

DATING THE EXPANSION OF THE INCA EMPIRE: BAYESIAN MODELS FROM ECUADOR AND ARGENTINA

Erik J Marsh^{1*} • Ray Kidd² • Dennis Ogburn³ • Víctor Durán¹

¹CONICET, Laboratorio de Paleo-Ecología Humana, Facultad de Ciencias Exactas y Naturales, Universidad Nacional de Cuyo, Mendoza, Argentina.

²Library and Historic Collections Department, University of Aberdeen, King's College, Aberdeen AB24 3FX, United Kingdom.

³University of North Carolina at Charlotte, Department of Anthropology, 9201 University City Blvd., Charlotte, NC 28223, USA.

ABSTRACT. The chronology of the Inca Empire has traditionally relied on ethnohistoric dates, which suggest that a northern expansion into modern Ecuador began in AD 1463 and a southern expansion into modern Argentina began in AD 1471. We test the validity of these dates with two Bayesian models, which show that the ethnohistoric dates are incorrect and that the southern expansion began before the northern one. The first model of seven dates shows that the site of Chumbe, Ecuador, was first occupied *cal AD 1410–1480 (95% probability)* and has a high probability of being built prior to the ethnohistoric date. The second is an outlier model of 26 ¹⁴C dates and 19 thermoluminescence (TL) dates from 10 sites along the empire's southeastern limit in northwestern Mendoza, Argentina. Here, the Inca occupation began *cal AD 1350–1440 (95% probability)*, also earlier than the ethnohistoric date. The model also suggests that the Inca occupation of Mendoza lasted 70–230 yr (95% probability), longer than previously thought, which calls for new perspectives on the timing and nature of Inca conquests and relationships with local groups. Based on these results, we argue it is time to abandon the traditional chronology in favor of Inca chronologies based on Bayesian models.

KEYWORDS: Inca chronology, Inca Empire, southern expansion, Bayesian modeling, Mendoza.

INTRODUCTION

The traditional chronology of the Inca Empire is primarily based on the three Spanish accounts of Inca oral history that included chronological information: Cabello Balboa (1945), Betanzos (1987), and Sarmiento de Gamboa (2007). Archaeologists have long relied on Rowe's (1944, 1945) interpretation that privileges Cabello Balboa's dates (see Tantaleán 2015: 14). This chronology has its limitations but for many years there was no viable alternative. The most likely candidates, calibrated radiocarbon or thermoluminescence (TL) dates, have error ranges that are often greater than the historically recorded duration of the empire, making them unlikely prospects for improving the situation (McEwan 2008: 53). However, this limitation can be overcome by using Bayesian models, which treat dates in aggregate rather than individually (Bronk Ramsey 2009a). The growing body of calibrated ¹⁴C and TL dates hints that Cabello Balboa's chronology underestimates the date of Inca expansions out of Cuzco, especially to the south (e.g. Pärssinen and Siirriäinen 1997; D'Altroy et al. 2007; Cornejo 2014), but Bayesian models have not been used to test this. Various problems with the traditional chronology and the potential of Bayesian models suggest that it is time to abandon Cabello Balboa's chronology and give priority to radiometric dates, as argued by Ogburn (2012: 231), whose recent article motivated this re-evaluation of dates from Mendoza, Argentina.

Toward an improved chronology of imperial expansion, we present two case studies from near the northern and southern extremes of the empire, in modern Ecuador and Mendoza, Argentina, respectively. These case studies illustrate three methodological issues relevant for Bayesian models of Inca dates. The model from Ecuador highlights the benefits of stratigraphic priors and using the appropriate calibration curve at a single site, while the model from Mendoza uses an outlier analysis to address both ¹⁴C and TL dates from multiple sites. Refined dates of the initial Inca occupation of both locations lead to a re-evaluation of the chronology of imperial expansion (Figure 1).

*Corresponding author. Email: emarsh@mendoza-conicet.gob.ar.

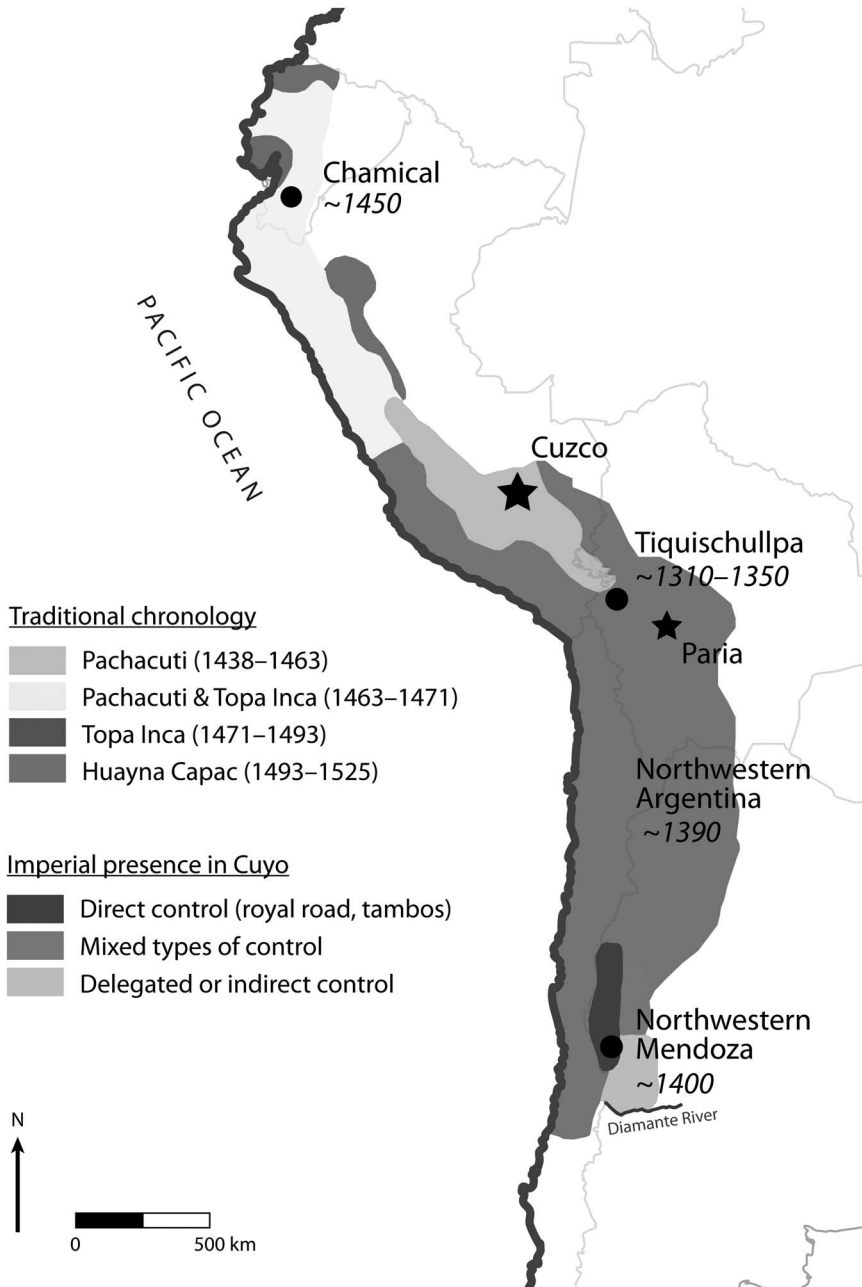


Figure 1 Map of the Inca Empire in western South America, based on Ogburn (2012: Figure 1). Modern countries are outlined in gray. The traditional chronology is from Rowe (1945). Inca control in the Cuyo region (the Argentine provinces of Mendoza, San Juan, and San Luis) is based on García's (2011b) proposal. Dates on the map are the median results of four Bayesian models of Inca dates, which indicate the beginning of Inca occupation in the area. This simplification is for the sake of the figure and does not disregard the probability ranges associated with each median. All dates are AD.

DEVELOPING A CHRONOLOGY FOR THE EXPANSION OF THE INCA EMPIRE

For more than half a century, Rowe's (1944, 1945) landmark publications have been the authoritative version of Inca chronology (Figure 1). This traditional chronology is based primarily on the dates of the chronicler Cabello Balboa (1945), which were the "most plausible" at the time (Rowe 1945: 277). However, Cabello Balboa's information has a series of problems. One possible reason Cabello Balboa even attempted an absolute chronology was to synchronize Inca and European histories (Julien 2000: 225). Only two other chroniclers proposed absolute dates for the Inca, most notably Sarmiento de Gamboa (2007), who offers an unrealistic chronology based on a subjective and eclectic mix of dates from the Bible, Greek texts, the Spanish royal line, and interviews (González Díaz 2015: 170–3). Cabello Balboa may have had similar influences, though this remains unclear because he does not report the source of his information (Rowe 1945: 277; Julien 2000: 223; Ogburn 2012: 230–1).

