Geochronology and Landscape Development Along the Middle Río Quequén Grande at the Paso Otero Locality, Pampa Interserrana, Argentina

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The Paso Otero Locality is a cluster of archaeological sites within the middle Río Quequén Grande basin located in the northern coastal plain of Argentina. The valley fill is Holocene alluvial, eolian, and palustrine sediment, including the top of the Guerrero Member (~10,000 ^{14}C yr B.P.), upper Río Salado Member (~3000 ^{14}C yr B.P.), and lower La Postrera Formation (~2400 ^{14}C yr B.P.). Regional soils include the Puesto Callejón Viejo (10,000 to 9400 ^{14}C yr B.P.) and the Puesto Berrondo (~4800 ^{14}C yr B.P.). Radiocarbon sampling of buried A-horizons on both sides of the river produced 17 dates considered reliable. The geoarchaeological information allows exploration of the implications for the formation of the archaeological record. Similar geological processes of differential intensity have resulted in contexts of different archaeological resolution and integrity. The Paso Otero Locality provides both a local and regional view of late Quaternary events and processes for the middle basin of the Río Quequén Grande.

INTRODUCTION

Alluvial deposits throughout the world contain multiple, stratified archaeological records that have played key roles in establishing local and regional cultural and paleoenvironmental sequences (e.g., Brown, 1997; Pitulko, 2011; Woodward & Huckleberry, 2011). The published record for stratified archaeological sequences within alluvial deposits within the Pampas of Argentina, however, is minimal. The stratified alluvial record reported here for the middle Río Quequén Grande, therefore, is significant in providing a glimpse of sequential hunter-gatherer activity in the region. This paper provides the alluvial stratigraphic, geochronologic, and paleoenvironmental framework for that archaeological record.

The Río Quequén Grande is one of the few rivers flowing through the Pampa Interserrana of Argentina, an expansive grassland situated between the Tandilia and Ventania mountains. The river heads in the Tandilia range and trends southeast across the Pampa joining the Atlantic Ocean near Necochea (Figure 1). The river has been an important regional source of water and offers diverse habitats for people and animals. Archaeological and geoarchaeological endeavors have focused on the middle Río Quequén Grande basin where at least three major archaeological localities are known: Zanjón Seco (Politis, Martínez, & Bonomo, 2001), La Horqueta (Zárate, Espinosa, & Ferrero, 1998), and Paso Otero (Martínez, 2006). Each of these localities represents a cluster of archaeological sites (Figure 1).

The purpose of this paper is to (1) describe the buried soil sequences in the Paso Otero Locality, (2) evaluate radiocarbon dates from the 1990s systematic organic sediments sampling program, (3) assess radiocarbon dates on organic sediments obtained since that sampling program, (4) examine the relationship between those dates and bone dates obtained at the sites, (5) explore local landscape development within the flood plain, and (6) relate the archaeology to the soils and paleolandscape. Seventeen radiocarbon ages based on organic sediments help to date not only the archaeology, but constrain the timing of sediment accumulation and landscape

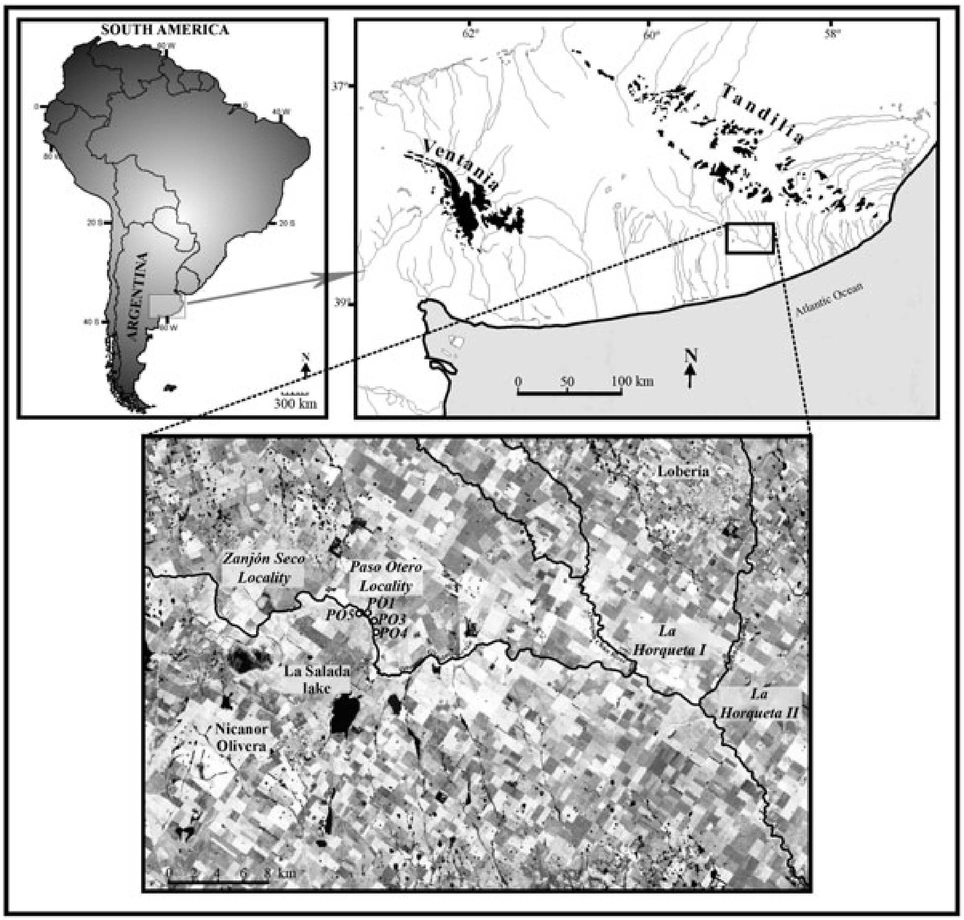

Figure 1 General location of the Paso Otero Locality in the Argentine Pampas within the middle basin of the Río Quequén Grande and its major archaeological localities (italicized); note that Ventania and Tandilia are the major mountain ranges on the Pampas.

stability. This study further places the archaeology in a firm lithostratigraphic and soil-stratigraphic context and provides insights into site formation processes.

PHYSICAL SETTING AND RESEACH BACKGROUND

The Río Quequén Grande rises in the Tandilia mountain system (Figure 1) and runs in a north-northwest to south-southeast direction. After a journey of ~173 km, it flows into the Atlantic Ocean. The drainage basin encompasses an area of ~10,000 km^2 and the Río Quequén Grande has the highest flow in the region with values ranging 10–17 m^3/s (Varela & Teruggi, 2002). The stream is perennial with a relatively flat channel bottom. The watercourse is developed on Quaternary sediments (e.g., Pampiano Formation), consisting mainly of primary and redeposited loess. River behavior has been controlled by tectonic effects, climate changes, and changes in sea level (Kruse et al., 1996; Campo de Ferrara & Piccolo, 1999). The middle Río Quequén Grande flood plain is currently entrenched and ~20-m wide, with banks up to 10-m high. The drainage network is dendritic, and the course of the river is meandering as it crosses the low-gradient (0.2%) coastal plain (Teruggi et al., 2004:154).

The Paso Otero Locality, the subject of this paper, is along the middle Río Quequén Grande (Figure 2) and is the focus of long-term geological and paleontological research (Tonni & Fidalgo, 1978; Tonni & Laza, 1980; Tonni et al., 1985; Bargo et al., 1986; Prado et al., 1987; Prado & Cerdeño, 1998), including an archaeological component that began in 1989 (Politis, Gutiérrez, & Martínez, 1991; Martínez, 1999). The locality is ~60 km from the mouth of the Río Quequén Grande at an elevation of ~80 m and contains a cluster of 12 sites on both sides of the river. The four excavated sites (Figure 1; Paso Otero 1, 3–5) are stratified, each having a number of buried

Figure 2 The Paso Otero Locality setting along the banks of the Río Quequén Grande.

Figure 3 A typical stratigraphic exposure at the Paso Otero Locality.

soils. The valley fill generally consists of the regional late Pleistocene and Holocene alluvial and lacustrine deposits (Figure 3) of the Luján Formation and La Postrera Formation (Fidalgo, De Francesco, & Colado, 1973; Fidalgo, De Francesco, & Pascual, 1975; Tonni & Fidalgo, 1978; Dillon & Rabassa, 1985; Fidalgo et al., 1991; Fidalgo, 1992; Carbonari, Huarte, & Figini, 1992; Bonadonna, Leone, & Zanchetta, 1995; Zárate, Espinosa, & Ferrero, 1996, 1998; Prieto et al., 1998; Prado & Alberdi, 1999; Tonni, Cione, & Figini, 1999, 2001; Zárate et al., 2000; Tonni et al., 2003).

The Luján Formation has three members. The lowermost La Chumbiada Member is a sandy fluvial and lacustrine unit. The middle Guerrero Member also is a sandy fluvial–lacustrine unit. Deposition of the La Chumbiada Member began prior to 29,000 ^{14}C yr B.P. while deposition of the Guerrero Member began ca. 29,000 ^{14}C yr B.P. and ceased between 11,000 ^{14}C yr B.P. and 10,000 ^{14}C yr B.P. A regional well-developed soil known as Puesto Callejón Viejo formed at the top of the Guerrero Member and separates it from the overlying Río Salado Member. The upper part of the A-horizon was dated as young as ~9000 ^{14}C yr B.P. to as old as ~10,000 ^{14}C yr B.P.

The Río Salado Member is a fluvial–lacustrine and paludal unit deposited post-9000 ^{14}C yr B.P. to ca. 3000–2700 ^{14}C yr B.P. Within the Río Salado is another regional buried soil known as Puesto Berrondo. Its age of formation is estimated between 5000 and 4000 ^{14}C yr B.P. (Zárate et al., 2000) but may be as young as 2000 ^{14}C yr B.P. (Tonni, Cione, & Figini, 2001). It is buried by flood deposits. The La Postrera Formation at the top of the sequence is a time-transgressive sandy deposit originally interpreted as eolian and dating post-3000 yr B.P. in alluvial valleys. No deposits older than the Guerrero Member have been exposed at the sites described and discussed in this paper.

A different perspective on the chronology of the Puesto Callejón Viejo and Puesto Berrondo paleosols than presented here recently has been offered. Tonni, Cione, and Figini (2001) have proposed that the main pedogenic events are located chronologically in the Early Holocene (10,000–7000 ^{14}C yr B.P.), defining an unnamed paleosol; the Middle Holocene (6500–4000 ^{14}C yr B.P.) represented by the Puesto Callejón Viejo Geosol; and the Late Holocene (3000–2000 ^{14}C yr B.P.) with the Puesto Berrondo Geosol (see also Fucks et al., 2007). The age of these soils can vary regionally (Tonni, Cione, & Figini, 2001; Fucks et al. 2007). In the middle basin of the Río Quequén Grande, the soil that developed within the upper Guerrero Member of the Luján Formation has yielded consistent Early Holocene dates and it is related to the Puesto Callejón Viejo Paleosol. Regarding the Puesto Berrondo Paleosol, well-developed regional buried A-horizons are dated to the Middle Holocene at the La Horqueta Locality (Zárate, Espinosa, & Ferrero, 1998).

