UC Berkeley
UC Berkeley Previously Published Works

Title
Procurement at the Chivay obsidian Source, Arequipa, Peru

Permalink
https://escholarship.org/uc/item/5bb8z31c

Journal
World Archaeology, 43(2)

ISSN
0043-8243

Authors
Tripcevich, Nicholas
Mackay, Alex

Publication Date
2011-07-14

Copyright Information
This work is made available under the terms of a Creative Commons Attribution-NonCommercial-ShareAlike License, availalbe at https://creativecommons.org/licenses/by-nc-sa/3.0/

Peer reviewed

eScholarship.org Powered by the California Digital Library
University of California

University of California, Berkeley

From the SelectedWorks of Nicholas Tripcevich, Ph.D.

June 2011

Procurement at the Chivay obsidian source, Arequipa, Peru

Contact Author

Start Your Own SelectedWorks

Notify Me of New Work

Available at: http://works.bepress.com/tripcevich/19

Procurement at the Chivay obsidian source, Arequipa, Peru

Nicholas Tripcevich and Alex Mackay

Abstract

Results of survey and test excavations at the Chivay obsidian source in highland Peru found evidence of use of the source area throughout much of the prehispanic past. An examination of a quarry pit and workshop suggest that quarrying and workshop production intensified at the end of the Preceramic period in the region. The high elevation Chivay source (71.5355° S, 15.6423° E) lies at 4950 masl and was the geological origin for prehispanic obsidian artifacts from throughout much of southern Peru and Bolivia. Radiocarbon dates on charcoal recovered from the lower levels of a test unit placed in a mound of obsidian debris at the workshop, together with an obsidian hydration sequence from test units at both the workshop and the quarry pit, point to an amplification of quarrying and workshop production during the Terminal Archaic, or the third and second millennium BC. Regional exchange networks and trade in exotic goods are extensive during later periods in Andean prehistory but these data suggest that obsidian as an early target of procurement over distance was prepared in a dense production deposit that reflects changes over time.

Keywords

Andes; obsidian; quarrying; workshop; Archaic; Formative; Inka.

Introduction

Growing evidence shows that the sweeping social changes that occurred over the last five millennia in the prehispanic Andes, an area that witnessed the emergence of ancient states, have their roots in accelerating transformations towards the end of the Preceramic period. During this period, referred to here as the Terminal Archaic and ranging from 3300 to 1800 calibrated years BC, scholars have documented the beginnings of pastoralism, reduced residential mobility and a new emphasis on valued objects found in burials and other contexts in the highland Andes. The rich ethnohistoric and archaeological record in the Andes attests to the importance of quarries in Andean cosmology. While much of the

Routledge Taylor & Francis Group *World Archaeology* Vol. 43(2): 271–297 *New Approaches to Stone Mines and Quarries: Materials and Materiality*
© 2011 Taylor & Francis ISSN 0043-8243 print/1470-1375 online
DOI: 10.1080/00438243.2011.581447

specific evidence for the social and symbolic power of stone comes from the later part of the prehispanic past, an early emphasis on material like obsidian beyond its functional cutting properties and its presence in ritual contexts in the surrounding region suggests that the social and religious significance of stone has deeper antiquity.

Here we present evidence for quarrying and intensification of obsidian artifact production during the Terminal Archaic and into the Middle Formative (1300–500 BC) at a high altitude obsidian source (Fig. 1) that supplied much of the highlands of southern Peru throughout the prehispanic period. Regional evidence for an increased use of obsidian in manufacture of a new projectile point style is linked in part to subsistence changes and a shift from hunting to herding; yet the timing of these changes at the obsidian source implies that an emphasis on obsidian procurement is also linked to broader engagement with particular materials imbued with social and symbolic power occurring at this time.

Background

Chivay obsidian in the South-Central Andes

A major source of obsidian in the south-central Andes, Chivay[1] is the geological origin for approximately 90 per cent of the over 500 obsidian artifacts analyzed from sites in the Lake Titicaca Basin lying 180km to the east of the source (Brooks et al. 1997; Burger et al. 1998, 2000; Craig et al. 2007; Craig et al. 2010; Glascock et al. 2007). Obsidian from Chivay has been found in archaeological sites in the south-central Andean highlands in contexts dating as early as the Early Archaic at Asana (Fig. 1), circa 8200 BC (Aldenderfer

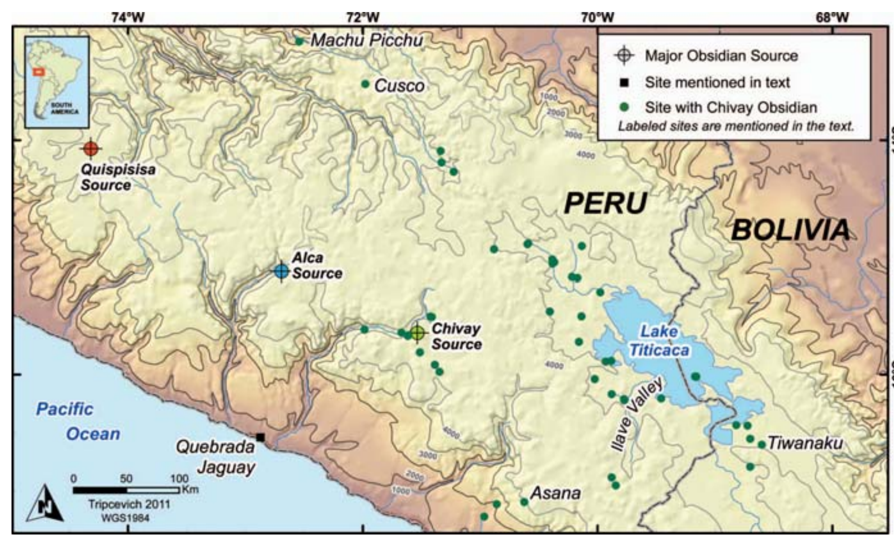

Figure 1 Map showing major obsidian sources and sites in the south-central Andes mentioned in text.

1998: 131,157),[2] through to the Inka period (AD 1476–1532) when small nodules of Chivay obsidian were deposited at Machu Picchu (Burger et al. 2000: 347). This article reports on quarrying evidence from the Terminal Archaic (3300–1800 BC), a time of substantial social and economic change in the Andean highlands, with the transition to a low-level food-production economy, a sedentary lifeway and the beginnings of social differentiation in the region (Aldenderfer 1998, 2009, Stanish 2003: 99–137). The herding of camelids, an important domesticate that provided fiber, meat and transportation in the form of llama and alpaca flocks, began by early estimates at approximately 5000–4000 BC (Wheeler et al. 1995) and by later estimates at 3000–2000 BC (Mengoni Goñalons and Yacobaccio 2006). The emergence of llama caravans bearing cargo on regular, perhaps seasonal routes would have affected the scale and consistency of trade relationships and material evidence of exchange (Browman 1981; Dillehay and Nuñez 1988).

A consideration of the larger role of obsidian in the economy of the highland Andes at the end of the Archaic period provides a context for interpreting activities at the source. Lithic materials such as high-quality cherts, fine-grained volcanics and obsidian were used regionally throughout the Archaic and studies show that small quantities of obsidian were transported long distances beginning with the earliest populations, probably by way of the high mobility of foragers (Aldenderfer 1998: 52–6, 295–303; Sandweiss et al. 1998). Social and economic changes in the south-central Andes beginning during the Terminal Archaic include the display of valued objects, hinting at an early manifestation of the important role exotic goods played in later periods in the Andes (Goldstein 2000). These early valued items include necklace beads of lapis lazuli (Craig 2005: 574) as well as gold pendants, among them the earliest gold found in the New World (Aldenderfer et al. 2008; Craig 2005: 588–662). Obsidian, virtually all of it from the Chivay source 200km distant, is encountered in the Ilave valley (Fig. 1) (Craig 2005: 571; Craig et al. 2007). Notably, obsidian was transported into the region despite the local availability of quality cherts and other lithic resources in the Titicaca Basin.

Past human engagement with obsidian defies simple categorization (Burger et al. 2000: 347–53; Lazzari 2010). It may have been a relatively mundane item, and it may have been imbued with symbolic value or power, but in regions far removed from the source the use of large pieces of obsidian implies at a minimum affiliation or membership in a community with access to this material (Tripcevich 2010). Where it is abundant among pastoralists in the highlands near volcanic formations, obsidian flakes and projectile points are common in rockshelter sites. Employed simply as sharp, freshly struck flakes, obsidian would have been useful for cutting tasks and for working with camelid fiber. Yet ritual associations occur where bifaces and flakes of Chivay obsidian are found in the Titicaca Basin in Terminal Archaic burials (Craig 2005: 571), mixed with flakes from other obsidian types in ritual mounds at Tiwanaku (Couture 2003: 215; Giesso 2003), and, as twenty-nine unmodified marekanites (nodules) under 5cm long, as far away as Machu Picchu (Burger and Salazar 2004; Burger et al. 2000: 347).While obsidian is renowned for its effectiveness as a cutting tool, it is important to note that this instance of Chivay nodules at Machu Picchu, in a natural form too small for knapping at 291 linear km distant, is one of the furthest examples of transport of Chivay material documented to date, but consistent with the scale of activities within the Inka empire. Thus in some contexts the brightness, aqueous appearance and unusual fracture

properties of this natural glass may have had important associations, for example, with the power of the volcanic landforms from which it derives (Lechtman 1984: 33–6; Saunders 1998; Tripcevich 2010: 69).

