WHEN DID THE INCAS BUILD MACHU PICCHU AND ITS SATELLITE SITES? NEW APPROCHES BASED ON RADIOCARBON DATING

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ABSTRACT. According to the classical chronology of the Inca State, the ascension to power of Pachacuti Inca took place around AD 1438 and the construction of Machu Picchu began by AD 1450–1460. However, the improvement in the accuracy of radiocarbon (^{14}C) dating resulting from the application of Bayesian analysis has changed our view of the historical chronology. This new research raises questions about our understanding of the cultural development of the Machu Picchu area, in the light of the new proposed chronological scheme. This paper presents a set of 11 new ^{14}C dates, derived from AMS, from the sites of Llaqta of Machu Picchu, Chachabamba, and Choqesuysuy. The latter two sites are situated within the Machu Picchu National Archaeological Park (Arqueología del Santuario Histórico Nacional y Sitio Patrimonio Mundial de Machu Picchu) and have been interpreted as being part of the contemporary Late Horizon Inca landscape. The new ^{14}C ages are modeled using Bayesian inference and present a revised dating framework for these sites and their chronological relationship with Llaqta of Machu Picchu.

KEYWORDS: chronology, Inca Empire, Machu Picchu, radiocarbon AMS dating.

INTRODUCTION

At the time of its greatest expansion, by AD 1530, the Inca Empire, known as Tahuantinsuyu, stretched over a territory of more than one million square kilometers (Figure 1), with a population of (according to the most plausible modern estimates) 10–14 million inhabitants (Szemiński and Ziółkowski 2018).

The interpretation of the chronology and phases of expansion of the empire, rests on the so-called historical chronology proposed by John H. Rowe in 1945. According to this chronological scheme, based mainly on the Spanish chronicle of Miguel Cabello Balboa (dated 1586), the imperial phase of the Inca State began with the ascension to power, around AD 1438, of Pachacuti Inca Yupanqui, the ninth sovereign according to the so-called traditional list of Inca rulers. He and his successors, mainly Tupac Inca Yupanqui and Huayna Capac Inca, extended the State first to the NW of the capital city of Cusco to present-day Ecuador and then to the SE to the territories of what is now Bolivia, Argentina, and Chile. According to this model, the reign of these three rulers, calculated based on data taken from chronicles, lasted ca. 100 years (Rowe 1945).

An important element of the socio-territorial organization of the Inca empire comprised the so-called royal estates, private property of the sovereign. Machu Picchu and the areas

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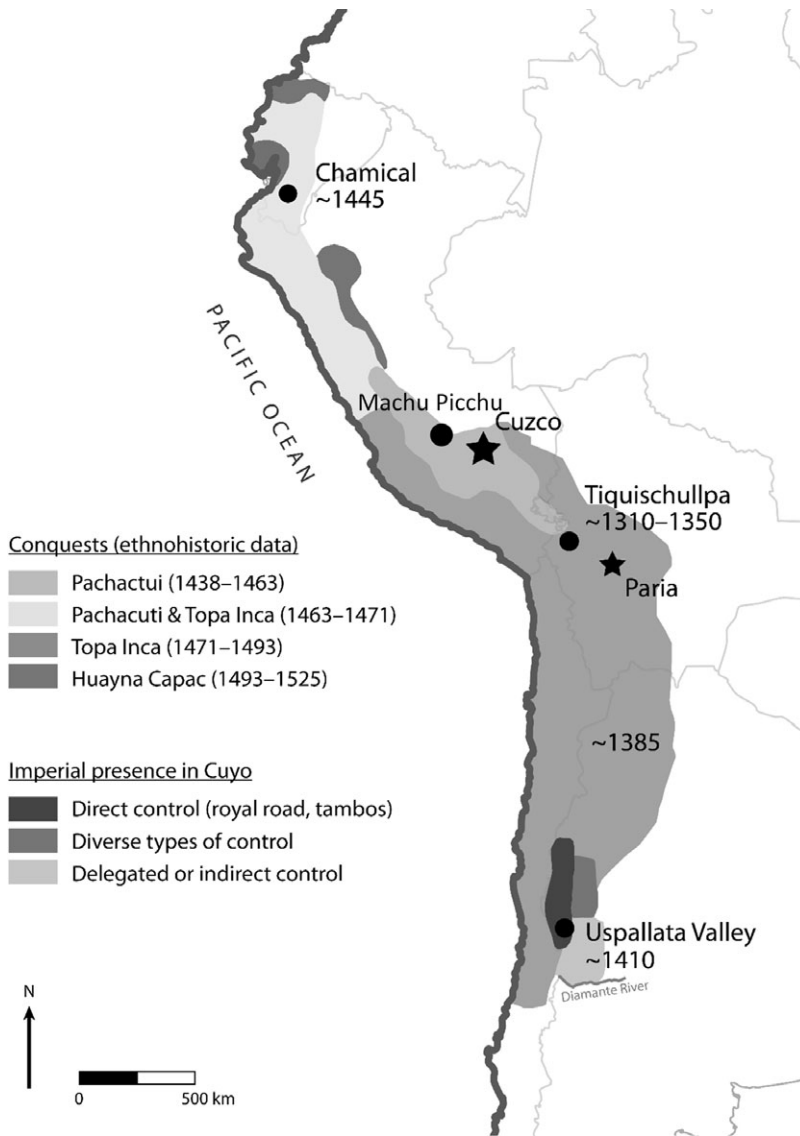
Figure 1   The Inca Empire reprint from Ogburn (2012: Figure 1).

surrounding this site constituted precisely one of these private holdings, attributed to Pachacuti Inca Yupanqui (Rowe 2003 [1986]). According to authors who base their opinions on historical sources, Pachacuti would have ordered the construction of the so-called Llaqta of Machu Picchu and a series of satellite sites by AD 1450 (Chavez Ballón 1971; Salazar 2004). This ceremonial and residential complex would have passed into the hands of the members of the Pachacuti clan (panaca), after the latter's death. This chronological scheme was, until recently, generally accepted by specialists and disseminated in the literature on the subject (Figure 1 and Table 1).