Both late Pliocene and late Pleistocene local faunas have been described for the Paso Otero Locality (Tonni & Laza, 1980; Prado et al., 1987, 2005; Prado & Cerdeño, 1998; Tonni, Cione, & Figini, 1999; Tonni et al., 2003). For the late Pleistocene Guerrero Member, the local fauna corresponds to the terminal Pleistocene expression of the Lujanian Land-Mammal Age (Bargo et al., 1986; Cione & Tonni, 1995, 1996). The local fauna is denoted by a variety of birds and rodents, large herbivores that primarily are grazing, open grassland species, along with three members of the carnivore guild. While most mammal taxa are extinct, the avian taxa are not. Most of the birds, however, no longer occur in the area today, with ranges contracting back to Patagonia or the Andean foothills (Tonni & Laza, 1980; Narosky & Yzurieta, 1993). Differences in the faunal assemblages between the La Chumbiada and Guerrero members reflect environmental and climatic change, from shrubby humid grassland (La Chumbiada) with a predominance of browsers in warm and humid conditions to dry steppe grassland (Guerrero) with grazers in cold and dry conditions (Prado & Alberdi, 1999; Prieto, 2000).

Securing a reliable radiocarbon chronology for the Paso Otero Locality has been problematic. Regionally, charcoal is scarce and bone and shell have provided most radiocarbon dates (e.g., Figini, 1987; Politis & Buekens, 1991; Figini et al., 1995; Barrientos et al., 1996; Zárate, Espinosa, & Ferrero, 1998; Tonni, Cione, & Figini, 1999; Tonni et al., 2003; Steele & Politis, 2009). More recently, bulk organic sediment samples have been used (e.g., Figini et al., 1995; Zárate, Espinosa, & Ferrero, 1998; Prieto, 2000). At the Paso Otero Locality, both bone and organic sediment samples have been dated. Many of these dates have been published elsewhere (Johnson et al., 1998; Holliday et al., 2003; Martínez, Gutiérrez, & Prado, 2004; Martínez, 2006; Grill et al., 2007; Osterrieth et al., 2008), but are provided here along with previously unpublished dates.

We follow the pampean archaeological scheme for subdivisions of the Holocene (Martínez & Gutiérrez, 2004), with middle Holocene beginning ca. 6500 ^{14}C yr B.P. and late Holocene beginning ca. 3000 ^{14}C yr B.P. The date for the Pleistocene/Holocene boundary is 10,000 ^{14}C yr B.P., following Pillans (2007).

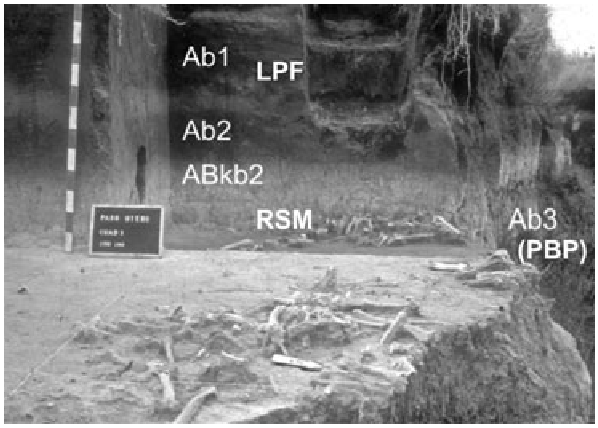

Figure 4 Buried A-horizons at Paso Otero 1 (note the guanaco bone piles in stratigraphic position); LPF, La Postrera Formation; RSM, Río Salado Formation; PBP, Puesto Berrondo paleosol.

SITES OF THE PASO OTERO LOCALITY

Three of the Paso Otero Locality sites (Paso Otero 1, 3, and 5) have undergone excavation and were the focus of the 1990s organic sediments sampling program. Since that program, a fourth site (Paso Otero 4; Figure 1) has been excavated recently and subsequently dated using organic sediments (Gutiérrez et al., 2011). Those results, however, are not included here. The other sites remain unexplored (Martínez, 1999).

Paso Otero 1

Paso Otero 1 is located on the eastern bank of the river (Figure 1; Politis, Gutiérrez, & Martínez, 1991; Johnson et al., 1998). Site stratigraphy includes the Luján Formation (with its Guerrero and Río Salado members) and the La Postrera Formation, with exposures in the excavation areas, along the riverbank, and in an arroyo just north of the excavations (Figure 4). Although originally defined as an eolian deposit (Fidalgo, De Francesco, & Colado, 1973), the stratigraphic section that corresponds to the La Postrera Formation in the Río Quequén Grande middle basin (particularly at Paso Otero 1 and 3) is not entirely eolian. Flood plain deposits (including a series of fluventic soils) alternate with eolian deposits. The section most likely is a facies of the formation, and for the purposes of this paper, the original nomenclature of the La Postrera Formation is maintained. This alternation of eolian and fluvial deposits subsequently has been described in more detail by Favier Dubois (2006).

Guanaco (*Lama guanicoe*) bone beds occur in at least three different levels, two just above buried A-horizons of the Río Salado Member (ABkb2 and Ab3) and one in between (in the Cb2). In the bone beds above the A-horizons, remains are in distinct, mixed piles of adult to fetal animals. The remains are characterized by the minimal occurrence of cut marks and helical fractures (less than 2% of the overall assemblage affected) as well as minimal carnivore, rodent, and trampling activity (Gutiérrez, 1998). Anatomical refits and element correspondence (Messineo & Kaufmann, 2001) indicate a high level of integrity within the assemblage. A few small flakes and a bipolar artifact made on a coastal pebble come from the lower bone bed (above Ab3). Originally identified as a guanaco kill site involving primary processing (Politis, Gutiérrez, & Martínez, 1991; Johnson et al., 1997), it now is interpreted as a natural accumulation by turbulent stream flow that has been augmented by human-processed remains from an unknown but nearby site (Gutiérrez & Kaufmann, 2007).

Strata within the Río Salado Member were subjected to two phases of erosion as indicated by disconformities. The first phase is represented by a channel cut into the middle buried soil A-horizon (Ab3) more than 40-cm deep. After the channel was created (a high-energy event), and the bone deposited, quiet waters and slow sedimentation resumed. The second phase produced a broad, irregular surface that truncated the buried A-horizon (Ab2). This disturbance represented an important change in fluvial dynamics during the late Holocene. It may be the result of a flooding event of a larger scale but less turbulent than the previous one (Favier Dubois, 2006). Quiet waters and slow sedimentation resumed once more after this event. On a regional basis, the dates for the Ab3 and Ab2 soils at Paso Otero 1 correlated well, respectively, with the chronology assigned to the Puesto Berrondo soil and the beginning age of the La Postrera Formation in the valley fills (Bonadonna, Leone, & Zanchetta, 1995; Zárate, Espinosa, & Ferrero, 1996, 1998; Zárate et al., 2000).

Paso Otero 3

Paso Otero 3 is located on the eastern bank of the river, about 0.5 km downstream from Paso Otero 1 (Figure 1; Martínez, 1999, 2001). The La Postrera Formation is the primary exposed unit, with perhaps the Río Salado Member at the bottom (Figure 5). The archaeological material comes from the bottom of the section, within the A-horizon of a buried soil (Akb7). Game animals include guanaco, pampean deer (*Ozotoceros bezoarticus*), and vizcacha (*Lagostomus maximum*; a large, communal rodent) with bones exhibiting cut marks and helical fractures. Rhea (*Rhea* spp.) eggs also are present.

The lithic assemblage consists of informal unifacial flakes and flake tools primarily from quartzite. Fracture-based bone butchering tools rounded out the tool kit. The guanaco remains were in a discrete bone pile that had marine gastropods and red ochre placed on top of it. The site originally was identified as a guanaco kill site involving primary processing (Martínez, 1999). Based on the various game animals and extensive lithic assemblage, it recently was reinterpreted as multiple occupations combining hunting and short-term domestic camps (Martínez, 2006).

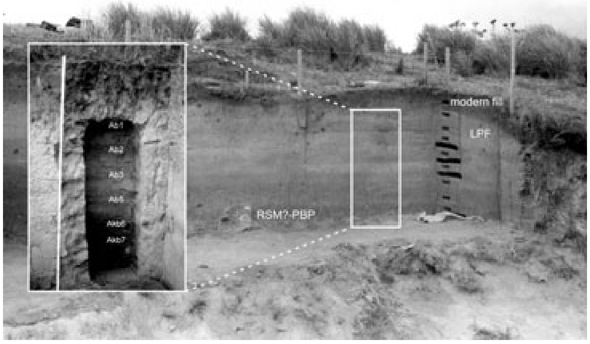

Figure 5 Buried A-horizons at Paso Otero 3; LPF, La Postrera Formation; RSM, Río Salado Formation; PBP, Puesto Berrondo paleosol.

Paso Otero 5

Paso Otero 5 is located on the western bank of the river across from Paso Otero 1 (Figure 1; Martínez, 1997, 2001; Martínez et al., 2003; Martínez, Gutiérrez, & Prado, 2004; Armentano, Martínez, & Gutiérrez, 2007). The section exposes the upper Guerrero Member with the regional Puesto Callejón Viejo soil buried by the Río Salado Member within the Luján Formation (Figure 6; Holliday et al., 2003).

Archaeological remains come from within the A-horizon of the Puesto Callejón Viejo soil. The recovered faunal remains reflect the Paso Otero late Pleistocene local fauna (Prado et al., 1987, 1996; Martínez, Gutiérrez, & Prado, 2004). Both extinct and extant species are present and the majority are large animals. Elements primarily are from forelimb and hind limb units. The bone assemblage has a very high proportion of burned bone (ca. 91%), the burning ranging from blackened to carbonized to calcined (Joly, March, & Martínez, 2005). Determining specific game animals was hampered by the high

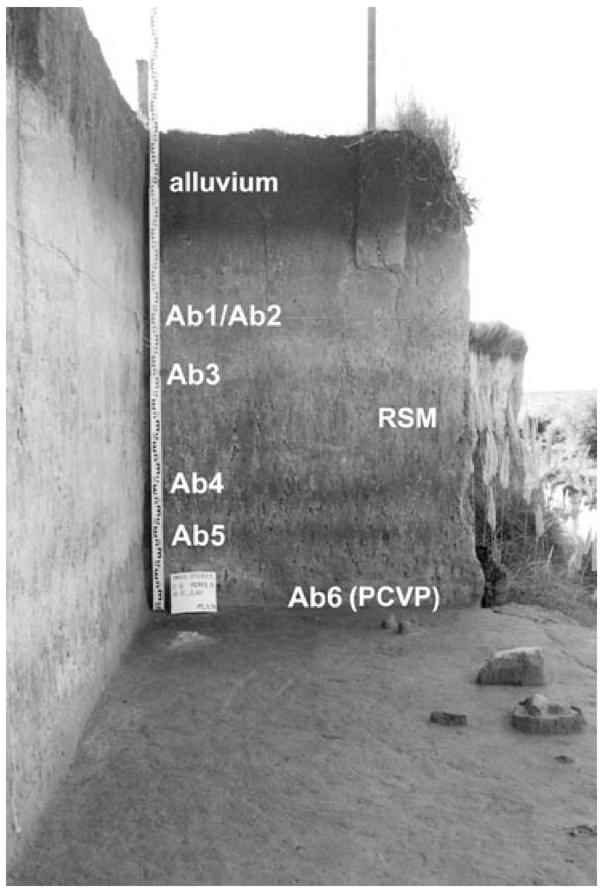

Figure 6 Buried A-horizons at Paso Otero 5; RSM, Río Salado Formation; PCVP, Puesto Callejon Viejo paleosol.

degree of fragmentation, caused by the burning and subaerial weathering. A helical fracture, however, occurs on one camelid (*Hemiauchenia* spp.) element, probably indicating marrow consumption by people (Martínez, 2001; Martínez & Gutiérrez, 2011).

