

Andean Past

Volume 11

Article 17

12-15-2013

Environmental Catastrophe and the Archaeological Record: Complexities of Volcanism, Floods, and Farming in South Coastal Peru, A.D. 1200-1700

Gregory Zaro

University of Maine, gregory.zaro@umit.maine.edu

Kenneth C. Nystrom

State University of New York at New Paltz, nystromk@newpaltz.edu

David K. Keefer

University of Maine, davidkkeefer@gmail.com

Follow this and additional works at: https://digitalcommons.library.umaine.edu/andean_past

 Part of the [Archaeological Anthropology Commons](#)

Recommended Citation

Zaro, Gregory; Nystrom, Kenneth C.; and Keefer, David K. (2013) "Environmental Catastrophe and the Archaeological Record: Complexities of Volcanism, Floods, and Farming in South Coastal Peru, A.D. 1200-1700," *Andean Past*: Vol. 11 , Article 17. Available at: https://digitalcommons.library.umaine.edu/andean_past/vol11/iss1/17

This Article is brought to you for free and open access by DigitalCommons@UMaine. It has been accepted for inclusion in Andean Past by an authorized administrator of DigitalCommons@UMaine. For more information, please contact um.library.technical.services@maine.edu.

ENVIRONMENTAL CATASTROPHE AND THE ARCHAEOLOGICAL RECORD:
COMPLEXITIES OF VOLCANISM, FLOODS, AND FARMING IN SOUTH COASTAL PERU,
A.D. 1200-1700

GREGORY ZARO

University of Maine, Orono

KENNETH C. NYSTROM

State University of New York, New Paltz

DAVID K. KEEFER

University of Maine, Orono

INTRODUCTION

The role of environmental change in societal transformation has long been of interest to social and environmental scientists alike. As global-scale climate change continues to be a major topic of discussion in both political and academic arenas, so has the importance of punctuated, catastrophic events. In archaeology, disaster studies have intensified over the past decade with a focus on the role of rapid environmental change or catastrophe in societal collapse or reorganization (Anderson *et al.* 2007; Bawden and Reycraft 2000; Cooper and Sheets 2012; Diamond 2005; Fisher *et al.* 2009; Mc Anany and Yoffee 2010; Redman 2004; Sandweiss and Quilter 2008a; Schwartz and Nichols 2010). Along the arid Andean coast, such studies have tended to focus on the impact of El Niño and catastrophic flooding on culture and landscape change (*e.g.*, Beresford-Jones 2011; Dillehay and Kolata 2004; Dillehay *et al.* 2004; Fontugne *et al.* 1999; Keefer *et al.* 1998; Keefer *et al.* 2003; Magilligan and Goldstein 2001; Magilligan *et al.* 2008; Moore 1991; Moseley and Keefer 2008; Nials *et al.* 1979; Rein *et al.* 2004; Richardson and Sandweiss 2008; Sandweiss *et al.* 2007; Wells 1987), though some also

emphasize volcanic eruption, tectonic activity, and drought as other potential environmental catalysts to change (Keefer and Moseley 2004; Moseley 1983; Moseley *et al.* 1992; Pearsall 2004; Satterlee *et al.* 2000).

In the Ilo region of far southern Peru (Figure 1), several large punctuated environmental events have received a fair amount of archaeological and historical attention. A major El Niño termed the Miraflores event is thought to have caused widespread catastrophic destruction to late fourteenth century habitation areas, irrigation systems, and agricultural fields (Clement and Moseley 1991; Keefer and Moseley 2004; Keefer *et al.* 2003; Moseley and Keefer 2008; Reycraft 1998, 2000; Satterlee 1993; Zaro 2007; Zaro and Umire 2005), while the convergence of this incident with a prolonged drought is argued to have catalyzed the disappearance of Late Intermediate Period (LIP) Chiribaya culture altogether (Satterlee *et al.* 2000). Approximately two centuries later, the Huaynaputina volcano, in the neighboring Moquegua highlands, erupted over the course of several weeks early in the year A.D. 1600, causing widespread devastation in the upper reaches of Arequipa and Moquegua (de Silva *et al.* 2000; de Silva

and Zielinski 1998; Thouret *et al.* 1999). Significant amounts of coarse volcanic debris and ash fell on fields and villages in the upper and middle valleys, while portions of the adjacent lower valleys and coast were blanketed with fine volcanic ash. Historic travelers in the area report that highland populations emigrated from severely impacted regions, though little mention was made of the coastal areas (de Silva *et al.* 2000; Vázquez de Espinosa 1942[1628]). Sometime later, and potentially within only a few years or decades, another El Niño-related flood, termed the Chuza event, left a significant amount of flood and debris flow sediment among lower and coastal landscapes of the Tambo-Ilo region (Keefer *et al.* 2003; Moseley and Keefer 2008; Satterlee 1993; Satterlee *et al.* 2000). These three punctuated events are well-represented in the geomorphic records along the Peruvian south coast, though only the Miraflores flood and Huaynaputina eruption have received significant archaeological and historical attention, respectively, and much of this attention has emphasized the destructive nature of such occurrences. Still, and despite the catastrophic tenor of the literature surrounding these events, the ability to chronologically resolve the relationships between punctuated environmental events and the archaeological record remains a significant challenge.

Central to any investigation of past catastrophe is the ability to unravel the temporal relationships between such occurrences and processes of change observed in the material record. Sandweiss and Quilter (2008b, 2012) frame their discussion of such relationships around the concepts of collation (events occur simultaneously), correlation (events of interest co-vary in a significant way), and causation (outcomes are the necessary result of specific conditions). The demonstration of each is a step along a continuum of increasingly rigorous requirements, where correlation cannot be demonstrated without first collation, or causa-

tion without correlation. Paramount to each of these is the chronological relationship that can be established between environmental change and human societal organization. Unfortunately, the archaeological record can vary significantly from one location to the next, and the degree of temporal resolution achieved is often dependent on both local taphonomy and the methodological tools available to the archaeologist. Still, and notwithstanding the difficulty of demonstrating causation in the archaeological record given the complexity and often unpredictability of human behaviors, the coarse chronological resolution normally available to the archaeologist will generally preclude the measurement of any statistically significant causal relationships between humans and marked periods of environmental change.

In this paper, we summarize the geomorphic evidence for the major environmental catastrophes mentioned above and outline our attempts to unravel the chronological relationship between them and human activity as reflected in the Cola de Zorro archaeological assemblage (Figure 1). As an intervalley coastal spring complex, Cola de Zorro was likely occupied intermittently and with varying degrees of intensity from the twelfth through the eighteenth centuries A.D., with the most pronounced activity reflected in twelfth through early fifteenth century material remains. The site lies abandoned today and has likely been so for at least a century or more. Specifically, our work sought to establish clearer chronological relationships between episodic periods of landscape abandonment and (1) the fourteenth century Miraflores El Niño, (2) the A.D. 1600 Huaynaputina volcanic eruption, and (3) the seventeenth century Chuza El Niño. Below, we describe the cultural and environmental context of the study region and outline our methodological approach to the study of environmental perturbations and land use around Cola de Zorro. Based on the results of our study, we

cannot label any of these three events as causal mechanisms of landscape abandonment around Cola de Zorro, and we find difficulty establishing even collation, despite their apparent catastrophic nature. Indeed, our data are more consistent with a period of landscape abandonment sometime in the fifteenth century, and apparently between major environmental perturbations evidenced in the geomorphic record, though ongoing drought may still have been a factor. While we propose that land use at Cola de Zorro survived for some time after the Miraflores flood, support for immediate pre- and post-Chuza occupation and land use is more tentative, though a degree of land use is clearly evident at some point after A.D. 1600. Unfortunately, the chronological resolution currently available does not permit easy separation or distinction between human and environmental events of the seventeenth century.

CULTURAL AND ENVIRONMENTAL CONTEXT OF THE STUDY AREA

The Tambo-Ilo coast of far southern Peru is a rugged landscape of steep escarpments and deeply incised canyons, many of which descend from the Cledesí Desert and support a series of fresh water springs (Figure 1). The region has been arid throughout much of the late Holocene, though it is occasionally interrupted by floods of varying intensity resulting from fairly regular, but infrequent, occurrences of El Niño (Fontugne *et al.* 1999; Keefer *et al.* 1998; Keefer *et al.* 2003; Maasch 2008; Quinn and Neal 1992; Sandweiss *et al.* 2001). The most severe episodes can produce massive floods and associated debris flows that cause widespread destruction and leave long-lasting signatures in the geomorphic and archaeological records (Beresford-Jones 2011; Beresford-Jones *et al.* 2009a; deFrance and Keefer 2005; Keefer *et al.* 2003; Magilligan *et al.* 2008; Moseley and Keefer 2008; Satterlee 1993; Satterlee *et al.* 2000). In general, events may lead to a variety of impacts

that include loss of crops and reduced productivity, damage to canals and terraces, increased disease among people and domestic animals, immediate reduction in agro-pastoral activity, inundation of planting surfaces and living spaces, river incision with decreased flood plain area, and changes in marine productivity (Beresford-Jones *et al.* 2009b; Oficina de Información Agraria 2000; Reitz *et al.* 2008). Other effects may include the recharging of coastal desert aquifers; and natural regeneration of *lomas* formations, including seed germination, dispersal, and establishment, which can lead to *lomas* expansion under favorable conditions (Dillon *et al.* 2003; Magilligan *et al.* 2008; Oficina de Información Agraria 2000).

Beginning late in the first millennium A.D., the Ilo River Valley and adjacent Tambo-Ilo intervalley coast supported a number of farming and fishing villages associated with Chiribaya ceramic decorative styles, a Late Intermediate Period manifestation (Bawden 1989; Buikstra *et al.* 2005; Knudson *et al.* 2007; Knudson and Buikstra 2007; Lozada and Buikstra 2002, 2005; Miranda and Álvarez 2007; Owen 1993, 2005; Sutter 2000, 2005; Tomczak 2003; Umire and Miranda 2001; Zaro 2007; Zaro *et al.* 2010; Zaro and Umire 2005). Chiribaya material expression lasted approximately 500 years, but in the fourteenth century, the combined effect of the Miraflores El Niño with a centuries-long drought is argued to have catalyzed the disappearance of this tradition (Reycraft 1998; Satterlee 1993; Satterlee *et al.* 2000). Population collapse appears to have been most pronounced along the Ilo River, while coastal villages may have had varying degrees of success in response to it (Reycraft 2000; Satterlee *et al.* 2000; Zaro 2005, 2007; Zaro *et al.* 2010; Zaro and Umire 2005). Though evidently reduced in numbers, those settlements that survived, or were re-occupied in the Spanish colonial period, may have been challenged by additional perturbations, including the Huaynaputina eruption,

tectonic activity, and the Chuza El Niño event (Clement and Moseley 1991; de Silva and Zielinski 1998; Keefer and Moseley 2004; Keefer *et al.* 2003; Moseley and Keefer 2008; Thouret *et al.* 1999; Vázquez de Espinosa 1942[1628]). Regardless, regional population numbers likely remained low until the mid twentieth century, when Southern Peru Copper Corporation established a smelter along the intervalley coast, precipitating a significant growth in Ilo as a company town (Hall 1992; Zaro *et al.* 2010). Today, the Tambo and Ilo River valleys serve as focal points of human settlement in the region, while only a handful of farmsteads continue to survive along the intervalley coast.

PRONOUNCED LATE HOLOCENE ENVIRONMENTAL PERTURBATIONS

Miraflores flood, ~A.D. 1350-1370

Flood and debris-flow deposits from a severe fourteenth century event were first identified in Quebrada Miraflores, situated approximately twenty kilometers north of the mouth of the Ilo River (Figure 1). Catastrophic flooding inundated most of the alluvial fan surface, completely burying a Chiribaya farming village and associated fields (Satterlee 1993; Satterlee *et al.* 2000). The deposits, collectively called the Miraflores unit, have arguably been identified at several other localities along the coast to the north and south of Ilo (Keefer *et al.* 2003; Moseley and Keefer 2008; Reycraft 1998; Zaro and Umire 2005), in the Ilo Valley (Reycraft 2000; Satterlee 1993; Satterlee *et al.* 2000), and farther inland among Moquegua River tributary channels (Magilligan and Goldstein 2001; Magilligan *et al.* 2008).

The deposits range in thickness from 0.34 to 2.14 meters and are mostly composed of silty sand with some coarser material up to 25 centimeters in diameter (Keefer *et al.* 2003:49). However, source material, and therefore compo-

sition, likely varies from location to location. In many places, the Miraflores unit immediately underlies an A.D. 1600 stratum of Huaynaputina tephra (see below).

