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## Reconstructing drowned terrestrial landscapes. Isotopic paleoecology of a late Pleistocene extinct faunal assemblage: Site GNL Quintero 1 (GNLQ1) (32° S, Central Chile)



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### ABSTRACT

Site GNL Quintero 1 (GNLQ1), located nearshore at Quintero bay in the central coast of Chile (32° S), is the only documented Late Pleistocene drowned terrestrial site along the Pacific coast of South America. During the last decade, through underwater archaeological operations conducted at GNLQ1, several clusters of shallowly buried bone deposits were documented and excavated, revealing a well preserved high-resolution *in situ* context. Taxonomic analysis of the faunal assemblage recovered yielded at least 26 individuals comprising extinct Camelidae, Cervidae, Equidae, Mylodontidae, and Xenarthra as well as Canidae, Myocastoridae, Octodontidae, Cricetidae, among others. By conducting stable isotope analyses ( $\delta^{13}\text{C}_{\text{ap}}$  and  $\delta^{18}\text{O}_{\text{ap}}$ ) on mammalian bioapatite, we aim to perform a first characterization of the GNLQ1 taxa paleoecology and carry out paleoenvironmental inferences. Regional records for the Last Glacial Maximum (LGM) suggest lower sea surface temperatures and more humid climatic conditions for Central Chile. Isotopic data obtained suggests a landscape of mixed vegetation areas, in good agreement with the sedimentary context of the fossil remains and a preliminary Quintero paleolandscapes model: a wetland environment developed under semiarid conditions prior to post-glacial sea level rise, with GNLQ1 located >6 km inland as the paleoshoreline was further out on the continental shelf.

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### 1. Introduction

Site GNL Quintero 1 (GNLQ1), located in nearshore waters of Quintero Bay (32°46' S–71°30' W), in the central coast of Chile, is a drowned terrestrial site containing fossil remains of a Late Pleistocene continental faunal assemblage (Fig. 1a–c). Through

submerged prehistoric archaeology research strategies largely undisturbed deposits on the seabed containing a stratigraphic context comprising micro, meso and megafauna remains were systematically studied (Cartajena et al., 2011, 2013; Carabias et al., 2014; López et al., 2012, 2016). Site formation was attributed to natural mortality events of a high diversity of taxa as cf. *Palaeolama*, Cervidae, cf. *Lama gracilis*, Mylodontidae, *Lycalopex culpaeus*, Octodontidae, Cricetidae, *Myocastor coypus*, *Abrocoma* sp., *Equus* (*Amerhippus*), among others (López et al., 2016).

Despite the identification of two possible cut marks in a proximal *Xenarthra* femur (López et al., 2016), human association at GNLQ1 cannot be conclusively ascertained at this stage of the research and will require further investigation. This issue is

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particularly relevant in the context of new debates on early peopling of South America that focus on the ambiguity of the archaeological evidence and stress the importance of formational studies for constructing adequate interpretive frameworks (Suárez et al., 2014; Borrero, 2015, 2016 among others).

Skeletal elements and molars of various taxa sampled from the GNLQ1 assemblage were directly dated by the AMS-radiocarbon method, using the bioapatite fraction, reporting  $^{14}\text{C}$  ages between  $19,280 \pm 40$  and  $24,890 \pm 70$  uncal BP (Table 1). Although this technique has been successfully applied for dating bone and tooth enamel samples, bioapatite diagenesis may affect radiocarbon ages (Cherkinsky, 2009). Recently, an initial paleolandscape model for Quintero Bay was created by combining a computer derived Relative Sea Level (RSL) curve with a mean estimated uplift rate of 0.5 m/ka (Carabias et al., 2014). This simulation proved consistent with eustatic sea-level curves (Lambeck et al., 2002). According to this model, by the Late Glacial Period 29,000–24,000 cal BP site GNLQ1 could have been located at an estimated distance of >6 km from the coastline.

winter months (281 mm/yr) that supports sclerophyllous shrubland vegetation. In the coastal area, scattered swamp forests are found, associated with small hydrographic basins where the water table rises close to the land surface, influenced by local rainfall. The recent onset of the wet climatic conditions originated the swamp forest near Quintero Bay at 2,000 uncal BP (Villa and Villagrán, 1997; Maldonado and Villagrán, 2002). Unfortunately, palynological records for GNLQ1 are still lacking, since attempts to obtain fossil pollen for the Late Pleistocene-Early Holocene from the continental shelf and nearby coastal lagoons has been unsuccessful so far. This fact can be attributable to prolonged periods of desiccation or differences in pollen preservation due to exposure or oxidation (Minckley et al., 2011).

Site GNLQ1 was highlighted as a primary source of data on now submerged paleolandscapes providing critical context to late glacial and early postglacial environment and habitats common to both extinct fauna and the initial populations of the Andean Pacific coast (Carabias et al., 2014). Considering the significant lack of paleoecological proxies for Late Pleistocene

**Table 1**

$^{14}\text{C}$  AMS dates on bioapatite fraction of bones and molars. \*Calibrated ages with OxCal 4.2, SH Cal 13 (Bronk et al., 2013). SI: Same individual.

