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Stages, Periods, and Radiocarbon: ^{14}C Dating in the Archaeology of the Central Andes

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Some of the earliest archaeological materials radiocarbon-dated were from the Central Andes, and archaeologists from the region were also involved in early efforts at meta-analysis of assemblages of radiocarbon dates and Bayesian chronological modeling. Nevertheless, regional chronological schema still vary surprisingly little from their pre-radiocarbon antecedents. As a result, significant scope for increasing the impact of radiocarbon dates, as well as making their use more robust and transparent, remains. Improved use of radiocarbon dates has the potential to reconfigure Central Andean chronologies, suiting them better to addressing many of the questions that archaeologists wish to ask. With this in mind, I here review the history of use of ^{14}*C dating in the archaeology of the Central Andes, before focusing on practical issues that confront archaeologists working in the region as they both employ* ^{14}*C dates and seek to be informed and critical consumers of published* ^{14}*C dates and chronologies.*

Algunas de las primeras muestras que se entregaron para fechar con radiocarbono vinieron de los Andes Centrales, y la región también ha liderado en los esfuerzos de meta-análisis de agrupaciones de fechados de radiocarbono y de modelaje cronológico bayesiano. Sin embargo, es bastante común encontrar en uso esquemas cronológicos que varían muy poco con respeto a sus antecedentes pre-radiocarbono. Aquí planteo que eso se debe no solo al costo y a los detalles científicos del método, que pueden ser desalentadores, sino también a un legado de escepticismo. Como resultado, existe ámbito amplio para hacer más robusto y transparente el uso de los fechados ^{14}*C, y también para aumentar su impacto. Aún más de medio ciclo después de su introducción, el uso de radiocarbono todavía tiene el potencial de reconfigurar las cronologías centroandinas, haciéndolas más apropiadas para contestar las preguntas que se formulan los arqueólogos. Pensando en ese potencial, aquí reviso la historia del uso del método radiocarbónico en la arqueología de los Andes Centrales. Después pongo el foco en los asuntos prácticos que se enfrentan los arqueólogos que trabajan en la región: calibración, reservorio marino, articulación de fechados* ^{14}*C entre si y con sus contextos arqueológicos, y el meta-análisis de compilaciones de fechados radiocarbónicos. Estos asuntos son importantes tanto para los arqueólogos que utilizan fechados* ^{14}*C como para los que aspiran a ser consumidores informados y críticos de los fechados* ^{14}*C publicados y las cronologías basadas en ellas.*

Keywords: Central Andean chronology, radiocarbon dating, cultural chronology

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Introduction

The desert coast of the Central Andean region[1] seems ideal for building ^{14}C-based chronologies of the human past. The remarkable preservation of organic materials in this arid environment raises the tantalizing prospect of plentiful samples from short-lived species, while the abundance of archaeological remains offers sealed contexts clearly linked to the events that archaeologists wish to date. In this setting, the chronological correlation of apparently related but geographically dispersed cultural materials (primarily but not exclusively ceramics, and extending across coast, adjacent highlands, and into the westernmost fringe of the Amazon Basin) has been a driving question in Central Andean archaeology since the earliest years of the discipline, since the initial construction of culture-historical frameworks entailed a search for chronological markers in the material culture of the region (i.e., the translation of commonalities across space into commonalities in time).

The fact that the seminal Ica Master Sequence (Menzel 1964; Rowe 1962), a ceramic reference chronology constructed by Dorothy Menzel, John Rowe, and Lawrence Dawson for the Ica Valley with the explicit intent that that it could serve as a chronological anchor for work elsewhere, is still in regular use half a century after its publication is testament to the thirst for such a tool. In addition to ordering the past in Ica, this sequence served as a tool for discussing cultural process—the occasional subsumption of Ica into larger Central Andean historical currents, marked by changes in ceramics and iconography—as a means of leveraging the archaeological preservation of the coast in other, less taphonomically-fortunate areas of the Central Andes. The lasting impact of this work (see Carmichael 2019) is testament to its quality, the richness of the archaeological record in Ica, and the keenness of the need. That the research was undertaken entirely without reference to ^{14}C dating is not surprising given the period in which it was carried out. What *is* surprising is the near-absence of subsequent efforts to test and/or refine this fundamental pillar of Central Andean archaeology through ^{14}C or other scientific dating. Other similar seriation-based sequences have also remained largely untouched by developments in scientific dating (though see Vaughn et al. 2014), in spite of the explosion in the numbers of ^{14}C dates produced since the advent of AMS dating (discussed in *The Second Radiocarbon Revolution*, below). This to-date limited influence notwithstanding, absolute dating offers the possibility of testing the postulates of these frameworks, and even getting at the social, political, and economic dynamics driving the patterns identified in the establishment of culture-historical periods.

The possibility of linking culture-historical frameworks—constructed in large part from floating seriations of ceramics, iconography, and architecture—to an absolute timescale continues to have obvious attraction. Initially this appeal resulted from the need to tie floating seriations to one another and to calendar time, linking spatially and chronologically dispersed sites into a sequential whole that could underpin a regional narrative. Subsequently focus shifted to defining archaeological stages and/or periods with respect to calendar years, and in recent decades to questions of cultural process over time. In spite of the desire for absolute time markers (e.g., Kubler 1948; Rowe 1945), early methodological complications created inconsistencies between ^{14}C results and other chronological diagnostics, producing a degree of skepticism about the reliability of ^{14}C results more generally (e.g., Rowe 1965). These include, for example, limitations in measurement accuracy produced by varying calculations of the half-life of ^{14}C, fluctuations in the proportion of atmospheric ^{14}C over time that are now dealt with through dendrochronologically-based calibration, and varying isotopic fractionation in different sample materials, not to mention such mundane issues as sample pretreatment and contamination, and relationship of dated to target event. As the radiocarbon community itself certainly recognized, error could be introduced at many different stages of the process and both technical and interpretive methods continued to evolve even as the technique was in active use (see Spriggs 1996). Caution was warranted, as for instance archaeologists in Island Southeast Asia the Island Pacific now routinely discount dates run in the 1960s and early 1970s at the Gakushuin Laboratory (GaK) in Japan as unreliable (Spriggs 1989:604, 1996).[2]

In fact both Junius Bird's (1951; Bird et al. 1985: Ch.5) guarded optimism and John Rowe's warnings about the incautious use of ^{14}C dates foreshadow Bayesian modeling strategies of formally incorporating archaeological information. These have in the last decade had remarkable success and become increasingly common (forming a second wave of the "Third Radiocarbon Revolution"; see Bayliss 2009:126). However, rather than stimulating development of rigorous programs of ^{14}C dating, skepticism like Rowe's provoked a continued reliance in the Central Andes on relative and local dating tools, primarily ceramic and iconographic seriations. With few exceptions, ^{14}C dates in the Central Andes have historically been used only as anchors for these sequences, through which particular sites or contexts are related to regional frameworks, rather than as means of developing detailed chronological models of site or regional trajectories (much less testing or unpacking culture-historical frameworks).

Following a brief review of the use of ^{14}C dating in the archaeology of the Central Andes, I focus here on practical issues that confront archaeologists working in the region as they both employ ^{14}C dates and seek to be informed and critical consumers of published ^{14}C dates and chronologies. I review general issues in ^{14}C dating as applied to the Central Andes, consider issues particular to the Central Andes and recent case studies in the application of ^{14}C dating within the region, and conclude with a discussion of salient ^{14}C-related questions that continue to demand research attention.

A Brief History of ^{14}C Dating in the Central Andes

The Impact of Three Global Radiocarbon Revolutions in the Central Andes

Renfrew (1973) and subsequently Taylor (1995) and Bayliss (2009) posit three distinct revolutionary impacts of radiocarbon dating on archaeology: the introduction of a reliable method of absolute dating, calibration that could relate those dates directly to calendar years, and methodological improvements (atomic mass spectroscopy [AMS]) that vastly increased the numbers of dates produced. These "radiocarbon revolutions" can all be detected in the Central Andes, where archaeologists have been both wary of and precocious in ^{14}C dating. Pioneering work—e.g., in relating ^{14}C dates to stratigraphic relationships (Bird 1951), meta-analysis of ^{14}C dates (Rick 1987), and Bayesian modeling (Zeidler et al. 1998)—has been accompanied by a surprisingly limited overall impact on regional chronological frameworks.

