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AMS ^{14}C dating of early human occupation of southern South America

James Steele [a,*], Gustavo Politis [b]

[a] AHRC Centre for the Evolution of Cultural Diversity, Institute of Archaeology, University College London, 31–34 Gordon Square, London WC1H 0PY, UK
[b] CONICET—Universidad Nacional del Centro de la Provincia de Buenos Aires, 7400 Olavarria, Argentina

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ABSTRACT

The time of appearance of a persistent and demographically-viable hunter-gatherer population in late Pleistocene southern South America must be determined by evaluating evidence from as large as possible a sample of candidate archaeological sites in the region. We co-ordinated the AMS dating of multiple bone and charcoal samples from previously-excavated strata at the following sites: Arroyo Seco 2, Paso Otero 5, Piedra Museo, and Cueva Tres Tetas (all in Argentina), and Cueva del Lago Sofia 1 and Tres Arroyos (both in Chile). With one possible exception, we did not obtain new results to confirm earlier observations of pre-Clovis-age cultural activity at any of the sites considered in this study. The possible exception, Arroyo Seco 2, is considered in detail elsewhere [Politis G., Gutierrez M.A., Scabuzzo, C. (Eds), in press. Estado actual de las Investigaciones en el sitio 2 de Arroyo Seco (región pampeana, Argentina). Serie Monográfica INCUAPA 5. Olavarría]. However, our results for the samples which were the most preferred indicators of cultural events (hearth charcoal and cut-marked bone) confirm that people were in the southern cone of South America at or soon after 11,000 BP (13,000 cal BP). Considered alongside recent age estimates for the Clovis culture in North America, these results imply the contemporaneous emergence of a consistent and archaeologically-robust human occupation signal at widely-separated locations across the Western Hemisphere. Such findings suggest that Palaeoindian demic expansion may have involved more than one terminal Pleistocene dispersal episode.

1. Introduction

Dating the earliest human occupation of the Americas by archaeological means has often been contentious. By some recent criteria, the earliest accepted date for a site from the oldest generally-recognized archaeological culture in North America, the "Clovis" culture, dates to no earlier than 11,080 ± 40 BP (the Lange-Ferguson site; Waters and Stafford, 2007). However, claims are frequently made of earlier dates for sites at widely dispersed locations throughout the Americas. Following the attention given to the case for late Pleistocene human occupation at Monte Verde in south Chile (Dillehay, 1997), interest has turned to other possible late Pleistocene archaeological sites in this and in adjacent parts of South America.[1] Although such candidates exist, in many cases the actual age of the oldest cultural evidence is poorly resolved due to ambiguities in radiocarbon dating evidence.

In this paper we draw attention to some candidate sites for a late Pleistocene human occupation of southern South America. The immediate scientific objective of this study was to obtain precise and accurate dates for late Pleistocene occupation layers from recently-excavated archaeological sites in this region, by dating multiple specimens from the oldest artefact-bearing stratigraphic units. The ultimate objective is to refine our understanding of the chronology of human expansion into the Americas, in order to constrain demographic reconstructions of this process.

The requirements for diagnosing and dating past human activity at an archaeological location are that there should be undeniable traces of humans (artefacts or skeletons) in undisturbed geological deposits, with indisputable dates (Haynes, 1969; Dincauze, 1984). A more detailed recent specification stipulates the following standards of validity for early Palaeoindian sites: there should be a consistent series of accurate and statistically precise radiometric

* Corresponding author.
E-mail addresses: j.steele@ucl.ac.uk (J. Steele), gpolitis@fcnym.unlp.edu.ar (G. Politis).

[1] We will not give further consideration to the Monte Verde site in this paper. At the time of publication of the second volume of the Monte Verde monograph (Dillehay, 1997) the repeatability of the observations and interpretations was assessed both through lab and site visits by an invited panel of external evaluators (Meltzer et al., 1997), and through public discussion of the completeness and accuracy of the published excavation records (Dillehay et al., 1999; Fiedel, 1999; Grayson, 2004). The monograph and its evaluations are in the public domain, and can be assessed independently by any archaeologically-competent investigator. In our view the most interesting scientific issue is that of the presence or absence of a persistent and demographically-viable hunter-gatherer population in southern South America during the late Pleistocene, and that issue is best addressed by evaluating evidence from as large as possible a sample of additional sites in this region.

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dates (error bars <300 years), based on taxonomically-identified single objects of carefully cleaned cultural carbon (which will be considered especially reliable if fruit/seed remains or purified amino acid fraction of bones/teeth of prey animals), found in primary stratigraphic association with artefacts, and with the results documented by peer-review publication (Roosevelt et al., 2002). Some scholars would further modify this to exclude samples with errors of more than ±1% of the mean age, in radiocarbon years.

Our specific objectives in this study were to reassess the age of the earliest cultural phases of a set of early archaeological sites in southern South America (Argentina and Chile). In each case, pre-existing radiocarbon dates suggested an age contemporary with or earlier than the North American Early Palaeoindian record. We wanted, in collaboration with these sites' investigators, to submit for AMS ^{14}C dating additional previously-excavated specimens from the same stratigraphic units. Our preference was for single pieces of hearth charcoal and for clearly cut-marked animal bones. Where such specimens were not available we also accepted burnt animal bone, and animal bone which was helically fractured by dynamic impact (although we were aware that such fracture patterns are not necessarily anthropogenic (Haynes, 1983, 1988) and that the argument for human agency must therefore be made from other aspects of the archaeological context). Finally, where no modified bone was available, we accepted specimens of unmodified animal bone; but we were aware that dates on such bone would be less reliable indicators of the age of human activity, because other taphonomic agents could have caused those bones to be present in the deposits. To control for potential error in interpreting ^{14}C measurements on bone and charcoal specimens (for example due to the burning of old wood, or to the difficulty of eliminating diagenetic contaminants from bone samples), a combination of both materials was selected where possible.

2. Materials and methods

Six sites in Argentina and south Chile were selected for re-dating by AMS of potentially late Pleistocene occupation layers. Their investigators were invited to submit specimens (preferably charcoal and/or culturally-modified animal bone) from the basal cultural units. The site locations are shown in Fig. 1. The sites are summarized below, and the specimens are listed in Table 1.[2]

2.1. Site name: Arroyo Seco 2, Argentina (AS2)

2.1.1. Background

A multi-component open air site located on a low ridge between a creek and a lagoon (38°21′38″ S, 60°14′39″ W), near the town of Tres Arroyos in the Argentinean Pampas. The early component includes a lithic industry mostly composed of unifacial, marginally retouched quartzite artefacts associated with bone remains of extant (*Lama guanicoe*, *Ozotoceros bezoarticus*, *Rhea americana*) and extinct megamammals (*Megatherium americanum*, *Equus neogeus*, *Hippidion* sp., *Toxodon platensis*, *Glossotherium robustus.* and *Paleolama wedelli.*; Gutierrez, 2004; Salemme, in press*)*. The stratum bearing these remains is, however, cut by human graves of early/mid-Holocene hunter-gatherers (dated between c. 7800 and 4500 BP; Scabuzzo and Politis, 2006; Politis et al., in press).

2.1.2. Pre-existing dates

Eleven radiocarbon dates had previously been obtained from animal bone from within the stratigraphic unit Y and S, all from specimens in close spatial and stratigraphic association with lithic artefacts, but with ages ranging from 12,240 ± 110 BP to 7320 ± 50 BP (see Politis and Steele, in press).

2.1.3. Specimens selected for this study

Four specimens of bone of extinct megamammals, in each case helically fractured through dynamic impact (see Table 1).

2.2. Site name: Cave 1, Cerro Tres Tetas, Argentina (C3T)

2.2.1. Background

Cave 1 of Cerro Tres Tetas (48°8′58″ S, 68°56′ W) is a multi-component site located in the Central Plateau of Santa Cruz Province, southern Patagonia (Argentina) at about 450 m above sea level, in a biogeographic zone characterized today by bush/shrub/steppe vegetation. The lower level of the site is characterized by the association of c. 500 lithics (including scrapers, side scrapers, bifacial tools, a chopper and a hammer) with scattered bones of *Lama guanicoe* (Paunero, 2003a).