It seems unlikely that Cabello Balboa had access to absolute dates that other chroniclers did not. According to another chronicler, local people did not give much importance to linear time: "they did not count their age in years; neither did they measure the duration of their acts in years; nor did they have any fixed points in time from which to measure historical events" (Cobo 1979: 252). This is also evident in the Spanish interviews conducted in Cuzco in 1571, which included questions on the royal Inca chronology (Julien 2000: 223–8; González Díaz 2015: 164–6). Responses were inconsistent and included implausibly long lifespans of 100 and 130 yr (Rowe 1945: 277). In fact, there is no convincing evidence that there were any prehispanic linear calendars in the Andes, so Cabello Balboa's dates were probably his own estimates (Bauer 1992: 38).

The sequence of conquered territories may not be correct either, as Inca histories do not appear to have been especially concerned with chronology. Instead, they relied on standardized narrative sequences (Ogburn 2012: 232–3), as would be expected for a principally oral history. Similar versions of royal Inca history are recorded in many sources, but perhaps most reliably in a set of voluntary interviews of direct descendants of the emperor Topa Inca and two of his brothers (Rowe 1985: 193–9). These are more reliable than other chronicles for a number of reasons, not least because they are based on *khipus*, the Incas' knot-and-string recording devices. While none of the descendants mention specific dates, they all list the conquered quarters in the same geographic order: Chinchaysuyu, Antisuyu, Collasuyu, and Condesuyu (Rowe 1985: 197). The same order is followed in other chronicles as well as lists of shrines (Pärssinen 1992: 75; Julien 2000: 132). Because the quarters are always listed in the same order, it initially seemed reasonable to assume that this was a chronological listing of events (Ogburn 2012: 232). However, conquered territories were often treated as accomplishments of each emperor and in these accounts, "genealogy, *not* chronology, is what gives the historical narratives their temporal order" (Julien 2000: 52, our emphasis). Hence while the chronicles do include rich and useful information, the sequence of conquered territories seems to be a geographically ordered narrative device that does not offer reliable chronological information (Ogburn 2012: 232–3).

This standard order of conquests and Cabello Balboa's dates are the foundation of Rowe's chronology, but elements of Inca oral histories may not have been exactly historical in the western sense and some scholars have suggested they are more mythical in nature (e.g. Zuidema 1982: 174). These underlying problems have gone unaddressed by many but not all (e.g. Bauer 1992: 38; Pärssinen and Siiriäinen 1997: 255–6), in part because there was no promising alternative for building an Inca chronology. The only possibility was radiometric dates, but the

empire's historic duration, at least according to Cabello Balboa, was shorter than the error range of most ^{14}C and TL dates. Hence, some researchers deemed it an unnecessary expense to process dates and continued to rely on Rowe's chronology (see Bauer 1992: 36–40).

Rowe's chronology places the conquest of the southern quarter, Collasuyu, mostly during the reign of Topa Inca, AD 1471–93 (Figure 1). However, growing sets of calibrated ^{14}C and TL dates from a number of sites in modern Bolivia, Chile, and northwestern Argentina suggest that Collasuyu was conquered earlier (Stehberg 1992; Pärssinen and Siiriäinen 1997; Muñoz Ovalle and Chacama Rodríguez 1988; Williams and D'Altroy 1998; Schiappacasse 1999; Leibowicz and Jacob 2012; D'Altroy et al. 2007; Lynch 2012). In recent years, statistical treatments of calibrated dates have shown that Inca expansion both north and south of Cuzco was earlier than Cabello Balboa's dates (Michczyński and Pazdur 2003; Ogburn 2012; Cornejo 2014). These include summed probability distributions, which have recently become popular, but have methodological limitations that are not always fully considered (e.g. Williams 2012). Even so, calibrated date ranges are consistent and suggest that the southern expansion into northern Chile and Argentina began cal AD 1370–1400. These dates cast doubt on Rowe's chronology and the sequence of conquests in ethnohistoric sources.

The next step in evaluating Rowe's chronology and building a reliable Inca chronology is the use of Bayesian models (Bronk Ramsey 2015). These models incorporate archaeological information and multiple dates to produce more reliable chronological estimates. They seem to be the only viable alternative for improving our chronology of the Inca. If we continue to rely on individual date ranges or summed probability distributions, additional dates may actually make the Inca period appear longer than it really was (see Bronk Ramsey 2003). Before Bayesian models or hemisphere-specific calibration curves were available, the Inca ^{14}C chronology could not effectively evaluate Rowe's dates (Adamska and Michczyński 1996: 50). Bayesian models should be the standard for working with Inca dates and offer an effective counter to doubts of an Inca chronology based on radiometric dates. To date, only two Bayesian models have been analyzed with Inca dates: one set of dates from a site in Ecuador (Ogburn 2012: 225–8) and a regional set of 33 dates from northwestern Argentina (Greco 2012: 408–11). Both are single-phase models that produced starting dates that were earlier than Balboa's chronology by 1–2 decades in Ecuador and nearly a century in Argentina.

METHODOLOGICAL ISSUES FOR BAYESIAN MODELS OF INCA DATES

Bayesian models have great potential to improve Inca chronologies, but like all models, they are only as good as the underlying assumptions (Bayliss and Bronk Ramsey 2004; Bayliss 2015; Buck and Meson 2015; Pettitt and Zilhão 2015; Wood 2015). It is important to include TL dates when they are available because they can directly date Inca-style ceramics and are free of the potentially ambiguous association between diagnostic ceramics and ^{14}C samples (Waterbolk 1971; Greco and Palamarczuk 2014). In this paper, we attempt to follow recently published reporting guidelines for dates and models (Millard 2014; Bayliss 2015), but legacy data often do not include all the relevant details, for example, $\delta^{13}\text{C}$ values, which were often neither measured nor reported. We use “cal AD” to refer to calibrated dates and *italicize* modeled dates, followed by their posterior probability and the name of event in the model (see Bayliss et al. 2007: 5). Models were run in OxCal v 4.2 (Bronk Ramsey 2009a) and dates were rounded by 10 yr. Multiple runs of the same model can have slightly different results, given the probabilistic nature of Markov chain Monte Carlo analysis. Multiple runs of the models presented were robust, showing minor differences of no more than a decade. Here, we address three relevant methodological issues: detailed stratigraphic sequences, choosing the most appropriate calibration curve, and dealing with outliers.

First, it is important to incorporate prior information such as stratigraphic sequences (Bayliss 2009; Bronk Ramsey 2009). Bayesian models merge this information with dates to arrive at posterior estimates, that is, prior assumptions \times probability distributions = posterior beliefs, or in other words, archaeological information (e.g. stratigraphy) \times radiometric dates = more accurate temporal estimates (see Bayliss 2009: 127–32). In the case of legacy data, detailed archaeological information is not always available, but basic assumptions can still significantly improve a site's chronology. For example, all the dates from a site can be grouped in a single phase, and the starting and ending boundaries of the phase are useful estimates of when the site was founded and abandoned, respectively.

The second issue is which calibration curve to choose, IntCal13 (Reimer et al. 2013) or SHCal13 (Hogg et al. 2013). The curves differ by around 20 yr for Inca-period dates, which is a small but relevant difference (Adamska and Michczyński 1996: 38; Ogburn 2012: 223). The Inca Empire is mostly located in the Southern Hemisphere, so SHCal might seem appropriate, but atmospheric mixing near the equator can extend as far south as Lake Titicaca, where IntCal is a better choice (see Finucane et al. 2007:581; Marsh 2012: 205–6, 2015: 15–6). Currently, there are insufficient data to identify which curve is most appropriate for the northern and central parts of the Inca Empire. To deal with this, Ogburn (2012: 227–8) compares results from both curves and suggests using a mixed curve that allows the full range of both IntCal and SHCal. We adopt a mixed curve because it provides more accurate dates, even though they are less precise in some parts of the curve (C Bronk Ramsey, personal communication, 2015). Accuracy is a priority because Inca chronologies are directly linked to events with reliable calendar ages, such as Pizarro's AD 1532 landing on the Peruvian coast.

To illustrate the benefits of modeling a stratigraphic sequence and using an appropriate calibration curve, we present a revised Bayesian model of the site Chamental in Ecuador (Appendix A, online Supplemental Data). The model mixes the IntCal13 and SHCal13 calibration curves. The site has seven dates with sufficient stratigraphic information to model a sequence of three phases (Table 1; see additional details in Ogburn 2012: 225–8, Table 2). After the starting boundary, the first phase is the site's construction, comprising two dates from posts (UGa-3457, UGa-8801) and one from the mortar of the outer wall (UGa-3458). Next, there was a prepared clay floor, stratigraphically separating the first two phases. The second phase is probably of the site's later occupation and subsequent destruction, which comprises three charcoal dates from above the floor, perhaps of burned roof material (UGa-8803, UGa-3459, UGa-8802). Cane roofs were often replaced and this material was likely harvested after the construction of the structure and before its abandonment. Next is a boundary that marks the end of the Inca occupation of the site. Finally, the latest date is from rubble that filled the primary entrance of the enclosure (UGa-3460), which postdates its use, most likely in the early Colonial period.

