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Trends in thermoluminescence date distributions for the Angostura micro region in Central Chile

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ABSTRACT

This article presents a series of thermoluminescence dates obtained from archaeological sites in the Angostura micro region, at the southern edge of the Santiago basin, an area occupied by Bato and Llolleo groups during the Early Ceramic period (200 BC–AD 1300). This series of dates, which cover a time span of around 1500 years, shows moments when dates are abundant and others when they are remarkably scant. We propose that a comparison of the relative frequency of dates can be used as an indirect measure of variations in the intensity of occupation of each of these groups in the zone. We used a summed probability analysis by decade to evaluate sets of dates according to cultural context and sectors of the study area. The results show that while the Bato and Llolleo were irrefutably contemporaneous, the Bato emerged slightly earlier, and that both –but especially the Llolleo– coexisted in later times with Aconcagua groups. At a micro regional scale significant differences as well as changes in Bato and Llolleo population dynamics were made clear. While the Bato display a natural growth curve and then declines, Llolleo increased their population significantly after AD 700, probably because of their reliance on maize crops. Not only did the chronological curves differ; the sectors where they placed their settlements varied over time depending on their specific horticultural practices, local climatic fluctuations, and each other's proximity.

1. Introduction

Since Rick (1987) proposed using dates from the pre-ceramic period in Peru to explore occupational patterns and trends, several studies have demonstrated the usefulness of using "dates as data" (Gamble et al., 2005; Smith et al., 2008; Steele, 2010; Williams et al., 2010; Bamforth and Grund, 2012; Méndez, 2013). Having a sizeable set of dates available gives the chronology new dimensions and enables the exploration of population dynamics and changes in occupational intensity over time (Kuzmin and Keates, 2005). To carry out this exploration, we present a series of thermoluminescence (TL) dates obtained from archaeological sites in the Angostura micro region, then explore their structure and discuss whether changes in the chronological record observed over time can be linked to human population dynamics at the micro regional level. This case differs in at least three ways from applications more commonly found in the literature. First, the dates were obtained using the thermoluminescence method, which has not been as widely used as radiocarbon dating worldwide, and which has different assumptions and challenges for defining the occupational probabilities of sites than ^{14}C dating. Contrary to its underutilization abroad, Chile has a longstanding tradition of TL chronology since it was introduced for dating archaeological ceramics at the Radioactivity and Thermoluminescence Laboratory of the Pontificia Universidad Católica de Chile (Román et al., 1983). Second, our scale is smaller than in the majority of studies, as the series of dates obtained for the sites analyzed comes from a limited area in Central Chile measuring around 200 km^2 and includes samples from all residential sites identified within that area. Lastly, the timeframe of 1500 years is comparatively short, and refers to a period of great diversity in which at least two distinct regional groups with different cultural identities coexisted in Central Chile, the Bato and Llolleo. These groups have been the focus of archaeological research for decades, showing that each is represented by specific cultural contexts characterized by certain types of archaeological remains constantly recurring together, as differing material expressions of everyday practices, representations, and intra-group shared ways of doing things that were reproduced over time

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(Falabella and Planella, 1979; Planella and Falabella, 1987; Falabella and Stehberg, 1989; Sanhueza et al., 2003; Falabella et al., 2007). Differences in subsistence practices, burial patterns, and bodily ornaments, types of smoking pipes, pottery, and lithic artifacts are distinctive, although ceramic styles are especially diagnostic. While the Llolleo people were sedentary horticulturists, and the crops they grew (maize, quinoa, beans, squash) were an essential part of their diet the Bato relied more heavily on hunting and gathering and small scale quinoa horticulture, and were well adapted to semi-sedentary or mobile settlement systems (Falabella et al., 2008). Both lived in dispersed farmsteads, each of which was likely based on an extended family group (Falabella and Sanhueza, 2005–06). No significant degree of hierarchy appears to have existed among settlements. This social landscape began to change around AD 1000–1200 when a new cultural scenario, known as Aconcagua in the local sequence, was introduced in some enclaves, until it came to dominate the so-called Late Intermediate period (Durán and Planella, 1989).

The relationship between the Bato and Llolleo peoples is an ongoing debate (Sanhueza, 2013). The main drawback has been a lack of research at the micro spatial scale and low chronological resolution for occupation durations of sites. Recent research in the Angostura micro region provided data on the distribution of a significant number of sites whose dates cover the whole time span of the Early Ceramic period. The direct dating of ceramic sherds with thermoluminescence technique provided an ideal method for determining occupation durations in Angostura, where archaeological deposits are located within the plough zone, scarce organic remains are recovered, and pottery is ubiquitous and abundant.

The objectives of this paper are to analyze the series of TL dates from Angostura a) to compare trends in date distributions and intensity of occupation during the Early Ceramic period, focusing on Bato and Llolleo differences, and b) to discuss population dynamics over time in relation to socio-cultural and environmental factors.

2. Regional setting

Central Chile (32–35° S) is a narrow land, 120 km at its widest point, situated between the Andes Mountains and the Pacific Ocean (Fig. 1). The region is characterized by two north to south trending mountain ranges: the Andes to the east, reaching altitudes of 6000 m asl, and the Coastal Range to the west, with an average height of 2000 m asl and a few peaks around 3000 m asl. West of the Coastal Range is a coastal plain that can reach 5 km in width. Lying between these two ranges sits an alluvial plain, which is interrupted by foothills connecting the Andes and Coastal mountains. One of these foothills shapes the Angostura region, and delimits the Basin of Santiago to the south.

The region has a temperate Mediterranean-like climate characterized by climatic fluctuations associated with the El Niño Southern Oscillation (ENSO), and well defined seasons: cold-rainy winters (May to September) and warm-dry summers (October to March). Paleoclimatic evidence indicates that the current climate came into effect ~3200 cal BP (Villa-Martínez et al., 2003). Studies of sediment, geochemistry, diatoms (Jenny et al., 2002) and pollen (Villa-Martínez et al., 2004) at Laguna de Aculeo, adjacent to the Angostura micro region, show that beginning in approximately AD 200 the lake was affected by a series of flood events that were likely caused by abundant rainfall of up to 1300 mm annually, a sharp contrast to the 500 mm estimated for a normal year. These events alternated with drier periods in which rainfall did not surpass an estimated 250 mm annually, representing moments during which El Niño episodes were either less frequent or on a smaller scale. Three intense periods of repeated large flood events have been documented (AD 200–400 cal, AD 500–700 cal, and AD 1100 cal and following (in Jenny et al., 2002)). In another study of Laguna de Aculeo, von Gunten et al. (2009) suggest that there was a period of "hot summers" between AD 1150 and 1350, which can be associated with times of drought. In other words, the climate of this zone presents periodic fluctuations that are manifested in multi-year time spans with abundant precipitation and others of intense drought.

2.1. Angostura micro region

The micro region of Angostura lies in the southern end of the Santiago Basin. The area is dominated by the confluence of the Maipo and the Angostura rivers, and by several streams descending from the Andes mountain range that attract a diversity of plant and animal communities. Three sectors can be distinguished in terms of their natural features. Valdivia de Paine to the west, Colonia Kennedy to the east, and Águila-Peuco to the south (Fig. 1). Colonia Kennedy and Valdivia de Paine are very humid sectors, in which the saturated zone reaches near the surface. In recent times, despite the drainage systems implemented by industrial farming operations, the water table is still found at an average depth of just two meters or less, with some areas inundated year round and others with groundwater upwelling just 50 cm beneath the surface (Venegas, 2006). Geological and sedimentological studies demonstrate that in several places more or less permanent lakes have formed in the past (Rauld and Flores, 2012). One of these, at the confluence of La Berlina and Cardonal streams, was confirmed by test pits showing a well-defined organic silt layer that represents a lake deposit dated between AD 180 and 1620 (Maldonado and Abarzúa, 2013). These conditions, coupled with the presence of several freshwater springs in these zones, make the area very sensitive to changes in groundwater levels and precipitation. In contrast, in the Águila-Peuco sector, from the western bank of the Angostura River southward, there is no upwelling of subsurface water, but the sector does have a permanent supply of water as it lies along the banks of the rain- and snow-fed Peuco and Angostura Rivers.