At the Tomb Site in the lower Ilo Valley (Figure 1), a charcoal sample recovered from a burned lens partly overlying and partially incorporated into the Miraflores deposit produced an uncalibrated radiocarbon date of 590 ± 35 B.P. (Satterlee *et al.* 2000:104), with 1σ calibrated age ranges of A.D. 1328-1336 and 1390-1428 (Figure 2 and Table 1, number 6). Farther inland in a Moquegua River tributary channel, Magilligan and Goldstein (2001:433) report a weighted mean date of A.D. 1300 for four radiocarbon dates associated with a deposit possibly laid down during the Miraflores flood (Figure 2 and Table 1, numbers 2-5). Elsewhere, decadal averages of wet season snow and dry season dust accumulations in the Quelccaya glacier of southern Peru reflect a pronounced El Niño signature from A.D. 1350-1370, which is argued to correspond to the Miraflores event (Satterlee *et al.* 2000:104-105; Thompson *et al.* 1985). However, the precision and accuracy with which such events can be identified in the glacial record has been questioned (Calaway 2005). Despite the variability in dating measures, a mid-to-late fourteenth century date for this event has been generally proposed.

N°	Site	Lab N°	Material	Context	Uncal. date	1 σ cal. date A.D. (relative probability)	2 σ cal. date A.D. (relative probability)	Reference
1	Geoprofile Site	Beta 222175	Wood	Flood deposit immediately above Huaynaputina tephra	250±50	1636-1686 (26.5%) 1729-1804 (41.7%)	1510-1578 (7.1%) 1620-1712 (33.2%) 1718-1814 (45.2%) 1835-1891 (6.1%) 1922-1953 (3.8%)	Magilligan et al. 2008
2	Geoprofile Site	Beta 142834	Wood	Debris flow beneath Huaynaputina tephra	620±70	1310-1360 (36.0%) 1379-1423 (32.2%)	1288-1444 (95.4%)	Magilligan and Goldstein 2001
3	Spring Channel Site	Beta 124116	Wood	Debris flow beneath Huaynaputina tephra	620±40	1320-1350 (36.8%) 1386-1410 (31.4%)	1300-1366 (51.0%) 1374-1429 (44.4%)	Magilligan and Goldstein 2001
4	Spring Channel Site	Beta 142835	Wood	Debris flow beneath Huaynaputina tephra	730±60	1274-1320 (39.0%) 1350-1386 (29.2%)	1228-1396 (95.4%)	Magilligan and Goldstein 2001
5	Lower Río Muerto	Beta 133794	Wood	Flood gravels near site M70	750±60	1234-1244 (4.6%) 1264-1318 (42.0%) 1352-1384 (21.6%)	1220-1392 (95.4%)	Magilligan and Goldstein 2001
6	Tomb Site Ilo Valley	PITT0948	Charcoal	Burned lens partly incorporated into Miraflores deposit	590±35	1328-1336 (5.9%) 1390-1428 (62.3%)	1319-1352 (21.3%) 1385-1440 (74.1%)	Satterlee et al. 2000
7	Carrizal	AA37179	Textile	Burial T7	561±51	1395-1444 (68.2%)	1314-1358 (14.8%) 1380-1459 (80.6%)	Owen 2005
8	Carrizal	AA37181	Textile	Burial T5	785±48	1226-1294 (68.2%)	1202-1320 (85.8%) 1351-1385 (9.6%)	Owen 2005
9	Wawakiki	GL30459	Charcoal	Domestic refuse	480±90	1402-1510 (52.8%) 1577-1620 (15.4%)	1320-1351 (3.7%) 1385-1644 (91.7%)	Zaro 2005
10	Wawakiki	AA56774	Charcoal	Habitation terrace	480±30	1432-1461 (68.2%)	1416-1496 (95.4%)	Zaro 2005
11	Wawakiki	AA56760	Charcoal	Marine refuse	575±31	1398-1428 (68.2%)	1326-1341 (5.5%) 1390-1442 (89.9%)	Zaro 2005
12	Wawakiki	AA56771	Charcoal	Habitation terrace	592±35	1328-1337 (8.0%) 1390-1427 (60.2%)	1318-1352 (23.3%) 1384-1439 (72.1%)	Zaro 2005
13	Wawakiki	AA56772	Charcoal	Habitation terrace	627±30	1320-1350 (41.3%) 1386-1405 (26.9%)	1306-1361 (56.2%) 1378-1417 (39.2%)	Zaro 2005
14	Wawakiki	GL30460	Charcoal	Habitation terrace	640±50	1311-1360 (45.2%) 1379-1405 (23.0%)	1292-1421 (95.4%)	Zaro 2005
15	Wawakiki	AA56761	Charcoal	Marine refuse	651±32	1316-1356 (50.9%) 1382-1396 (17.3%)	1300-1404 (95.4%)	Zaro 2005
16	Wawakiki	AA56762	Charcoal	Marine refuse	685±33	1299-1322 (25.5%) 1348-1387 (42.7%)	1290-1394 (95.4%)	Zaro 2005
17	Wawakiki	GL30458	Charcoal	Agricultural terrace	700±60	1286-1325 (30.6%) 1342-1390 (37.6%)	1234-1244 (1.1%) 1264-1410 (94.3%)	Zaro 2005
18	Wawakiki	GL30461	Charcoal	Habitation terrace	720±90	1271-1393 (68.2%)	1187-1427 (95.4%)	Zaro 2005
19	Wawakiki	AA56773	Charcoal	Habitation terrace	727±30	1284-1310 (41.0%) 1360-1378 (27.2%)	1274-1322 (54.9%) 1348-1388 (40.5%)	Zaro 2005
20	Wawakiki	AA56759	Charcoal	Domestic refuse	935±32	1052-1076 (18.1%) 1148-1204 (50.1%)	1044-1089 (26.3%) 1104-1218 (69.1%)	Zaro 2005
21	Quebrada Chololo	AA78833	Bovine bone	Near base of debris flow immediately overlying Huaynaputina tephra	219±43	1650-1695 (21.4%) 1726-1806 (46.8%)	1641-1816 (76.6%) 1828-1892 (11.8%) 1920-1954 (6.9%)	First reported here
22	Cola de Zorro, Sector 4 corral	AA78828	Charcoal	Thin deposit between sterile sediments and Huaynaputina tephra	560±36	1402-1434 (68.2%)	1326-1340 (3.1%) 1390-1450 (92.3%)	Zaro et al. 2010
23	Cola de Zorro, Sector 4 corral	AA78831	Camelid dung	Thin deposit between sterile sediments and Huaynaputina tephra	569±36	1399-1432 (68.2%)	1324-1342 (6.4%) 1389-1446 (89%)	Zaro et al. 2010
24	Cola de Zorro, Sector 3 agricultural furrows	AA78830	Charcoal	Agricultural soils immediately beneath Huaynaputina tephra, south pampa rim	617±36	1320-1350 (34.4%) 1386-1412 (33.8%)	1304-1362 (48.2%) 1377-1428 (47.2%)	Zaro et al. 2010
25	Cola de Zorro, Sector 3 debris flow	AA78829	Camelid bone	Debris flow matrix in primary channel beneath Huaynaputina tephra	735±44	1276-1316 (42.8%) 1356-1382 (25.4%)	1232-1246 (2.7%) 1264-1392 (92.7%)	Zaro et al. 2010

Table 1: Tabular data accompanying Figure 2. All originally reported radiocarbon ages (B.P.) were calibrated using Oxcal 4.1.7 (Bronk Ramsey 2009), with a southern hemisphere atmospheric curve (McCormac et al. 2004).

Huaynaputina eruption, A.D. 1600

Historical records from southern Peru indicate that the Huaynaputina volcano erupted over the course of about two weeks in A.D. 1600, beginning February 19 following a series of seismic tremors, and lasting until March 5 (Vázquez de Espinosa 1942 [1628]:503-509). Historical accounts testify to variable socioeconomic consequences of this event on peoples of southern Peru, ranging from total destruction of villages, farmland, and livestock near the volcano to more modest disturbances farther afield (de Silva *et al.* 2000; Rice 2009). However, no direct historical accounts of its impact on the port of Ilo or neighboring Tambo-Ilo coast have been reported.

Geologic work suggests this was the largest volcanic explosion in historic times in the Andes (Thouret *et al.* 1999), and it possibly contributed to global-scale climatic cooling (de Silva and Zielinski 1998). The ash fall deposit from the eruption covered an area of approximately 300,000 square kilometers in parts of southern Peru, Bolivia, and Chile, although the thickest deposits (1.5-2.0 meters) fell directly west of the volcano, within a range of about twenty kilometers (Thouret *et al.* 1999). Along the Tambo-Ilo coast, Huaynaputina ash ranges generally from 2-4 centimeters in thickness (see isopach map in Thouret *et al.* 1999: figure 2), though its preservation varies with slope and aspect of the terrain along with subsequent geophysical and cultural activity (Zaro and Umire 2005:724). The tephra is identified by its distinctive gray/white color and by its mineral assemblage, prominently including quartz and biotite mica (Thouret *et al.* 1999). There have been no other volcanic eruptions of this magnitude reported for southern Peru for the late prehispanic or Spanish colonial periods, leaving little doubt as to the origin and date of this deposit in the geomorphic record. Additionally, recent analysis of volcanic ash from the Cola de

Zorro site has geochemically confirmed its Huaynaputina origin and further suggests ash fall in the area may have occurred during the later stages of the eruption (Britta Jensen, University of Alberta, personal communication).

Chuza flood, ~A.D. 1650

Deposits from the severe seventeenth century Chuza El Niño event are generally present throughout the same area as the Miraflores unit, and the Chuza unit often immediately overlies Huaynaputina tephra (when present). Chuza deposits range in thickness from 0.10 to 1.40 meters and they generally consist of silt, sand, and an abundance of small angular rock fragments (Keefer *et al.* 2003:53). The compositional makeup of the Chuza unit may be in part the result of a severe earthquake (magnitude 8.7) that struck the region in A.D. 1604, creating a “shattered landscape” upon which torrential El Niño rains poured (Keefer and Moseley 2004). However, as with the Miraflores unit, the composition of the Chuza deposit likely varies with source material.

Given its sharp contact with the A.D. 1600 tephra deposit, Satterlee *et al.* (2000:105) suggest that the Chuza unit may be associated with the El Niño event of A.D. 1607-08 recorded in Quinn and Neal (1992), the first strong event following the Huaynaputina eruption. However, Magilligan *et al.* (2008:19) report an uncalibrated radiocarbon date of 250 ± 50 B.P. from a flood deposit immediately above Huaynaputina tephra at the Geoprofile Site in the upper Rio Muerto (Moquegua tributary), with 1σ calibrated age ranges of A.D. 1636-1686 and 1729-1804 (Figure 2 and Table 1, number 1). Along the Tambo-Ilo coast, we recovered a fragment of bovine femur from a flood deposit identified in the main channel of Quebrada Chololo (Figure 1). The bone was extracted from the lower portion of a debris flow deposit that generally exhibits the physical characteris-

tics of the Chuza unit and immediately overlies a thin lens of Huaynaputina ash. The bone fragment returned an uncalibrated radiocarbon date of 219 ± 43 B.P., with 1σ calibrated age ranges of A.D. 1650-1695 and 1726-1806 (Figure 2 and Table 1, number 21), which are consistent with those from the Geoprofile Site noted above. Unfortunately, because the radiocarbon calibration curve corresponding to the Spanish colonial period exhibits a number of plateaus, the date of the Chuza event is difficult to pin down radiometrically. Nevertheless, while the two dates mentioned here are suggestive of a later date than the A.D. 1607-08 event proposed by Satterlee and colleagues, the fact that associated debris flow deposits immediately overlie volcanic tephra within drainage channels (*i.e.*, high energy environments) would lend support to an occurrence within a few years or decades after the eruption, rather than up to a century or more. If much time had passed between A.D. 1600 and the Chuza flood, other presumably smaller events would have either buried or erased the Huaynaputina signature, and neither scenario appears to be supported by the geomorphic record.

THE COLA DE ZORRO ARCHAEOLOGICAL SITE

The Cola de Zorro site is on Pampa Dispensilla, a broad, sloping alluvial plain situated along the northern half of the Tambo-Ilo coast. The site is characterized by a complex of agricultural, domestic, and mortuary sectors scattered for approximately two kilometers along a dry wash that extends from the inland hills toward the Pacific Ocean (Figure 3). While the channel does not currently contain an active spring, remains of primary canals extend from the steep-sided canyon of the inland hills, suggesting a former spring source near the channel somewhere above 400 m.a.s.l. The agricultural landscape consists of stone-faced terraces and canals throughout the site, with small terraces, perimeter walls, poorly preserved

furrows, and corrals characterizing the inland-most sectors and to some extent the inland hills. Interestingly, while most spring systems along the Tambo-Ilo coast show evidence of olive cultivation at some point in their Spanish colonial histories (*e.g.*, living trees, standing trunks, or depressions from uprooting), neither Cola de Zorro nor its neighboring dry wash channels on Pampa Dispensilla appear to have supported this practice. The reason for the lack of olive cultivation here remains unclear. Nevertheless, the location and intensity of agricultural, residential, and mortuary features at the site are similar to those identified among other spring sources in the area, which seem more suited for permanent occupation and land use rather than simple advantageous farming during infrequent bouts of coastal rainfall (Zaro *et al.* 2010).