The First Radiocarbon Revolution

The first decades of archaeological ^{14}C dating in the Central Andes formed part of to the "first radiocarbon revolution": the adoption of a reliable method of absolute dating (see Bayliss 2009; Taylor 1995, after Renfrew 1973). Andeanists were among the pioneers: ^{14}C dates from 14 Central Andean samples (of which 12 were archaeological, provided primarily by Junius Bird but also by George Kubler and Donald Collier) appeared in print as early as 1951, included amongst the first samples of unknown age dated by the radiocarbon method (Arnold and Libby 1951:119–120; Bird 1951). Even as these were first published (and re-published in Spanish shortly thereafter [Bird 1952]), Bird was already attempting to use the stratigraphic relationships between these dates to constrain the possible dates, and grappling with how to interpret the probabilistic nature of the data (e.g., Bird 1951: Fig. 1 and p47). Construction of macro-scale chronologies (e.g., Bird 1951:Table 2) for the region was the primary concern. In fact the advent of ^{14}C dating coincided with a larger research imperative in the archaeology of the Central Andes: establishing chronological frameworks and understanding what cultural processes had produced the observed patterning (e.g., Bennett 1948; Larco Hoyle 1948; see Ramón Joffré

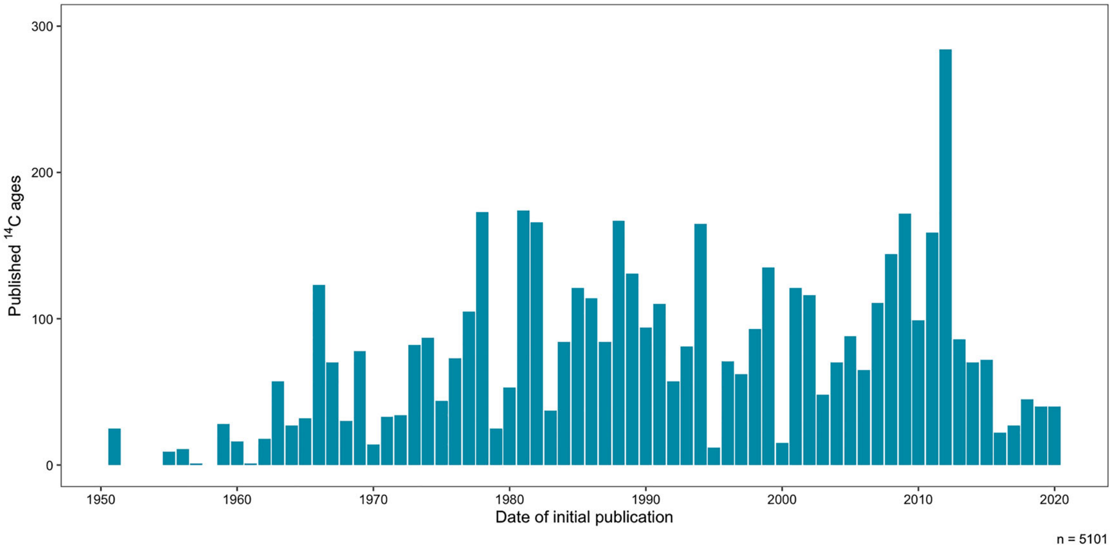

Figure 1. Publication of ^{14}C dates for the Central Andes, 1951–2020. While post-1994 dates are certainly undercounted, the overall pattern remains a coherent one of adoption, incremental increase until a jump in the late 1970s, and then relative stability until a second increase in the early twenty-first century. Data sources in Table 1.

2005; Kaulicke 2010). Bennett and Bird (1964:226) observed that the number of published dates over the first decade in which ^{14}C dating was available went from 16 in 1951, to 50 in 1956, to ~120 in 1959.

The Second Radiocarbon Revolution

Renfrew (1973) termed the impact of dendrochronological calibration—namely the reliable linkage of ^{14}C dates to calendar years—the "second radiocarbon revolution" for its impact on archaeological understandings of culture history. In the Central Andes, dominated more by broad recognition of the need to *construct* a chronological framework than by established ideas about chronological relationships, this second revolution perhaps had a less dramatic effect. Whereas in Europe "radiocarbon dating shattered the carefully constructed edifices of cultural interrelationships" (Roberts and Vander Linden 2011:4), in the Central Andes those edifices still remain largely intact. The major impact was felt along with that of the first revolution: contrast for example the timescales of Bennett (1946:80) and Willey (1948: Table 1) with subsequent formulations (e.g., Bennett and Bird 1964:Fig. 8; Lanning 1967: Table 2; Lumbreras 1974:14–18), which maintain largely comparable schema but extend the timespan by approximately a millennium. In fact, both before and after calibration of ^{14}C dates was recognized as a necessity, enthusiasm about the potential contribution of ^{14}C dates to Central Andean chronology-building was tempered by caution about methodological complications and the need for interpretive care in their use (e.g., Bennett and Bird 1964:223–228; Engel 1963; Rowe 1965; both Bennett and Bird and Rowe include in their concerns the complications raised by recognition that calibration was necessary).

The Third Radiocarbon Revolution

An approximation of the rate at which ^{14}C dating was adopted by archaeologists working in the region can be provided by aggregating the initial year of publication of the ^{14}C dates included in regional compilations (Gayo et al. 2015; Goldberg et al. 2016; Rademaker et al. 2013; Riris 2018; Roscoe et al. 2021; Ziółkowski et al. 1994). This is an imperfect proxy for the frequency with which Andeanist archaeologists employed the method, but

Table 1. Sources of ^{14}C dates included in Figures 1 and 2 (with duplicates removed). The first six are regional compilations, while the remainder have been included to mitigate undercounting of recently published radiocarbon dates.

Reference	*Number of ^{14}C dates*
Gayo et al 2015	567
Goldberg et al 2016	652
Rademaker et al 2013	26
Riris 2018	424
Roscoe et al 2021	417
Ziolkowski et al 1994	3104
Burger 2019	17
Capriles et al 2016	15
Cherkinsky and Urton 2014	33
Fuchs et al 2009	30
Haas et al. 2017	19
Inokuchi 2008	70
Janusek 2011	17
Jones et al. 2019	40
Kembel and Haas 2015	32
Reindel and Isla 2018	23
Rick et al 2009	50
Sakai and Martínez 2008	25
Seki et al 2008	23
Sharratt 2019	21
Tantaleán et al 2013	17
Unkel et al 2012	27
Van Gijseghem et al 2018	17

unfortunately year of laboratory analysis is very rarely available. The results ($n = 5101$, accounting for duplicates; see Figure 1) show only very modest increase until the late 1970s. An average of just over 100 ^{14}C dates/year were published in the 1980s, before a slight decline in the 1990s that probably reflects the slower pace of research during the years of the Shining Path insurgency in Peru. Although the subsequent twenty-first century increase is surprisingly modest in scale, the data certainly undercount for the post-1994 period, since the last compilation that attempted comprehensive coverage appeared with the release of the University of Warsaw's ANDES ^{14}C database in 1994 (Ziółkowski et al. 1994); now available at https://andesc14.pl/en/. Compilations that have appeared since have generally been more specifically targeted: Rademaker and colleagues (2013) focused on pre-7000 BP dates, SCAR (Gayo et al. 2015) on the South-Central Andes, Roscoe and colleagues (2021) on the coast of Peru.[3] In short, post-1994 ^{14}C dates are certainly much more abundant than is apparent here, but in the absence of any single centralized database it is (increasingly) challenging to be cognizant of them all. The totals used here also include several recent studies that have published significant quantities of dates in an attempt to mitigate undercounting (see Table 1), but are certainly not comprehensive. The potential impact of problems of quality control and completeness on meta-analyses of ^{14}C dates is explored below in *Databases and Meta-Analyses*.

The apparently cautious uptake likely reflects budgetary constraints and response to the warnings of Rowe and others, as well as a tendency to rely on relative dating and/or typological assignment to existing chronological frameworks. Even after the advent of ^{14}C dating, periodization remained more a focus than absolute chronologies (Kaulicke 2008, 2010; Ramón Joffré 2005; Rowe 1962). The ambiguities and even inconsistencies produced by the juxtaposition of ^{14}C dates and other chronological information (notably that derived from seriation and stratigraphic relationships) produced a disciplinary atmosphere in which ^{14}C dates were often seen as less reliable than the pre-existing cultural chronologies into which those dates were meant to fit. In fact dates from the early decades of the radiocarbon dating method probably should be treated with caution (see Spriggs 1996:941, who goes so far as to suggest that, "we should be very cautious in interpreting radiocarbon dates run before 1970."). As a result, ^{14}C dates were more generally used to identify the broad spans of time within which material-culture-based periods should fall than as tools for refining understandings of those periods themselves. This is particularly notable for more recent archaeological periods that have been considered better understood, and has held largely true over time for several decades in spite of the increase in the number of ^{14}C dates apparent in Figure 1. This is evident in the scarcity of explicit attention to ^{14}C dates in synthetic treatments of Central Andean archaeology, including such influential syntheses as those of Lanning (1967), Willey (1972), Lumbreras (1974), and Keatinge (1988); even where the