Taxa/Sample	ID sample	Sample provenance	$^{14}\text{C}$ age years BP	Calibrated years BP*	$\delta^{13}\text{C}_{\text{ap}}$ (‰)	$\delta^{18}\text{O}_{\text{ap}}$ (‰)
Sedimentary matrix	UGAMS 9194	Unit 2	$13,640 \pm 40$	16,716–16,878	–25,4	–
<i>Equus</i> ( <i>Amerhippus</i> ) sp.	UGAMS 15535	Tooth enamel	$24,890 \pm 70$	27,159–26,679	–12,3	–3,0
<i>Equus</i> ( <i>Amerhippus</i> ) sp.	UGAMS 20838	Tooth enamel (SI)	$24,010 \pm 60$	26,270–25,816	–12,2	–3,4
<i>Equus</i> ( <i>Amerhippus</i> ) sp.	UGAMS 20839	Bone (SI)	$23,110 \pm 50$	25,605–25,250	–11,4	–3,0
<i>Equus</i> ( <i>Amerhippus</i> ) sp.	UGAMS 20847	Tooth enamel	–	–	–12,3	–3,5
Cervidae	UGAMS 15536	Tooth enamel	$23,720 \pm 70$	25,974–25,659	–12,6	–2,5
Cervidae	UGAMS 20840	Tooth enamel	–	–	–14,1	–4,9
Cervidae	UGAMS 20842	Tooth enamel	–	–	–11,4	–3,1
Cervidae	UGAMS 20850	Tooth enamel	–	–	–14,2	–1,7
Cervidae	UGAMS 20852	Tooth enamel	–	–	–13,5	–2,5
cf. <i>Palaeolama</i>	UGAMS 15537	Tooth enamel	$21,580 \pm 60$	24,037–23,735	–13,5	–2,7
cf. <i>Palaeolama</i>	UGAMS 15539	Bone	$21,690 \pm 50$	24,103–23,834	–11,6	–2,6
cf. <i>Palaeolama</i>	UGAMS 20843	Tooth enamel	–	–	–12,2	–2,9
Mylodontidae	UGAMS 15538	Bone	$23,060 \pm 60$	25,574–25,202	–12,0	–3,2
Mylodontidae	UGAMS 20846	Bone	–	–	–13,3	–3,3
Mylodontidae	UGAMS 20848	Bone	–	–	–14,3	–3,8
Octodontidae	UGAMS 20844	Tooth enamel	$19,280 \pm 40$	21,481–21,002	–12,7	–2,3
Octodontidae	UGAMS 20849	Tooth enamel	–	–	–12,6	–2,5
<i>Lycalopex culpaeus</i>	UGAMS 20845	Tooth enamel	–	–	–13,6	–3,4
<i>Myocastor coypus</i>	UGAMS 20841	Tooth enamel	$20,040 \pm 45$	22,312–21,911	–14,7	–5,6

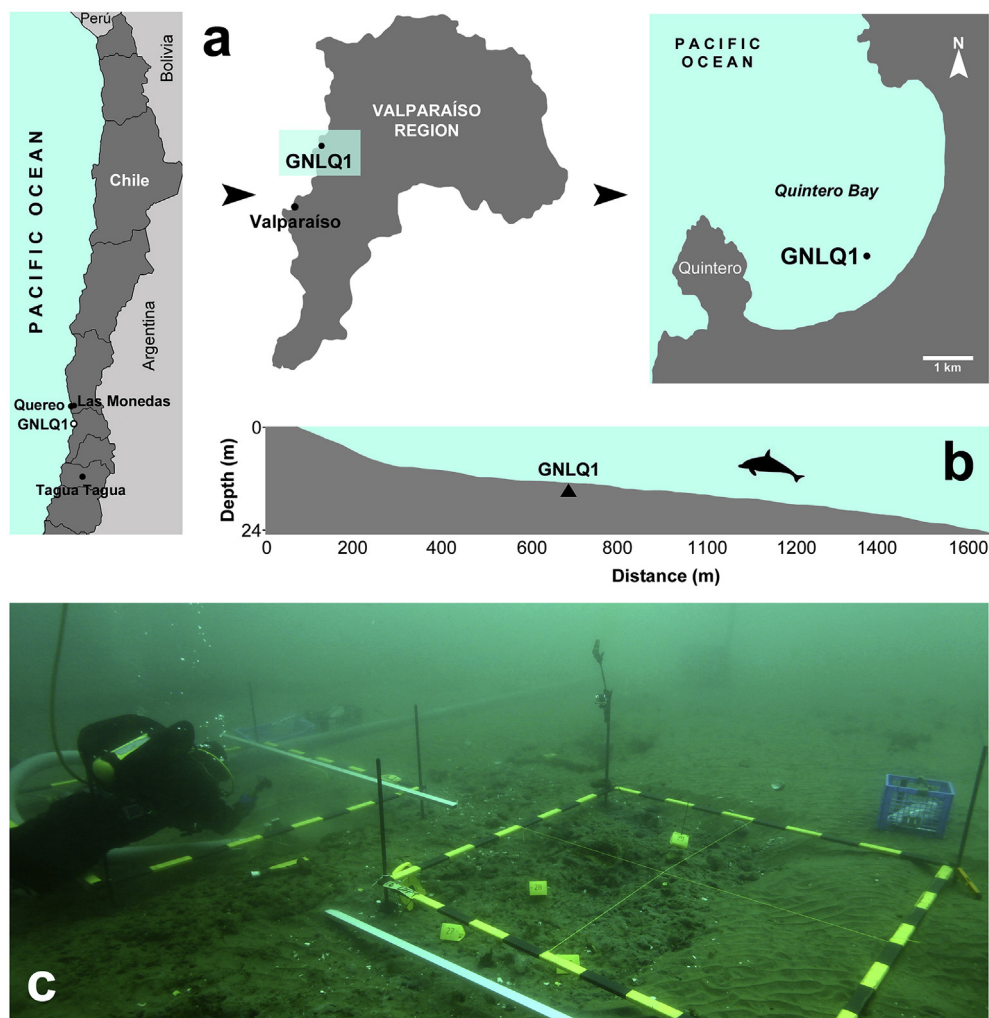
Morphological and sedimentological analysis performed on a marine core (T1), provides a complete stratigraphic sequence for the site, with three stratigraphic units exhibiting clearly different sedimentological features. From top to bottom, according the Unified Soil Classification System (USCS), Unit 1 contains well-sorted fine sand (SW) related to the current coastal dynamics. Sediments belonging to Unit 2 were classified as clast-supported clayey gravel (GC), characterized by gravel-sized highly resistant rounded masses (hereinafter referred to as 'agglomerates') composed of fine sand and clay in a sandy to clayey matrix (Fig. 2a). Agglomerates exhibit evidence of oxidation and carbon residue (Fig. 2b). The colour, the presence of charcoal lenses, and the very fine size of the grains observed in both the matrix as well as in the agglomerated fragments suggests that sedimentation of Unit 2 occurred within a very low-energy environment, possibly a floodplain. The faunal remains were registered in the upper portions of Unit 2 and exhibit a similar staining pattern to that present on sediments (Fig. 2c). On the other hand, the orange hues observed at Unit 3 and at the base of Unit 2 were interpreted as a transition from a subaerial deposition environment (Unit 3) to an underwater environment (Unit 2) (Cartajena et al., 2013; Carabias et al., 2014).