The model has an acceptable agreement index (121) and estimates the starting boundary as *cal AD 1430–1460 (68% probability)* and *cal AD 1410–1480 (94% probability, Start Inca occupation)*. Querying the model with the Difference command, we can compare this date with Cabello Balboa's date of AD 1463. There is a high probability (89%) that Chamental was founded before AD 1463. The model reduces the error ranges of individual dates to 10–15 yr for six of the dates. The site's occupation lasted *<30 yr (68% probability)* and ended *cal AD 1450–1500 (68% probability, End Inca occupation)*. This means that the site was probably abandoned while the Inca were still occupying other parts of Ecuador. The Inca army may have consolidated this area before continuing north, or perhaps they felt a small-scale military presence was only necessary to secure the area for a short period. It was likely built as an outpost during the military advance into Ecuador, so its starting date is a reliable estimate of the initial Inca incursion into the

Table 1 Dates and sequence used in the Bayesian model of Chamental.

Phase or boundary	Lab code (UGa-)	$\delta^{13}\text{C}$ (‰)	^{14}C age	\pm	Material and context
Start Inca occupation					
Construction	3457	-26.1	450	30	Wood fragment from the outermost layer of a post underneath a prepared clay floor, unit 2-B
	3458	-11.4	450	25	Seed fragments extracted from mortar of the northeast enclosure wall
	8801	-25.5	410	25	Wood fragment of post below prepared floor, unit 2-C
Burning, above floor	8803	-23.8	440	25	Charcoal from an ash layer above prepared floor, unit A, depth 100–110 cm
	3459	-26.4	410	25	Charcoal from burnt cane or reed (roofing material?), from above prepared clay floor, unit 2-A
	8802	-25.6	380	25	Charcoal from burnt cane or bamboo, above floor, unit 2-A
End Inca occupation					
Post-Inca use of site	3460	-25.2	300	25	Charcoal from within rubble filling primary entrance into the compound, unit 4-A

The sample $^{13}\text{C}/^{12}\text{C}$ ratios were measured separately using a stable isotope ratio mass spectrometer and expressed as $\delta^{13}\text{C}$ with respect to PDB, with an error of less than 0.1‰. Dates were corrected for isotope fractionation.

Table 2 Dated Inca sites in Mendoza.

Site	Description	¹⁴ C dates	TL dates
Ciénaga de Yalguaraz	Secondary site on Inca road	5	3
Tambillos	Inca tambo	5	5
Ranchillos	Inca administrative center	6	6
Tambillitos	Inca tambo	2	2
Agua Amarga	Secondary Inca site	1	3
Cerro Aconcagua	Inca sacrifice (child mummy)	2	
Agua de la Cueva	Rock shelter with Inca ceramics	1	
Cerro Penitentes	Tertiary Inca site	1	
Potrero Las Colonias	Burial with Inca ceramics	1	
Odisa	Burial with Inca ceramics	1	
	Total	26	19

region (Ogburn 2012: 225–6). It also agrees well with the documented-based expectation that the Inca occupied Ecuador before Huayna Capac's birth in Ecuador in AD 1457 or 1458 (Ogburn 2012: 231), also prior to Cabello Balboa's date of AD 1463. Additional models of nearby sites and quantified comparisons would make it possible to piece together details of the invasion and consolidation within Ecuador with more veracity than documentary sources.

The third methodological issue is dealing with potential outliers (Bronk Ramsey 2009b), particularly important for shorter periods like the Inca Empire. Given the need to reassess the Inca chronology with ¹⁴C dates, we must now contend with outliers. Apparent outlier dates can be identified subjectively, as Greco (2012: 409) does in his model of Inca dates from northwestern Argentina. Here, we use outlier models to both detect outliers for manual removal and down-weight outliers that remain in the model (Bronk Ramsey 2009b: 1024). These models are an effective way to deal with dates of unexpected ages when the reason for the unexpected age is unclear, for both ¹⁴C and TL dates (Bronk Ramsey 2009b: 1023–4). We use the General Outlier model because we had no reason to justify a specific outlier model (Bronk Ramsey 2009b: 1028). An outlier model was appropriate for quantitatively evaluating the legacy data from Mendoza.

THE INCA OCCUPATION OF MENDOZA: PREVIOUS STUDIES AND CHRONOLOGY

The clearest material indicators of the Inca occupation in Mendoza are found in the Uspallata Valley (Figure 2). They include Inca-style ceramics, rectilinear stone structures, and sites connected by the royal road, which were recognized by early historians and archaeologists (Morales Guiñazú 1938; Aparicio 1940; Rusconi 1962: 232–63). The valley sits at 1700–2100 m asl and is located in the northwestern corner of the Province of Mendoza near the Chilean border (Figures 1, 2). The valley was near the southern limit of the empire and is also the southern limit of the puna environment with which the Incas would have been most familiar. This valley and surrounding highlands are attractive to human settlement and have been occupied since the Late Pleistocene (García 2003). The region's principal river flows along the valley's southern edge. Following the river valley west is the simplest route for crossing the Andes at this latitude, and a string of small Inca sites over this mountain pass suggest they also used this route.

The bulk of Inca research in Mendoza has been directed by Bárcena (1979, 1988, 1998a, 1998b, 2008; Bárcena and Román 1990; Bárcena et al. 2013), though recent studies have seen a reinvigorated interest by other scholars (e.g. Ots and Cahiza 2013; see reviews in García 2009, 2011a).

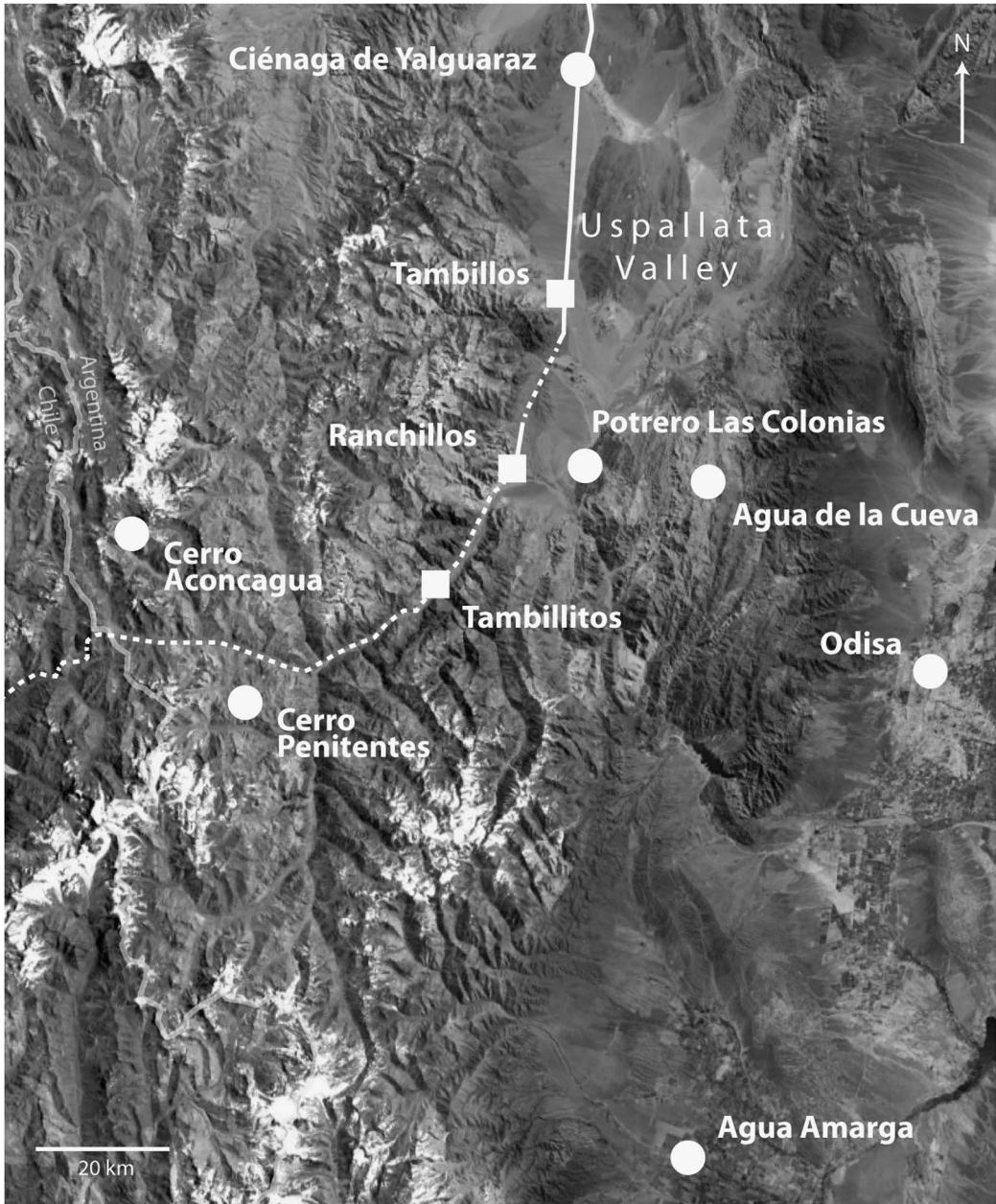


Figure 2 Map of dated Inca sites in Mendoza. Tambos with Inca architecture are indicated as squares, other sites as circles. The white line indicates the extant (solid) and likely (dotted) portions of the Inca road.