Table 1 Historical chronology of the Inca Empire cf. John H. Rowe (Rowe 1945).

Year (AD)	Events
1438	Pachacuti deposes Viracocha, beginning of imperial conquest.
1438–1471 (33 years)	Pachacuti ruled
1463	Pachacuti remains in Cuzco. Sons of Pachacuti including Topa Inca lead the army on campaigns of expansion
1471–1493 (22 years)	Topa Inca succeeds Pachacuti
1473	Chile conquered
1493–1525 (32 years)	Huayna Copac ruled
1525–1532 (7 years)	Huayna Copac dies, succeeded by Huascar, whose rule was contested by Atahuallpa
1532	Pizarro captured Atahuallpa in Cajamarca

Critics of the Historical Chronology from Historical and Archaeological Points of View

Although the historical chronology is the most accepted version of events it does not mean there are no divergent models. Some authors have questioned the historical validity of the whole Inca dynastic list (Zuidema 1982), or, at least, the duration and chronological position of the reigns of the sovereigns in the list and the deeds that were attributed to them (Covey 2006; Ogburn 2012; Cornejo 2014). This position has been synthesized by Alan Covey:

"Archaeological data and comparative historical evidence indicate the traditional twelve-generation king list cannot be treated as a complete plausible account of Inca succession and chronology [...] Pachacuti myth cannot explain the available evidence adequately, 1438 should not be used as a starting date for the Inca polity and history" (Covey 2006: 173–174).

For the purposes of this paper, however, of greater interest are studies concerning the absolute chronology of the development phases of the Inca State not based on historical sources but on natural science, mainly on radiocarbon (^{14}C) dating.

Unfortunately, the application of ^{14}C dating for the differentiation of the phases of formation and expansion of the Inca Empire has been relatively limited to date. This circumstance is the result of the preconceived notion that the imperial period of the existence of the Inca State was so short (a century or less) that the best, most precise ^{14}C dates available in the 1980s or 1990s lacked the precision to contribute usefully to the temporal differentiation of the phases of its expansion. Other techniques, such as dendrochronology, were at that time practically irrelevant in the Andean region and only in recent years have these begun to gain some importance (Ghezzi and Ródriguez 2015).

However, even with these limitations, a 1996 study based on the composite probability distribution of calibrated ^{14}C dates relating to the pre-imperial and imperial phases of the expansion of the Inca Empire, offers some interesting and novel conclusions (Adamska and Michczyński 1996). This analysis indicated that, at 68% probability, the pre-imperial phase of the Inca State could be placed between AD 1280–1396, while the expansive or imperial phase would have occurred between AD 1401–1518. This study thus pointed to the expansion of the Inca state beginning several decades before the AD 1438 date commonly accepted as the starting point of the Imperial phase, derived from the historical chronology (Adamska and Michczyński 1996).

An important step in the process of the rejection of the "historical chronology" was undoubtedly the work of Dennis Ogburn at the Inca site of Chamical in Ecuador. There, in an unquestionably Inca settlement, it was possible to differentiate a series of layers relating to different phases of the construction of Inca structures. Based on the Bayesian analysis of the sequence of ^{14}C dates, Ogburn formulated the following conclusion:

"Our chronology of Inca expansion can no longer be based on the historical accounts, and we should not be judging ^{14}C dates against the traditional chronology. Instead, we must base our chronology on ^{14}C dates, and evaluate the historical record in relation to them. [...] [14]C dates will not provide the level of precision we might desire within the short span of the Inca empire. But they can still provide a level of accuracy that is not possible within the framework of the historical account of Inca provincial expansion [...] [W]e may be able to obtain dates of sufficient precision and accuracy to date the Inca incorporation of different provinces within a range of about 2 decades" (Ogburn 2012: 235).

Another very important step was the study by Marsh and collaborators of the Inca presence in Argentina. The Bayesian model based on 26 ^{14}C dates and 19 TL dates allowed the authors of the study to formulate the following conclusions:

"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)." (Marsh et al. 2017: 20–21: Figure 1)

Similar results were obtained with the analysis of 59 ^{14}C and 155 TL dates from different Inca sites in Chile. Apparently, the Inca occupation here occurred almost 100 years before 1470 AD, although differences between analyzed regions exist (Cornejo 2014).

RADIOCARBON DATING OF MACHU PICCHU

The chronology of the Machu Picchu region thus far has been based mainly on the model of Rowe (1945), more precisely, on this author's evaluation of the reign of Pachacuti Inca Yupanqui between AD 1438 and AD 1471. It has been estimated that the construction of llaqta of Machu Picchu would have been started about 10 years after the beginning of the reign of Pachacuti, that is around AD 1450 (Chavez Ballón 1971; Salazar 2004).

But what remains of this chronology, if now we are questioning the reliability of the time scale proposed by Rowe and in particular, the estimated dates of Pachacuti's rule?

A question arises: When (and on whose behalf) was Machu Picchu built?

In this context it will be necessary to consider not only the main site, the Llaqta of Machu Picchu itself, but also its 60 satellite sites; what was the chronological relationship between the latter and the principal site?

Table 2 Machu Picchu: radiocarbon dates from the test pit excavated in 1983 (reprint from Berger et al. 1988).