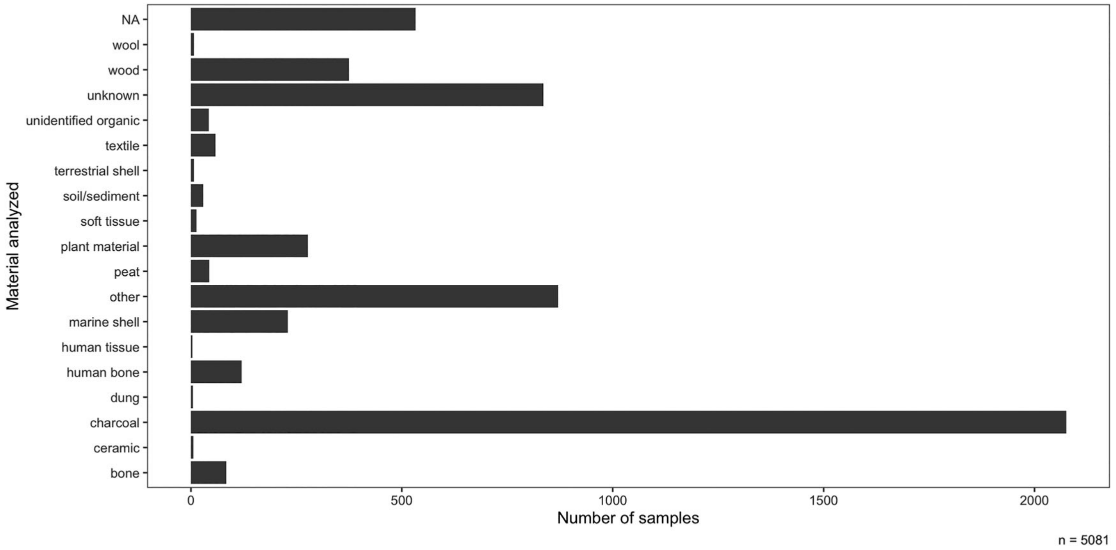

Figure 2. Central Andean ^{14}C dates, by categories of material dated.

chronological charts they produce are described as grounded in radiocarbon dates, the specific dates and the process of synthesis are not described. Ravines' early compilation of radiocarbon dates (Ravines and Alvarez Sauri 1967, updated in Ravines 1982) presumably informed his (1982) synthesis, but not in any explicit way. This marginality is reflected in radiocarbon's near-absence from both state-of-the-field reviews (Burger 1989; Schaedel and Shimada 1982; Shimada and Vega-Centeno Sara-Lafosse 2011) and retrospectives (Matos Mendieta 1990; Ramón Joffré 2005; Tantaleán 2014; Tantaleán and Astahuamán 2013).

The increase apparent beginning in the 1990s corresponds to Taylor's (1995) "third radiocarbon revolution": the proliferation of ^{14}C dates brought about by the increasingly wide availability of the atomic mass spectroscopy (AMS) technique, as well as the ensuing drop in analysis costs and relaxation of limitations on samples suitable for analysis. Bayliss (2009) argues that this third revolution is ongoing, as the effects of this proliferation of ^{14}C dates enabled by AMS dating include innovations that are changing the ways in which ^{14}C dates contribute to archaeological interpretation. She refers primarily to Bayesian modeling (i.e., the formal incorporation of other types of chronological information into calculation of the probability density functions used to describe calibrated ^{14}C dates), but one might reasonably also include meta-analysis (primarily summed probability distributions of ^{14}C dates; critiques of validity notwithstanding, it certainly is both becoming more common and having a wide impact on the field) and even the proliferation of paleoecological records that are increasingly chronologically precise as age-depth models are based on more ^{14}C dates and more rigorous modeling methods. Bayesian modeling was applied relatively early in the Central Andes (Zeidler et al. 1998), but that early effort did not stimulate widespread embrace of the method, which only recently is being more widely used (e.g., Contreras in press; Koons and Alex 2014; Marsh 2012; Marsh et al. 2017; Sharratt 2019; see *Particular Central Andean Concerns*, below). Similarly, the meta-analysis of ^{14}C dates as a tool for examining prehistoric cultural and demographic patterns was pioneered in the Central Andes (Rick 1987) but only recently has been first more widely adopted and then revisited in the Central Andes (e.g., Goldberg et al. 2016; Marsh 2015; Riris 2018; Roscoe et al. 2021; see *Particular Central Andean Concerns*, below).

The Revolution Will Not Be Uncritically Embraced

Even with the "third revolution" underway, methodological concerns—e.g., marine reservoir effects and appropriate calibration for tropical southern latitudes—continue to be relevant, as I discuss below in *Particular Central Andean Concerns*. In addition, any broad sample of published ^{14}C dates from the nearly 70 years during which these have been produced will encounter problematic dates (as noted by Ziółkowski 1994 in his commentary on the difficulties of compiling ^{14}C dates for the region). The early caution expressed by Bird (1951), Engel (1963), and Rowe (1965) was at least in part justified, as subsequent decades witnessed the sometimes cavalier use of ^{14}C dates in the Central Andes. Whether due to budgetary limitations, inadequate understandings of the method, or sheer optimism, there are many examples in which few or even single dates have anchored entire site chronologies, contextual relationships have been insecurely documented, materials dated have not been identified, or dates have been idiosyncratically selected in order to produce chronologies that conform to the expectations of their authors. The periodic and continuing publication of cautions about the pitfalls of using ^{14}C dates (e.g., Kaulicke 2008; Velarde 1998; Ziółkowski 1994) and extensive revisions of earlier efforts at building ^{14}C-based chronologies (e.g., Marsh's [2012] reassessment of Ponce Sanginés' [1972] Tiwanaku chronology; Rick and colleagues' [2009] reassessment of Burger's [1981] Chavín chronology) are testament to the persistence of such problems. The Central Andes are far from unique in this, as Bayliss (2009:126) scathingly observed in 2009: "routinely still far too little attention is paid to the association between the sample, the context from which it was recovered, and the archaeological event that our dating targets."

Many of these problems were recognized in Ziółkowski and colleagues' pioneering effort to construct a regional database of ^{14}C dates (Michczyński et al. 1995; Ziółkowski et al. 1994), and are described in Ziółkowski's contribution to the publication (Ziółkowski 1994) specifically because of the challenges they raise in the apparently straightforward task of juxtaposing ^{14}C dates from diverse sources. As this early effort at compiling a database of ^{14}C dates from the region demonstrated, if a database is to be more than just a catalog of dates as published, it will have to deal with publications that may or may not calibrate dates or specify calibration method, published dates that may or may not identify the material dated or specify its context and relationship to the target event, and even for some early publications omissions of measurement uncertainty (e.g., Engel 1963:Table 1, which provides only mean values; there is more often a problem in the construction of chronologies based on the median values of ^{14}C dates than with incomplete publication). Such efforts at quality control as calibrating previously uncalibrated ^{14}C measurements, rating the reliability of samples, or looking for patterns within the included dates confront problems that require more than simple compilation.

Ziółkowski and colleagues struggled with these problems because they (a) attempted to exercise some quality control on the dates included in the ANDES ^{14}C database, and (b) worked to meaningfully juxtapose dates, attempting to not only make them available but consider the use of the database as an analytical tool. Compilations of dates that did not aspire to be more than lists (e.g., Bird 1951; Engel 1963; Ravines 1982; Ravines and Alvarez Sauri 1967) did not face this challenge, while targeted thematic compilations (e.g., Burger 1992: Appendix [Initial Period and Early Horizon]; Lau 2004 [Recuay]; Paul 1991 [Paracas]; Watson 1986 [North Coast]) have tended to focus on collection and selection of dates and not explicitly recognized methodological issues of juxtaposition of dates or their use to create chronologies (note for instance that the compilation of dates in Burger 1992: Appendix specifies no calibration information and provides single intercepts rather than probability ranges). This results in part from the goals of topically-driven compilations, which implicitly consider previous chronological schemes to be reliable systems of periodization into which ^{14}C dates can be fit. This may be a manifestation of what Politis (2003:118) has described as the continued dominance of a fundamentally culture-historical paradigm within South American archaeology, within which ^{14}C dates could be comfortably deployed, forming part of "culture history with more sophisticated analytical methods."

In contrast, the overarching analytical goals of subsequent database projects (e.g., deFrance et al. 2009; Gayo et al. 2015; Goldberg et al. 2016; Rademaker et al. 2013), whose stated aim is pattern analysis, make such issues vital: where analytical outcomes are contingent on sample density in time and space, those outcomes can be very sensitive to inclusion or exclusion of particular samples (particularly if the corpus in question has few samples for a given time period or region). Nevertheless these recent projects have also struggled with the problem of filtering dates for quality, particularly as databases get larger (see Note 1 on Goldberg et al. 2016, as well as Rademaker et al. 2013:35). Although such "chronometric hygiene"(careful screening of dates to include only accurately dated events that reliably match target events; see Spriggs 1989) is vital to constructing robust archaeological interpretations, the challenge of appraising large numbers of published dates—often published with varying degrees of thoroughness—is such that meta-analyses often rely on the hopeful principle that large samples of ^{14}C dates can obviate the need for scrutiny of individual dates.

Meta-analysis of collections of ^{14}C dates was pioneered in the Central Andes, where John Rick (1987) argued that collections of ^{14}C dates could enable analyses of broad demographic patterns in space and time. In spite of various confounding factors (e.g., preservation and research biases), Rick argued, ^{14}C dates could serve as a population proxy for coastal and highland regions of Peru during the preceramic period (defined for analytical convenience as 20,000–3,000 radiocarbon years BP), since the production of datable material should be roughly proportional to population size (see Rick 1987:Fig. 1). In excluding the last three millennia he avoided problems of variable interest in ^{14}C dating by researchers focused on different periods.