Bárcena tracked the Inca road and excavated the principal sites in the Uspallata Valley, including the large site of Ranchillos (Rusconi 1962; Bárcena 1998b).¹ From there, the road then turns west into

¹There is another dated Inca site, Potrero de La Chanchería, located the modern town of Uspallata east of Ranchillos. Surface collections included painted Inca and other late period sherds, ground stone, and projectile points (Rusconi

the mountains, along which there are a few smaller sites (Durán et al. 2011), including the child sacrifice on Aconcagua Mountain (Fernández et al. 1999; Schobinger 1999, 2001). The name of the valley has Quechua roots (Canals Frau and Semper 1956: 8; García 2011b: 58), unlike other regional place names that have roots in Huarpe, the local language and culture that was present when the Inca arrived (Michieli 1983). There were translators between Huarpe and Quechua in the second half of the 16th century, who may have been brought in with *mitmaqkuna*, laborers relocated from elsewhere in the empire (Canals Frau 1943: 303–5, 1946: 40, 46, 1956:8; Michieli 1983:107; García 2011a: 168). Based on historical documents, Bárcena (1994: 27, 39–41) suggests that Uspallata might have been the name of an important Inca person and that the Incas may have considered it part of an administrative division or imperial province named Cuyo, which is the current name of the region.

Inca architecture has been identified at only three sites in the Uspallata Valley, and there is little evidence of direct Inca presence at other sites. Historical documents hint that their influence extended to the populations living in lower-altitude valleys to the south and east, though the nature of this influence remains under debate (Bárcena 1994; Cahiza and Ots 2005; Parisii 2005; García 2011a, 2011b; Ots and Cahiza 2013). One likely material expression of this influence is the production of Viluco pottery, which seems to be a local variant of Inca ceramic techniques and styles (García 1992, 1996, 1999; Prieto Olavarría and Chiavazza 2009, 2015; Prieto Olavarría 2012). The debated chronology of Viluco pottery and its relation to the Inca and Spanish empires is an excellent example of an issue that could be tackled with Bayesian models.

Despite sustained interest in the Inca occupation of Mendoza, its chronology has not been a point of discussion. Bárcena (1979, 1994, 1998a, 2008) and his students (Cahiza and Ots 2005; Parisii 1994, 2005; Ots and Cahiza 2013) have consistently relied on Cabello Balboa's date of AD 1471 for the Incas' arrival, often rounded to AD 1470 or 1480, even though radiometric dates from adjacent regions are consistently earlier (Stehberg 1992; Muñoz Ovalle and Chacama Rodriguez 1988; Williams and D'Altroy 1998; Schiappacasse 1999). A series of ^{14}C and TL dates from Inca ceramics and sites in Mendoza have been processed, but they have only been used in equivocal comparisons to Rowe's chronology (Bárcena 1998a). Despite thorough reference to historical documents (Bárcena 1994; Parisii 1994), the radiometric dates have not been critically evaluated nor have they been used to improve our understanding of Inca chronology. The unquestioned veracity of AD 1471 may be the result of decades of academic inertia, deference to historical documents, or the clear advantage of uniformly following Rowe's chronology, which avoids the "wide inconsistency in the chronological information embedded in the historical sources" (Ogburn 2012: 231), not to mention the error ranges of radiometric dates. While this chronology was certainly the "most plausible" (Rowe 1945: 277) before ^{14}C dating was possible, it should be treated as a hypothesis to be tested (Pärssinen and Siiriäinen 1997: 256–7). We do this with Bayesian models of dates from Mendoza.

MATERIALS AND METHODS: A BAYESIAN MODEL OF INCA DATES IN MENDOZA

We use Bayesian models of the Inca dates in Mendoza to test to the hypothesis that the Inca arrived earlier than AD 1471. We can safely use the SHCal calibration curve, as Mendoza is well south of the area that may be affected by the Northern Hemisphere's atmosphere. The ending boundary of the models was constrained by a date of AD 1595, when two first-hand travelers' accounts describe

(Note continued)

1962: 206–10). A more recent surface collection of 2161 sherds reported that 52% were decorated, one of the highest percentages of all Inca sites in Mendoza, second only the largest site, Ranchillos (Bárcena et al. 2013). Five TL dates have been run on decorated sherds, but the dates and the ceramic styles of the dated sherds have not been published, so they are not included here. The dates have medians spanning from AD 1345 to 1570, which broadly agree with the other dates from the area.

the Inca sites in ruins (Parisii 1994: 55). They may have been in ruins as early as AD 1561 (Bárcena 1994: 26–30), as inferred from indirect references, but this seems too speculative to include in the model. The models use 26 ^{14}C dates associated with Inca ceramics or architecture and 19 TL dates on sherds from 10 sites (Tables 2–4, Figure 2). TL dates were run on Inca-style sherds (Table 4; Bárcena 1998a; Ots 2007b) and were corrected with readings from on-site dosimeters at four sites in the Uspallata Valley (Bárcena 1998a: 150–1, 225, 235–6, 241).

We began with separate models of each site (Appendix B). The sites do not have enough stratigraphic information to build a model like the one used for Chemical, so all dates from each site were modeled as a single uniform phase (Bronk Ramsey 2009a: 343). The major challenge was dealing with outliers. Bárcena (1998a: 359–64) reported an unexplained discrepancy between TL dates and paired ^{14}C and calendar dates, but overall, Inca-period TL dates seem more accurate than older TL dates. This is unexpected because TL dates in Chile are considered very reliable (e.g. Falabella et al. 2015). Hence, all dates were treated as potential outliers. Dates were manually removed if they had a >0.05 (5%) posterior probability of being outliers and models were rerun to test for additional outliers, following Bronk Ramsey (2009b: 1023–4). For better chronological control, it is preferable to work with single-component sites such as Chemical. In Mendoza, the three principal Inca sites of Ranchillos, Tambillos, and Tambillitos as well as Cerro Penitentes have relatively shallow stratigraphy and a single occupational layer. At three other sites, Ciénaga de Yalguaraz, Agua Amarga, and Agua de la Cueva, there were pre-Inca occupations that were excluded from this analysis. The following section briefly describes each site's dates and model, from north to south (Figure 2).

Ciénaga de Yalguaraz. The site Ciénaga de Yalguaraz is the northernmost Inca site in Mendoza, located near a dry lake bed (see Bárcena 1979: 679–88). The site was originally identified because it is roughly 22–24 km from Inca sites to the north and south, which is the typical spacing between Inca road way stations, or *tambos*. The site is near the Inca road and Inca ceramics were found on the surface and in excavation, though no Inca architecture was present. The ceramics from surface collections and excavation were similar and approximately 10% were decorated. The decorated ceramics included Inca styles similar to those from Tambillitos (Bárcena 1979: 675), with “typical Cusco motifs” but no Inca Diaguita or classic Diaguita styles. Forms included plates with modeled birds and one convex rim that appeared to be from an aryballoid (Bárcena 1979: 682–3). Other artifacts included lithic scrapers, projectile points, and bones of camelids and Rhea. Nine circular or semicircular mounds with archaeological features were identified. Occupation layers were separated by 2-cm saline laminates, suggesting to Bárcena (1979: 682) that the site was occupied seasonally in the spring and summer.