2.2.2. Pre-existing dates

The oldest cultural deposit had previously been dated to 11,560 ± 140 BP (LP-525, a conventional ^{14}C date on hearth charcoal). The top of the basal cultural layer was dated by charcoal from a separate hearth feature to 10,260 ± 110 BP (LP-800), which gave a *terminus ante quem* for the underlying deposits.

2.2.3. Specimens selected for this study

A sample of the same large lump of charcoal which had previously been dated to 11,560 ± 140 BP, and another piece of charcoal from the same hearth (see Table 1).

2.3. Site name: Cueva del Lago Sofia 1, Chile (CLS)

2.3.1. Background

A cave (51°32′ S, 72°32′ W) located in the northern periphery of Lake Sofia, Ultima Esperanza province, Magallanes (south Chile), about 35 km from Mylodon Cave (Prieto, 1991). In the lower level a hearth was recovered which contains broken and burned bones of extinct fauna, bifacial and unifacial flakes, and bone tools (a retoucher and a bird bone awl).

2.3.2. Pre-existing dates

Two radiocarbon dates had previously been obtained from the earliest levels: 11,570 ± 60 B.P. (PITT-0684) and 12,990 ± 490 B.P. (PITT-0939) (Prieto, 1991). It is probable that the older of these dates, on unmodified animal bone (*Mylodon*) from Level 3, reflects the age of a palaeontological assemblage pre-dating human occupation (Jackson and Prieto, 2005).

2.3.3. Specimens selected for this study

Six bone specimens were submitted. The submitter's notes state that most of the specimens come from the surroundings of the Layer 2a hearth, and that they mostly bear cut-marks. However, this was not differentiated at the level of the individual specimens. The only specimen individually identified by the submitter as culturally-modified had been used as a tool, a bone retoucher (illustrated in Jackson Squella, (1989–90), figure 1c) (see Table 1).

2.4. Site name: Paso Otero 5, Argentina (PO5)

2.4.1. Background

An open air site on the bank of the Rio Quequen river in the Argentinean Pampas (38°12′08″ S, 59°06′58″ W) A single archaeological component on a palaeosol, located at the bottom of a 2.5 m-thick series of Holocene flood plain sediments

[2] We use the term "specimen" to denote the entity submitted by the investigator, and "sample" to denote the fraction of that entity which was used by an individual lab for the actual ^{14}C measurement.

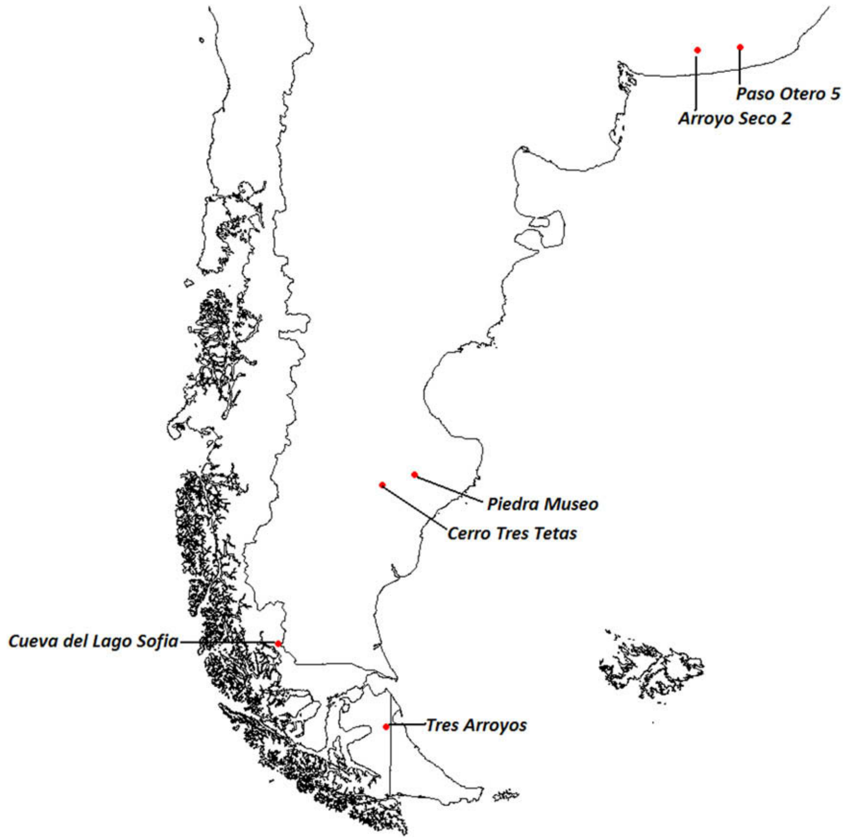

Fig. 1. Location map of the six archaeological sites in southern South America selected for reanalysis.

(interspersed with incipient palaeosols) (Martínez, 1999, 2001; Martínez et al., 2003). Stratigraphy, artefact typology and faunal composition suggest an age close to the Pleistocene-Holocene boundary. An area of 98 m^2 was excavated yielding bones of extinct (*Megatherium americanum*, *Equus neogeus*, *Toxodon* sp., *Glossotherium* sp., *Hemiauchenia* sp., *Glyptodon* sp. among others) and extant mammals (*Lama guanicoe*), and lithic tools (including two fractured fishtail projectile points). Analysis of the bone assemblage has identified burnt bones in which the temperatures exceeded those from a grass fire. Use of bone for fuel is hypothesised by the researchers (Martínez et al., 2004; Joly et al., 2005; Martínez, 2006)

2.4.2. Pre-existing dates

An AMS date from a piece of burned megamammal bone from this context yielded an age of 10,190 ± 120 BP (AA-19291), which is consistent with dates from other southern South American sites with similar stone tools. In the course of this study the investigator also obtained another date on the burned bone assemblage (GX-29795) which is however significantly younger (9560 ± 50 BP). A date on the organic material from the soil which contains the deposit gave an age of 9399 ± 116 BP (DRI-3573), which is interpreted as consistent with the older of the bone dates since soil is a very open system and specimens tend to incorporate younger carbon (Martínez, 2006). During the course of this study, attempts by the investigator to obtain collagen dates on unburned bone samples from a third lab were unsuccessful, producing a set of stratigraphically inconsistent Middle/Late Holocene dates for the megafauna assemblage which the investigator has rejected (Martínez, 2006).

2.4.3. Specimens selected for this study

Six specimens of bone of extinct megamammals, three burned, one possibly burned, and two unburned (see Table 1). Other than the burning, the specimens had no evidence of cultural modification.

2.5. Site name: Piedra Museo AEP-1, Argentina (PM)

2.5.1. Background

A multi-component site in a small rockshelter, located in the central plateau of Santa Cruz province, Argentinean Patagonia (47°53′42″ S, 67°52′04″ W) (Miotti, 1992, 1996; Miotti et al., 2003). Two main strata were identified, the upper one an aeolian sediment (Unit 1) and the lower one a palaeosol containing five units (Unit 2 to Unit 6) distinguishable by their sedimentological characteristics. Unit U4 yielded a fragmented red chert fishtail projectile point in addition to a few other artefacts and animal bones (mainly *Lama guanicoe*, but including those of the extinct horse *Hippidion saldiasi* and extinct camelid *Lama [vicugna] gracilis*). Lower units (4/5 and 6) were interpreted as belonging to the same component. (Miotti et al., 2003: 100–101).

2.5.2. Pre-existing dates

Layer 5 had a single previously-obtained AMS radiocarbon date on unmodified bone of 10,400 ± 80 BP (AA-8428). The underlying U6 cultural layer - containing bones of extinct megamammals such as *Equus neogeus*—has three previously-obtained AMS dates on charcoal (10,470 ± 60, GRA9837; 11,000 ± 65 BP, AA-27950; 12,890 ± 90 BP, AA-20125; Miotti et al., 2003).