Such analyses depend in large part on sample sizes relative to the spans of time and space under consideration (i.e., sampling density). Rick drew on 328 ^{14}C dates, while as Figure 1 makes clear considerably larger samples are now available, particularly when longer spans of time are considered. Ziółkowski and colleagues initially were able to compile approximately 2,650 ^{14}C dates from Ecuador, Bolivia, and Peru in ANDES ^{14}C (1994), Gayo and colleagues incorporate 1,661 South Central Andean ^{14}C dates in SCAR (as of publication in 2015), and Goldberg and colleagues draw on 3,124 ^{14}C dates from the Central Andes (2016). That said, Rademaker and colleagues (2013) were able to compile only 308 dates for the period 13,000–7,000 BP, while Riris (2018) compiled 1180 dates for the period between 14,000 and 3,000 BP and Roscoe and colleagues (2021) keep 745 dates (following some chronometric hygiene) for the period 10,000–1,000 BP Peruvian coast. Evidently the increases in sheer numbers of ^{14}C dates since the introduction of AMS are not evenly distributed across sites of all time periods. It should also be noted that these data bases overlap in the ^{14}C dates they include. The totals presented in Table 1 account for these overlaps, eliminating all double-counted dates; as pointed out above, recently-published dates are certainly undercounted in these totals.

Finally, it is worth stating an obvious fact that rarely is noted in the archaeological literature: ^{14}C dates from archaeological contexts are not the only archaeologically relevant ^{14}C dates in the Central Andes. Paleoenvironmental dates are increasing vital in archaeological interpretation as they often serve as the link between archaeological and paleoenvironmental data (see Contreras 2010; Marsh 2015; Rademaker et al. 2013). Flantua and colleagues' recent synthesis (2016), for instance, demonstrates the relevance of paleoenvironmental data to archaeological synthesis (e.g., Flantua et al. 2016:Fig. 13 and Table 3). These paleoenvironmental data are generally grounded in ^{14}C dates, which serve as the basis of age-depth models of paleoenvironmental data archives (e.g., lake and peat cores) as well as markers of such phenomena as extreme El Niño—Southern Oscillation (ENSO) events and glacial advance and retreat. These dates rarely if ever figure in archaeological databases, although they may feature—generally indirectly—in site or regional interpretations, as human and environmental trajectories are interpretively linked. Archaeologists working in the Central Andes should note, however, that analytical improvements affecting the utility of ^{14}C dates (with regard, e.g., to calibration or marine/lacustrine reservoir effects) are as likely to come from the paleoecological community as from the archaeological community.

Universal Concerns

Fundamental issues and general concerns with respect to ^{14}C dating in archaeology have been amply covered (e.g., Bayliss 2009; Taylor 1995; Taylor and Bar-Yosef 2014), and I only mention these briefly here, before turning to more particularly Central Andean ^{14}C issues.

In the Central Andes as elsewhere, two types of concerns loom large over the aspects of ^{14}C dating that are within the control of archaeologists: methodological and interpretative. Methodological concerns comprise sample selection (including material, context, and documentation) and reporting conventions, while interpretative concerns stem primarily from the probabilistic nature of ^{14}C results, and include both analysis via Bayesian chronological modeling and meta-analysis via summed probability distributions. Issues of calibration and correction (e.g., of ΔR) fall into both categories.

The archaeological application of ^{14}C dating depends on the relationship of the dated event (i.e., the calendar date measured by the ^{14}C assay) to the target event (i.e., the episode in the past whose calendar date of occurrence the archaeologist wishes to determine). The selection of samples for dating must be guided by identification of a target event, understanding of what the dated event will be, and elucidation of the relationship between the two. This may be complicated by the age of samples at deposition or by any reservoir effects, as well as by such basic archaeological concerns as the relationship of depositional event to target event, number of depositional episodes, and post-depositional disturbance. Relating the depositional event to other contexts of interest is of course a further fundamentally archaeological task.

The analysis or compilation of published archaeological ^{14}C dates must also confront the relationship of target event and dated event, often with the added complication that these are incompletely described in the original publications. Ziółkowski (1994) describes the difficulties of even juxtaposing dates encountered in the compilation of the ANDES ^{14}C database, and decisions about the inclusion or exclusion of dates in meta-analyses as early as Rick's (1987) and as recent as Goldberg and colleagues' (2016), Riris' (2018), and Roscoe and colleagues' (2021) are fundamentally assessments about the reliability of published dates. These challenges are exacerbated when analyses are more complex, or are focused on site or catchment (rather than regional or continental) scales, when the relative relationships of target events that are close together in time are the subjects of investigation. With this in mind Bayliss (2015:681–690, particularly Tables 3 and 4) has suggested (following Millard [2014]) more thorough and rigorous reporting conventions for archaeological ^{14}C dates:

(1) details of laboratory analysis, including both
   (a) the commonly published laboratory number, radiocarbon age and measurement error, and calibration details, and
   (b) the more rarely seen details of calculation, laboratory pre-treatment, synthesis and measurement, δ^{13}C measurement, and reservoir correction

and

(2) archaeological context, including
   (a) material dated, ideally identified to species level and with indication whether it is derived from a single entity,
   (b) appropriate ^{14}C reservoir, and
   (c) details of association.

Such standards facilitate chronometric hygiene like that proposed by Spriggs (1989); the goal is to make the reliability of published dates easily assessable by future researchers.

The more ample information that Bayliss advocates publishing as a matter of course is necessary if published ^{14}C dates are to be incorporated into Bayesian chronological models. These are becoming the gold standard in the construction of archaeological chronologies, both achieving more precise dating of events and more explicitly describing uncertainties in chronology where those exist. Bayesian models, building on the probabilistic nature of calibrated ^{14}C determinations, formally incorporate of other types of chronological information into calculation of the probability density functions used to describe calibrated ^{14}C dates, producing posterior probabilities that can often be substantially constrained relative to the prior probabilities of stand-alone calibrated ^{14}C dates (see Bayliss et al. 2007).

The obvious appeal of the posterior probabilities produced by Bayesian models is that where sufficient chronological information—for example sequencing of dated events through stratigraphic relationships—is available they are often more precise than unmodeled ^{14}C dates. In addition, they serve to underscore the probabilistic nature of ^{14}C dates. While this should need no emphasis, having been recognized since the earliest archaeological applications of the method, nevertheless it remains common to see calibrated ^{14}C dates—asymmetrically distributed probability density functions (PDFs)—implicitly presented as if they were normal or uniform distributions. It is common to see probabilities illustrated as if they were equally distributed amongst all dates in the time ranges that span the 68% or 95% confidence intervals (e.g., Bauer 1996:Figures 4 and 5; deFrance et al. 2009:Figure 5; Dillehay et al. 2012: Table 1 and Figure 5; Görsdorf and Reindel 2002: Figures 4 and 5; Janusek 2003; Lau 2003: Cuadro 2; Quilter et al. 2012:Table 5). While it is difficult to summarize PDFs otherwise, the suggestion that probability is equally distributed across these ranges can be misleading, as the probabilities are irregularly distributed across the period in question and the area of highest probability is not necessarily associated with the center of the distribution. When used in chronology-building these effects can multiply.

The difficulty of how to interpret irregular probability distributions also animates debates over the utility and reliability of meta-analyses of archaeological ^{14}C dates that rely on summed probability distributions. As the irregular PDFs produced by calibrating ^{14}C dates cannot be simply binned in order to examine their changing frequencies in time and space, the recent revival (see Contreras and Meadows 2014; Crema and Bevan 2021; Williams 2012) of Rick's (1987) dates-as-data meta-analysis has been founded on the adoption of the summed probability approach. Where Rick avoided the problem by working with uncalibrated dates and radiocarbon years before present, increasing recognition that calibrated dates are necessary for archaeological interpretation has necessitated a means of summarizing frequencies of PDFs. The sum approach combines the PDFs of individual ^{14}C dates by summing the heights of every individual date at every calendar date for which any of the dates has a probability and normalizing the result; the height of resulting cumulative PDF is then implicitly understood to reflect the number of individual ^{14}C dates for any given calendar age. Generally that number of dates over time is argued (or assumed) to be proportional to population, methodological and theoretical concerns notwithstanding (Contreras and Meadows 2014:591–592).

