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# Late Chiribaya Agriculture and Risk Management along the Arid Andean Coast of Southern Perú, A.D. 1200–1400

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Recent investigations at the coastal spring site of Wawakiki in southern Perú have identified an intensive, late pre-Hispanic agricultural production strategy along a sea cliff some 30 km north of the Ilo River. Excavations identified buried stone-faced agricultural terraces underlying Spanish colonial and post-colonial furrows, and long irrigation canals that transported water along steep hill slopes from inland springs. Depositional patterns, cultural debris, and calibrated radiocarbon age ranges suggest the site was farmed most intensively between A.D. 1200 and 1400, a period characterized by prolonged highland drought and recurrent El Niño-induced floods in southern Perú. Farmers transformed this arid coastal promontory into a productive agricultural landscape by exploiting multiple spring sources, steep canals, and stone-faced terraces in an area where water is a very limited commodity and steep barren hills are highly prone to erosion. Furthermore, high-relief terrain left much of the agricultural infrastructure well protected from periodic floods. © 2005 Wiley Periodicals, Inc.

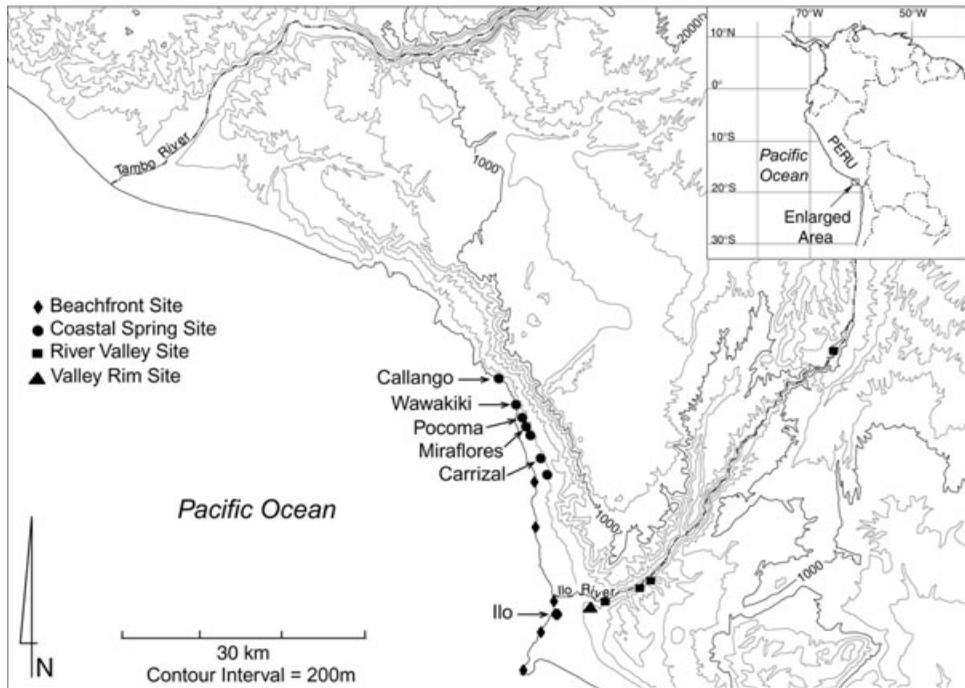
## INTRODUCTION

Agricultural landscapes are often very fragile and ephemeral remains in the archaeological record because field technologies and planting surfaces are constructed, cultivated, modified, abandoned, recultivated, and abandoned again, often resulting in partial or total destruction of evidence for earlier production strategies. Consequently, chronological control and identification of agricultural features often present the greatest obstacles to investigations of past agrarian production systems. To properly identify and assess ancient agricultural technologies in what are often long and complicated trajectories of production, multidisciplinary approaches involving archaeology, geology, paleoclimatology, and geography are required.

The coastal spring site of Wawakiki near the Osmore drainage in far southern Perú displays the effects of over 900 years of intensive, though probably intermittent, agricultural production strategies. While early cultivation likely occurred at the site during the early half of the 1st millennium A.D., large investments in landscape modification beginning ca. A.D. 1200 and followed by subsequent periods of abandonment

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**Figure 1.** Map of the coastal Tambo and Ilo Rivers showing the locations of Wawakiki and other principal Chiribaya-phase settlements.

and cultivation by Spanish colonial and modern-era farmers have left a very complex pattern of land use. Using a multidisciplinary approach, analyses of recent excavation and profile data from the site revealed intensive land use during the late pre-Hispanic era, reaching its most extensive form between A.D. 1200 and 1400.