For analytical purposes, Cola de Zorro is divided into four sectors based on the site's bisection by the coastal road, the distribution of materials around primary and secondary runoff channels, and on internal coherence of cultural remains (Figure 3). Sector 1 encompasses the farthest inland portion of the site and lies at the base of the inland hills. It reflects a moderate density of Spanish colonial and younger artifacts, including glazed ceramic wares, porcelain, glass, and metal artifacts across the surface, and it shows some indication of associated agricultural, pastoral, and domestic activities. Sectors 2 and 3 are on either side of the modern road and exhibit the most pronounced surface remains, including domestic structures, agricultural terraces, and cemeteries. Chiribaya ceramic styles from surface and excavated contexts were common throughout these two sectors, and clearly animals were also penned in the upper portion of Sector 2 sometime after A.D. 1600 (Zaro and Dávila 2010; Zaro and Umire 2007). Sector 4 is in a secondary drainage channel and consists exclusively of a series of agglutinated enclosures suggestive of animal pens. No artifacts were recovered from surface

survey or limited excavation, but camelid dung and charcoal samples obtained from very thin deposits overlying culturally sterile strata returned two radiocarbon dates that are consistent with early fifteenth century use (Figure 2 and Table 1, numbers 22, 23).

While most diagnostic ceramics identified in surface survey (Zaro and Umire 2007) and excavations (Zaro and Dávila 2010) around Cola de Zorro reflect Chiribaya decorative styles, some broader interaction is evident during the LIP, as indicated, for example, by one ceramic fragment associated with the Gentilar culture of northern Chile. These results are consistent with findings at other archaeological sites along the Tambo-Ilo coast, where the most pronounced occupation was associated with Late and Terminal Chiribaya culture (~A.D. 1200-1400) (Clement and Moseley 1991; Reyecraft 1998, 2000; Satterlee *et al.* 2000; Umire 1994, 1996; Zaro 2007; Zaro *et al.* 2010; Zaro and Umire 2005, 2007), and in some instances, a small highland LIP Estuquiña component subsequent to the cessation of Chiribaya cultural expression (Reycraft 1998, 2000). As is the case among many other coastal spring systems in the area, a Spanish colonial component is present at the site but in reduced form.

To assess the relationship between cultural activities and manifested tephra and debris flow deposits, data were collected from a total of twenty-one excavation units and eighteen geologic profiles, the latter exposed in dry-wash channels and smaller rills that often cut through terraced fields and other land management features. All excavation units measured two by two meters and were designed to recover information concerning chronology, subsistence, and general cultural activity. Sixteen units were situated in Sectors 2 and 3, with four additional units placed in agglutinated enclosures of Sector 4. Due to time constraints, only one unit was excavated in Sector 1. All units were excavated

by cultural stratigraphy, and sediments were passed through 1/8-inch mesh for artifact recovery.

SITE STRATIGRAPHY, CULTURAL REMAINS, AND LAND USE

Archaeological signatures of fourteenth and seventeenth century events at Cola de Zorro

A two to four centimeter thick layer of Huaynaputina ash typically remains intact along the Tambo-Ilo coast, either in buried or surficial contexts where there has been minimal subsequent disturbance. At Cola de Zorro, Huaynaputina ash is regularly found within the main drainage channel, where it is usually buried by subsequent alluvial deposits. Beyond the channel margins on the surrounding pampa, Huaynaputina ash is generally found in surficial or very shallow contexts where little subsequent cultural or geophysical activity has occurred. It is notably absent from the depositional record in Sector 1, where it was encountered neither in excavations, nor in geologic profiles in this farthest inland part of the site. However, a relatively intact blanket of ash (surficial or buried) was encountered in most excavations and geologic profiles in Sectors 2-4, with the only exceptions being several upper Sector 2 locations that appear to have been re-utilized after A.D. 1600.

In contrast to the widespread distribution of Huaynaputina ash, all signatures of late Holocene debris flows are confined to the dry wash channel along which Cola de Zorro lies. In an ideal situation, channel stratigraphy would be expected generally to reflect a sequence of Miraflores-Huaynaputina-Chuza signatures (from bottom to top). The Miraflores and Chuza debris flows may, in most cases, be tentatively identified based on their stratigraphic relationships to Huaynaputina ash, their composition, associated cultural remains, and/or radiometric

dating. Geologic profiles revealed a buried stratum within the channel that we interpret to be the Miraflores deposit. In many cases, it immediately underlies Huaynaputina ash and consists of silt, sand, angular to sub-angular stones, some rounded cobbles, and a small number of late prehispanic plain ware ceramic fragments (Figure 4). In one instance, a fragment of camelid vertebra recovered from this deposit returned an uncalibrated radiocarbon age of 735 ± 44 B.P., with 1σ calibrated age ranges of A.D. 1276-1316 and 1356-1382 (Figure 2 and Table 1, number 25). A two to three centimeter deposit of Huaynaputina ash often overlies this stratum, and the entire sequence is capped by a debris flow containing a mix of small angular rock fragments and small-to-medium angular to sub-angular stones and cobbles, which is inferred to be the seventeenth century Chuza unit based on stratigraphic position.

In other cases, cultural strata are stratigraphically positioned within the proposed Miraflores-Huaynaputina-Chuza sequence. For instance, along the channel margins in Sectors 2 and 3, geologic profiles reveal stone retention walls and terrace fill immediately overlying the debris flow deposit that we suggest was produced by the Miraflores event. These agricultural terraces are capped with an intact stratum of Huaynaputina ash, with no intervening debris flow or other alluvial deposit (Figure 5). Based on this sequence, we propose that at least some channel margin terraces were constructed or repaired after the Miraflores event, but were abandoned prior to tephra deposition in A.D. 1600 (see further discussion below). It is unlikely that these terraces would have been in existence at the time of the Miraflores event and left unaffected given the scale of the event, their proximity to the center of the drainage channel, and the prominence of debris flows across the width of the channel itself.

Late prehispanic occupation

Occupation and subsistence. The combination of an intact stratum of Huaynaputina ash, available radiocarbon dates, and the distribution of LIP ceramic styles indicates that the most extensive occupation of Cola de Zorro likely occurred during the thirteenth through early fifteenth centuries and that the central and seaward portions of the site were abandoned well before A.D. 1600. While some Chiribaya material remains were identified in all four sectors of the site, the density of classic Chiribaya ceramic styles, including rim fragments decorated with a dark line and white dots, was by far the highest in Sectors 2 and 3 (Sector 1 is dominated by artifacts from the colonial and possibly post-colonial eras, and there was virtually no artifact recovery in Sector 4). Most of the Chiribaya ceramic styles were collected from excavations within presumed residential zones characterized by complexes of agglutinated quadrangular enclosures and other habitation terraces, which are along the rim of the pampa overlooking the main dry wash channel, or just below the pampa rim along the channel margin itself.

Excavation of these structures to sterile strata yielded classic Chiribaya ceramic styles, and all structures were outside the path of identifiable debris flows confined to the drainage channel itself. Consequently, there is no stratigraphic break within these domestic contexts that would clearly reveal an immediate pre-versus post-Miraflores occupation. However, we did find a few pieces of evidence that are consistent with both pre- and post-Miraflores activity at Cola de Zorro. First, the presence of classic Chiribaya ceramic decorations elsewhere along the coast and within the Ilo Valley would normally be interpreted to reflect occupation sometime in the early second millennium A.D. Second, the presence of a limited amount of cultural debris identified in geologic profiles expos-

ing deposits we interpret as Miraflores, including a camelid vertebra that yielded a probable fourteenth century radiocarbon date (Figure 2 and Table 1, number 25), provides support for pre-Miraflores activity. Third, while not conclusive given the error in the calibration curve, a charcoal fragment obtained from agricultural furrows beneath an intact stratum of Huaynaputina ash returned an uncalibrated date of 617 ± 36 B.P., with 1σ calibrated age ranges of A.D. 1320-1350 and 1386-1412 (Figure 2 and Table 1, number 24). This small patch of lightly preserved furrows was identified in Sector 3 along the pampa rim overlooking the primary Cola de Zorro drainage channel and may reflect pre-Miraflores land use. These furrows were not impacted by debris flows. Evidence for post-Miraflores land use comes from early fifteenth century use of the corrals in Sector 4 and agricultural terrace construction atop the debris flow suggested here to reflect the Miraflores event and capped with Huaynaputina ash, with no intervening alluvial deposit (see *Farming* and *Herding* discussions below).

A total of eight stone-constructed residential complexes were identified within Sectors 2 and 3. These range in size from about 60 square meters to 290 square meters, but most measure around 200 square meters. Most are constructed in a similar linear arrangement of two or three agglutinated enclosures (Figure 6). In several cases, the central enclosure exhibits a double-faced stone foundation wall with mud and gravel mortar, preserved to heights of 40 to 80 centimeters above culturally sterile deposits (Figure 7). Conversely, the exterior enclosures of these complexes are constructed more expeditiously, with walls faced to either the interior or exterior, and may have constituted patio space or other activity areas. On one occasion, excavations identified an internal division or step within a central enclosure. A number of subsistence indicators were recovered that suggest residents commonly accessed camelids, guinea

pigs, fish, shellfish (rocky littoral and sandy beach specimens), maize, beans, squashes/pumpkins, and molle. Given the diverse ecology of the intervalley coast, each of these products was likely procured locally (see Bawden 1989; Zaro 2007; Zaro *et al.* 2010; Zaro and Umire 2005).

All excavations in residential complexes encountered an intact lens of Huaynaputina ash, which is consistent with residential abandonment before A.D. 1600. Importantly, while most wall collapse appears to have occurred after the volcanic ash was deposited, it is also clear that some structural collapse happened prior to A.D. 1600. Although collapse associated with tectonic activity during the days and weeks before the Huaynaputina eruption cannot be ruled out, it is likely that abandonment occurred long before the eruption, given the uninterrupted and fairly uniform nature of the tephra lens, which suggests that roofs were probably no longer present and that residents did not rummage through dwellings at any time after the event. More importantly, radiocarbon dates available from other coastal spring sites such as Carrizal and Wawakiki are consistent with our findings at Cola de Zorro, which is more broadly suggestive of widespread abandonment of the Tambo-Ilo coastal region well before A.D. 1600 (Figure 2 and Table 1, numbers 7-20 and numbers 22-25). While a coastal Inca component has been identified south of Ilo (Covey 2000), the paucity of Late Horizon artifacts along the intervalley coast provides further support for our conclusion. Only a single ceramic fragment with Inca decorative style was found during archaeological survey along this coast in 2006 (Zaro and Umire 2007).

Farming. Approximately 12 hectares of land were farmed at Cola de Zorro, all of it near the channel margins or primary canals. Sections of canals are visible on both the north and south banks of the main dry-wash channel, extending

from the base of the inland hills. Preserved sections of canals also extend towards Sectors 2 and 3 of Cola de Zorro from the dry wash channel immediately south of the site (approximately 0.5 to 0.75 kilometers away). The use of multiple sources of water to irrigate a single area of farmland has been recognized elsewhere along the Tambo-Ilo coast and argued to have been a key component of risk management in the area (Zaro and Umire 2005).

Stone-faced terraces and furrowed fields are preserved to varying degrees around Cola de Zorro. Along the pampa rim south of (and just outside) the main channel in Sector 3, serpentine or perhaps E-type furrows (see Denevan 2001:150-151) are faintly visible on the surface. A probe confirmed that these fields are capped by Huaynaputina ash. Field sediments contained moderately dense concentrations of organic material, including charcoal fragments and marine shell. As noted above, a radiocarbon date associated with these deposits reflects probable use of these fields during the fourteenth century (Figure 2 and Table 1, number 24), though it is unclear whether these fields were cultivated prior to or after the Miraflores event (or both). Like the surrounding pampa surface, these furrows do not appear to have been impacted by the major debris flows identified in the adjacent channel itself.

Terraces constitute the most pronounced agricultural features at the site and are found primarily within and along the margins of the primary channel in Sectors 2 and 3 (Figure 8). Terrace walls were evidently constructed to heights of at least 0.90 meters and were reinforced along the channel's course with a stone wall, effectively canalizing the primary runoff channel itself. As noted earlier, geologic profiles of channel margin terraces revealed several cases of an underlying stratum that we interpret to be the Miraflores event. Though difficult to confirm, the angular to sub-angular rocks noted

within the deposit are generally similar to the stones used in terrace construction, which may reflect earlier terraces possibly destroyed in the flood. The camelid vertebra from this deposit returned a calibrated radiocarbon age consistent with the Miraflores event dated elsewhere (Figure 2 and Table 1, number 25). In several documented cases, an intact lens of Huaynaputina ash was deposited directly on top of terrace fill with no intermediate alluvial deposit recorded (see Figure 5).

This stratigraphy indicates that many of these terraces were in excellent shape in A.D. 1600 and were either not affected by the Miraflores El Niño or were constructed after the event. The former is unlikely because terraces extend nearly to the center of the channel and would almost certainly be affected by a flood event of any severity, let alone one such as the Miraflores. Thus, it seems probable that most of the well-preserved terraces visible today within and along the immediate channel margins were constructed after the Miraflores event.