Calibration of ^{14}C dates is obviously vital to archaeological interpretation, whether of dates in isolation, through Bayesian modeling, or via meta-analysis. While this is a general archaeological problem, selection of calibration curve can be geographically specific, and calibration issues in the Central Andes are discussed in *Particular Central Andean Concerns*, below. Here it is sufficient to note that while radiocarbon laboratories will provide calibrated dates, it is also now routine for archaeologists to calibrate ^{14}C determinations themselves, as multiple computational tools are now readily available. These include OxCal (https://c14.arch.ox.ac.uk/oxcal.html), CALIB (http://calib.org/calib/), Bacon (http://www.chrono.qub.ac.uk/blaauw/bacon.html), Chronomodel (https://chronomodel.com/), and CalPal (http://monrepos-rgzm.de/forschung/ausstattung.html#calpal), as well as the **BChron** (Parnell 2015), **clam** (http://www.chrono.qub.ac.uk/blaauw/clam.html andhttps://github.com/SimonGoring/clam), and **RChronoModel** (Philippe and Vibet 2017) packages for R. These tools also facilitate dealing with marine reservoir corrections and other dating offsets, where those are known or calculable, and OxCal, Bacon, BChron, clam, and Chronomodel are also designed for age-depth modeling and/or construction of Bayesian models and calculation of posterior probabilities.

Particular Central Andean Concerns

Archaeologists in the Central Andes face not just general methodological and interpretive challenges in archaeological ^{14}C dating, but also problems particular to the region. Methodologically, the Central Andes are particularly prone to complications stemming from complications of ^{14}C calibration and marine reservoir correction. The appropriate treatment of these problems in the regions remains an open research subject, and so it is unsurprising that it has historically been a significant challenge as well. In addition, incorporating the results of ^{14}C dating into pre-existing chronological frameworks (or even rebuilding those frameworks entirely), and "big data" approaches to ^{14}C dates present interpretive challenges specific to the Central Andes.

^{14}C Calibration in the Central Andes

The need for calibration was recognized beginning in the 1960s (see Taylor et al. 1996), and high-precision calibration became manageable for non-specialists with the publication of the CALIB program in the mid-1980s (Stuiver and Reimer 1986). However, calibration continued to be seen as a topic sufficiently arcane that it remained unremarkable in the literature on Central Andean archaeology to publish only uncalibrated ^{14}C dates as late as the early 1990s (e.g., Burger 1988; Fung Pineda 1988; Ponce Sanginés 1993) and led Silverman to complain as recently as 2004 that, "there is chaos in the literature, with most scholars using uncorrected [uncalibrated] dates or both kinds of dates." (Silverman 2004:13)

A further complication is that both Northern and Southern Hemisphere calibrations continue to be used in publication of ^{14}C dates from the Central Andes. Uncertainty about which calibration curve was applicable stemmed first from the various attempts to establish an appropriate correction for secular variation in atmospheric ^{14}C over time and the use of various curves by Andeanist archaeologists (see Ziółkowski 1994), but even after the establishment of a single high-precision calibration curve by the radiocarbon community (Stuiver and Kra 1986) and its subsequent periodic updating, researchers have continued to use both Northern and Southern Hemisphere calibrations (i.e., various updates of IntCal and SHCal curves; see https://c14.arch.ox.ac.uk/oxcalhelp/hlp_curves.html for a selection of current and past curves). A Southern-Hemisphere-specific calibration curve did not appear until 2002 (McCormac et al. 2002), when it was (necessarily, given the data available) based on relatively high-latitude data, and only in 2004 was SHCal extended back earlier than 1000 BP (McCormac et al. 2004). While earlier samples are increasingly incorporated, these still cover only approximately 18% of the last 13,000 years, and SHCal still relies on dendrochronological calibration from relatively high-latitude southern samples, from which a hemispheric offset is calculated and applied to periods for which no southern dendrochronological time-series of atmospheric ^{14}C is available (summarized in Hogg et al. 2013, 2020). While the result of extrapolating to earlier periods is likely robust (i.e., more accurate than using the Northern Hemisphere curve) for high latitudes in the Southern Hemisphere, within the zone impacted by the Intertropical Convergence Zone (ITCZ) uncertainty is higher and smaller offsets are likely appropriate.

This has produced concern that neither the calibration curve developed for the Northern Hemisphere (IntCal20, most recently [Reimer et al. 2020]) nor the correction developed for the

Southern Hemisphere (SHCal20, most recently [Hogg et al. 2020]) is appropriate for tropical southern latitudes within the range of atmospheric mixing of the ITCZ. Calibration curves for the post-bomb period separate the globe into five latitudinal zones (Hua et al. 2013: Fig. 2) rather than simply into hemispheres, on the basis of atmospheric circulation patterns marked by the summer and winter positions of the ITCZ and the Northern Hemisphere Ferrel cell—Hadley cell boundary. Unfortunately, insufficient data still prevent reconstructions of atmospheric ^{14}C with this level of spatial resolution for the pre-bomb period, but the post-bomb data serve to emphasize that for the Central Andes neither IntCal nor SHCal is likely to be entirely appropriate. Marsh and colleagues (2018), following a detailed review, conclude that three zones can be identified in South America, within which IntCal, SHCal, or a mix of the two is appropriate; Hogg and colleagues (2020:773–774) agree in principle. Moreover, given the proximity of the ITCZ to the region and the mobility of the ITCZ throughout the Holocene, the appropriate offset for Central Andean ^{14}C dates is likely to vary in space within the region, and in time throughout the Terminal Pleistocene and Holocene periods of interest to Andeanist archaeologists. An additional layer of complication is the seasonal variation in the location of the ITCZ and consequently the source of the CO_2 incorporated by plants during the growing season (see Finucane et al. 2007:581; Ogburn 2012:223–224), which may not conform to the kinds of spatial mapping of interannual means offered by Hua and colleagues for the post-bomb period. Hogg and colleagues (2020:774) recognize this complexity but suggest a 50:50 mix of northern and southern curves as a practical solution.

In principle this might be addressed through development of long dendrochronological sequences for multiple parts of the region, but in spite of the potential for wood preservation in archaeological contexts on the coast and for long-lived tree specimens in the *sierra*, dendrochronology in the Central Andes has proved a significant challenge (see Boninsegna et al. 2009). Thus, while development of a region-specific ^{14}C calibration curve may eventually be realized, a more immediate and practical alternative remains necessary for archaeological ^{14}C dating. Where archaeologists have considered the issue in detail, solutions have included preferring IntCal (Rick et al. 2009:91–93; Ziółkowski 1994:14), using a mixed calibration curve (Marsh et al. 2017:5), adopting an offset intermediate between IntCal and SHCal as well as publishing results using both calibrations (Cadwallader et al. 2015:768; Unkel et al. 2012:2300), and using either IntCal or SHCal in different parts of the region (Ogburn 2012:224). Recently Marsh and colleagues (2018:933) have argued for a modeling approach that allows the proportions of a mixed curve to fluctuate, producing results with slightly greater uncertainty that accounts for the additional unknown of which exact mixture is appropriate. Fortunately the scale of difference between IntCal and SHCal is generally <50 years (varying over time with a mean of 36 ±27 (Hogg et al. 2020:773)), and with the exception of the chronology of Inca Expansion archaeological chronologies in the region are rarely sufficiently precise for a difference of that magnitude to have interpretive ramifications.

Marine Reservoir Effects in the Central Andes

In addition to calibration, marine reservoir effects can also impact ^{14}C dates on the Central Andean coast. As early as 1964 Bennett and Bird used dates on marine shell, aquatic plants, and animal bone and skin from a sealed archaeological context of approximately known date to demonstrate that dates on marine shell could be problematic (Bennett and Bird 1964:225–226). Taylor and Berger (1967) documented this offset more systematically and accurately, as well as discussing (following Berger et al. 1966) the atmospheric and oceanic dynamics that produced different ^{14}C ages in marine and terrestrial materials. However, there has been little specific consideration of marine reservoir issues by the archaeological community (though see Owen 2002 and

Southon et al. 1995). Instead the response seems to have been to largely avoid dating marine shell: there has been relatively little dating of bone or shell in the region (of 4836 samples with information on material available, nearly half are on charcoal, with <300 on bone and <300 on marine shell; see Figure 2). Owen's work demonstrates considerable ΔR (on the order of 350 years, roughly consistent with what Taylor and Berger had observed), and the strong possibility of spatial and temporal variability therein. Jones and colleagues (2010) found similar cause for concern and offsets of comparable magnitude.

This is not to say that dating marine shell should necessarily be abandoned as inappropriate. If ΔR offsets can be measured and modeled, marine materials may offer a means of avoiding some problems involved in dating terrestrial material. Kennett and colleagues (2002) argue, on the basis of anomalously old charcoal dates from the site of Kilometer 4, that old wood problems are a significant risk in the coastal Central Andes, and that developing better understanding of the magnitude and variation of ΔR is needed in order to enable ^{14}C dating of marine shell, which ultimately has the potential to provide better archaeological dating (i.e., to provide ^{14}C dates that more closely match the date of the target event). Analysis of ΔR can also be seen as an end unto itself, as it offers a means of analyzing past variability in coastal upwelling (e.g., Andrus et al. 2005; Etayo-Cadavid et al. 2013, 2019; Fontugne et al. 2004; Jones et al. 2019; Latorre et al. 2017; Ortlieb et al. 2011). Lacustrine ΔR (and consumption of freshwater as well as marine resources) can also produce anomalously old ^{14}C dates (Keaveney and Reimer 2012), but this issue remains largely unexplored in the Central Andes (though see Marsh 2015:16–17).