Projectile points are the most common formal artifact made from obsidian in the Ilave valley during the Terminal Archaic (Aldenderfer 2005; Craig 2005: 684) and this continues to be true at Tiwanaku three millennia later (Giesso 2003). Points in small, triangular forms (Plate 1) appear during the Terminal Archaic, probably linked to adoption of the bow and arrow, and this point style persists in use for the remainder of the prehispanic period (Klink and Aldenderfer 2005).

Excavation data combined with diagnostic points found during a survey of the Ilave Valley of western Lake Titicaca Basin show that it is during the Terminal Archaic that obsidian projectile points become prevalent in the area, representing 1–2 per cent of point forms from earlier Archaic time periods, and 14 per cent of all projectile forms from the Terminal Archaic onwards (Craig 2005: 475; Tripcevich 2007: 201). Decisions in projectile point manufacture reflect changing practices occurring during the Terminal Archaic and Formative, including a reduced need for hunting, expanding herds of llama and alpaca, possible conflict and defense of herds against theft and animal predation. An obsidian-tipped projectile is visibly sharp, simultaneously communicating effective weaponry and possible social alliances through ties to trade networks with access to obsidian.

There is a decrease in usage of obsidian towards the end of the prehispanic period (Burger et al. 2000: 344), though it continues to be used as basic flakes and knapped into

Plate 1 A type 5D projectile point measuring 26.3x13.8x3.9mm, weighing 1.2g. This unfinished point (Lot 70.3) came from test unit 4, level 7, below a hearth dated to the end of the Late Formative, AD 334–534, at 'Pausa', a site 15km east of the obsidian source (Tripcevich 2007: 747–57).

small, triangular projectile points right up until arrival of the Spanish. There is evidence that obsidian continued to be have symbolic meaning and, because obsidian sources are relatively rare in the Andes, possession of this material possibly conveyed geographical associations. Today, the Chivay source area is also known as 'Cotallalli' (Brooks et al. 1997) in reference to a peak that lies on the western margin of the obsidian source (Fig. 2) that is sacred to Colca valley communities and the subject of an annual ascent by

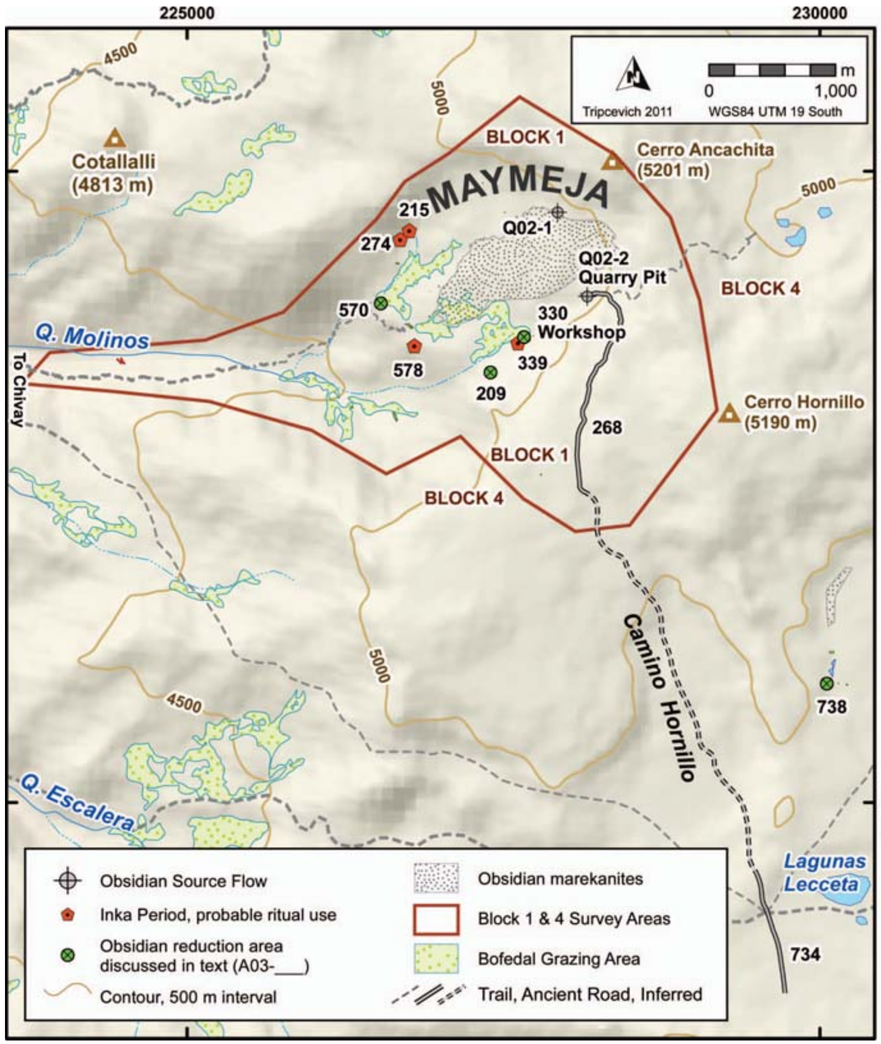

Figure 2 Map of Chivay source area showing archaeological sites, landforms and available obsidian. Shows sample geochemistry collection locations.

worshippers. During Inka times some subject populations were relocated elsewhere within the empire as a part of Inka imperial strategy. The offering of unmodified obsidian from Chivay at the gateway of Machu Picchu source may been an example of a Colca valley resident bringing a portion of their sacred landscape to the Inka royal estate akin to a widespread practice described in an sixteenth-century ethnohistoric account (Duviols 1967; Ogburn 2004b:124). One expression of the ritual significance of mining in the Andes by chronicler Bernabé Cobo (Cobo and Jiménez de las Espada 1890 [1653] XIII, ch. 11, p. 166) describes the worship of hills and mines by the miners as *huacas* (shrines) with dancing, drink and candles as the mines were asked to provide mineral wealth.

Intimations of symbolic power linked to obsidian on a regional scale are strongest during the Inka period, but, as will be described below, the principal evidence of obsidian exploitation that we encountered at the Chivay source dates to a much earlier time. Transformations in the regional use of Chivay obsidian and other non-local valued objects in the south-central Andes, with a new importance of such objects in ritual and in social differentiation, were linked to an intensification of quarrying activities at the Chivay obsidian source at the end of the Preceramic.

Geological context

Obsidian nodules belonging to the 'Chivay' chemical group are found in primary contexts in the upper portions of Tertiary volcanic flows to the east of the town of Chivay in the Colca Valley between 4700 and 5050 meters above sea level (masl). Burger et al. (1998: 204) report nodules as large as 30cm across along the margins of 'Hornillo', a collapsed rhyolitic dome, and occurring at the contact between the Pliocene (5.3–1.8 Ma) Barroso layer and the underlying Miocene (23.8–5.3 Ma) Tacaza layer. Our research has confirmed that obsidian deposits are found around the base of the Hornillo volcanic feature, with the largest and most homogeneous nodules situated in 'Maymeja' a large volcanic depression that has been eroded into a cirque to the north of Hornillo (Fig. 2). This volcanic depression is delimited by the two largest peaks in the obsidian source area, Cerro Hornillo and Cerro Ancachita (Plate 2), which appear to be vents that extruded transversal flows of rhyolitic magma during the Barroso group magmatism. Geological studies published by the Peruvian government (INGEMMET) indicate that Barroso eruption ages are clustered around 6 and 1 Ma (Klinck and Palacios 1985; Palacios et al.

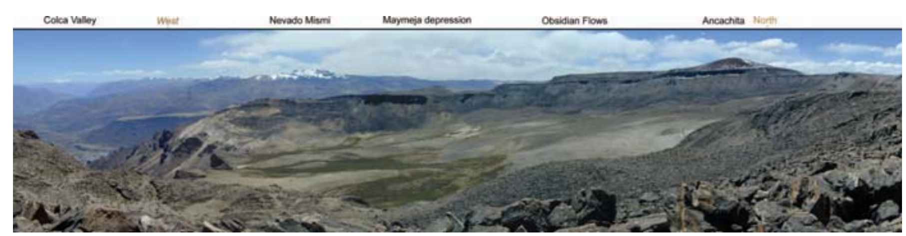

Plate 2 Panoramic photo of the Chivay source area.

1993; Thouret et al. 2007). Early Pliocene extrusion dates are supported by a fission track date of 3.52 ± 0.15 Ma acquired directly from a sample of Chivay/Cotallalli obsidian (Poupeau and Labrint 2006 pers. comm.).

Contrary to the longstanding view that the Andes is a very young mountain range (Clapperton 1993; Gregory-Wodzicki 2000), recent studies suggest that uplift, glaciation and valley incision occurred before 3.8 Ma and perhaps started as early as 11 Ma (Schildgen et al. 2009; Thouret et al. 2007). The extrusion of Chivay obsidian at high altitude in a potentially subglacial context, depending on Pliocene climatic conditions (Strecker et al. 2007), may explain the presence of perlitized obsidian nodules in certain sectors of the Chivay source (Tuffen et al. 2001).