The lithic assemblage consists of fish-tailed projectile points, informal tools, and small debitage. While the debitage reflects primarily quartzites from the Tandilia and Ventania ranges, one of the points is made from exotic raw material (silicified limestone). The site is interpreted as a series of short-term occupations oriented toward secondary processing of megamammal remains and final stages of lithic reduction. The intensive and extensive burning of megamammal bone at the site suggests that bone was used as fuel. Paso Otero 5 is the first recorded site in the Pampa Interserrana to demonstrate a clear association between fish-tailed projectile points and megamammals (Martínez, 2001; Armentano, Martínez, & Gutiérrez, 2007; Martínez & Gutiérrez, 2011).

METHODS

Soil-stratigraphic exposures were described using standard soil and stratigraphic nomenclature. For convenience, buried soils are referred to by their numbered sequence in the soil descriptions unless they are one of the named regional soil-stratigraphic units. Thus, an Ab2-Cb2 sequence is the "b2" soil.

Radiocarbon dating relied on both soil organic matter and bone. Sampling of organic sediments for radiocarbon dating occurred three times over a 5-year period (1993, 1995, 1998). Samples were collected from exposed cutbank profiles and excavation profiles. Sampling methodology followed Haas, Holliday, & Stuckenrath (1986), with profiles cleaned and samples removed after excavating back into the profile. The depth of excavation into the exposure prior to sampling varied from 30 cm back from a fresh exposure to 50 cm back from a weathered exposure. The sample target generally was the upper 5–10 cm of the buried A-horizon. All depths were measured from the local ground surface. A sample consisted of three 8 × 10 inch, new, self-closing, polyethylene bags. The same lab (Desert Research Institute [DRI]) ran all samples to insure consistency (Martin & Johnson, 1995).

The approach to dating soil organic matter had two variations. For all but one sample, both the humate fraction (NaOH-soluble humic acid extraction) and residue (NaOH-insoluble or humin fraction) were dated in order to test for possible younger carbon contaminants. This approach produced a pair of dates per sample and allowed each date to be evaluated to yield an even more accurate age. The older of the two dates was considered closer to the true age of the soil as contamination by younger carbon is more likely than by older carbon (Head, Zhou, & Zhou, 1989; Hammond et al., 1991; Holliday, 1995; Martin & Johnson, 1995; Wang, Amundson, & Trumbore, 1996). Results are expressed in both uncorrected and isotopic fractionation-corrected radiocarbon ages (e.g., Stuiver & Polach, 1977) but are not calibrated (Table I).

One sediment sample taken during 1993 was treated only to obtain soil humates (i.e., the humic acid or NaOH-soluble fraction) for ^{14}C dating, yielding the one age per sample. For this sample, NaOH was used to digest the sediment, and then a moderately strong humate solution was decanted. Distilled water was added to the humate solution and all particulate matter was allowed to settle before another decanting. This process was repeated five times.

After the 1990s investigation, research continued at the Paso Otero Locality and included a radiocarbon dating program that focused on organic sediments and bone collagen. The same procedure for sampling organic sediments was followed but a different lab (University of Arizona) assayed the soil organic matter dating both fractions because the radiocarbon dating program at DRI no longer existed. Collagen was extracted from bone at the Geochron and Arizona labs and dated by AMS, each lab following their standard procedures.

Dating organic sediments and soils has not been without its problems (e.g., Scharpensell, 1979; Gilet-Blein, Marien, & Evin, 1980; Matthews, 1980, 1985; Geyh et al., 1983; Hammond et al., 1991; Scharpenseel & Becker-Heidmann, 1991; Martin & Johnson, 1995; Wang, Amundson, & Trumbore, 1996; Holliday, 2004). Shifts have been made from dating bulk samples (total fraction), to dating only the residue or humic acid fraction with no agreement as to which is best, to dating both fractions and evaluating the results (Martin & Johnson, 1995; Holliday, 2004). These shifts reflect endeavors to resolve the problems and improve the reliability of the resulting ages. Organic soils and sediments can provide reliable age control (Haas, Holliday, & Stuckenrath, 1986; Martin & Johnson, 1995).

The degree of preservation of organic matter in the buried soil and the pretreatment methodology used to isolate organic fractions are factors in obtaining reliable ages (Matthews, 1980; Head, Zhou, & Zhou, 1989). Various studies demonstrate that no fraction is consistently the oldest (e.g., Matthews, 1980; Hammond et al., 1991; Martin & Johnson, 1995; Holliday, 2004). The discrepancies in age between fractions appear to be the result of a number of factors, including normal soil organic matter decomposition with its inherent variability, preburial

Table I Radiocarbon dates for the Paso Otero Locality based on 1990s organic sediments sampling program.

Site	Buried A-Horizon	^{14}C Field Number	Sample Material	Lab Number	Uncorrected Date (RCYBP)	Corrected Date (RCYBP)	∂^{13} C Value
Paso Otero 1	Ab3	CPO1-1	Humate	DRI-2829	4820 ± 110	4855 ± 110	−22.92
Paso Otero 1	Ab3	CPO1-1	Humate	DRI-2830	4720 ± 60	4750 ± 60	−23.22
Paso Otero 1	Ab3	CPO1-1	Residue	DRI-3361	4392 ± 90	4414 ± 90	−23.63
Paso Otero 1	ABkb2	CPO1-2	Humate	DRI-2837	2690 ± 40	2720 ± 40	−22.82
Paso Otero 1	ABkb2	CPO1-2	Residue	DRI-3362	2935 ± 46	2974 ± 48	−22.58
Paso Otero 1	Ab4	CPO1-3	Humate	DRI-2831	9880 ± 70	9950 ± 70	−20.63
Paso Otero 1	Ab4	CPO1-3	Residue	DRI-3363	8699 ± 190	8700 ± 200	−24.92
Paso Otero 3	Ab3	CPO3-1	Humate	DRI-3066	1658 ± 50	1731 ± 50	−20.47
Paso Otero 3	Ab3	CPO3-1	Residue	DRI-3364	2221 ± 140	2286 ± 140	−20.98
Paso Otero 3	Ab4	CPO3-2	Humate	DRI-3067	1825 ± 70	1907 ± 70	−19.92
Paso Otero 3	Ab4	CPO3-2	Residue	DRI-3365	3274 ± 120	3327 ± 120	−21.73
Paso Otero 3	Ab5	CPO3-3	Humate	DRI-3068	2006 ± 50	2070 ± 50	−21.02
Paso Otero 3	Ab5	CPO3-3	Residue	DRI-3366	2592 ± 140	2646 ± 140	−21.68
Paso Otero 3	Abk1b7	CPO3-4	Humate	DRI-3069	4719 ± 60	4756 ± 60	−22.70
Paso Otero 3	Abk1b7	CPO3-4	Residue	DRI-3367	4573 ± 80	4598 ± 80	−23.46
Paso Otero 3	Ab2	CPO3-5	Humate	DRI-3554	1485 ± 60	1571 ± 60	−19.65
Paso Otero 3	Ab2	CPO3-5	Residue	DRI-3555	1308 ± 60	1381 ± 60	−20.50
Paso Otero 3	Ab3	CPO3-6	Humate	DRI-3556	1694 ± 60	1759 ± 60	−20.98
Paso Otero 3	Ab3	CPO3-6	Residue	DRI-3557	1995 ± 70	2061 ± 70	−20.88
Paso Otero 3	Ab5	CPO3-7	Humate	DRI-3570	1101 ± 60	1170 ± 60	−20.71
Paso Otero 3	Ab5	CPO3-7	Residue	DRI-3571	2070 ± 70	2137 ± 70	−20.81
Paso Otero 3	Abkb6	CPO3-8	Humate	DRI-3509	2348 ± 80	2460 ± 70	−21.67
Paso Otero 3	Abkb6	CPO3-8	Residue	DRI-3520	2199 ± 100	2262 ± 110	−21.09
Paso Otero 3	Akb7	CPO3-9	Humate	DRI-3519	3002 ± 80	3020 ± 80	−23.88
Paso Otero 3	Akb7	CPO3-9	Residue	DRI-3518	2969 ± 60	3003 ± 60	−22.90
Paso Otero 3	Abk1b7	CPO3-10	Humate	DRI-3517	4594 ± 90	4634 ± 90	−22.55
Paso Otero 3	Abk1b7	CPO3-10	Residue	DRI-3516	4675 ± 60	4713 ± 60	−22.60
Paso Otero 5	Ab3	CPO5-1	Humate	DRI-3603	6524 ± 130	6629 ± 130	−18.50
Paso Otero 5	Ab3	CPO5-1	Residue	DRI-3604	6331 ± 90	6412 ± 100	−19.98
Paso Otero 5	Ab4	CPO5-2	Humate	DRI-3601	7253 ± 80	7366 ± 90	−18.02
Paso Otero 5	Ab4	CPO5-2	Residue	DRI-3602	7684 ± 70	7794 ± 70	−18.20
Paso Otero 5	Ab5	CPO5-3	Humate	DRI-3605	8315 ± 90	8415 ± 90	−18.79
Paso Otero 5	Ab5	CPO5-3	Residue	DRI-3606	8683 ± 90	8793 ± 90	−18.20
Paso Otero 5	Ab6	CPO5-4	Humate	DRI-3572	8767 ± 290	8863 ± 290	−19.06
Paso Otero 5	Ab6	CPO5-4	Residue	DRI-3573	9292 ± 110	9399 ± 120	−18.40

humification and translocation processes, and postburial effects such as continued microbial activity and dissolved transport of young carbon contaminants being moved down the profile (Matthews & Dresser, 1983; Trumbore, Vogel, & Southon, 1989; Hammond et al., 1991; Martin & Johnson, 1995). Dating both fractions for evaluation addresses the susceptibility of buried soils to contamination by younger carbon that can lead to aberrant young dates. Currently, evaluating both fractions, then, appears among the best methods (Hammond et al., 1991; Martin & Johnson, 1995).

Successful bone dating is also difficult and fraught with problems, among which are the quality and quantity of collagen and residual contamination (Taylor, 1987; Stafford et al., 1987; DeNiro & Weiner, 1988). Other factors affecting the outcome of dating bone are lab methodology (Longin, 1971; Stafford et al., 1991; Hedges & van Klinken, 1992) and burial environment (Nielsen-Marsh & Hedges, 2000; Jans et al., 2004). Even using the most exacting method of collagen fractionation and dating of specific amino acids, however, does not guarantee a reliable date (e.g., Holliday, Johnson, & Stafford, 1999). As a general guideline, van Klinken (1999) suggests that bone samples should have at least 1% collagen (of the total, original content of collagen in the bone) for successful dating.

