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Early Holocene climate change and human occupation along the semiarid coast of north-central Chile

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ABSTRACT: The brief, terminal Pleistocene archaeological site at Santa Julia (SJ, 31° 50′ S; 71° 45′ W) is the only one with fluted projectile preforms and megafauna consumption known from the Chilean semiarid coastline. Here, we present the climatic history at SJ during the early Holocene reconstructed from pollen and charcoal analyses spanning 13.2–8.6 ka ($=10^3$ calibrated ^{14}C yr BP). Elevated charcoal concentrations confirm human activity by 13.2 ka. Human occupation decreased in intensity and charcoal practically disappears from the record after 10.6 ka, followed by wetland expansion at SJ between 10.5 and 9.5 ka. Local dominance of coastal shrubland reveals that dry phases occurred between >11.2–10.5 and 9.5–9.0 ka. Overall, these findings imply that by modulating available resources at both local and landscape levels climate change may have played an important role in explaining the peopling of semiarid coastal Chile. Copyright © 2010 John Wiley & Sons, Ltd.

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KEYWORDS: Palaeoindian; semiarid Chile; southern westerlies; pollen record; charcoal.

Introduction

Climate change can either facilitate or constrain human exploratory movements and settlement patterns, particularly in the currently arid to semiarid regions of South America (Moreno *et al.*, 2009). Documenting these changes remains crucial for understanding and even predicting the location of archaeological sites (Nuñez *et al.*, 1994; Jackson *et al.*, 2007; Santoro and Latorre, 2009). Evidence for early settlement as well as local climatic conditions have been gathered at Santa Julia (SJ, Fig. 1), an exceptional South American Late Pleistocene archaeological site located along the semiarid coast of north-central Chile (Jackson *et al.*, 2007).

Records of Holocene climate change from this area are scarce. This is further confounded by widespread drying out of many depositional environments between ca. 8.6 and 6.2 ka (Villagrán and Varela, 1990; Maldonado and Villagrán, 2006; Kaiser *et al.*, 2008). In this paper, we describe the pollen and charcoal results from a unique ca. 5 ka continuous sequence exposed along the base of the SJ section (Jackson *et al.*, 2007) and discuss the palaeoenvironmental and climate context of the early human occupation of this region.

Study area and methods

SJ Site LV. 221 (31° 50′ S, 71° 30′ W) is exposed along the rim of a small, E–W oriented arroyo that drains into the Pacific Ocean near Los Vilos (Fig. 1). The site was exposed by down-cutting of former sandy and wetland sediments along the south bank during the late Holocene. Continuous, fine-grained sediments occur along the base of the section (Fig. 2).

The region lies within the subtropical zone of central Chile, receives 260 mm a^{-1} of frontal winter rainfall and mean annual temperature is 14°C (Almeyda and Saez, 1958; Miller, 1976; Fuenzalida, 1982; Montecinos *et al.*, 2000). Semiarid, Asteraceae-dominated shrublands populate the adjacent coastal plains. Sclerophyll and local swamp forests (<0.1 km^2) occur alongside wetlands in the deepest, wettest gullies.

We measured, described and sampled the lowermost 68 cm of sediment from the western profile of the archaeological

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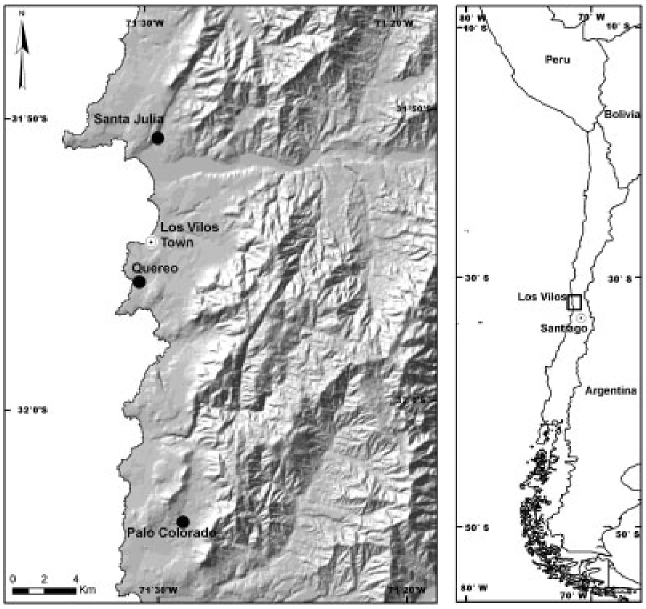