2.5.3. Specimens selected for this study

One charcoal specimen and three animal bone specimens (two helically fractured, one cut-marked) from the basal cultural layer (Unit 6), and two charcoal specimens from the contact with the overlying layer (Unit 5/6) (see Table 1). The cut-marked equid specimen is illustrated in Miotti and Cattáneo, 2003, including a high-magnification image of the cut-marks.

Table 1
List of samples with results obtained by the AMS labs

Site and sample	Lab. No.	$\delta^{15}N$	$\delta^{13}C$	^{14}C yrs BP	Specimen details
AS2-S1	OxA-9242	5.75	−15.3	11,730 ± 70	Bone, extinct megamammal sp. indet. Helically fractured
AS2-S2	OxA-9243	5.75	−15.3	12,070 ± 140	Bone, midshaft long bone, extinct megamammal sp. indet. Helically fractured
AS2-S3	OxA	–	–	Failed	Bone, *Hippidion* sp. 3rd metatarsal. Helically fractured
AS2-S3	AA39365	–	−20.8	11,320 ± 110	Bone, *Hippidion* sp. 3rd metatarsal. Helically fractured
AS2-S4	OxA10387	5.2	−19.7	12,155 ± 70	Bone, *Megatherium americanum*, tibia. Helically fractured
AS2-S4	OxA15871	5.2	−19.5	12,170 ± 55	Bone, *Megatherium americanum*, tibia. [Rpt, ultra-filtration] Helically fractured
C3T-S1	OxA-9244	–	−22.2	10,915 ± 65	Charcoal (for redating, cf LP-525). *Schinus* sp.
C3T-S1	AA39366	–	−23.5	10,853 ± 70	Charcoal (for redating, cf LP-525). *Schinus* sp.
C3T-S2	AA39368	–	−23.0	11,015 ± 66	Charcoal. *Schinus* sp.
C3T-S2	OxA-10745	–	−22.5	11,145 ± 60	Charcoal. *Schinus* sp.
CLS-S1	OxA	–	–	Failed	Bone, *Hippidion saldiasi*
CLS-S2	OxA-9319	2.73	−20.3	10,780 ± 60	Bone, *Hippidion saldiasi*
CLS-S3	OxA-8635	3.84	−20.2	10,710 ± 70	Bone, ?*Lama guanicoe*. Femur. Usewear (used as stone tool retoucher)
CLS-S4	OxA-9505	7.7	−19.5	10,140 ± 120	Bone, *Pseudalopex culpaeus*
CLS-S5	OxA-9504	2.1	−20.6	10,310 ± 160	Bone, *Hippidion saldiasi*
CLS-S6	OxA-9506	4.4	−20.1	12,250 ± 110	Bone, *Mylodon darwinii*
PM-S1	OxA-8527	3.97	−18.1	10,390 ± 70	Bone, *Lama guanicoe*, femoral diaphysis. Helically fractured
PM-S2	OxA-9507	4.6	−17.7	10,100 ± 110	Bone, diaphysis of long bone, *Lama* (?). Helically fractured
PM-S3	OxA-8528	0.60	−19.3	10,925 ± 65	Bone, *Hippidion saldiasi*, distal humerus. Cut-marked
PM-S3	OxA-15870	2.2	−18.7	10,675 ± 55	Bone, *Hippidion saldiasi*, distal humerus. [Rpt, ultra-filtration]. Cut-marked
PM-S3	AA39362	–	−22.1	9952 ± 97	Bone, *Hippidion saldiasi*, distal humerus. Cut-marked
PM-S4	OxA-9508	–	−21.2	9350 ± 130	Charcoal. *Schinus* sp.
PM-S5	OxA-9509	–	−10.5	9950 ± 75	Charcoal. *Schinus* sp.
PM-S6	OxA-9249	–	−26.6	10,470 ± 65	Charcoal. *Schinus* sp.
PM-S6	AA39367	–	−26.2	10,400 ± 79	Charcoal. *Schinus* sp.
PO5-S1	OxA	–	–	Failed	Bone, *Megatherium* rib. Part of burnt bone accumulation
PO5-S1	AA39363	–	−19.8	10,440 ± 100	Bone, *Megatherium* rib. Part of burnt bone accumulation
PO5-S2	OxA	–	–	Failed	Left calcaneus of *Megatherium* cf. *M. americanum* (giant ground sloth). Unburned
PO5-S3	OxA	–	–	Failed	Bone, *Equus neogeus* distal radio-cubitus
PO5-S3	AA39364	–	–	Failed	Bone, *Equus neogeus* distal radio-cubitus
PO5-S4	OxA	–	–	Failed	Bone. Megamammal, sp. indet. Burned
PO5-S5	OxA	–	–	Failed	Bone. Poss. *Glossotherium*. Left distal humerus. Unburned
PO5-S6	OxA	–	–	Failed	Bone. *Megatherium* cf. *M. americanum*. First phalanx. ?Burned
TA-S1	OxA-9666	–	−27.5	10,130 ± 210	Charcoal. Not identifiable
TA-S2	OxA	–	–	Failed	Bone, *Mylodon darwinii*
TA-S3	OxA-9248	6.59	−18.6	11,085 ± 70	Bone, *Panthera onca mesembrina*
TA-S4	OxA-9247	0.92	−20.5	10,685 ± 70	Bone, *Equidae*. First phalange
TA-S5	OxA-9246	3.32	−19.8	10,630 ± 70	Bone, *Vicugna vicugna*
TA-S6	OxA-9245	8.18	−19.4	10,575 ± 65	Tooth, *Dusicyon avus*

2.6. Site name: Tres Arroyos 1, Chile (TA)

2.6.1. Background

The site of Tres Arroyos (53°23′ S, 68°47′ W), on the island of Tierra del Fuego, is located 20 km from Bahia San Sebastián on the Atlantic coast and presents a clear association between hearths, marginally retouched artefacts, and the bones of guanaco, *Hippidion*, *Canis (Dusicyon) avus* (extinct canid), and extinct camelid (Massone, 1987, 1996; Mengoni Goñalons, 1988). It is clear that there were several agents (including both humans and carnivores) responsible for the terminal Pleistocene bone assemblage. Additionally, rabbits and other bioturbation agents caused vertical migrations of material which affected the integrity of these deposits (Borrero, 2003).

2.6.2. Pre-existing dates

Three radiocarbon dates on bone had previously been obtained from the earlier levels: 10,420 ± 100 BP (DIC-2333), 10,280 ± 110 BP (DIC-2732), and 11,820 ± 250 BP (Beta-20219) (Massone, 1987). The oldest of these dates was on a composite sample of partly-calcined bone recovered from within the bounds of a hearth deposit. Two additional dates had been obtained from hearth charcoal: 10,600 ± 90 BP (Beta-101023) and 10,580 ± 50 BP (Beta-13171) (Massone, 2004).

2.6.3. Specimens selected for this study

One specimen of charcoal and four specimens of unmodified animal bone from the basal cultural layer, and one unmodified animal bone specimen from the immediately overlying layer (see Table 1).

2.7. Repeatability

The primary dating facility for all specimens included in this study was the Oxford Radiocarbon Accelerator Unit. We evaluated technical repeatability of ^{14}C determinations by blind submission, in seven cases (three charcoal and four bone specimens), of the same specimen to a second AMS lab (University of Arizona NSF Facility). In the case of two specimens sampled by the Oxford lab (one of which had also been sampled by the Arizona lab), we were later able to obtain repeat dates on the same samples by the same lab after introduction of a new ultrafiltration bone pre-treatment protocol (Bronk Ramsey et al., 2004).