UCLA no.	Level	Depth (cm)	^{14}C age (yr BP)	Calibrated age	Context
2538A	1	0–10	595 ± 105	AD 1250–1450	—
2538B	4	31–40	2775 ± 160	800–1200 BC	—
2538E	7	61–70	380 ± 40	AD 1450	Floor I
2538F	7	61–70	390 ± 40	AD 1450	Floor I
2538K	10	91–100	2700 ± 50	900–1000 BC	—
2538O	12	111–120	1365 ± 45	AD 650	Floor II. Wall base
2538P	13	121–130	2660 ± 45	800–1000 BC	—

Machu Picchu has not been intensively investigated by ^{14}C dating; there are only 7 ^{14}C dates on samples from a test pit excavated in 1983, and 5 more from human bone collected by the Peruvian Yale Expedition in 1912 and 1915 (Berger et al. 1988; Ajie et al. 1992).

In regard of the latter (i.e. the human bone), the samples did not come from stratigraphic contexts, so they cannot be directly related to the deposits of the test pit excavated in 1983. The samples were first dated using the collagen fraction by Berger et al. in 1988 and then by Ajie et al. in 1992, on the gelatin and osteocalcin fraction. Even taking the corrected values obtained in 1992, dates with uncertainties between 90 and 150 years do not allow any conclusions about the construction or abandonment phases of Llaqta of Machu Picchu.

The test pit excavated in 1983 and the dates obtained from the various levels assigned arbitrarily within it, according to Berger et al.: "indicate two distinct occupation levels recognizable so far at Machu Picchu: the last well-known during the Inca period (Lumbreras 1969) and an earlier one of the 7th century AD" (Berger et al. 1988: 709).

Comparison of the dates obtained from the different levels shows that these contexts represent in fact a rather disturbed stratigraphy. The two dates of floor I (Inca) context (level 7, UCLA 2538E and F) corresponding to AD 1450 are framed by dates of 800–1200 BC (UCLA 2538B) and 900–1000 BC (UCLA 2538K) obtained from levels 4 (above) and 10 (below), respectively (Table 2; Berger et al. 1988: 709; Bastante et al. 2017).

It is also necessary to emphasize, that the spatial and stratigraphic relationship between the excavations of 1983 and new work in 2017 by the Polish-Peruvian project reported here can only be established approximately, since there is no plan of the excavation of 1983, nor is a profile available with the precise location of the place where the samples were taken (compare Berger et al. 1988).

The distance between excavation units from 1983 and now 2017 is approximately 25 m in a straight line. Both locations are in the same living area called Sector V. It seems that the place where excavations were conducted in 1983 is basically at the same level as excavations in the Patio from 2017. However, these two excavations were conducted in different terraces.

Because of these problems of compatibility between the two excavations, we base our preliminary new study on a series of 11 recent ^{14}C dates from Llaqta of Machu Picchu and
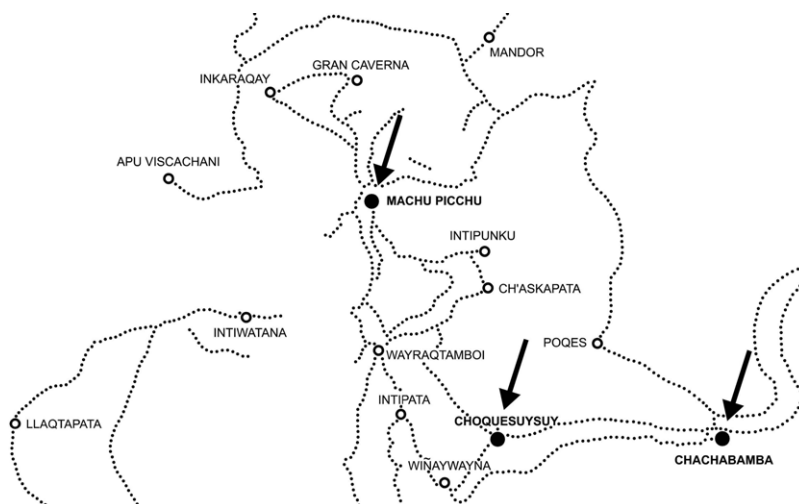
Figure 2 Location of Machu Picchu, Chachabamba, and Choqesuysuy (drawing by Jacek Kościuk).

2 satellite sites (Figure 2) carried out by the University of Waikato laboratory using AMS ^{14}C dating. Sample numbers have been allocated employing the Waikato laboratory codes and come from the following locations:

1. Llaqta of Machu Picchu—3 samples;
2. Chachabamba—5 samples;
3. Choqesuysuy—3 samples.

The contexts from which the samples derive are detailed below. We state at the outset that the new data so far available are inadequate for a thorough chronology. They at best support the need for more work. We have very few dates, and especially lack dates on short-lived samples which might be regarded as contemporary with the relevant find contexts. We also lack replication for most contexts so far, limiting the ability to identify residual material. Unfortunately, the wood-charcoal samples offering typically TPQ estimates were not identified to species, nor considered in terms of characterization (whether heartwood, outer rings, roundwood, etc.) before dating. This limits our ability to comment on the likely scale of possible in-built age.

The Llaqta of Machu Picchu Site and Sampling

To begin, we will discuss the stratigraphy of the newly acquired samples based on date estimates resulting from the 2017 excavation data e.g. relative stratigraphic position, associated pottery, etc. (Figure 3). The first charcoal sample (Waikato 48116) came from excavation Unit 02-2017 (located on the so-called patio in the urbanized sector), layer III, interpreted as an Inca floor. The date obtained is associated with the construction phase of this Inca floor, and its period of use. Moreover, another sample of charcoal (Waikato 46935) came from layer IV situated below the Inca floor. It was found within the layer that predated the construction of the floor and related to the construction of the part of this sector, predating the Inca use of this space (Bastante et al. 2017). The last sample comes

Figure 3 Relationship between samples from excavation in Llaqta of Machu Picchu in 1983 and 2017 (PIAISHM archives).

from the neighboring nearby context to the patio area, from the extension to Unit 02-2017, and is related to the adjacent space. Here, within the second layer, a feature comprising a sacrificial context (number 01) was found. It was determined that it corresponded to the level of the Inca floor contemporary with the level of Inca occupation, which was rich in elements of charcoal (Waikato 46936). Due to the fact that the described unit is not uniquely related to 02-2017, it is difficult to establish whether it is older or younger than the described samples. Nevertheless, it is certain that the sacrifice was made during Inca Times.