Today, the study area has a Mediterranean semi-arid climate, with maritime influence and rainfall concentrated during the

extinct mammals in Central Chile, the high taxonomic diversity of GNLQ1 is particularly relevant for reconstructing isotopic paleoecology. In the present study, carbon and oxygen isotopes analyses from the bioapatite fraction of the GNLQ1 herbivore assemblage were conducted with the purpose of characterizing its paleoecology (Feranec et al., 2010; Iacumin et al., 2010; Domingo et al., 2012; Kovács et al., 2012; Gąsiorowski et al., 2013; Prevosti and Martin, 2013; Bocherens et al., 2016), and carrying out paleoenvironmental inferences about this now-submerged landscape preserved on the nearshore continental shelf. Isotope data of the taxa is presented and discussed considering previous stable isotope data for the Southern Cone of South America (28°–38°S). Finally a new set of direct radiocarbon dates on the bioapatite fraction of different taxa of the GNLQ1 mammalian assemblage is presented and chronological issues are discussed.

## 2. Material and methods

We analysed a total of 19 bone and teeth samples from *Equus* (*Amerhippus*) sp. (N = 4), Cervidae (N = 5), cf. *Palaeolama* sp. (N = 3), Mylodontidae (N = 3), Octodontidae (N = 2), *L. culpaeus* (N = 1) and *M. coypus* (N = 1) (Table 1). The collected samples did



**Fig. 1.** A. Location map of GNLQ1 in Quintero Bay and the Quereo, Las Monedas and Tagua Tagua sites mentioned in the text, B. Bathymetric NW-SE profile depicting GNLQ1, and C. Underwater archaeological excavation of fossil remains *in situ* (Photo by: David Letelier P.).

not exhibit signs of weathering, but oxidation stains were extensive. Analyses were performed on the bioapatite fraction of the samples due to poor collagen preservation at the Center for Applied Isotopes Studies (CAIS), University of Georgia, following the methodology outlined by [Cherkinsky \(2009\)](#) and [Cherkinsky et al. \(2013\)](#).

The bone was cleaned by wire brush and washed, using ultrasonic bath. After cleaning, the dried bone was gently crushed to small fragments. The crushed bone was treated with diluted 1N acetic acid to remove surface absorbed and secondary carbonates. Periodic evacuation insured that evolved carbon dioxide was removed from the interior of the sample fragments, and that fresh acid was allowed to reach even the interior micro-surfaces. The chemically cleaned sample was then reacted under vacuum with 100% phosphoric acid to dissolve the bone mineral and release carbon dioxide from bioapatite. The residue was filtered, rinsed with deionized water and under slightly acid condition (pH = 3) heated at 80 °C for 6 h to dissolve collagen and leave humic substances in the precipitate.

The resulting carbon dioxide was cryogenically purified from the other reaction products and catalytically converted to graphite using the method of [Vogel et al. \(1984\)](#). Graphite  $^{14}\text{C}/^{13}\text{C}$  ratios were measured using the CAIS 0.5 MeV accelerator mass spectrometer. The sample ratios were compared to the ratio measured

from the Oxalic Acid I (NBS SRM 4990). The sample  $^{13}\text{C}/^{12}\text{C}$  and  $^{15}\text{N}/^{14}\text{N}$  ratios were measured separately using a stable isotope ratio mass spectrometer with respect to PDB and to atmospheric nitrogen, correspondently.

The main discussion regarding the reliability of bioapatite dates is determined by possible contamination due to exchange of carbon with environmental carbonates and carbon dioxide, and the lack of adequate methods to test for contamination or degradation in structural carbonate and phosphate extracted from sampled bones ([Cherkinsky et al., 2013, 2015](#); [Eriksson, 2013](#)). Besides,  $\delta^{13}\text{C}$  ratios in bioapatite might increase during diagenesis and no unequivocal method to evaluate the accuracy of the obtained data has been recognized yet ([Schoeninger and DeNiro, 1982](#); [Brown and Brown, 2011](#)).

