Late Ice-Age Human Settlement of the High-Altitude Peruvian Andes

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Abstract: *A synthetic understanding of the timing and migration routes involved in the initial human settlement of the Americas remains elusive. Although site-level investigations have provided a wealth of information on adaptations to specific ecological zones, fundamental information is lacking on landscape-scale patterns of mobility, settlement, and inter-site connections. Beginning with the source of exotic obsidian artifacts found at the Paleoindian coastal site Quebrada Jaguay in southern Peru, my research integrated a number of approaches to locate Paleoindian hunter-gatherer archaeological sites in the high Andes, with the ultimate objective of understanding early coast-highland links. This interdisciplinary work has demonstrated that despite colder temperatures, more extensive glaciers, and low-oxygen conditions, successful human colonization of the high-altitude Andes began ~12,400–12,000 years ago at the end of the last ice age. Investigation of linkages between early coastal and highland sites is ongoing.*
Keywords: *South America, Peru, Andes, high-altitude settlement, late Pleistocene, predictive modeling*

Späteiszeitliche Besiedlung der Peruanischen Hochanden

Zusammenfassung: Ein umfassendes Verständnis darüber, wann und auf welchen Wegen die erste Besiedlung Nord- und Südamerikas erfolgte, ist nach wie vor schwer zu gewinnen. Obwohl die Untersuchung einzelner Fundplätze eine große Anzahl an Informationen über menschliche Adaptionen an bestimmte ökologische Zonen geliefert hat, fehlen immer noch grundlegende Einsichten in den Umfang und die Art der Mobilität von Menschengruppen innerhalb der Landschaft, in Siedlungs- und Landschaftsnutzungsmuster sowie in Verbindungen zwischen den einzelnen Siedlungsplätzen. Ausgehend von der Frage nach der Herkunftsregion ‚exotischer' Obsidianartefakte aus der paläoindianischen Fundstelle Quebrada Jaguay an der Küste Südperus, verfolgte der Verfasser in seinen Forschungen mehrere Ansätze und verwendete verschiedene Methoden, darunter die Anwendung Geographischer Informationssysteme und die Methode der vorhersagenden Modellierung, um paläoindianische Jäger-Sammler-Plätze mit archäologischen Funden in den Hochanden zu lokalisieren. Das erklärte Ziel hinter diesen Forschungen war es, frühe Verbindungen zwischen Küstenlinie und Hochgebirge aufzudecken. Durch interdisziplinäre Forschungen konnte gezeigt werden, dass trotz kälterer Temperaturen, größerer Gletscherausbreitung und sauerstoffarmen Lebensbedingungen eine erfolgreiche Besiedlung der Hochanden bereits vor 12.400–12.000 Jahren, am Ende der letzten Eiszeit, einsetzte. Durch spezifische Werkzeugtypen und spezifische Rohmaterialien lassen sich darüber hinaus schon für diese Zeit eindeutige Verbindungen zwischen den peruanischen Hochanden und der Küstenregion nachweisen. Die Arbeiten hierzu werden weiter fortgeführt. Einen besonderen Höhepunkt der Forschungsexpeditionen stellte die Entdeckung eines vor fast 12.500 Jahren, im Spätpleistozän, von Menschen besiedelten Felsschutzdaches, Cuncaicha Rockshelter, in einer Höhe von 4500 m über dem Meer dar, in dessen Nähe sich das Herkunftsgebiet einer spezifischen Obsidianvarietät, des Alca-Obsidians, befindet. Mit der Höhe von 4500 m ist Cuncaicha Rockshelter gegenwärtig der höchstgelegene archäologische Fundplatz aus dem Pleistozän weltweit.
Schlagwörter: Südamerika, Peru, Anden, Hochgebirgsbesiedlung, Spätpleistozän, vorhersagende Modellierung

Introduction

The initial human settlement of the Americas was the most recent, rapid, and geographically extensive biogeographic expansion of our species. After ~15 thousand years ago (ka)[1], hunter-gatherers exited Beringia, the now-drowned land mass connecting eastern Siberia and western Alaska (Hoffecker et al. 2014), and within ~2 thousand years (ky) dispersed throughout the western hemisphere. Evidence for human presence in the continental Americas has been discovered as early as ~14.6 ka at several archaeological sites and is clearly indicated by ~14.0–13.0 ka at sites throughout the western hemisphere (Goebel et al. 2008 and references therein).

Understanding the timing, adaptations, and environmental changes involved in this biogeographic expansion is important not only for understanding American prehistory but also for comparing with other expansions of our species that happened earlier, elsewhere in the world. Relative to previous expansion episodes, archaeologists can study the peopling of the Americas at fine chronological resolution, thanks to the applicability of accelerator mass spectrometry (AMS) ^{14}C dating for the entire period of settlement. Yet, dramatic variations in the ^{14}C concentration of the atmosphere in the Terminal Pleistocene (Fiedel 1999), along with the rapid rate of human colonization of the entire hemisphere (Surovell 2000), and substantial landscape taphonomic issues (Moseley 1983), have posed problems for understanding the colonization process.

While site-level archaeological investigations throughout the hemisphere have provided glimpses of diverse Paleoindian adaptations in specific ecological zones, fundamental questions have yet to be resolved. Exactly when and by what routes did people colonize the Americas? How do early sites in different ecological zones relate to one another? Were various specialized adaptations present at the inception of colonization of the hemisphere, or did these develop in sequence?

Most Terminal Pleistocene sites are inferred to have been occupied over brief time spans by highly mobile hunter-gatherers (Kelly 1996), so studying how individual sites articulate within systems of subsistence, settlement, and mobility is important for understanding larger landscape-scale processes of colonization. The problem is that most Terminal Pleistocene sites have been discovered by chance and are widely scattered, limiting our ability to understand linkages between sites and the development of diverse cultural adaptations. What is needed is investigation of Paleoindian settlement systems, series of potentially linked, contemporary early sites situated in multiple ecological zones.

Despite the challenges of locating and investigating sites dating from the initial period of settlement, many Paleoindian sites throughout the Americas hold clues to where additional, linked sites can be discovered. These clues are provided by exotic plant, animal, and especially lithic resources, transported from sources at considerable distance. Exotic lithic materials are common among Terminal Pleistocene artifact assemblages in North America (Meltzer 1989; Anderson 1990; Tankersley 1991; Erlandson et al. 2011), and numerous cases of long-distance inter-zonal movements of lithic materials are emerging from South America (Borrero and Franco 1997; Borerro 1999; Flegenheimer et al. 2003; Mendez et al. 2012).

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[1] All ka ages and ranges are 2-σ calibrated with Calib 7.0.0 (Stuiver and Reimer 1993) and SHCal13 (Hogg et al. 2013).

If the source areas of exotic materials at early sites could be identified with sufficient resolution, field survey and excavation near exotic material sources should locate additional contemporary sites constituting related parts of the same Paleoindian settlement system. It then would be possible to conduct an array of comparative studies. Comparison of high-resolution chronologies could indicate the order of settlement of different areas, revealing migration patterns. Determining seasonality of contemporary sites might show functional linkages and establish at a minimum how many separate groups of people were responsible for creating the sites. Similarities and differences among artifact assemblages might reveal cultural connections or boundaries across space, as well as continuities or discontinuities through time. Exotic materials at newly discovered sites could suggest where even more early sites could be located, and so on. Through systematic effort, chains of related early sites could be traced throughout a region, shedding light on the timing and routes involved in the initial settlement phase.

Quebrada Jaguay and Alca Obsidian

Terminal Pleistocene-age sites such as Quebrada Tacahuay (Keefer et al. 1998; deFrance et al. 2001, 2009; deFrance and Umire Álvarez 2004) and Quebrada Jaguay (QJ-280) (Fig. 1) (Sandweiss et al. 1998) indicate that some of South America's earliest inhabitants were settling the Pacific Coast of southern Peru in the Terminal Pleistocene, taking advantage of rich fisheries and littoral zones. However, QJ-280's well-dated Paleoindian-age component also contains material evidence of a connection with interior zones. This evidence includes artifacts made of petrified wood, a raw material that crops out ~30 km north of the site (Tanner 2001), and seeds from *Opuntia* cf. *ficus-indica*, or prickly pear cactus (Sandweiss 2003), found today at elevations between 2400 and 3600 m above sea level (masl).