In our modeling analysis the two dates from level 7 of the test pit excavated in 1983, although related to an Inca Classic pottery sherds deposit (Berger et al. 1988), haven't been included because of the uncertain stratigraphy of this excavation (Valencia Zegarra and Gibaja Oviedo 1992).

The Chachabamba Archaeological Site and Sampling

Chachabamba is located on the left bank of the Vilcanota river at the 104th kilometer of the Cusco-Machupicchu Pueblo railway line. This site comprises a ceremonial complex related to the presence of its water-related shrine including 14 ceremonial baths. Excavations were conducted within the ceremonial sector of Chachabamba, designated sector A or 1. Most of the samples belong to the same excavation unit (03-2017). The most recent sample is part of layer III, while the oldest sample in this unit belongs to layer VIII. Within layer III, the level of Inca occupation was identified. Within this layer (i.e. III), it was possible to distinguish feature (01), which consisted of a ceramic *arybalo* type vessel comprising an offering including numerous pieces of charcoal. It is probable that they disintegrated under the weight of layer II. The Waikato 46938 sample pertains to this context. Just below (01), we found (03), consisting of a lens filled with charcoal and tiny branches (Waikato 48113). A further layer rich in charcoal in unit 03-2017 was layer VI (Waikato 46939). Finally, from within layer VIII, samples were taken associated with ceramics (Waikato 48114). The second excavation unit from which samples were taken was Unit 05-2017. A sample was included from layer VI, from the context of a circular wall located in the south-east corner of the excavation (Waikato 46940). Considering the direct level on which sample Waikato 46940 was deposited, which was higher than for sample Waikato 48114, it could be argued that the former is the oldest sample of those taken in Chachabamba.

The Choqesuysuy Archaeological Site and Sampling

Choqesuysuy is well known because of its multiple terraces but it is also important to mention its ceremonial and urban functions. It consisted of numerous residences and well-planned ceremonial structures as well as agricultural infrastructure. The ^{14}C samples from Choqesuysuy originate from two different excavation units from sector B (urban). The first sample came from the context of a collapsed wall which had fallen into the room in excavation Unit 01-2017. Sample Waikato 48115 was from the rubble derived from the post-Inca abandonment phase of use of the building. Layer IV of the same excavation unit corresponds to the level of Inca occupation. Furthermore, an additional charcoal sample was tested (Waikato 46933). The next sample came from excavation Unit 02-2017 in the same sector as Unit 01-2017. In layer II of Unit 02-2017, considerable amounts of charcoal were present (Waikato 46934), associated with numerous fragments of pottery (Bastante et al. 2017).

Table 3 Results of radiocarbon dating of samples from Llaqta of Machu Picchu, Chachabamba, and Choqesuysuy, calibrated with OxCal 4.3.2 (Bronk Ramsey 1995, 2001). Mixed (50%:50% ±10%) SHCal13 and IntCal13 curve was used for calibration. Unmodeled data.

Lab code Waikato	Material	^{14}C age (BP)	Cal AD 1 σ	Cal AD 2 σ
Machu Picchu				
48116	Charcoal	560 ± 20	1400–1421 (68.2%)	1329–1338 (3.7%) 1393–1432 (91.7%)
46935	Charcoal	490 ± 18	1430–1445 (68.2%)	1420–1450 (95.4%)
46936	Charcoal	441 ± 17	1444–1460 (68.2%)	1439–1479 (95.4%)
Chachabamba				
48113	Charcoal	434 ± 19	1445–1468 (68.2%)	1440–1490 (94.5%)
48114	Charcoal	475 ± 19	1434–1450 (68.2%)	1425–1455 (95.4%)
46938	Charcoal	338 ± 18	1514–1529 (14.2%) 1539–1585 (43.5%) 1620–1631 (10.5%)	1499–1600 (77.7%) 1613–1640 (17.7%)
46939	Charcoal	391 ± 15	1463–1497 (54.8%) 1602–1611 (13.4%)	1454–1510 (68.4%) 1590–1619 (27.0%)
46940	Charcoal	499 ± 15	1428–1441 (68.2%)	1420–1446 (95.4%)
Choqesuysuy				
48115	Charcoal	209 ± 20	1666–1676 (11.6%) 1740–1798 (56.6%)	1656–1684 (20.9%) 1732–1804 (71.6%) 1943–modern (2.9%)
46933	Charcoal	423 ± 16	1450–1472 (68.2%)	1445–1493 (94.2.5%) 1604–1607 (1.2%)
46934	Charcoal	567 ± 16	1440–1415 (68.2%)	1328–1340 (5.2%) 1392–1425 (90.2%)

RESULTS

The results of the dating of the 11 samples from Llaqta of Machu Picchu, Chachabamba, and Choqesuysuy are presented in Table 3. The calibrated ages were obtained using OxCal 4.3.2 (Bronk Ramsey 1995, 2001, 2009a). For calibration and modeling, the mixed SHCal13.14c and IntCal13.14c curves were used (Hogg et al. 2016; Marsh et al. 2018).