Diagenetic studies at Paso Otero 1 (Gutiérrez, 1998, 2001) and Paso Otero 5 (Gutiérrez, Martínez, & Nielsen-Marsh, 2001) indicate that microbial activity after burial was continuous and intense, leading to protein (collagen) degradation and histological alterations affected by time and the presence of water. Samples that yielded reliable ages were from bone that was burned as fuel prior to burial (Martínez, Gutiérrez, & Prado, 2004). Burning causes alteration to bone structure and content that apparently favored protein preservation (Shipman, Foster, & Schoeninger, 1984; Gutiérrez, Martínez, & Nielsen-Marsh, 2001).

Table II Description of Soils and Strata at Paso Otero 1.

Formation, Member, or *Regional Soil*	Soil Horizon	Depth (cm)	Description/ Comments
Modern fill		0–21	Loose S (1980 flood?)
La Postrera films	A	21–34	v dk gray (10YR 3/1d 2/1m) SL; wk gr and sbk; CS
	AC	34–50	v dk gray brown (10YR 3/2d 2/2m) SL; wk gr and sbk; CS (some mixing w/underlying horizon)
	Ab1	50–92	v dk gray (10YR 3/1d 2/1m) SL; mod sbk and wk pr; AI
	Cb1	92–107	dk gray (10YR 4/1d 2/1m) loose S (common shell and shell fragments); AS
	Ab2	107–124	v dk gray (10YR 3/1d 2/1m) SL; mod sbk and wk pr; AI
(Transition)	2ABkb2	124–140	v dk gray (10YR 3/1d 2/1m) L; mod gr and abk; common carb films and thr on ped faces; CS
Río Salado Member	2Cb2	140–175	Light gray (10YR 7/2d 6/2m) M marl; some carb films and thr; CS
Puesto Berrondo	2Ab3	175–185	v dk gray (10YR 3/1d 2/1m) L; mod sbk; CS
	2Cb3	185–265	Light gray (10YR 7/2d 6/2m) M marl; bedded w 6–8 v wk A-horizons; CS
Puesto Callejón Viejo/ Guerrero Member	2Ab4	265–275	v dk gray (10YR 3/1d 2/1m) SL; wk sbk

Colors follow Munsell: m, moist; d, dry; v, very; dk, dark. Texture: S, sand; L, loam; SL, sandy loam; SiL, silt loam; SiC, silty clay. Structure: sg, single grain; M, massive; v wk, very weak; wk, weak; mod, moderate; str, strong; gr, granular; sbk, subangular blocky; abk, angular blocky; pr, prismatic. Boundary: CS, clear smooth; AS, abrupt smooth; AI, abrupt irregular. Comments: carb, carbonate; thr, threads; w, with; v, very.

SOIL STRATIGRAPHY

Four well-developed buried soils are exposed in the stratigraphic sequence along the middle Río Quequén Grande. They are traceable within the Paso Otero basin and two are formally recognized as soil-stratigraphic units (Puesto Callejón Viejo and Puesto Berrondo). The lowermost soil is at the top of the Guerrero Member of the Luján Formation and identified as the Puesto Callejón Viejo soil. The next buried soil is within the overlying Río Salado Member of the Luján Formation and identified as the Puesto Berrondo soil. A third soil has formed at the top of the Río Salado member. A number of very weakly developed A-horizons also occur within the Río Salado Member between the ones described and dated. The fourth (uppermost) buried A-horizon of note is within the La Postrera Formation.

Paso Otero 1

The two profiles described at Paso Otero 1 consist of the lower section along the arroyo wall to the north and the upper section in the excavation area (Figure 4; Table II).

Together, they constitute a 275-cm profile including the upper Guerrero Member with the Puesto Callejón Viejo soil (lower section, 265+ cm), the Río Salado Member (lower section, ca. 140–265 cm), and the La Postrera Formation (upper section, ca. 0–140 cm). The three main buried A-horizons (Ab2, Ab3, Ab4) can be traced around the arroyo and along the river.

In the lower section, the Puesto Callejón Viejo soil is dark gray, silty, and underlain by clayey, mottled Guerrero Member. The Río Salado Member consists of two silty, highly calcareous layers including a weakly developed soil within (2ACb3) and a moderately developed soil (2ABkb2) at the transition zone between the Río Salado Member and overlying La Postrera Formation. On close examination and troweling, the calcareous C-horizons in the Río Salado display faint bedding and perhaps some very weak A-horizons that were not described. As many as six faint A-C soil profiles may be present in the Cb3 horizon.

The parent materials for the soils of the Río Salado Member (i.e., the C-horizons) appear to be carbonates formed in place, perhaps through evaporation from saturated waters, that is, a kind of marl. A moist setting is indicated by (1) the thickness of the three main A-horizons and their dark colors (10R 3/1 and 2/1) that suggest high organic matter content (Schulze et al., 1993; Holliday, 2004:193–194), and (2) the dull gray colors (10YR 7/2 and 6/2) and mottles of oxidized iron in the subhorizons indicative of gleying and fluctuating high water tables. The flood plain probably was an aggrading marsh with the carbonate being precipitated just below the surface. How the vertical accretion took place is uncertain, perhaps by occasional flooding that added some sediment to the marl. The buried soils indicate that marsh sedimentation was episodic. The marls are very low density, probably due to the presence of diatoms and redeposited volcanic ash (Zárate, Espinosa, & Ferrero, 1998).

Radiocarbon dating (Table I) of the upper portion of the three primary A-horizons associated with the Río Salado shows that: the Ab4 was buried ∼9950 ^{14}C yr B.P.; the Ab3 (associated with the lower bone bed) was buried ∼4850 ^{14}C yr B.P.; and the ABkb2 (associated with the uppermost bone bed) was buried ∼3000 ^{14}C yr B.P.

The A-horizons of the Río Salado Member have developed on top of the marls within a very moist setting that generated significant amounts of organic matter (based on color) under poorly drained conditions (likewise based on color). They either are decalcified marl (that unmasked the darker colors) or cumulic A-horizons formed during slow alluviation in a valley-margin wet-meadow setting immediately adjacent to the river. Typical vegetation would have been grasses and reeds. The eastern wall of the arroyo, in particular, exhibits a classic flood plain profile with a series of very weakly to better developed buried soils. They are fairly horizontal indicating repeated flat valley margins in this particular place along the river for several thousand years. The very weak soils do not occur in the original excavation area.

The La Postrera Formation is a sandy deposit reflecting episodic sedimentation. The buried soil at the base of the formation (Ab2) is welded to the transitional soil (2ABkb2) between the Río Salado and La Postrera. Presence of the calcic horizon (k) in an AB suggests that the soil at the top of the Río Salado was initially an A-C profile. An ABk profile then was superimposed (or welded) to the A-C. The presence of the secondary calcium carbonate also suggests that the water table was somewhat deeper than just below the surface. Subsequent aggradation of sand was episodic, as indicated by the presence of the weak Ab1-Cb1 profile within the sand. The modern surface soil is an A-AC profile 30-cm thick, suggesting further relatively slow aggradation. The modern soil developed in the La Postrera Formation.

Paso Otero 3

At Paso Otero 3 (Figure 5; Table III), the lower section may be the Río Salado Member (162–205+ cm); the upper section is a facies of the La Postrera Formation (0–162 cm). The lower section is a muddy deposit (silt loam) relatively high in organic matter in the past based on the dark colors (that will persist long after much of the measurable soil organic matter has oxidized; Holliday, 2004:285–286). The soil structure and dark colors expressed from 162 to 195 cm (Table III) indicate that this part of the lower section is a cumulic (overthickened) A-horizon. This interpretation is supported by radiocarbon dating that indicates more than 2300 radiocarbon years separate the top of the unit (i.e., the top of the Akb6 horizon) and the top of the ABk1b7 horizon. These ages also date the archaeological materials that were in place in the sediments (i.e., in the sediments of the Akb7) prior to the development of the A-horizon. Those materials are older than ∼3020 ^{14}C yr B.P. and younger than ∼4700 ^{14}C yr B.P. (Table I). Correlated with the Puesto Berrondo paleosol, this cumulic soil probably represents a backswamp setting on a flood plain. The soil is modified by weathering in the form of some post-depositional calcium carbonate (Bk horizon). This carbonate probably is related to aggradation of and soil formation in the next higher layer (132–152 cm). The exposed lower section in the profile is not typical of the Río Salado Member (much darker in color than usual); but a more typical Río Salado Member expression was encountered at a depth of 51–68 cm below the bottom of the excavated profile (2Cb7) during hand-augering. Soil cumulization, topographic

Table III Description of Soils and Strata at Paso Otero 3.

Formation, Member, or *Regional Soil*	Soil Horizon	Depth (cm)	Description/ Comments
Modern fill		0–12	Loose S (1980 flood?)
La Postrera Formation	A	12–28	dk gray brown (10YR 4/2d, 2/1m) SL; mod gr and sbk; v. soft; CS
	Bw	28–45	Gray brown (10YR 5/2d, 3/2m) SL; v. wk sbk; CS
	Ab1	45–48	dk gray brown (10YR 4/2d, 2/1m) SL; v. wk sbk; CS (v faint horizon)
	Cb1	48–63	Gray brown (10YR 5/2d, 3/2m) SL; v. wk sbk; few lenses of shell; CS
	Ab2	63–71	dk gray brown (10YR 4/2d, 2/1m) SL; v. wk sbk; CS
	Cb2	71–90	Gray brown (10YR 5/2d, 3/2m) SL; v. wk sbk; CS
	Ab3	90–99	dk gray brown (10YR 4/2d, 2/1m) SL; v. wk sbk; scattered shell fragments; CS
	Cb3	99–115	Gray (10YR 5/1d, 3/1m) SL; v. wk sbk; scattered gastropods; CS
	Ab5	115–125	dk gray brown (10YR 4/2d, 3/1m) SL; v. wk sbk; scattered shell fragments; CS
	Cb5	125–132	Gray (10YR 5/1d, 3/1m) SL; v. wk sbk; CS
	Akb6	132–140	dk gray (10YR 4/1d, 2/1m) SL; med, f pr and sbk; few, thin carb films and thr on ped faces; CS
	ABkb6	140–152	dk gray (10YR 4/1d, 2/1m) SL; mod pr and sbk; common, thin carb films and thr ped faces; CS
	Akb7	152–162	v dk gray (10YR 3/1d 2/1m) SL; wk pr and mod sbk; common, thin carb films and thr on ped faces; CS
Río Salado Member?/*Puesto Berrondo*	2ABk1b7	162–185	v dk gray (10YR 3/1d 2/1m) SiL; wk pr and mod sbk; v. common, thin carb films and thr on ped faces; CS
	2ABk2b7	185–195	v dk gray (10YR 3/1d 2/1m) SiL; wk pr and mod sbk; common, thin carb films and thr on ped faces; CS
	2Cb7	195–205+	v dk brown (10YR 2/2d 2/1m) SiC; mod abk.