Fig. 1: *Photo of Quebrada Jaguay (site QJ-280) facing north toward the Andes.*

The most dramatic material evidence of contact with interior zones is a small bifacial tool fragment and associated debitage made of obsidian (Tanner 2001; Rademaker 2006) recovered from directly dated Terminal Pleistocene and Early Holocene contexts. Radiocarbon dates from these deposits span ~13.4–10.2 ka and indicate at least two separate obsidian procurement events. Neutron activation analysis of a sample of QJ-280 obsidian debitage determined the provenance to be the Alca source (Sandweiss et al. 1998). This obsidian source was discovered ~170 km to the north near the town of Alca in the Cotahuasi Canyon (Fig. 2) when a local resident brought anthropologist Paul Trawick a block of obsidian collected from above 4000 masl. Richard Burger and others characterized this sample, along with small pyroclasts collected from a local tuff exposure at ~2710 masl (Burger et al. 1998); all of these samples matched the Quebrada Jaguay obsidian artifacts.

The connection between QJ-280 and the Alca obsidian source is one of the only known material links between specific coastal and highland locales during the period of initial human settlement of the Americas. Since there is no geologic mechanism capable of bringing Alca obsidian to the Pacific Coast, either a single group of foragers was moving between coastal and highland ecological zones or separate coastal and highland groups (or a sub-set of those groups) were trading with each other. Under either scenario, people must have accessed primary Alca obsidian outcrops in the Andean highlands, so the QJ-280-Alca connection has presented an opportunity to locate and study a series of linked Terminal Pleistocene-age sites situated in multiple environmental zones spanning the Pacific Ocean to the Andes.

Fig. 2: *Photo of Cotahuasi Canyon with original Alca obsidian sample location.*

The idea that Quebrada Jaguay's obsidian had its source in the *base* of the Cotahuasi Canyon at ~2700 masl was important for supporting a synthetic model of initial colonization of the high Andes. Based on the lack of acceptably dated Terminal Pleistocene Andean sites above 4000 masl, Mark Aldenderfer (1998, 1999, 2006, 2008) proposed a "high-altitude barrier model" emphasizing the physiographic and biological challenges inherent to these extreme environments. This model emphasized that (a) high-elevation Andean environments were too harsh for humans until climatic amelioration in the Early Holocene, and (b) development of genetic adaptations to high-altitude conditions would have been a prerequisite for successful colonization. Due to both of these factors, initial settlement of the high Andes high-elevation environments must have substantially post-dated initial lowland occupation.

Because humans begin to experience symptoms of hypoxia (low-oxygen pressure) at ~2500 masl, Paleoindian acquisition of Alca obsidian would have constituted a logistical exploration of higher elevations and an early exposure to hypoxic conditions close to the lower limit of this stress. This early foray into the highlands would not pose a challenge to the barrier model because the Alca obsidian source was thought to be located in the base of the Cotahuasi Canyon, an idea now known to be incorrect.

I attempted to use the QJ-280-Alca linkage to answer questions about migration, inter-zonal connections, and initial high-elevation settlement for my Ph.D. thesis work (Rademaker 2012). The first step in this effort was the discovery of one or more additional contemporary Terminal Pleistocene sites in the intervening ~170 km between Quebrada Jaguay and the Alca obsidian source. This intermediate area includes all ecological zones on the western Andean slope, from the Pacific Ocean to the high-elevation Andean plateau, and is bounded by the extensive Cotahuasi and Colca Canyons, two of the deepest canyon systems in the world (Fig. 3).

Given the size and complexity of project area, it was necessary to narrow the search area by using predictive modeling and to conduct extensive field work. The project included creation of a digital database of archaeological radiocarbon data (Rademaker et al. 2013a), geochemical characterization of the Alca obsidian source (Rademaker et al. 2013b), quantitative geographic information systems (GIS) predictive modeling (Rademaker et al. 2012), region-level archaeological survey, geophysical surveys, test excavations, and systematic surface collections (Rademaker 2012; Sandweiss and Rademaker 2013), and AMS dating of the Cuncaicha rockshelter (4480 m elevation), the highest Pleistocene archaeological site yet discovered in the world (Rademaker et al. 2014). Concurrent with these archaeological investigations, Gordon Bromley led glacial geologic investigations of Nevados Coropuna, Solimana, and Firura (Fig. 3) to construct local, high-resolution paleoclimate records (Bromley et al. 2009, 2011a, 2011b; Bromley 2010).

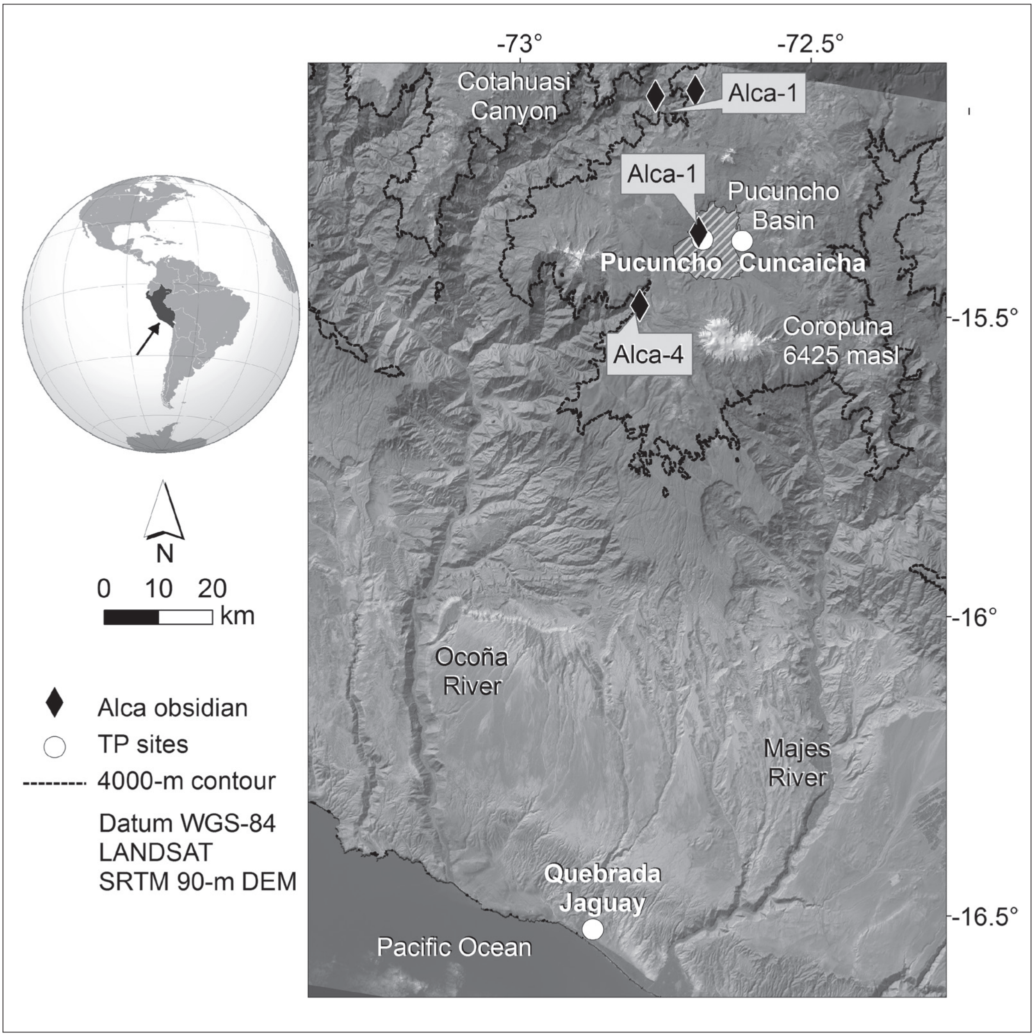

Fig. 3: *Project area map showing Terminal Pleistocene (TP) sites Quebrada Jaguay (QJ-280), Pucuncho, and Cuncaicha, and the locations of Alca-1 and Alca-4 obsidian outcrops.*

Database of archaeological radiocarbon data

A solid grasp of the archaeological and paleoenvironmental chronologies of Peru was essential to interpret new regional and site-specific data generated by this project. I synthesized the available radiocarbon data from Peruvian archaeological sites for the Terminal Pleistocene through Middle Holocene 13,000–7000 ^{14}C BP (~15.5 to ~7.8 ka). The Peru archaeological radiocarbon database, published as a spreadsheet with 27 fields of data, contains 308 radiocarbon dates from 109 archaeological sites and 43 projects of investigation. The Peru radiocarbon database accompanied others generated for Argentina, Brazil, Chile, Colombia, Ecuador, Uruguay, and Venezuela collected in a special volume of *Quaternary International*.