Modeled Chronology for Llaqta of Machu Picchu, Chachabamba, and Choqesuysuy

The sequence model was obtained using OxCal 4.3.2 (Bronk Ramsey 1995, 2009a) and is based on 11 dates from 3 Inca sites, Llaqta of Machu Picchu, Chachabamba, and Choqesuysuy. The two ^{14}C dates from Llaqta of Machu Picchu from excavations in 1983 (Berger et al. 1988) have not been included in the model because we are not convinced about their relation to the archaeological context of the samples from unit 02-2017. Because the sites are located around the edge of the ITCZ region, and especially since there are indications that in periods like the Little Ice Age partly contemporary with the Inca that the ITCZ boundary may have moved further south (e.g. Lechleitner et al. 2017), it is unclear whether to use the Southern Hemisphere (SH) or Northern Hemisphere (NH) or a mixed SH+NH ^{14}C calibration curve (see Hogg et al. 2016; Marsh et al. 2018). We tried to use different calibration curves to estimate consistent

chronologies for those sites. We have tried to build models using IntCal13 and SHCal13 (Hogg et al. 2016) and mixed IntCal13+SHCal13, however the differences in chronologies for each of the calibration curves were negligible. For the modeling (Model 1), a mixed curve (~50%:50%) was used (Hogg et al. 2016). We have decided that a mixing approach is most appropriate for this region. Model 1 is based on the sequence inferred from the archaeological investigations. Each site is considered in a separate Sequence. A mixed curve of 50:50 ±10% was employed. All dates are cal AD.

The results of the modeled chronology for Llaqta of Machu Picchu, Chachabamba, and Choqesuysuy are shown in the Figure 4. Most of the samples comprise carbonized wood, and thus offer *terminus post quem* (TPQ) information, except one which is a charred nut. All dated samples were included in the modeling. The OxCal General Outlier model (Bronk Ramsey 2009b) was applied to each element to assess the scale of outlier issues. Dates which could be too old (in-built age) are to be anticipated given wood charcoal samples and some potentially long-lived species (e.g. *Cedrela angustifolia*). We anticipated one particular problem. Assuming the stratigraphy is correctly recognized, it is evident that the sample used for Wk48116 must include either old wood (inner tree rings) or be residual material since it is clearly much older than the stratigraphically older context but more recent ^{14}C age of Wk46935 (and also Wk46936 as well as the two dates from Berger et al. (1988) from around the same horizon: UCLA 2538E, UCLA2528F). This sample returns the only contradictory (out of stratigraphic sequence) larger outlier probability (~23%). The other wood-charcoal dates, although likely involving varying amounts of in-built age, can work with the stratigraphic information. Chachabamba Layer III is the one other issue. Here within the same layer there is a marked difference in ages. Given just two samples and so no control, we can only assume that the more recent age offers the better (closer) TPQ and regard the older age as either inner tree-rings or residual material. The common initial dated event range across the three sites, gray bar in Figure 4, is 1391–1460 (95.4% probability, 1401–1452 68.2% probability).