In the more immediate past, glaciers probably persisted in the cooler, south-facing parts of the Maymeja depression during initial human presence in the region. Evidence for a Younger Dryas (*c*. 11,000–9400 BC) glacial re-advance as low as 4,650 masl on the east flanks of the Chivay source area has been reported by Borns and Sandweiss (in Sandweiss and Richardson 2008: 99). The researchers use this evidence to suggest that the absence of Chivay obsidian artifacts in the Terminal Pleistocene and Early Holocene layers at Quebrada Jaguay (Fig. 1) (Sandweiss et al. 1998), but presence of flakes from the nearly equidistant Alca source may have been due to glacial cover at the higher elevation Chivay source. While the largest nodules in the Maymeja depression may indeed have been covered by glaciers, our research also found obsidian nodules in secondary moraine contexts as low as 4400 in Quebrada de los Molinos (Fig. 2), draining Maymeja to the west, and smaller nodules scattered in other zones surrounding Hornillo that appear to have been free of glacier cover (Tripcevich 2007: 499). In light of our new data, Sandweiss (personal communication 2011) retracts the argument that glacial cover accounts for the absence of Chivay obsidian at Quebrada Jaguay and suggests that other factors such as territoriality must be at play.

Field research

From 2001 to 2004 a field project was undertaken at the Chivay source and surrounds. The goals of the project included an examination of lithic procurement at the obsidian source, how it changed over time, and how those changes relate to local and Andean developments more generally. Fieldwork consisted of survey and test excavations at the Chivay source itself as well as at two additional zones within one day's travel from the source. We thus targeted three zones: the high elevation Chivay source area itself, a herding area 15km to the south-east and a lower elevation agro-pastoral valley 20km to the north of the source. Research in the broader area of the Chivay source was designed using reconnaissance survey in 2001 and 2002 combined with satellite image analysis and locational modeling to examine the source region and target zones for closer study (Tripcevich 2007: 323–421). The majority of fieldwork occurred in 2003 when we conducted pedestrian survey (< 15m spacing) in the three survey zones totaling $33km^2$ and did more rapid prospection in 'reconnaissance zones' targeting high likelihood site locations. In addition, a total of eight 1x1m test excavations provided stratigraphic information.

Survey work focused on recording cultural and geological features into a customized version of ESRI Arcpad mobile GIS system with a differential GPS horizontal error of

< 3m (Tripcevich 2004; Tripcevich and Wernke 2010). The GIS-based fieldwork permitted us to record the varying concentrations of artifacts in the continuum of lithic material that is typical of a lithic source by recording 'site' polygons, for government compliance, as the lowest of four levels of artifact density concentrations; our approach thus borrowed from 'siteless survey' concepts (Dunnell and Dancey 1983; Ebert 1992). The present article focuses on survey at the Chivay source itself and on evidence from layers in test units 2 and 3 at the source dating to the Terminal Archaic period.

Test units were excavated in cultural levels but when cultural levels were thick they were arbitrarily divided at 10cm intervals. The test unit at the obsidian workshop (test unit 3) was virtually all flaked stone and, typical for quarry research, robust sampling methods were needed. At test unit 3 a collection strategy was employed where only flakes were recovered from a single 25cm quad (north-west) of the 1x1m unit, but other items including carbon samples and artifacts like retouched flakes, cores and tools were collected from throughout the unit. Thus, counts and weights for simple flakes are proportionally 25 per cent of the amount of other artifact types collected from the test unit 3 excavations. Flake collections were further sampled to only 5 per cent by weight (1.25 per cent of the original unit) to arrive at the target range of 150–300 complete flakes per level for technical analysis.

Research findings

Obsidian exposures in the Chivay source area

Tool-quality obsidian at Chivay was principally encountered in nodule form as disarticulated outcrops blanketed by a matrix of perlite and rhyolite. Our reconnaissance survey in the larger source region (Block 1, see Fig. 2) in 2002 and 2003 determined that the sole source of large obsidian nodules at Chivay is the Maymeja depression where systematic survey in 2003 delineated exposures, a quarry pit and several workshops. Only in the Maymeja source area are obsidian nodules encountered over 10cm long in non-cultural contexts; the largest nodule found was 23cm.

Angular pieces of perlite and small, non-hydrated nodules (marekanites) blanket the upper slopes of the Maymeja depression as well as the northern and eastern flanks of Hornillo below approximately 4950 masl. Marekanites are sometimes of homogeneous, tool-quality material (Shackley 2005), and, while they are rarely over 5cm in size, the high concentrations of small obsidian flakes that we encountered at a nearby site with Inka period sherds suggest that even these small pieces were of utility, perhaps for producing small points or flakes for expedient cutting tasks related to animal herding. Analysis suggests that exploitation of these small nodules may account for much of the obsidian consumption in the herding and agro-pastoral contexts surveyed around the source (Tripcevich and MacKay in press).

Today, the greatest densities of obsidian occur as angular marekanites (< 3cm in size) remaining on exposed and deflated moraine ridges of tuff, pumice and perlite. Obsidian also occurs in flow form at Chivay in contexts where erosion has exposed underlying deposits (Q02-1), but these flows are largely unsuitable for tool production because the glass flow contains many vertical, sub-parallel fractures. Small scatters of flaked obsidian are found in a number of locations throughout the source, typically in sheltered locations on ridge tops overlooking grazing areas which appear to have been hunting or herding stations where periodic knapping, especially primary reduction, occurred. Retooling was evident at the source area in the form of two chert and one andesite foliate projectile point bases found in the course of survey work that were snapped along the width axis; these points were likely broken in the haft and retooled with obsidian points. Sixteen obsidian samples collected from across the obsidian source have been provided to the Missouri University Research Reactor source sample inventory and Neutron Activation Analysis and X-ray fluorescence conducted on the samples indicate that there is little geochemical variation or identifiable sub-source areas at the Chivay source (Michael Glascock 2005 pers. comm.).

Transparent obsidian with thin cortex

Like most high-quality obsidian, Chivay material has excellent conchoidal fracture properties and is largely free of heterogeneities. Across the source area Chivay obsidian varies from black to very light gray that appears transparent on thin artifacts. Gray banding is common and is generally the result of magnetite crystals ($<15\ \mu$m) in the glass (Ma et al. 2007). Our findings suggest that the transparent gray and gray-banded obsidian were most commonly used in antiquity. Small, low-quality pieces of brownish obsidian were observed to the north of Cerro Hornillo, though no examples of the purplish hue reported by Burger et al. (1998: 204) were found.

The cortex on Chivay obsidian nodules is highly variable and this can result from differences in lava cooling rates, contact and melting of adjacent materials and weathering effects. Much of the surface obsidian in the lower reaches of the source has a rough, weathered cortex that likely results from tumbling and glacial erosion. We noted that much of the artifactual obsidian actually has a very thin cortex and nodules in the perlite matrix near the Q02-2 quarry pit have virtually no cortex save for a slight dullness and discoloration. This thin cortex has little effect on fracture mechanics and knappers could thus acquire squarish nodules that were of high proportional utility because the nodules were effectively free of rough cortex. It seems probable that many nodules were not processed at the source area, but were exported in unmodified form. If the interior quality of the obsidian nodules was sufficiently predictable then whole nodules may have been easier to transport, particularly with the aid of cargo llamas, than cores or blanks with sharp and delicate edges. In the case of nodules with extremely thin cortex, the exterior surface does not appear to have posed an impediment to knapping, and indeed a number of preforms and utilized bifacial tools were encountered where thin cortex remained on one or other face.

Obsidian procurement at Chivay

Results from this survey work, aiming to be comprehensive, indicate that obsidian acquisition occured by two principal means: obsidian was quarried from the Q02-2 quarry pit (Plate 3) and it was recovered from surface contexts and secondary deposits like moraines and stream beds. The Q02-2 pit is a depression that measures approximately 4x5m with a depth of 1.5m and a total affected area measuring 10x12m (Figs. 3 and 4). The

Plate 3 Excavating test unit 2 at the quarry pit Q02-2.

quarry is excavated into loose perlite matrix that, for lack of maintenance, has partially refilled (Fig. 4A). We estimate that 12.8m^3 of material was removed from the pit by subtracting a surface model generated from 50cm interval total station postings from a hypothetical surface in ArcGIS Spatial Analyst (McCoy and Johnston 2001) and calculating the volumetric difference (Fig.4B).

This pit can be compared with ellipsoidal quarry pits ringed by semi-circular piles of quarry debris and debitage that were described at obsidian sources in central Mexico (Darras 1999: 80–84; Healan 1997), although this quarry pit at Chivay is modest by Mexican standards and debitage is relatively scarce. The Quispisisa source in southern Peru has dozens of quarry pits in various sizes and this sole pit at Chivay is comparatively small (Tripcevich and Contreras 2011). At the nearby Alca obsidian source, a number of small and medium-sized quarry pits in a rhyolite and perlite matrix have been found at the high altitude primary deposits with quarry debris and debitage (Rademaker 2006: 154). A contrasting technique can be noted in the pyroclastic flows in the lower reaches of the Alca source area obsidian nodules were extracted by way of tunneling into a soft tuff matrix (Jennings and Glascock 2002).