At this stage, it is not possible to assess thoroughly the effects of potential contamination or diagenesis on the bioapatite fraction of the GNLQ1 faunal assemblage considering its complex terrestrial and marine depositional history ([López et al., 2016](#)). In order to address this issue, we tested possible discrepancies by selecting two samples belonging to the same individual (bone and molar from *Equus [Amerhippus]* sp.), considering that enamel bioapatite is generally denser, has higher crystallinity and fewer carbonate substitutions than bone bioapatite ([Eriksson, 2013](#)) (see below).



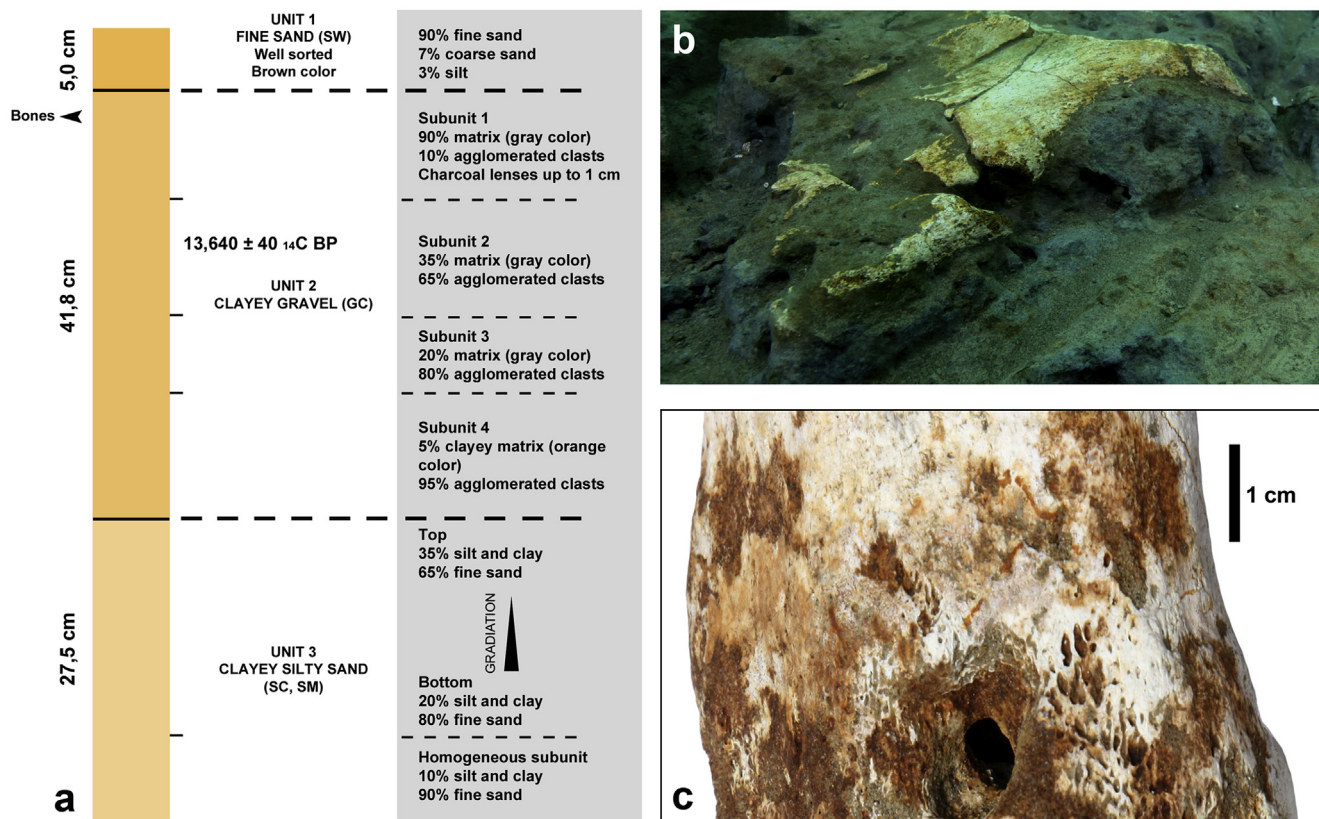


Fig. 2. A. Stratigraphic sequence of GNLQ1 site (Core T1). Based on Carabias et al. (2014). B. *In situ* bone fragment, embedded within Unit 2 stratum, and C. Oxidation signs on the bone surface of radio-ulna from *Palaeolama* sp. (Photo by: Álvaro López M.).

### 3. Results

Carbon ( $\delta^{13}\text{C}_{\text{ap}}$ ) isotope values for the whole GNLQ1 dataset show a variation between  $-11.4\text{‰}$  and  $-14.7\text{‰}$  ( $\bar{X} = -12.9$ ;  $\text{SD} = 1$ ), whereas oxygen ( $\delta^{18}\text{O}_{\text{ap}}$ ) isotope values vary between  $-5.6\text{‰}$  and  $-1.7\text{‰}$  ( $\bar{X} = -3.2$ ;  $\text{SD} = 0.9$ ) (Fig. 3).  $\Delta^{13}\text{C}_{\text{ap}}$  and  $\delta^{18}\text{O}_{\text{ap}}$  values of Cervidae ( $\delta^{13}\text{C}_{\text{ap}}$ ,  $\bar{X} = -13.2$ ;  $\text{SD} = 1.2/\delta^{18}\text{O}_{\text{ap}}$ ,  $\bar{X} = -2.9$ ;  $\text{SD} = 1.2$ ) and Mylodontidae ( $\delta^{13}\text{C}_{\text{ap}}$ ,  $\bar{X} = -13.2$ ;  $\text{SD} = 1.2/\delta^{18}\text{O}_{\text{ap}}$ ,  $\bar{X} = -3.4$ ;  $\text{SD} = 0.3$ ) show the highest intra taxa variability. However, ANOVA analysis results ( $N = 19$ ) suggest no statistically significant variations ( $p < 0.05$ ) between taxa for  $\delta^{13}\text{C}_{\text{ap}}$  ( $p > 0.05$ ,