I assessed the validity of all radiocarbon dates according to well-defined criteria (Haynes 1969; Dincauze 1984; Roosevelt et al. 2002; Steele and Politis 2009). Problematic dates were discarded if they had 1-σ errors >300 ^{14}C yr, if they were obtained on inappropriate material (e.g., bone apatite fraction, animal feces), if they exhibited substantial disagreement with other, more precise ages from the same stratigraphic context and/or site, if the dating laboratory indicated contamination issues, or if there was poor or no association between dated material and cultural materials.

Compilation of the Peru dataset provided a new opportunity to examine trends in archaeological site distributions, occupation intensity, and climatic events from the Terminal Pleistocene to Mid-Holocene and to identify major taphonomic and research biases affecting the current state of knowledge (Rademaker et al. 2013a). In the 2013 publication I calibrated radiocarbon dates using IntCal09 (Reimer et al. 2009). The dates and ranges below use the subsequently published southern hemisphere calibration SHCal13 (Hogg et al. 2013).

Of the 14 archaeological sites providing radiocarbon dates from the Terminal Pleistocene, only four sites have occupations constrained with more than one accepted date: Jequetepeque-996 (n=4 Terminal Pleistocene dates) (Maggard 2010), Guitarrero Cave (n=9 Terminal Pleistocene dates) (Lynch 1980; Jolie et al. 2011), Quebrada Jaguay (n=12 published Terminal Pleistocene dates) (Sandweiss et al. 1998), and Quebrada Tacahuay (n=9 Terminal Pleistocene dates) (Keefer et al. 1998; deFrance et al. 2001; deFrance and Umire Álvarez 2004). Radiocarbon data plotted against elevation (Fig. 4) suggest several major trends for the initial settlement period:

- The Pacific Coast was initially occupied possibly as early as ~13.8 ka and definitely by ~12.5 ka, with earliest occupation of elevations up to ~2500 masl occurring by ~12.1–11.8 ka. Elevations above 3500 masl were initially occupied after ~11.5 ka in the Early Holocene.
- There is a near total absence of radiocarbon dated Terminal Pleistocene to Mid-Holocene archaeological sites between 600 masl and 2500 masl.
- Strong research biases affect the absolutely dated Terminal Pleistocene to Mid-Holocene archaeological record. Much more research has been conducted below 1200 masl than above 1200 masl. In three out of the last five decades, virtually no highland dates were contributed to the record. We lack basic settlement and chronological information from elevations >1200 masl in Peru.
- An increase in the number of sites from the Terminal Pleistocene to Early Holocene may indicate biogeographic expansion into highland valleys and the plateau from lower-elevation areas (Aldenderfer 2006), although the relative lack of earlier Terminal Pleistocene settlement data from the Peruvian Andes may result from inadequate sampling rather than the absence of people.

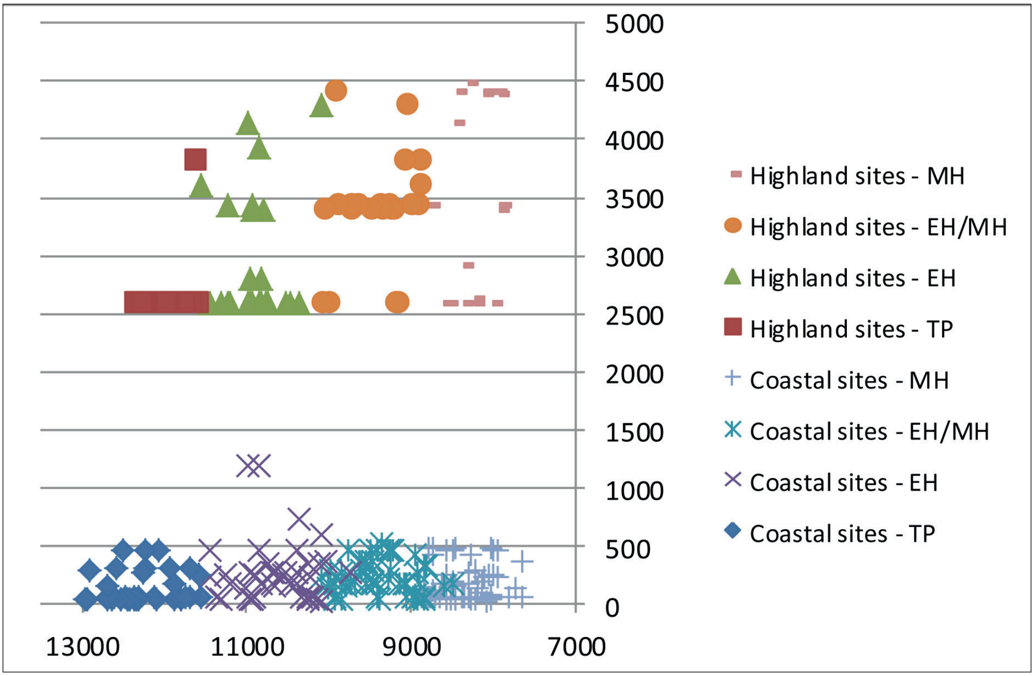

Fig. 4: *One-sigma calBP median values on X-axis plotted against elevation (in masl) on Y-axis for all Peru radiocarbon dates, arranged by time period for coastal and highland archaeological sites. Time periods: TP -Terminal Pleistocene, EH - Early Holocene, EH/MH - Early to Mid-Holocene, MH - Mid-Holocene. From Rademaker et al. (2013a).*

Geochemical characterization of the Alca obsidian source

Identification of the total extent of Alca obsidian outcrops was a necessary first step for identifying potential highland obsidian source areas exploited by people in the Terminal Pleistocene, which allowed subsequent generation of a predictive model and systematic survey efforts to locate early archaeological sites related to Quebrada Jaguay.

Following the initial discovery and characterization of the Alca obsidian source (Burger et al. 1998), Jennings and Glascock (2002) mapped and characterized additional outcrops of Alca obsidian within a 50 km^2 area in the Cotahuasi Canyon up to ~4300 masl. Neutron activation analysis (NAA) and x-ray fluorescence (XRF) analyses indicated three geochemically distinct Alca obsidians, designated Alca-1, Alca-2, and Alca-3, though the spatial distributions of these Alca “sub-sources” remained unknown. The majority of analyzed samples were Alca-1, which matched the original source samples characterized by Burger et al. (1998), and the Paleoindian obsidian debitage from Quebrada Jaguay (Sandweiss et al. 1998). Jennings and Glascock also reported that local Cotahuasi Canyon residents knew of large outcrops of obsidian located at higher elevation near the rim of the volcanic plateau, but these outcrops remained unexplored and unstudied.

I mapped and characterized additional Alca-1 and Alca-3 samples from the Cotahuasi Canyon and from outcrops east of the canyon (Rademaker 2006). The Cerro

Condorsayana rhyolite dome on the east rim from 4000 to 4830 masl contained a ~412 ha exposure of Alca-1 obsidian and extensive reduction debris from extraction and workshop activity. Given the geochemical variability of obsidian in the canyon and discovery of the extensive Condorsayana dome at the plateau edge, I suspected that the Alca source was larger and more geochemically complex than previously thought. I continued to map and characterize Alca obsidian outcrops in the Cotahuasi Canyon and on the volcanic plateau from 2005 to 2010. Samples were collected judgmentally from surfaces of outcrops, talus, and secondary fluvial and glaciofluvial deposits and characterized using NAA, wavelength-dispersive and energy-dispersive XRF, and portable energy-dispersive XRF. Results from mapping and characterization of the Alca obsidian source were published in *Geology* (Rademaker et al. 2013b).