Digging tools used for excavating the quarry pit were not found at the Chivay quarry area with the exception of rhyolite slabs common in this area. At other quarries, tools are found made from organic materials such as pieces of wood, deer antler or long bones from large mammals that, in the highland Andes, would include camelids or deer. At Chivay

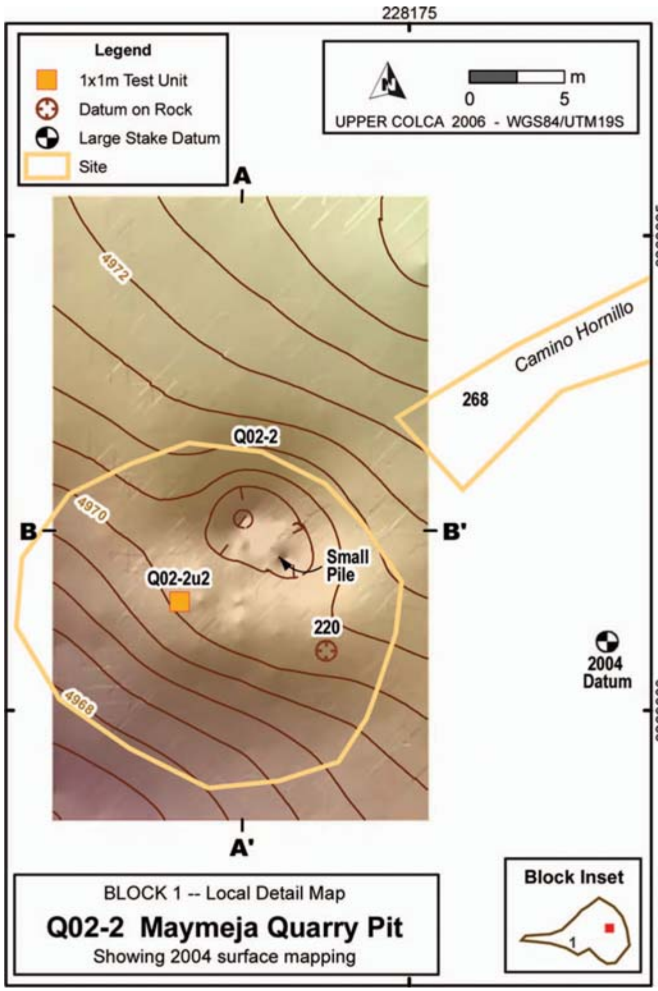

Figure 3 Quarry Pit Q02-2 showing placement of test unit 2, extent of area affected around quarry pit and approach of Camino Hornillo.

such materials have since disappeared; perhaps they were reused by local pastoralists. At the Alca source quarry pits researchers encountered hammerstones as well as sticks that were likely carried up to the quarry from lower elevations (Rademaker 2006: 154–5). The Inka used hammerstones of quartzite and other materials at stone quarries (Protzen 1985: 168), and an exceptional array of first millennium AD prehispanic implements for loose matrix mining were found in a collapsed tunnel with the 'Copper Man' atacamite miner in northern Chile (Bird 1979). Basic mining tools known from outside the Andes include stone hammers or sledges, wedges, grooved mauls, prying sticks, bone and antler and are

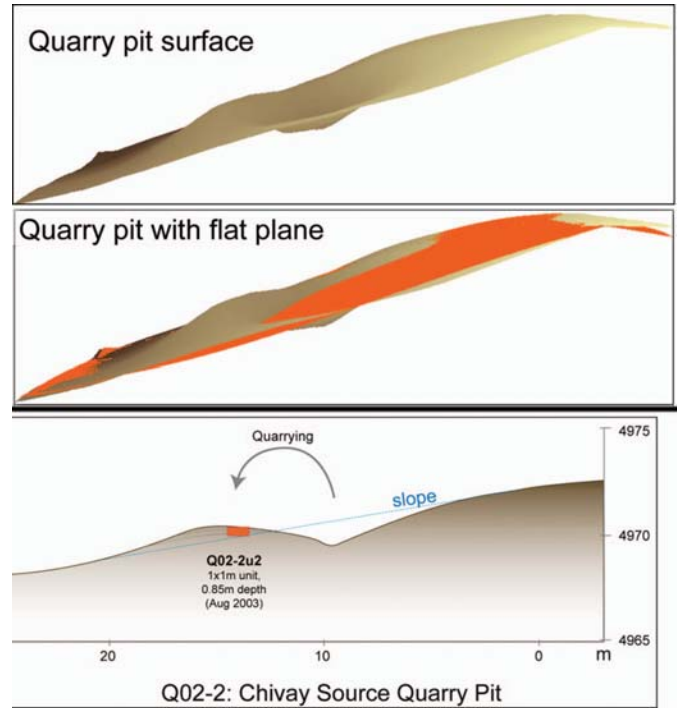

Figure 4 Side views of quarry pit Q02-2. A: quarry pit bisected with an inferred natural slope providing an estimated removed obsidian volume of 12.3m^3; B: showing quarrying and debris accumulation.

sometimes encountered archaeologically (Bradley and Edmonds 1993: 78; Holmes 1919: 218, fig. 96).Tools are also described ethnographically (Binford and O'Connell 1984; Burton 1984: 241; Gallagher 1977; Stout 2002). However, quarrying tools also may be absent at regionally important quarries, perhaps due to the looseness of the source matrix or because of tool recycling (Fladmark 1984; Reher 1991: 274; Torrence 1986).

Test unit 2: the quarry pit

A 1x1m test unit (test unit 2) was placed in the discard pile below the quarry pit, but the 85cm deep unit produced no datable carbon and little evidence of actual obsidian reduction (Tripcevich 2007: 687–702, 741–3). Only two cores, eighty-one flakes of probable cultural origin and two bifacially knapped artifacts were found in the unit. This small collection, together with an absence of hammerstones, suggests that obsidian nodules were rarely knapped at the quarry pit. Time constraints in the field precluded the excavation of additional test units in other locations around the pit or excavating into the base of the pit itself.

Test unit 2 indicates that the matrix excavated and discarded during quarrying consisted of small pieces of perlite and tuff, tephra and many small fragments of obsidian that had been fractured by geological processes. The stratigraphy of test unit 2 at the quarry is marked by variation in the matrix and tephra deposits that likely derive from nearby Quaternary volcanoes (Delacour et al. 2007; Gerbe and Thouret 2004; Noble et al. 2003), revealing a sequence of excavation and discard in the digging of the quarry pit.

Stratigraphic evidence from test unit 2 suggests that quarrying began gradually but that there were two periods of intensified digging during the final sequences of work at the quarry. No datable organic materials were recovered from the actual quarry, but obsidian hydration (Tripcevich et al. in prep) serves to link radiocarbon dates recovered from the test unit 3 placed in the obsidian workshop 600m downslope. The hydration results point to relatively early dates for digging at the Q02-2 pit as these layers contain hydration rind thicknesses comparable to the Terminal Archaic layers with calibrated 14C dates ranging from 2800 to 2400 BC at the workshop (Table 1).

The uppermost levels of test unit 2 (levels 2, 2a and 3) were between 10 and 25cm in thickness and derive from deepest digging at the quarry in the reversed stratigraphy of this debris pile. The lower levels of the test unit were only 5–10cm in thickness (Fig. 5). During episodes of intensified digging, corresponding to upper levels in the test unit, nodules of obsidian were discarded that were up to 7cm long, while in other levels the discarded nodules were no more than 5cm. The two cores and three bifaces found in test unit 2 were found below level 3. If thicker deposition levels in the debris pile correspond with intensified quarrying, then it appears that minimal reduction occurred with the export of large nodules during those final episodes of use of the quarry pit. In other words, the quarry was excavated on an intermittent basis with some reduction by the quarry until some of the final quarrying levels, or levels 2 and 3 of the test unit, when a strategy of intensified quarrying and removal of whole nodules from the area was employed. An alternative explanation is that the obsidian nodules were simply encountered at a lower density in the perlite matrix at these lower levels, resulting in thicker strata in test unit levels 2, 2a and 3.

Test unit 3: the Maymeja workshop

A concentrated mound of flaked obsidian, interpreted as a workshop was encountered during survey work at an elevation of 4900 masl, approximately 600m downslope from the quarry in a site designated A03-330 (Plate 4; Fig. 6). The interpretation of obsidian workshops is notoriously challenging (Clark 1990, 2003: 27–30; Torrence 1986), and, as central Andean obsidian workshops consisted exclusively of bifacial production,

Table 1 Test unit 3 AMS radiocarbon dates on charcoal at University of Arizona showing the two sigma, southern hemisphere calibration (McCormac et al. 2004; Stuiver et al. 1998) from CALIB v6.0

Level	*Lab code*	*Lot no.*	*Uncal.* BP	*Error*	*Calibrated* BC *range*	*Area under 2 sigma curve*
4	AA57940	162.8	3149	± 53	1494–1212	1.00
6	AA61375	164.5	4063	± 39	2639–2453	0.95
7	AA57940	166.79	4160	± 43	2872–2567	0.96

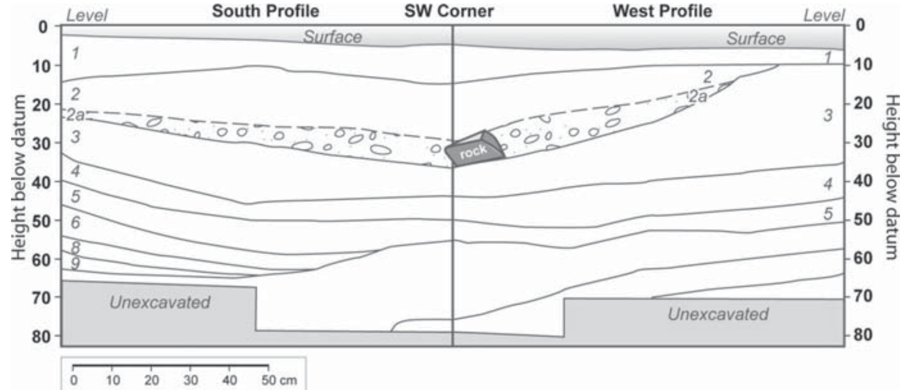

Figure 5 South and west stratigraphic profiles from test unit 2 at quarry pit Q02-2.

Plate 4 Excavating test unit 3 at the workshop A03-330.

comparisons can be made to studies of bifacial obsidian industries elsewhere in the world (Byram et al. 1999; Darras 1999; Ozbun 1991), although these other examples did not include the possibility of cargo animal transport.