Herding. Quantities of camelid excrement in three of the four excavations in the agglutinated enclosures of Sector 4, along with a near absence of artifacts from surface and excavated contexts, strongly suggest their use as animal pens (Figure 9). Stone-walled enclosures were constructed expediently within a small secondary drainage, perhaps to take advantage of runoff and growth of grassy vegetation accompanying El Niño rains. All excavations within these compounds encountered thin cultural deposits (generally two to ten centimeters in thickness) overlying sterile sediments and capped by Huaynaputina ash. There is no evidence of alluvium or debris flow deposits between cultural layers and Huaynaputina ash. Fragments of charcoal and camelid dung recovered during excavation returned uncalibrated radiocarbon ages of 560 ± 36 B.P. (1σ cal. A.D. 1402-1434) and 569 ± 36 B.P. (1σ cal. A.D.

1399-1432), respectively, suggesting their use early in the fifteenth century and almost certainly after the Miraflores event (Figure 2 and Table 1, numbers 22, 23). Evidence for camelid herding prior to the Miraflores flood is less certain, but initial observation of faunal assemblages from domestic contexts at Cola de Zorro indicates that camelids were probably not an uncommon component of the local diet. Nonetheless, the corrals associated with fifteenth century dates are the only prehispanic animal pens identified at the site and may represent greater investment in such activities after the Miraflores flood.

Spanish colonial occupation

Occupation and subsistence. Moderate concentrations of Spanish colonial glazed ceramic ware, glass, porcelain, and metal were identified in Sector 1 and in the upper reaches of Sector 2. Coupled with the absence of an intact layer of Huaynaputina ash, artifact recovery in these areas suggest that post A.D. 1600 occupation and land use were centered on the inland portions of the Cola de Zorro site. While late prehispanic villagers appeared to have utilized much of the two-to-three kilometer-long drainage, post A.D. 1600 occupation reflects a significant upslope contraction.

Apart from the few surface scatters of Spanish colonial artifacts, few domestic structures from this period were identified. In Sector 1, a single excavation unit placed in a small, multi-roomed stone complex confirmed its construction and use exclusively during the Spanish colonial period and perhaps later. The 250 square meter structure is near the base of the inland hills, just downslope from the channel neck. Construction consisted of mortarless walls of stacked stone. The excavation, which was continued to sterile sediments, recovered fragments of Spanish colonial glazed ceramic ware, glass, metal, marine shell, marine and terrestrial

fauna, and some macrobotanical remains, consistent with a domestic function.

In the upper portions of Sector 2, an excavation unit placed within a rectangular stone structure encountered few material remains, suggesting a lightly used shelter. Its association with animal pens (see section on *Herding* below) and the absence of Huaynaputina ash point to its use sometime after A.D. 1600.

Farming. Much like the habitation component, Spanish colonial and potentially later farming also appears to have been restricted to the farthest inland sectors of Cola de Zorro, representing a significant upslope contraction from the late prehispanic era. The remains of a modest area (~1.5 hectares) of lightly sculpted linear furrows survive at the base of the inland hills along the north bank of the drainage channel, just across from the Spanish colonial domestic structure. A perimeter wall surrounding the fields also extends onto the south bank, perhaps indicating the presence of cultivated fields there as well, though the surface is highly deflated and exhibits little evidence of the fields themselves. The narrow and linear-patterned furrows are strongly indicative of the cultivation of smaller plants like maize or beans. While other Spanish colonial field systems along the Tambo-Ilo coast exhibit distinct field patterns indicative of olive tree cultivation, no such patterns have been identified at Cola de Zorro specifically or on Pampa Dispensilla more generally. However, a single olive pit recovered from the Sector 1 structure indicates that olives were probably part of the local economy, but obtained from nearby areas along the coast.

Herding. Excavation and surface collections in the upper portion of Sector 2 point to an investment in herding sometime after A.D. 1600, where late prehispanic agricultural terraces were stripped of their retention walls and the material redirected towards the construction of a stone

enclosure (Figure 10). Excavations to sterile deposits within and immediately around the complex did not encounter Huaynaputina ash, suggesting significant disturbance to the ground surface after A.D. 1600. A surface collection conducted within the lower portion of the enclosure identified much animal dung, principally that of equines and caprines. No camelid dung was recognized during surface collection or excavation. Fragments of goat horns and horse-shoes were also found, further indicating a focus on European-introduced species.

DISCUSSION

Miraflores El Niño, ~A.D. 1350-1370

The immediate physical impact of the Miraflores debris flow was restricted to the primary drainage channel around which the Cola de Zorro site was organized. Excavations in residential structures and on field surfaces beyond the margins of the channel did not encounter evidence of debris flows associated with such an event (Miraflores or otherwise). While the specifics of pre-Miraflores occupation and land use are difficult to glean from currently available data, the distribution of classic Chiribaya ceramic styles within residential structures coupled with two radiocarbon dates consistent with thirteenth or fourteenth century activity provide support for a pre-Miraflores component.

Post-Miraflores activity at Cola de Zorro seems a bit clearer, particularly along the margins of primary and secondary dry wash channels. Direct evidence of post-Miraflores farming is derived from geologic profiles that reveal the stratigraphic relationship of agricultural terraces to debris flows and Huaynaputina tephra. In a number of cases, terraces were clearly constructed on top of a major debris flow, but capped by Huaynaputina tephra with no intervening alluvial deposits. Significant efforts were also made to reinforce the channel-side walls of

terraces, effectively canalizing the drainage. The extent to which this strategy was in place prior to Miraflores is unknown, but such reinforcement would have successfully strengthened terrace construction in the face of significant floods. The success of this strategy is perhaps most evident in the several surviving examples of channel reinforcement at Cola de Zorro today, despite the occurrence of subsequent extreme events (most notably Chuza).

Perhaps the most pronounced post-Miraflores occurrence is the investment in camelid herding, evidenced by the early fifteenth century use of Sector 4 corrals. Although their potential construction prior to the Miraflores event cannot be ruled out, the regular presence of camelid dung, radiocarbon dated along with charcoal to the early fifteenth century, is consistent with post-Miraflores activity. The fact that this dated material came from thin deposits overlying culturally sterile sediments also suggests that the corrals were probably constructed in the early fifteenth century as well, with no prior use. If we are correct that the site experienced a period of abandonment sometime in the fifteenth century—as the broader suite of intervalley coastal radiocarbon dates would suggest—then the post-Miraflores activity likely lasted for less than a century, and perhaps for only a few decades. In addition to aquifer recharge, rains associated with El Niño are known to catalyze lomas blooms that benefit herbivores. Consequently, the Miraflores event may have fostered improved conditions for grazing, a fact not lost on the surviving population. However, the intensity of agricultural terrace construction that occurred along the channel margins after the Miraflores event seems much more in line with long-term intentions rather than a projected short term response.

Huaynaputina Eruption, A.D. 1600

An intact lens of Huaynaputina ash covers much of the Cola de Zorro archaeological site, including buried contexts within the drainage channel itself and on pampa surfaces to its immediate north and south. While the deposit along the Tambo-Ilo coast in A.D. 1600 was almost certainly greater than the two to four centimeters observed today, historical records indicate that highland settings like Moquegua were covered with much thicker deposits and still served as a refugee destination from those towns and villages more closely positioned to the volcano (de Silva *et al.* 2000). Consequently, if Cola de Zorro had been occupied, the impact may not have been catastrophic enough to have led to abandonment. Regardless, the tephra deposit blankets field surfaces, agricultural terraces, animal pens, and residential areas associated largely with fourteenth and early fifteenth century occupation. The nearly continuous nature of the tephra deposit throughout Sectors 2-4, coupled with the pattern exhibited by regionally available radiocarbon dates and the absence of Late Horizon artifacts at the site, point to abandonment significantly before A.D. 1600, possibly by as much as a century or more. Consequently, we conclude that the Huaynaputina event was not a factor in site abandonment.

The evidence suggests, however, that the upper portion of the site came to be utilized again at some point after the Huaynaputina eruption. Tephra was not encountered in Sector 1, or in specific portions of the upper part of Sector 2. Spanish colonial farmers after A.D. 1600 may have deemed lower portions of the site to have been either unsuitable or unnecessary for their intended land use practices.

Chuza El Niño, ~A.D. 1650

The Chuza deposit is confined to the main drainage channel and does not appear to have had an impact on the area of the Spanish colonial occupation in Sector 1. Since stratigraphic information is confined to the channel itself and only a few radiocarbon dates with large error bars are available for study, it is difficult to chronologically evaluate the relationship between the archaeological record and the Chuza flood at Cola de Zorro. Furthermore, while the lack of tephra in the upper portions of the site does suggest some degree of post A.D. 1600 land use, we cannot state definitively that land use was post-Chuza as well. If the Chuza flood occurred within a few years of the Huaynaputina eruption, as Satterlee *et al.* (2000) propose, then the likelihood is high that historic era land use evident in this study occurred after the Chuza flood as well. However, if the Chuza event occurred decades later, as several radiocarbon dates might suggest, then the inference of post-flood land use is somewhat more tenuous, though still probable given the presence of porcelain, glass, and other materials that are likely associated with seventeenth or even eighteenth century activity. Nevertheless, while limited farming is evident in Sector 1 after A.D. 1600, and potentially post-Chuza, evidence of the presence of European-introduced animals after A.D. 1600 and also potentially after the Chuza event is clearer. The evidence is clearest in the upper portion of Sector 2, where abandoned prehispanic agricultural terraces were stripped of their stones for the purpose of constructing a stone enclosure. Increased pasturage is a documented outcome of El Niño rains along the Peruvian coast, particularly among extensive *lomas* like those documented ethnohistorically for the Ilo region (Rostworowski 1981). If this is the case, then one potential parallel outcome of the Miraflores and Chuza floods—though spaced centuries apart—might be the improved conditions for animal herding that local farmers

recognized. Again, however, this is somewhat speculative given the imprecise dating measures for the periods in question, and particularly for the relationship between historic era land use and the Chuza event.

CONCLUSION

At Cola de Zorro, there is little archaeological evidence to suggest that any of the previously identified late Holocene events directly led to abandonment of the site. Although settlement and land use appear to have been intermittent over the course of about five to six centuries, our data do not support any direct relationship between site abandonment(s) and punctuated environmental perturbations—principally the Miraflores-Huaynaputina-Chuza events discussed here. Part of the problem is the nature of the archaeological record and the precision with which we can chronologically relate these events to changes in human settlement. The radiocarbon calibration curve associated with the period of interest exhibits several plateaus, including during the Late Intermediate and early Spanish colonial periods. Consequently, while the Huaynaputina event is clearly dated, margins of error for radiocarbon plots are substantial and pose a challenge to assigning precise dates to the Miraflores and Chuza events. Fortunately, the stratigraphic relationship of these debris flow deposits to Huaynaputina tephra offers good insight into their chronological placement, but at the Cola de Zorro site, those relationships are restricted to the drainage channel itself while most archaeological remains—cemeteries, domestic structures, animal pens, agricultural furrows—are situated just beyond the channel margins and were left unaltered by these major events.

When combined with archaeological data, all published late prehispanic radiocarbon dates from the intervalley coast suggest that land use at Cola de Zorro persisted beyond the Miraflores

event but witnessed a significant decline (or collapse) in settlement and land use around the middle of the fifteenth century and apparently between major punctuated events addressed here. The reason for this remains unclear, though a persistent drought may still have been an environmental stressor on fresh water availability, both in the Ilo Valley and among coastal springs (Satterlee *et al.* 2000).

A wetter period from about A.D. 1500-1720 (Thompson *et al.* 1985) may have created conditions once again favorable for small scale farming and other resource opportunities in the Late Horizon and early Spanish colonial periods, but along the intervalley coast land use appears to remain relatively inactive until the late sixteenth or early seventeenth centuries. Cola de Zorro does not appear to have been occupied when the Huaynaputina event occurred, but even with minor inland occupation, it is unlikely the site would have been abandoned because tephra deposition was minor compared to some highland regions that still survived the event (*e.g.*, Moquegua).

While determining the timing of the Chuza event poses some challenges, the greater issue may be its relative temporal relationship to the archaeological record. At Cola de Zorro, debris flows were confined to the drainage channel, while most of the archaeological record (prehispanic and Spanish colonial) were left unaltered beyond the margins of the channel. Consequently, the relationship between colonial period cultural remains and debris flows cannot be assessed stratigraphically.

Although site abandonment is not supported, our results may reflect a relationship between the occurrences of major El Niños and subsequent land use practices that accentuated animal herding. Aquifer recharge and regeneration of *lomas*-related forests and desert pasture land are documented outcomes of significant El

Niño episodes in coastal Peru. In the case of Cola de Zorro, investments in camelid herding in the early fifteenth century and European livestock sometime after A.D. 1600 may reflect responses to the Miraflores and Chuza events, respectively, though certainly much greater chronological precision is needed to further evaluate this relationship, and particularly with respect to the articulation of the archaeological record and the Chuza event.