Because this remains an active area of research (see *Pending ^{14}C-Related Research Questions in the Central Andes*, below) no simple correction for marine ΔR exists. The complex temporal and spatial dynamics of the marine reservoir suggest that solutions are more likely to be particular than generalizable. The magnitude of documented marine ΔR, meanwhile, suggests that any analyses of marine shell (or bone where marine dietary protein is likely) must specifically address the relevant ΔR, at least recognizing the scale of the resulting uncertainty in interpretation and preferably directly investigating the local offset.

Articulation of ^{14}C Dates and Cultural Chronologies

As the number of ^{14}C dates in the Central Andes has increased, the possibility—and indeed necessity—of revisiting the region's chronological frameworks is being actively explored. Discomfort or frustration produced by juxtaposing existing chronologies with accumulating radiocarbon evidence is not new (e.g., Burger 1981, Paul 1991, Pozorski and Pozorski 1999, Rick et al. 2009, Velarde 1998), but revisions have become increasingly ambitious. These include both relatively short-term and high-precision chronologies (e.g., of the Inca Empire [Adamska and Michczynski 1996; García et al. 2021; Marsh et al. 2017; Ogburn 2012] and the Moche state (s) [Koons and Alex 2014]) and longer-term regional trajectories (e.g., the Early and Middle Horizons [Augustyniak 2004; Contreras in press; Marsh 2012]). Various strategies have been pursued, ranging from the conventional compilation of published dates and provision of new ones to innovative projects focused on new dating methodologies to construction of complex Bayesian models. In addition to these regional-scale chronologies, construction of more robust chronologies for individual sites and regions has also become a priority (e.g., Dillehay et al. 2012; Marsh 2012, 2015; Unkel et al. 2012).

These projects confront two basic problems:

1. how (and if) ^{14}C dates articulate with
   - (a) existing chronological frameworks derived from seriations of ceramics, iconography, and architecture,
   - (b) models of such cultural phenomena as conquest, conversion, and diffusion, and
   - (c) (for more recent periods) ethnohistoric and documentary sources, and
2. space–time systematics, i.e., ideas about the contemporaneity or even simultaneity of

similar phenomena across regions of various scales.

Reassessing existing chronological frameworks has involved revision or reformation of chronological frameworks for sites and regions, based on simple compilation of dates and addition of new ones (e.g., Adamska and Michczynski 1996; Augustyniak 2004; Dillehay et al. 2012; Finucane et al. 2007; Kembel and Haas 2015; Lau 2004; Rick et al. 2009; Santoro and Núñez 1987; Unkel et al. 2007; Unkel and Kromer 2009), as well as Bayesian models incorporating both ^{14}C dates and other chronological information (e.g., Cadwallader et al. 2015; Contreras in press; Greco and Palamarczuk 2014; Koons and Alex 2014; Marsh 2012, 2015, 2017; Marsh et al. 2017; Ogburn 2012; Unkel et al. 2012). The former rely on revising existing frameworks, while for the latter, the question of when to consider existing chronological frameworks as prior information and when to tear them down in order to rebuild them from scratch is a central challenge.

Robust chronological models for particular sites are vital elements in any regional approach, but their construction is only beginning to be adequately addressed. A few Central Andean projects were ahead of their time in exploring the potential of ^{14}C dating and Bayesian modeling (Michczyński and Pazdur 2003; Zeidler et al. 1998), and more recently an increasing number of projects have focused on the development of high-precision robust site chronologies, often through Bayesian modeling methods (e.g., Korpisaari et al. 2014; Marsh 2012; Marsh et al. 2019; Michczyński et al. 2003, 2007; Millaire 2020; Rademaker and Hodgins 2018; Sharratt 2019; Takigami et al. 2014; Vega-Centeno Sara-Lafosse 2008; Yaeger and Vranich 2013). These contrast sharply with the still-common use of ^{14}C dates largely in isolation from their contexts, as indicators of antiquity rather than building blocks in detailed chronologies (e.g., Dillehay et al. 2007; Haas et al. 2004; Pozorski and Pozorski 2005; Shady Solis et al. 2001). While use of ^{14}C dates to establish approximate calendar ages is necessary to the construction of basic chronological frameworks, explanatory analyses are likely to require the higher-precision site and regional chronologies produced by Bayesian modeling approaches.

Approaches to Central Andean chronologies more generally engage with fundamental archaeological problems involved with large-scale patterns in subsistence practices and material culture, as well as theoretical approaches to culture process. The archetypal example is the appearance of Chavinoid ceramics (i.e., first millennium BCE ceramics associated with the so-called Early Horizon that share characteristics of surface finish and decoration, as well as to a lesser extent vessel form) in Ica that forms the basis of the Rowe-Lanning chronology. In practice employing Chavinoid ceramics as a chronological marker has implied a virtual simultaneity in adoption of such ceramics throughout the Central Andes. Periodization schemes for the region more generally implicitly adopt similar stances with respect to, for example, the adoption of plant and animal domesticates, the appearance of ceramics, use of irrigation technology, early construction of monumental architecture, and subsequent spreads of particularly identifiable styles in iconography, ceramics, and architecture. The pace and directionality of such phenomena are fundamental to the interpretation of the cultural processes involved, and ^{14}C chronologies thus have the potential to improve both empirical reconstructions and theoretical models.

Databases and Meta-analyses

Several Central Andean projects have seen compilation and analysis of published archaeological ^{14}C dates as a productive means of engaging with such regional questions. Early compilations, Rick's (1987) pioneering meta-analysis, and the ANDES ^{14}C database (Ziółkowski et al. 1994) have been discussed above in *A Brief History of ^{14}C Dating in the Central Andes*. More recent efforts have, probably in response to both the increasing numbers of available dates and the increasing ease of digitally manipulating them, combined these impulses of comprehensive collection and meta-analysis.

Where Rick's efforts had temporal and spatial limits and a particular research question—the relative magnitudes of early human activity in the sierra and on the coast—the more recent revival of the method has tended to be more ambitious in its coverage and more general in its questions. Goldberg and colleagues (2016) provide the most extreme example: their scope is the entire South American continent and nearly the entire span of the Holocene. Others (e.g., deFrance et al. 2009; Marsh 2015; Rademaker et al. 2013) have compiled more geographically and/or temporally limited databases to address particular questions, but research at regional or continental scales and employing quantitative meta-analysis is increasingly common both within (Gayo et al. 2015; Muscio and López 2016; Riris 2018; Roscoe et al. 2021) and outside (Flantua et al. 2016; Goldberg et al. 2016) the field of archaeology. This resurgence of dates-as-data approaches mirrors a global trend (e.g., Peros et al. 2010; Shennan 2013; Williams 2012, among many) of compilation and analysis of archaeological ^{14}C assemblages across regional and millennial scales.

In the Central Andes as elsewhere the analytical tool of choice has been the sum approach (e.g., Gayo et al. 2015; Goldberg et al. 2016; Riris 2018; Riris and Arroyo-Kalin 2019; Roscoe et al. 2021). This enables researchers to work with calibrated dates (in contrast to Rick's analysis of dates in radiocarbon years with normally distributed uncertainties) and avoids the difficulty of attempting to bin irregular probability density functions (as in frequency analysis of single-year data). However, as even practitioners acknowledge, theoretical and methodological challenges remain. A few difficulties stand out:

(1) the challenge of summarizing data that incorporate uncertainty and thus comprise irregular distributions of probability (see Bronk Ramsey 2017); the sum approach has been broadly adopted but without generally applicable solutions for its weaknesses (that is, the problems which must be overcome have to be dealt with in each case, and cannot be generally dismissed via any methodological sleight-of-hand; see Contreras and Meadows 2014), and

(2) the vulnerability of meta-analyses to uneven spatial and temporal sampling and small sample sizes common in archaeological datasets (and increased significance of database incompleteness and/or poor chronometric hygiene under such circumstances[4]).

These problems have been recognized and are the subject of active research attention (e.g., Brown 2015; Crema et al. 2017; Crema and Bevan 2021), but may be resistant to one-size-fits-all solutions (see Contreras and Meadows 2014; Mökkönen 2014).

In the case of the Central Andes, although site locations are not available for all dates, meta-analyses must for example take into account the fact that dates are unevenly distributed in space (Figure 3), reflecting some combination of past population distributions, research attention, and modern population density.

Pending ^{14}C-Related Research Questions in the Central Andes

The recent research reviewed in *Particular Central Andean Concerns*, above, is much-needed in the Central Andes, where improving site and regional chronologies are vital tools with which to construct more accurate and precise culture-historical frameworks and thus enable more active and constructive engagement with anthropological archaeological questions about (for instance) culture process and human-environment interactions.