The mound of flaked obsidian at A03-330 measures 3x4m with an estimated mean depth of 60cm and is adjacent to a large Andean *bofedal* (rich high altitude grazing area) fed by a perennial spring (Plate 4). Test unit 3 measuring 1x1m was placed into this mound and encountered sterile, moist soil at a depth of 72cm. Portions of a sloping yellow surface denoted 'stratum 3' (Fig. 7) overlying the similarly sloping stratum 4 are suggestive of a prepared floor associated with obsidian production in this area. While a single 1m test unit provides little spatial extent for inference, the strata at two distinct angles are perhaps the result of mounding occurring initially downslope from the test unit location and the placement of the stratum 3 yellow surface on the upslope side of the older, stratum 4 lower mound.

The seven excavated levels in test unit 3 (Fig. 7) consisted almost entirely of flaked stone. On the whole the unit included 339 cores among a total quantity of artifacts that we estimate weighed 750kg from this one test unit. Relatively few preforms or bifaces were encountered (n = 44), and the thirty-three bifaces that were encountered were all broken. While there was no evidence of pressure flaking at the obsidian workshop area, in our study of sites 15km from the source many obsidian and chert bifaces had pressure flake removals.

Dates on charcoal recovered from test unit 3 (Table 1) place the bulk of activities at the workshop between the Terminal Archaic (2872 BC) and the Early Formative (1212 BC), early dates that are consistent with the largely aceramic nature of the site. The earliest components of the workshop thus overlap in time with activities at the quarry pit, though later levels do not.

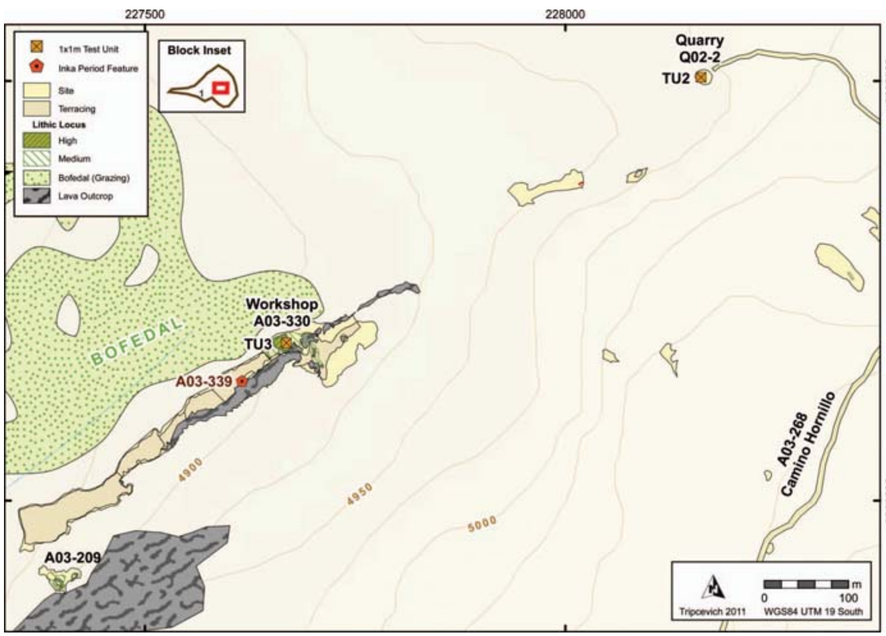

Figure 6 Detailed map of southern portion of Maymeja showing obsidian quarry pit, workshop and associated features.

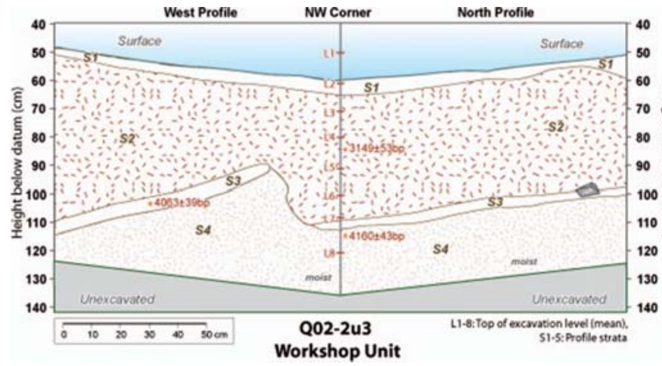

Figure 7 North and west stratigraphic profiles from test unit 3 at workshop A03-330. The unit was excavated in levels (L1–8) while cultural strata (S1–4) derive from the interpretation of the profile.

Analysis of artifacts from test unit 3 (n = 1544) provides diachronic data on knapping activities (Tripcevich 2007: 743–5, 794–9; Tripcevich and MacKay in press). Evidence for the discard of relatively large cores and long flakes in levels 5 and 4, and to a lesser extent in level 3 (Tables 2, 3 and 4), was found in the workshop test unit, implying that large obsidian nodules were abundant during those occupation levels. Interestingly, however, these levels post-date the period for which the quarry appears to have been active. Only the oldest levels 6 and 7, which contain a relatively small number of large cores, are directly coeval with the period of quarrying based on analysis of hydration rinds (Tripcevich et al. in prep.). It may thus be that little processing of extracted obsidian occurred during this period, or that test unit 3 was not positioned to reveal those older layers considering that the workshop mounding appears to have shifted, as shown by the angle of stratum 3. Cores and cortical flakes continued to be large in levels 4 and 5 of the workshop, post-dating the apparent cessation of quarrying based on hydration evidence. This implies either that material was still available to be extracted from the quarry pit after it had ceased to be actively maintained, or that alternative means of sourcing suitable tool-stone had been found, or potentially both. The pattern is largely reversed in level 3 where it appears that initial core size was small and flakes were dramatically smaller, suggesting that both scavenging of existing material at the workshop and/or further increases in processing were occurring at the workshop. The substantial increase in core numbers in the later levels, as well as a trend towards flakes with less dorsal cortex, also suggests that on-site processing may have increased in intensity.

Adjacent to the workshop (A03-330) a number of small highly eroded terraces are found on lava benches near the Maymeja workshop area (Fig. 6). The dating and function of these terraces are ambiguous: these constructions are high above the cultivation zone at over 4,900 masl, and, while the terraces bear some flakes of obsidian reduction, there are very few pot sherds. The presence of several Inka burial structures in the area raises the possibility that, despite the lack of pottery, these terrace features may be later, Inka period constructions (Plate 5). During the rainy season the margins of the bofedal wet areas expand and the preferred place for short-term residential occupation may have been dry spaces among the lava benches with maximum solar insolation.

Table 2 Length for complete cores and count of broken bifaces by level from the Chivay source, test unit 3

Level	Cal. years BC	*Length of complete cores (mm)* 20–30	30–40	40–50	50–60	>60	Cores Total	*Count of all bifaces (all broken)* 20–30	30–40	40–50	Bifaces Total
1		2	14	17	16	3	52		2		2
2		2	22	15	7	2	48	5		1	6
3	1494–1212	1	18	32	13	5	69	4	5	3	12
4		2	18	43	19	9	91	3	2	2	7
5		2	19	25	7		53	1	2	2	5
6	2639–2453		2	2	1	1	6		1		1
7	2872–2567		2	10	4	1	17				
TOTAL		9	95	144	67	21	336	13	12	8	33

Table 3 Length for complete flakes by level from the Chivay source, test unit 3

Level	*Length of complete flakes (mm)* 0–10	10–20	20–30	30–40	40–50	50–60	>60	Total
1	20	64	27	26	7	4	1	149
2	13	72	40	16	8	1	1	151
3	46	138	71	15	6			276
4	11	71	70	35	13	2	2	204
5	13	99	55	12	6	1	1	187
6	6	22	15	5	1	3		52
7	3	16	16	3	4	1		43
TOTAL	112	482	294	112	45	12	5	1062

Table 4 Dorsal cortex for complete flakes by level from the Chivay source, test unit 3

Level	*Percentage of dorsal cortex, all flakes* 0–24	25–49	50–74	75–100	Total
1	101	20	20	16	157
2	66	30	24	35	155
3	134	53	53	41	281
4	77	30	42	67	216
5	56	31	48	59	194
6	36	12	7	7	62
7	35	9	3	4	51
TOTAL	505	185	197	229	1116

Plate 5 Inka style cutstone masonry corner of possible square chulpa (A03-339) and sherds from 18cm diameter of Local Inka Horizon plate found 88m west of the obsidian workshop. Exposed yellow tape indicates 50 cm.

A high concentration of flaked obsidian was found on the far western edge of this cluster of features at an overlook location referred to as A03-209 (Fig. 6). While this is not a mound of flaked stone as at the workshop, this high density knapping locus is contiguous with other cultural features along the lava benches. The principal feature of this location is that one can see far down into the Colca valley, while remaining only a few hundred meters from the obsidian source and workshop. A visibility index for the Chivay source area derived using ArcGIS (Tripcevich 2007: 437–40, 791) shows that the A03-209 location has approximately one-and-a-half times greater than the typical visibility when all the site locations in Maymeja are considered.

It is conceivable that A03-209 was a location for monitoring the valley during times of conflict and that knappers were acquiring obsidian and knapping while observing activities in the valley below. However, the knapping occurring at this location is typically early stage reduction. Other evidence of advanced biface production, like broken preforms or bifacial thinning flakes, was not encountered here during surface collection work. A small, looted cave burial with Late Intermediate Period pottery sherds was found in the cliff behind this dense obsidian scatter, suggesting that perhaps this location had stronger links to ritual activities than to conflict.

