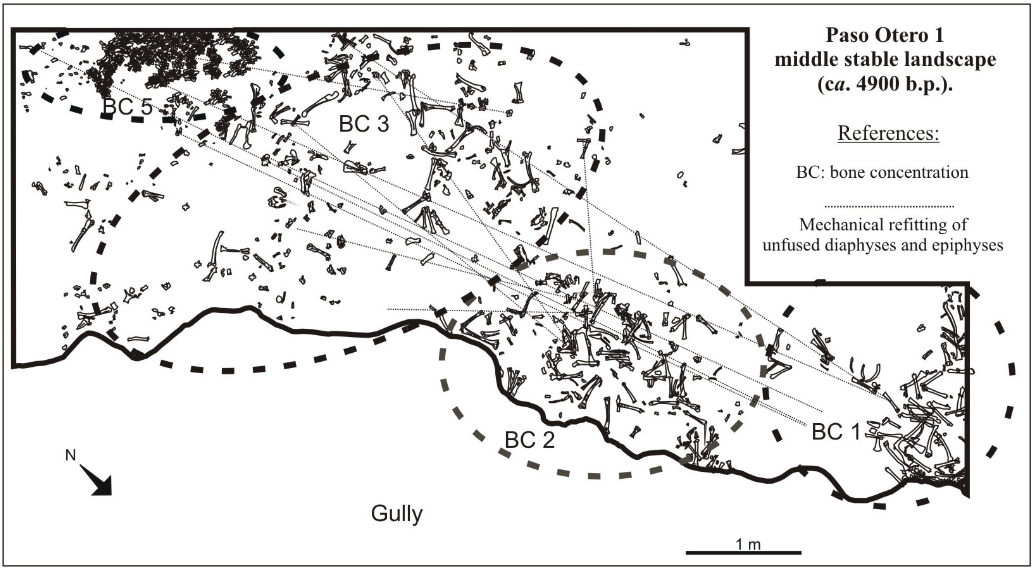

Figure 7. Scheme of Paso Otero excavation where the unfused diaphyses and epiphyses mechanical refittings can be observed.

field maps (N=650). The orientation degrees are grouped into eighteen units, of 10 degrees each, and the frequency distribution was calculated for each unit (Shipman, 1981). Once grouped, they were presented in a rose diagram that consists of 18 wedges radially disposed. The length of each wedge depends on the number of bones that fall within the limits of each unit (Shipman, 1981). The single-sample continuous-data Kolmogorov-Smirnov-test (Sokal & Rohlf, 1995) was applied to establish whether the orientation of the bones in the field corresponds to a preferred alignment or whether it is random. The test is based on the cumulative distribution of the observed and expected frequencies for the bone orientation. The significance level attained was 0.05.

Figure 8 shows the results of the bone orientation frequency distribution (empirical distribution) together with the uniform distribution (null uniform distribution) that the Kolmogorov-Smirnov test yielded. The results of this statistical test indicate that the bone material orientation in PO1 can not be distinguished from the randomly expected distribution, that is, they do not present a preferred direction, as would be expected from river flow. Taking Favier Dubois' (2006) geoarchaeological studies into account, a turbulent and dense flow is suggested to have been associated with the

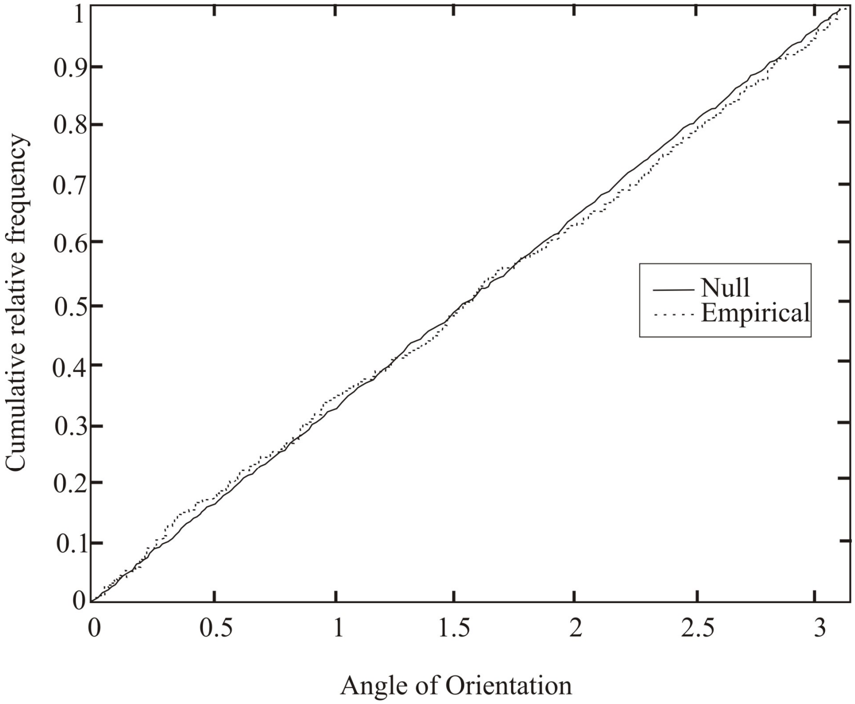

Figure 8. Empirical distribution (bones orientation) *versus* null uniform distribution graphic (taken from Gutierrez, 1998).

first erosive discordance. It is believed that this flow may have caused massive transport with no alignment of the elements transported. In addition, the possibility that in this instance some of the carcasses may have been articulated must also be considered.