Colors follow Munsell: m, moist; d, dry; v, very; dk, dark. Texture: S, sand; L, loam; SL, sandy loam; SiL, silt loam; SiC, silty clay. Structure: sg, single grain; M, massive; v wk, very weak; wk, weak; mod, moderate; str, strong; gr, granular; sbk, subangular blocky; abk, angular blocky; pr, prismatic. Boundary: CS, clear smooth; AS, abrupt smooth; AI, abrupt irregular. Comments: carb, carbonate; thr, threads; w, with; v, very.

position, and high content of sedimentary clay (2Cb7) may be masking the characteristics of the Río Salado Member in the exposed lower section.

The rest of the section is a sandy deposit with multiple, weakly expressed soils. Most of the soils have A-C profiles. The surface soil (buried by deposits from the 1980 flood) exhibits some weak color and structure development (A-Bw profile) and the lowest soil (b6) contains secondary carbonate (Bk horizon) and some structure development (both characteristics 140–152 cm and in the underlying soils of the lower section). Radiocarbon dating (Table I) indicate these buried soils (b6 through b2) developed and were buried over a ~830 year span (b6 at ~2400 ^{14}C yr B.P.; b2 at ~1570 ^{14}C yr B.P.) within the late Holocene.

Paso Otero 5

At Paso Otero 5 (Figure 6; Table IV), only the Luján Formation is present. The high sand content of the modern A-horizon (0–42 cm) may represent alluvium. The Río Salado Member (ca. 42–213 cm) is exposed in most of the rest of the section, with the Guerrero Member (ca. 213–240+ cm) in the lower section. The Guerrero Member has been subjected to some weathering in the form of both gleying and oxidation, giving it a mottled appearance (hence Cg1b6 and Cg2b6 horizons). This weathering is related to formation of the regional Puesto Callejón Viejo soil, that represents the transition between the Guerrero Member and the Río Salado Member. The associated A-horizon (Ab6) contains the archaeological remains that yielded two accepted radiocarbon ages on megamammal burned bone, one at ~10,190 ^{14}C yr B.P. and the other ~10,440 ^{14}C yr B.P. (Martínez & Gutiérrez, 2011). Steele and Politis (2009:425) average the two dates as 10,340 ± 77 ^{14}C yr B.P. The top of the A-horizon dates to ~9400 ^{14}C yr B.P. (Table I), indicating that the bone bed was in place prior to soil development.

Table IV Description of Soils and Strata at Paso Otero 5.

Formation, Member, or *Regional Soil*	Soil Horizon	Depth (cm)	Description/ Comments
Alluvium?	A	0–42	v dk gray brown (10YR 3/2d 2/1m) SL; str gr and wk sbk; gradual
Río Salado Member	Bk1	42–72	Gray (10YR 6/1d 4/2m) L; wk pr and mod sbk; common carb films and thr on ped faces; CS
	Bk2	72–90	Gray (10YR 6/1d 4/2m) L; wk pr and mod sbk; carb films and thr on ped faces are less common and less obvious than above; CS
	Ab1	90–100	dk gray brown (10YR 4/2d 3/1m) L; str gr and wk sbk; very hard; CS
	Cb1	100–120	Pale brown (10YR 6/3d 4/3m) M marl; CS NOTE: locally, the sediments of the Cb1 are missing or very thin, resulting in the welding of the Ab1 and Ab2 (see Ab1/Ab2 in Table VII)
	Ab2	120–130	dk gray brown (10YR 4/2d 3/1m) L; str gr and wk sbk; very hard; CS
	Cb2	130–140	Pale brown (10YR 6/3d 4/3m) M marl; CS
	Ab3	140–153	dk gray brown (10YR 4/2d 3/1m) L; str gr and wk sbk; very hard; CS
	Cb3	153–166	Pale brown (10YR 6/3d 4/3m) M marl; CS
	Ab4	166–172	dk gray brown (10YR 4/2d 3/1m) L; str gr and wk sbk; very hard; CS
	Cb4	172–186	Pale brown (10YR 6/3d 4/3m) M marl; CS
	Ab5	186–197	dk gray brown (10YR 4/2d 3/1m) L; str gr and wk sbk; very hard; CS
	Cb5	197–213	Pale brown (10YR 6/3d 4/3m) M marl; CS
Puesto Callejon Viejo/Guerrero Member	Ab6	213–224	v dk gray brown (10YR 3/2d 2/1m) SiL; str gr and wk sbk; very hard; CS
	Cg1b6	224–240	Light gray (2.5Y 7/2d 5/2m) SL; M; faint, common iron oxide stains on ped faces; CS
Guerrero Member	Cg2b6	240+	Pale yellow (2.5Y 7/3d 4/3m) SL; M; faint, common iron oxide stains on ped faces

Colors follow Munsell: m, moist; d, dry; v, very; dk, dark. Texture: S, sand; L, loam; SL, sandy loam; SiL, silt loam; SiC, silty clay. Structure: sg, single grain; M, massive; v wk, very weak; wk, weak; mod, moderate; str, strong; gr, granular; sbk, subangular blocky; abk, angular blocky; pr, prismatic. Boundary: CS, clear smooth; AS, abrupt smooth; AI, abrupt irregular. Comments: carb, carbonate; thr, threads; w, with; v, very.

The Río Salado Member at Paso Otero 5 is similar to that at Paso Otero 1, consisting of a series of carbonate layers or marls each with a weakly developed soil (producing A-C or ABk profiles). The marls at both Paso Otero 5 and 1 are very low density, again likely due to presence of diatoms, and volcanic ash mixed with diatoms (Zárate, Espinosa, & Ferrero, 1998). The A-horizons either are decalcified marl or they are cumulic (i.e., aggraded due to slow alluviation). From the top of the Puesto Callejón Viejo to the Ab3, the dated A-horizons are approximately 1000 radiocarbon years apart: that is, Ab6 at ~9400 ^{14}C yr B.P., Ab5 at ~8800 ^{14}C yr B.P., Ab4 ~7800 ^{14}C yr B.P., and Ab3 at ~6600 ^{14}C yr B.P. (Table I). These sediments and buried soils, then, span much of the early and middle Holocene. The younger soils, Ab1 and Ab2, were observed to merge (i.e., they are locally welded) in the section investigated, indicative of localized variability in landscape stability and pedogenesis.

RADIOCARBON ASSAYS OF ORGANIC-RICH SEDIMENTS

Thirty-five assays from the 1990s sampling program have been conducted on organic-rich sediment samples from the Paso Otero Locality (Table I). Of these, 17 are pairs (both humate and residue fractions) and one is a humate-only date. These assays, then, have produced 18 ages, 15 of which are considered reliable (Table V) and date the buried soil sequence of the locality and provide a

Table V Organic Sediment Radiocarbon Dates from the 1990s Sampling Program Considered Valid for the Paso Otero Locality.

Site	Lab Number	Date (RCYBP)	Buried A-horizon	Formation, Member, or Regional Soil
Paso Otero 1	DRI-3362	2974 ± 48	ABkb2	La Postrera Films
Paso Otero 1	DRI-2830	4750 ± 60	Ab3	Río Salado Member/*Puesto Berrondo*
Paso Otero 1	DRI-2829	4855 ± 110	Ab3	Río Salado Member/*Puesto Berrondo*
Paso Otero 1	DRI-2831	9950 ± 70	Ab4	Guerrero Member
Paso Otero 3	DRI-3554	1571 ± 60	Ab2	La Postrera Films
Paso Otero 3	DRI-3557	2061 ± 70	Ab3	La Postrera Films
Paso Otero 3	DRI-3571	2137 ± 70	Ab5	La Postrera Films
Paso Otero 3	DRI-3509	2460 ± 70	Abkb6	La Postrera Films
Paso Otero 3	DRI-3519	3020 ± 80	Akb7	Río Salado Member?
Paso Otero 3	DRI-3069	4756 ± 60	Abklb7	Río Salado Member?/*Puesto Berrondo*
Paso Otero 3	DRI-3516	4713 ± 60	Abklb7	Río Salado Member?/*Puesto Berrondo*
Paso Otero 5	DRI-3603	6629 ± 130	Ab3	Río Salado Member
Paso Otero 5	DRI-3602	7794 ± 70	Ab4	Río Salado Member
Paso Otero 5	DRI-3606	8793 ± 90	Ab5	Río Salado Member
Paso Otero 5	DRI-3573	9399 ± 120	Ab6	Guerrero Member/*Puesto Callejón Viejo*

framework for the archaeological record. The reliable ages should approximate the age of burial for those soils (Matthews, 1980, 1985; Holliday, 2004).

For Paso Otero 1, three buried A-horizons were dated (Table I). Samples for the two upper buried A-horizons come from the west wall of the excavation while the sample for the lowermost buried A-horizon was from the northwestern bank of the river (Figure 4). The two assays from the Ab3 horizon are from the same organic sediment sample and were run for comparative purposes. The DRI-2830 date (~4750 ^{14}C yr B.P.) is from the first humate extraction while the DRI-2829 date (~4855 ^{14}C yr B.P.) was from the second humate extraction. These dates overlap at the one-sigma level and indicated that no significant fractionation occurred during partial extraction of the humates (Johnson et al., 1998). The four ages are in stratigraphic order and show internal consistency. The ages of the three buried A-horizons (Table V), then, denote early, middle, and late Holocene stable land surfaces in the river valley (~9950 ^{14}C yr B.P.; ~4800 ^{14}C yr B.P. and ~2970 ^{14}C yr B.P., respectively).

For Paso Otero 3, six of the seven buried A-horizons were dated. The uppermost (Ab1) was not dated as it was weakly expressed. Four (Ab3, Ab4, Ab5, Abk1b7) initially were dated. Three of these A-horizons (Ab3, Ab5, Abk1b7) were resampled during the last collecting episode along with samples from three other buried A-horizons in the sequence (Ab2, Ab6, Ab7). The Ab4 horizon was not resampled because it pinches out, that is, is laterally discontinuous. While the original samples came from the south wall of the excavation, the second set of samples was from the eastern wall (Figure 5). Of the 10 organic sediment ages for Paso Otero 3, seven were considered the most reliable (Table V).

The reliable ages for the buried soil sequence at Paso Otero 3 are internally consistent and provide a sequence of dates in chronologic order from middle to late Holocene. The age for Ab4 (~3327 ^{14}C yr B.P., CPO3-2; DRI-3365; Table I) is an anomaly. Placing it within the sequence of reliable ages for the buried soil sequence (Table V) disrupts the internal consistency of that sequence. The date is not concordant and, therefore, is considered unreliable. That being the case, then, the age of two of the buried soils (Ab1 and Ab4) is unknown. For Ab4, however, it is very closely bracketed between the dates for the Ab3 (~2061 ^{14}C yr B.P.) and Ab5 (~2137 ^{14}C yr B.P.).

The ages on Ab3 (~2286 ^{14}C yr B.P.; CPO3-1; DRI-3364) and Ab5 (~2646 ^{14}C yr B.P.; CPO3-3; DRI-3366) from the original column also are anomalous (Table I). Although in chronological order within that column, they are older and do not overlap at one sigma with the ages for Ab3 (~2061 ^{14}C yr B.P.; CPO3-6; DRI-3557) and Ab5 (~2137 ^{14}C yr B.P.; CPO3-7; DRI-3571) from the second column. The age for Ab3 from the original column (~2286 ^{14}C yr B.P.; CPO3-1; DRI-3364) also is older than the age for Ab5 (~2137 ^{14}C yr B.P.; CPO3-7; DRI-3571) in the second column (Tables I, V). As both sampling columns were taken from fresh exposures, the incongruent ages are baffling. To maintain the internal consistency of the second column, these two ages are discounted.