Camino Hornillo

Together with the quarry pit and the workshop, a third feature associated with obsidian procurement is a broad path or road (Plate 6; Figs 2 and 6) departing to the south-east from

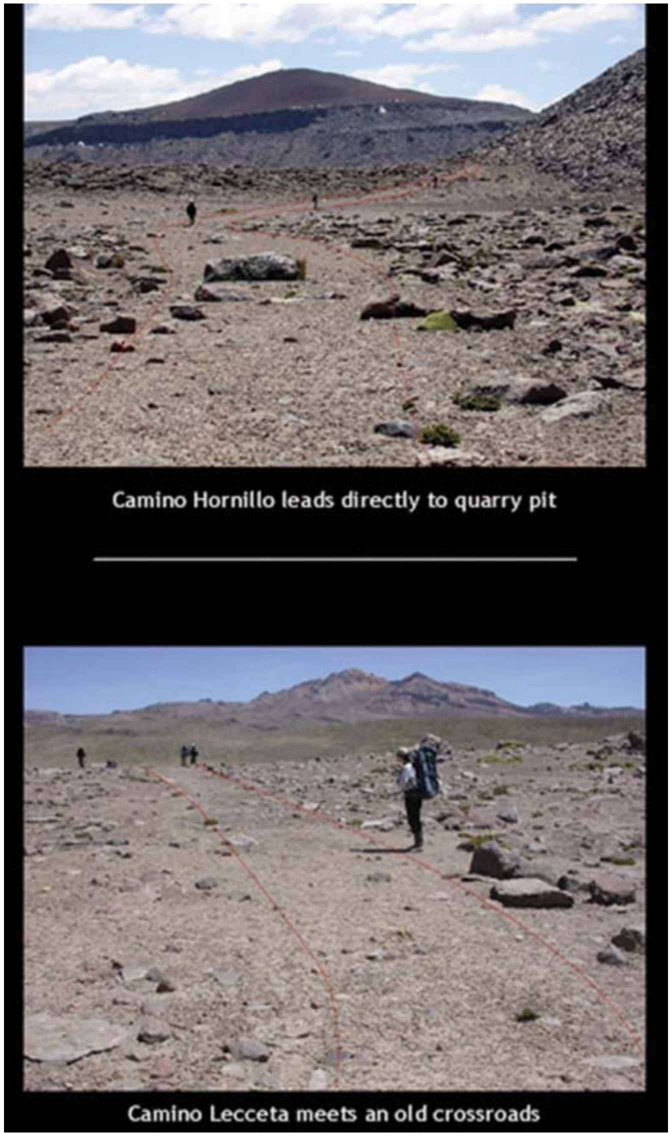

Plate 6 Two views of Camino Hornillo. Thin lines have been added to indicate the edges of the swept road.

the Q02-2 quarry pit sweeping around the west flank of Cerro Hornillo, predictably following the least steep route out of Maymeja, and then departing towards the south (Tripcevich 2007: 495–6, 585–90). The road was mapped in two segments A03-268 and A03-734, totaling 3km in length interrupted by a sandy portion where road features become

indistinguishable (the inferred route is shown as a dashed line on maps). The road is 3–4m wide and is swept clear of all rocks under 75cm long. The route fits the description of a 'cleared road type. . .systematically cleared of all stones or other debris' (Beck 1991: 75–6), No pottery or architectural features were found in association with this road, although an obsidian projectile point of type 4F diagnostic to the latter part of the Late Archaic and through the Terminal Archaic or 3800–2000 BC (Klink and Aldenderfer 2005) was encountered along the route. Roads are often difficult to date, especially given the frequency of reuse of certain lands in mountainous areas near raw material sources (Hyslop 1984: 246–8, 271–4), but this road is linked strongly to the quarry pit as it ends precisely at the Q02-2 quarry. As a road for loaded cargo llamas through loose lava talus blocks, this path would reduce the chance of injury for camelids and lead caravans back to Camino Escalera, a principal prehispanic road out of the Colca valley near a prominent cairn. We tenuously assign a Terminal Archaic date to the Camino Hornillo road, primarily because the area has little evidence from later components; it was likely an existing track, widened with exploitation of the quarry, that has probably had some use ever since.

Valdevia

A final obsidian production area of interest is the site of Valdevia (A03-572). This site contrasts in an informative way with the obsidian workshop A03-330 because it is a multi-component site commonly encountered in grazing areas that have been in use by herders for millennia. At 4760 masl the site is lower in elevation, near a prominent overlook and adjoining the main trail descending to the Colca valley below, and provides views of prime grazing lands. A structure, occupied seasonally by alpaca herders, is situated adjacent a large corral where sherds of undecorated, coarse pottery in styles from the Formative through to modern times are evident.

Obsidian nodules in this lower section of Maymeja are up to 10–15cm in length and appear to be in a secondary context having been tumbled by erosional (probably glacial) processes and production at this site, included initial knapping, to decorticate the nodules. An analysis of surface materials from Valdevia reveals that biface production and advanced reduction stages of manufacturing occurred here. This contrasts with the Maymeja workshop (A03-330) which emphasizes a predominantly early-stage production strategy focusing on flake blanks and perhaps large cores for export during most of the sequence, and apparently dating to the end of the Terminal Archaic.

Inka period ritual activities

The cosmological significance of stone, stone sources and transport, and mountain landscape features have been documented in Inka studies (Dean 2010; Ogburn 2004a, 2011: Protzen 1983). The strongest evidence for symbolic power within the Chivay source area is in the form of several looted Inka period mortuary structures known as *chulpas* in the southern highlands of Peru, as well as a possible looted cave burial from the same time period. The three chulpas found in the Maymeja area of the Chivay source are approximately 2m in diameter, a typical size and consistent with the chulpas documented at the Kachiqhata granite quarry near Ollantaytambo in Cusco (Protzen 1983: 185).

Pottery fragments found near the chulpas were manufactured during the Inka period but primarily in the local 'Collagua III' style with the exception of one Cusco style rim sherd (Tripcevich 2007: 640; Wernke 2003:Appendix A). One circular structure that is still standing had a 70cm-high entryway and pottery fragments, another is just a base with pottery. One corner of cutstone masonry found just 88m west of the obsidian workshop among a series of eroded terraces is likely the remnant corner of a square chulpa together with a local Inka period (Collagua III) rim sherd (Fig. 6, Plate 5). While chulpas are not uncommon on promontories in the larger region, our pedestrian survey found a relatively high concentration at the obsidian source. Thus, while direct evidence of Inka period quarrying was modest, the cultural significance and possible control of the source area that occurred during the Terminal Archaic appears to have persisted into later Andean prehistory.

Discussion

As considered above, it is often difficult to discern the nature of demand for obsidian, and to assess the many levels at which exchange in this material may have been significant: how it conveyed information and how it may have constituted the very social relationships through which it was borne. The timing of changes to extraction and processing at the Chivay source supports previous analysis of local consumption patterns in implicating regional social dynamics in the Terminal Archaic as a critical element in a shift towards a new, increasingly social or symbolic role for obsidian.

The timing of quarrying activities in Maymeja is broadly coincident with the commencement of a regional suite of changes in social and economic organization which began early in the Terminal Archaic. Quarrying at the Chivay source begins around 2800 BC and amplifies soon after. It is interesting that quarrying precedes evidence for heavy processing at the Maymeja workshop site, and it is worth considering why this might have occurred. Presumably surface sources of obsidian were readily available around 2800 BC, given the absence of evidence for significant processing of cobbles at the source prior to this point. As quarrying represents a considerable investment in labor, this implies that early concerted exploitation of the source may have been targeting cobbles of a size or quality not available on the surface. One possibility is that the superficial matrix layer protected the nodules at Q02-2 from thermal fluctuations and glacial erosion, while surrounding surface cobbles were more often flawed. Exploitation of the Chivay source does not cease with the end of active quarrying, and indeed the workshop site suggests that rates of processing may have increased after 2400 BC. It is conceivable that this 'second phase' of exploitation of Chivay source material may have been driven by changes in projectile technology, as is implied by the evidence of increased obsidian use and wide use of type 5D projectile point style that is potentially linked to the adoption of the bow and arrow. As Klink and Aldenderfer (2005) note, type 5B and type 5D points are generally quite small relative to earlier forms, meaning that many projectile points can be produced from a single nodule and there should be a lessened need for large starting nodules for their production. Other changes, such as in the nature of warfare or perhaps in newly available poisons that make small, sharp projectiles effective (Ellis 1997), could have

changed the demand for obsidian. Later periods, however, benefit from millennia of obsidian dissemination into the region and thus, despite population increases and apparently greater demand for obsidian with Series 5 projectile points, their very small size means that smaller nodules scavenged in later periods would have sufficed. While chronological control is lacking for the uppermost levels of test unit 3, it appears that much of the evidence for advanced reduction persists above level 3, suggesting that the demand for specific artifact forms continued.

Throughout much of the prehispanic period obsidian had significance as a uniquely sharp cutting tool and a distinctively luminous material with an apparent role in ritual and as a marker of social ties in the region. Direct evidence from activities at the Chivay source points to an emphasis in production toward the end of the Preceramic period with a shift in production from the export of whole nodules and flake blanks during the Terminal Archaic to more advanced reduction in more recent times. While the functional cutting properties of obsidian have long been appreciated, obsidian sources as flows of natural glass also had enduring significance in the Andean landscape.