Figure 1 Map of the study area indicating the locations of Santa Julia (SJ), Quebrada Quereo and Palo Colorado

excavation at SJ (strata 36–38) (Jackson *et al.*, 2007). Three accelerator mass spectrometry (AMS) radiocarbon dates were previously obtained on organic matter (Jackson *et al.*, 2007) (Table 1). Loss-on-ignition was done at 1 cm intervals using conventional methods (Dean, 1974; Heiri *et al.*, 2001). Pollen was sampled at 5 cm intervals but was preserved only in the upper 40 cm. Samples were treated with conventional extraction and identification methods (Faegri and Iversen, 1989). Charcoal particle counts were analysed continuously along the profile in 1 cm thick sections with 1 cm^3 subsamples (Whitlock and Larsen, 2001; Whitlock and Anderson, 2003). Charcoal influx (particles cm^{-2} a^{-}) was calculated using CHAPS software (P. Bartlein, unpublished).

Without local data, fire event calibration is difficult. Extrapolation from calibration studies obtained from temperate forests (e.g. Higuera *et al.*, 2005; Whitlock *et al.*, 2006, 2007; Carcaillet *et al.*, 2007) is not warranted, given that SJ lies within semiarid scrub with considerably less biomass. We thus utilise our charcoal record for visualising broad-scale relationships between fire/climate change/human activity rather than estimate individual fire events or local fire activity (Whitlock *et al.*, 2006; Higuera *et al.*, 2007).

Figure 2 Photograph of the SJ site, showing archaeological excavation and stratigraphy. Note the abundant laminations of light-coloured sands and dark organic sediments at the base of the section. This figure is available in colour online at www.interscience.wiley.com/journal/jqs

Results

The stratigraphy records intercalated clayey silt layers to fine sands. Variable clay amounts occur and the overall organic content is low (<10%) (Fig. 3). The chronology reveals a linear increase in age vs. sediment depth from 13.2 to 8.6 ka (Table 1). Average accumulation rate is 65–70 a cm^{-1} and pollen samples are spaced at approximately 280 years.

Pollen was retrieved from samples dated between ca. 11.2 and 8.6 ka. The resulting analyses were divided into three zones. Zone 1 (SJ-1: 40–30 cm; ca. 11.2–10.5 ka) is dominated by shrub and herbaceous taxa, mostly Poaceae (8–30%) and Asteraceae–Tubuliflorae (15–34%), representing the shrub component. Zone 2 (SJ-2: 30–15 cm; ca. 10.5–9.5 ka) has the highest percentages of the wetland obligate *Gunnera tinctorea* (50–70%) and low percentages of Poaceae (9–18%), Asteraceae–Tubuliflorae (7–12%) and Chenopodiaceae (1–3%). Other wetland indicators, such as Cyperaceae (42%) and *Typha* (24%), also reach maximum values. Zone 3 (SJ-3: 16–0 cm; ca. 9.5–8.6 ka) shows increases in Poaceae (16–27%) and Asteraceae–Tubuliflorae (12–38%) and a concomitant decrease in *Gunnera tinctorea* (16%) and *Typha* (6%) at 9.2 ka, although these increase afterwards until the end of the record.

Charcoal amounts are low (~0–70 particles >250 μm and ~0–700 particles <250 to >125 μm). We regard the general trend in charcoal influx as a measure of local fire activity, so only particles >125 μm were examined (Whitlock and Anderson, 2003; Higuera *et al.*, 2007; Ali *et al.*, 2009). Two distinct periods with charcoal occur (Fig. 3). The most prominent is at ca. 13–12.3 ka, coeval with the archaeological occupation at SJ (Jackson *et al.*, 2007). A second period occurs at 11.8–10.6 ka, after which charcoal levels fall to almost zero for the rest of the record (Fig. 3).

Palaeoecology, regional palaeoclimate and human occupation

Very high charcoal influx values occur between ca. 13 and 12.3 ka. Yet regional climate was either wetter/cooler, as documented by swamp forest expansion at nearby Quebrada Quereo (Villagrán and Varela, 1990) and by cold sea surface temperatures (SSTs) in an offshore marine core (Kaiser *et al.*, 2008). Furthermore, low regional plant cover values and absence of natural ignition sources are not conducive to natural fires under modern conditions. Hence it is highly probable that the charcoal is of local human origin. Our maximum charcoal peak is also coeval with the SJ occupation (Jackson *et al.*, 2007).