The site's five ^{14}C samples were from burning events (Bárcena 1998a: 98). Four of these samples were from 33, 60, 70, and 85 cm below the surface but the dates do not follow the stratigraphic sequence (Table 3). The same is true of the three TL dates, from sherds in levels that were 26–36, 36–56, and 56–66 cm below the surface (Bárcena 1998a: 227–8, 369). This may be explained by taphonomic processes (Bárcena 1979: 680) or perhaps the occupation was too short for radiometric dates to show a clear sequence. The oldest date (UZ-2524/ETH-5317) is from the deepest level (III), which has only undecorated ceramics (Bárcena 1979: 682–3, 1998a: 98–9). This date is not included in the model because the associated level is interpreted as pre-Inca. The model takes a conservative approach and does not use any stratigraphic priors. It groups the dates from levels I and II in a single phase. A single outlier was identified and removed (Table 5). The estimated starting boundary for the Inca occupation is *cal AD 1330–1500 (95% probability, Start Cienaga de Yalguaraz)*.

Table 3 ¹⁴C Inca dates from Mendoza. All samples are charcoal unless otherwise noted.

Site	Lab code	¹⁴ C age	±	δ ¹³ C (‰)	Context and material	Depth below surface (cm)
Ciénaga de Yalguaraz	GIF-4607*	180	80			
Ciénaga de Yalguaraz	GaK-7312	390	90		Mound 2, Level I	
Ciénaga de Yalguaraz	UZ-2527/ETH-5320	420	60		Mound 1, Level I	33
Ciénaga de Yalguaraz	UZ-2526/ETH-5319	540	55		Level II	60
Ciénaga de Yalguaraz	UZ-2525/ETH-5318	485	60		Level II	70
Ciénaga de Yalguaraz	UZ-2524/ETH-5317	605	60		Level III (pre-Inca)	85
Tambillos	Beta-25221*	770	50		SIII	
Tambillos	Beta-26283	410	70		SIII UA R2	
Tambillos	I-16637	290	130		SII UD R4, floor	
Tambillos	I-16908	300	80		SII UD R4, floor	
Tambillos	I-16907	310	80		SI UB, test pit 3	
Ranchillos	Beta-62946*	890	80		SII UB R2 cA1	
Ranchillos	Beta-69934*	640	50		SII UB R2 cA31	
Ranchillos	Beta-69933	430	50		SII UA R7	
Ranchillos	I-17002	290	80		SII UA R4	
Ranchillos	I-17003*	220	80		SII UA R5 sIII	
Ranchillos	I-17004	300	80		SII UA R5 sIII	
Tambillitos	Beta-88786	540	100		Test pit G9-H1	Upper level
Tambillitos	Beta-88787	460	80		Test pit G9-H1	Lower level
Agua Amarga	Beta-261727	450	50			
Cerro Aconcagua	GX-19991	370	70	-10.8	Mummy, rib collagen	
Cerro Aconcagua	Beta-88785	480	40	-14.7	Mummy, hair	
Cerro Penitentes	Beta-98941	550	50			
Potrero Las Colonias	AA-66564	569	38	-11.0	Human bone	
Agua de la Cueva	AC-1563**	470	80	-21.7	Unit B (SW), level 16	51
Odisa	AA-90284	529	42	-12.0	Human bone	

*Identified as an outlier and removed. Context abbreviations are as reported (Bárcena 1998a). They seem refer to the sector (S), excavation unit (U), structure (R), room (h), level (c), and test pit (s), as suggested by the initial letter of Spanish terms.

**The sample's δ¹³C was measured by conventional isotopic ratio mass spectrometry and was used to correct the ¹⁴C date (Albero and Angiolini 1983).

Table 4 TL Inca dates from Mendoza.

Site	Lab code	Age (AD)	±	P (Gy)	D (Gy/yr) × 10 ⁻³	Context	Depth below surface (cm)	Description
Ciénaga de Yalguaraz	UCTL-322	1520	40	1.57 ± 0.10	3.36	Level I	26–36	Thick walls, roughly smoothed light brown exterior, sand temper
Ciénaga de Yalguaraz	UCTL-321	1540	40	1.10 ± 0.03	2.46	Level I	36–56	Thick walls, smoothed dark brown exterior and interior, soot
Ciénaga de Yalguaraz	UCTL-315	1440	60	1.44 ± 0.15	2.62	Level II	56–66	Base, roughly smoothed brown exterior, inside black, reddish brown paste
Tambillos	UCTL-302*	1630	40	1.14 ± 0.06	3.17	SII UD R4, 1st floor	68	Decorated in white and black on red, roughly smoothed red interior
Tambillos	UCTL-304	1355	70	2.54 ± 0.16	4.00	SII UD R5, 2nd floor	86	Decorated
Tambillos	UCTL-306	1510	50	1.72 ± 0.72	3.59	SIII UA R1, floor		Orange, smoothed
Tambillos	UCTL-303	1510	50	1.14 ± 0.12	2.99	SI UA R3 A'-6b (RPC), floor		Red, smoothed
Tambillos	UCTL-301*	1350	60	2.58 ± 0.06	4.01	SI UC R4, stairs, entrance		Red, smoothed
Tambillos	UCTL-316**	1480	40	1.80 ± 0.06	3.54	SI UC R4, stairs, entrance		Glazed, colonial <i>mayólica</i> in the style <i>Puente del Arzobispo</i>
Ranchillos	UCTL-488	1490	50	1.68 ± 0.14	3.36	SII UB R2		Smoothed orange exterior, roughly smoothed interior
Ranchillos	UCTL-499	1480	50	1.66 ± 0.19	3.26	SII UB R2		Undecorated, gray, soot, sand temper
Ranchillos	UCTL-317*	1620	30	1.08 ± 0.08	2.90	Surface		White-slipped exterior, light gray interior, roughly smoothed, sand temper
Ranchillos	UCTL-337	1595	45	1.10 ± 0.12	2.77	SII UA (RPC) R3 c5		Red-slipped exterior, white-slipped interior with painted black design
Ranchillos	UCTL-785	1480	50	1.54 ± 0.15	2.98	SII UE R1 haA1		White slip
Ranchillos	UCTL-786	1555	45	1.64 ± 0.10	3.35	SII UE R1 hbCB2		Greyish brown
Tambillitos	UCTL-323	1555	45	1.72 ± 0.18	3.95	Test pit G9-H1, upper level		Grayish brown, roughly smoothed surfaces, sand temper, soot
Tambillitos	UCTL-787	1440	60	2.16 ± 0.19	3.89	Test pit G9-H1, lower level		Red-slipped exterior, roughly smoothed brown interior
Agua Amarga	UCTL-1724a	1630	40	1.72 ± 0.13	4.6	S VIII g 4		Red slip, orange, painted
Agua Amarga	UCTL-1724b	1585	40	1.72 ± 0.13	4.1			
Agua Amarga	UCTL-1724c*	1608	40			(Average of 1724a and 1724b)		
Agua Amarga	UCTL-1725a	1475	50	1.86 ± 0.18	3.5	S VII a 16		Rim of closed vessel, red slip on both surfaces
Agua Amarga	UCTL-1725b	1390	60	1.86 ± 0.18	3.0			
Agua Amarga	UCTL-1725c	1433	55			(Average of 1725a and 1725b)		
Agua Amarga	UCTL-1726a	1590	45	1.65 ± 0.11	4.0	S XII e 14		Red slip, orange, painted
Agua Amarga	UCTL-1726b	1535	50	1.65 ± 0.11	3.5			
Agua Amarga	UCTL-1726c	1563	48			(Average of 1726a and 1726b)		

*Identified as outliers and removed. See Table 3 for context abbreviations.

**Not included in the models.

Table 5 The 10 dates removed and their posterior probabilities of being outliers. The prior probability for all dates was set at the default 0.05 (5%).

Site	Lab code	Independent site models	Inca phase model
Ciénaga de Yalguaraz	GIF-4607	0.11	0.21
Ranchillos	Beta-62946	0.53	0.92
Ranchillos	Beta-69934	0.33	0.76
Ranchillos	I-17003	0.06	0.06
Ranchillos	UCTL-317	0.11	0.22
Tambillos	Beta-25221	0.09	0.74
Tambillos	UCTL-301	0.06	0.13
Tambillos	UCTL-302	0.09	0.27
Tambillos	UCTL-304	0.06	0.08
Agua Amarga	UCTL-1724c	0.06	0.12

Tambillos. Moving south along the Inca road, the next site is the tambo Tambillos (Rusconi 1962: 261–3; Bárcena 1988; Bárcena and Román 1990). The site includes a built surface area of 4618 m² of round and rectilinear buildings with stone foundations (Bárcena 2008: 329) made of cobbles, presumably from the dry river bed that runs through the site. The architecture includes a characteristically Inca “compound perimeter rectangle” shape (or RPC, in the Spanish acronym) with two rows of four rooms each. Surface collection and excavation recovered a variety of decorated Diaguita and Inca-Pacajes sherds, in addition to other styles from Chile and Cusco; forms included plates, bowls, and aryballoids. Analysis suggests that ceramics were produced here, perhaps by *mitmaqkuna* from northern Chile (Bárcena 1988: 416; Bárcena and Román 1990: 56, 65, 73; Garcia Llorca 1995: 172).