Natural bone modification: abrasion and polish

Bone concentrations 1 and 2 yielded the highest percentage of bone elements that show evidence of abrasion and polish (21% and 27%, respectively) (Table 3). Most of these elements show the typical abrasion of stages 1 and 2, characterized by the presence of gloss or sheen, soft texture, and blunt edges. This type of abrasion is not severe and is characteristic of *in situ* abrasion caused by contact with the sediment transported suspended in the water. In bone concentrations 3 and 5 the abrasion percentage of the guanaco bone elements is low (8% and 3%, respectively), and all the abrasion percentages appear in a proportional way (Table 3). In contrast, all the bone concentrations present a variable quantity of bone elements in an advanced abrasion stage (stage 3), many of which present weathering traces and had been fractured prior to the abrasion.

Contextual information: evidence of cultural activity

Cut marks rarely appear in the analyzed bone concentrations (1%). The type of dynamic fracture, characterized by a helical fracture pattern (*sensu* Johnson, 1985), is also scarce in the analyzed bone material. This pattern only appears in bone concentration 1 (2%) and 2 (3%) (Gutierrez, 1998). In the faunistic context, only five small flakes (< 4 cm) and a bipolar artifact (coastal pebble) were recovered. The dominant raw material is quartzite (Martínez, 1999).

Discussion and conclusions

The most problematic aspect of the taphonomic history of PO1 corresponds to the cause/s of the death of the guanacos found at the site. There is usually no direct evidence from paleontological and archaeological sites about the factor that caused the death of animals. The data that derived from the age structure and the sedimentary and geomorphologic characteristics of the site can provide valuable information in this respect (Behrensmeyer & Hook, 1992; Kahlke & Gaudzinski, 2005).

There are natural disasters that may affect a large part of an animal community in a short time span. In the case of terrestrial mammals, these catastrophes include freezing, snowstorms, ash rain, fires, and droughts (Badgley, 1986). This type of events seems to be common in the case of gregarian mammals such as guanacos (Saba, 1987; Cévoli, 2005). Several cases of monospecific mass death in very short time-spans have been recorded in restricted areas of the landscape. Examples include deaths caused by sudden inundation (*i.e.*, bison: Haynes, 1982, 1988; cervids: Kahlke & Gaudzinski, 2005), river and lake crossings (*i.e.*, wildebeest: Talbot & Talbot, 1963; Watson, 1967; Schaller, 1972; Boaz, 1982; Capaldo & Peters, 1995), and famine derived from snowfall and severe winters (*i.e.*, guanacos: Saba, 1987; Cajal & Ojeda, 1994; Borrero, 2001; Estevez & Mameli, 2000; Cévoli, 2005; caribou:

O'Hara *et al.*, 2003). Conversely, there is also evidence of mass deaths that occurred over longer time spans (a few months), such as drought-induced famine (*i.e.*, cattle: Darwin, 1951; elephants: Haynes, 1984, 1988). Darwin (1951:174-175) mentioned the cattle mass death due to severe drought conditions during 1827 and 1832 in the North of Buenos Aires and the South of Santa Fe Provinces:

"*Un testigo ocular me refiere que las bestias de ganadería se precipitaban por ir a beber en el Paraná en rebaños de muchos miles de cabezas; agotados por la falta de alimento esos animales, érales imposible volver a subir luego las escurridizas márgenes del río y se ahogaban… Sin duda ninguna, perecieron así en el río cientos de miles de animales; viéronse flotar sus cadáveres descompuestos dirigiéndose hacia el mar, y probablemente gran número de ellos se depositaron en el estuario de la Plata […] Después de la gran sequía de 1827-1832 sobrevino una estación muy lluviosa que trajo consigo vastas inundaciones. Por tanto, es casi seguro que millares de esqueletos han quedado sepultos por los sedimentos del año mismo que siguió a la sequía*" (Darwin, 1951:174-175).

As previously mentioned, the bones at PO1 are in contact with a sedimentary erosive unconformity with a channel structure that yields evidence of a turbulent flow for that moment (Favier Dubois, 2006). This evidence in addition to the results presented here would indicate that the guanaco carcasses and the disarticulated bones were deposited at the site through hydric transport. Refitting analysis reveals that some of the bone elements were found in a next-to articulation position. As a consequence, it can be established that parts of the carcasses possibly arrived at the site due to flotation, helped by the actions of the currents and wind, and were grouped together at the margins of the shallower bodies of water.