3. Archaeological background

The micro region of Angostura presents several residential sites from the Early Ceramic period distributed spatially in the three sectors (Fig. 1). Archaeological data show that these sectors not only differ from one another in terms of their natural features, but also in the distribution of settlements and networks of social interaction. The distribution of settlements is based on archaeological investigations with systematic full-coverage surveys (Parsons, 1990) along transects spaced every 100 m that covered approximately 60% of the study area, as roads and urbanized land were not surveyed, as well as on excavations of test pits and surface collections in places with identified human occupations (Cornejo et al., 2012). These occupations correspond only to residential areas as evidenced by artifact assemblages and garbage recovered from what is left of midden deposits. Clusters of high-density concentrations of artifacts were delineated within the archaeological sites, and separated from one another by lower density buffers (Falabella et al., 2014). As Fig. 1 shows, most of the clusters are assigned to Bato or Llolleo occupations; a few of them ($n = 5$) have mixed Bato–Llolleo deposits and three have only an Early Ceramic period (ECp) affiliation. Three aspects of the archaeological information from Angostura are particularly interesting. First, the evidence shows that these groups were remarkably interlaced: their settlements were adjacent, in some cases adjoining or even overlapping. Second, residential Bato and Llolleo occupations vary widely, and include a) artifact scatters with two or more high density concentrations covering 6 ha or more that suggest permanent residence

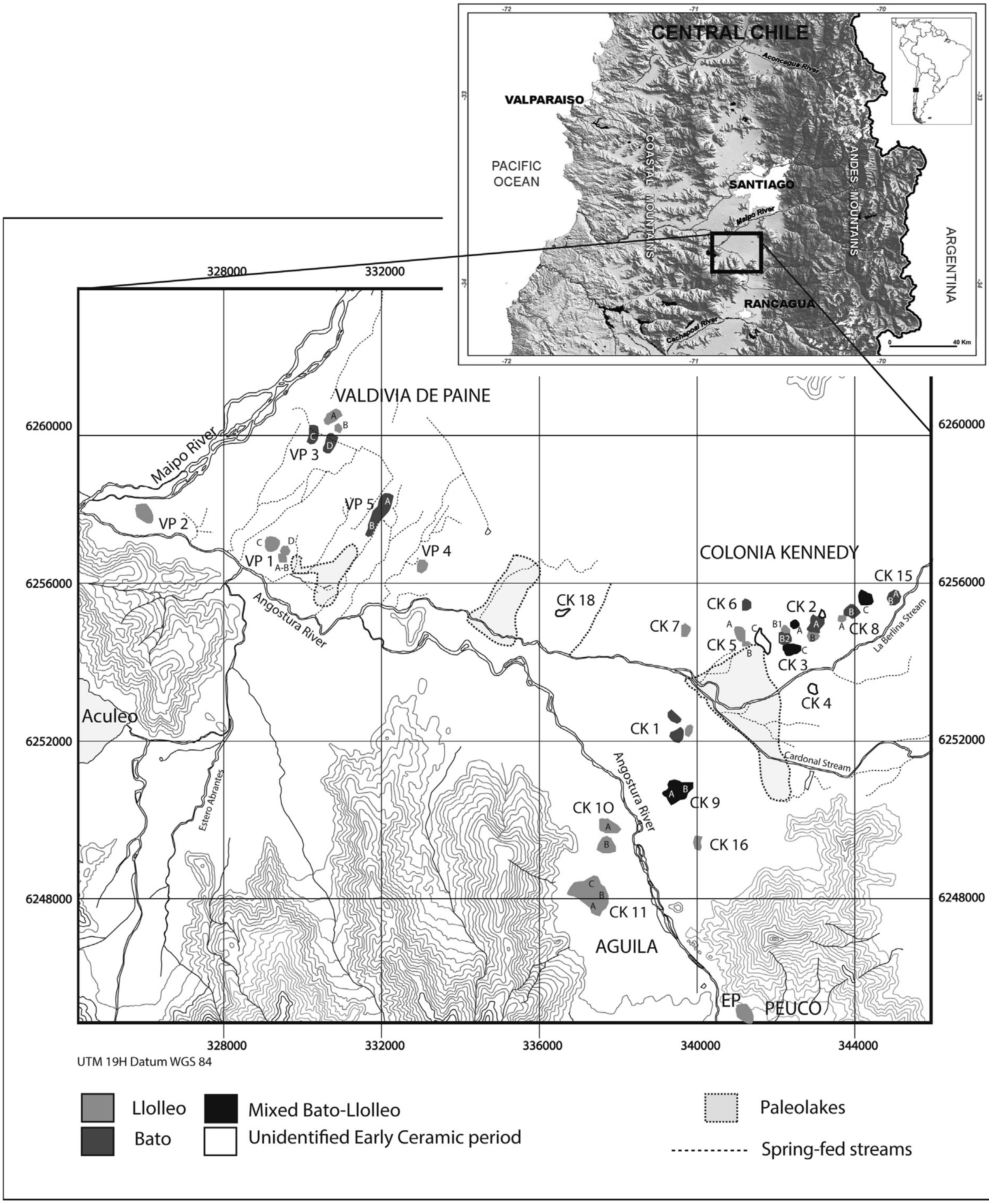

Fig. 1. Map of Angostura micro region, showing the location of Valdivia de Paine, Colonia Kennedy and Aguila-Peuco sectors, sites, and the cultural affiliation of occupations with TL dates discussed in the text.

over time, b) smaller and/or less dense artifact concentrations that point to less intense residential occupations, and c) very small clusters probably from middens of individual dwellings and/or very transitory occupations that are distributed differently in different sectors (Sanhueza, 2013; Falabella et al., 2014). Lastly, according to the analysis of the provenance of raw materials, ceramic manufacture and stylistic features, the social and economic networks operating in the locality of Valdivia de Paine were separate from those of Colonia Kennedy and Águila-Peuco (Falabella et al., 2013).

4. Material and methods

4.1. Material

The chronological information was derived from 152 ceramic sherds (Table 1) obtained from 44 high density clusters of artifacts interpreted as representing different occupations of the Early Ceramic period—13 in the Valdivia de Paine sector, 26 in Colonia Kennedy and five in Águila-Peuco (Fig. 1). For each one of these clusters, between two to five dates were obtained by thermoluminescence (Table 2). The full-coverage strategy used for surveying resulted in a sample that is highly representative of the distribution of pre-Hispanic residential sites in the Angostura micro region, which is advantageous for evaluating the population dynamics of this zone (Cornejo et al., 2012). The investigation in this micro region was not without difficulties, however. The first is that the study area is intensively farmed, and since the depth of most of the archaeological sites studied did not exceed 60 cm, plow machinery has obliterated the limits of ancient occupations and stratigraphic layers. Our minimum unit of analysis was an archaeological deposit delimited by differences in density (depositional area *sensu* Carr, 1984), as a result of one or more superimposed middens associated with dwellings occupied over time. The second difficulty is that some deposits, as mentioned in Section 3, have no clear cultural assignation because they contain a mixture of Bato and Llolleo cultural features or because the materials, while obviously belonging to the Early Ceramic period, yielded insufficient information to determine the cultural affiliation.

The samples were selected from intensive surface collections and from excavated layers in the same deposits, given that any occupational period is as likely as any other to be represented. Where possible, we chose sherds with diagnostic features (e.g. decorations, attributes with particular shapes) that could identify either the morpho-functional category of the vessel or the cultural affiliation within the Early Ceramic period.

4.2. Methods

The chronology we present is based on the thermoluminescence dating method, which has not been exempt from difficulties in the course of its historical development (i.e. Roberts, 1997; Ege et al., 2007). Despite these problems, nowadays it is an accepted archaeometric dating method (Feathers, 2003). Although it has been only sparingly employed in some parts of the world, especially in North America, it has seen wider application in Europe (Wintle, 2008), whilst in Chile and, partially in Argentina, it has contributed

Table 1
Thermoluminescence samples in the database.