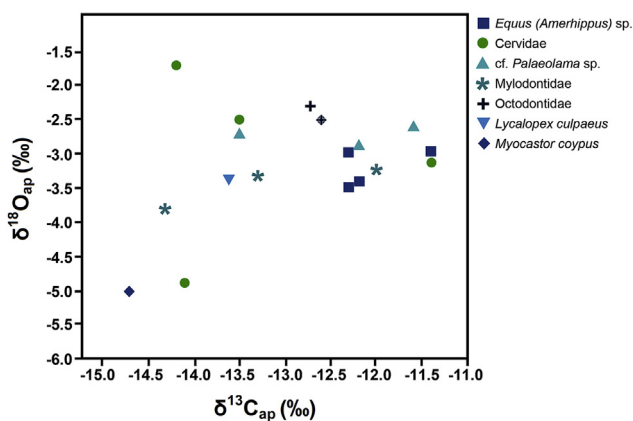
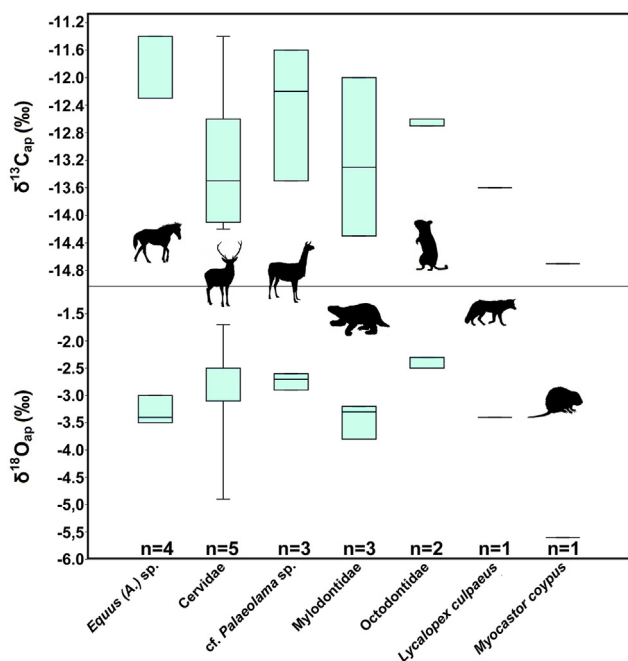


Fig. 3.  $\delta^{13}\text{C}_{\text{ap}}$  (‰) and  $\delta^{18}\text{O}_{\text{ap}}$  (‰) values in bioapatite extracted from bone samples of *Equus (Amerhippus)* sp., Cervidae, cf. *Palaeolama* sp., Mylodontidae, Octodontidae, *Lycalopex culpaeus* and *Myocastor coypus* from GNLQ1.

$gl = 16$ ,  $F = 1.05$ ) and  $\delta^{18}\text{O}_{\text{ap}}$  ( $p > 0.05$ ,  $gl = 16$ ,  $F = 0.821$ ) values. Therefore, carbon and oxygen isotope results indicate that all GNLQ1 sampled taxa occupied a  $\text{C}_3$  plant-dominated environment. However, *Equus (A.)* sp. and cf. *Palaeolama* sp.  $\delta^{13}\text{C}_{\text{ap}}$  values ( $\bar{X} = -12.2$ ;  $\text{SD} = 0.67$ ) are slightly higher than those of Mylodontidae and Cervidae ( $\bar{X} = -13.2$ ;  $\text{SD} = 1.21$ ) (Fig. 4), possibly reflecting vegetation consumption preferences of these taxa for open areas with higher  $\delta^{13}\text{C}$  values. Octodontidae  $\delta^{13}\text{C}_{\text{ap}}$  values are even more uniform ( $\bar{X} = -12.7$ ;  $\text{SD} = 0.07$ ), and given their high abundance in terrestrial ecosystems, short life spans, and small habitat size, despite their selective dietary preferences (Bozinovic, 1997), they can be considered good recorders of the local environment (Gehler et al., 2012).

These minor variations within a  $\text{C}_3$  vegetation environment can also be explained on account of different nutrients, water, temperature and  $\text{CO}_2$  levels, since plants in water-stressed conditions with poor  $^{13}\text{C}$  contents, can reduce transpiration, resulting in lower  $\delta^{13}\text{C}$  values (Gehler et al., 2012). This coincides with GNLQ1  $\delta^{13}\text{C}_{\text{ap}}$  values for *M. coypus* and some Mylodontidae and Cervidae samples, considering the latter to have a similar dietary behaviour to *Blasotocerus dichotomus*.