The primary aim of this initial dating exercise is to determine the beginning date of Inca activity at each locus. We accept the dates on charcoal offer TPQ ranges. We thus placed an Outlier query against Wk48116 and Wk48113 in a revision of Model 1 (Model 2). We apply a First query to each site Phase as an estimate of the first dated TPQ event within the Phase. The results are shown in Figure 5. A mixed curve of 50:50 ±10% was employed as in Figure 4. The probabilities for Wk48116 and Wk48113 lying in the Sequence are 0% and 1%. There are inevitably loose upper and lower boundaries given the lack of data and constraints. The more restricted First estimates at an indicative 68.2% probability are Llaqta of Machu Picchu 1422–1448, Chachabamba 1412–1444, and Choqesuysuy 1354–1420. Date queries, the period between the start and end Boundaries for each site Phase (long in the case of Choqesuysuy with its post-Inca date), are also illustrated. Finally, even if very approximately, we might try to include an estimate of the TPQ involved. We can consider the Charcoal Plus Outlier model (Dee and Bronk Ramsey 2014) as perhaps the most appropriate for this data-poor and poorly constrained case. We employ all the data except Wk48116 (which prevents the model converging in most cases) with the Charcoal Plus Outlier model applied to the wood charcoal samples and the General outlier model applied to the nut (Model 3): Figure 6. This model assumed a 50:50 SH/NH mixed curve (and no error this time). The in-built age assumption of the Charcoal Plus Outlier model modifies (widens and especially extends) the First query assessments at 68.2% probability to: Llaqta of Machu Picchu 1421–1476, Chachabamba 1406–1480, and Choqesuysuy 1336–1470.
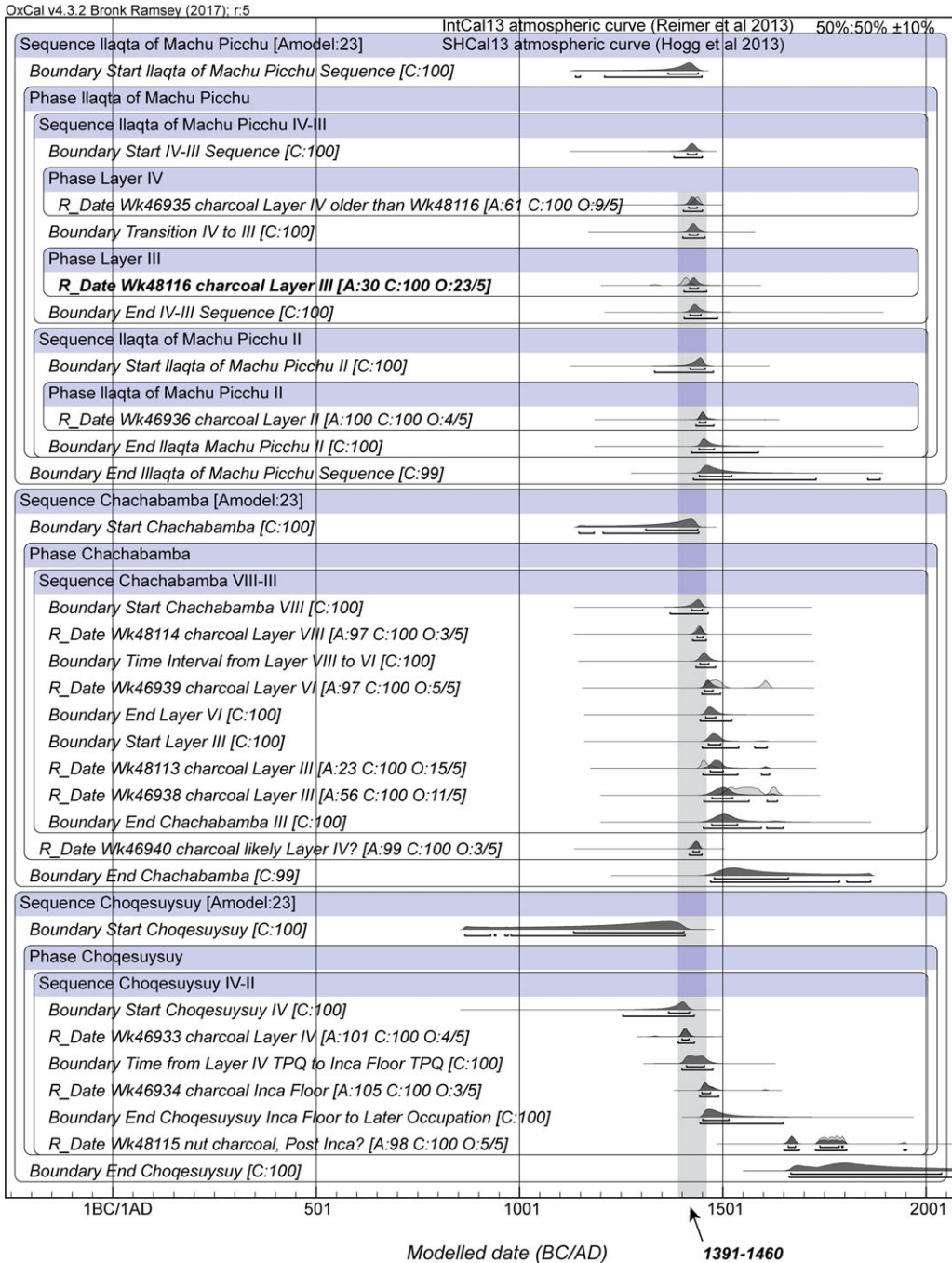
Figure 4 Modeled chronology for Llaqta of Machu Picchu, Chachabamba, and Choqesuysuy (Model 1) applying the OxCal General Outlier model. Mixed SHCal13 and IntCal13 curves (50:50 ± 10%) were used to build the model. The large out-of-sequence outlier Wk48116 is indicated in bold. Gray bar indicates the first dated sample range across all three sites.
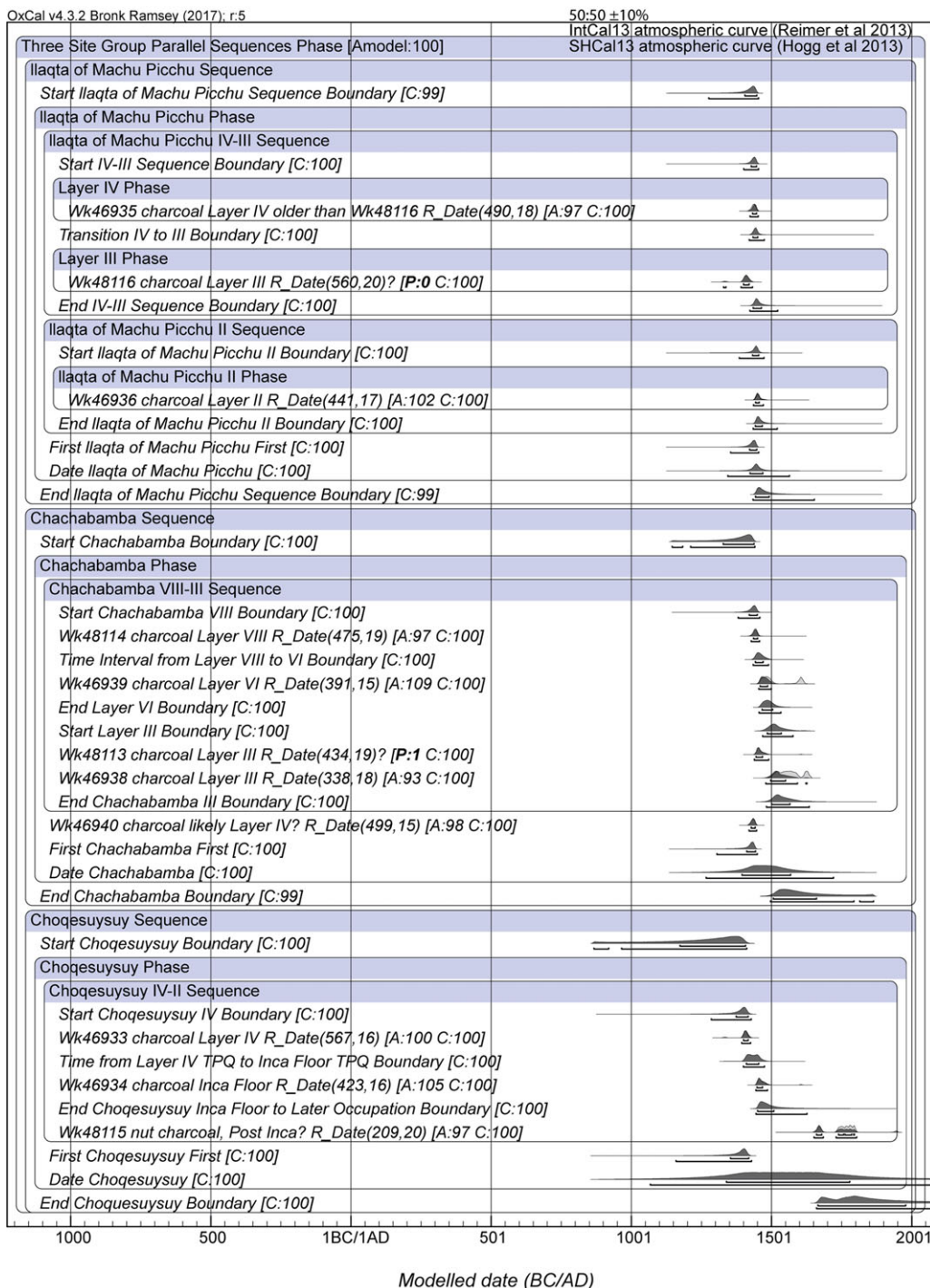
OxCal v4.3.2 Bronk Ramsey (2017); r:5   50:50 ±10%