Returning briefly to the discussion introduced by Sandweiss and Quilter (2008b, 2012), the current lack of chronological resolve concerning the Miraflores-Huaynaputina-Chuza events (and particularly Chuza) as they articulate with the archaeological record around Cola de Zorro means that achieving even collation with human activities (site abandonment or other activities) poses a difficult challenge. Nonetheless, it is interesting to note that while an economic emphasis on animal herding is not a necessary outcome of post-El Niño conditions (causation), future research in the area may conclude that it constituted an important activity on the heels of such events and even co-varied in a significant way (correlation).

ACKNOWLEDGEMENTS

This research was funded, in part, by the Heinz Foundation for Latin American Archaeology, the University of Maine, and the State University of New York-New Paltz. Permits to conduct archaeological survey and excavation were granted by the National Institute of Culture in Lima, Peru (now the Ministry of Culture). Additional logistical support was provided by the Museo Contisuyo, and we particularly recognize Antonio Oquiche Hernani, Patrick Ryan Williams, and Michael E. Moseley for their continued encouragement of our research along the coast. We thank the participants of the 29th Northeast Conference on Andean Archaeology and Ethnohistory held at Drew University (October 2010), where some of these ideas were first presented. We also thank David Beresford-Jones and Bruce Owen for their candid and very helpful reviews of an earlier version of this manuscript. Finally, we recognize Alfredo Bar, Adán Umire Álvarez, Daniel Iván Dávila Manrique, Antoine Carranza, Louis Fortin, and Alissa Dubois for their part in

various phases of this research. While we are grateful for the contributions of others, any shortcomings of this paper remain strictly our own.

REFERENCES CITED

- Anderson, David G., Kirk A. Maasch, and Daniel H. Sandweiss, editors
2007 *Climate Change and Cultural Dynamics*. New York: Elsevier.
- Bawden, Garth
1989 Settlement Survey and Ecological Dynamics on the Peruvian South Coast. *Andean Past* 2:39-67.
- Bawden, Garth and Richard M. Reycraft, editors
2000 *Environmental Disaster and the Archaeology of Human Response*. Albuquerque: University of New Mexico Press.
- Beresford-Jones, David G.
2011 *The Lost Woodlands of Ancient Nasca: A Case Study in Ecological and Cultural Collapse*. Oxford and New York: British Academy Postdoctoral Monograph Series. Published for the British Academy by Oxford University Press.
- Beresford-Jones, David G., Susana Arce T., Oliver Q. Whaley, and Alex J. Chepstow-Lusty
2009a The Role of *Prosopis* in Ecological and Landscape Change in the Samaca Basin, Lower Ica Valley, South Coast Peru from the Early Horizon to the Late Intermediate Period. *Latin American Antiquity* 20:303-332.
- Beresford-Jones, David G., Helen Lewis, and Steve Boreham
2009b Linking Cultural and Environmental Change in Peruvian Prehistory: Geomorphological Survey of the Samaca Basin, Lower Ica Valley, Peru. *Catena* 78:234-249.
- Bronk Ramsey, Christopher
2009 Bayesian Analysis of Radiocarbon Dates. *Radiocarbon* 51:337-360.
- Buikstra, Jane E., Paula D. Tomczak, Maria Cecilia Lozada Cerna, and Gordon F. M. Rakita
2005 Chiribaya Political Economy: A Bioarchaeological Perspective. In *Interacting with the Dead: Perspectives on Mortuary Archaeology for the New Millennium* edited by Gordon Rakita, Jane E. Buikstra, Lane A. Beck, and Sloan R. Williams, pp. 66-80. Gainesville: University Press of Florida.
- Calaway, Michael J.
2005 Ice-cores, Sediments, and Civilization Collapse: A Cautionary Tale from Lake Titicaca. *Antiquity* 79:778-790.

- Clement, Christopher O. and Michael E. Moseley
1991 The Spring-Fed Irrigation System of Carrizal, Peru—a Case-Study of the Hypothesis of Agrarian Collapse. *Journal of Field Archaeology* 18:425-443.
- Cooper, Jago and Payson Sheets, editors
2012 *Surviving Sudden Environmental Change: Answers from Archaeology*. Boulder: University Press of Colorado.
- Covey, R. Alan
2000 Inka Administration of the Far South Coast of Peru. *Latin American Antiquity* 11:119-138.
- deFrance, Susan D., and David K. Keefer
2005 Quebrada Tacahuay, Southern Peru: A Late Pleistocene Site Preserved by a Debris Flow. *Journal of Field Archaeology* 30:385-399.
- Denevan, William M.
2001 *Cultivated Landscapes of Native Amazonia and the Andes: Triumph over the Soil*. Oxford and New York: Oxford University Press.
- de Silva, Shanaka L., Jorge Alzueta, and Guido Salas
2000 The Socioeconomic Consequences of the A.D. 1600 Eruption of Huaynaputina, Southern Peru. In *Volcanic Hazards and Disasters in Human Antiquity* edited by Floyd W. McCoy and Grant Heiken, pp. 15-24. Boulder, Colorado: *Geological Society of America Special Paper* 345.
- de Silva, Shanaka L. and Gregory A. Zielinski
1998 Global Influence of the A.D. 1600 Eruption of Huaynaputina, Peru. *Nature* 394:455-458.
- Diamond, Jared
2005 *Collapse: How Societies Choose to Fail or Succeed*. New York: Viking Press.
- Dillehay, Tom D. and Alan L. Kolata
2004 Long-term Human Response to Uncertain Environmental Conditions in the Andes. *Proceedings of the National Academy of Sciences (PNAS)* 101:4325-4330.
- Dillehay, Tom D., Alan L. Kolata, and Q. Mario Pino
2004 Pre-industrial Human and Environment Interactions in Northern Peru During the Late Holocene. *The Holocene* 14:272-281.
- Dillon, Michael O., Miyuki Nakazawa, and Segundo Leiva Gonzáles
2003 The Lomas Formations of Coastal Peru: Composition and Biogeographic History. In *El Niño in Peru: Biology and Culture Over 10,000 Years; Papers from the VIII Annual A. Watson Armour III Spring Symposium, May 28-29, Chicago* edited by Jonathan Haas and Michael O. Dillon, pp. 1-9. *Botany* 43, Chicago: Field Museum of Natural History Publication 1524.
- Fisher, Christopher T., J. Brett Hill, and Gary M. Feinman
2009 *The Archaeology of Environmental Change*. Tucson: University of Arizona Press.
- Fontugne, Michel, Pierre Usselman, Danièle Lavallée, Michèle Julien, and Christine Hatté
1999 El Niño Variability in the Coastal Desert of Southern Peru during the Mid-Holocene. *Quaternary Research* 52:171-179.
- Hall, Arthur C.
1992 *Nothing Down*. Tucson, Arizona: Sundance Press.
- Keefer, David K. and Michael E. Moseley
2004 Southern Peru Desert Shattered by the Great 2001 Earthquake: Implications for Paleoseismic and Paleo El Niño-Southern Oscillation Records. *Proceedings of the National Academy of Sciences (PNAS)* 101:10878-10883.
- Keefer, David K., Susan D. deFrance, Michael E. Moseley, James B. Richardson III, Dennis R. Satterlee, and Amy Day-Lewis
1998 Early Maritime Economy and El Niño Events at Quebrada Tacahuay, Peru. *Science* 281:1833-1835.
- Keefer, David K., Michael E. Moseley, and Susan D. deFrance
2003 A 38,000-year Record of Floods and Debris Flows in the Ilo Region of Southern Peru and its Relation to El Niño Events and Great Earthquakes. *Palaeogeography, Palaeoclimatology, Palaeoecology* 194:41-77.
- Knudson, Kelly J., Arthur E. Aufderheide, and Jane E. Buikstra
2007 Seasonality and Paleodiet in the Chiribaya Polity of Southern Peru. *Journal of Archaeological Science* 34:451-462.
- Knudson, Kelly J. and Jane E. Buikstra
2007 Residential Mobility and Resource Use in the Chiribaya Polity of Southern Peru: Strontium Isotope Analysis of Archaeological Tooth Enamel and Bone. *International Journal of Osteoarchaeology* 17:563-580.
- Lozada, María Cecilia and Jane E. Buikstra
2002 *El señorío de Chiribaya en la costa sur del Perú*. Lima: Instituto de Estudios Peruanos.
- 2005 Pescadores and Labradores among the Señorío of Chiribaya in Southern Peru. In *Us and Them: Archaeology and Ethnicity in the Andes* edited by Richard M. Reycraft, pp. 206-225. Los Angeles: Cotsen Institute of Archaeology, University of California.
- Maasch, Kirk A.
2008 El Niño and Interannual Variability of Climate in the Western Hemisphere. In *El Niño, Catastrophism, and Culture Change in Ancient America* edited by Daniel H. Sandweiss and Jeffrey Quilter, pp. 43-65. Washington, D.C.: Dumbarton Oaks Research Library and Collection.

- Magilligan, F. J. and Paul S. Goldstein
2001 El Niño Floods and Culture Change: A Late Holocene Flood History for the Rio Moquegua, Southern Peru. *Geology* 29(5):431-434.
- Magilligan, Francis J., Paul S. Goldstein, G. Burch Fisher, Benjamin. C. Bostick, and Rebecca B. Manners
2008 Late Quaternary Hydroclimatology of a Hyper-arid Andean Watershed: Climate Change, Floods, and Hydrologic Responses to the El Niño-Southern Oscillation in the Atacama Desert. *Geomorphology* 101:14-32.
- McAnany, Patricia, and Norman Yoffee
2010 *Questioning Collapse: Human Resilience, Ecological Vulnerability, and the Aftermath of Empire*. Cambridge and New York: Cambridge University Press.
- McCormac, F. G., A. G. Hogg, Paul G. Blackwell, E. Buck Caitlin, T. F. G. Higham, and Paula J. Reimer
2004 SHCal04 Southern Hemisphere Calibration, 0-11 Cal kyr BP. *Radiocarbon* 46(3):1087-1092.
- Miranda, Ana and Adán Umire Álvarez
2007 *Costumbres sepulcrales y contextos funerarios: Informe de excavación arqueológica en un cementerio Chiribaya, Quebrada Chuza, Ilo-Perú*. Arequipa, Peru: Arequipa Gráfica G&C.
- Moore, Jerry D.
1991 Cultural Responses to Environmental Catastrophes: Post-El Niño Subsistence on the Prehistoric North Coast of Peru. *Latin American Antiquity* 2:27-47.
- Moseley, Michael E.
1983 The Good Old Days were Better: Agrarian Collapse and Tectonics. *American Anthropologist* 85:773-799.
- Moseley, Michael E. and David K. Keefer
2008 Deadly Deluges in the Southern Desert: Modern and Ancient El Niños in the Osmore Region of Peru. In *El Niño, Catastrophism, and Culture Change in Ancient America* edited by Daniel H. Sandweiss and Jeffrey Quilter, pp. 129-144. Washington, D.C.: Dumbarton Oaks Research Library and Collection.
- Moseley, Michael E., David Wagner, and James B. Richardson, III
1992 Space Shuttle Imagery of Recent Catastrophic Change along the Arid Andean Coast. In *Paleoshorelines and Prehistory: An Investigation of Method* edited by Lucille Lewis Johnson and Melanie Stright, pp. 215-235. Boca Raton, Florida: CRC Press.
- Nials, Fred, Eric Deeds, Michael E. Moseley, Shelia Pozorski, Tom Pozorski, and Robert Feldman
1979 El Niño: The Catastrophic Flooding of Coastal Peru. *Bulletin of the Field Museum of Natural History* 50:4-14.
- Oficina de Información Agraria
2000 *Áreas perdidas y afectadas durante el fenómeno "El Niño"*. Lima: Ministerio de Agricultura.
- Owen, Bruce D.
1993 *A Model of Multiethnicity: State Collapse, Competition, and Social Complexity from Tiwanaku to Chiribaya in the Osmore Valley, Peru*. Ph.D. dissertation, University of California, Los Angeles.
- 2005 Distant Colonies and Explosive Collapse: The Two Stages of the Tiwanaku Diaspora in the Osmore Drainage. *Latin American Antiquity* 16:45-80.
- Pearsall, Deborah M.
2004 *Plants and People in Ancient Ecuador: The Ethnobotany of the Jama River Valley*. Belmont, California: Thompson/Wadsworth Learning.
- Quinn, William H. and Victor T. Neal
1992 The Historical Record of El Niño Events. In *Climate Since A.D. 1500* edited by Raymond S. Bradley and Philip D. Jones, pp. 623-648. New York: Routledge.
- Redman, Charles L.
2004 *The Archaeology of Global Change*. Washington, D.C.: Smithsonian Institution.
- Rein, Bert, Andreas Luckge, and Frank Sirocko
2004 A Major Holocene ENSO Anomaly During the Medieval Period. *Geophysical Research Letters* 31(L17211):1-4.
- Reitz, Elizabeth J., C. Fred T. Andrus, and Daniel H. Sandweiss
2008 Ancient Fisheries and Marine Ecology of Coastal Peru. In *Human Impacts on Ancient Marine Ecosystems* edited by Torben C. Rick and Jon M. Erlandson, pp. 125-145. Berkeley and Los Angeles: University of California Press.
- Reycraft, Richard M.
1998 *The Terminal Chiribaya Project: The Archaeology of Human Response to Natural Disaster in South Coastal Peru*. Ph.D. dissertation, University of New Mexico, Albuquerque.
- 2000 Long-Term Human Response to El Niño in South Coastal Perú, Circa A.D. 1400. In *Environmental Disaster and the Archaeology of Human Response* edited by Garth Bawden and Richard M. Reycraft, pp. 99-120. *Anthropological Papers* 7, Albuquerque: Maxwell Museum of Anthropology.
- Rice, Prudence M.
2009 Volcanoes, Earthquakes, and the Spanish Colonial Wine Industry of Southern Peru. In *Andean Civilization: A Tribute to Michael E. Moseley* edited by Joyce Marcus and Patrick Ryan Williams, pp. 379-392. Los Angeles: UCLA Cotsen Institute of Archaeology Press.