There are five ¹⁴C dates and six TL dates from the site (Tables 3–4; Bárcena 1998a: 85–91, 231–8, 245, 369–70). Most of these dates are directly associated with occupation floors of Inca-style buildings or contexts with decorated Inca pottery. Colonial ceramics were also found at this site, suggesting occupation that extended beyond the Inca occupation. The one TL date (UCTL-316) from a Spanish *mayólica* sherd was earlier than expected; it was not included in the model (Table 4). There seems to be some stratigraphic superposition of the samples (Bárcena 1998a: 231), but following a conservative approach, we modeled all the dates as a single phase. We removed four dates that had a greater than 5% probability of being outliers (Table 5). A phase of the remaining six dates resulted in an estimated starting boundary and site founding at *cal AD 1400–1570 (95% probability, Start Tambillos)*.

Ranchillos. This is the largest Inca site in Mendoza, with a built surface area of 6648 m² (Bárcena 2008: 329). Its ruins have been mentioned in numerous historic sources (Bárcena 1998b: 7–14). Early archaeologists mapped a series of RPCs on either side of the Inca road that runs through the center of the site (Aparicio 1940; Rusconi 1962: 232–61). Based on its size and architecture, it has been interpreted as the regional administrative center (Bárcena 1998b). It is located in a narrow valley with a reliable water source along the eastern edge of the Uspallata Valley. Diagnostic Inca sherds in red, black, and white have been identified as Diaguita and Inca provincial styles (Rusconi 1962: 256–60; Bárcena 1998b: 24–33). A variety of forms were documented such as plates, *pucos*, jars, cups, and aryballoids. The site is shallow, with occupational deposits no deeper than 30–40 cm below the surface. There are no indications of occupations before or after the Inca occupation.

The site includes 12 dates (Bárcena 1998a: 101–2, 238–44, 247, 370–1) and 4 were identified as outliers (Table 5). Wide differences between ^{14}C and TL were interpreted as the result of taphonomic disturbance or old wood (Bárcena 1998a: 240–3). The single-phase model estimates the starting boundary at *cal AD 1400–1560 (95% probability, Start Ranchillos)*.

Tambillitos. The smallest of the three sites with Inca architecture (Rusconi 1962: 252), Tambillitos, has a built surface area of 2820 m² (Bárcena 2008: 329). It is notable for its rectangular stone architecture and decorated Inca ceramics (Bárcena 1979: 670–9). The segments of the Inca road that would have connected it to neighboring sites have been destroyed by modern construction. Like Ranchillos, occupation layers are no more than 40 cm below the surface and mostly likely represent a single occupation. Decorated sherds are in the Inca Polychrome and Coripata Cuzco Polychrome styles. Other styles were identified as being originally from northern Chile and northern Argentina (Bárcena 1979: 674–7). Small triangular projectile points and fragments of marine shell were also found, like at the other Inca sites. The four radiometric dates have clearer stratigraphic relationships than at other sites; no outliers were identified (Bárcena 1998a: 156, 248–56, 371). The single-phase model estimates the starting boundary for the Inca occupation of the site at *cal AD 1170–1550 (95% probability, Start Tambillitos)*.

Agua Amarga. Agua Amarga is located around 90 km south of the Uspallata Valley at a lower elevation (1100 m asl) in an agriculturally productive area. Excavations of secondary refuse deposits included a variety of lithics, bones, and notably, a very high density of domestic maize and beans, so people probably grew crops near the site (Ots et al. 2011: 77–8). While there is no Inca architecture or direct connection to the main Inca road, surface collections identified sherds in the Inca Diaguita (Phase III) and Viluco Inca styles, which were also found at Tambillos and Ranchillos in the Uspallata Valley (Ots 2007a: 208, 258, 261). Forms included *pucos*, *keros*, and aryballoids (Ots and Cahiza 2013: Table 2). There was no evidence of post-Inca occupation (Ots 2007a: 260; Ots et al. 2011: 68).

The Inca occupation of Agua Amarga is dated with one ^{14}C date and three TL dates (Ots 2007a: 190–1, 2007b: 484; Ots et al. 2011: 68). On-site TL dosimetry was not available so two alternative corrections were used by the laboratory: (a) the average dosimetry from other sites in the region, which have similar sediments, and (b) the isochron method (Table 4). The results of these two methods were interpreted as minimum and maximum ages for each dated sample (Ots 2007a: 191, 2007b: 484). We averaged the results using a sum of squares of the error ranges, which are listed in Table 4 as UCTL-1724c, 1725c, and 1726c. These averages were used in the site's model, which estimates the starting boundary at *cal AD 660–1560 (95% probability, starting boundary)* or *cal AD 1360–1500 (68% probability, Start Agua Amarga)*. The starting boundaries for the individual Inca sites have error ranges of at least 160 yr, though the medians are within a century of each other (Table 6). The next step was to group these independent site models into one large model.

Inca phase model. The Inca phase model groups the site models within a single Inca phase, adding a simple but significant assumption to the model: all the dates and sites belong to the same phase. This is based on their shared material associations with Inca architecture or ceramics. In addition to the models described above, the Inca phase model includes six other dates from five other sites, which we briefly describe from west to east (Figure 2; Tables 2–4).

Table 6 Starting boundaries for independent site models and the Inca phase model, showing medians and 95% probability ranges. The A indices for individual sites are from the independent site models. The number of dates and outliers were the same in both the independent models and the Inca phase model.

	Independent site models		Inca phase model		A index	Number of dates	Outliers removed
	Median	95%	Median	95%			
Ciénaga de Yalguaraz	1420	1330–1500	1440	1395–1495	111	8	1
Tambillos	1490	1400–1570	1490	1425–1545	145	10	4
Ranchillos	1500	1400–1560	1490	1425–1545	104	12	4
Tambillitos	1410	1170–1550	1450	1390–1510	101	4	–
Agua Amarga	1420	660–1560	1455	1390–1510	92	4	1
5 other sites (see Table 2)						6	–
Inca Occupation of Mendoza			1400	1350–1440	106	44	10

The first is a high-altitude child sacrifice that included a variety of Inca grave goods on Aconcagua mountain. The two dates are from the child’s rib collagen and hair (Bárcena 1998a: 107; Fernández et al. 1999: 37). Given the high rate of collagen turnover in young bones, these dates should be equivalent, so they were combined prior to calibration. Next, there is another high-mountain site near the Inca road, Cerro Penitentes (Bárcena 1998b: 12). In the bottom of the Uspallata Valley, Rusconi (1962: 213–22) excavated a series of human burials at Potrero Las Colonias, and the grave goods included a painted *puco*. The associated human bones have been recently dated (Gil et al. 2014: 219). The site Agua de La Cueva is a rockshelter in the Precordillera mountains (Durán and García 1989: 56–7). One unpublished ¹⁴C date (AC-1563) is from a 5-cm level that includes Inca-style ceramics. Finally, Rusconi (1967: 9–13) excavated the Odisa site in the modern city of Mendoza. The site included a series of burials and two polychrome vessels in the Viluco Inca style. One of the burials has been recently dated (Gil et al. 2014: 220) and the associated materials come from the same layer, though the association is admittedly less than certain (see Waterbolk 1971: 16). Although this is not the most reliable data point, it is the best chronological information for the low-altitude areas to the east of the Andes. The ceramics and possibly the Inca influence may have been similar to those of Agua Amarga, as hinted at by documentary references (Bárcena 1994). All six of these dates were incorporated in the Inca phase model; none of them were identified as outliers.

For the Inca phase model (Appendix B), the 10 outliers detected from the independent site models were confirmed and removed (Table 5). The remaining 44 dates were included as a General Outlier model, with prior outlier probabilities of 0.05 (5%), allowing model averaging to statistically down-weight the data (Bronk Ramsey 2009b: 1024). The model has an acceptable agreement index (106), though it should be noted the agreement index is no more than a diagnostic for outlier models, as it is affected by down-weighted outliers.