2.8. Statistical tests, procedure for averaging multiple dates, and calibration curve

Statistical analyses and calibration was carried out using OxCal 4.0 (Bronk Ramsey, 1995, 2001). When we wanted to determine the statistical likelihood that multiple samples could have been derived from a single event, we used the OxCal "R_Combine" routine's chi-square test; the same routine was used to calculate averages, using the Ward and Wilson (1978) procedure. OxCal reports the test statistic *T*, which has a χ^2 distribution with $n-1$ degrees of freedom under the null hypothesis, and which is recommended by Ward and Wilson (1978) for testing the hypothesis that each of a set of determinations represent the same underlying value; OxCal also reports the value of *T* below which an observed value must fall if the null hypothesis of no difference is to be upheld with respect to a threshold $\alpha = 0.05$. In the following sections, we therefore report the results of comparisons of two or more determinations in the format "average = *nn,nnn* ± *nn* BP, *n* d.f., *T* = *n.n*, 5% = *n.n*"; where the reported value for *T* exceeds the value for the 5% threshold, we conclude that the determinations in question should not be averaged. Where calibrated dates are given, these are based on the INTCAL04 calibration curve (Reimer et al., 2004) as implemented in OxCal 4.0 and are reported as a two-sigma (95.4 confidence interval) age range, rounded to a decadal resolution. OxCal 4.0, which implements the SHCal southern hemisphere calibration curve (McCormac et al., 2004) for the period to 11,000 cal BP, does not implement a southern hemisphere offset correction for pre-Holocene dates. The mean offset from recent dendrochronological control data is 56 ± 24 years, SHCal-calibrated dates being that much younger than those calibrated using a northern hemisphere curve; but McCormac et al. (2004) note that this offset should not be generalized to pre-Holocene situations because of the unknown effects of large-scale carbon reservoir changes.

3. Results

The results are given in Table 1. We report and discuss results primarily as uncalibrated determinations; calibrated dates are graphed in Fig. 2, and further consideration is given to calibrated ages when discussing dispersal chronologies in the final section. Twenty-three out of 30 specimens obtained for analysis were dated by at least one lab (including all six charcoal specimens). On 11 occasions, bone specimens failed to yield sufficient datable carbon in at least one lab (10 submissions to the Oxford lab, one submission to the Arizona lab). We discuss the interpretation of individual results in the next section. The Oxford lab also measured δ^{15}N and δ^{13}C for the dated animal bone samples. The results are given in Table 1 and plotted in Fig. 3 (below).

Inter-lab repeatability (Table 2) was very high for the three charcoal specimens; in each case, differences between results obtained by the two labs were not statistically significant.

Inter-lab repeatability for the bone specimens was less high. In two cases, the Arizona lab was able to obtain a determination on a specimen which had failed to yield sufficient carbon in the Oxford lab. In one of these cases (PO5-S1), this discrepancy is hard to explain, since both labs treated the specimen as burned bone (although it is well-known that burned bone is a difficult material to date accurately by the radiocarbon method; Jacobi et al., 2006)[3]. At the Oxford lab the sample received a ZR treatment (acid-base-acid treatment, usually used for charcoal) giving a low pre-treatment yield described in the lab notes as "ash-like", and effectively no carbon in the sample to date (0.002 mg from 5.4 mg, F. Brock pers. commun). At Arizona, a sample taken from the same piece of bone was also treated as burned bone but the lab notes indicate that 3.69 mg of carbon were recovered from an 11.14 mg sample—a percentage carbon yield that is vastly greater than that obtained by the Oxford lab. We speculate that this may reflect variation in the carbon content preserved at different sampling locations in the bone specimen. In the second case (AS2-S3), an unburned bone sample for which the Arizona lab had obtained a very low collagen yield (0.10%), the Oxford lab had evidently abandoned the attempt to extract datable material prior to the stage at which chemical composition would have been recorded. In a third case (PM-S3) both labs extracted sufficient collagen to obtain a determination, but the results were very significantly different. Both labs had obtained similar collagen yields (Oxford: 0.51%, Arizona: 0.57%), and the Oxford protocol in this case was centrifuged gelatinization pre-treatment (the sample had been dated prior to the introduction of ultrafiltration at that lab), which should have enhanced comparability with the Arizona results. Nevertheless, the Arizona determination was nearly 1000 ^{14}C years younger than the Oxford one, and the δ^{13}C measurements also differ. We interpret the discrepancy as due to specimen contamination. For this specimen we were able subsequently to obtain a re-measurement of retained sample by the Oxford lab, using the new ultrafiltration protocol (and with the new filter cleaning routine, see Bronk Ramsey et al., 2004). The second Oxford date was slightly younger than that lab's original measurement, but the δ^{13}C measurement did not converge with the Arizona observation. We are therefore inclined to discount the two dates originally obtained for this specimen, and to place greatest reliance on the more recently-obtained Oxford result.

4. Discussion

We now discuss the results for each site, the megafauna and stable isotope ecology, and the overall settlement chronology for southern South America as indicated by this study.

4.1. Site-by-site analysis

4.1.1. Arroyo Seco 2

Bone specimens had been selected based on the presence of fracture patterns which were interpreted by the taphonomists as cultural modifications probably associated with marrow extraction or bone quarrying (Eileen Johnson, pers. commun., 1999; Gutierrez, 2004; Salemme, in press; Politis et al., in press). Corroborating evidence for a human association includes the association of a unifacial lithic assemblage in the same stratigraphic unit; the selective representation in this assemblage of appendicular skeletal elements; and the open setting of the site on a low loess dune, which is viewed by the investigators as inconsistent with a natural accumulation of such a diversity of megamammals. These features of the site are detailed in the forthcoming site monograph (Politis et al., in press).

The new dates obtained on animal bone include a determination of 12,155 ± 70 BP (OxA-10387) on *Megatherium*, which is consistent with a previously-obtained determination on the same specimen by the Lawrence Livermore AMS Laboratory of 12,200 ± 170 BP (CAMS-58182) (average = 12,162 ± 65, 1 d.f., *T* = 0.1, 5% = 3.8), and almost consistent with a slightly younger determination of 11,770 ± 120 BP (AA-62514) on the same specimen previously obtained from the Arizona AMS Laboratory (average = 12,078 ± 57, 2 d.f., *T* = 8.1, 5% = 6.0). The new Oxford date was closely replicated by the same lab after ultrafiltration of the original sample (12,170 ± 55 BP; OxA-15871). These determinations are not however consistent with a determination of 7320 ± 50 BP (TO-1506) on the same specimen previously obtained from a fourth lab, Toronto AMS Lab, and which we therefore now reject. A conventional determination of 8470 ± 240 BP (LP-53) had

[3] "…we consider [burned bone] as a problematic dating material for a number of reasons. Burning reduces the protein content of bone significantly, making excessively burnt material impracticable for dating when targeting collagen. The material selected for dating is often only approximately characterizable as carbonaceous material insoluble in acid or alkali, and is usually pyrolized collagen further degraded and leached following burial. Often, sediment-derived carbon contamination cannot be ruled out and the detection of problem cases relies essentially on an analysis of the δ^{13}C value of the extracted carbon and comparison with sediment carbon stable isotopes" (Jacobi et al., 2006: 560–561).