Sample	Site/occupation, unit	Context[a]	P (Gy)	D (Gy/year)	TL years BP	TL date
UCTL 2116	VP1/B, 21-cL	Llolleo	2.42 ± 0.23	$2.90*10^{-3}$	835 ± 80	AD 1175
UCTL 2117	VP1/B, 21-cL	Llolleo	2.48 ± 0.18	$3.60*10^{-3}$	690 ± 70	AD 1320
UCTL 2118	VP1/B, 21-cL	Llolleo	2.46 ± 0.29	$2.94*10^{-3}$	835 ± 80	AD 1175
UCTL 2119	VP1/B, 21-cM	Bato	4.45 ± 0.44	$2.70*10^{-3}$	1650 ± 160	AD 360
UCTL 2120	VP1/B, 21-cM	Llolleo	2.26 ± 0.23	$2.30*10^{-3}$	980 ± 100	AD 1030
UCTL 2121	VP1/A, 21-cD	Llolleo	3.06 ± 0.28	$3.02*10^{-3}$	1010 ± 100	AD 1000
UCTL 2122	VP1/A, 21-cG	Llolleo	3.40 ± 0.35	$3.02*10^{-3}$	1100 ± 110	AD 910
UCTL 2123	VP1/A, 21-cI	Llolleo	2.88 ± 0.29	$2.81*10^{-3}$	1025 ± 100	AD 985
UCTL 2124	VP1/A, 21-cJ	Llolleo	2.77 ± 0.25	$2.94*10^{-3}$	940 ± 95	AD 1070
UCTL 2125	VP1/A, 21-cE	Bato	4.50 ± 0.45	$2.81*10^{-3}$	1600 ± 160	AD 410
UCTL 2126	VP1/C, 2-P4.3	Llolleo	1.45 ± 0.15	$2.08*10^{-3}$	700 ± 70	AD 1310
UCTL 2127	VP1/C, 2-P42.1	Llolleo	3.00 ± 0.30	$3.25*10^{-3}$	920 ± 90	AD 1090
UCTL 2128	VP1/C, 2-P36.3	Llolleo	2.76 ± 0.28	$2.87*10^{-3}$	960 ± 100	AD 1050
UCTL 2130	VP1/C, 2-P39.1	Llolleo	3.26 ± 0.36	$2.90*10^{-3}$	1125 ± 110	AD 885
UCTL 2131	VP3/A, R3i-6.134.2	Llolleo	3.37 ± 0.25	$3.18*10^{-3}$	1060 ± 100	AD 880
UCTL 2132	VP3/A, R3i-6.129.4	Llolleo	2.25 ± 0.22	$2.55*10^{-3}$	890 ± 100	AD 1120
UCTL 2133	VP3/A, R3i-6.137.5	Llolleo	1.45 ± 0.14	$2.17*10^{-3}$	670 ± 70	AD 1340
UCTL 2134	VP3/A, R3i-6.126.4	Llolleo	2.26 ± 0.11	$2.73*10^{-3}$	830 ± 80	AD 1180
UCTL 2135	VP3/A, R3i-6.123.2	Llolleo	2.45 ± 0.24	$2.65*10^{-3}$	925 ± 90	AD 1085
UCTL 2136	VP3/B, R3i-6.10.1	Llolleo	4.67 ± 0.44	$3.00*10^{-3}$	1555 ± 150	AD 455
UCTL 2137	VP3/B, R3i-6.18.2	Llolleo	1.62 ± 0.16	$2.79*10^{-3}$	580 ± 50	AD 1430
UCTL 2138	VP3/B, R3i-6.21.2	Llolleo	2.17 ± 0.18	$2.91*10^{-3}$	745 ± 70	AD 1265
UCTL 2139	VP3/C, R3i-6.101.2	Bato	4.14 ± 0.42	$2.90*10^{-3}$	1425 ± 140	AD 585
UCTL 2140	VP3/C, R3i-6.93.3	Bato	4.69 ± 0.46	$3.39*10^{-3}$	1380 ± 135	AD 630
UCTL 2141	VP3/C, R3i-6.90.3	Bato	2.26 ± 0.23	$3.21*10^{-3}$	705 ± 70	AD 1305
UCTL 2142	VP3/C, R3i-6.99.3	Bato	3.67 ± 0.03	$2.81*10^{-3}$	1305 ± 130	AD 705
UCTL 2143	VP3/D, R3i-6.30.3	Bato	5.00 ± 0.49	$2.71*10^{-3}$	1845 ± 185	AD 165
UCTL 2144	VP3/D, R3i-6.30.2	Bato	4.13 ± 0.40	$2.68*10^{-3}$	1540 ± 150	AD 470
UCTL 2145	VP3/D, R3i-6.51.3	Bato	5.57 ± 0.56	$3.04*10^{-3}$	1830 ± 180	AD 180
UCTL 2157	VP3/D, R3i-6.30.2	Bato	3.63 ± 0.58	$2.40*10^{-3}$	1510 ± 160	AD 500
UCTL 2158	VP3/D, R.31-6.40.3	Bato	3.69 ± 0.17	$2.35*10^{-3}$	1570 ± 100	AD 440
UCTL 2159	VP4, 23.T2.1	Llolleo	3.13 ± 0.32	$3.01*10^{-3}$	1040 ± 100	AD 970
UCTL 2160	VP4, 23.P5.2	Llolleo	3.36 ± 0.30	$2.76*10^{-3}$	1215 ± 120	AD 795
UCTL 2161	VP4, 23.P3.2	Llolleo	1.85 ± 0.18	$2.34*10^{-3}$	650 ± 60	AD 1360
UCTL 2167	VP5/A, V-18.9.5	Bato	2.00 ± 0.20	$1.91*10^{-3}$	1050 ± 100	AD 960
UCTL 2168	VP5/A, V 18.12.1	Bato	2.58 ± 0.25	$2.57*10^{-3}$	1005 ± 100	AD 1005
UCTL 2352	VP5/A, V-18.15.1	Bato	3.75 ± 0.26	$2.43*10^{-3}$	1540 ± 150	AD 470
UCTL 2169	VP5/A, V 18.17.5	Bato	4.45 ± 0.44	$2.17*10^{-3}$	2050 ± 200	40 BC
UCTL 2170	VP5/A, V-18.8.5	Bato	2.72 ± 0.27	$1.90*10^{-3}$	1430 ± 140	AD 580
UCTL 2171	VP5/B, V-18.5.3	Bato	4.21 ± 0.17	$1.77*10^{-3}$	2055 ± 145	45 BC
UCTL 2172	VP5/B, V-20 P27.3	Bato	2.89 ± 0.29	$2.19*10^{-3}$	1320 ± 130	AD 690
UCTL 2173	VP5/B, V-18.16.4	Bato	4.25 ± 0.37	$2.44*10^{-3}$	1740 ± 170	270 BC
UCTL 2174	VP5/B, V-18.20.2	Bato	3.37 ± 0.32	$3.77*10^{-3}$	895 ± 90	AD 1115
UCTL 2175	VP5/B, V-20-cN	Bato	1.92 ± 0.19	$1.78*10^{-3}$	1080 ± 110	AD 930
UCTL 2176	VP2/A, 8.c21.2	Llolleo	2.32 ± 0.22	$4.22*10^{-3}$	550 ± 45	AD 1460
UCTL 2177	VP2/A, 8.c14.4	Llolleo	2.56 ± 0.20	$3.67*10^{-3}$	695 ± 65	AD 1315
UCTL 2178	VP2/A, 8.c20.3	Llolleo	2.46 ± 0.29	$4.21*10^{-3}$	685 ± 65	AD 1325
UCTL 2179	VP2/B, 8.c6.4	Llolleo	4.14 ± 0.41	$4.38*10^{-3}$	945 ± 95	AD 1065

Table 1 (*continued*)