Lastly, the differentiation within the b7 soil was not recognized when originally sampled. Nevertheless, the original sample CPO3-4 (DRI-3069) was taken from within the bone bed as was the Abklb7 sample (CPO3-10; DRI-3516) during the second sampling. The resultant dates (Table I) were the same (~4756 ^{14}C yr B.P. and ~4713 ^{14}C yr B.P., respectively).

For Paso Otero 5, four of the six buried A-horizons were dated (Table I; Figure 6), with the two uppermost buried A-horizons not dated in the 1990s sampling program as they were very weakly developed. All samples were from the north wall of the excavation. The reliable ages for the buried A-horizons (Table V) were internally consistent and the lowermost date (~9400 ^{14}C yr B.P) corresponds to a pair of bone dates (~10,190 ^{14}C yr and ~10,440 ^{14}C yr B.P.) that should be and are slightly older (Table VI). The dates provided a chronologic sequence in order from early to middle Holocene.

Since the 1990s sampling program, two additional organic-rich sediment samples have produced four other assays based on both fractions dated (Table VII). Of these, two ages (from the welded Ab1/Ab2 soils and the Bk1 horizon) are considered valid (Table VIII). They enhance and extend the buried soil sequence and archaeological framework. The samples are from the uppermost soils above those dated in the 1990s sampling program. As excavations extended, the two uppermost A-horizons merged. One of the samples comes from the welded Ab1/Ab2 (Figure 6). The older of the pair provides an age of ~4210 ^{14}C yr B.P. (Table VII; Grill et al., 2007). This date provides a minimum age for the onset of formation of Ab2 and a maximum age of burial of Ab2. The date maintains internal consistency and is in chronologic order within the Paso Otero geochronology and provides an indication of landscape age in the latter part of the middle Holocene. This date is slightly later than the Paso Otero 1 Ab3 (~4800 ^{14}C yr B.P.; DRI-2829, DRI-2830; Table V) and Paso Otero 3 Abklb7 (~4700 ^{14}C yr B.P.; DRI-3069, DRI-3516; Table V).

Table VI Radiocarbon Dates for the Paso Otero Locality Based on Bone Samples Taken After the 1990s Sampling Program.

Site	Buried A-Horizon	Bone Date (RCYBP)	Lab Number	Taxon
Paso Otero 1	Ab3	3050 ± 42	AA-72844	*Lama guanicoe*
Paso Otero 5	Ab6	10,190 ± 120	AA-19291	Megamammal
		10,440 ± 100	AA-39363	Megamammal
		4150 ± 30	GX-29792	*Macrauchenia patachonica*
		2090 ± 40	GX-29793	*Lama guanicoe*
		2110 ± 30	GX-29794	*Equus neogenous*
		9560 ± 50	GX-29795	*Megatherium americanum*

The other organic sediment sample comes from the Bk1 horizon (Osterrieth et al., 2008), part of the soil profile for the modern soil and above the Ab1/Ab2 (Figure 6). The older of the pair provides an age of ~2490 ^{14}C yr B.P. (Table VII). This date is stratigraphically consistent with the underlying dates and may be from organic carbon indicative of the beginning of the final phase of stability at Paso Otero 5.

BONE DATES FROM THE PASO OTERO LOCALITY

Seven bone collagen dates are available for the locality, one from Paso Otero 1 and six from Paso Otero 5, run by two different labs (Table VI). The Paso Otero 1 bone date is from a guanaco molar that comes from a bone pile just above an erosional disconformity on top of the Ab3 soil (Table VI; Martínez, 2006; Gutiérrez & Kaufmann, 2007). The date of ~3050 ^{14}C yr B.P. is in good stratigraphic agreement with the minimum burial age of ~4800 ^{14}C yr B.P. for Ab3 (DRI-2829, DRI-2830; Table V). The dates indicate that erosion took place sometime between ~4800 and ~3050 ^{14}C yr B.P., probably closer to the younger age. No evidence has been found for a lengthy hiatus between erosion and deposition of the bone. In relation to the organic sediment dates from the section, the bone date is reliable (Table VIII).

The six Paso Otero 5 bone dates are based on postcranial samples from different species but all from the occupation/bone bed coincident with dated soil Ab6 (Table VI; Martínez, 2001; Martínez, Gutiérrez, & Prado, 2004; Steele & Politis, 2009; Martínez & Gutiérrez, 2011). Dates from the guanaco (2090 ± 40 ^{14}C yr B.P.), horse (2110 ± 30 ^{14}C yr B.P.), and long-necked, three-toed ungulate (4150 ± 30 ^{14}C yr B.P.) samples are very young, were considered anomalous (Martínez, Gutiérrez, & Prado, 2004), and, therefore, discounted. The remaining dates from ground sloth (9560 ± 50 ^{14}C yr B.P.) and megamammal (10,190 ± 120 ^{14}C yr B.P.; 10,440 ± 100 ^{14}C B.P.) samples are older than the burial age of ~9400 ^{14}C yr B.P. for Ab6 (DRI-3573; Table V). With the bone bed already in place prior to soil development and burial, these three dates, then, are consistent with that age. In relation to the organic sediment date, they are reliable (Table VIII).

ALLUVIAL LANDSCAPE EVOLUTION

The Holocene stratigraphy of the Río Quequén Grande has many characteristics of a typical aggrading flood plain system in a semiarid/subhumid environment: a low-gradient, suspended-load, meandering stream exposing

Table VII Radiocarbon Dates for the Paso Otero Locality Based on Organic Sediments Taken from the 1990s Sampling Program Considered Valid.

Site	Buried A-Horizon	Sample Material	Lab Number	Uncorrected Date (RCYBP)	Corrected Date (RCYBP)	∂13C Value
Paso Otero 5	Bk1	Humate	A-13765.1	2430 ± 70	2490 ± 70	−21.20
Paso Otero 5	Bk1	Residue	A-13765	2170 ± 50	2220 ± 50	−22.00
Paso Otero 5	Ab1/Ab2	Humate	AA-58224	3905 ± 35	3950 ± 35	−19.70
Paso Otero 5	Ab1/Ab2	Residue	A-13037	4125 ± 70	4210 ± 70	−19.50

a thick alluvial stratigraphic sequence with multiple layers of fine-grained sediment, most containing soils (locally gleyed or mottled due to a high water table; especially in the Guerrero Member), providing evidence for cyclic sedimentation and stability (Ferring, 2001; Gladfelter, 2001). Several characteristics of the stratigraphy are not typical of most flood plain systems: the parent materials are high in diatoms and redeposited volcanic ash, providing a relatively low bulk density. Further, the soils are highly calcareous, but the carbonate is pervasive and very finely divided that, together with the low density of the sediments and soils, suggests that it is a primary precipitate (a kind of marl) rather than a secondary carbonate (e.g., the calcic horizon of a soil). The relatively dark A-horizons of the soils formed in the calcareous parent material suggest that the soils are formed under high water-table conditions. This setting would prevent downward water movement and removal or translocation of calcium carbonate. Such conditions would also support a relatively high biomass, in turn forming dark-colored soil A-horizons relatively high in organic carbon.

The numerous buried A-horizons on both sides of the Río Quequén Grande in the Paso Otero Locality indicate a number of stable land surfaces within the flood plain throughout the late Quaternary. Most appear developed under high water-table conditions indicating marshy to saturated ground. The regional Puesto Callejón Viejo soil is exposed on both sides of the modern river at Paso Otero 1 and 5. A composite of the dated A-horizons (Table IX) demonstrates that most of these Holocene A-horizons do not correlate with each other. They do not represent the same land surface on either side of the waterway.

While the exposure of buried A-horizons at Paso Otero 1 and 5 extends down to the Guerrero Member, that is not the case for Paso Otero 3 with its deepest exposed and oldest dated A-horizon of middle Holocene age (Table IX). At Paso Otero 5, three dated A-horizons occur between the two regional soils, while at Paso Otero 1, multiple undated and very weakly developed A-horizons were noted. If any correlate with the dated A-horizons at Paso Otero 5, they are much less developed probably due to more frequent floods that buried them more quickly.

Table IX Composite of Dated Buried A-Horizons and Their Stable Carbon Isotope Values for the Paso Otero Locality.

Site	Buried A-Horizon	Date (RCYBP)	∂13C Values
Paso Otero 3	Ab2	1571 ± 60	−19.65
	Ab3	2061 ± 70	−20.88
	Ab5	2137 ± 70	−20.81
	Abkb6	2460 ± 70	−21.67
Paso Otero 1	Ab2	2974 ± 48	−22.58
Paso Otero 3	Ab7	3020 ± 80	−23.88
	Abklb7	4713 ± 60	−22.6
	Abklb7	4756 ± 60	−22.7
Paso Otero 1	Ab3	4750 ± 60	−23.22
	Ab3	4855 ± 110	−22.92
Paso Otero 5	Bk1	2490 ± 70	−21.2
	Ab1/2	4210 ± 70	−19.5
	Ab3	6629 ± 130	−18.5
	Ab4	7794 ± 70	−18.2
	Ab5	8793 ± 90	−18.2
	Ab6	9399 ± 120	−18.4
Paso Otero 1	Ab4	9950 ± 70	−20.63

Table VIII Organic Sediment and Bone Radiocarbon Dates for the Paso Otero Locality from the Post-1990s Sampling Program Considered Valid.

Site	Lab Number	Dated Material	Date (RCYBP)	Buried A-horizon	Formation, Member, or *Regional Soil*
Paso Otero 1	AA-72844	Bone	3050 ± 42		Río Salado Member
Paso Otero 5	A-13765.1	Organic sediment	2490 ± 70	Bk1	Río Salado Member
Paso Otero 5	A-13037	Organic sediment	4210 ± 70	Ab1/Ab2	Río Salado Member
Paso Otero 5	GX-29795	Bone	9560 ± 50	Ab6	Guerrero Member
Paso Otero 5	AA-19291	Bone	10,190 ± 120	Ab6	Guerrero Member
Paso Otero 5	AA-39363	Bone	10,440 ± 100	Ab6	Guerrero Member

At Paso Otero 1 and 3 (on the same side of the river), radiocarbon ages for buried A-horizons Ab3 (~4800 ^{14}C yr B.P.; PO1) and Abk1b7 (~4730 ^{14}C yr B.P.; PO3), respectively, overlap at one sigma. These two buried A-horizons most likely represent the same stable land surface, correlated to the regional Puesto Berrondo soil. The 1990s dated sequence at Paso Otero 5 lacks ages for middle and late Holocene A-horizons. Buried A-horizons Ab2 (PO5) and Ab1 (PO5) represent this time period. Their very weak development suggests that the Ab2 may not be the regional Puesto Berrondo soil. The recently obtained date on the welded Ab1/Ab2 (PO5), provides a younger age (~4210 ^{14}C yr B.P.) than the buried A-horizons Ab3 (~4800 ^{14}C yr B.P.; PO1) and Abklb7 (~4730 ^{14}C yr B.P.; PO3). The Ab1/Ab2 at PO5 is buried, indicative of an interruption of landscape stability and pedogenesis and leaving a more weakly expressed b2.