Acknowledgements

A debt of gratitude is owed to Timoteo Valdevia for welcoming us to camp among his alpaca flock at the obsidian source with a *pago a la tierra* that included ochre shaved with a chert biface. Research at the obsidian source succeeded with help from Cheyla Samuelson, students from the University of Oxford and from California, the enthusiastic support of Peruvian collaborators Willy Yepez and Saul Morales. We had the institutional support of the Center for Archaeological Investigation in Arequipa (CIARQ) and the University of California, Santa Barbara. Research was funded by a grant from the National Science Foundation (#0331181).

Nicholas Tripcevich, *University of California Berkeley*
Alex Mackay, *Australian National University*

Notes

1 This obsidian chemical group has been referred to in the literature as 'Chivay' (Burger et al. 1998), 'Cotallalli' (Brooks et al. 1997) and 'Titicaca Basin Type' (Burger and Asaro 1977, 1978).

2 All dates are reported as calibrated years BC.

References

Aldenderfer, M. S. 1998. *Montane Foragers: Asana and the South-central Andean Archaic*. Iowa City: University of Iowa Press.

Aldenderfer, M. S. 2005. Preludes to power in the highland Late Preceramic Period. In *Foundations of Power in the Prehispanic Andes* (eds K. J. Vaughn, D. Ogburn and C. A. Conlee). Arlington, VA: American Anthropological Association, pp. 13–35.

Aldenderfer, M. 2009. Key research themes in the south-central Andean Archaic. In *Andean Civilization: A Tribute to Michael E. Moseley* (eds J. Marcus, P. R. Williams and M. E. Moseley). Los Angeles: Cotsen Institute of Archaeology, University of California, pp. 75–88.

Aldenderfer, M., Craig, N. M., Speakman, R. J. and Popelka-Filcoff, R. 2008. Four-thousand-year-old gold artifacts from the Lake Titicaca basin, southern Peru. *Proceedings of the National Academy of Sciences*, 105: 5002.

Beck, C. 1991. Cross-cutting relationships: the relative dating of ancient roads on the north coast of Peru. In *Ancient Road Networks and Settlement Hierarchies in the New World* (eds C. D. Trombold). Cambridge: Cambridge University Press, pp. 66–79.

Binford, L. R. and O'Connell, J. F. 1984. An Alyawara day: the stone quarry. *Journal of Anthropological Research*, 40: 406–32.

Bird, J. B. 1979. The copper man: a prehistoric miner and his tools from northern Chile. In *Pre-Columbian Metallurgy of South America* (ed. E. P. Benson). Washington, DC: Dumbarton Oaks Research Library and Collections Trustees for Harvard University, pp. 105–32.

Bradley, R. and Edmonds, M. R. 1993. *Interpreting the Axe Trade: Production and Exchange in Neolithic Britain*. Cambridge: Cambridge University Press.

Brooks, S. O., Glascock, M. D. and Giesso, M. 1997. Source of volcanic glass for ancient Andean tools. *Nature*, 376: 449–50.

Browman, D. L. 1981. New light on Andean Tiwanaku. *American Scientist*, 69: 408–19.

Burger, R. L. and Asaro, F. 1977. *Trace Element Analysis of Obsidian Artifacts from the Andes: New Perspectives on Pre-Hispanic economic interaction in Peru and Bolivia – LBL6343*. Berekeley, CA: Lawrence Berkeley Laboratory.

Burger, R. L. and Asaro, F. 1978. Obsidian Distribution and Provenience in the Central Highlands and Coast of Peru during the Preceramic Period. *Contributions to the University of California Archaeology Research Facility*, 36: 61–83.

Burger, R. L. and Salazar, L. C. 2004. *Machu Picchu: Unveiling the Mystery of the Incas*. New Haven, CT: Yale University Press.

Burger, R. L., Asaro, F., Salas, G. and Stross, F. 1998. The Chivay obsidian source and the geological origin of Titicaca Basin type obsidian artifacts. *Andean Past*, 5: 203–23.

Burger, R. L., Mohr Chávez, K. L. and Chávez, S. J. 2000. Through the glass darkly: Prehispanic obsidian procurement and exchange in southern Peru and northern Bolivia. *Journal of World Prehistory*, 14: 267–362.

Burton, J. 1984. Quarrying in a tribal society. *World Archaeology*, 16: 234–47.

Byram, R. S., Connolly, T. J. and Musil, R. R. 1999. Newberry Crater debitage analysis. In *Newberry Crater: A Ten-Thousand-Year Record of Human Occupation and Environmental Change in the Basin-Plateau borderlands* (ed. T. J. Connolly). Salt Lake City: University of Utah Press, pp. 131–50.

Clapperton, C. M. 1993. *Quaternary Geology and Geomorphology of South America*. New York: Elsevier.

Clark, J. E. 1990. Fifteen fallacies in lithic workshop interpretation: an experimental and ethnoarchaeological perspective. In *Etnoarqueología: Primer coloquio Bosch-Gimpera* (eds Y. Sugiura and M. C. Serra). Mexico City: UNAM, pp. 497–513.

Clark, J. E. 2003. A review of twentieth-century Mesoamerican obsidian studies. In *Mesoamerican Lithic Technology: Experimentation and Interpretation* (ed. K. G. Hirth). Salt Lake City: University of Utah Press, pp. 15–54.

Cobo, B. and Jiménez de la Espada, M. 1890 [1653]. *Historia del Nuevo mundo: Sociedad de bibliófilos andaluces*. Sevilla: Imp. de E. Rasco.

Couture, N. C. 2003. Ritual, monumentalism, and residence at Mollo Kontu. In *Tiwanaku and Its Hinterland: Archaeology and Paleoecology of an Andean Civilization*, Vol. 2 (ed. A. L. Kolata). Washington, DC: Smithsonian Institution Press, pp. 202–25.

Craig, N. M. 2005. The formation of early settled villages and the emergence of leadership: a test of three theoretical models in the Rio Ilave, Lake Titicaca Basin, Southern Peru. PhD dissertation, University of California, Santa Barbara. AAT 3175165.

Craig, N. M., Speakman, R. J., Popelka-Filcoff, R. S., Glascock, M. D., Robertson, J. D., Shackley, M. S. and Aldenderfer, M. S. 2007. Comparison of XRF and PXRF for analysis of archaeological obsidian from southern Perú. *Journal of Archaeological Science*, 34: 2012–24.

Craig, N. M., Speakman, R. J., Popelka-Filcoff, R., Aldenderfer, M.S., Flores Blanco, L., Brown Vega, M., Glasscock, M. and Stanish, C. 2010. Macusani obsidian from southern Peru: a characterization of its elemental composition with a demonstration of its ancient use. *Journal of Archaeological Science*, 37–3: 569–576.

Darras, V. 1999. *Tecnologías prehispánicas de la obsidiana: los centros de producción de la región de Zináparo-Prieto, Michoacán, México*. México: Centre Français d'Études Mexicaines et Centraměriaines.

Dean, C. 2010. *A Culture of Stone: Inka Perspectives on Rock*. Durham, NC: Duke University Press.

Delacour, A., Gerbe, M.-C., Thouret, J.-C., Wörner, G. and Paquereau-Lebti, P. 2007. Magma evolution of Quaternary minor volcanic centres in southern Peru, Central Andes. *Bulletin of Volcanology*, 69: 581–608.

Dillehay, T. D. and Nuñez, L. 1988. Camelids, caravans, and complex societies. In *Recent Studies in Precolumbian Archaeology*, Vol. 421 (eds N. J. Saunders and O. de Montmollin). Oxford: BAR International, pp. 603–33.

Dunnell, R. C. and Dancey, W. S. 1983. The siteless survey: a regional scale data collection strategy. *Advances in Archaeological Method and Theory*, 6: 267–87.

Duviols, P. 1967. Un inédit de Cristobal de Albornoz: La instrucción para descubrir todas las guacas del Pirú y sus camayos y haziendas. *Journal de la Société des Américanistes*: 7–39.

Ebert, J. I. 1992. *Distributional Archaeology*. Albuquerque: University of New Mexico Press.

Ellis, Christopher J. 1997. Factors influencing the use of stone projectile tips. In *Projectile Technology* (ed. Heidi Knecht). New York: Plenum Press, pp. 37–74

Fladmark, K. R. 1984. Mountain of glass: archaeology of the Mount Edziza obsidian source, British Columbia. *World Archaeology*, 16: 139–56.

Gallagher, J. P. 1977. Contemporary stone tools in Ethiopia: implications for archaeology. *Journal of Field Archaeology*, 4: 407–14.

Gerbe, M.-C., and Thouret, J.-C. 2004. Role of magma mixing in the petrogenesis of tephra erupted during the 1990–98 explosive activity of Nevado Sabancaya, southern Peru. *Bulletin of Volcanology*, 66: 541–61.

Giesso, M. 2003. Stone tool production in the Tiwanaku heartland. In *Tiwanaku and Its Hinterland: Archaeology and Paleoecology of an Andean Civilization*, Vol. 2 (ed. A. L. Kolata). Washington, DC: Smithsonian Institution Press, pp. 363–83.

Glascock, M., Speakman, R. J. and Burger, R. L. 2007. Sources of archaeological obsidian in Peru: descriptions and geochemistry. In *Archaeological Chemistry: Analytical Techniques and Archaeological Interpretation* (eds M. Glascock, R. J. Speakman and R. S. Popelka-Filcoff). Washington, DC: Oxford University Press, pp. 522–52.

Goldstein, P. S. 2000. Exotic goods and everyday chiefs: long-distance exchange and indigenous sociopolitical development in the south central Andes. *Latin American Antiquity*, 11: 335–61.

Gregory-Wodzicki, K. M. 2000. Uplift history of the Central and Northern Andes: a review. *Geological Society of America Bulletin*, 112: 1091–105.