From 11.2 ka onwards, dominance of coastal shrub pollen indicates a climate drier than today until 10.5 ka, in agreement with other records (Villagrán and Varela, 1990; Kaiser *et al.*, 2008). Persistent human presence (though not likely at the site itself) is revealed by the relatively high charcoal influx from 11.8 to 10.6 ka (Fig. 3) as well as the presence of other, slightly younger settlements in the area (Jackson and Mendez, 2005). Local human subsistence strategies associated with coastal adaptations persisted until 10.8 ka (Jackson and Mendez, 2005). This subsistence strategy is significantly different from that at SJ, which is characterised by megafauna consumption and a lack of marine resources (Jackson *et al.*, 2007).

Increased percentages of *Gunnera tinctorea* and Cyperaceae herald wetland expansion between 10.5 and 9.6 ka. Small, local wetlands (<1 ha) expand primarily as a response to heightened groundwater levels, which are associated with local

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Table 1 Radiocarbon (AMS) dates from Quebrada Santa Julia (31° 50′ S, 71° 30′ W) (from Jackson *et al.*, 2007)

Laboratory no.	Depth (cm) or level	Age (^{14}C a BP)	Age, midpoint (cal. a BP) ($P > 95\%$, 2σ)	δ^{13}C‰	Material
Beta-204523	0–1	7 830 ± 40	8 633 ± 95	−26.0	Bulk
Beta-204524	36–37	9 640 ± 50	10 985 ± 205	−26.7	Bulk
Beta-194725	60–62 (archaeological level)	10 920 ± 80	12 920 ± 113	−27.0	Charcoal

Dates were calibrated using CALIB 5.0.1/INTCAL04 (Stuiver *et al.*, 2005).

precipitation increases (Maldonado, 1999). Charcoal influx dwindled practically to zero (Fig. 3) and human settlements moved towards ravines and interior valleys, only sporadically reaching the coast between ca. 10.5 and 8.8 ka as climate became wetter (Jackson and Mendez, 2005).

Herbaceous and shrubland taxa, all indicative of drier conditions at SJ, increased in importance after 9.6 ka. This trend was interrupted by a dry period at ca. 9.2 ka, after which wetland indicators gradually increased until 8.6 ka. Wetland formation ended abruptly with the subsequent onset of aeolian sand deposition, suggesting increased aridity. The Palo Colorado record also provides evidence for drought at 9.2 ka as well as corroborating that the driest period began by 8.6 ka and lasted until 6.2 ka (Maldonado and Villagrán, 2006).

Marine and continental records show SST increases after ca. 15 ka, with maximum temperatures probably peaking around 7.5 ka (Veit, 1996; Kim *et al.*, 2002; Kaiser *et al.*, 2008). The last regional major glacial advance in the high Andes, however, occurred between 13 and 11 ka (Zech *et al.*, 2008). This advance was coeval with the latter half of the Central Andean Pluvial Event documented in the Atacama Desert and adjacent Altiplano, when summer rainfall was significantly higher between ca. 17.5 and 9.5 ka (Betancourt *et al.*, 2000; Latorre *et al.*, 2005, 2006; Maldonado *et al.*, 2005; Quade *et al.*, 2008; Placzek *et al.*, 2009).

In semiarid Chile, a palaeopedological study shows wet conditions between ca. 10 and 8 ka, followed by drought (Veit, 1996). Further south, the Tagua Tagua record (35° S) suggests wetter conditions until 11.5 ka (Valero-Garcés *et al.*, 2005). Along with the Laguna Aculeo record (33° S), both evince increased aridity that culminated by ca. 8 ka (Jenny *et al.*, 2002; Valero-Garcés *et al.*, 2005). Rapid facies shifts in the Aculeo record between >9.4 and 8.4 ka could also be related to moisture changes seen in our record.