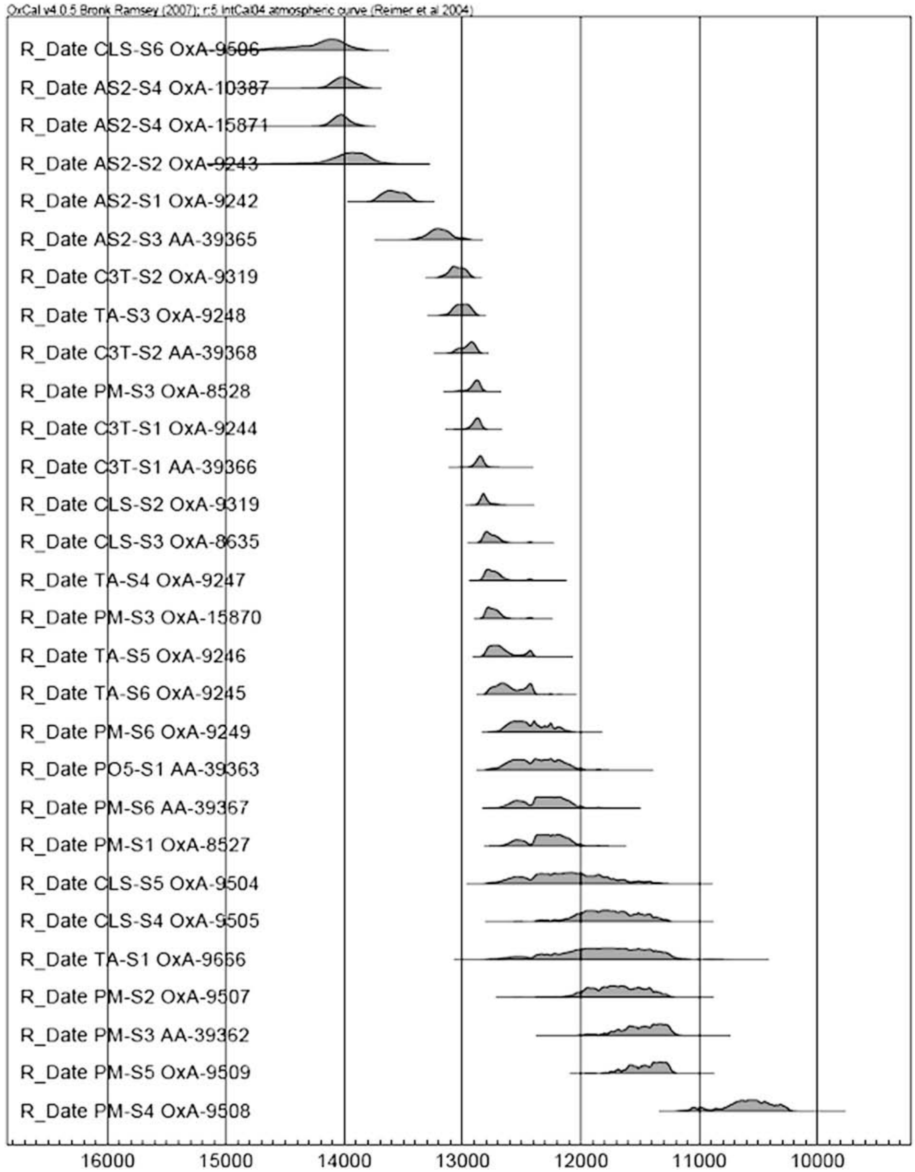

Fig. 2. Calibrated probability distributions for the 29 ^{14}C determinations obtained in this study. Calibrations from the INTCAL04 calibration curve (Reimer et al., 2004) as implemented in OxCal 4.0 (Bronk Ramsey, 1995, 2001).

previously been obtained on a separate specimen of *Megatherium* from another quadrant of the site, and must also now be considered suspect.

Two further determinations were obtained in the present study on helically-fractured specimens of indeterminate extinct megamammal, with ages of 12,070 ± 140 BP (OxA-9243) and 11,730 ± 70 BP (OxA-9242). Dates from the same range had previously been obtained from a single specimen of unmodified *Toxodon platensis* (dated independently by two separate labs to 11,750 ± 70 BP, CAMS-16389, Lawrence Livermore Lab; and 11,590 ± 90 BP, AA-7964, Arizona AMS Lab, average = 11,691 ± 56 BP, 1 d.f., $T = 2.0$, 5% = 3.8). We also obtained a new determination on a specimen of extinct American horse (*Hippidion* sp.) of 11,320 ± 110 BP (AA-39365), which is comparable to previously-obtained measurements on separate specimens of a second species (*Equus* 11,250 ± 105 BP, AA-7965; 11,000 ± 100 BP, OxA-4590), but not consistent with an additional determination on a separate equid sample obtained previously from the Toronto AMS Lab (8890 ± 90 BP, TO-1504), and which we now also reject.

We conclude that this megafaunal assemblage contains at least three different dates-of-death for the animals sampled (*Megatherium*, c. 12,150 BP, i.e. 14,170–13,840 cal BP; *Toxodon*, c. 11,750 BP, i.e. 13,710–13,350 cal BP; *Equus* and *Hippidion*, c. 11,200 BP, i.e. 13,210–12,950 cal BP). This increase in the consistency and resolution of the radiocarbon chronology for the megafaunal component is the major outcome of the present study with respect to the Arroyo Seco 2 site. The other significant issue is the date of the earliest cultural episode at the site. As summarised above, the argument for human agency depends not primarily on the helical fracture patterns but on other aspects of the archaeological context. If the Pleistocene animal bone deposits are anthropogenic, then the question also arises of how many cultural accumulation events took place involving transport to the site and processing of skeletal elements (if there was only one then the youngest date-of-death would necessarily provide the *terminus post quem*, or date at or after which that cultural event occurred). Such taphonomic issues cannot be resolved by radiocarbon dating. The site's lead investigators consider that the *Megatherium. Hippidion* and *Equus* remains provide evidence of human activity, in each case timed at or shortly

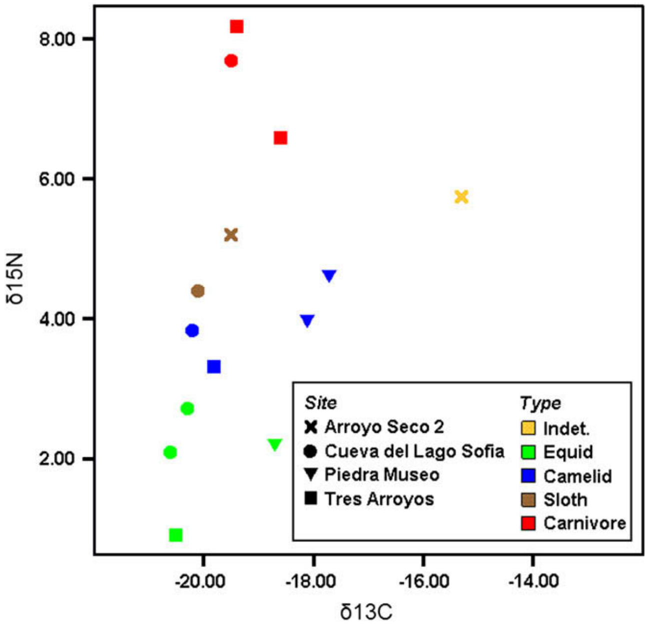

Fig. 3. δ^{15}N and δ^{13}C values for animal bone samples from four archaeological sites (see Table 1). The more recently-obtained values only are plotted for the two specimens which had repeat measurements taken by the Oxford lab.

after the death of the animals (Politis et al., in press). The forthcoming monograph will set out in detail the basis for these arguments, enabling open scientific discussion of the agencies potentially responsible for such fracture patterns, and of comparisons with other late Pleistocene bone assemblages where cases have been made for human involvement on the basis of bone modifications (e.g. Arroyo-Cabrales et al., 2006; Johnson, 2007).

4.1.2. Cueva 1, Cerro Tres Tetas

The two charcoal specimens from the hearth feature were each dated independently by the Oxford and the Arizona labs. For both specimens the two replicate measurements were consistent, giving averages of 10,886 ± 48 BP (specimen C3T-S1, 1 d.f., $T = 0.4$, 5% = 3.8) and of 11,087 ± 45 BP (specimen C3T-S2, 1 d.f., $T = 2.1$, 5% = 3.8). The average of 10,886 ± 48 BP for C3T-S1 is however inconsistent with the previously-obtained conventional ^{14}C determination of 11,560 ± 140 BP (LP-525) on the same charcoal specimen, and this conventional measurement is therefore now rejected. The two specimens dated in the present study are not consistent in age, one coming from wood that was slightly but significantly older than the other. If both specimens derive from a single hearth episode (and not two separate episodes re-using the same feature), then we must take the younger charcoal specimen as dating the fire itself. If the hearth was reused (which the stratigraphy does not enable us to distinguish), then both dates may be valid indicators of human occupation. We conclude that there was human activity at this site at c. 10,900 BP (12,920–12,820 cal BP) and possibly also at c. 11,100 BP (13,100–12,910 cal BP).