Healan, D. M. 1997. Pre-hispanic quarrying in the Ucareo-Zinapecuaro obsidian source area. *Ancient Mesoamerica*, 8: 77–100.

Holmes, W. H. 1919. Handbook of Aboriginal American Antiquities, Part I, Introductory: The Lithic Industries. *Bulletin of American Ethnology*, 60.

Hyslop, J. 1984. *Inka Road System*. Orlando, FL: Academic Press.

Jennings, J. and Glascock, M. D. 2002. Description and method of exploitation of the Alca obsidian source, Peru. *Latin American Antiquity*, 13: 107–18.

Klinck, B. A. and Palacios, O. 1985. *Mapa geológico del cuadrangulo de Chivay, Hoja 32-s, scale 1:100,000*. Instituto Geológico Minero y Metalúrgico.

Klink, C. and Aldenderfer, M. 2005. A projectile point chronology for the south-central Andean Highlands. In *Advances in Titicaca Basin Archaeology-1* (eds C. Stanish, A. Cohen and M. S. Aldenderfer). Los Angeles, CA: Cotsen Institute of Archaeology, pp. 25–54.

Lazzari, M. 2010. Landscapes of circulation in northwest Argentina: the workings of obsidian and ceramics during the first millennium AD. In *Social Archaeologies of Trade and Exchange: Exploring Relationships among People, Places, and Things* (eds A. A. Bauer and A. Agbe-Davies). Walnut Creek, CA: Left Coast Press, pp. 49–68.

Lechtman, H. 1984. Andean value systems and the development of prehistoric metallurgy. *Technology and Culture*, 25: 1–36.

Ma, C., Rossman, G. R. and Miller, J. A. 2007. The origin of color in fire obsidian. *The Canadian Mineralogist*, 45: 551–7.

McCormac, F., Hogg, A., Blackwell, P., Buck, C., Higham, T. and Reimer, P. 2004. SHCal04 southern hemisphere calibration 0 – 1000 cal BP. *Radiocarbon*, 46: 1087–92.

McCoy, J. and Johnston, K. 2001. *Using ArcGIS Spatial Analyst*. Redlands, CA: Environmental Systems Research Institute.

Mengoni Goñalons, G. and Yacobaccio, H. D. 2006. The domestication of South American camelids: a view from the south-central Andes. In *Documenting Domestication: New Genetic and Archaeological Paradigms* (eds M. A. Zeder, D. G. Bradley, E. Emshwiller and B. D. Smith). Berkeley, CA: University of California Press, pp. 228–44.

Noble, D. C., Navarro, P. A., Quispesivana, L., Peters, L. and McKee, E. H. 2003. Ash-flow sheets of early Miocene and Early Pliocene age are present in the Castillo de Callalli, Arequipa department, Southern Peru. *Boletín de la Sociedad Geológica del Perú*, 95: 33–8.

Ogburn, D. E. 2004a. Evidence for long-distance transportation of building stones in the Inka empire, from Cuzco, Peru to Saraguro, Ecuador. *Latin American Antiquity*, 15: 419–39.

Ogburn, D. E. 2004b. Power in stone: the long-distance movement of building blocks in the Inca Empire. *Ethnohistory*, 51: 101–35.

Ogburn, D. 2011. Inca manipulation of the Sacred Landscape of Saraguro, Ecuador. *Ñawpa Pacha*, 30:165–86.

Ozbun, T. 1991. Boulders to bifaces: initial reduction of Obsidian at Newberry Crater. *Journal of California and Great Basin Anthropology*, 13: 147–59.

Palacios, O., de la Cruz, J., de la Cruz, N., Klinck, B. A., Allison, R. A. and Hawkins, M. P. 1993. *Geología de la Cordillera Occidental y Altiplano al oeste del Lago Titicaca-sur del Perú*. Lima: INGEMMET, República del Perú, Sector Energía y Metalúrgico.

Protzen, J.-P. 1983. Inca quarrying and stonecutting. *Ñawpa Pacha*, 21: 183–214.

Protzen, J.-P. 1985. Inca quarrying and stonecutting. *The Journal of the Society of Architectural Historians*, 44: 161–82.

Rademaker, K. 2006. Geoarchaeological investigations of the Waynuna Site and the Alca Obsidian Source. MS thesis, University of Maine.

Reher, C. A. 1991. Large scale lithic quarries and regional transport systems on the high plains of eastern Wyoming: Spanish diggings revisited. In *Raw Material Economies among Prehistoric Hunter-Gatherers*, Vol. 19 (eds A. Montet-White and S. Holen). Lawrence: University of Kansas Publications in Anthropology, pp. 251–84.

Sandweiss, D. H. and Richardson, J. B. 2008. Central Andean environments. In *The Handbook of South American Archaeology* (eds H. Silverman and W. H. Isbell). New York: Springer, pp. 93–104.

Sandweiss, D. H., McInnis, H., Burger, R. L., Cano, A., Ojeda, B., Paredes, R., Sandweiss, M. C. and Glascock, M. D. 1998. Quebrada Jaguay: early South American maritime adaptation. *Science*, 281: 1830–2.

Saunders, Nicholas J. 1998. Stealers of light, traders in brilliance: Amerindian metaphysics in the mirror of conquest. *RES: Anthropology and Aesthetics*, 33: 225–252.

Schildgen, T. F., Ehlers, T. A., Whipp, D. M., van Soest, M. C., Whipple, K. X. and Hodges, K. V. 2009. Quantifying canyon incision and Andean Plateau surface uplift, southwest Peru: a thermochronometer and numerical modeling approach. *Journal of Geophysical Research – Earth Surface*, 114: F04014. DOI: 10.1029/2009JF001305.

Shackley, M. S. 2005. *Obsidian: Geology and Archaeology in the North American Southwest*. Tucson: University of Arizona Press.

Stanish, C. 2003. *Ancient Titicaca: The Evolution of Complex Society in Southern Peru and Northern Bolivia*. Berkeley: University of California Press.

Stout, D. 2002. Skill and cognition in stone tool production: an ethnographic case study from Irian Jaya. *Current Anthropology*, 43: 693–722.

Strecker, M. R., Alonso, R. N., Bookhagen, B., Carrapa, B., Hilley, G. E., Sobel, E. R. and Trauth, M. H. 2007. Tectonics and climate of the southern central Andes. *Annual Review of Earth and Planetary Sciences*, 35: 747.

Stuiver, M., Reimer, P. J. and Braziunas, T. F. 1998. High-precision radiocarbon calibration for terrestrial and marine samples. *Radiocarbon*, 40: 1127–51.

Thouret, J.-C., Wörner, G., Gunnell, Y., Singer, B., Zhang, X. and Souriot, T. 2007. Geochronologic and stratigraphic constraints on canyon incision and Miocene uplift of the Central Andes in Peru. *Earth and Planetary Science Letters*, 263: 151–66.

Torrence, R. 1986. *Production and Exchange of Stone Tools: Prehistoric Obsidian in the Aegean*. Cambridge: Cambridge University Press.

Tripcevich, N. 2004. Flexibility by design: how mobile GIS meets the needs of archaeological survey. *Cartography and Geographic Information Science*, 31: 137–51.

Tripcevich, N. 2007. Quarries, caravans, and routes to complexity: Prehispanic obsidian in the south-central Andes. PhD dissertation, University of California, Santa Barbara. AAT 3252788.

Tripcevich, N. 2010. Exotic goods, Chivay obsidian, and sociopolitical change in the south-central Andes. In *Trade and Exchange: Archaeological Studies from History and Prehistory* (eds C. Dillian and C. White). New York: Springer.

Tripcevich, N. and Contreras, D. A. 2011. Quarrying evidence at the Quispisisa obsidian source, Ayacucho, Peru. *Latin American Antiquity*, 22: 121–36.

Tripcevich, N. and MacKay, A. in press. Spatial and temporal variation in stone raw material provisioning in the Chivay obsidian source area. In *Advances in Titicaca Basin Archaeology 2* (eds C. Stanish and E. A. Klarich).

Tripcevich, N. and Wernke, S. A. 2010. On-site recording of excavation data using mobile GIS. *Journal of Field Archaeology*, 35: 380–97.

Tripcevich, N., Eerkens, J. and Carpenter, T. in prep. Obsidian hydration at high elevation: quarrying at the Chivay source, southern Peru.

Tuffen, H., Gilbert, J. and McGarvie, D. 2001. Products of an effusive subglacial rhyolite eruption: Bláhnúkur, Torfajökull, Iceland. *Bulletin of Volcanology*, 63: 179–90.

Wernke, S. A. 2003. An archaeo-history of andean community and landscape: the Late Prehispanic and Early Colonial Colca Valley, Peru. PhD dissertation, University of Wisconsin. AAT 3113610.

Wheeler, J. C., Russel, A. J. F. and Redden, H. 1995. Llamas and alpacas: pre-conquest breeds and post-conquest hybrids. *Journal of Archaeological Science*, 22: 833–40.

Nicholas Tripcevich (PhD 2007, University of California, Santa Barbara) is a laboratory manager at the University of California, Berkeley. He specializes in Andean archaeology, ancient mining and quarrying, digital data recording and spatial analysis, and transport and exchange models. He has done archaeological work in Peru and California.

Alex Mackay (PhD 2009, Australian National University) is a post-doctoral fellow in the School of Archaeology at the Australian National University. He specializes in the analysis and interpretation of flaked stone artefacts, with a particular emphasis on the economic elements of technological organization. He has done stone artefact analysis on assemblages from southern and central Africa, India, Australia and Peru.