The Puesto Callejón Viejo soil exposed on both sides of the river indicates a former continuous land surface that now has been cut through by the modern river. Developed under saturated conditions due to diminished water flow and depth (Zárate et al., 2000), this soil represents widespread soggy ground. This situation implies a different course for the river somewhere within the Paso Otero Locality during the latest Pleistocene, but not in the site areas investigated.

Another change in the landscape and shift in the waterway seemed to have occurred between Guerrero Member and Río Salado Member times. Assuming that the composite of dated buried soils reflects the overall situation at the Paso Otero Locality, then, the river channel altered its course again and flowed near or through the Locality. Broad margins of saturated ground occurred on one side or the other of the present channel throughout the Holocene. During Río Salado times, perhaps a channel did not exist, just a broad, marshy surface (Zárate, Espinosa, & Ferrero, 1998; Zárate et al., 2000). No indication of a buried channel (that would suggest a change in channel position) occurred in any exposure. The buried soils at Paso Otero 1, in particular, resembled cienegas (i.e., wetland or spring-fed marsh soils).

Another question is why did the river cut its present deep channel following aggradation throughout much of the Holocene. The most likely explanation is base-level stabilization as postglacial sea-level stabilized (Zárate et al., 2000). Incision occurs <3000 ^{14}C yr B.P. after the final stages of alluviation (end of deposition of the Río Salado Member), more or less coincident with regional eolian activity (La Postrera Formation). Incision also is coincident with establishment of the modern coastline (~60 km from the study area) in the late Holocene (Zárate et al., 2000).

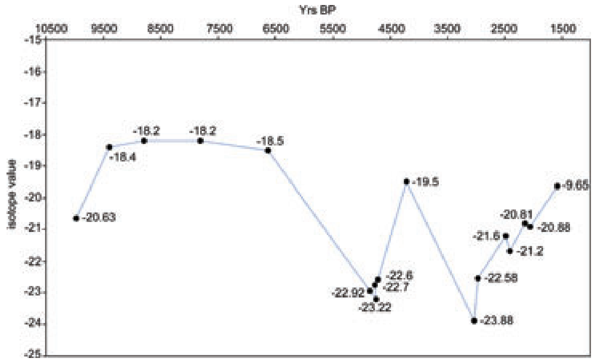

Figure 7 Stable carbon isotope values for the Paso Otero Locality.

The chronology of middle Holocene marine transgressive and regressive events is still a matter of debate. Aguirre and Whatley (1995:244) argue that the climatic optimum lasted from ~8000 to ~4500 ^{14}C yr B.P., with a transgressive maximum at ~7600^{14}C yr B.P. On the other hand, Isla et al. (1986:115) indicate the existence of a Holocene regression during the last 7000 years. Transgressions have affected the Buenos Aires Province coastlines differentially, particularly in regards to the characteristics of the coast (e.g., low gradient, presence of cliffs; Isla et al., 1986; Aguirre & Whatley, 1995; Prieto et al., 2004). A transgression is recorded at ~7600 ^{14}C yr B.P. at the mouth of the Río Quequén Grande (Isla, 1989; Isla et al., 1986; Stutz et al., 1999).

The assays from organic sediments also provide ∂^{13}C values. Stable carbon isotope data provide proxy indicators of the vegetation communities at the time the carbon was introduced. The isotopic value reflects the C_3 and C_4 plant biomass. A positive correlation exists between the proportions of C_3 and C_4 biomass and ∂^{13}C values (Cerling, 1984; Bowen, 1991; Nordt et al., 1994; Boutton, 1996; Boutton et al., 1998; Kelly et al., 1998). The C_3 plants (lighter isotopic composition; organic matter with a mean ∂^{13}C value of around −26 parts-per-million) are comprised of cool season grasses, most aquatic plants, and trees. The C_4 plants (heavier isotopic composition; organic matter with a mean ∂^{13}C value of around −13 parts-per-million) are composed primarily of warm season grasses (Bowen, 1991:129). Each part-per-million change represents a shift of about 7% in the ratio of C_3–C_4 biomass (Bowen, 1991; Nordt et al., 1994).

Overall, the stable carbon isotope data for the Paso Otero Locality (Figure 7; Table IX) indicate several major shifts in isotope values, beginning in the early Holocene. The first shift records a marked change from a dominance of C_3 plants to C_4 plants (2.43 parts-per-million change; ca. 17% change in the ratio) that lasts at least around

3000 radiocarbon years. The C_3 plants regain dominance (4.47–5% parts-per-million change; ca. 33–35% change in the ratio) in a dramatic middle Holocene shift. After that shift, isotope values fluctuate over a ca. 3000 radiocarbon year period between higher and lower ratios of C_3–C_4 biomass.

This alternating pattern most likely reflects both the regional temperature regime as well as the riparian setting of the valley and its wet meadows in which the soils developed. The early Holocene increase of warm season grasses indicates drier ground with greater subaerial exposure. This shift takes place between periods of regional stability and formation of the two major regional soils. It may also reflect the river channel continuing its shift farther away. For the middle and late Holocene, the isotope values indicate a rebounding and then fluctuation in C_3 vegetation. The ca. 33–35% increase in C_3 vegetation most likely reflects an increase in aquatic (marsh) plants and cool season grasses that implies more water is near the surface or flowing in the local area of the Paso Otero Locality. The alternating C_4/C_3 dominance throughout the late Holocene (Table IX; Figure 7) may be reflecting movement in the river channel, with decreased or increased water flow in the local area.

Data from the isotopes contrast with field observations of the soils and sediments in the Paso Otero Locality. All soils and sediments below the La Postrera Formation indicate high water-table conditions, with evidence of reduction (gleying) or preservation of carbonates. A lowering of the water table should result in at least initial stages of decalcification under well-drained conditions in the surface or near-surface soils. However, the carbonates in all of the Holocene soils are well-preserved both macroscopically and microscopically.

ARCHAEOLOGICAL IMPLICATIONS

Geoarchaeological information presented here allows an exploration of the dynamic, local landscape development within the middle Río Quequén Grande flood plain, and its implications for the formation of the archaeological record. At Paso Otero 1, the part of the stratigraphic profile that contains the faunal assemblages (Ab3) was affected by important erosional events that have produced disconformities (Favier Dubois, 2006). The bone bed was located above an unconformity, as a result of a turbulent erosive flow that truncated the top of the Ab3 soil (Favier Dubois, 2006). The guanaco carcasses were deposited as part of a natural event. The anatomical units were reorganized into bone concentrations as a result of additional floods of smaller scale, evidenced by the presence of freshwater gastropods in association with the bones (Gutiérrez & Kaufmann, 2007). Consequently, the carcasses were not incorporated in to the soil as part of a pedogenic or cultural process, but as a result of fluvial action. The chronology of this fluvial event ($\sim$4850 ^{14}C yr B.P.) is different from the one that deposited the carcasses and rearranged the anatomical units ($\sim$3000 ^{14}C yr B.P.).

The majority of the carcasses entered the site as part of this high fluvial energy event. Evidence on some skeletal parts, however, indicates hunting and processing of guanacos by people took place in the vicinity. These elements also would have been added to the bone concentrations (Gutiérrez & Kaufmann, 2007). The presence in this same context of scarce lithic materials, cultural fractures, and cutmarks that originally supported the cultural origin of the deposit (Gutiérrez, 1998; Martínez, 1999) could be due to the possible occasional exploitation or scavenging of the carcasses (Martínez, 2006).

A different situation occurs at Paso Otero 3. Unlike Paso Otero 1 where pedogenic episodes were strongly affected by soil truncations, archaeological materials in Paso Otero 3 are within a cumulic soil. Also, unlike Paso Otero 1, the association, amount, and variety of the recovered materials are indicative of the cultural origin of the deposit (Martínez, 1999, 2001). Although the site is related to adjacent areas of the flood plain, its location in a backswamp and in a cumulic soil suggests an important stability of the landscape. The obtained chronology indicates that the materials were deposited between $\sim$4700 and 3000 ^{14}C yr B.P. The contextual and chronological information suggests the site is the product of different human occupations, related both to specific activities (e.g., hunting and primary processing) and to multiple activities (e.g., residential basis of short duration).

The archaeological component of Paso Otero 5 is located almost exclusively in the Puesto Callejón Viejo soil (Ab6), with a chronology of $\sim$10,440–10,190 ^{14}C yr B.P. Unlike the soil identified in Paso Otero 3, this one is of moderate development. The bone is $\sim$1000 years older than the age of burial of the soil. It is the aggrading surface that buried and preserved the materials in place. The early stage of pedogensis may have started by the latest occupation. That aggrading surface appears to have been stable enough to allow brief occupations and incorporation of anatomical units of several mammals (i.e., at least 12 genera, from which 10 are extinct species). The presence of this high number of taxa has been explained by the use of bones as fuel, human exploitation for consumption, and possible natural incorporation to the deposit (Martínez & Gutiérrez, 2011).

In spite of the similarity in the processes that acted in each of the sites, the intensity of pedogenesis and/or of differential erosional processes have resulted in contexts of different archaeological resolution and integrity.

Clearly, the surfaces of landscape stabilization constitute excellent benchmarks for predicting past human occupations (Martínez, 2003-2004). These surfaces of landscape stability also help to predict states of preservation (e.g., patterns of bone diagenetic alteration) and formation processes (e.g., floods) affecting the archaeological record along the middle basin (Gutiérrez, 2001; Gutiérrez, Martínez, & Nielsen-Marsh, 2001; Gutiérrez & Kaufmann, 2007).

DISCUSSION

The study of buried soils in the Argentinean Pampas is a relatively recent effort that began in the 1970s (Imbellone & Teruggi, 1993; Zárate & Imbellone, 1998). Pedogensis has played a significant role in the Quaternary evolution of the pampean landscape due to prevailing regional depositional environments and sedimentary processes (Zárate & Blasi, 1993; Zárate & Imbellone, 1998; Tonni, Cione, & Figini, 2001; Fucks et al., 2007). Episodic deposition of loess is the primary sedimentary process, within both primary and secondary settings, and has produced sequential sedimentary-pedologic packages within stratigraphic units. Four stratigraphic units are identified within the late Quaternary loess deposits (Zárate & Blasi, 1991). The loess source area is the lower Colorado River Valley, more than 425 km to the southwest. Volcaniclastic materials are common in the loess, coming from the source area but also through incorporation of volcanic ash falls (Zárate & Blasi, 1991, 1993).