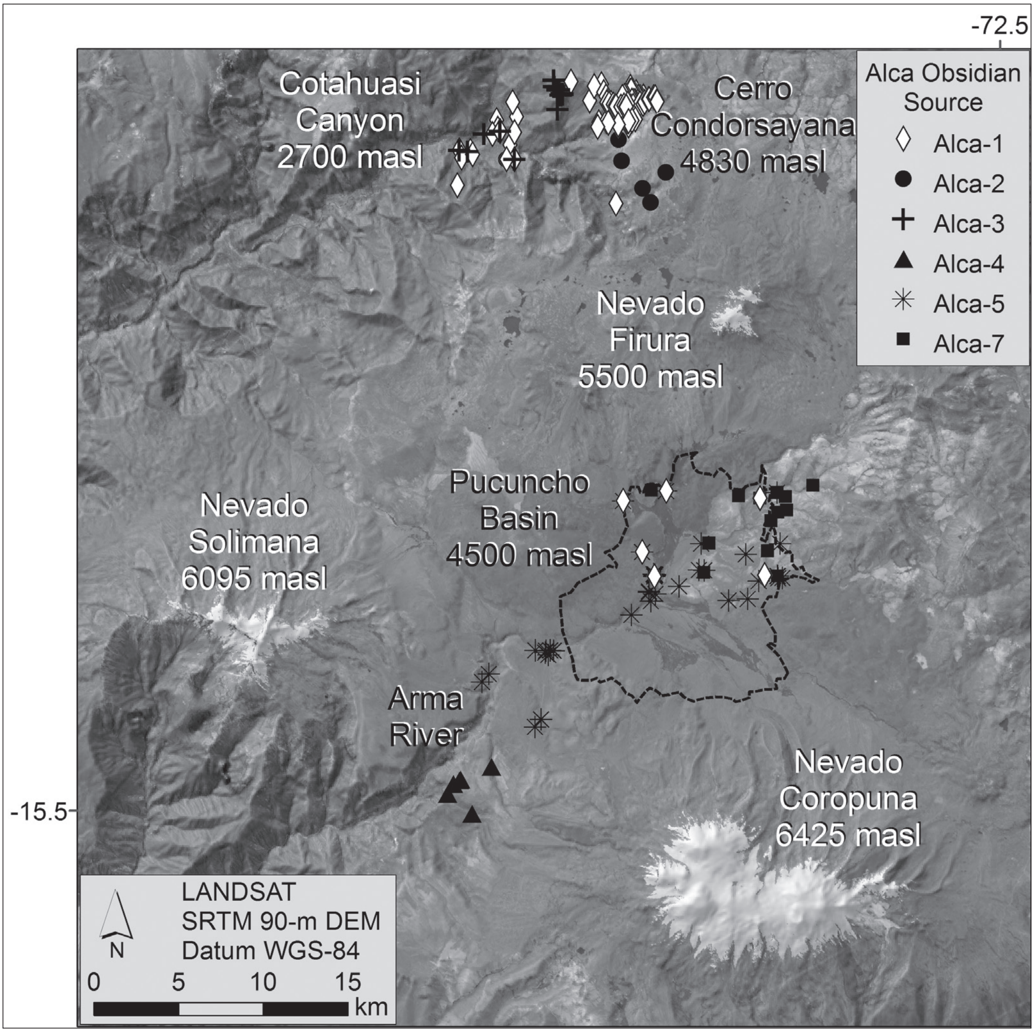

Fig. 5: *Map of volcanic plateau showing Alca obsidian sample locations by sub-source.*

Alca obsidian occurs in eroded rhyolite domes, ignimbrite sheets, and fluvial and glaciofluvial deposits from 2710–5165 masl over >330 km^2 south and east of the Cotahuasi River, a source region nearly seven times larger than previously known (Fig. 5). The largest concentrations of obsidian are at the east rim of the Cotahuasi Canyon and in the Pucuncho Basin. This mapping establishes Alca as one of the most extensive sources of obsidian known from South America.

Alca-1, Alca-2, and Alca-3 obsidian pyroclasts within the Cotahuasi Canyon, including samples characterized previously (Burger et al. 1998; Jennings and Glascock 2002), geochemically match obsidian at three distinct rhyolite domes at the plateau edge. These domes include Cerro Condorsayana (4000–4830 masl), containing Alca-1 obsidian bedrock and fractured blocks up to 50 cm in talus (Rademaker 2006). West of Condorsayana, ~5–10 cm fragments of Alca-3 obsidian are exposed between 4250 and 4340 masl at Cerro Aycano. South of Condorsayana, ~5–10 cm Alca-2 obsidian fragments occur at 5000–5165 masl at Nevado Sapojahuana. Approximately 20–30 km south of the rhyolite domes, sub-rounded ~5–20 cm Alca-1, Alca-5, and Alca-7 obsidian pebbles and cobbles are exposed on alluvial fans within the Pucuncho Basin, and Alca-5 cobbles also are found in alluvium along the Arma River. Southwest of the Pucuncho Basin and west of the Nevado Coropuna compound stratovolcano, angular ~10–30 cm Alca-4 obsidian fragments are exposed at 4140–4395 masl.

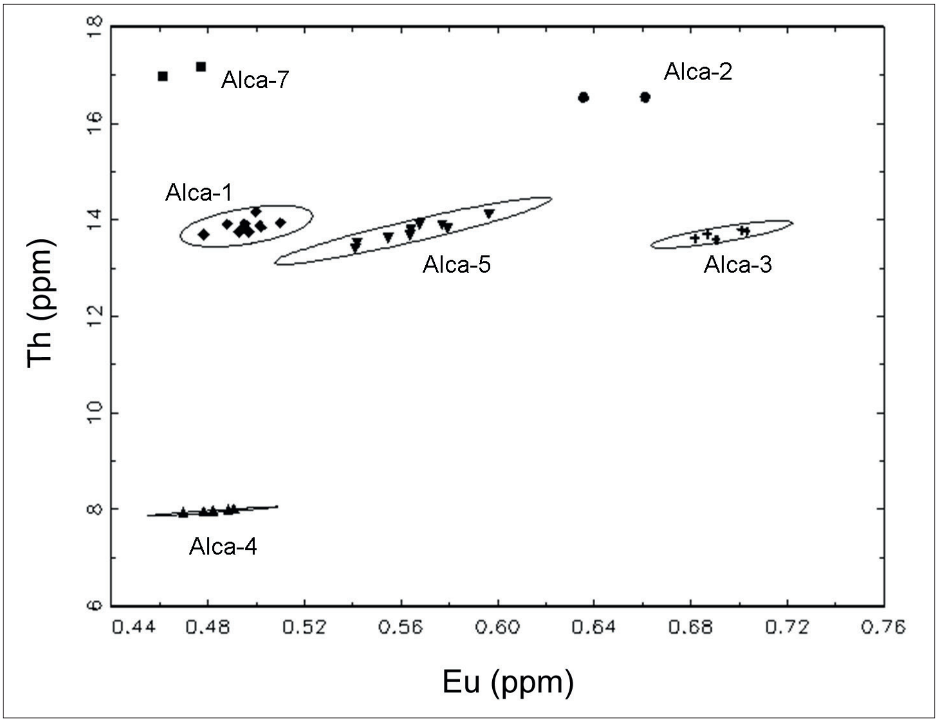

Fig. 6: *Bivariate plot of neutron activation analysis of Alca sub-sources with 95% confidence ellipses. From Rademaker et al. (2013b).*

Geochemical data are provided by 386 analyses on 252 samples, not counting many replicate analyses. Samples initially analyzed with ED-XRF and NAA clustered into seven distinct sub-sources designated Alca-1–Alca-7. Alca-6 samples were interspersed within the large Condorsayana Alca-1 exposure, so Alca-6 was subsumed within the Alca-1 sub-source. All techniques used in this study identified the same six Alca sub-sources (Fig. 6).

GIS predictive modeling

Alca-1 obsidian crops out near the town of Alca (2720 masl), on Cerro Condorsayana (4000–4830 masl), and on the western margin of the Pucuncho Basin (4355 masl). Once all potential source areas for Quebrada Jaguay's Alca-1 obsidian were mapped, it was possible to search for potentially early sites in their vicinity and in the intervening area between Alca-1 outcrops and site QJ-280. The region encompassing the QJ-280-Alca-1 corridor (Fig. 1) is vast and physiographically and ecologically complex, so generation of a predictive model was useful for targeting the most likely areas for early sites. I used quantitative GIS least-cost analysis to evaluate possible forager routes connecting site QJ-280 with Alca-1 obsidian outcrops. Methodology and results of the least-cost modeling were published in Rademaker et al. (2012).

The predictive model was based on two primary concepts of optimal foraging theory (Winterhalder and Smith 1981; Kelly 1983; Kelly and Todd 1988). In a high-relief region such as the QJ-280–Alca-1 corridor, forager routes should follow paths of least topographic resistance (Anderson and Gillam 2000; Kelly 2003). Areas of gentle topography obviously facilitate movement more readily than steeper, rugged terrain, but low-slope areas offer additional benefits. For a colonizing forager group entering a new or unfamiliar landscape for the first time, large-scale movements should occur along easily traceable geographic features, such as river valleys or canyons, linear mountain chains, or ecologic corridors such as coasts, a pattern consistent with landscape learning principles (Kelly 2003). In high-altitude, arid mountain environments such as the Andean plateau, where water and faunal resources are clustered in patches (Winterhalder and Thomas 1978), foragers should situate their residential sites in optimal central places that afford easy access to multiple high-quality resources (Kaplan and Hill 1992; Marín Arroyo 2009). Such a strategy would minimize the high energetic costs of movement and subsistence in high-altitude mountain terrain (Aldenderfer 1998).