By A.D. 1000, the lower reaches of the Osmore drainage of southern Perú largely consisted of farming communities associated with the Chiribaya culture (A.D. 800–1375). The majority of currently known Chiribaya settlements occupied the banks of the Ilo River (as the Osmore drainage is termed in the lower valley), extending about 25 km inland from the river mouth (Ghersi, 1956; Jessup, 1990, 1991; Owen, 1993, 1994; Umire and Miranda, 2001), and along the coastal plain to the north of the Ilo River (Umire, 1994, 1996; Umire and Miranda, 2001: Figure 1).

Along the Ilo River, the Chiribaya constructed major canals to irrigate alluvial terraces on the floor of the valley and a limited area surrounding the mouth of the river (Owen, 1993). Most noteworthy of all lower-valley Chiribaya hydraulic endeavors was a roughly 7-km-long canal that transported water above several discontinuous alluvial terraces, sometimes clinging to near-vertical bedrock faces. While current evidence suggests that this canal was ultimately destroyed by massive floods and debris flows associated with a devastating mid-14th century El Niño–Southern Oscillation event (Reycraft, 2000; Satterlee et al., 2001), agriculture in general may have already

been in sharp decline in the lower valley due to centuries of below-average precipitation in the adjacent highlands. The ancient practice of intensive agriculture identified at Wawakiki, then, is generally correlated with both long-term drought and punctuated flooding episodes that constituted climatic hardships for many coastal and main-valley farming communities in far southern Perú.

## STUDY REGION

### Climate

Located in the dry Pacific Andean watershed, the Osmore drainage is one of the southernmost valleys of Perú. Oceanic and topographic elements of coastal Perú have maintained a relatively stable arid climate for several thousand years (Aldenderfer, 1997:49), perhaps for as long as 38,000 years (Keefer et al., 2003). Oceanic currents bring cold water to the surface along the Peruvian shoreline, creating a relatively cold ocean surface adjacent to a warm, tropical land mass. As clouds pass from these cold to warm surfaces, they expand and ascend the Andes. Upon reaching elevations of 2000 m.a.s.l., they begin to cool and precipitate (Moseley, 1975). Thus, rain rarely falls below this elevation except during recurrent El Niño episodes. Because rainfall is virtually nonexistent, prehistoric agriculture throughout much of the middle and lower valleys of the Osmore drainage depended upon highland rainfall and floodwater and canal-irrigation technologies.

While hyperaridity characterizes the western Andean watershed, analyses of ice cores from the Quelccaya ice cap (5670 m.a.s.l.) in southern Perú demonstrate variability in highland precipitation over the past 1500 years, and decadal ice-accumulation trends suggest a marked dry period from A.D. 1040 to 1490 (Thompson et al., 1994:85). Sediment cores taken from Lake Titicaca in the Bolivian altiplano also indicate several centuries of below-normal highland rainfall during this period (Abbott et al., 1997; Binford et al., 1997; Moseley, 1997). A substantial decrease in highland precipitation would have spelled disaster for agriculturalists in the lower and coastal reaches of the drainage who were dependent on highland runoff. An estimated 20–30% decline in runoff from the headwaters of the Osmore drainage by the late Chiribaya period (A.D. 1200–1375) would have been exacerbated in the lower valley as transport distances increased (Satterlee et al., 2001:96–97).