Sample	Site/occupation, unit	Context[a]	P (Gy)	D (Gy/year)	TL years BP	TL date
UCTL 2180	VP2/B, 8.c6.4	Llolleo	4.10 ± 0.21	$3.81*10^{-3}$	1075 ± 55	AD 935
UCTL 2181	VP2/B, 8.c6.2	Llolleo	3.15 ± 0.26	$3.61*10^{-3}$	870 ± 80	AD 1140
UCTL 2182	VP2/C, 8.P31.3	Llolleo	4.25 ± 0.46	$3.29*10^{-3}$	1290 ± 130	AD 720
UCTL 2183	VP2/C,8.P26.3	Llolleo	4.14 ± 0.42	$4.21*10^{-3}$	980 ± 100	AD 1030
UCTL 2184	VP2/C, 8.P25.5	Llolleo	5.33 ± 0.50	$3.72*10^{-3}$	1430 ± 140	AD 580
UCTL 2217	CK2/N, G11.45.2	Bato	3.36 ± 0.25	$4.01*10^{-3}$	840 ± 80	AD 1170
UCTL 2218	CK2/N, G11.22.4	Bato	2.79 ± 0.20	$2.50*10^{-3}$	1115 ± 90	AD 895
UCTL 2219	CK2/N, G11.49.1	Bato	3.58 ± 0.20	$2.39*10^{-3}$	1495 ± 90	AD 515
UCTL 2220	CK2/N, G11.29.2	Bato	2.32 ± 0.10	$2.46*10^{-3}$	945 ± 75	AD 1065
UCTL 2221	CK2/S, G11.32.5	Llolleo	2.00 ± 0.16	$2.58*10^{-3}$	775 ± 60	AD 1235
UCTL 2222	CK2/S, G11.13.5	Llolleo	4.28 ± 0.40	$2.18*10^{-3}$	1960 ± 190	AD 50
UCTL 2223	CK2/S, G11.12.3	Llolleo	2.55 ± 0.24	$2.40*10^{-3}$	1060 ± 100	AD 950
UCTL 2224	CK2/S, G11.7.4	Llolleo	1.93 ± 0.19	$1.87*10^{-3}$	1030 ± 100	AD 980
UCTL 2225	CK3/A3, G13.cM	B-L	1.45 ± 0.14	$1.83*10^{-3}$	790 ± 80	AD 1220
UCTL 2226	CK3/A3, G13.cN	B-L	2.58 ± 0.23	$2.43*10^{-3}$	1060 ± 100	AD 950
UCTL 2227	CK3/B1, G13.cG	Llolleo	3.53 ± 0.17	$2.03*10^{-3}$	1740 ± 100	AD 270
UCTL 2228	CK3/B1, G13.cG	Llolleo	2.35 ± 0.23	$2.03*10^{-3}$	1160 ± 110	AD 850
UCTL 2229	CK3/B1, G13.cH	Llolleo	2.80 ± 0.25	$1.93*10^{-3}$	1450 ± 140	AD 560
UCTL 2230	CK3/B1, G13.cH	Llolleo	2.59 ± 0.24	$2.33*10^{-3}$	1110 ± 100	AD 900
UCTL 2231	CK3/B2, G13.cD	Bato	3.71 ± 0.36	$2.03*10^{-3}$	1825 ± 180	AD 185
UCTL 2232	CK3/B2, G13.cF	Bato	4.57 ± 0.40	$2.54*10^{-3}$	1800 ± 180	AD 210
UCTL 2233	CK3/B2, G13.cF	Bato	2.73 ± 0.26	$2.74*10^{-3}$	995 ± 90	AD 1015
UCTL 2234	CK3/B2, G13.cF	Bato	4.59 ± 0.45	$4.09*10^{-3}$	1120 ± 110	AD 890
UCTL 2235	CK3/C, G16.cC	B-L	3.55 ± 0.35	$2.77*10^{-3}$	1280 ± 90	AD 730
UCTL 2236	CK3/C, G16. cCa	B-L	3.89 ± 0.20	$2.25*10^{-3}$	1730 ± 170	AD 280
UCTL 2237	CK4, G5.P.B.4	ECp	2.55 ± 0.25	$2.16*10^{-3}$	1180 ± 100	AD 830
UCTL 2238	CK4, G5. cA	ECp	3.71 ± 0.37	$2.13*10^{-3}$	1740 ± 170	AD 270
UCTL 2239	CK4, G5. cA	ECp	2.25 ± 0.22	$2.06*10^{-3}$	1090 ± 100	AD 920
UCTL 2240	CK4, G5. cB	ECp	3.15 ± 0.17	$2.18*10^{-3}$	1445 ± 140	AD 565
UCTL 2241	CK1/6, c6-sec B.3	Llolleo	4.60 ± 0.39	$2.91*10^{-3}$	1580 ± 140	AD 430
UCTL 2242	CK1/6, c6r.6	Llolleo	3.41 ± 0.32	$2.34*10^{-3}$	1460 ± 100	AD 550
UCTL 2243	CK1/6, c6amp-R.7	Llolleo	2.99 ± 0.10	$3.15*10^{-3}$	950 ± 60	AD 1060
UCTL 2244	CK1/7, c7amp.2	Bato	3.22 ± 0.10	$1.76*10^{-3}$	1830 ± 100	AD 180
UCTL 2245	CK1/7, c7amp.5a	Bato	2.65 ± 0.20	$1.47*10^{-3}$	1800 ± 180	AD 210
UCTL 2246	CK1/7, c7amp.7	Bato	3.56 ± 0.34	$2.51*10^{-3}$	1420 ± 140	AD 590
UCTL 2247	CK1/8-9, c8.2	Bato	4.94 ± 0.35	$2.71*10^{-3}$	1820 ± 130	AD 190
UCTL 2248	CK1/8-9, c8.3	Bato	2.16 ± 0.21	$1.43*10^{-3}$	1510 ± 150	AD 500
UCTL 2249	CK1/8-9, c9.2	Bato	3.51 ± 0.33	$2.15*10^{-3}$	1650 ± 160	AD 360
UCTL 2298	CK6, P14.1	Bato	3.31 ± 0.21	$4.11*10^{-3}$	805 ± 50	AD 1205
UCTL 2299	CK6, cA	Bato	3.03 ± 0.30	$3.52*10^{-3}$	860 ± 80	AD 1150
UCTL 2300	CK7, P1.2	Llolleo	2.08 ± 0.20	$2.95*10^{-3}$	705 ± 70	AD 1305
UCTL 2301	CK7, P2.1	Llolleo	2.38 ± 0.22	$3.39*10^{-3}$	700 ± 70	AD 1310
UCTL 2302	CK7, P2.1	Llolleo	3.73 ± 0.38	$3.41*10^{-3}$	1090 ± 100	AD 920
UCTL 2303	CK16, P1.1	Llolleo	1.72 ± 0.16	$2.94*10^{-3}$	585 ± 50	AD 1425
UCTL 2304	CK16, P4.3	Llolleo	2.57 ± 0.20	$3.60*10^{-3}$	715 ± 55	AD 1295
UCTL 2305	CK8/A, P22.2	Llolleo	5.93 ± 0.38	$3.16*10^{-3}$	1875 ± 150	AD 135
UCTL 2306	CK8/A, P10.2	Llolleo	3.52 ± 0.32	$3.15*10^{-3}$	1120 ± 100	AD 890
UCTL 2307	CK8/A, cZ	Llolleo	2.41 ± 0.21	$2.38*10^{-3}$	1010 ± 100	AD 1000
UCTL 2308	CK8/A, cZ	Llolleo	2.08 ± 0.20	$2.40*10^{-3}$	865 ± 80	AD 1145
UCTL 2309	CK8/B, P12. 4	Bato	2.35 ± 0.23	$2.79*10^{-3}$	840 ± 80	AD 1170
UCTL 2310	CK8/B, P12.3	Bato	1.85 ± 0.18	$2.64*10^{-3}$	700 ± 70	AD 1310
UCTL 2311	CK8/B, P12.2	Bato	2.94 ± 0.27	$3.16*10^{-3}$	930 ± 90	AD 1080
UCTL 2312	CK8/B, cM	Bato	2.40 ± 0.22	$2.58*10^{-3}$	930 ± 90	AD 1080
UCTL 2313	CK8/C, P47.2	B-L	3.13 ± 0.30	$3.02*10^{-3}$	1035 ± 100	AD 975
UCTL 2314	CK8/C, P42.2	B-L	2.61 ± 0.23	$2.63*10^{-3}$	990 ± 90	AD 1020
UCTL 2315	CK8/C, P37.3	B-L	3.26 ± 0.32	$2.70*10^{-3}$	1205 ± 120	AD 805
UCTL 2316	CK9/B, cC	B-L	3.65 ± 0.33	$2.33*10^{-3}$	1565 ± 150	AD 445
UCTL 2317	CK9/A, cB	B-L	3.75 ± 0.35	$2.68*10^{-3}$	1400 ± 140	AD 610
UCTL 2318	CK9/A, P17.1	B-L	3.50 ± 0.34	$2.20*10^{-3}$	1590 ± 60	AD 420
UCTL 2319	CK9/A, cA	B-L	4.46 ± 0.43	$2.85*10^{-3}$	1565 ± 150	AD 445
UCTL 2320	CK9/A, P12.4	B-L	3.40 ± 0.34	$2.13*10^{-3}$	1600 ± 160	AD 410
UCTL 2321	CK9/B, cC	B-L	3.41 ± 0.32	$1.83*10^{-3}$	1860 ± 180	AD 150
UCTL 2322	CK9/B, cC	B-L	4.06 ± 0.40	$2.80*10^{-3}$	1450 ± 140	AD 560
UCTL 2323	CK5/B, cD	Llolleo	1.64 ± 0.16	$2.09*10^{-3}$	780 ± 80	AD 1230
UCTL 2324	CK5/A, cB	Llolleo	3.45 ± 0.34	$3.08*10^{-3}$	1120 ± 100	AD 890
UCTL 2325	CK5/A, cA	Llolleo	3.02 ± 0.29	$3.09*10^{-3}$	980 ± 90	AD 1030
UCTL 2326	CK5/B, cD	Llolleo	2.66 ± 0.24	$2.73*10^{-3}$	975 ± 90	AD 1035
UCTL 2340	CK5/B, P19.5	Llolleo	5.57 ± 0.54	$2.99*10^{-3}$	1860 ± 180	AD 50
UCTL 2341	CK5/A, P1.2	Llolleo	2.88 ± 0.25	$3.19*10^{-3}$	900 ± 90	AD 1110
UCTL 2342	CK5/A, P1.3	Llolleo	3.17 ± 0.23	$3.59*10^{-3}$	885 ± 60	AD 1125
UCTL 2343	CK5/B, P19.1	Llolleo	1.77 ± 0.16	$3.06*10^{-3}$	580 ± 50	AD 1430
UCTL 2344	CK5/C1, P40.2	ECp	2.73 ± 0.26	$2.71*10^{-3}$	1005 ± 100	AD 1005
UCTL 2345	CK5/C1, P40.5	ECp	1.70 ± 0.17	$2.75*10^{-3}$	620 ± 60	AD 1390
UCTL 2346	CK5/C2, P55.3	ECp	2.26 ± 0.22	$3.17*10^{-3}$	710 ± 70	AD 1300