Energy probably was the most significant limiting resource for most hunter-gatherer populations (Jenike 2001). Energy expended in walking over terrain has been parameterized via human physiological experiments, and White (2007, 2012, and references therein) developed a method for integrating these parameters in least-cost analysis, which I used for this project.

Despite varying input parameters to allow for maximum variance in model results, least-cost paths to all three Alca-1 outcrops followed the east or west rim of the Quebrada Jaguay canyon to ascend the high-altitude plateau (Fig. 7). No solutions followed the Ocoña-Cotahuasi drainage, even to access the Alca-1 obsidian outcrop at the base of the Cotahuasi Canyon. Comparison of all least-cost solutions shows that at a distance of ~145 km, the Pucuncho Basin is the closest of the three Alca-1 outcrops to Quebrada

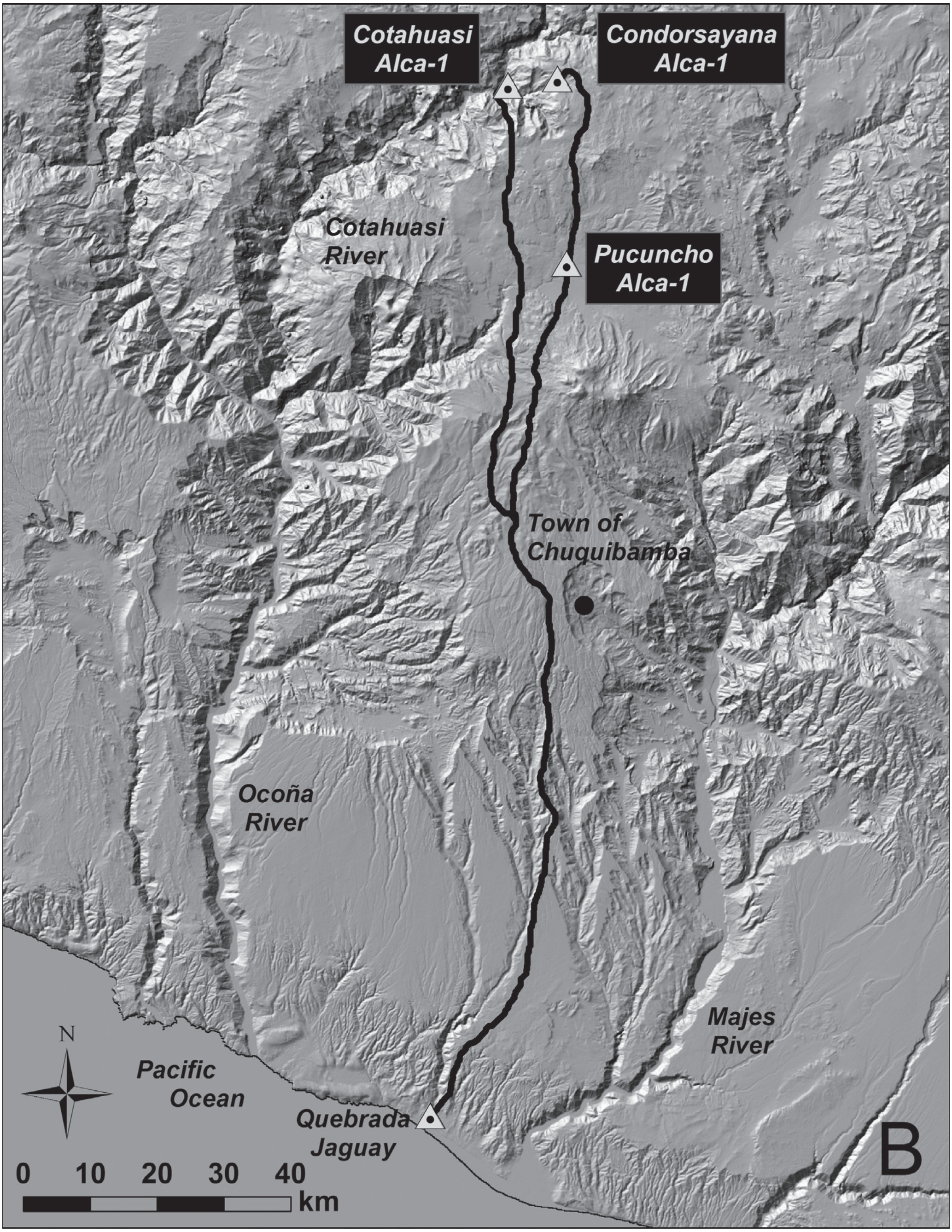

Fig. 7: *Shuttle Radar Topography Mission digital elevation model with least-cost path solution between Quebrada Jaguay and Alca-1 obsidian outcrops. From Rademaker et al. (2012).*

Jaguay. Moreover, the Pucuncho Alca-1 outcrop is the least energetically costly of the three obsidian outcrops to access from QJ-280, and the Cotahuasi Canyon Alca-1 outcrop is the most costly to access.

Region-level archaeological survey

Between 2004 and 2010 I organized eight field seasons of archaeological surveys in the intervening area between Quebrada Jaguay site QJ-280 and Alca-1 obsidian outcrops, guided by the GIS predictive model results. These region-level investigations were designed to discover sites of potential Terminal Pleistocene age, although I discovered

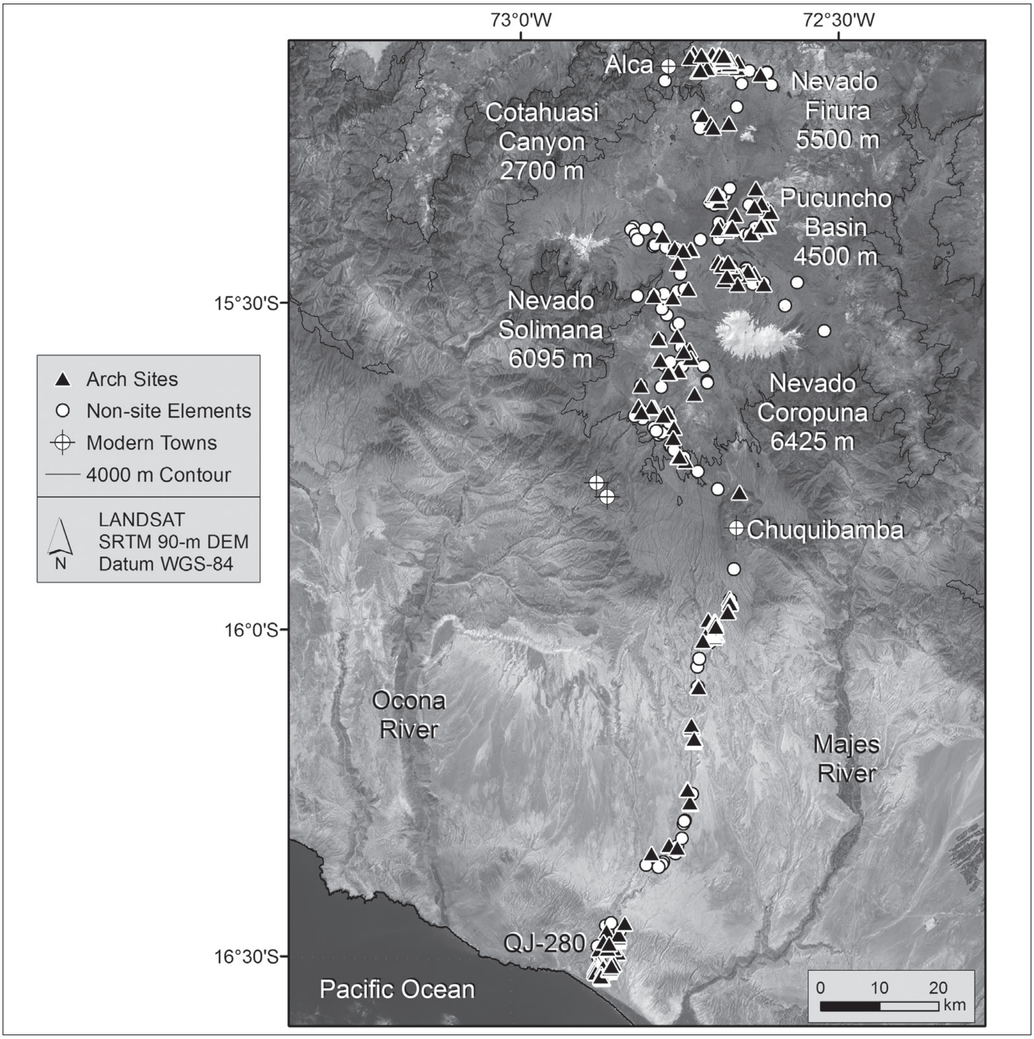

Fig. 8: *Map showing survey coverage with 194 sites and 151 non-site elements identified from 2004-2010. From Rademaker (2012).*

and documented sites of all ages. These surveys resulted in the identification of 194 new archaeological sites and 151 "non-site elements," defined as isolated artifacts, architectural features, or minor concentrations of artifacts and features (Rademaker, 2012) (Fig. 8).