RESULTS AND DISCUSSION

The starting boundary of the Inca phase model represents our current best estimate of when the Inca arrived in Mendoza (Figure 3): *cal AD 1380–1430 (68% probability)* and *cal AD 1350–1440 (95% probability, Start Inca occupation)*. The model confirms the hypothesis that

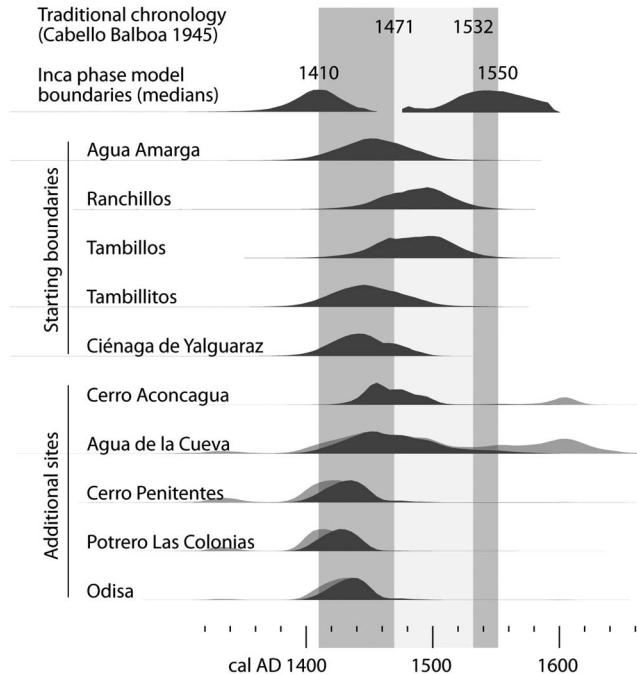


Figure 3 Comparison of probability density functions from the Inca phase model and the traditional chronology. Gray curves indicate calibrated date distributions; black curves indicate modeled posterior date distributions. For sites with multiple dates, the figure shows the starting boundaries. The vertical gray bar indicates the median dates of the Inca presence in Mendoza, based on the model's starting and ending boundaries. The white vertical bar indicates the span suggested by Cabello Balboa (1945) that is currently used in Inca research in Mendoza.

the Inca arrived well before Cabello Balboa's date of AD 1471, by around 70 yr ($30\text{--}130$, 95% probability, *Start v. AD 1471*), according to a Difference query. The starting boundary is clearly earlier than the ethnohistoric data of AD 1471, even at the 99% probability range (*cal AD 1280–1450*). A summed probability distribution shows that the dates are well distributed within the Inca phase (Sum command). The cumulative occurrence of events can be graphically summarized with a tempo plot (Dye 2016: 2), which includes 11 events: the starting boundary of the model, the starting boundaries of each site, and the dates from the five smaller sites (Figure 5). The shape of the curve suggests a rapid accumulation of events, that most sites were occupied or founded during the 15th century, and that 6–9 events occurred before AD 1471 (at 1σ). Table 6 shows the improvement in precision of the Inca phase model as compared to the individual site models. Overall, these results strongly reinforce Ogburn's (2012: 231) call to abandon the traditional document-based chronology and give priority to ^{14}C dates. We extend this call to include TL dates and most importantly, Bayesian models.

We can make some tentative site comparisons using the Order function, which gives the probable sequence of events in the Inca phase model (Table 7). These comparisons can be visualized in OxCal by mapping probability distributions from each site (Figure 4), which provides a general idea of which sites were contemporary. The earliest sites are small sites with one date each (Cerro Penitentes, Potrero Las Colonias, and Odisa), which may reflect the

Table 7 Order of events, showing the probability that the event in the column on left was prior to the corresponding event at the top of the table. Probabilities of 0.90 or greater are indicated in bold.

	Initial Inca occupation of Agua Amarga	Founding of Ranchillos	Founding of Tambillos	Founding of Tambillitos	Initial Inca occupation of Ciénaga de Yalguaraz	Cerro Aconcagua	Agua de la Cueva	Cerro Penitentes	Potrero Las Colonias	Odisa
Initial Inca occupation of Agua Amarga		0.82	0.80	0.45	0.38	0.68	0.64	0.26	0.19	0.29
Founding of Ranchillos	0.18		0.49	0.15	0.10	0.27	0.34	0.50	0.28	0.06
Founding of Tambillos	0.20	0.51		0.18	0.12	0.30	0.36	0.62	0.35	0.07
Founding of Tambillitos	0.55	0.85	0.82		0.44	0.72	0.68	0.33	0.25	0.36
Initial Inca occupation of Ciénaga de Yalguaraz	0.62	0.90	0.88	0.60		0.81	0.74	0.37	0.27	0.42
Cerro Aconcagua	0.32	0.73	0.70	0.28	0.19		0.50	0.07	0.02	0.08
Agua de la Cueva	0.36	0.66	0.64	0.32	0.26	0.50		0.16	0.10	0.18
Cerro Penitentes	0.74	0.95	0.94	0.67	0.63	0.93	0.84		0.38	0.57
Potrero Las Colonias	0.81	0.97	0.96	0.76	0.73	0.98	0.90	0.62		0.70
Odisa	0.71	0.94	0.93	0.64	0.58	0.92	0.82	0.43	0.31	

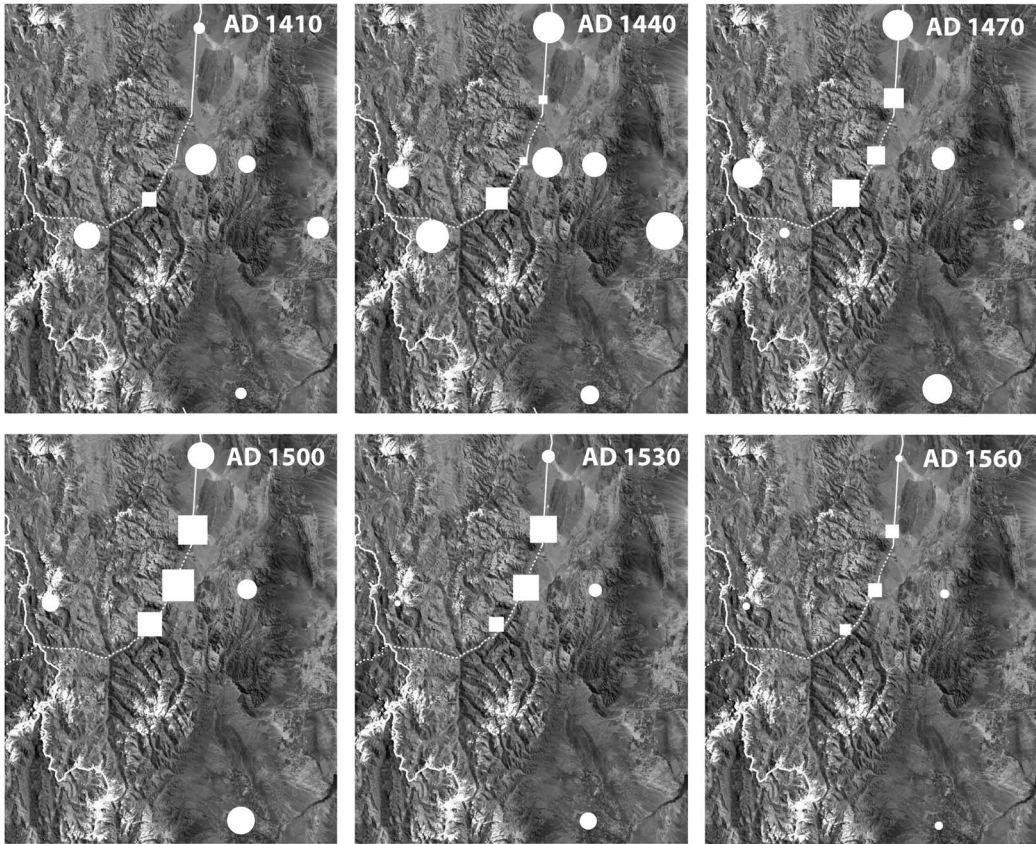


Figure 4 Map of 95% probability densities of dates at Inca sites. The larger the dot, the greater the probability density (see Figure 2 for map details and site names).

arrival of Inca material culture prior to any significant imperial presence. Next are the three smaller Inca sites with multiple dates (Ciénaga de Yalguaraz, Tambillitos, and Agua Amarga), perhaps reflecting a cautious investment in site-building, followed by the Aconcagua mountain sacrifice. This sacrifice may have marked the beginning of a greater commitment to the valley. The two largest sites, Ranchillos and Tambillos, were probably founded last, suggesting increasing imperial interest during the 15th century, as implied by the tempo plot (Figure 5). These comparisons involve highly overlapping probability distributions, so they remain tentative. In an earlier version of that model that included stratigraphic priors, the starting boundary was very similar, but as would be expected, the order of events was different. Hence, the model could be improved with a larger sample and more explicit stratigraphic priors, for both previous and future excavations. In terms of TL dates, greater care could be given to the identification and description of ceramic styles, which may have overlapping but not identical temporal spans. In this paper, the results of the Order command, tempo plot, and map of probability distributions are meant to demonstrate the range of the chronological tools available for exploring the data set. The results of these tools remain tentative.