As noted above, some issues in the application ^{14}C dating in the Central Andes are fundamental to ^{14}C measurement in the region. Scientific dating in the archaeology of the Central Andes, in this respect, waits on (1) research into the specific history of ITCZ movement throughout the Holocene, and (2) development of more detailed marine ΔR corrections. As noted in *^{14}C Calibration in the Central Andes*, above, any solution for ^{14}C calibration that

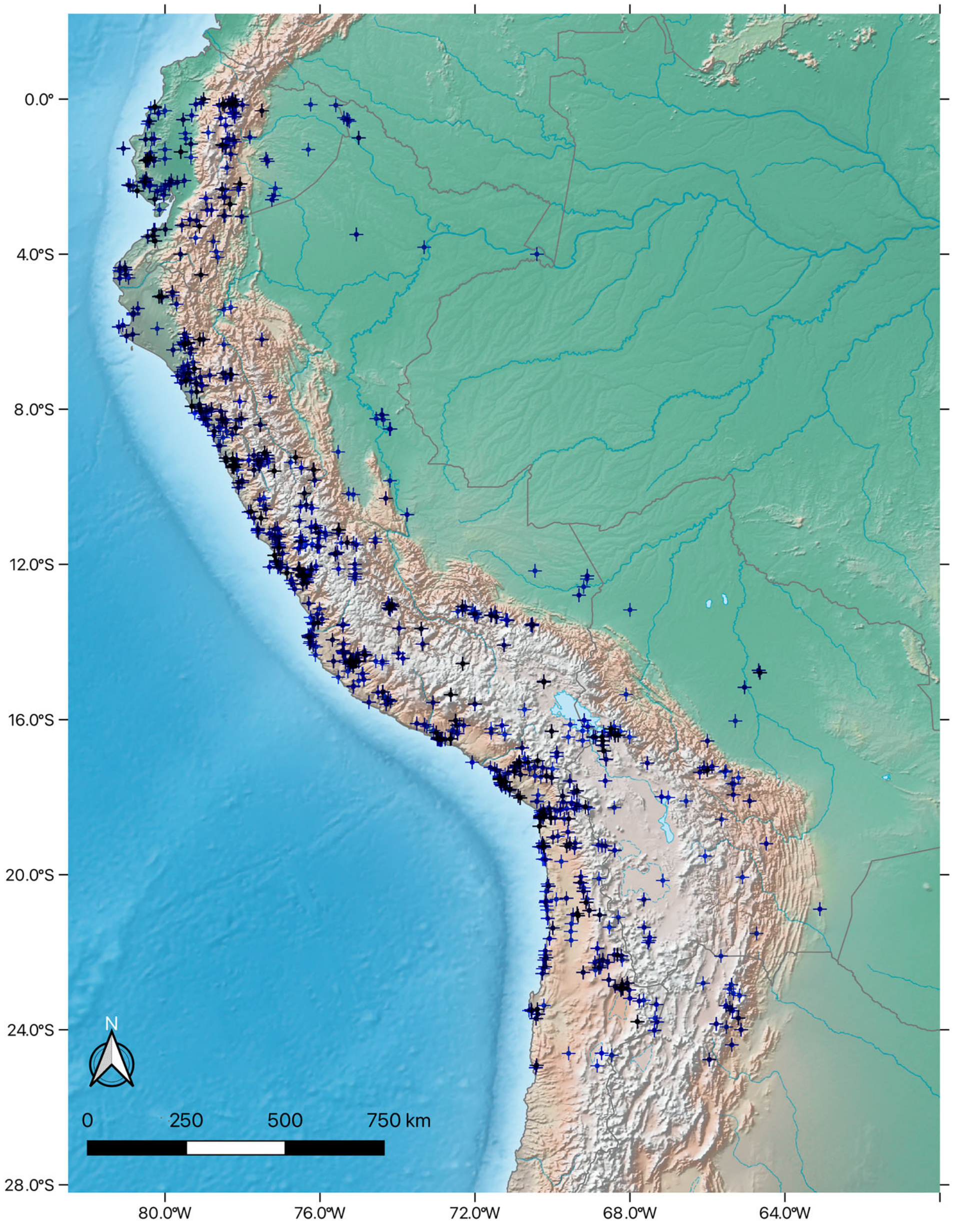

Figure 3. Central Andean ^{14}C dates for which locations are available (*n* = 4943, from 1278 sites). Basemap made with Natural Earth data (naturalearthdata.com).

involves modeling of ITCZ history may need to be spatially variable across the region, taking into account the differing effects of the ITCZ in different parts of the Central Andes (as well as, potentially, how these patterns may have differed at various times in the past). With respect to ΔR, as several of the researchers cited above in *Marine Reservoir Effects in the Central Andes* note, variation over time as upwelling patterns have changed is both a topic of research in itself and a confounding factor for dating. ΔR correction for the region needs to both take this temporal variation into account and consider spatial variability along the Central Andean littoral.

Both ITCZ and ΔR issues may be subject to indirect as well as direct solutions: development of local dendrochronological series in the Central Andes (see, e.g., Boninsegna et al. 2009; Ghezzi and Rodríguez 2015; Morales et al. 2013) offers the possibility of developing regional rather than hemispheric calibration curves. These would face the same challenges of spatial and temporal variation in the ITCZ; i.e., we should not expect a calibration curve derived in the sierra to be simply applicable to the coast, and latitudinal variation is also likely (see *^{14}C Calibration in the Central Andes*, above).

An additional complication to ΔR corrections is the role that marine dietary components play in altering dates on bone. On the Central Andean coast, marine foods made up a significant portion of dietary protein, as has been well-explored through analyses of δ^{15}N of human tissue (e.g., Knudson et al. 2015; Slovak and Paytan 2011, among many). The effects of marine diet on ^{14}C dates from bone are well-recognized in principle but specifically addressing these in the Central Andean region is dependent on the availability of ΔR corrections as well as interpretation of δ^{15}N analyses (which have their own complications; see Szpak et al. 2012). While it is not common in the Central Andes to date bone (see Figure 2), human bone is often a desirable material for dating as the relationship between date and target event can be relatively straightforward. In the case of burials, for instance, recycling of material culture raises the risk that dates (whether ^{14}C or stylistic) on mortuary goods may not date the burial itself. Directly dating bone avoids this problem, though in the context of Central Andean mortuary practices, entry and re-entry into tombs and manipulation of human remains also raise the possibility that dates on bone may date an event—death, approximately—different than the original interment ritual. These issues have only begun to be explored through programs of detailed dating (e.g., Cadwallader et al. 2015; Santana-Sagredo et al. 2017; Takigami et al. 2014). Such research considers the effect of consumption of marine products on ^{14}C dates on bone, but is complicated by the complexity of Central Andean mortuary practice and limited by the coarseness of available date on local ΔR correction (and, conversely, can contribute to improved understanding of ΔR through analyzing paired dates on distinct materials, presuming their contemporaneity can be convincingly argued).

Conclusions

It is clear (and is not a new observation; see Kubler 1970) that neither periods nor stages are sufficient as explanatory tools; we use them to narrate the prehispanic past not by design but by default. Improved exploratory and explanatory frameworks for the Central Andean past, as a result, cannot simply consist of increasingly precise start and end dates for the periods and/or stages currently in use. Improving chronologies involves not only more accurately and precisely locating the transitions between one block of time and another, but also reconsidering the utility of the blocks themselves. Radiocarbon dating can contribute to both efforts in the Central Andes, but only to the extent that problems of how to more accurately and precisely date target events —i.e., the methodological challenges outlined here —are addressed.

Silverman (2004:13) suggests that there are pragmatic benefits of more rigorously tying regional chronologies to calendar years rather than relying on either stages or periods, highlighting improved communication and ease of comparison between regions. There are also broader questions of both accuracy and adequacy to be asked about chronologies that rely on describing the past in sequential blocks of undifferentiated time.

Accuracy

While common schema may be accurate in their broad outlines, neither their general accuracy not their applicability in a particular case should be taken for granted; the validity of these schema should be tested rather than assumed. They have been remarkably durable, but we should ask whether the limited impact of radiocarbon dating on Central Andean chronological schema (see *The*

Second Radiocarbon Revolution, above) resulted from the fundamental accuracy of existing frameworks, or from their entrenchment (what Kubler [1970:128] calls the "hardening of the periods" and Ramón [2005:7] refers to as "la permanencia [directa o indirecta] de las categorías planteadas en la primera época").

Theoretical Adequacy

Accuracy, moreover, may not be sufficient. Silverman's (2004:11) description of "the now oppressive temporal framework within which we work" reflects frustration with the interpretive limits imposed by systematizing time exclusively in obdurate blocks. Swenson and Roddick (2018), similarly, have recently argued that cultural chronologies risk obscuring the ways in which temporal change occurred even as they are used to identify it.

The root of these frustrations is that chronological frameworks that divide time across space in blocks are simultaneously *overly precise*—in locating transitions discretely—and *imprecise*—in that apart from these moments of transitions nothing may be located with temporal exactness. As such, they are also homogenizing in both time (within periods) and space (within the regions to which those periods are applied).

These aspects result in time–space systematics that do not permit interpretation or explanation at the temporal or spatial scales at which we aspire to work—or at least not at all of those scales. As Ian Morris (2000:Part I) has observed of archaeology more generally, the use of coarse periodization sits uncomfortably with the theoretical need to (following Braudel [1995[1949]]) recognize and incorporate temporal change occurring at various scales (geographical, social, and individual time).