Although surveys included exploration of the least-cost path between QJ-280 and the plateau edge at ~4000 masl, my team and I failed to find any potentially early sites at intermediate elevation. We focused survey efforts on the northern portion of the coast-highland corridor, corresponding to the plateau edge and the three Alca-1 obsidian outcrops (Fig. 7). All least-cost paths pass through this area, and the relative geomorphic stability makes it the most likely area for extant Terminal Pleistocene sites. Relative to corridor drainages such as the Majes River, the plateau is conducive to archaeological investigations for several reasons. First, low sedimentation rates and limited fluvial erosion result in good landform preservation and site visibility. Second, limited human disturbance of archaeological sites has occurred, since there are no major population centers or agriculture. Third, rockshelters are abundant here, and rockshelters commonly were used as campsites by early hunter-gatherers elsewhere in the Central Andes (Rick 1980; Santoro and Núñez 1987; Lavallee et al. 1995; Núñez et al. 2002) and exhibit great potential for preservation of datable organics (Goldberg and Macphail 2006).

My team discovered rockshelters in andesite exposures and open-air archaeological sites on alluvial fans surrounding the Pucuncho Basin and along drainages southwest of Nevado Coropuna. Several of these sites contain artifacts made of coastal lithic materials, substantiating Pacific Coast–high Andes connections (Sandweiss and Rademaker 2013). At 4665 masl we discovered a Type 4A projectile point (~11.2–8.5 ka) (Klink and Aldenderfer 2005; Rademaker 2012) made of pink chalcedony, a material that crops out on the coast between the Ocoña and Majes Rivers. At Pampa Colorada, just west of site QJ-280, McInnis (2006) identified six Type 4A specimens, one made of petrified wood and five of obsidian. The obsidian specimens have not yet been sourced geochemically, but they likely are made of Alca obsidian.

Fig. 9: *Photograph of the Pucuncho open-air workshop site (4355 masl), where Alca-1 and Alca-5 obsidian crop out. Two fluted Fishtail projectile points at this site indicate a Terminal Pleistocene occupation ~12.8-11.5 ka. From Sandweiss and Rademaker (2013).*

On the western margin of the Pucuncho Basin where the least-cost path intersects the Pucuncho Alca-1 outcrop, we identified an open-air workshop (4355 masl) containing debitage and hundreds of stone tools (Fig. 9), including two fluted Fishtail projectile points (Fig. 10A). These are the highest fluted points known in the Americas and indicate that people were in the high-altitude Pucuncho Basin between ~12.8 and 11.5 ka (Jackson 2006). The Pucuncho site likely provided the Alca-1 obsidian found at Quebrada Jaguay on the Pacific Coast, ~145 km distant.

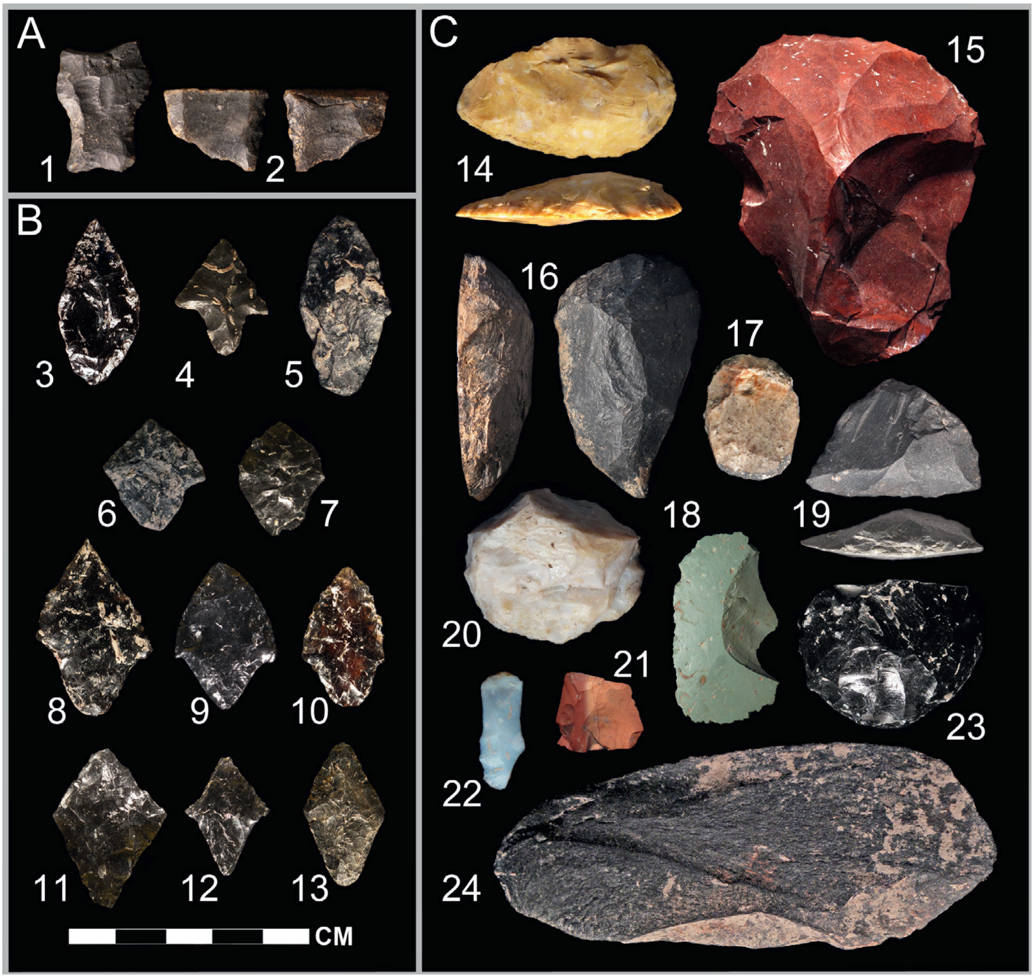

Fig. 10: *Terminal Pleistocene artifacts from Pucuncho workshop (A) and Cuncaicha rockshelter (B and C).*

Site-level investigations

The region-level survey phase was followed by intensive site-level investigations. My team and I conducted geophysical survey of the seven best rockshelter sites we had identified during survey to assess their potential for containing intact, early occupation evidence. We selected the four shelters with the deepest sedimentary sequences for test excavations to examine their stratigraphy, determine the maximum age of occupation, and recover a sample of artifacts, faunal, and paleobotanical remains. Of the four rockshelter sites tested, three shelters had sequences dating to <4 ka based on the presence of ceramics to the base of deposits (Perry et al. 2006). Results from these investigations are summarized in Rademaker (2012).

Seven km east of the Pucuncho workshop site, the Cuncaicha workshop site (4445 masl) occupies an alluvial fan where Alca-5 and Alca-7 obsidian pyroclasts crop out (Fig. 11). This surface palimpsest contains debitage and over 500 projectile points and nondiagnostic bifaces, scrapers, and other unifacial tools, representing thousands of years of episodic occupation. Above the alluvial fan is Cuncaicha rockshelter (4480 masl), comprising two north-facing alcoves formed by slab exfoliation of the andesite bedrock. Both alcoves exhibit sooted ceilings, rock art, and anthropogenic floor sediments, indicating use as campsites. The rockshelter is protected from westerly winds and offers a commanding view of wetland and grassland habitats.