- Richardson, James B. III and Daniel H. Sandweiss
2008 Climate Change, El Niño, and the Rise of Complex Society on the Peruvian Coast during the Middle Holocene. In *El Niño, Catastrophism, and Culture Change in Ancient America* edited by Daniel H. Sandweiss and Jeffrey Quilter, pp. 59-75. Washington, D.C.: Dumbarton Oaks Research Library and Collection.
- Rostworowski, María
1981 *Recursos naturales renovables y pesca, siglos XVI y XVII*. Lima: Instituto de Estudios Peruanos.
- Sandweiss, Daniel H., Kirk A. Maasch, Richard L. Burger, James B. Richardson III, Harold B. Rollins, and Amy Clement
2001 Variation in Holocene El Niño Frequencies: Climate Records and Cultural Consequences in Ancient Peru. *Geology* 29:603-606.
- Sandweiss, Daniel H., Kirk A. Maasch, C. Fred T. Andrus, Elizabeth J. Reitz, James B. Richardson III, Melanie Riedinger-Whitmore, and Harold B. Rollins
2007 Mid-Holocene Climate and Culture Change in Coastal Peru. In *Climate Change and Cultural Dynamics* edited by David G. Anderson, Kirk A. Maasch, and Daniel H. Sandweiss, pp. 25-50. New York: Elsevier.
- Sandweiss, Daniel H. and Jeffrey Quilter, editors
2008a *El Niño, Catastrophism, and Culture Change in Ancient America*. Washington, D.C.: Dumbarton Oaks Research Library and Collection.
- Sandweiss, Daniel H. and Jeffrey Quilter
2008b Climate, Catastrophe, and Culture in the Ancient Americas. In *El Niño, Catastrophism, and Culture Change in Ancient America* edited by Daniel H. Sandweiss and Jeffrey Quilter, pp. 1-11. Washington, D.C.: Dumbarton Oaks Research Library and Collection.
- 2012 Collation, Correlation, and Causation in the Prehistory of Coastal Peru. In *Surviving Sudden Environmental Change: Answers from Archaeology* edited by Jago Cooper and Payson Sheets, pp. 117-141. Boulder: University Press of Colorado.
- Satterlee, Dennis R.
1993 *Impact of a Fourteenth Century El Niño on an Indigenous Population near Ilo, Perú*. Ph.D. dissertation, University of Florida, Gainesville.
- Satterlee, Dennis R., Michael E. Moseley, David K. Keefer, and Jorge E. Tapia A.
2000 The Miraflores El Niño Disaster: Convergent Catastrophes and Prehistoric Agrarian Change in Southern Peru. *Andean Past* 6:95-116.
- Schwartz, Glenn M. and John J. Nichols
2010 *After Collapse: The Regeneration of Complex Societies*. Tucson: University of Arizona Press.
- Sutter, Richard C.
2000 Prehistoric Genetic and Culture Change: A Bioarchaeological Search for Pre-Inka Altiplano Colonies in the Coastal Valleys of Moquegua, Perú, and Azapa, Chile. *Latin American Antiquity* 11:43-70.
- 2005 Non-Metric Cranial Trait Variation and Prehistoric Biocultural Change in the Azapa Valley, Chile. *American Journal of Physical Anthropology* 123:130-145.
- Thompson, Lonnie G., Ellen Mosley-Thompson, John F. Bolzan, and Bruce R. Koci
1985 A 1500-year Record of Tropical Precipitation in Ice Cores from the Quelccaya Ice Cap, Peru. *Science* 229(4717):971-973.
- Thouret, Jean-Claude, Jasmine Davila, and Jean-Philippe Eissen
1999 Largest Explosive Eruption in Historical Times in the Andes at Huaynaputina Volcano, A.D. 1600, Southern Peru. *Geology* 27:435-438.
- Tomczak, Paula D.
2003 Prehistoric Diet and Socioeconomic Relationships within the Osmore Valley of Southern Peru. *Journal of Anthropological Archaeology* 22:262-278.
- Umire Álvarez, Adán
1994 Inventario arqueológico de la costa norte de Ilo. Field report submitted to the Instituto Nacional de Cultura, Lima, Perú (now the Ministerio de Cultura).
- 1996 Inventario arqueológico de la costa norte de Ilo: Segunda temporada 1995-1996. Field report submitted to the Instituto Nacional de Cultura, Lima, Perú (now the Ministerio de Cultura).
- Umire Álvarez, Adán and Ana Miranda
2001 *Chiribaya de Ilo*. Arequipa, Perú: Eskann.
- Vázquez de Espinosa, Antonio
1942 [1628] *Compendium and Description of the West Indies* translated by Charles Upson Clark. Washington, D.C.: *Smithsonian Miscellaneous Collection* 102.
- Wells, Lisa E.
1987 An Alluvial Record of El Niño Events from Northern Coastal Peru. *Journal of Geophysical Research* 92:14463-14470.
- Zaro, Gregory
2005 *Human Ecology and Ancient Agrarian Land Use at Wawakiki Spring, South Coast Peru, A.D. 1000-2000*. Ph.D. dissertation, University of New Mexico, Albuquerque.
- 2007 Diversity Specialists: Coastal Resource Management and Historical Contingency in the Osmore Desert of Southern Peru. *Latin American Antiquity* 18:161-179.

- Zaro, Gregory and Daniel Iván Dávila Manrique
2010 Informe técnico: Proyecto arqueológico Pampa
Dispensilla 2010. Field report submitted to the
Instituto Nacional de Cultura, Lima, Peru (now
the Ministerio de Cultura).
- Zaro, Gregory, Kenneth C. Nystrom, Alfredo Bar, Adán
Umire-Alvarez, and Ana Miranda
2010 Tierras Olvidadas: Chiribaya Landscape Engi-
neering and Marginality in Southern Peru. *Latin
American Antiquity* 21:355-374.
- Zaro, Gregory and Adán Umire Álvarez
2005 Late Chiribaya Agriculture and Risk Manage-
ment along the Arid Andean Coast of Southern
Peru, A.D. 1200-1400. *Geoarchaeology—An
International Journal* 20:717-737.
- 2007 Informe técnico: Proyecto Arqueológico Tambo-
Ilo 2006. Field report submitted to the Instituto
Nacional de Cultura, Lima, Peru. (Now the
Ministerio de Cultura).

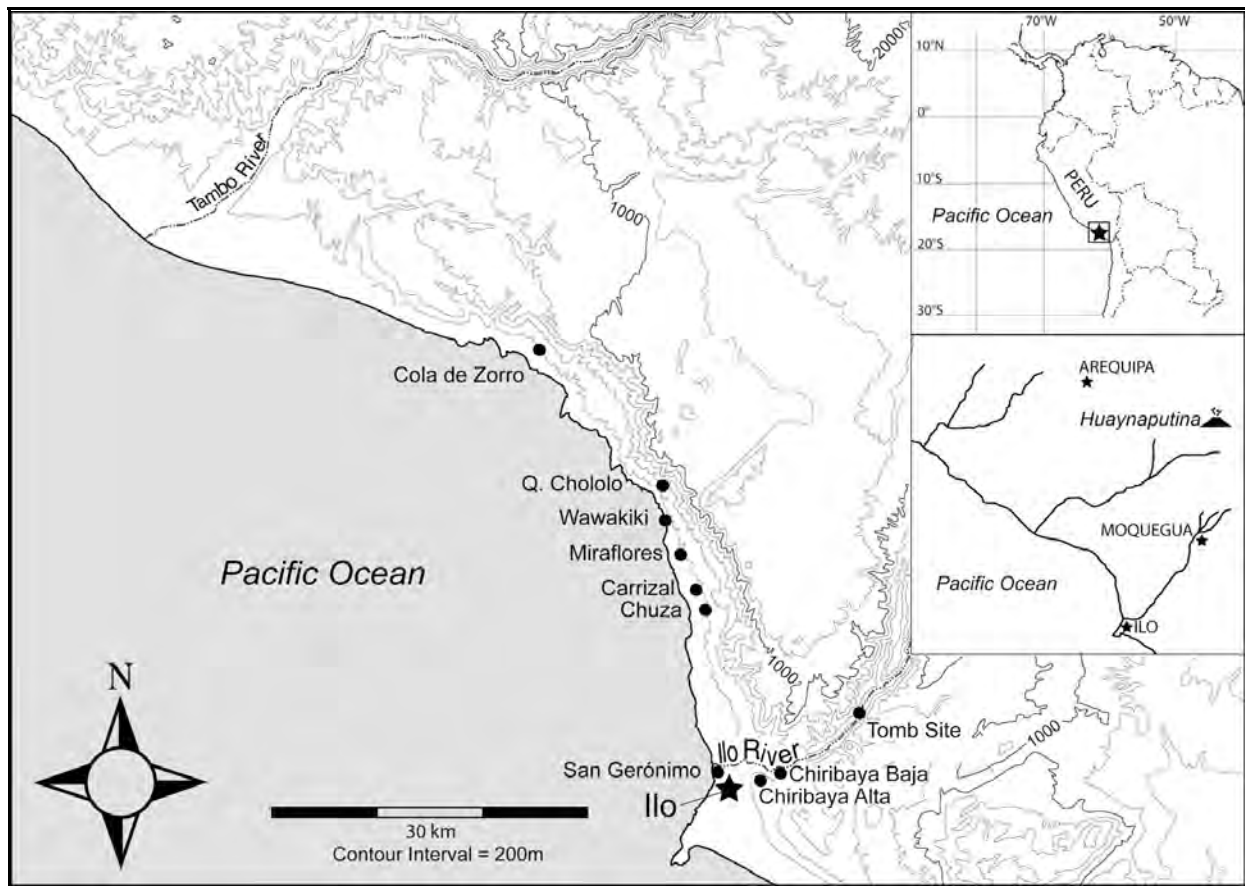


Figure 1.: Location of the study region in southern Peru and principal sites mentioned in the text.