(*continued on next page*)

Table 1 (*continued*)

Sample	Site/occupation, unit	Context[a]	P (Gy)	D (Gy/year)	TL years BP	TL date
UCTL 2347	CK5/C2, P55.2	ECp	3.66 ± 0.35	$2.30*10^{-3}$	1590 ± 150	AD 420
UCTL 2353	CK10/A, P8.2	Llolleo	2.17 ± 0.21	$3.20*10^{-3}$	680 ± 60	AD 1330
UCTL 2354	CK10/B, P12.2	Llolleo	4.38 ± 0.19	$2.70*10^{-3}$	1620 ± 100	AD 390
UCTL 2355	CK10/B, P13.3	Llolleo	3.13 ± 0.30	$4.17*10^{-3}$	750 ± 70	AD 1260
UCTL 2356	CK10/A, P24.1	Llolleo	1.92 ± 0.12	$3.62*10^{-3}$	530 ± 40	AD 1480
UCTL 2357	CK10/B, P38.1	Llolleo	3.00 ± 0.30	$2.32*10^{-3}$	1290 ± 130	AD 720
UCTL 2358	CK10/B, P39.2	Llolleo	3.13 ± 0.30	$2.12*10^{-3}$	1475 ± 140	AD 535
UCTL 2359	CK10/B, P40.3	Llolleo	3.12 ± 0.30	$2.32*10^{-3}$	1335 ± 130	AD 675
UCTL 2360	CK11/A, P12.2	Llolleo	1.33 ± 0.13	$2.07*10^{-3}$	640 ± 60	AD 1370
UCTL 2361	CK11/A, P12.6	Llolleo	3.22 ± 0.32	$2.56*10^{-3}$	1260 ± 120	AD 750
UCTL 2362	CK11/A, P20.3	Llolleo	1.06 ± 0.08	$2.05*10^{-3}$	515 ± 50	AD 1495
UCTL 2363	CK11/A, P25.6	Llolleo	2.88 ± 0.28	$2.88*10^{-3}$	1000 ± 100	AD 1010
UCTL 2364	CK11/B, P35.4	Llolleo	3.41 ± 0.27	$2.73*10^{-3}$	1250 ± 120	AD 760
UCTL 2365	CK11/B, P35.6	Llolleo	3.13 ± 0.31	$2.39*10^{-3}$	1310 ± 130	AD 700
UCTL 2366	CK18, P6.1	ECp	2.00 ± 0.02	$3.61*10^{-3}$	555 ± 50	AD 1455
UCTL 2367	CK18, P15.1	ECp	3.71 ± 0.37	$2.50*10^{-3}$	1485 ± 140	AD 525
UCTL 2368	CK15/A, cD	Bato	2.63 ± 0.25	$2.32*10^{-4}$	1130 ± 110	AD 880
UCTL 2369	CK15/A, cD	Bato	4.05 ± 0.40	$2.10*10^{-3}$	1925 ± 190	AD 85
UCTL 2370	CK15/A, cE	Bato	3.79 ± 0.34	$2.09*10^{-3}$	1810 ± 180	AD 200
UCTL 2371	CK15/A, cF	Bato	2.65 ± 0.25	$2.36*10^{-3}$	1120 ± 100	AD 890
UCTL 2372	CK15/B, cG	Bato	2.23 ± 0.22	$2.61*10^{-3}$	855 ± 80	AD 1155
UCTL 2373	CK15/B, cH	Bato	2.35 ± 0.23	$1.81*10^{-3}$	1300 ± 130	AD 710
UCTL 2374	CK15/B, cI	Bato	4.15 ± 0.41	$1.90*10^{-3}$	2185 ± 200	175 BC
UCTL 1666	EP, U4-R1. planta	Llolleo	3.86 ± 0.28	$2.86*10^{-3}$	1350 ± 110	AD 650
UCTL 1667	EP, R.1. planta	Llolleo	3.01 ± 0.23	$3.13*10^{-3}$	960 ± 85	AD 1040
UCTL 1668	EP, U3 Amp w. R.1b	Llolleo	3.13 ± 0.31	$2.60*10^{-3}$	1175 ± 120	AD 825
UCTL 1669	EP, U10.1 b	Llolleo	3.07 ± 0.29	$2.76*10^{-3}$	1100 ± 110	AD 900
UCTL 1108	CK1/8-9, c9.1	Bato	1.04 ± 0.22	$1.60*10^{-3}$	1325 ± 130	AD 670
UCTL 1109	CK1/7, c7amp.5	Bato	1.96 ± 0.23	$1.36*10^{-3}$	1440 ± 150	AD 555
UCTL 1110	CK1/6, c6amp-R.6	Llolleo	3.11 ± 0.18	$2.17*10^{-3}$	1435 ± 130	AD 560

[a] B–L = mixed Bato–Llolleo; ECp = undetermined Early Ceramic period context.

successfully to the construction of chronologies in the last 25 years (i.e. Deza and Román, 1986; Berenguer et al., 1988; Bárcena, 1998; Román and Jackson, 1998; Uribe et al., 2007; De La Fuente et al., 2010).

In this study, all TL dating was performed at the Radioactivity and Thermoluminescence Laboratory of the Pontificia Universidad Católica de Chile, using the quartz inclusion technique (Fleming, 1970). Error estimations were calculated using the method proposed by Aitken (Aitken and Alldred, 1972). The annual doses for the environment and ceramic sherds were calculated using a dosimeter with calcium sulfate crystals doped with disprosium ($CaSO4{:}Dy$) (see Deza and Román, 1986). One or two dosimeters to measure the environmental rate of radiation dosage were buried for one year at the edges of each of the farmed fields from which the samples were obtained, as the fields where the archaeological deposits themselves were located, were periodically plowed. While this could limit the accuracy of the results, ^{14}C dates obtained in four Angostura sites also yielded dates within the corresponding TL date ranges, indicating that burying the dosimeters some meters away from the place where the sampled sherds were collected did not significantly affect the dates obtained (Falabella et al., 2014).

The 152 dated samples consist of sherds of ceramic vessels obtained from residential middens. The relevance of this approach lies in the direct association of the date with the artifact and the archaeological occupation. Each date indicates the moment when the vessel to which the sampled fragment belonged was heated for the last time (to at least 500 °C or as low as 300 °C if the duration of heating was long), most probably when the pot was fired or when it was used (Feathers, 2003). Based on ethnographic studies of traditional potters, we can estimate that the average lifespan of most ceramic vessels used in households is between three and ten years, with those used for cooking having a shorter lifespan and those used for storage and ritual events lasting longer (Rice, 1987). In light of this information, the chronological resolution was deemed sufficiently precise for the purposes of this study.