IntCal13 atmospheric curve (Reimer et al 2013)
SHCal13 atmospheric curve (Hogg et al 2013)

Three Site Group Parallel Sequences Phase [Amodel:100]
Ilaqta of Machu Picchu Sequence
    Start Ilaqta of Machu Picchu Sequence Boundary [C:99]
    Ilaqta of Machu Picchu Phase
        Ilaqta of Machu Picchu IV-III Sequence
            Start IV-III Sequence Boundary [C:100]
            Layer IV Phase
                Wk46935 charcoal Layer IV older than Wk48116 R_Date(490,18) [A:97 C:100]
            Transition IV to III Boundary [C:100]
            Layer III Phase
                Wk48116 charcoal Layer III R_Date(560,20)? [P:0 C:100]
            End IV-III Sequence Boundary [C:100]
        Ilaqta of Machu Picchu II Sequence
            Start Ilaqta of Machu Picchu II Boundary [C:100]
            Ilaqta of Machu Picchu II Phase
                Wk46936 charcoal Layer II R_Date(441,17) [A:102 C:100]
            End Ilaqta of Machu Picchu II Boundary [C:100]
        First Ilaqta of Machu Picchu First [C:100]
        Date Ilaqta of Machu Picchu [C:100]
    End Ilaqta of Machu Picchu Sequence Boundary [C:99]
Chachabamba Sequence
    Start Chachabamba Boundary [C:100]
    Chachabamba Phase
        Chachabamba VIII-III Sequence
            Start Chachabamba VIII Boundary [C:100]
            Wk48114 charcoal Layer VIII R_Date(475,19) [A:97 C:100]
            Time Interval from Layer VIII to VI Boundary [C:100]
            Wk46939 charcoal Layer VI R_Date(391,15) [A:109 C:100]
            End Layer VI Boundary [C:100]
            Start Layer III Boundary [C:100]
            Wk48113 charcoal Layer III R_Date(434,19)? [P:1 C:100]
            Wk46938 charcoal Layer III R_Date(338,18) [A:93 C:100]
            End Chachabamba III Boundary [C:100]
        Wk46940 charcoal likely Layer IV? R_Date(499,15) [A:98 C:100]
        First Chachabamba First [C:100]
        Date Chachabamba [C:100]
    End Chachabamba Boundary [C:99]
Choqesuysuy Sequence
    Start Choqesuysuy Boundary [C:100]
    Choqesuysuy Phase
        Choqesuysuy IV-II Sequence
            Start Choqesuysuy IV Boundary [C:100]
            Wk46933 charcoal Layer IV R_Date(567,16) [A:100 C:100]
            Time from Layer IV TPQ to Inca Floor TPQ Boundary [C:100]
            Wk46934 charcoal Inca Floor R_Date(423,16) [A:105 C:100]
            End Choqesuysuy Inca Floor to Later Occupation Boundary [C:100]
            Wk48115 nut charcoal, Post Inca? R_Date(209,20) [A:97 C:100]
        First Choqesuysuy First [C:100]
        Date Choqesuysuy [C:100]
    End Choqesuysuy Boundary [C:100]

1000   500   1BC/1AD   501   1001   1501   2001

Modelled date (BC/AD)