Downstream from Paso Otero at La Horqueta II (Zárate et al., 2000), depositional environments vary somewhat from those seen at the Paso Otero Locality. The Guerrero Member equivalent is a fine-grained alluvial deposit, as it is at Paso Otero, with the Puesto Callejón Viejo soil formed at the top. Above, however, are a series of diatomite layers. These deposits "accumulated within a series of interconnected longitudinal pools of flowing water partially covered by aquatic vegetation" (Zárate et al., 2000:482). This comment could be a description for some marls of the Río Salado Member, but marl precipitates from standing or slow moving water. As well, deposition in the Paso Otero area is episodic, as indicated by the buried soils. These two slightly different depositional environments represent facies of one another, with episodic sedimentation and carbonate precipitation upstream and more or less perennial standing water and diatomite deposition downstream. The entire region has a very low gradient (Teruggi et al., 2004) but La Horqueta II is even more shallow than Paso Otero. This situation could have led to more permanent sluggish water at La Horqueta. Precipitation of carbonate in the Paso Otero area also could have changed the water chemistry (raising the pH) sufficiently to allow formation and/or preservation of abundant diatomite downstream as well as facilitated bone preservation.

While the pampean uplands provide the Pleistocene to early Holocene record, Holocene stratigraphic resolution is best preserved in the flood plain alluvial stratigraphy of its major rivers (Zárate et al., 2000). One of the major issues hindering both local and regional correlations has been the lack of chronometric control (Zárate & Blasi, 1991, 1993). The systematic radiocarbon dating of buried soils at the Paso Otero Locality is the first such program for the Pampas and provides an expanded radiometric database and more detailed understanding of local and regional events during the Holocene.

Of the 39 ages based on organic sediments, 17 are considered reliable (Tables V, VIII). These ages span the Holocene and provide a framework for both the archaeology and local landscape development. The ages approximate the time of burial of the A-horizons and provide minimum age estimates for the archaeological and paleontological remains located within soil A-horizons. This situation is underscored by the megafauna-related occupation at Paso Otero 5 in which the buried A-horizon is dated at $\sim$9400 ^{14}C yr B.P. and the occupation at $\sim$10,200–10,450 ^{14}C yr B.P. The dated sequence encompasses two formations (Luján and La Postrera) and two members of the Luján Formation (Guerrero and Río Salado). The majority of the dates come from the Río Salado Member and the La Postrera Formation. The Paso Otero geochronology, then, is one of the best-dated Holocene sequences for the region.

At Paso Otero 1, the weak soil development and lack of weathering in the carbonates is surprising considering the amount of time represented between each soil. Several possibilities account for the chronology. Some erosion occurred, apparently before soil formation and burial by the next higher deposit (Favier Dubois, 2006). This interpretation is suggested by the broad undulations of each soil, especially the Ab2 and Ab3. If erosion occurred after pedogenesis, then the soils would be truncated. Another possibility is that the water table was just below the surface during soil formation, inhibiting pedogenesis. This situation is quite likely given the nature of the parent materials. Further, much of the time between the Ab4 and the Ab3 also may be represented by the numerous albeit weakly developed buried soils noted within the Cb3 horizon. Finally, the Ab2 soil is better expressed (i.e., ABk horizonation) than either the Ab4 or Ab3 and probably required more time to develop than either of those lower soils.

La Postrera deposits began to accumulate ca. 3000 ^{14}C yr B.P., allowing an average of around 1000 years for parent material deposition and formation of each sediment—soil couplet (Ab2, Ab1-Cb1, and A-AC). Initially, the sedimentation was very slow, allowing formation of a calcic horizon (Bk) in the Ab2 horizon of the Río Salado Member. The resulting ABkb2 horizon represents the transition from the Río Salado Member to the La Postrera Formation. The Ab1 horizon demonstrates that sedimentation was episodic with one significant hiatus following burial of the Ab2.

At Paso Otero 3, each set of sediment/soil spans at most a few hundred radiocarbon years. The Ab4-Cb4 soil/sediment package is discontinuous. The ages of these deposits and the degree of soil development in them is very similar to the section of the La Postrera Formation at Paso Otero 1. The sediments at Paso Otero 3, therefore, probably represent a sandy facies of the La Postrera Formation and may be fluvial (i.e., representing part of a flood plain sequence; Favier Dubois, 2006). This section may have been closer to a channel than Paso Otero 1, but no exposure provided any indication of where the channel was.

Because of the similarities between Paso Otero 5 and 1, the differences in dates in the lower section of each site are surprising. The lowest soil at each site (Ab6 at Paso Otero 5 and Ab4 at Paso Otero 1) is buried at about the same time (a little less than 10,000 ^{14}C yr B.P.). They then are buried by a series of similar deposits, each with similar weakly developed soils. The two soil/sediment packages above the lowest soil at Paso Otero 1, however, are much younger than those above the lowest soil at Paso Otero 5. At Paso Otero 5, the amount of time between each buried soil (about 1000 or a little more radiocarbon years) seems appropriate based on the minimal soil development. Furthermore, these soils all form under high water-table conditions (Zárate et al., 2000:485) that would inhibit downward leaching of carbonate in each soil. And, as noted for Paso Otero 1, multiple weakly expressed buried soils just above the lowest soil (i.e., in the Cb3 horizon, 185–265 cm) may account for much of the early Holocene. Both Paso Otero 1 and 5, therefore, provide evidence that the early Holocene landscape was one of slow, episodic accretion.

The relatively old dates for the lower soils at Paso Otero 5 mean that the upper sediment/soil packages span much more time than degree of soil development suggests. Several possibilities may account for this situation. A high water-table and minimal leaching conditions would inhibit soil development. Some erosion could have taken place (as now known for Paso Otero 1) that also would inhibit soil development, but no obvious evidence of this process has been noted at Paso Otero 5. Also, the package of sediment/soil represented by the Ab2 and Ab1 soils may each only amount to 1000–1500 years (as suggested by the lower dates), leaving ca. 3000 years for the surface soil development. The latter scenario is reasonable given that the surface soil is 90-cm thick with evidence for carbonate translocation (requiring more time to form), in contrast to the underlying soils that are only A-horizons and at most 13-cm thick (representing relatively brief intervals of stability).

The Holocene alluvial sequences contain two regional buried soils (Puesto Callejón Viejo and Puesto Berrondo), both of which are represented at the Paso Otero Locality. The dates on the Puesto Callejón Viejo soil at Paso Otero 1 and 5 indicate burial of the Guerrero Member in the early Holocene (Tables I, V). A bulk organic sediment date of 9000 ± 70 ^{14}C yr B.P. from the top of the Puesto Callejón Viejo soil 20 km downstream at La Horqueta II also indicates an early Holocene, albeit later burial of the Guerrero Member (Zárate, Espinosa, & Ferrero, 1998). Burial appears to have been gradual locally and in the middle basin over almost a 1000-year period. Elsewhere in the region to the northwest, a bulk organic sediment date of 8940 ± 130 ^{14}C yr B.P. (Figini et al., 1995; Tonni, Cione, & Figini, 1999) indicates a similar late burial as at La Horqueta II. As these are bulk (total fraction) dates, they most likely are relatively young ages, and burial of the Guerrero Member probably took place over a shorter period of time.

Zárate et al. (2000:485) note that the diminished water flow and depth at La Horqueta II during the early Holocene is not due to channel movement (as suggested at Paso Otero), but rather an overall reduction of water flow within the river leading to ephemeral flows. This condition suggests a low volume, sluggish to ephemeral river in at least the middle Río Quequén Grande basin with extensive marshes to water-soaked ground.

The age of the Puesto Berrondo soil has been estimated at 5000–4000 ^{14}C yr B.P. (e.g., Zárate et al., 2000). Assuming that the identification of this regional soil at the Paso Otero Locality is correct, then the dates on that soil from Paso Otero 1 and 3 corroborate that age estimate (4855 ^{14}C yr B.P., 4750 ^{14}C yr B.P.; 4756 ^{14}C yr B.P., 4713 ^{14}C yr B.P.; Tables I, V, VIII). The Paso Otero Locality dates are among the few radiocarbon dates available for the Puesto Berrondo soil (Zárate, Espinosa, & Ferrero, 1998; Tonni, Cione, & Figini, 2001; Fucks et al., 2007).

At the Paso Otero Locality, stable carbon isotope data (Table IX) indicate a significant increase in C_3 vegetation during the Holocene that implies water-saturated ground in proximity to the river channel. Based on different lines of evidence, Zárate et al. (2000:486) note the time of the Puesto Berrondo soil at La Horqueta II as one of desiccation and subaerial exposure of the land surface, again with ephemeral water flow. These situations 20 km apart suggest the continuation of a low discharge stream that may be decreasing in flow downstream in at least the middle Río Quequén Grande basin with far more restricted marshes and saturated ground.

Quaternary paleoenvironmental reconstructions of climate and vegetation communities have been based on mammalian faunas, pollen diagrams, phytoliths, and oxygen isotope data. These approaches produce an overview of alternating humid and dry conditions with changing grassland types (Paez & Prieto, 1993; Quattrocchio, Borromei, & Grill, 1994; Prieto, 1996, 2000; Iriondo, 1999; Prado & Alberdi, 1999; Tonni, Cione, & Figini, 1999; Prado et al., 2001; Grill et al., 2007; Osterrieth et al., 2008; Quattrocchio et al., 2008). The time periods of both the Puesto Callejón Viejo soil and Puesto Berrondo soil are noted as temperate and humid conditions. The general time period of 9000–7000 ^{14}C yr B.P. generally is interpreted as dry based on animal communities (Prado & Alberdi, 1999; Tonni, Cione, & Figini, 1999; Prado et al., 2001) but subhumid–humid based on vegetation (Prieto, 1996, 2000; Osterrieth et al., 2008).

Generally, the stable carbon isotope data are a local expression, and in this case, reflecting the riparian habitat of the river valley. Nonetheless, the distinctive dry period of ∼9500–6600 ^{14}C yr B.P. may be reflecting the regional dry conditions as well. The sediments and soils, however, suggest that the local water table stayed high throughout this period. The dominant C_4 grasses in the valley also may be reflecting the broader regional steppe.

The regional soils at Paso Otero apparently developed under general humid conditions, but development at particular locations was affected by local conditions. This local effect appeared to be the case for differences in the development of the Puesto Berrondo soil at Paso Otero and La Horqueta II just 20 km apart. At Paso Otero, this soil developed under marshy or high water-table conditions. Yet, downstream at La Horqueta II, the water table was depressed, the sediments were well-drained, and the soil developed under dry conditions (Zárate et al., 2000).

CONCLUDING REMARKS

The Paso Otero Locality provides both a local and regional view of late Quaternary events and processes for the middle basin of the Río Quequén Grande in the Argentinean Pampas. Based on the evaluation of the organic sediment dates of the 1990s sampling program from the three sites within the Paso Otero Locality, 15 ages are considered reliable. The two more recently obtained ages on organic sediment samples from the upper column at Paso Otero 5 also are considered reliable. These ages complement and expand the regional chronology and stratigraphy. Three of the seven bone dates from the Locality (from Paso Otero 1 and 5) are considered reliable. Both the Paso Otero 1 middle bone bed and the bone date from it postdate the burial age of the soil that developed before the sedimentation from flooding. The Paso Otero 5 bone dates are older than the burial age of the soil that developed after bone bed deposition. The flood plain is the dominant landscape feature, and the Paso Otero Locality exhibits multiple buried soils in the mode of classic flood plain settings. Channel location, water-table depth, and vegetation change through time. Two regional Holocene soils are expressed within this alluvial sequence, influenced by local conditions. The previous estimated age of the Puesto Callejón Viejo is corroborated while that of the Puesto Berrondo is confirmed by the dates presented here from the Paso Otero Locality.

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