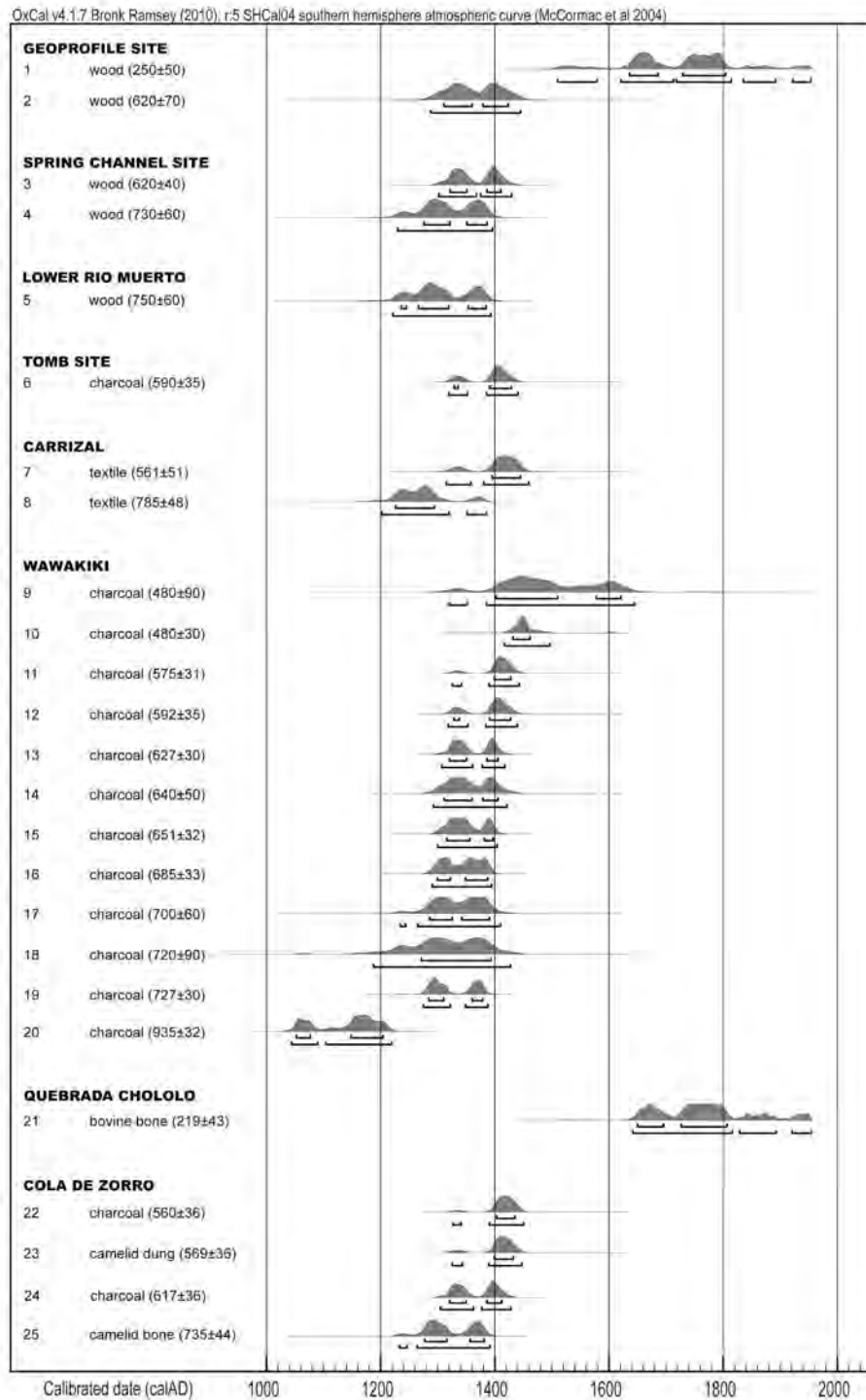


Figure 2: Calibrated radiocarbon probability distributions for samples discussed in the text. Brackets indicate 1σ and 2σ confidence limits. All dates were calibrated using Oxcal 4.1.7 (Bronk Ramsey 2009), with a southern hemisphere atmospheric curve (McCormac et al. 2004). The Geoprofile, Spring Channel, and Lower Río Muerto sites are associated with the middle Moquegua Valley drainage, while the Tomb Site is situated in the lower Moquegua/Ilo Valley. Carrizal, Wawakiki, Quebrada Chololo, and Cola de Zorro are all found along the intervalley coast.

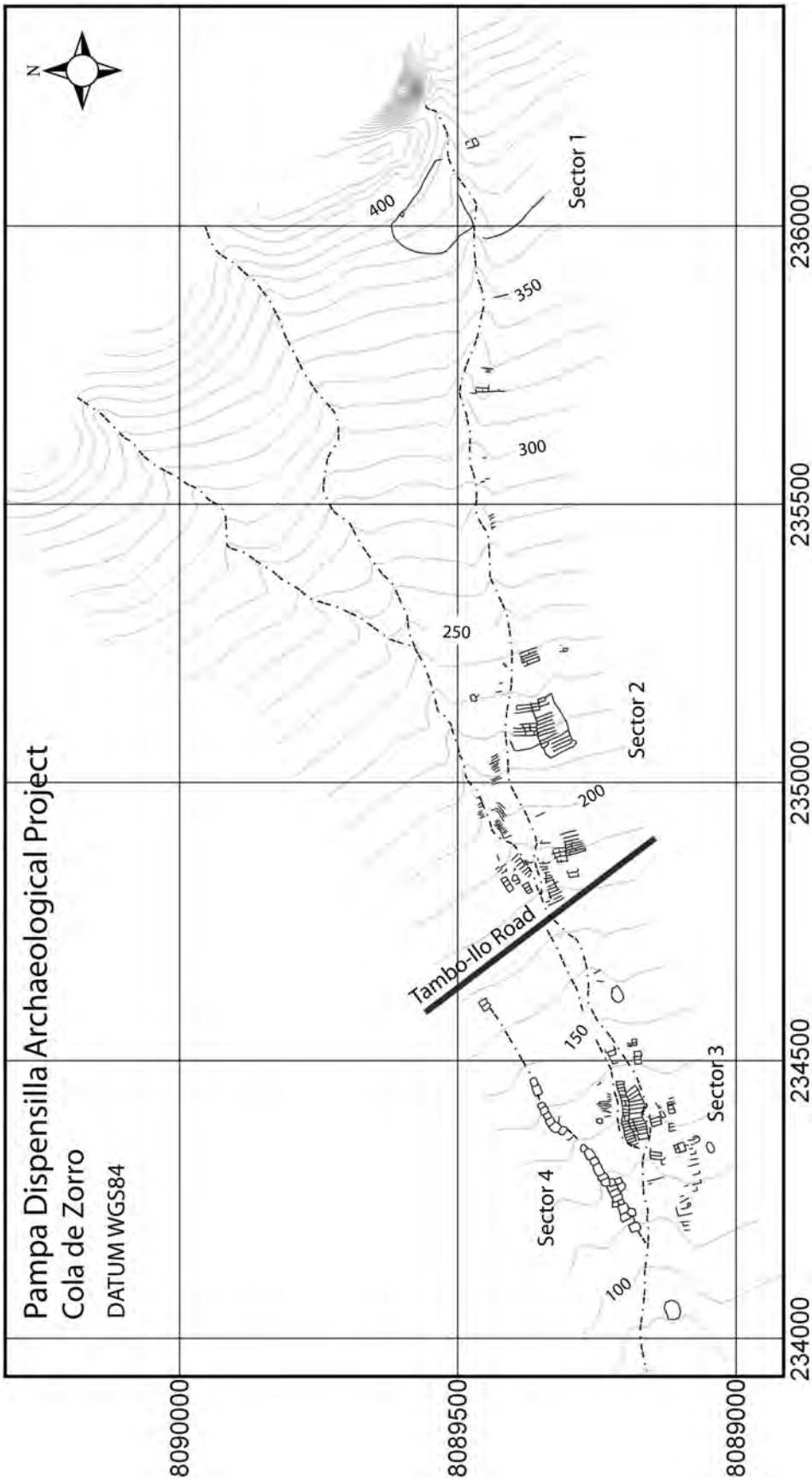


Figure 3: Plan of the Cola de Zorro archaeological site showing primary architectural features, including agricultural terraces, corrals, and domestic structures.

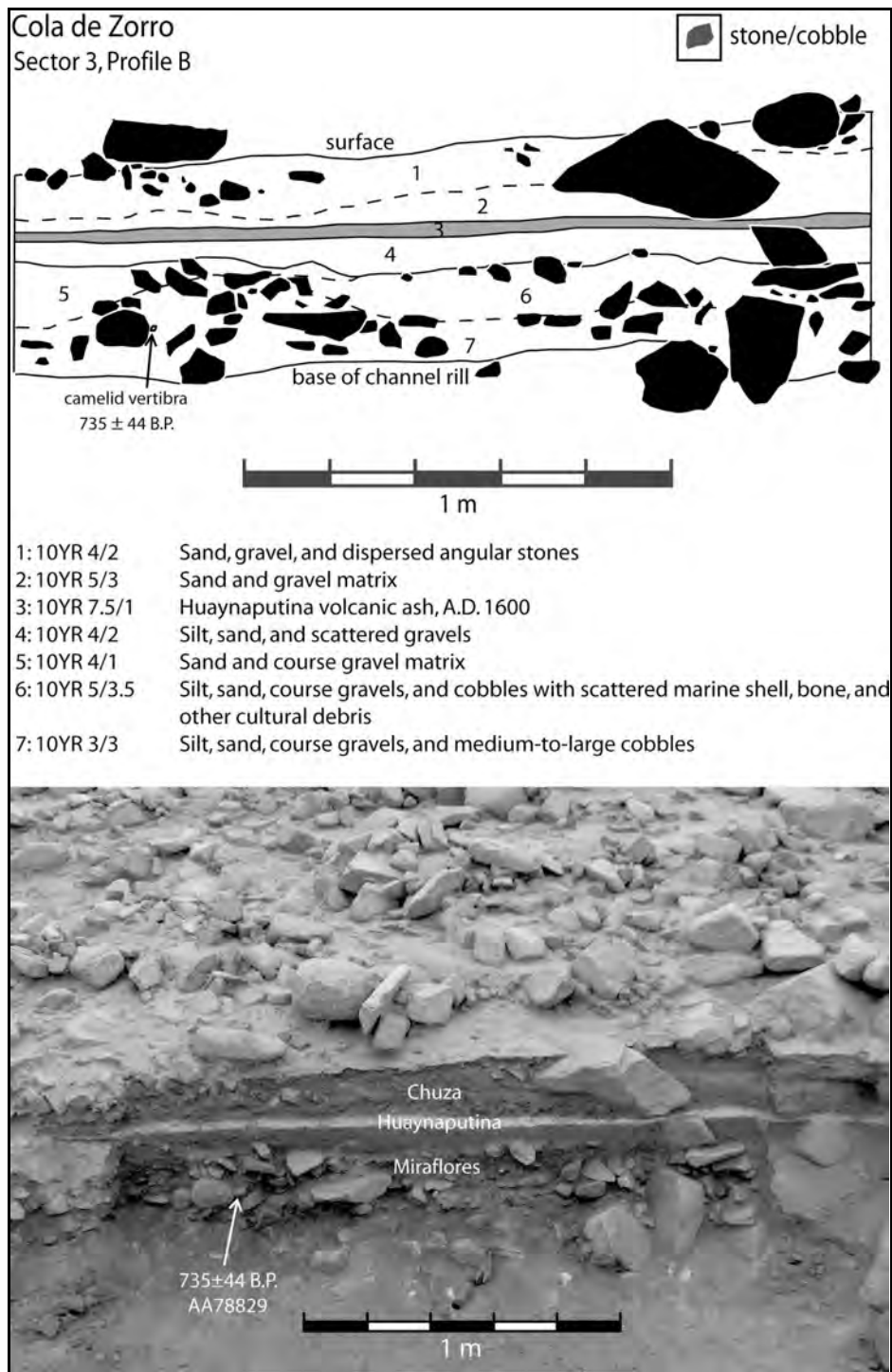


Figure 4: Geologic profile showing the relationships among debris flow deposits (proposed Miraflores and Chuza) and Huaynaputina tephra in the Sector 3 portion of the main channel of Cola de Zorro.

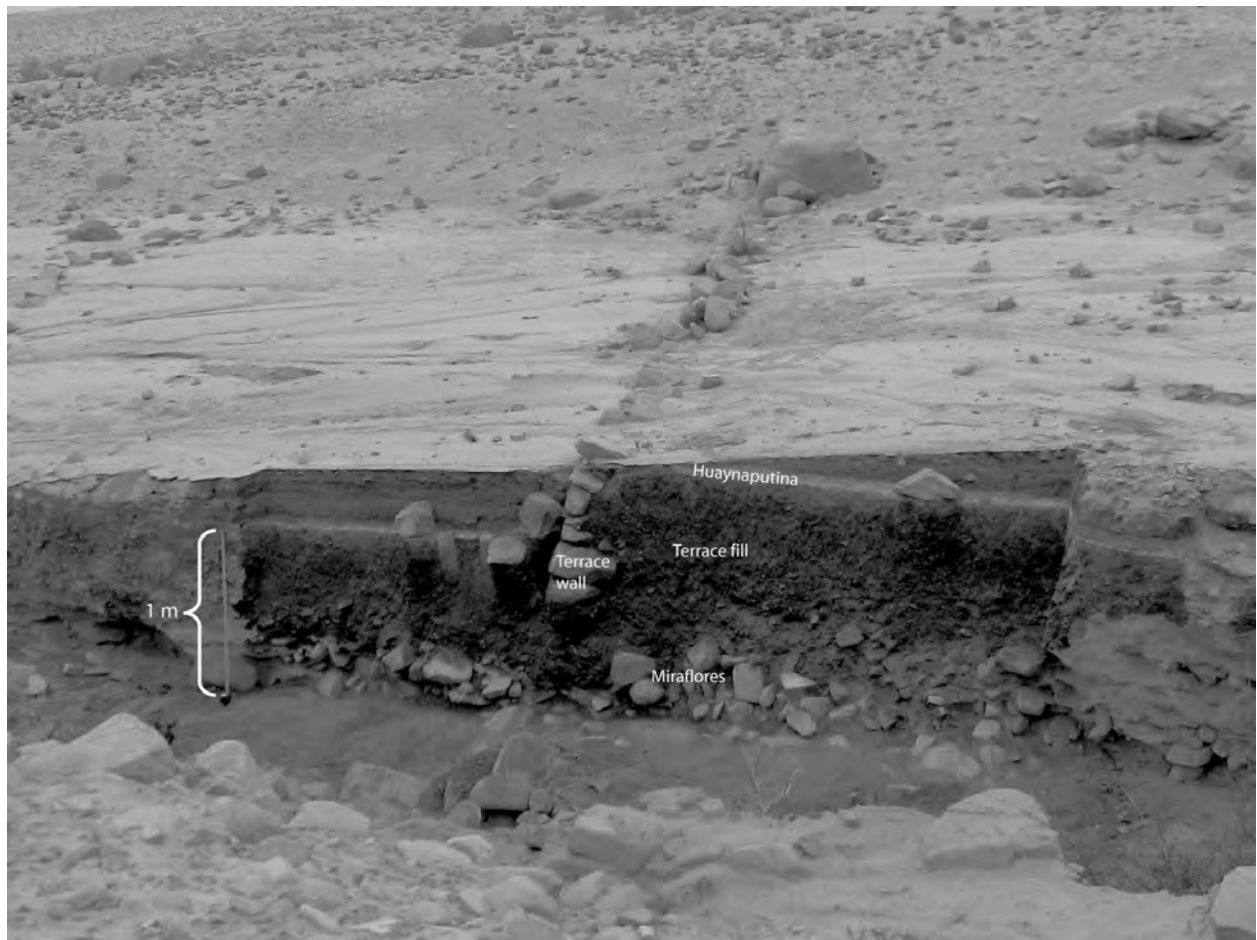


Figure 5: Geologic profile revealing channel margin terraces identified in Sector 2 at Cola de Zorro. Terrace fill overlies a debris flow interpreted to be the result of the Miraflores event, and it is immediately capped by Huaynaputina tephra. Multiple lenses of alluvium immediately overlie Huaynaputina tephra. This sequence is identified among channel margin terraces in both Sectors 2 and 3.