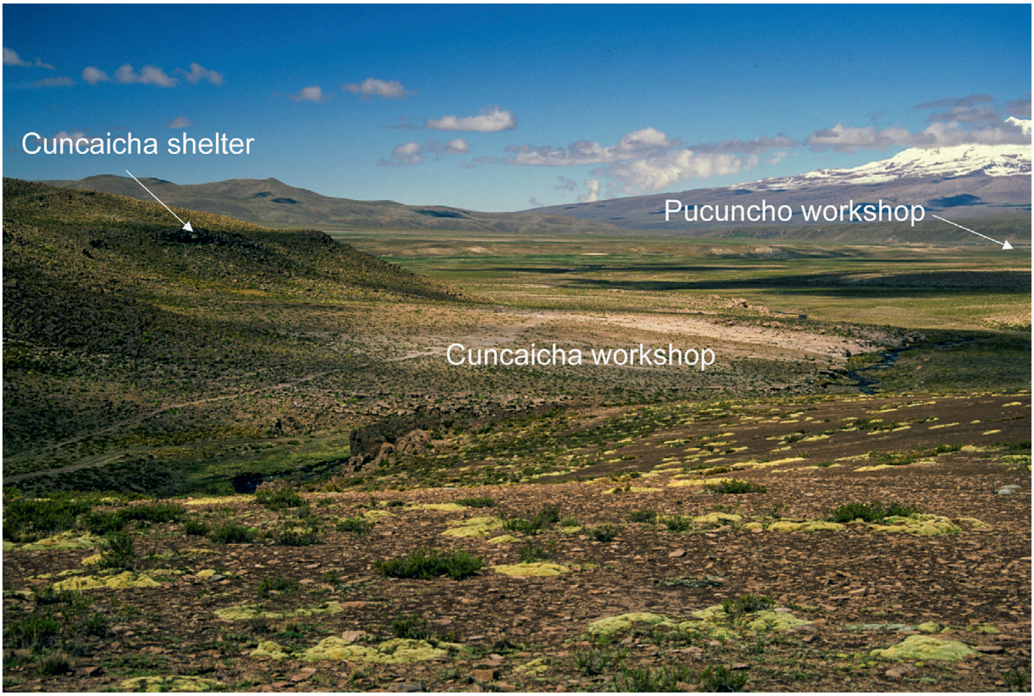

Fig. 11: *Photograph of Pucuncho Basin, facing west, showing Terminal Pleistocene sites Cuncaicha shelter and workshop and Pucuncho workshop. From Rademaker et al. (2014).*

My team's investigations at Cuncaicha rockshelter sampled the minimum volume needed to document the stratigraphy and establish a precise absolute chronology of occupation. Ground-penetrating radar revealed collapsed roof slabs and depth of sediments to bedrock, allowing targeted excavations. Sediments are ~1.2 m deep, both within the shelter and outside the drip line over ~150 m^2. My team excavated 5.5 m^2 (<4%) of these deposits in 2010 and 2012.

I dated the Cuncaicha sequence using large mammal bone specimens in direct association with abundant, unequivocal artifacts. Faunal and other organic remains exhibit outstanding preservation in this cold, dry setting. Moreover, dating large bone specimens avoided the risk of sampling remains vertically translocated via rodent bioturbation, a process shown to affect Andean rockshelters elsewhere (Lynch 1980). Geoarchaeological analysis indicates only small-scale cryo- and bio-turbation of deposits.

I obtained thirty-five AMS ages at three laboratories using distinct pretreatment protocols on bone collagen. Dates on split samples at multiple labs are statistically indistinguishable. The AMS-dated bone specimens are in correct stratigraphic order, without reversals. Cuncaicha rockshelter contains occupation components corresponding with five distinct strata (Fig. 12). Hiatuses correspond with clear stratigraphic signatures and are well-constrained with AMS ages (Table 1).

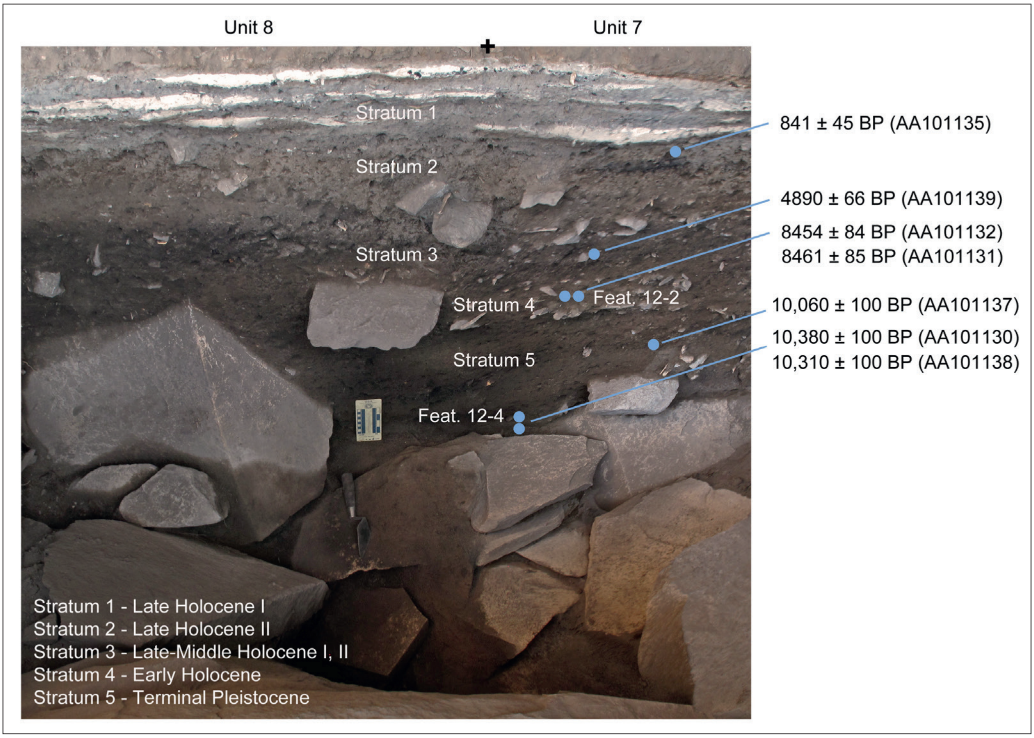

Fig. 12: *Photograph of Cuncaicha rockshelter Unit 7 and 8 south profile showing stratigraphy and uncalibrated AMS ages from Unit 7. From Rademaker et al. (2014).*

Lab No.	Context	Depth (cm)	^{14}C B.P.	δ^{13}C	2-σ cal range	Component
AA 101135	U.7, L.3	22-23.5	841 ± 45	-19.7	788-664	LH II
AA 96338	U.2, L.3	31-41	2098 ± 48	-19.0	2152-1900	LH I
AA 101133	U.6, L.4-5, F. 12-1	31-33	4584 ± 59	-20.1	5447-4974	LMH II
AA 101134	U.6, L.4-5, F. 12-1	31-33	4683 ± 73	-19.4	5584-5056	LMH II
AA 96340	U.2, L.3	31-41	4599 ± 57	-19.1	5450-4978	LMH II
AA 96339	U.2, L.3	31-41	4826 ± 58	-19.1	5641-5324	LMH I
AA 96335	U.2, L.4	41-52	4898 ± 66	-19.6	5740-5332	LMH I
AA 101139	U.7, L.5	43-44	4890 ± 66	-19.4	5732-5330	LMH I
AA 96337	U.1, L.4b	33-50	8363 ± 82	-19.0	9492-9035	EH
AA 96336	U.2, L.4	41-52	8361 ± 82	-18.9	9491-9034	EH
AA 96331	U.1-2, L.6	57-63	8404 ± 82	-19.6	9523-9134	EH
AA 96329	U.1-2, L.6	57-63	8483 ± 83	-19.9	9553-9146	EH
AA 101132	U.7, L.7, F.12-2	60-62	8454 ± 84	-20.6	9543-9140	EH
AA 101131	U.7, L.7, F.12-2	60-62	8461 ± 85	-19.8	9545-9141	EH
AA 96330	U.1-2, L.6	57-63	10,086 ± 97	-19.3	11,953-11,253	TP
AA 101137	U.7, L.8, F.12-3	77-78	10,060 ± 100	-20.1	11,945-11,238	TP
AA 96321	U.2, L.8b	69-79	10,034 ± 97	-19.6	11,924-11,222	TP
AA 96322	U.2, L.8b	69-79	10,127 ± 98	-19.9	11,991-11,282	TP
AA 94257	U.2, L.9	79-83	10,055 ± 67	-19.7	11,793-11,250	TP
AA 96318	U.2, L.9	79-83	10,084 ± 99	-19.7	11,954-11,250	TP
AA 96319	U.2, L.9	79-83	10,100 ± 99	-19.2	11,962-11,266	TP
AA 96312	U.2, L.11	90-98	10,163 ± 71	-18.9	12,009-11,393	TP
AA 94256	U.2, L.11	90-98	10,200 ± 69	-20.1	12,039-11,405	TP
AA 96309	U.2, L.12	98-108	10,189 ± 77	-19.4	12,035-11,399	TP
AA 94255	U.2, L.12	98-108	10,211 ± 69	-20.5	12,051-11,406	TP
Beta 297423#	U.2, L.13	108-115	10,050 ± 50	-20.0	11,746-11,269	TP
AA 94254#	U.2, L.13	108-115	10,321 ± 73	-21.6	12,403-11,765	TP
AA 96306*	U.2, L.13	108-115	10,132 ± 71	-18.8	11,969-11,388	TP
PRI-12-029-04b*	U.2, L.13	108-115	10,205 ± 35		12,008-11,629	TP
AA 96307**	U.2, L.13	108-115	10,306 ± 72	-18.9	12,403-11,724	TP
PRI-12-029-05b**	U.2, L.13	108-115	10,265 ± 35		12,040-11,770	TP
AA 96308***	U.2, L.13	108-115	10,260 ± 72	-19.2	12,384-11,502	TP
PRI-12-029-06b***	U.2, L.13	108-115	10,180 ± 40		12,008-11,413	TP
AA 101138	U.7, L.10, F.12-4	105-108	10,310 ± 100	-19.6	12,428-11,509	TP
AA 101130	U.7, L.10, F.12-4	102	10,380 ± 100	-19.5	12,546-11,773	TP