The error limits in thermoluminescence dates are estimated considering each sample's variance and all systematic uncertainties, i.e. the instruments' calibration (Aitken and Alldred, 1972). The laboratory's quoted error is, therefore, the overall predicted error taking into account all quantifiable sources of uncertainty, and is expressed as a percentage of the calculated age that, in our dated samples, has a mean value of ±9.23% ($s = 1.25$). Based upon these error limits we determined the probable temporal range for each date. By analyzing them as pooled series of dates, we built up a summed probability distribution that can be interpreted as a proxy for the variation in the intensity of human occupation in the territory over time.

This kind of reasoning on series of dates has been increasingly employed in recent years in archaeology, though mainly applied to radiocarbon calibrated dates using Bayesian statistics to estimate each date's probabilities or the probabilities of sets of dates (i.e. Gamble et al., 2005; Riede, 2009; Shennan, 2009). There are few published cases of summed probabilities application in TL dating, and these have been focused on other kinds of objectives (i.e. Barnett, 2000). Moreover, summed probability analysis for TL dates differs from its application to series of radiocarbon dates. First, the probable time range in TL dating is an estimated percentage of the age, not a standard deviation as in radiocarbon dating. Second, thermoluminescence gives dates directly in calendar years, without needing to estimate a probability when calibrating dates as in ^{14}C dating. Considering TL's characteristics, we constructed cumulative probability curves for each cultural context in the study area considering each date as a normal probability distribution (Feathers, 2003) and separating them in 10 year intervals. The basic assumptions employed in this study are that each deposit was formed at the same time that its associated residential unit was in use and that time ranges with a higher frequency should correspond to periods with a greater number of occupations.

To represent the chronology, graphs were constructed to display the cumulative probability curves by decade. In all graphs the *X*-

Table 2
Number of dated samples in each sector, site/occupation and cultural context.

	Site/occupation	Bato	Llolleo	Bato and Llolleo	Early ceramic period
Aguila-Peuco	CK10/A		2		
	CK10/B		5		
	CK11/A		4		
	CK11/B		2		
	EP		4		
	Total Aguila-Peuco = 17		17	0	0
Colonia Kennedy	CK1/6		4		
	CK1/7	4			
	CK1/8-9	4			
	CK15/A	4			
	CK15/B	3			
	CK16		2		
	CK18				2
	CK2/N	4			
	CK2/S		4		
	CK3/A			2	
	CK3/B1		4		
	CK3/B2	4			
	CK3/C			2	
	CK4				4
	CK5/A		4		
	CK5/B		4		
	CK5/C				4
	CK6	2			
	CK7		3		
	CK8/A		4		
	CK8/B	4			
	CK8/C			3	
	CK9/A			4	
	CK9/B			3	
	Total CK = 82	29	29	14	10
Valdivia de Paine	VP1/B	1	4		
	VP1/C		4		
	VP2/A		3		
	VP2/B		3		
	VP2/C		3		
	VP3/A		5		
	VP3/B		3		
	VP3/C	4			
	VP3/D	5			
	VP4		3		
	VP5/A	5			
	VP5/B	5			
	Total VP = 53	21	32	0	0
	Total Angostura $N = 152$	50	78	14	10

axis corresponds to the chronology in calendar years and the *Y*-axis expresses the number of deposits likely to correspond to each decade.

5. Results

The decade-based probability curve of the 152 TL samples of the Angostura micro region (Fig. 2) displays a progressive rise until ca. AD 300 when the population density apparently reached one of the highest levels during the Early Ceramic period. After an interval of ca. 400 years (AD 300–700), a new and higher plateau was reached (AD 800–1000) showing the moment of most intensive human occupation. After a rapid decrease ca. AD 1000, the curve plateaus again until AD 1380 when the curve definitely drops down. This general structure, however, obscures important differences in the population dynamics of the Bato and Llolleo occupations, as well as the time period when the three sectors were more intensively occupied. In the following analyses the results are organized by cultural context and sectors of the Angostura micro region, and consequently are based only in the 128 occupations unambiguously identified as Bato or Llolleo.

The decade-based probability curves of the deposits by the Bato and Llolleo groups in the Angostura micro region display interesting differences (Fig. 3). Early on, at AD 60, the Bato curve plateaus out and remains at the same level until AD 65, and then drops to yet another plateau, from AD 790–1240. The Llolleo curve, in contrast, rises gradually up to AD 770, then spikes twice, once between AD 850 and 1070 and again between AD 1300 and 1380.

The occupational trends of these cultural groups are very different from one another in different sectors of Angostura. In Colonia Kennedy, before AD 700, the peaks and troughs of the Bato and Llolleo curves follow the same trend, although with a higher probability among the Bato deposits. After AD 700, the trends diverge and the number of Llolleo dates rises (Fig. 4). In Valdivia de Paine, the Bato and Llolleo curves hardly coincide (Fig. 5). An initial moment can be seen, before AD 700, with higher probabilities for Bato deposits and hardly any for the Llolleo, then in a second moment, post-AD 700, the trend inverts and the probability of Llolleo deposits increases while that of the Bato decreases. In the Águila-Peuco sector, all occupations recorded to date are Llolleo, and while the number of dates ($N = 17$) is rather scant for constructing a cumulative probability curve, the samples seem to be concentrated between AD 630 and 850 and around AD 1300.

Examining the results by sector, without differentiating Bato and Llolleo occupations, other interesting situations can be identified (Fig. 6). For example, there are three pulses indicating an overall decrease in occupational densities: the trough that occurs for Colonia Kennedy around AD 400, determined primarily by a decrease in Bato occupations; the trough in the probability curve for Colonia Kennedy between AD 700 and 770, which coincides chronologically with the moment in which the dates available for Águila-Peuco thus far are concentrated and marks the moment at which the balance between the intensity of Bato and Llolleo deposits shifts in Angostura; and the trough around AD 1250 in Valdivia de Paine, which marks the beginning of a new pulse in the Llolleo occupations and the end of the Bato occupation in all sectors. The decrease in probability curves seen from AD 1250 onward does not reflect the end of the human occupation of Angostura, however, but is rather an effect of the emergence of the Aconcagua culture in Central Chile and on the exclusion of such occupations in this study.

6. Discussion

In their general outline, the dates obtained for Early Ceramic occupations in the Angostura micro region show irrefutably that the Bato and Llolleo were contemporaneous and that the Bato emerged slightly earlier, as would be expected judging by dates obtained elsewhere in Central Chile (Falabella and Stehberg, 1989; Vásquez et al., 1999; Sanhueza et al., 2003). Importantly, these results clearly indicate that the end dates for these cultural units are significantly later than those previously proposed (Falabella and Stehberg, 1989), and extend into the first half of the second millennium of our era, which means that these groups, particularly the Llolleo, coexisted for at least 400 years with the agricultural Aconcagua groups, which had a markedly different culture.

The main contribution of our results, however, is that they offer a perspective at the local scale based on comparing the chronology of inhabited places and allowing the shapes of the curves and their pulses to illustrate population changes during the Early Ceramic period. Starting from the premise that the cumulative frequencies of probabilities can be linked to higher or lower numbers of

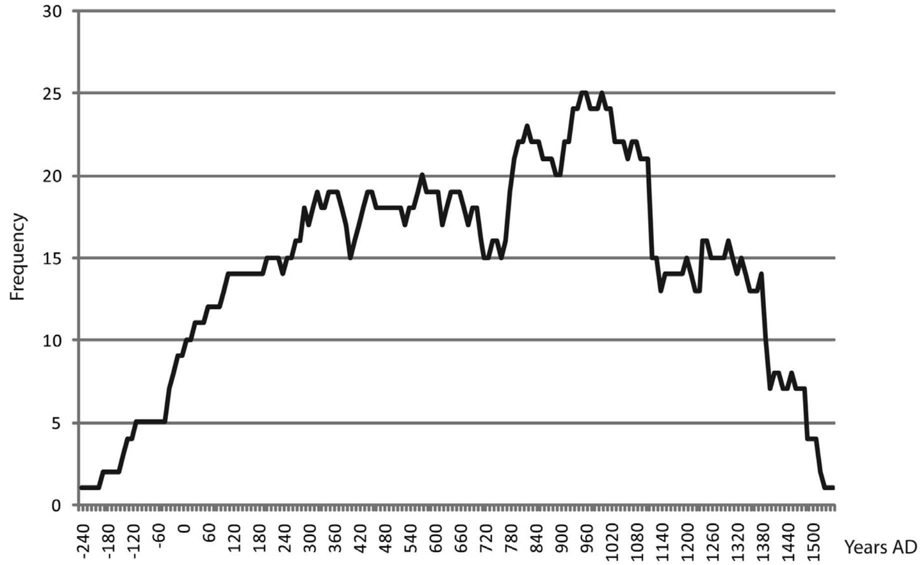

Fig. 2. Cumulative probability curve by decade of the Early Ceramic period occupations ($N = 152$) in Angostura micro region.

inhabited sites in these localities, the results indicate significant differences as well as changes in Bato and Llolleo population dynamics at the micro regional level. To understand these changes, we will now consider some aspects of the subsistence-settlement system and sociopolitical organization and the environmental conditions of the period.