According to the data derived from the mortality profile (Kaufmann, 2001, 2005) the faunal assemblage at PO1 corresponds to a live guanaco population with a slight over-representation of neonate individuals. A significant number of adults were pregnant females; some were neonates. According to the age range of the neonates and to the presence of unborn individuals, there is evidence to suggest that the bone assemblage of the site may have derived from a few death events that involved mainly guanaco family groups between the months of October and May. Therefore, the possible candidates for cause of death include a series of natural events that may have caused the drowning of guanaco family groups. However, death by alimentary stress as a result of seasonal drought in an area close to a water source should not to be discarded as a possibility, since there could have been a re-grouping of the carcasses when the normal water body dynamics were restored in the flood plain. These events may also have incorporated bones with different taphonomic histories, where the bone elements of individuals that may have been hunted by human groups in the surrounding area are included. There is evidence of the intensive and recurrent use made by hunter-gatherers of the flood plains during the Late Pleistocene and Holocene (Martínez, 1999).

The sedimentary information and the presence of gastropods such as *Biomphalaria peregrina* and *Littoridina perchapi* indicate that after the bone material was deposited the fluvial energy was low in general (Steffan, 2000; Favier Dubois, 2006). The high availability of decaying flesh and the difficult access to it are determinant factors for arguing against the significance of the action of rodents and carnivores on the bone assemblage (Haynes, 1982; Capaldo & Peters, 1995).

Once the disarticulation of the carcasses had advanced, water selected the bone elements that were easily transported such as vertebrae and ribs and transported them out of the excavated area. Even so, the results obtained from the different lines of evidence drawn on in this paper enable two areas at the site that may have functioned differently in reference to fluvial action to be identified. In this sense, the proportions of diaphysis and epiphysis clearly indicate that water was selecting bone elements from bone concentrations 1 and 2 and depositing them in sectors where there was some sort of trap (*e.g.*, vegetation) and where the depth of the body of water was inconsiderable (bone concentration 5). The water energy in this instance could have produced *in situ* abrasion. The possibility of performing unions between the juvenile elements from different bone concentrations strengthens the idea that many of the unfused epiphyses that left concentrations 1 and 2 may have been deposited in concentrations 3 and 5. Moreover, it is interesting to note that bone concentrations 3 and 5, even though made up of low bone density skeletal parts, present little evidence of abrasion. This could be due to the fact that this sector may have behaved as an area of low energy accumulation when compared to the rest of the excavated surface. Bones would have been transported by suspension or flotation, having limited contact with sediments. Once deposited, they could have been buried rapidly, favoring their preservation since they were protected from hydric erosion. Conversely, the bone specimens that present advanced polish and abrasion traces would be the ones that underwent substantial hydric transport. These bones must have entered the site in a first high energy instance or were trapped in the bone concentrations during a second instance when the energy was lower.

Summing up, the taphonomic history of the site is considered to involve at least two formation instances where the energy implicated in each varied significantly. The first formation instance was linked to high energy and a turbulent flow and, as a consequence, had a higher probability of transport and erosion. The time involved in this event would have been a relatively short episode in the history of the site formation. The taphonomic consequence of this instance was the deposition of guanaco carcasses that were complete or semi-complete and articulated or semi-articulated; that is, the bone accumulation would have originated in this instance. The second instance, in contrast, is linked to very low energy and to a selective transport capacity. The time span involved was longer than the first instance and the taphonomic consequences were the disarticulation and re-organization of the bone elements.

The bone concentrations generated particular depositional conditions, principally linked to the creation of "protective" microenvironments that could speed up or delay the rhythm and intensity with which certain agents and processes affected the bones. Despite the variability that such microenvironments presented, they all had common factors such as the presence of temporary water, reducing conditions and intense microorganism activity (Gutierrez *et al.*, 2001).

The presence of bone modifications of anthropic origin is generally scarce, irrespective of the origin of the site. When originally considered as a hunting and guanaco processing site, the interpretations were that the guanacos had not been intensely exploited or that a more complex processing strategy had been involved (Gutierrez, 1998; Martínez, 1999). Taking the new interpretations into account, the scarce evidence of human modifications suggests that some bone elements from guanaco carcasses that were processed by hunter-gatherers in the surrounding area could have been added to those of the animals that died naturally, resulting into a mixture of materials of anthropic and natural origin.

The results obtained in this paper constitute an important advancement towards the identification of diagnostic criteria for evaluating archaeofaunistic assemblages derived from sites where water played a leading role in their formation. Moreover, they provide a database and an innovative reference framework for a species that has yet to be studied from such a perspective, with a special emphasis placed on the individual's age group.

The variables presented in this study represent a useful methodological approach for analyzing similar archaeological contexts. They also help identify diagnostic traces of water action in the bone record of lacustrine and fluvial environments, as well as how such action can influence the formation of the record. It is argued that by integrating the results of the impact of these variables archaeological interpretations are strengthened. In fact it would be inappropriate to apply them independently since none of them in isolation can provide enough information to identify the nature of the formation of a bone assemblage. Consequently, a detailed evaluation of the archaeological and geological contexts will provide a range of associated information which can be used to adequately interpret the taphonomic history of the bone assemblage.

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