Stable isotope data of Late Pleistocene extinct mammals is still very limited for Chile, particularly for the study area. For example, in North and South America equids are well-studied, emphasizing latitudinal effects on stable isotopes, however there are only few samples from Chile (MacFadden and Shockey, 1997; MacFadden et al., 1999; Sánchez et al., 2006; Alberdi et al., 2007; Prado et al., 2011; Domingo et al., 2012; Prevosti and Martin, 2013). Early to Late Pleistocene subgenus *Equus (Amerhippus)* samples from Colombia, Peru, Ecuador, Bolivia, Brazil and Argentina suggest that these were grazers, similar to their modern analogues, with



**Fig. 4.** Box plot showing variation of  $\delta^{13}\text{C}_{\text{ap}}$  (‰) and  $\delta^{18}\text{O}_{\text{ap}}$  (‰) values in bioapatite material extracted from bone samples of *Equus (Amerhippus)* sp., Cervidae, cf. *Palaeolama* sp., Mylodontidae, Octodontidae, *Lycalopex culpaeus* and *Myocastor coypus* from GNLQ1.

different dietary patterns which included the consumption of  $\text{C}_3$  and  $\text{C}_4$  plants (Prado et al., 2011). *E. (A.) neogeus* samples from Buenos Aires Province (Argentina) show preferences for  $\text{C}_3$  plants while *E. (A.) andium* from Ecuador and *E. (A.) insulates* from Bolivia exhibit a mixed  $\text{C}_3$ – $\text{C}_4$  diet. In contrast, *E. (A.) santaeelenae* from coastal Ecuador (La Carolina,  $2^\circ 13'S$ – $80^\circ 51'W$ ) and Brazil (Bahia,  $10^\circ 58'S$ – $41^\circ 04'W$ ) show in general high  $\delta^{13}\text{C}$  values indicative of  $\text{C}_4$  vegetation (Prado et al., 2011).

On the other hand, only few  $\delta^{13}\text{C}$  values for Mylodontidae are available for South America. *Myiodon darwini* bone collagen samples from several southern sites dated between  $9700 \pm 100$  and  $14,240 \pm 60$  uncal BP show mainly  $\text{C}_3$  plants consumption (Prevosti and Martín, 2013), as already observed by Steele and Politis (2009). In addition, Late Pleistocene *Glossotherium robustum* from the Buenos Aires Province, feature a similar dietary pattern (Barrientos, 1999; Czerwonogora et al., 2011; Prado et al., 2015; Bocherens et al., 2016).

In the case of modern cervids, *B. dichotomus* exhibits dental morphology typical of browsers (Weber and González, 2003). However, other authors suggest for this extant taxon an intermediate feeding strategy (Tomas and Salis, 2000).  $\Delta^{13}\text{C}$  values for modern and archaeological *Blastocerus* from the Paraná basin suggest mainly  $\text{C}_3$  plant consumption (Loponte and Corriale, 2013). Lastly, *Palaeolama* dietary behavior was linked to feeding on deep forest and woodland by Kohn et al. (2005) and MacFadden et al. (1994), respectively. However,  $\delta^{13}\text{C}$  values obtained by Domingo et al. (2012) for *Palaeolama* are considered indicative of more open  $\text{C}_3$  environments (grasslands).

The GNLQ1 fossil record shows strong affinities with Late Pleistocene sites in the Quereo locality ( $31^\circ 55' S$ – $71^\circ 30' W$ ), located in the semiarid region, ~90 km north of Quintero (Núñez et al., 1994a; López, 2007; Méndez et al., 2011). Within these habitats supporting high taxonomic diversity variations in plant consumption is not exclusively related to dietary preferences but to intra and interspecific competition among taxa (Lima and Dill,

1990; Loponte and Corriale, 2013), as well as to differences in digestive physiology between species (Passey et al., 2005). Therefore, observed variation in isotopic values for the GNLQ1 large mammals (i.e. Cervidae, Mylodontidae, cf. *Palaeolama* and *Equus* [A.]) might be explained by ingestion of vegetation with different nutritional values that need to be assessed considering paleoecological niches and taxa similar to the Quintero locality.

Oxygen isotope values in the study area show relevant variations due to the strong altitude gradient that characterizes the physical environment between the Pacific coast and the Andes cordillera, over the ~200 km transect along an East–West direction (Sanhueza and Falabella, 2010). This substantial altitudinal change determines a decrease of  $\delta^{18}\text{O}$  values from the coast ( $-3.5\text{‰}$ ) to inland areas ( $-17.3\text{‰}$  at 4.200 m.a.s.l.) (Moser et al., 1972; Insel et al., 2013). Though these oxygen isotope values variations are also visible along a North–South direction, they are not as apparent as the East–West profile connecting the coast and the Andes ( $32^\circ S$ ). It should be noted that this altitudinal effect has been archaeologically observed for the prehistoric cultural sequence of Central Chile. Bioapatite oxygen stable isotope values for coastal human populations average  $-3.7\text{‰}$  ( $N = 25$ ,  $SD = 0.8$ ), whereas central valley groups (550 m.a.s.l.) exhibit a mean value of  $-8.2\text{‰}$  ( $N = 62$ ,  $SD = 1.4$ ) (Falabella et al., 2007).

Isotopic data obtained for the GNLQ1 mammalian taxa suggests that the faunal assemblage occupied mainly a Pacific coastal buffer excluding inland seasonal movement or animal migration. Higher variability in oxygen isotope values for Cervidae might be explained by inland movement of water sources during arid conditions as currently reported for *B. dichotomus* (Beccaceci, 1996), as well as ingestion of water from local microenvironments connected to regional ground-water flow systems. On the other hand, minimal  $\delta^{18}\text{O}_{\text{ap}}$  values for *M. coypus* reflect low isotopic value variation reported for freshwater organisms (Falabella et al., 2007).