Table 1: *^{14}C AMS ages from Cuncaicha rockshelter bone samples.*
*Stratigraphic abbreviations: U–Unit, L–Level, F–Feature. Component abbreviations: LH–Late Holocene, LMH-Late-Middle Holocene, EH–Early Holocene, TP–Terminal Pleistocene. All AMS measurements are corrected for ^{12}C/^{13}C isotopic fractionation. AA samples are ultra-purified bone collagen measured at University of Arizona AMS Lab, Tucson, Arizona, USA. Beta sample is bone collagen measured at Beta Analytic, Miami, Florida, USA. PRI samples are XAD ultra-purified bone collagen prepared at PaleoResearch, Inc., Golden, Colorado, USA and measured at Keck Carbon Cycle AMS Facility, University of California, Irvine, California, USA. Samples with # are splits prepared and analyzed at Beta Analytic and Arizona. Samples with *, **, and *** are splits prepared at Arizona AMS and PaleoResearch, Inc.*

Cuncaicha contains a rich assemblage of chipped-stone tools, cores, and debitage (Fig. 10B-C), faunal material, bone beads and quartz crystals, and fragments of red ochre. A complete lithic operational chain is present at Cuncaicha shelter and the workshop below. Most lithic tools and debitage at Cuncaicha are made from locally-available Alca-1, -5, and -7 obsidian, andesite, and jasper. Lithic tools indicate hunting and butchering activities, consistent with the limited subsistence options on the plateau.

The inhabitants of Cuncaicha hunted vicuña (*Vicugna vicugna mensalis*), guanaco (*Lama guanaco*), and taruka (*Hippocamelus antisensis*). Preliminary analysis of camelid age profiles suggest predation at the end of the rainy season when vicuña are born (March-April) and possibly during the dry season (May-November) when vicuña bands aggregate (Franklin 1981). The even representation of mammal fore- and hind-limb elements indicates dismembering of whole carcasses at the shelter. First and second phalanges are abundant, and the skinning of animals to the toes attests to careful processing of all animal foods, including meat and fat within the bone.

Cuncaicha is ~40–50 km from elevations ≤2500 masl, so it is unlikely the site was merely a logistical station for the collection and processing of lithic material, meat, and hides for transport to low-elevation base camps. Together, the quantity and diversity of early tool types, emphasis on local lithic materials and animals, complete lithic operational chains and animal carcasses, and location in the heart of the plateau suggest that Cuncaicha was a base camp.

The Pucuncho Basin constituted a high-altitude oasis ideal for a specialized hunting (and later, herding) adaptation. Vicuña births coinciding with the end of the wet season and maintenance of permanent territories by vicuña bands (Franklin 1981) would have permitted predictable scheduling of subsistence activities and year-round plateau residence. However, wet-season storms and hazard of hypothermia, as well as maintenance of extended social networks and collection of edible plant resources, may have encouraged regular descents to lower elevations.

Lithic tools and debitage of non-local fine-grained rocks, some with stream-polished cortex (Fig. 10C), suggest that Terminal Pleistocene and Early Holocene plateau residents ventured periodically to high-energy rivers below the plateau. Formal tools of Alca-4 obsidian at Cuncaicha originated in outcrops near the plateau edge ~22 km southwest (Fig. 3). An additional Terminal Pleistocene site linked to Cuncaicha likely is located near the Alca-4 outcrops.

Quebrada Jaguay and nearby Early Holocene sites on the Pacific Coast contain Alca-1, -4, and -5 obsidian tools and debitage (Sandweiss et al. 1998; Rademaker 2012); the only source of these three obsidians is the Pucuncho Basin and surrounding plateau (Rademaker et al. 2013b). The oldest dates at Quebrada Jaguay and Cuncaicha overlap at 2-σ. These sites likely constitute end-members in a coast-highland Paleoindian settlement system that continued into the Early Holocene.

Pucuncho Basin sites and high-altitude biogeographic barriers

It has been argued that the high-altitude Andes posed extreme challenges for early human colonizers, including greater ice extents as physiographic barriers to migration, colder temperatures, and the physiological effects of hypoxia (Aldenderfer 1998, 1999, 2006, 2008). Glacial geologic evidence from Nevado Coropuna and archaeological information from Pucuncho Basin archaeological sites do not support this hypothesis.

On the basis of glacial-geomorphic reconstructions made throughout the Peruvian Andes, it is clear that nowhere did the late-glacial advance present a significant physical barrier to human migration, and at Nevado Coropuna (Fig. 3), late-glacial ice did not extend lower than ~4700 masl. Glaciers on Nevados Coropuna, Solimana, and Firura advanced during the late-glacial period (Bromley et al. 2009) in response to an atmospheric cooling of as much as 3°C, but this advance pre-dated the initial occupation of the Pucuncho Basin sites (Rademaker et al. 2014). These locally generated and comparable paleoenvironmental and archaeological chronological data indicate that late-glacial temperatures were not significantly colder than today's, and that the high-elevation Peruvian Andes probably were already warming by the time people first were entering high elevations.

Conclusions

The Fishtail projectile points found at the Pucuncho open-air site (4355 masl) suggest an age of ~12.8–11.5 ka, and the Terminal Pleistocene component at Cuncaicha rockshelter (4480 masl) is securely dated to 12.4–11.3 ka. These inferred and absolute ages make these Pucuncho Basin sites among the oldest archaeological sites in Peru and the highest-altitude Pleistocene archaeological sites in the world. Cuncaicha has contributed more published Terminal Pleistocene radiocarbon dates than any other coastal or highland site in Peru.

If hypoxia was a formidable barrier to successful colonization of high-altitude environments, one expected archaeological signature would be ephemeral initial occupation events indicating short-term forays or failed colonization attempts. The Terminal Pleistocene anthropogenic deposits at Cuncaicha contain rich assemblages of artifacts and faunal remains, and various characteristics indicating that Cuncaicha was a residential base camp. In summary, data from Nevado Coropuna and the Pucuncho Basin archaeological sites do not support the high-altitude barrier model, which suggested that climatic amelioration and a lengthy period of human adaptation were necessary for successful human colonization of the high Andes. My team's research extends the residence time of humans above 4000 masl by nearly a millennium, implying greater physiological capabilities for Pleistocene humans than previously assumed.

The discovery of Paleoindian highland sites linked with coastal site Quebrada Jaguay attests to the potential of this interdisciplinary research design combining provenance analysis of exotic lithic materials, optimal foraging theory, predictive modeling, paleoenvironmental study, and extensive and systematic archaeological field work to find early hunter-gatherer archaeological sites. The overlapping age ranges of the Pucuncho Basin sites with Quebrada Jaguay on the Pacific Coast, and the presence of exotic lithic materials indicating complementary exchange or direct acquisition from the opposing zone, suggest these sites are end-members of a Paleoindian settlement system spanning all ecological zones of the western Andes. Now that these sites have been identified, new investigations are aimed at locating additional linked sites at intermediate elevation, determining the exact chronological relationship among the end-member sites, and understanding the nature of this early link between specialized Paleoindian hunters on the Andean plateau and Paleoindian fishers at the Pacific Coast of South America.

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