Spatially, the Bato and Llolleo were organized into co-residential units that were spatially disperse but had a certain degree of grouping at the level of the residential community and the locality (Falabella et al., 2014). Both of these peoples were horticulturalists. In the case of the Bato, the macrobotanical remains recovered from sites in Central Chile show that they relied heavily upon wild resources and their main food crop was quinoa (*Chenopodium quinoa*). Maize (*Zea mays*) has been recorded in small quantities and does not appear in all sites. Stable isotope analyses of Bato individuals are coherent with archeobotanical findings, both indicating a predominance of C3 plants and revealing that maize was consumed only rarely and irregularly (Falabella et al., 2008). Of major interest is that direct dates for Bato human remains shown to have consumed maize, obtained with enriched ^{13}C, are all later than AD 500 (Planella et al., 2013). Contrastingly, in the Llolleo sites quinoa and maize are recurrent, associated with beans (*Phaseolus* sp.), gourds (*Lagenaria* sp.) and squash (*Cucurbita* sp), at least as early as ca. AD 500 (Planella and Tagle, 2004), a very common feature of groups that already relied on horticulture for their subsistence. Furthermore, documented changes indicate the introduction of new varieties of maize after AD 900 (Planella, 2005; Falabella et al., 2010; Planella et al., 2013). Stable isotope studies confirm that maize was part of the Llolleo subsistence base (Falabella et al., 2008; Tykot et al., 2009).

This point of comparison is relevant because quinoa and maize have different requirements. Quinoa adapts well to different conditions; even to rainfed farming, and does not require a substantial amount of care between sowing and harvesting, making it

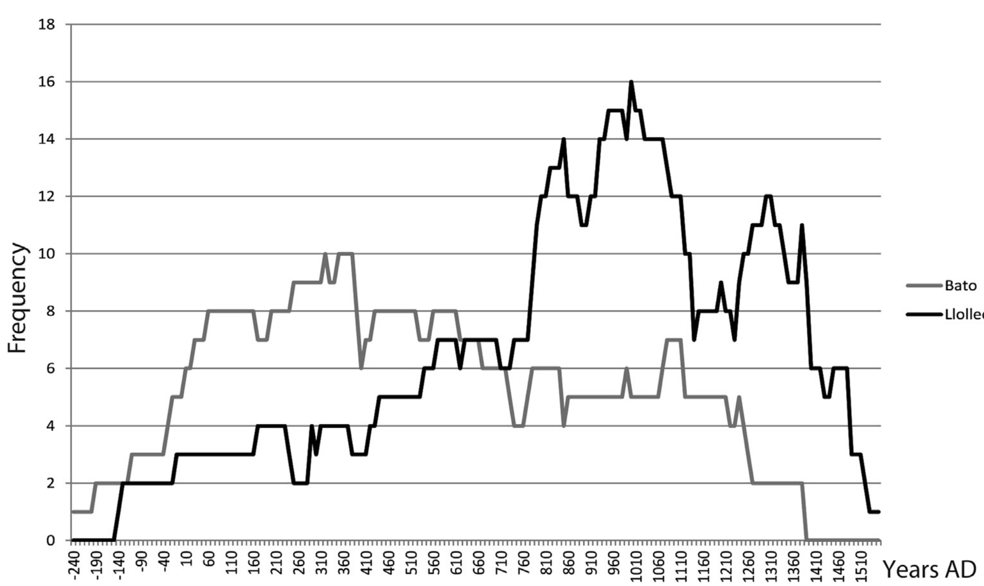

Fig. 3. Cumulative probability curves by decade of the Bato and Llolleo occupations in Angostura micro region (Bato samples $N = 50$; Llolleo samples $N = 78$).

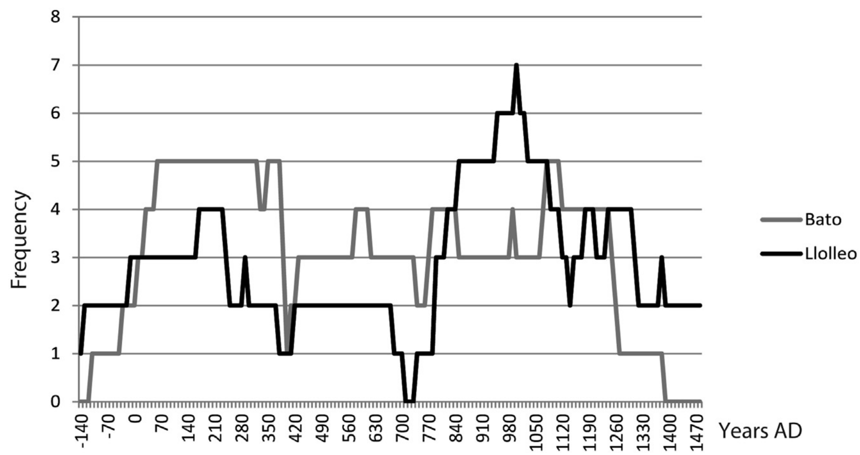

Fig. 4. Cumulative probability curves by decade of the Bato and Llolleo occupations in Colonia Kennedy sector (Bato samples $N = 29$; Llolleo samples $N = 29$).

compatible with a settlement system that includes residential mobility (Tagle and Planella, 2002; Carrasco and Bazile, 2009; Planella et al., 2010). Maize, on the other hand, though adaptable to different conditions, needs more intensive care, including more watering to ensure a good harvest, which means that groups growing this crop must remain near their gardens and therefore would tend to have a more sedentary residential pattern (Planella et al., 2010; Planella and Falabella, 2013).

Conditions throughout the Angostura micro region were favorable for the settlement of small groups of horticulturalists, whatever their technology. The soil was fertile; water was readily available in lakes, freshwater springs, spring-fed streams, and rivers that inundated the land when they swelled, and thereby providing the moisture required to grow crops (Venegas, 2006). Even today in Central Chile, such lands and conditions are considered to be ideal for growing quinoa, maize, beans, and potatoes (Planella et al., 2010). Even so, each sector within the micro region had its own particular features: Colonia Kennedy had the largest tracts with abundant surface moisture, Valdivia de Paine benefited from inundation by the Maipo and Angostura rivers and from springs and spring-fed streams, and Águila-Peuco had the waters of the Angostura/Peuco river to offset the lack of accessible groundwater in this sector.

In this context, then, the population histories of the Bato and Llolleo peoples revealed in the date curves appear quite different from one another. On the one hand, the Bato occupation reached its peak intensity around AD 360 after a quick rise that began 410 years before. After peaking, the population began to slowly and steadily decrease until AD 1270. Meanwhile, throughout most of the Bato population's peak period in Angostura, the Llolleo groups were present at a much lower frequency; beginning in AD 770, however, their population begins to rise rapidly to its own peak, 280 years later. After this peak, in contrast to the Bato, the number of Llolleo occupations drops as abruptly as it rose, until AD 1230, when it seems to rise slightly again to a lower peak in AD 1300 and then drops again at the beginning of the 15th century.