The reliability of dating the bioapatite fraction of samples has been discussed (Cherkinsky, 2009). In order to assess potential differences on radiocarbon age of the samples, a maxillary bone (sample UGAMS 20839) and incisive teeth enamel (sample UGAMS 20838) from the same individual (*Equus [Amerhippus]* sp.) were dated. The resulting 900  $^{14}\text{C}$  years difference may be due to the higher porosity of bones, increasing the possibility of contamination in comparison to enamel bioapatite (Cherkinsky et al., 2013). Furthermore, isotopic value variation between enamel and bone samples is minimal and consistent with their structural properties (Table 1 SI).

On the other hand, the organic fraction of the sedimentary matrix containing the faunal assemblage (Unit 2), obtained from core T1, has been  $^{14}\text{C}$  dated and reported  $13,640 \pm 40$  uncal BP (sample UGAMS 9194). These differences might be explained by the transgression processes related to post-glacial sea-level rise and subsequent reworking of sediments deposited on the continental shelf (Lamy et al., 1998). However, the effects of terrestrial depositional processes prior to sea level transgression cannot be ruled out either. In Quereo, Núñez et al. (1994a) identified two levels containing fauna (e.g. cervids, gomphoterres, camelids, equids, among others), separated by an erosional unconformity. The Quereo I level was dated between  $11,400 \pm 145$  and  $11,600 \pm 190$  uncal BP and the Quereo II level between  $11,100 \pm 150$  and  $9370 \pm 180$  uncal BP, however the first was presumably corrupted and a more likely 22,000 uncal BP date was suggested (Núñez et al., 1994a). Similar early events were recently stratigraphically observed near Quereo in Quebrada Mal Paso ( $31^\circ 50'S$ – $71^\circ 29'W$ ), associated with terrestrial mammalian samples dated  $25,860 \pm 90$  uncal BP (Jackson et al., 2014). Finally, in the Central Chile Tagua Tagua site ( $34^\circ 30'71''S$ ) exhibits an erosional unconformity between Member 4 of the stratigraphy, estimated ca.

27,000–21,700 uncal BP, and Member 3 dated  $11,380 \pm 320$  uncal BP (Montané, 1968; Núñez et al., 1994b). In consequence, the GNLQ1 chronostratigraphic evidence requires further comprehensive analysis currently ongoing.

#### 4. Discussion and conclusions

The results of isotopic analyses carried out on Late Pleistocene mammals from GNLQ1 site are consistent with expected  $\delta^{13}\text{C}$  values for pure  $\text{C}_3$  feeders in different habitats: mesic/woodlands ( $-16\text{‰}$  to  $-11\text{‰}$ ) and wooded  $\text{C}_3$  grassland to open arid  $\text{C}_3$  grassland ( $-11\text{‰}$  to  $-8\text{‰}$ ) (Domingo et al., 2012). Compared with previous isotopic studies for the Southern Cone of South America, GNLQ1 values are similar to those reported for Las Monedas ( $31^\circ 55' \text{S}$ – $71^\circ 29' \text{W}$ ), a Late Pleistocene coastal site located in the Quereo locality  $\sim 90$  km north of GNLQ1 (Méndez et al., 2011), but closer to some southern localities ( $35^\circ \text{S}$ ). Isotopically, both sites can be clearly discriminated from other sites located at the same latitude, but in the eastern slope of the Andes near to the Argentinian Atlantic (Politis et al., 2009; Prado et al., 2011) (Table 2, Fig. 5a and b).

**Table 2**  
 $\delta^{13}\text{C}_{\text{ap}}$  values for Late Pleistocene–Mid Holocene mammals reported for several sites located in the Southern Cone of South America ( $28^\circ$ – $38^\circ \text{S}$ ). LP: Late Pleistocene, EH: Early Holocene, MH: Mid Holocene, Ch: Chile, Ar: Argentina.

Site	Taxon	Period	Latitude	$\delta^{13}\text{C}_{\text{ap}}$ (‰)	References
Las Monedas (Ch)	<i>Palaeolama</i>	EH	$31^\circ \text{S}$	–12,7	Méndez et al., 2011, Table 1
Las Monedas (Ch)	<i>Equus (Amerhippus)</i>	EH	$31^\circ \text{S}$	–13,9	Méndez et al., 2011, Table 1
La Banda (Ar)	<i>Equus (Amerhippus)</i>	LP	$28^\circ \text{S}$	–0,96	Prado et al., 2011, Table 1
Esperanza, Santa Fé (Ar)	<i>Equus (Amerhippus)</i>	LP	$32^\circ \text{S}$	–0,8	Prado et al., 2011, Table 1
Magdalena (Ar)	<i>Equus (Amerhippus)</i>	LP	$35^\circ \text{S}$	–10,6	Prado et al., 2011, Table 1
Luján (Ar)	<i>Equus (Amerhippus)</i>	LP	$35^\circ \text{S}$	–11,43	Prado et al., 2011, Table 1
Cant.Vial Prov. (Ar)	<i>Equus (Amerhippus)</i>	LP	$35^\circ \text{S}$	–9,48	Prado et al., 2011, Table 1
Arroyo Tapalqué (Ar)	<i>Equus (Amerhippus)</i>	LP	$36^\circ \text{S}$	–8,23	Prado et al., 2011, Table 1
Quequén Salado (Ar)	<i>Equus (Amerhippus)</i>	LP	$38^\circ \text{S}$	–8,69	Prado et al., 2011, Table 1
P. Hermengo (Ar)	<i>Equus (Amerhippus)</i>	LP	$38^\circ \text{S}$	–7,21	Prado et al., 2011, Table 1
Paso Otero (Ar)	<i>Equus (Amerhippus)</i>	LP	$38^\circ \text{S}$	–10,62	Prado et al., 2011, Table 1
Centinela del Mar (Ar)	<i>Equus (Amerhippus)</i>	LP	$38^\circ \text{S}$	–9,99	Prado et al., 2011, Table 1
Zanjón Seco (Ar)	<i>Equus (Amerhippus)</i>	LP	$38^\circ \text{S}$	–10,81	Prado et al., 2011, Table 1
Arroyo Seco 2 (Ar)	<i>Equus (Amerhippus)</i>	EH	$38^\circ \text{S}$	–9,2	Politis et al., 2009, Table 1
Campo Laborde (Ar)	<i>Megatherium americanum</i>	EH-MH	$38^\circ \text{S}$	–4,7	Politis et al., 2009, Table 1
Manqui Malalal (Ar)	<i>Megatherium americanum</i>	EH	$35^\circ \text{S}$	–8,8	Praderio et al., 2012, Table 1