The early arrival of the Incas in Mendoza has important implications for our understanding of the nature of Inca control in the region. One scenario describes enclaves that were directly

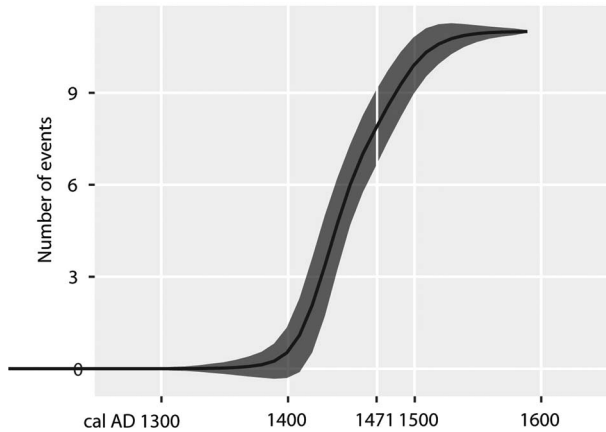


Figure 5 Tempo plot of 11 Inca events in Mendoza. The dark line represents the mean number of cumulative events that took place prior to dates along the x axis; the shaded area represents 1 σ (see Dye 2016: 2).

controlled by the empire (Bárcena 1994; Parisii 2005; Ots and Cahiza 2013) while another suggests that control was delegated to the Diaguita group from Chile (García 1996, 1999, 2009, 2010, 2011a, 2011b). Both scenarios can now be re-evaluated based on a much longer occupation than suggested by Cabello Balboa. The Bayesian model estimates that the occupation lasted *70–230 yr (95% probability)* or *100–190 yr (68% probability)*. This raises new questions, for example, did the Inca initially enter Mendoza from the west or north? Despite a presence lasting multiple generations, they did not build imperial centers in the valley bottom nor in the adjacent lowland valleys, both of which are agriculturally fertile areas that were occupied by local Huarpe groups. Despite their rapid and early expansion to Uspallata, they did not continue farther south, despite negligible armed resistance. The reasons they halted their expansion here are unclear, but one potential factor is that they reached the continent’s southern limit of the puna environment with which they were most familiar. The documentary evidence has little information, but a descendant of Topa Inca offered a plausible suggestion: “as they saw that all the people were poor, they stopped conquering them” (Rowe 1985: 198, our translation). This is a reminder that empires conquer people, not territories (Schreiber 1992: 11), and would have stopped where there were no more people worth conquering. The area may have been annexed into the personal holding of an Inca conqueror, perhaps one of Pachacuti’s three sons, who were active in military campaigns. The conqueror may have left one of his lieutenants in charge, perhaps named Uspallata (Bárcena 1994: 27). Another possibility is that there was no need to impose direct control because the lowlands were administered indirectly (García 2009). One historical document hints the Inca explored as far south as the Diamante River in central Mendoza (Figure 1), where they left a marker and turned around (Bibar 1966: 155, cited in García 2011a: 158; see Ots and Cahiza 2013: 39). All of these possibilities could be better evaluated with a more explicit interpretation of the Empire’s material signature (see García 2011a, 2011b; Tantaleán 2015) in addition to an improved chronology. Bayesian models from neighboring regions would make it possible to define sequences from neighboring regions of central Chile, north-central Chile, and the Province of San Juan.

The model results agree well with Bayesian models from other regions, which begin to outline a radiometric chronology of the southern expansion. It was begun quite early and prior to the

northern expansion, suggesting a major revision to the traditional chronology. Just south of Lake Titicaca at the Inca provincial capital Tiquischullpa (Figure 1), a preliminary Bayesian model of radiocarbon dates published by Pärssinen and Siiriäinen (1997: Table 1) suggests that the Inca occupation, associated with three ^{14}C dates, took place between *cal AD 1310–1350* (medians of the First and Last dates of the Inca phase, with overlapping 68% probabilities of *cal AD 1270–1400*), estimated with IntCal13. Moving south, the Inca arrived in northwestern Argentina slightly later, around *cal AD 1380–1400* (68% probability, Starting boundary) (Greco 2012: Figure 8.15b). This range is similar to estimates for northern and central Chile (Schiappacasse 1999; Cornejo 2014). Finally, the Inca continued south and arrived in Mendoza at around *cal AD 1380–1430* (68% probability, Start Inca occupation). Hence, the southern expansion was probably completed before the initial incursion into Ecuador at around *cal AD 1430–1460* (68% probability, Start Inca occupation) as estimated from the model of Chamental. Overall, this chronology suggests that the empire began expanding at least a century earlier than proposed by the traditional chronology. It also supports the idea that the conquerors moved rapidly through large territories and then consolidated gradually, at least in the southern part of the empire where there was little armed resistance. Future research on the southern expansion would benefit from radiometric dates and a Bayesian model of the empire's recently rediscovered southern capital near Oruro, Paria (Pärssinen et al. 2010), which was probably the logistical base for forays into Chile and Argentina (Figure 1). The site's large size of 100 ha and rich documentary information gives it great potential to shed light on the nature and timing of incursions farther south.

While inaccurate about the chronology of territorial expansion, historic documents do offer information on the people involved. The southern conquest is attributed to the reign of emperor Topa Inca by various chroniclers, which seem to have had similar sources of information (Rowe 1985: 200–1, 210). They suggest that the southern expansion was begun by Topa Inca's father Pachacuti (Figure 1). Topa Inca's brothers Amaro Topa and Topa Yupanqui probably participated (Rowe 1985: 199) in order to conquer their own lands, because they would not inherit their father's holdings (Ogburn 2012: 233–4). Since the chronicles reflect official royal versions of history, they may be attributing the conquests of the three brothers to only Topa Inca. The three brothers may have been expanding in multiple directions before or after their father's death and established the empire's southern limit in Mendoza. The official histories generally attribute entire regions to a single emperor, but large, rapid conquests were probably led by multiple leaders at the same time and then simplified in oral accounts.

The end of the Inca occupation of Mendoza is unclear. The ending boundary of the model is *cal AD 1500–1600* (95% probability, End Inca occupation). This boundary is heavily influenced by the historical date that the sites were in ruins by AD 1595, so it does not offer a robust estimate of when the occupation ended (Figure 3). It is possible that Inca sites in Mendoza were abandoned soon after Pizarro's AD 1532 arrival in Peru, but it may also be that occupation continued into the Colonial period. One site, Tambillos, had a diagnostic Colonial sherd (Table 4), though this is quite limited evidence to argue for a post-Inca occupation. Additional models with dates and priors from the Inca occupation and the early Colonial occupation could significantly improve the estimate of the Inca departure from Mendoza.

CONCLUSION

The emerging archaeological chronology of the Inca expansion confirms that dates in documentary sources are incorrect and strongly supports the argument to build an Inca chronology with radiometric dates and Bayesian models. Contrary to the traditional sequence of conquests, the southern expansion began first. Inca forces arrived in northern Argentina and Chile in the final decades of the 14th century. They probably arrived at the southeastern edge of

their empire in Mendoza at *cal AD 1380–1430 (68% probability)*. At this point, the empire stopped expanding southward and occupied the area for the next *100–190 yr (68% probability)*. Conquering leaders then looked north and marched on Ecuador beginning *cal AD 1430–1460 (68% probability)*. To improve our picture of how Inca expansions progressed, dates and detailed stratigraphic priors should be harnessed with site-specific Bayesian models. Regional models can be useful in establishing the sequence of Inca occupations in different parts of the empire, toward refining and testing the expansion chronology outlined here.

One challenge for improving the Inca chronology will be for Inca ethnohistorians and archaeologists to learn to use Bayesian modeling or establish partnerships to take advantage of this method. Bayesian analysis has been used by UK researchers since the 1990s (e.g. Buck et al. 1996; Buck and Millard 2004; Buck and Meson 2015) and has become increasingly common in archaeology throughout the world (Bayliss 2015). It was featured in a 2015 special issue of *World Archaeology* (volume 47, issue 4). Computer programs have made these analyses increasingly more accessible, among which OxCal stands out as a free, powerful, and continuously updated program (Bronk Ramsey 2009a).

The main goal of this paper was to test the hypothesis that the Inca began expanding the empire earlier than suggested by the traditional ethnohistoric chronology. This was confirmed for both Ecuador and Mendoza with Bayesian models. The more general goal of this paper was to make a case for more abandoning the traditional Inca chronology for radiometric dates and Bayesian models. While individual dates have little promise to refine Inca chronologies, Bayesian models certainly do, especially when informed by detailed stratigraphic relationships and ceramic descriptions. Bayesian modeling of Inca dates is just beginning, so it still holds great potential. Better chronologies can improve our understanding of the empire's history, internal workings, the nature of expansion, and interactions with local groups.

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SUPPLEMENTARY MATERIAL

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