It is worth interpreting these differences in light of the cultural and social developments mentioned above for these populations, which had different emphases in their subsistence patterns and different historical trajectories. To begin, the way the Llolleo probabilities are distributed can be linked to two factors. First, the Llolleo groups began with maize-based horticulture in Central Chile. While initially this crop may have been grown for ritual purposes, during the second half of the first millennium of the present era it became a major food crop (Falabella et al., 2008) that had the potential to increase the population, a factor that could have triggered the abovementioned rise in dates that began in AD 770. Indeed, it is precisely in this period that larger and denser settlements are observed in Valdivia de Paine, indicating that the population was higher and more concentrated (Sanhueza, 2013).

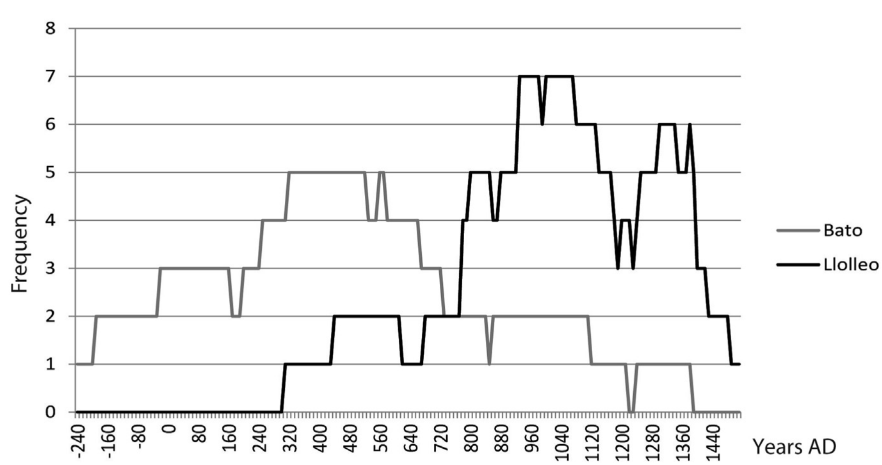

Fig. 5. Cumulative probability curves by decade of the Bato and Llolleo occupations in Valdivia de Paine sector (Bato samples $N = 21$; Llolleo samples $N = 32$).

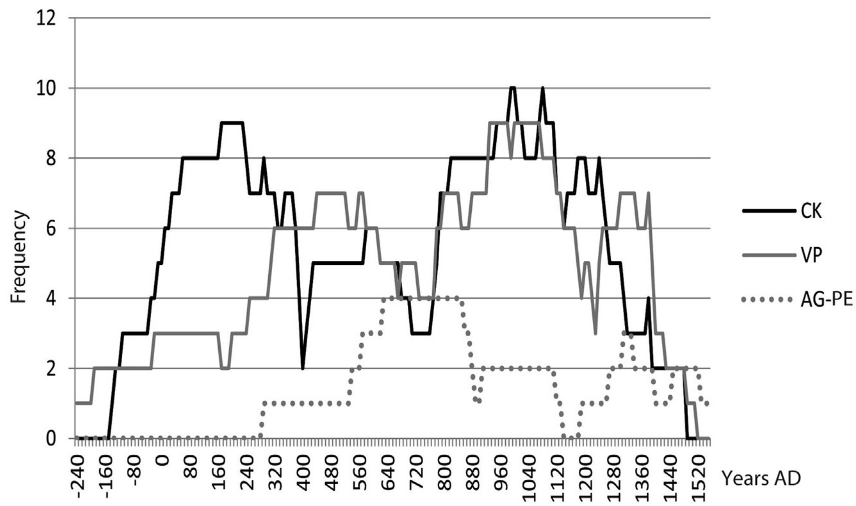

Fig. 6. Cumulative probability curves by decade of both Bato and Llolleo occupations in Valdivia de Paine (VP), Colonia Kennedy (CK) and Aguila-Peuco (AG-EP) sectors (CK samples $N = 58$, VP samples $N = 53$, AG-PE samples $N = 17$).

This process coincides with the successful diversification of crops and the siting of settlements in sectors that do not necessarily have available surface water, at least in this area. Second, the rapid drop that occurs after AD 1000 could be associated with the emergence of the Aconcagua culture in the region, whose cultural and economic development was markedly different from those of the Bato and Llolleo peoples under study in this paper.

For their part, the Bato, whose way of life was based more on hunting and gathering and linked to quinoa cultivation, had a different sociopolitical dynamic with no large settlements that could point to an increase in the size of their permanent residential complexes. The drop in Bato occupations after AD 770 occurs only in Valdivia de Paine, which is the same time and place in which the Llolleo occupation begins to show larger scale residential sites that probably held more people. This development no doubt affected the Bato's possibilities for occupying this area and the characteristics of their settlements. Certainly, these processes reconfigured the local socio-territorial panorama and influenced the occupational possibilities and decisions of both groups in that space. Thus, the Bato and Llolleo occupation of this micro region should be understood in the context of how the processes occurring within each of these groups were unfolding, and how they affected each other. Accordingly, the population panorama of these groups could essentially be an effect of their individual cultural evolution and of the coexistence of different populations, which seems to have been the norm in Central Chile before the arrival of the Incas (Sánchez et al., 2004; Cornejo and Sanhueza, 2011).

Furthermore, if we take into account environmental conditions, the decrease in occupations associated with the lakeside environment of Colonia Kennedy around AD 400 and around AD 700, that affected the Early Ceramic period occupations, suggests that there may have been a local environmental constraint—some event or condition(s) that prevented or hindered the feasibility of household or horticultural activities associated with the residential complexes situated in those places. Changes in environmental conditions could have affected Bato and Llolleo horticulturalists differently, as they had different practices, crops, technologies and types of settlements. It is also possible that areas closest to lakes and wetlands, such as Colonia Kennedy, were uninhabitable during times when El Niño was more prominent, owing to the increased rainfall and the resulting flooding, which would have hindered horticulture by flooding their gardens. It is also possible that the opposite kind of climatic event—a pronounced and prolonged drought—could have decreased soil moisture dramatically, affecting horticultural practices that relied on such moisture for horticulture. While the present scale and detail of paleoclimatic information and chronology does not allow us to relate the fluctuations described for Laguna de Aculeo to variations in occupational density in the Angostura micro region, our data shows that Llolleo groups occupied the fluvial terraces in the Águila-Peuco sector at times when the occupational density at Colonia Kennedy dropped, which could indicate that these groups moved their settlements to less flood-prone territories during such times. However, the same does not occur with the Bato, probably because their horticultural technology relied to a great extent on the natural moisture of the soil and during such times they would have had to move their settlements to other places having wetter conditions, most probably located beyond the area we analyzed in this paper.

7. Conclusions

The method used to determine the probable fluctuations in occupational density has enabled us to identify a complex process that unfolded over the nearly 1500-year occupational history of this region. While these events were identified for the micro local scale in which we worked, they could also be useful for formulating some general hypotheses that could put into perspective the population histories of groups living during the Early Ceramic period in Central Chile.

It is evident that their different ways of life led the Bato and Llolleo groups to construct different histories while sharing the same very small territory. Accordingly, the natural growth of the Bato population is represented in an upward curve that reaches a peak and then declines steadily over time, but without any dramatic events. For their part, the Llolleo groups may have dramatically increased the scale of their development at a certain point by choosing to emphasize maize as a horticultural crop, and increased their population significantly as a result. As the population peaked, the Llolleo faced the emergence of a new society in the region, one that very likely grew out of a powerful cultural change in a segment of their own society (Massone, 1978; Cornejo, 2010). This development, at a time in which Central Chile was inhabited by three distinct social groups, the Bato, Llolleo and Aconcagua, not to mention the hunter-gatherer groups that occupied parts of the

Andes mountains (Cornejo and Sanhueza, 2003), marks the abrupt decline of the Llolleo people and very likely explains its demise to a large degree. Nevertheless, these three groups would continue to coexist for at least 300 years.

On a more local scale, the differences observed in Bato and Llolleo historical trajectories and spatial distribution could have been caused by factors such as the availability of surface water, which was different in the three localities indicated. Nevertheless, we do not have sufficient data to propose that episodes involving a substantial increase in precipitation provoked flooding that influenced the decision to temporarily abandon certain sectors of Angostura, or that periods of prolonged drought had the same effect.

Looking at a territorial scale as small as the one considered has provided the opportunity to visualize what happens within a micro region, but limits our comprehension of the spatial mobility of these populations, as their territories extended beyond the area studied. Future investigations should focus on expanding this territorial scale and conducting the same type of analysis on other regions of Central Chile, as well as on obtaining more precise information on paleoclimatic fluctuations in the zone.

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