Both latitude and altitude are determinant on vegetation distribution, geographical factors also affecting  $\delta^{18}\text{O}$  values, which show a general decrease with latitude. According to Domingo et al. (2012), *Cuvieronius hyodon* and *Stegomastodon platensis*  $\delta^{18}\text{O}_{\text{CO}_3}$  values for Central Chile ( $32^\circ \text{S}$ ) are lower than in samples recovered in Argentinian localities ( $32^\circ \text{S}$ – $36^\circ \text{S}$ ). In addition,  $\delta^{13}\text{C}$  values obtained from Late Pleistocene and Holocene equids and gomphotere, tend to increase from high to low latitudes (Domingo et al., 2012). The absence at GNLQ1 and other Late Pleistocene Central Chile coastal sites of *Hippidion* sp. which has a more restricted diet, in contrast to the presence of *Equus (Amerhippus)* with a major dietary plasticity, suggests less woody areas with a predominant grassland vegetation during this time period. This record may be indicating that not the whole range of continental mammals inhabited coastal areas at the end of the Pleistocene, since distribution was determined by dissimilar adaptation and dietary behavior.

Site GNLQ1 presents a complex taphonomic record including both terrestrial and maritime-based site formation processes (López et al., 2016). Diagenetic processes investigation at GNLQ1 mainly focused on bone oxidation, revealed framboids (formed indirectly via iron monosulphides) (López et al., 2012; Cartajena et al., 2013). During the marine phase, the presence of

exogenous carbonates, resulting from shell dissolution, biochemical processes and input of terrestrial carbonates among other sources is expected. However, despite potential exposition of bone and tooth samples to isotope exchange, the dates obtained for the different GNLQ1 taxa, including not only herbivores but carnivores and rodents as well, consistently falls within the range  $19,280 \pm 40$  to  $24,980 \pm 70$  uncal BP.

During LGM several paleoclimate records are available for the subtropical region of Chile ( $36^\circ 50' \text{S}$ – $29^\circ 55' \text{S}$ ) (Heusser, 1990). Independent proxies from sediment core samples obtained both from the continental shelf ( $33^\circ \text{S}$  and  $30^\circ \text{S}$ ) and inland areas ( $34^\circ \text{S}$ ) suggest cooler and more humid climate conditions than today (Heusser, 1990; Lamy et al., 1999; Kim et al., 2002; Valero-Garcés et al., 2005; Kaiser et al., 2008). Cold sea surface temperatures occurred simultaneously with enhanced humidity, increase of Coastal Range local rainfall, and abundant vegetation. Late Pleistocene vegetation was dominated by  $\text{C}_3$  vegetation, with a less heavy  $\delta^{13}\text{C}$  signature characteristic of humid conditions (Kaiser et al., 2008). Semi-humid woodlands of southern beech (*Nothofagus dombeyi* pollen type) and podocarp (*Prumnopitys andina*)

were extensive, co-occurring with increasing amounts of Gramineae, Tubuliflorae, and *Acaena* (Heusser, 1990). However, superimposed on the overall humid conditions of the last glaciation, a cold and less humid interval between 26,000 and 22,000 cal BP was established in the Coastal Range (Lamy et al., 1999). Sea surface temperature reached its lowest value between 23,000 and 22,000 cal BP (Kim et al., 2002) with the most humid conditions attained during the LGM 22,000–18,000 cal BP (Lamy et al., 1999). The inferred paleoecology of GNLQ1 mammals is in general in good agreement with this Late Pleistocene paleoenvironmental scenario. Although most of the bioapatite dated bones fall into the semiarid interval, isotopic signatures do not reflect differences attributed to more arid conditions or heavier signatures (Kaiser et al., 2008). Reduced water availability, associated with arid conditions, could lead to increased  $\delta^{13}\text{C}$  values in  $\text{C}_3$  species. However, due to the fact that proxies record variations at different time scales and are site specific (Grosjean et al., 2003), further local research needs to be performed in order to address more accurately the paleoclimatic variability.

Sedimentary evidence suggests that the GNLQ1 site developed in a low-energy fluvial continental environment, probably a floodplain with shallow marshes (Carabias et al., 2014). This landscape was somewhat similar to the contemporary Quintero coastal





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