Figure 5   Model 2 chronology for Llaqta of Machu Picchu, Chachabamba, and Choqesuysuy applying Outlier queries against Wk48116 and Wk48113. Mixed SHCal13 and IntCal13 curves were used to build the model (50:50 ±10%). First and Date queries are shown for each site Phase.
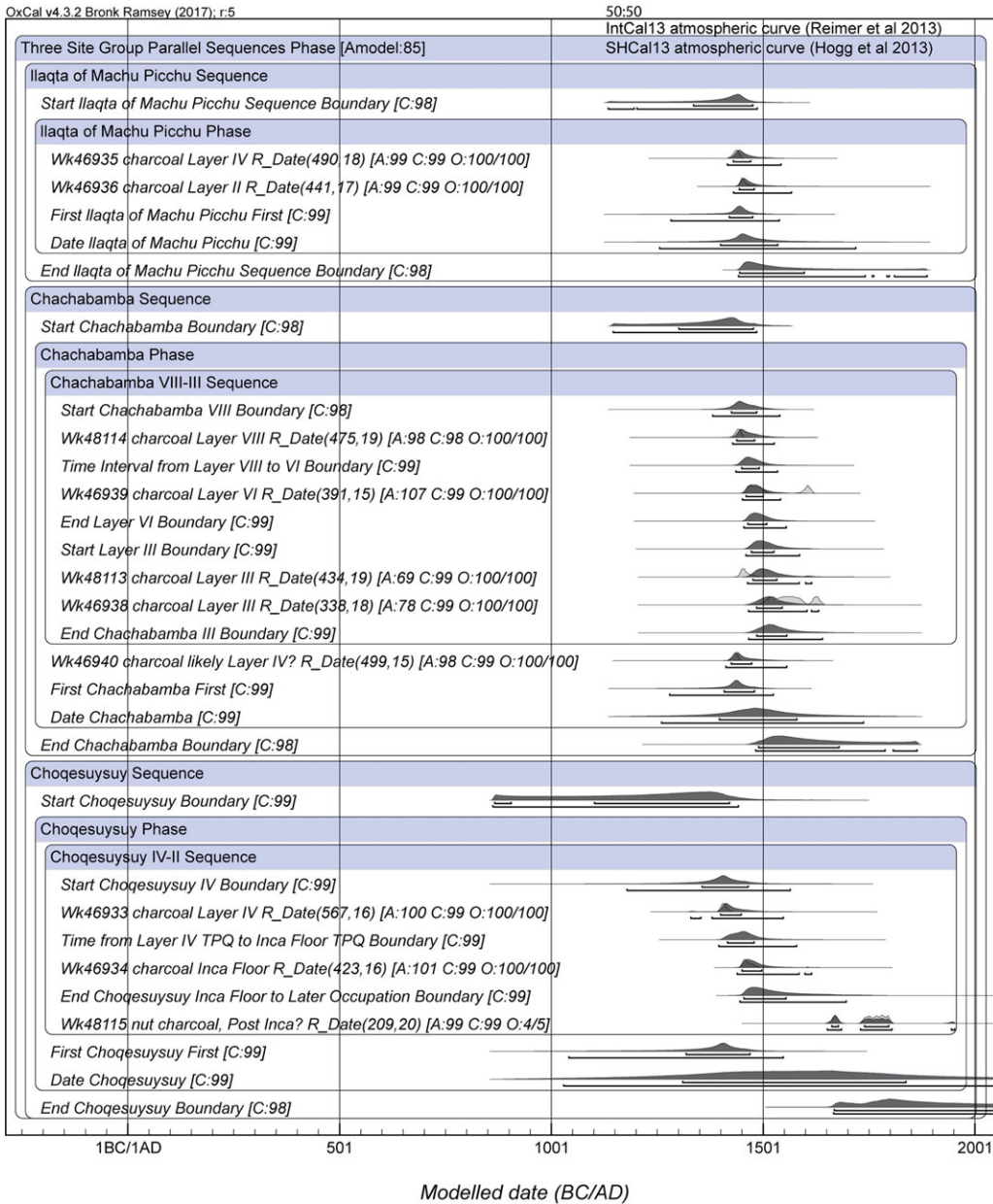
Figure 6 Model 3 chronology for Llaqta of Machu Picchu, Chachabamba, and Choqesuysuy applying the Charcoal Plus Outlier model (Dee and Bronk Ramsey 2014) against all the dates on wood charcoal to allow approximately for in-built age. The out-of-sequence outlier, Wk48116, has been excluded. The General Outlier model is applied to the nut sample (Wk48115). Mixed SHCal13 and IntCal13 curves were used to build the model (50:50 with no error). First and Date queries are shown for each site Phase.

Based on the results from Models 1 and 2, the initial phase for Llaqta of Machu Picchu and Chachabamba likely overlap (or are close in time), which may suggest that the construction of both sites commenced at the same time. For Choqesuysuy, Models 1 and 2 may suggest a possibility of a time span earlier than that obtained for Llaqta of Machu Picchu and

Chachabamba. The attempt to allow approximately for the TPQ involved in all the dates relevant to the initial phases of the three sites (Model 3) could be consistent, but also allows that Choqesuysuy could in fact also be an early-mid 15th century construction. This limited data highlights the urgent need for a better chronology. Additional ^{14}C dates are necessary and especially on (i) annual or short lifespan organics associated with each phase at the site, and/or (ii) on wood charcoal samples using a wiggle-match or ordered sequence of dates to refine placement of outermost tree-rings (and hence human use or a best TPQ). Our results which involve the first use of Bayesian inference modeling of ^{14}C dates of sites in the Machu Picchu National Archaeological Park demonstrates the applicability of the methodology and the urgent need for further AMS dates on samples with known species identifications using Bayesian modeling.

CONCLUSIONS

The method based on Bayesian analysis described in this paper is the first attempt to use it to estimate the chronology of archaeological sites of Llaqta of Machu Picchu, Chachabamba, and Choqesuysuy. The proposed model suggests that Llaqta of Machu Picchu and Chachabamba were established around the same time period. On the other hand, the modeled chronology of Choqesuysuy suggests that it may have been built earlier than Llaqta of Machu Picchu and Chachabamba.

Because the investigated sites are in the area of the ITCZ, which may shift with even slight climatic changes, it will be necessary to investigate the impact of any such climatic events during periods of the sites' occupation. This would result in appropriate correction of the relevant Northern, Southern or mixed ^{14}C calibration curves.

This analysis was based on samples from three sites and for obvious reasons more comparative material from different contexts is needed. However, based on the results of the current research, corrections to the chronology of Machu Picchu region for the first half of the 15th century are indicated.

Another important finding is that the Llaqta of Machu Picchu may have been preceded by other Inca installations in the area, specifically as indicated in our model by the site of Choqesuysuy.

This conclusion has additional support in the analysis of certain representations of rock art in the area that show that the site had a ceremonial importance several centuries before the occupation of this territory by the Incas (Astete et al. 2016, reinterpreted by Orefici 2017).

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