Table 2
Repeatability results for specimens which were dated more than once, whether twice by the same lab or once by each lab independently

Site	Specimen details	Lab. No.	δ^{13}C	Date
CHARCOAL				
Piedra Museo AEP 1	*Schinus* sp. Single piece	OxA-9249	−26.6	10,470 ± 65
		AA39367	−26.2	10,400 ± 79
Tres Tetas	*Schinus* sp. Single piece	OxA-9244	−22.2	10,915 ± 65
		AA39366	−23.5	10,853 ± 70
Tres Tetas	*Schinus* sp. Single piece	OxA-10745	−22.5	11,145 ± 60
		AA39368	−23.0	11,015 ± 66
BONE				
Arroyo Seco 2	*Megatherium americanum*	OxA-10387	−19.7	12,155 ± 70
		OxA-15871	−19.5	12,170 ± 55
Arroyo Seco 2	*Hippidion* sp. 3rd metatarsal. Helically fractured	OxA	[insufficient carbon]	
		AA39365	−20.8	11,320 ± 110
Paso Otero 5	*Megatherium* rib. Burned	OxA	[insufficient carbon]	
		AA39363	−19.8	10,440 ± 100
Paso Otero 5	*Equus neogeus* distal radio-cubitus	OxA	[nil carbon]	
		AA39364	[insufficient carbon]	
Piedra Museo AEP 1	*Hippidion saldiasi*, distal humerus, cut-marked	OxA-8528	−19.3	10,925 ± 65
		OxA-15870	−18.7	10,675 ± 55
		AA39362	−22.1	9952 ± 97

4.1.3. Cueva del Lago Sofia 1

The date obtained on unmodified *Mylodon* bone of 12,250 ± 110 (OxA-9506) is consistent with the previously-obtained determination of 12,990 ± 490 BP (PITT-0939) on the same species, giving an average of 12,290 ± 108 BP (1 d.f., $T = 2.4$, 5% = 3.8). This is consistent with the determinations on *Mylodon* remains from the nearby Mylodon Cave, and is interpreted by the investigator as indicating the age of *Mylodon* occupation of these caves without any implied human presence (Jackson and Prieto, 2005). The culturally modified bone tool (the retoucher) yielded a determination of 10,710 ± 70 BP (OxA-8635), which is consistent with the date of 10,780 ± 60 BP (OxA-9319) on horse bone. These new results are however inconsistent with the previously-obtained determination of 11,570 ± 60 BP (PITT-0684) on hearth charcoal. The bone tool determination of 10,710 ± 70 BP (OxA-8635) is also inconsistent with the two youngest determinations on our other animal bone specimens, 10,310 ± 160 BP (OxA-9504) and 10,140 ± 120 BP (OxA-9505), which are themselves consistent and average to 10,202 ± 97 BP (1 d.f., $T = 0.7$, 5% = 3.8), and must derive from one or more later events. While we have reproduced the age of the palaeontological assemblage of *Mylodon* at c. 12,300 BP, we have not reproduced the previously-obtained hearth charcoal age for the cultural episode. Our results indicate, however, that the deposits in the basal cultural layer are time-averaged over a 2000-year span; the charcoal date now needs to be evaluated by further determinations on charcoal from the same hearth feature. We meanwhile conclude from the one date in this study on individually-identified culturally modified bone (the retoucher tool), that human activity at this site occurred at c. 10,700 BP (12,860–12,420 cal BP).

4.1.4. Paso Otero 5

The animal bone proved to have very little preserved collagen, and the six specimens (two of which were submitted to both the Oxford and the Arizona labs) yielded only one ^{14}C determination of 10,440 ± 100 BP (AA-39363) on a burned bone sample, which is consistent with the previously-obtained determination of 10,190 ± 120 BP (AA-19291) and gives an average age of 10,340 ± 77 BP (1 d.f., $T = 2.5$, 5% = 3.8). The animal bone from Paso Otero 5 was too degraded to enable cut-mark identification (had any originally been present), and the basis for associating these specimens with the cultural event is their close stratigraphic relationship with fractured Fishtail Points and the fact that the bone had been heated to a high temperature (consistent with their use as fuel, but not with a non-anthropogenic burning event). In light, however, of the additional determination on burned bone obtained by the site's investigator while this study was in progress and which is significantly younger (9560 ± 50 BP, GX-29795), we can only tentatively infer from our observations that there may have been human activity at this site at c. 10,300 BP (12,610–11,830 cal BP).

4.1.5. Piedra Museo AEP-1

A cut-marked horse bone from the lowest cultural layer (Unit 6) yielded a determination of 10,925 ± 65 BP (OxA-8528), which is consistent with a previously-obtained determination of 11,000 ± 65 BP (AA-27950) on charcoal. However, this Oxford bone determination was subsequently re-measured after ultrafiltration of the same sample (using the new Oxford filter cleaning protocol) yielding a date of 10,675 ± 55 BP (OxA-15870), which is inconsistent with the earlier result (1 d.f., $T = 8.7$, 5% = 3.8). Neither of these Oxford bone values was consistently replicated by the Arizona lab determination of 9952 ± 97 BP (AA-39362) on the same specimen (which also has an anomalous $\delta^{13}C$ value, and which we now discount).

It was indicated at the time of submission that there were two discrete clusters of animal bone in the basal cultural layer, consistent with two cultural episodes. The next-oldest three determinations from that layer (one on helically-fractured animal bone and two replicate measurements on charcoal) are consistent with each other, and give an average of 10,424 ± 41 BP (2 d.f., $T = 0.8$, 5% = 6.0); the remaining helically-fractured animal bone specimen from that layer is slightly younger and its determination just fails to achieve statistical consistency with these three (average of all four samples = 10,387 ± 39 BP, 3 d.f., $T = 8.2$, 5% = 7.8). These results are also consistent with a previously-obtained charcoal determination also from the bottom of Unit 6 (10,470 ± 60 BP, GRA9837). A previously-obtained determination on unmodified bone (originally reported as from Unit 4, but subsequently re-assigned to the middle of Unit 5 and stratigraphically associated with a Fishtail Point) was dated to 10,400 ± 80 BP (AA-8428; Miotti et al., 2003: 100). A block of soil from a stratum reportedly sealing the basal cultural layer, and containing dense charcoal, was sampled for individual pieces at its upper and lower limits. The dates obtained were inconsistent (1 d.f., $T = 15.4$, 5% = 3.8), the lower sample (9950 ± 75 BP, OxA-9509) being significantly older than that from the upper part of the block (9350 ± 130 BP, OxA-9508). The submitters had originally indicated their expectation that this block indicated re-use of the same hearth feature over multiple occupation episodes. None of our samples reproduced the previous interpretation of a cultural event at 12,890 ± 90 BP (AA-20125), determined from a charcoal sample and which we now consider to be an unexplained outlier. The separately-obtained charcoal date of 11,000 ± 65 BP (AA-27950) now also needs to be evaluated by further determinations on charcoal from the same hearth feature. We meanwhile conclude from the results of this study from the basal cultural layer (Unit 6) that there was human activity here at c. 10,700 BP (12,840–12,420 cal BP), and again at c. 10,400 BP (12,610–12,120 cal BP).

4.1.6. Tres Arroyos

The animal bone was too degraded to enable cut-mark identification (had any originally been present). Our samples from two carnivore species indicated that they had been present at the site at 11,085 ± 70 BP (OxA-9248) (*Panthera onca*) and at 10,575 ± 65 BP (OxA-9245) (*Dusicyon avus*). The *Dusicyon* age is consistent with the determinations from the two other animal bone specimens. These are also consistent with previously-obtained determinations on hearth charcoal of 10,600 ± 90 BP (Beta 113171) from Hearth 2, and 10,580 ± 50 BP (Beta 113171) from Hearth 3. The single charcoal date obtained in the present study is also consistent with these observations because of its large error term, giving an average of all three hearth charcoal measurements (one in this study, two previously-obtained) of 10,567 ± 43 BP (2 d.f., $T = 4.3$, 5% = 6.0). Because of the contemporaneity of the canid and human occupation episodes (assuming that *Dusicyon avus* occupied the cave independently), we are reluctant to interpret the other unmodified animal bone dates as definitely cultural. We have not reproduced, with our new samples, the previously-observed conventional determination of 11,880 ± 250 BP (Beta 20219) on a composite sample of partly-calcined bone recovered from within the bounds of Hearth 1. This conventional date is an outlier in relation to the cave stratigraphy (see discussion in Massone, 2002) and might also be considered insecure because of the known problems in precise and accurate dating of burned bone samples, even when using AMS techniques (see discussion of Paso Otero 5, above). We conclude from the consistency of our new results with those previously obtained from the hearth features that human activity at this site occurred at c. 10,600 BP (12,770–12,400 cal BP).