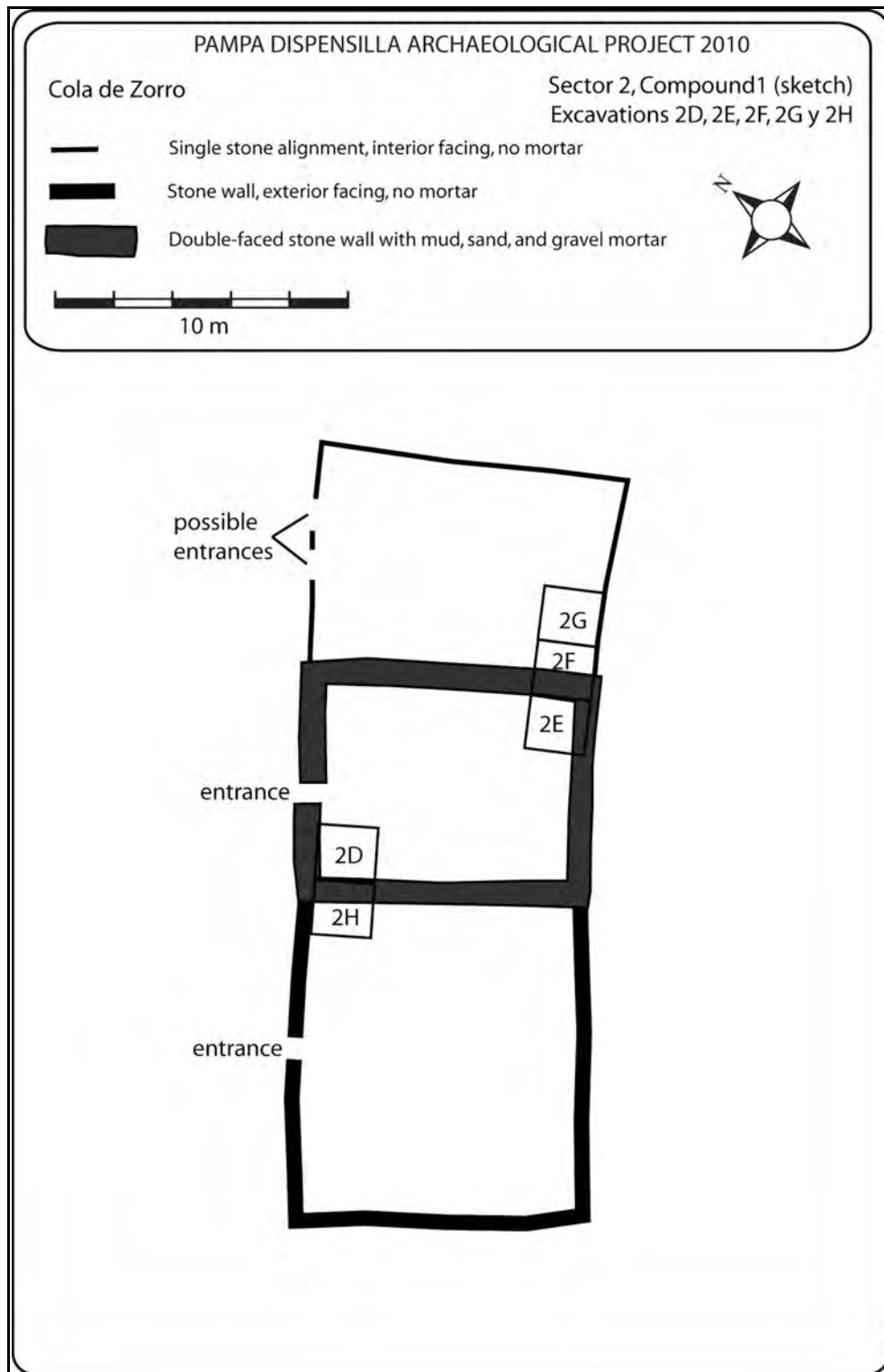


Figure 6: A Chiribaya domestic structure in Sector 2 at Cola de Zorro. Excavation units within the enclosures are indicated by a number-letter designator.



Figure 7: Excavation 2D in a Chiribaya domestic structure in Sector 2 (see Figure 6). Exposed architecture is the interior face of a double-faced wall foundation with mud and gravel mortar.

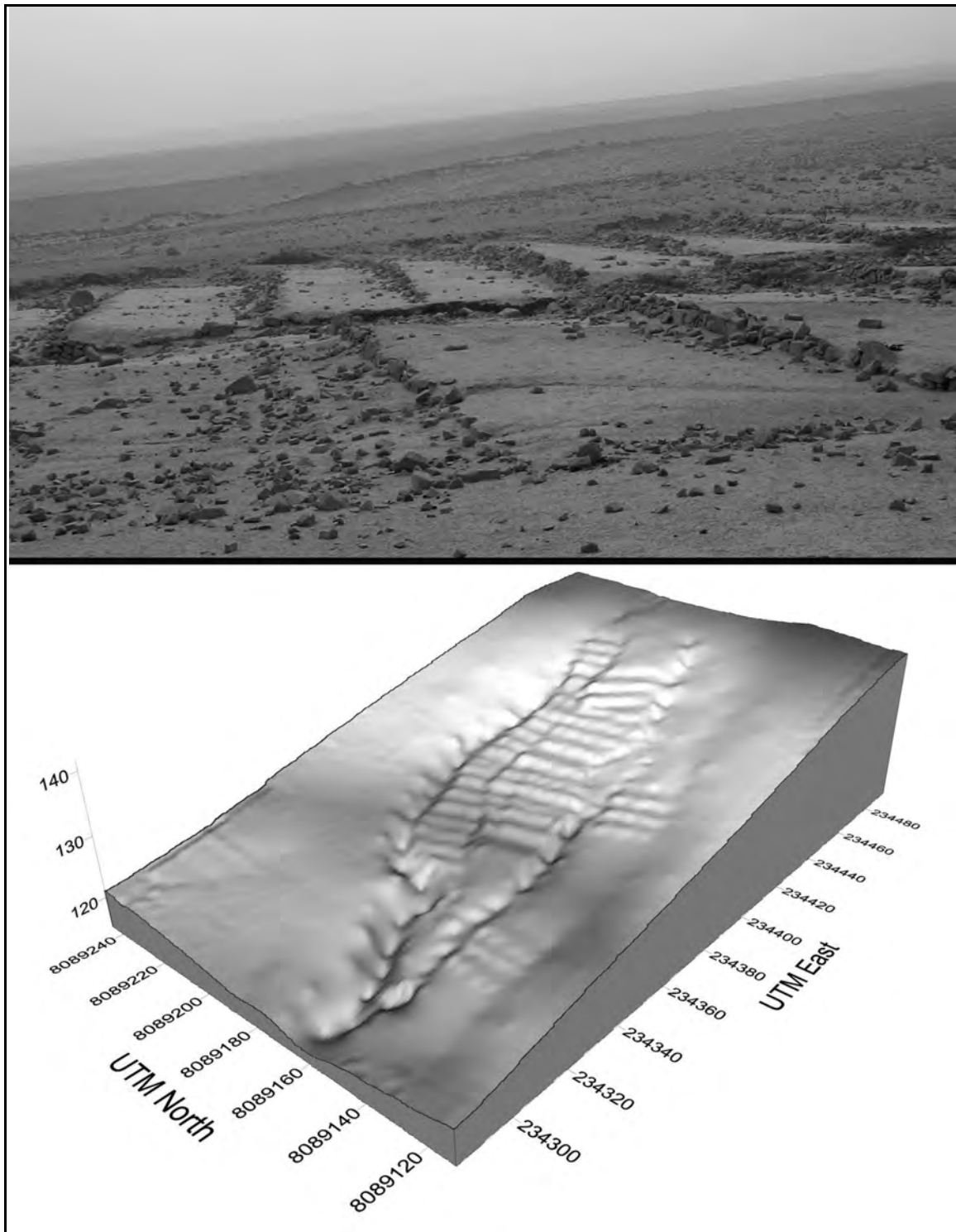


Figure 8: A segment of channel margin terraces in Sector 3 at Cola de Zorro. Similar to Sector 2 (see Figure 5), geologic profiles here identified Huaynaputina tephra immediately overlying terrace fill.

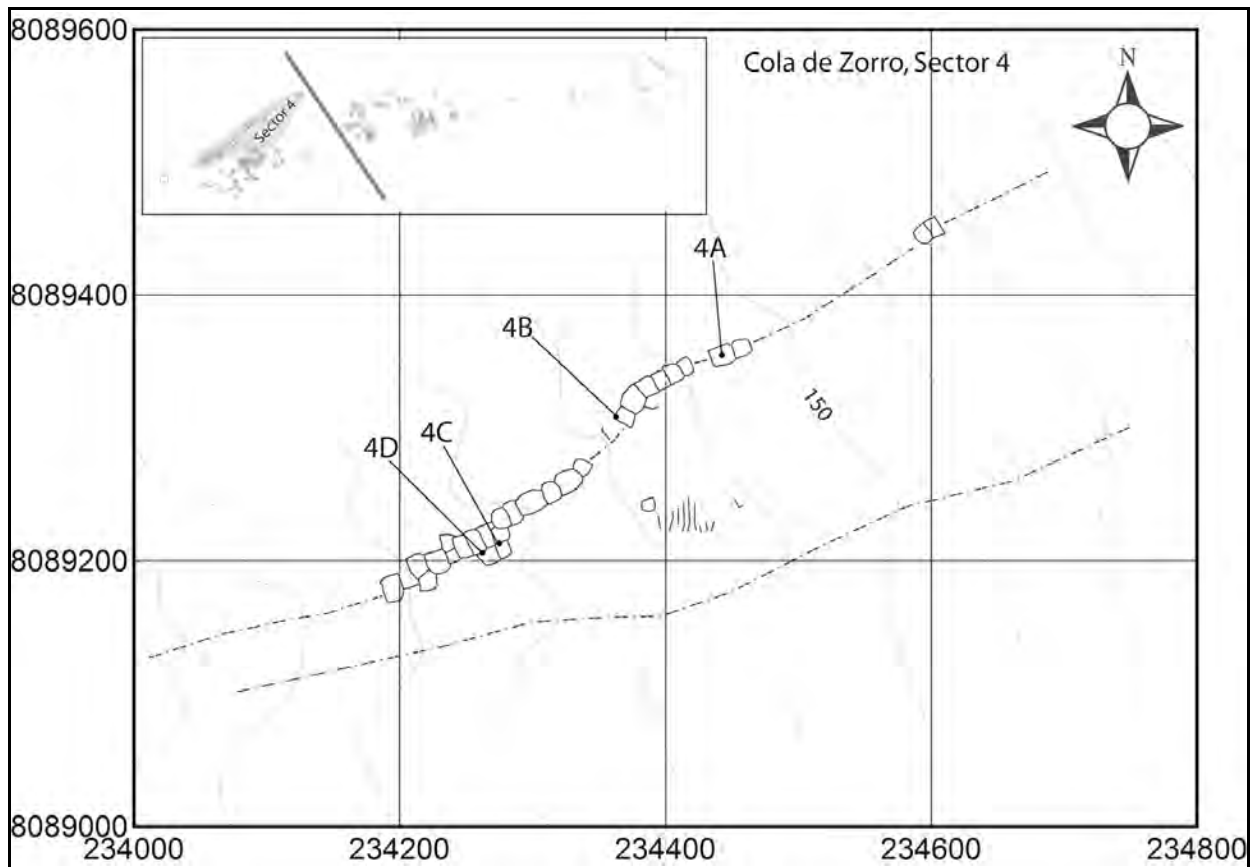


Figure 9: Plan of Sector 4 corrals at Cola de Zorro. Note their position within a secondary drainage channel. Locations of four excavation units are noted.



Figure 10: Prehispanic agricultural terraces identified in Sector 2 at Cola de Zorro. At some point, stones from retention walls were removed and redirected towards the construction of a corral (visible in the middle ground of the photo). No intact lens of Huaynaputina tephra was encountered, and only fauna from European-introduced species were identified.