In summary, our pollen and charcoal records from SJ reveal a series of wet–dry intervals during the Late Pleistocene/early Holocene. Initial occupation of SJ at ca. 13 ka occurred under wetter conditions, in agreement with other records. Climate became drier after 11.2 ka and perhaps even as early as 11.8 ka (as inferred from charcoal trends). Wetland expansion at 10.5 ka along with evidence for increased available regional

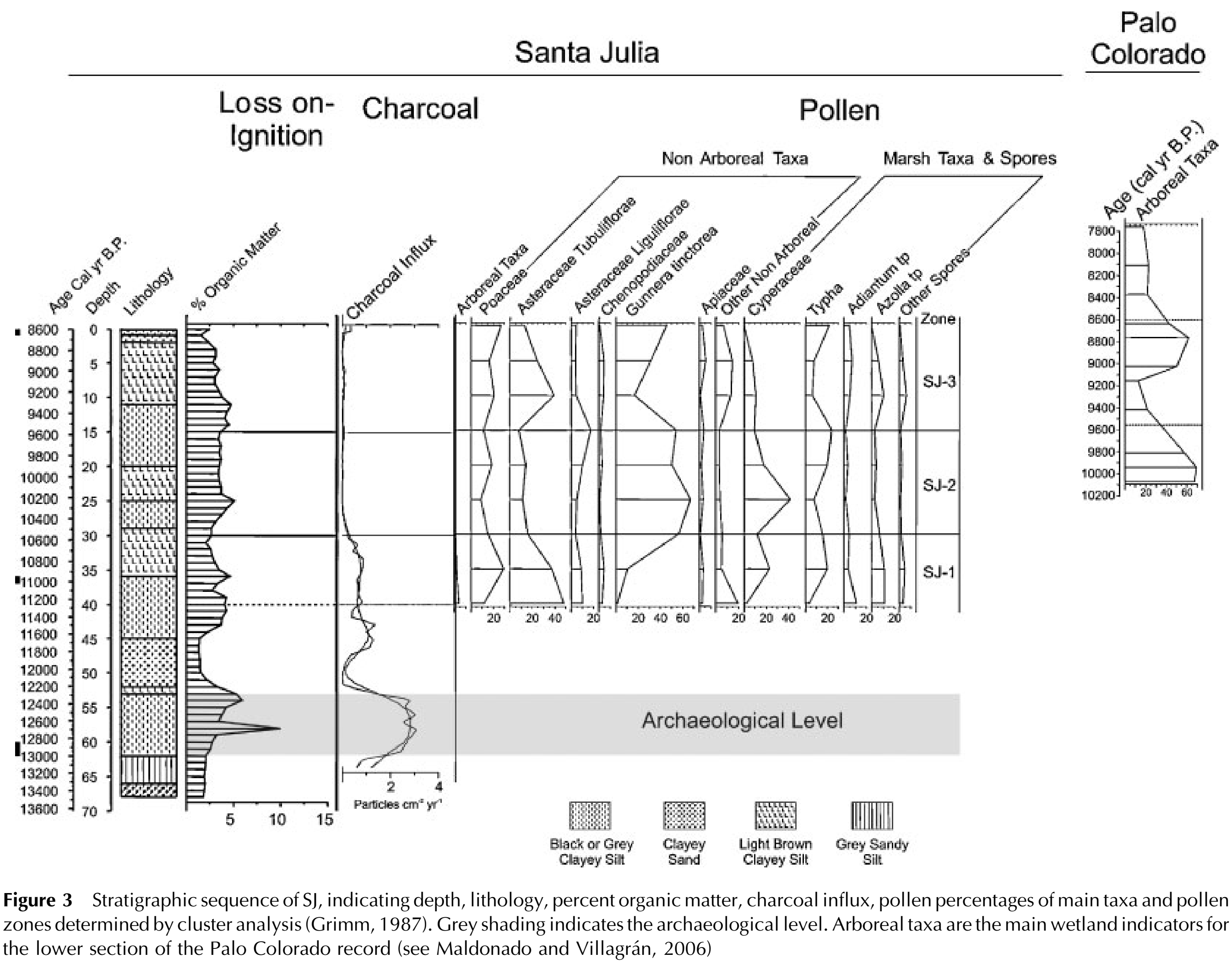

Figure 3 Stratigraphic sequence of SJ, indicating depth, lithology, percent organic matter, charcoal influx, pollen percentages of main taxa and pollen zones determined by cluster analysis (Grimm, 1987). Grey shading indicates the archaeological level. Arboreal taxa are the main wetland indicators for the lower section of the Palo Colorado record (see Maldonado and Villagrán, 2006)

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moisture, and an almost complete lack of charcoal in the record, imply that climate was wet enough to inhibit fire propagation. Fire activity is thus linked to interactions between climate (facilitated by drought), with local human activity as the ignition source. Arid conditions prevailed again from 9.6 to 9.2 ka, followed by wetland expansion until 8.6 ka. Widespread regional aridity followed, perhaps resulting in a paucity of early to mid Holocene archaeological sites and implying a major shift in settlement patterns.

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