4.2. Stable isotope ecology and dating of the megafauna

Stable isotope abundances of ^{15}N and ^{13}C are tabulated in Table 1, and the results for the animal bone samples are graphed in Fig. 3. The charcoal dates were all on single entities, usually selected from larger samples of material recovered in soil blocks. The entities dated from Cueva Tres Tetas and from Piedra Museo were provisionally identified to genus *Schinus* (family Anacardiaceae) by Dr Tim Lawrence of the Royal Botanical Gardens in London, on the basis of the South American comparative specimens available in their reference collection. A small amount of charcoal in the soil block sample submitted from Unit 6 at Piedra Museo came from a second group, with some resemblance to woody members of the family Compositae, but positive identifications were not made due to the paucity of reference material. The $\delta^{13}C$ values of the dated samples from these two sites and from Tres Arroyos (where the material lacked diagnostic criteria) are those of C3 plants (observed range −27.5‰ to −21.2‰; C3 plant reference mean = −27‰, reference range = −35‰ to −21‰, Kelly, 2000), with one exception—the specimen from the base of the soil bock at the U5/U6 interface at Piedra Museo, and dated to 9950 ± 75, which has the $\delta^{13}C$ value (−10.5‰) of a C4 plant (C4 plant reference mean = −13‰, reference range = −14‰ to −10‰, Kelly, 2000).

The $\delta^{13}C$ values for the animal bone samples are also consistent with a C3 plant-based diet. Observed values for equids and camelids were in the range −20.6‰ to −17.7‰, compared with a reference value of −18.3 ± 4.2‰ for herbivore C3 feeders (Kelly, 2000). Observed values for carnivores were in the range −19.5‰ to −18.6‰, compared with a reference value of −19.8 ± 2.1‰ for carnivore C3 feeders (Kelly, 2000). The samples from extinct sloths (*Megatherium americanum* and *Mylodon darwinii*) were also in this C3 plant feeding range, but the two unidentified megamammal specimens from Arroyo Seco 2 were comparatively ^{13}C-enriched (−15.3‰) for reasons that are not yet apparent. The presence of a C4 plant component at Piedra Museo suggested by the charcoal evidence would also be consistent with the $\delta^{13}C$ values for the three herbivore specimens from that site, which are slightly ^{13}C-enriched compared with those from other sites (see Fig. 3), although the sample size is too small for this to be more than suggestive.

Trophic level effects are evident in the bone collagen $\delta^{15}N$ values measured. Laboratory and field evidence suggests that an increase of one trophic level yields an average 3–4‰ enrichment in ^{15}N due to isotopic fractionation (Kelly, 2000). $\delta^{15}N$ values for the three carnivore samples from Tres Arroyos and Cueva del Lago Sofia were in the range 6.59–8.18‰. This shows enrichment of the order expected from the reference data, compared with the observed values for herbivores (including sloths) in our sample ($\delta^{15}N$ mean = 3.55‰, range = 0.92–5.2‰). The camelids and sloths are ^{15}N-enriched compared with the equids, which may reflect differences in diet and in dietary physiology—at Rancho La Brea (Coltrain et al., 2004), ruminant (including camelid) ^{15}N was enriched by on average 2.3‰ relative to non-ruminants (equids). At Rancho La Brea the ground sloths were intermediate between ruminant and non-ruminant feeders in terms of δ^{15}N values; in our sample the one specimen of *Megatherium* from Arroyo Seco 2 was relatively ^{15}N-enriched compared with the equids, as was the *Mylodon* specimen from Cueva del Lago Sofia. If the giant sloths were non-ruminants then this ^{15}N enrichment may reflect a more omnivorous diet, although the observed pattern could also be consistent with the sloths having a semi-ruminant physiology (cf. Coltrain et al., 2004).

Among the faunal remains analysed in this study were bones from several extinct species of Pleistocene megafauna. These included equids taxonomically identified to *Hippidion saldiasi* with dates of 10,780 ± 60 BP (OxA-9319) and 10,310 ± 160 BP (OxA-9504) at Cueva de Lago Sofia 1, and of 10,675 ± 55 BP (OxA-15870) at Piedra Museo; the equid specimen from Tres Arroyos dated to 10,685 ± 70 BP (OxA-9247) has also subsequently been assigned to this taxon (Borrero, 2008). The *Hippidion saldiasi* remains from Piedra Museo have been discussed by Alberdi et al. (2001), who suggest that the species was an important prey resource for late Pleistocene Patagonian hunter-gatherers.

Carnivore remains dated in this study include a extinct large Pleistocene felid (*Panthera onca mesembrina*, the Patagonian panther) at Tres Arroyos at 11,085 ± 70 BP (OxA-9248), an extinct species of fox (*Dusicyon avus*, a large fox with craniodental characteristics implying a moderately carnivorous diet; Prevosti and Vizcaino, 2006) at Tres Arroyos at 10,575 ± 65 BP (OxA-9245), and a specimen of an extant wild canid (*Pseudalopex culpaeus*, the Patagonian or Andean fox) at Cueva del Lago Sofia at 10,140 ± 120 BP (OxA-9505).

Ground sloth remains were also dated (*Megatherium* dated to 12,155 ± 70 BP (OxA-10387) and 12,170 ± 55 BP (OxA-15871) at Arroyo Seco 2, and to 10,440 ± 100 BP (AA-39363) at Paso Otero 5; *Mylodon* dated to 12,250 ± 110 BP (OxA-9506) at Cueva del Lago Sofia). These dates are within the range recognized by Steadman et al. (2005), although Borrero (2008), Politis and Messineo (2007) and others have drawn attention to other South American candidate sites with sloth remains that may be of Early Holocene age. The results of our study do, however, confirm that the Holocene ages previously reported for *Megatherium* at Arroyo Seco 2 should now be rejected (see above, Section 4.1; those previous measurements obtained from the Toronto AMS and La Plata conventional radiocarbon labs continue to be cited as evidence of a late survival of ground sloth at Arroyo Seco 2, e.g. by Hubbe et al., 2007, but this should be discontinued).

4.3. Early human occupation of southern South America

As we indicated in the Introduction, in our view the main scientific question for this study is that of the presence or absence of a persistent and demographically-viable hunter-gatherer population in southern South America during the late Pleistocene, and that issue is best addressed by evaluating evidence from as large as possible a sample of sites in the region. What we are looking for is a consistent settlement signal from multiple sites with multiple well-controlled ^{14}C dates. With one possible exception, we have not obtained new results to confirm earlier observations of pre-Clovis-age cultural activity at any of the sites considered in this study. The possible exception, Arroyo Seco 2, is considered in detail elsewhere (Politis et al., in press). In the light of the results of this study, which appear to have resolved many of the dating issues surrounding the Arroyo Seco 2 Pleistocene component, debate must now focus on the taphonomic arguments for humans as the agents of bone accumulation and bone modification.