For example, in concrete Central Andean terms, the Early Horizon garners attention precisely because it constitutes a particular cultural phenomenon that archaeologists would like to explain. That is, it is of interest not just as a chronological marker, but also because particular cultural processes produced a phenomenon that archaeologists can recognize through remnant material culture. Those cultural processes themselves can and should be an object of investigation (Burger 1993). As a result, it is not only the timing of the beginning and ending of the Early Horizon that is of interest, but also what happened during that block of time—i.e., the ways in which social and individual time intersected geographical time.

In other words, identifying a site, phase, or event as occurring within the span of the Early Horizon is insufficient (see Sayre 2018 on the example of Chavín). Rather, archaeologists in Central Andes need conceptual tools and vocabulary, as well as the ability to discern events and patterns with sufficient temporal resolution to describe the particular relationships and events that constituted the Early Horizon. This is not the only challenge. There is also a need to describe, for instance, events during the seventh century BCE that, while contemporary with the Early Horizon, might *not* form part of the phenomenon of interaction that the term encompasses.[5]

The former can be conceived of as making space for recognizing the ways in which—and timings with which—particular sites flirted with, embraced, assimilated, and/or rejected the regional currents (and, by those actions, contributed to *constituting* those regional currents). The latter can be conceived of as making interpretive space for currents that run *through* the time demarcated as the Early Horizon, and events that happen *within* it, without being necessarily related to it.

Rowe did not exclude these temporal scales from analysis, or make any theoretical claims about their significance or lack thereof, but focused on the practical limitations of ceramic dating: "chronological subdivisions can be made as fine as the stylistic subdivisions which can be distinguished in the master sequence" (1962:50). His ambition for his system of periodization was primarily that it could address the methodological problem—introduced in linking chronological assignment to stylistic or typological classification—of separating chronological assignment from interpretive description. Improved temporal resolution, more theoretically adequate to describe cultural change, was an additional benefit (Menzel 1969).

As Rowe (1962:49) recognized, the system of periods that he proposed relied on the possibility of establishing contemporaneity across space: "A particular cultural unit in some other part of Peru will be assigned to the Early Horizon, for example, because there is some reason for thinking that it is contemporary with a cultural unit at Ica which is dated to the Early Horizon, and without regard to whether there is any stylistic or technological resemblance between them." However, for all that he was concerned with escaping the trap of circular argumentation (Rowe 1962:51), without a means of independently measuring time that contemporaneity was (and still is) in practice judged by stylistic or technological resemblance.

Rowe (1962:49) in fact suggests radiocarbon dating as one likely way of escaping this trap by independently establishing contemporaneity across space, but nothing in his subsequent work suggests that he attempted to realize this potential. I close by considering the prospective contribution of radiocarbon dating to not only establishing contemporaneity but to refashioning chronologies.

The (Potential) Role of ^{14}C Dating

Addressing the question of accuracy requires means of assessing chronology—identifying and dating transitions, more precisely, and/or identifying and assessing the durations of phases—that are independent of classification, among which radiocarbon is the most obvious candidate (though Berenguer and colleagues [1988] and Vaughn and colleagues [2014] address this issue through thermoluminescence and optically-stimulated luminescence dating of ceramics, respectively). Whether radiocarbon-based chronologies can achieve this does not depend simply on the radiocarbon dates themselves. If collections of radiocarbon dates were in themselves sufficient, Ravines' compilation of radiocarbon dates and accompanying synthesis (1982) would have revolutionized the field. Instead, Ramón (2010:23) has observed "el poco valor de las listas de fechados calibrados si no se aclara el concepto que los hace significativos." That is, any collection of archaeological radiocarbon dates constitutes a series of dated events, and the rationale for associating those dated events with one another (and excluding others) constitutes an *a priori* argument about the structure of the human past. While careful use (and Bayesian modeling) of those dates can improve the *precision* with which that structure is described, the *accuracy* with which it is described depends not only the ^{14}C dates and their use but also on the accuracy of the *a priori* information. Precisely described periods that impose structure where there was none, or insist on a particular structure that may be at odds with the evidence, cannot succeed in improving the accuracy with which we describe the Central Andean past.

Theoretical issues, too, if they are to be addressed, require chronological information independent of the phenomena under investigation (which might include periods themselves). The key points are (1) to separate chronological assignment from classification, so that the temporal relationships of material ("stylistic and technological") culture can themselves become objects of investigation, and (2) to achieve chronological assignment with sufficient resolution to examine social and individual time as well as geographical time. Radiocarbon dates are one tool that can potentially achieve these goals. As in the case of achieving improved accuracy, avoiding the significant confusion that can result from mismatches between dated event and target event requires chronometric hygiene and—more generally—careful consideration of the relationships between dated events and target events. This is paramount for new dating programs, and particularly challenging in use of legacy data. Bayesian modeling like that discussed in *Articulation of ^{14}C Dates and Cultural Chronologies*, above, offers a means of careful and explicit consideration of the implications of ^{14}C dates and other sources of chronological information.

An additional consideration is the integration of cultural and environmental chronologies, whether to investigate environmental drivers of human activity or human impacts on their environments. Such integration requires archaeological data that are specifically grounded in calendar years rather than broadly tied to spans of time. Given that sequencing is vital to interpretation—e.g., whether an increase in local population preceded or followed a change in aridity is fundamental to exploring any relationship between the two—precise chronologies are a fundamental tool for research that aspires to explore human-environment interactions. In the Central Andes as elsewhere, radiocarbon dating remains one of items in the archaeological toolkit best suited to the task, but accuracy, precision, and appropriate *a priori* information are critical.

While database compilation and ensuing meta-analyses may be useful for generating regional-scale hypotheses that can be further tested, the importance of the quality of the information going into these databases means that significant attention to local detail (in the form of excavation-linked programs of ^{14}C dating, efforts at chronometric hygiene, construction of Bayesian models, etc.) will likely be required before large-scale analyses can produce robust results.

Even as acquiring ^{14}C dates continues to become easier, the quantity of ^{14}C dates available for analysis increases dramatically, and the methods of employing ^{14}C dates to address archaeological questions expand, enthusiasm for such research programs should be tempered by caution mirroring that expressed by the archaeologists of the Central Andes who first confronted ^{14}C dates.

Notes

1 Defined here—artificially but pragmatically—as extending from 0° to −25° latitude, and from −62.5° (effectively the western limits of the Amazon Basin; very few dates east of the *ceja de selva* are included) to the Pacific Coast. This incorporates areas whose chronologies have in some cases been treated as distinct (e.g., the South-Central Andes), and it is possible to identify multiple research traditions, splitting rather than lumping across, e.g., national boundaries and/or environmental zones.

2 With this in mind it is interesting to note that the recent compilation of South American ^{14}C dates by Goldberg and colleagues (2016) includes 48 GaK dates from the Central Andes that figure in the analyses. Although the dates of analysis are not obvious, as the sources are prior compilations (Gayo et al. 2015 and Ziółkowski et al. 1994), at least several (from Kotosh, Las Haldas, and Tiwanaku, minimally) were analyzed during the period in question.

3 The Goldberg et al. (2016) dataset attempts to be continentally comprehensive, but though more recent is not much more complete than ANDES ^{14}C: compare for example the number of dates included for Chavín de Huántar ($n = 21$, all from Ziółkowski et al. 1994) with the number reported in Rick et al. (2009) ($n = 75$, including the 21 appearing in Goldberg, 4 that appear in Ziółkowski but not in Goldberg, and 50 drawn from 6 previous post-1994 publications or appearing for the first time) and Kembel and Haas (2015) ($n = 32$, none of which appear in the other publications). While Chavín may not be representative of Central Andean sites generally (having been the subject of extensive and in part chronology-focused investigation since the late 1990s), similar patterns can be observed for Pacopampa ($n = 3$ in Goldberg and $n = 23$ in Seki et al. [2008]) and Kuntur Wasi (which does not appear in Goldberg, though Inokuchi [2008, 2014] reports 70 ^{14}C dates). This may reflect a neglect, since Ziółkowski's wide-ranging efforts, of Spanish-language publications (excepting Gayo and colleagues [2015], who draw extensively on material published in South America). This tendency is exacerbated by the common reliance on previous compilations.

4 See Note 1 on salient missing dates from Goldberg et al. 2016, and note also that of the 21 dates for Chavín de Huántar that do appear in the database compiled by Goldberg and colleagues, many were deemed problematic after detailed review by Rick and colleagues (2009:95–105). In few cases are such detailed reviews available, but Tiwanaku is another salient example: Marsh (2012:206) excluded 10 of 21 relevant dates on a variety of grounds.

5 As strictly defined, the Early Horizon is a period, and all events form part of the span of time that corresponds to it. In practice, however, this definitional elegance is compromised by the practical challenge of identifying as belonging to the Early Horizon contemporary sites that both embrace and eschew the material culture, iconography, and technology that typifies the period.

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