Leaving Arroyo Seco 2 aside, our results on the specimens which were the most preferred indicators of cultural events (hearth charcoal and cut-marked bone) confirm that people were in the southern cone of South America at or soon after 11,000 BP. This observation is corroborated by the new results obtained from this study for at least three of the six sites in our own sample: Cerro Tres Tetas (11,087 ± 48 BP and 10,886 ± 48 BP, hearth charcoal, both averaged from two replicate determinations); Cueva del Lago Sofia 1 (10,710 ± 70 BP (OxA-8635), bone tool); Piedra Museo (10,675 ± 55 BP (OxA-15870), cut-marked bone). In addition, Tres Arroyos has two secure hearth charcoal dates (10,600 ± 90 BP (Beta 113171) 10,580 ± 50 BP (Beta 113171)) obtained independently of this study but which are consistent with the results we obtained. Finally, independently-obtained hearth charcoal dates from two of the sites in our sample (Cueva de Lago Sofia 1, 11,570 ± 60 BP (PITT-0684); Piedra Museo, 11,000 ± 65 BP (AA-27950)) suggest somewhat earlier dates for first occupation which our own observations did not directly confirm, but which remain plausible in principle in terms of stratigraphic context (and which should now be revisited by additional determinations on charcoal from the same features).

Similar evidence to that obtained here has been reported from other sites in the southern cone of South America (see Table 3; only sites/components with charcoal dates older than c. 10,600 BP included). These include—in the Humid Pampas sub-region—Cerro La China 1 (10,706 ± 40 BP, average of five charcoal dates), Cerro La China 2 (with charcoal dates of 10,560 ± 75 BP and 11,150 ± 130 BP), Cerro La China 3 (with a single charcoal date of 10,610 ± 180 BP), and Cerro El Sombrero (with four charcoal dates in the range 10,270 ± 85 BP to 10,725 ± 90 BP). In Uruguay, the site of Urupez 2 has two charcoal dates (10,690 ± 60 BP and 11,690 ± 80 BP; Meneghin, 2004, 2006). In southern Patagonia an additional key site is Cueva Casa del Minero (10,983 ± 39 BP, average of two charcoal dates; Paunero, 2003b). Cueva del Medio has four charcoal dates in the range 10,930 ± 230 to 9595 ± 115 (Nami and Makamura, 1995). Finally, we also mention here two

Table 3
Sites and carbonized plant dates referred to in Section 4.3

Site	Sample	Date	Average
Cerro La China 1, Argentina (Flegenheimer and Zárate, 1997)	AA-8953 (charcoal)	10,804 ± 75	10,706 ± 40
	AA-1327 (charcoal)	10,790 ± 120	
	AA-8952 (charcoal)	10,745 ± 75	
	I-12741 (charcoal)	10,720 ± 150	
	AA-8954 (charcoal)	10,525 ± 75	
Cerro La China 2, Argentina (Zárate and Flegenheimer, 1991)	AA-8955 (charcoal)	11,150 ± 135	N/A
	AA-8956 (charcoal)	10,560 ± 75	
Cerro La China 3, Argentina (Zárate and Flegenheimer, 1991)	AA-1328 (charcoal)	10,610 ± 180	10,610 ± 180
Cerro El Sombrero Abrigo 1, Argentina (Flegenheimer and Zárate, 1997)	AA-4765 (charcoal)	10,725 ± 90	N/A
	AA-4767 (charcoal)	10,675 ± 110	
	AA-5220 (charcoal)	10,480 ± 70	
	AA-4766 (charcoal)	10,270 ± 85	
	AA-5221 (charcoal)	8060 ± 140	
Urupez II, Uruguay (Meneghin, 2004. 2006)	Beta-211938 (charcoal)	11,690 ± 80	N/A
	Beta-165076 (charcoal)	10,690 ± 60	
Cueva Casa del Minero, Argentina (Paunero, 2003)	AA-37208 (charcoal)	10,967 ± 55	10,983 ± 39
	AA-37207 (charcoal)	10,999 ± 55	
Cueva del Medio, Chile (Nami and Nakamura, 1995)	Beta-39081 (charcoal)	10,930 ± 230	N/A
	Beta-52522 (charcoal)	10,430 ± 80	
	GrN-14913 (charcoal)	10,310 ± 70	
	PITT-0244 (charcoal)	9595 ± 115	
Quebrada Santa Julia, Chile (Jackson et al., 2007)	Beta-215089 (charcoal)	11,090 ± 80	11,024 ± 47
	Beta-215090 (wood)	11,060 ± 80	
	Beta-194725 (charcoal)	10,920 ± 80	
Caverna da Pedra Pintada, Brazil (Roosevelt et al., 1996, 2002)	GX-17413 (burned palm seeds)	11,145 ± 135	11,077 ± 107
	GX-17406 (burned palm seeds)	11,110 ± 310	
	GX-17407 (burned palm seeds)	10,905 ± 295	
	GX-17414 (burned palm seeds)	10,875 ± 295	

The right-hand column gives the average of the dates, when these are all sufficiently similar in terms of OxCal's significance criterion ($\alpha = 0.05$). N/A, Not Applicable (i.e. multiple dates not statistically similar enough for averaging).

sites from lower latitudes in South America which have multiple ^{14}C measurements that appear to be quite consistent and well-controlled, and are of similar age: in the semi-arid Andean Pacific region of Chile, a layer at Quebrada Santa Julia has recently been dated to 11,024 ± 47 BP (average of two charcoal and one wood samples; Jackson et al., 2007); and in addition, the Initial A stratum at Caverna da Pedra Pintada in Brazilian Amazonia has a date for its basal cultural layer of 11,077 ± 107 BP (average of four burned palm seed dates; Roosevelt et al., 1996, 2002).

In general, then, the archaeological record as it is currently understood (including the results from the southernmost sites in the present sample) implies the contemporaneous emergence of a consistent and archaeologically-robust human occupation signal at widely-separated locations across the Western Hemisphere. The assessment by Waters and Stafford (2007) of the most secure dates for sites in the USA with Clovis points puts them in the interval 11,080 ± 40 BP (Lange-Ferguson, Texas; average of three dates; calibrated age range at 2σ is 13,090–12,910 cal BP) to 10,765 ± 25 BP (Jake Bluff, Oklahoma; average of three dates, calibrated age range at 2σ is 12,850–12,780 cal BP), which is very similar to the ages observed in the South American Palaeoindian sites summarized above, for example 10,886 ± 48 BP at Cerro Tres Tetas (calibrated age range at 2σ is 12,920–12,820 cal BP). We are aware of no plausible demographic model that would predict the contemporaneous first archaeological appearance at such widely-separated locations of a population expanding from a single initial dispersal event. Steele et al. (1998) found that a colonization wave spreading into North America from a northwestern origin at 6–10 km/calendar year would produce time-averaged densities of discarded artefacts with a spatial pattern consistent with the recorded North American projectile point sample. Alroy (2001) used the same origin and the same estimates for human mobility and intrinsic rate of increase but with carrying capacity varying dynamically as a function of predator-prey interactions, finding that a colonizing population expanding at that speed could readily induce the observed rates of North American megafaunal extinction. Most recently, Hamilton and Buchanan (2007) fitted a linear least-squares regression model to a very small sample of Clovis-age uncalibrated ^{14}C dated sites in North America and estimated that initial dispersal from Edmonton (the southern end of the ice-free corridor) took place at about 11,300 BP (95% CI: 11,114-11,607 BP), with the population front advancing at a speed of 5–8 km/^{14}C-year. If a North American dispersal event of that age and with the same spread dynamic also gave rise to the first colonization of South America, then the predicted first occupation dates for the earliest southern South American sites in our sample should be of the order of 1500–2400 ^{14}C-years after initial entry (taking Cerro Tres Tetas as a representative example, which is located ~12,000 km from Edmonton in Canada on a Great Circle route). The observed dates of the South American sites are clearly not consistent with that dispersal chronology. Such findings suggest that Palaeoindian demic expansion may have involved more than one terminal Pleistocene dispersal episode. A recent report of human activity dated to ~12,300 BP (~14,270–14,000 cal BP) at a cave site in south-central Oregon (Gilbert et al., 2008) seems to us to be more consistent with the southern South American settlement chronology summarized here. Perhaps there are other sites to be discovered in North America south of the ice sheets with human occupation dating to somewhat earlier than 11,000 BP (13,000 cal BP), but where the evidence has not yet been excavated or generally recognized.

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