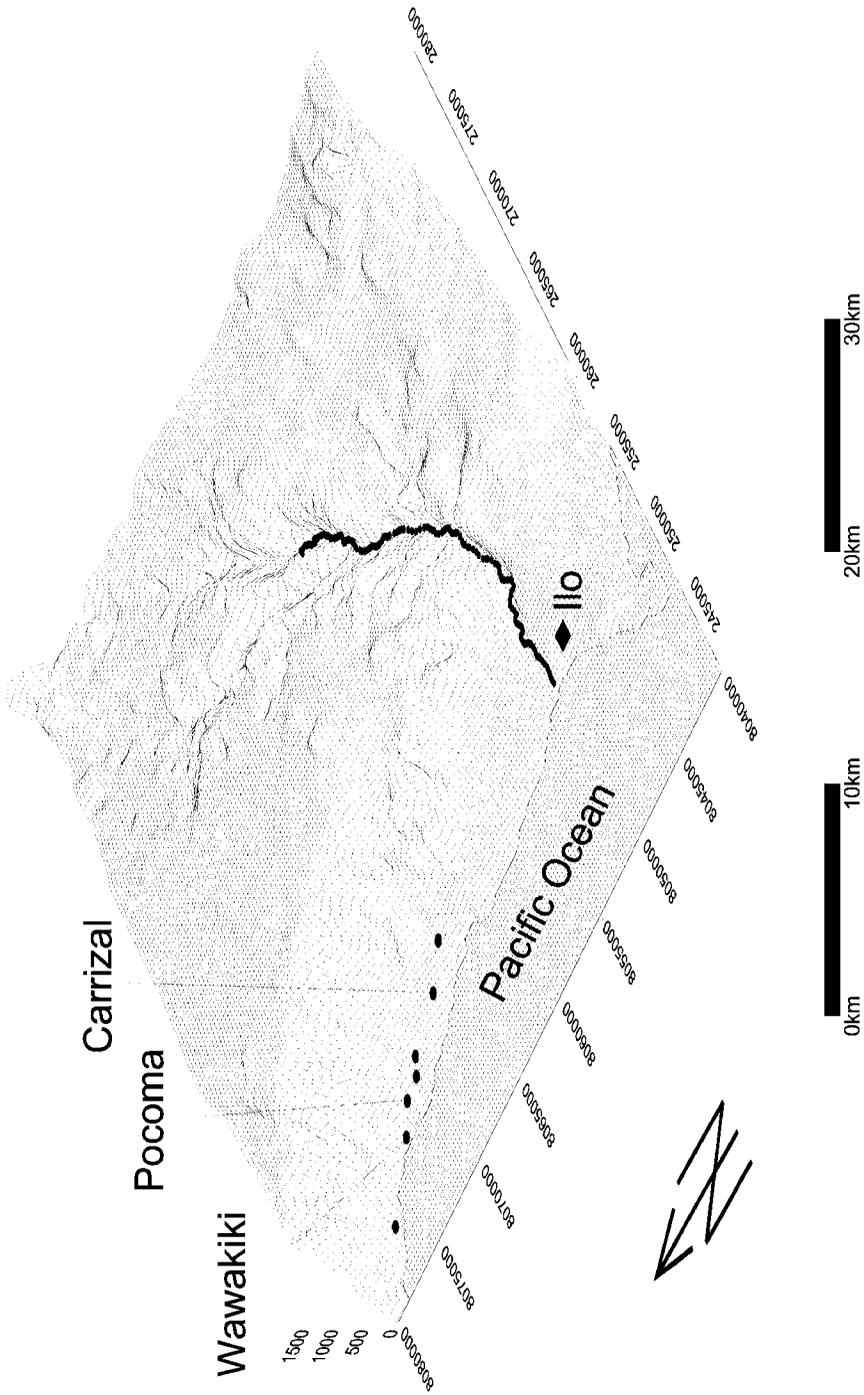
Periodically, El Niño episodes dramatically interrupt the normally arid climatic pattern along the coast, and the accompanying heavy rains are destructive to the landscape below ca. 1500 m.a.s.l., washing away canals, fields, and reservoirs (Nials et al., 1979; Oficina de Información Agraria, 2000). Historical records of El Niño activity in Perú since A.D. 1525 document the occurrence of “strong” events roughly every 4 years and “very strong” events roughly every 9 years (Quinn and Neal, 1995). “Mega” events, on the other hand, may have occurred only on extremely rare occasions, with sometimes hundreds or even thousands of years passing between these massive flooding episodes (Keefer et al., 2003). Along the Pacific coast of South America, El Niño-induced flooding is typically most intense along the coasts of Ecuador and northwestern Perú, with the effects of particularly strong events reaching farther south (Quinn and Neal, 1995).

Despite the potential destruction of El Niño events, their effects were differentially felt by farming communities throughout coastal valleys of Perú, often depending on variables such as the strength of the event, local topography, and degree of seismic activity prior to such an occurrence, as well as the organization of production on both local and regional scales (Reycraft, 2000; Satterlee et al., 2001; Magilligan and Goldstein, 2001; Keefer et al., 2003; Dillehay and Kolata, 2004; Moseley and Keefer, in press). However, a “mega” El Niño event documented archaeologically for the Ilo region at ca. A.D. 1300–1400 may have ultimately led to the demise of the Chiribaya culture (Satterlee, 1993; Reycraft, 1997, 2000). Satterlee et al. (2000) have recently extended this argument, suggesting that it was the destruction resulting from convergent catastrophes—this “mega” El Niño following several centuries of below-normal highland rainfall—that ultimately catalyzed the Chiribaya collapse. Annual deposits of wet-season snow and dry-season dust documented in the Quelccaya ice core may have dated this “mega” event more precisely between A.D. 1350 and 1370 (Thompson et al., 1984; Satterlee et al., 2001:105).

### **The Ilo River Valley and Coastal Quebradas**

Generally, the Osmore drainage can be divided into upper, middle, and lower sectors. In the upper sector of the valley, headwaters originate above 3500 m.a.s.l., where three tributaries capture water from melting snow and seasonal highland rainfall. These tributaries converge in the middle valley at 1400 m.a.s.l. to create the Moquegua River. The valley reaches its maximum width here and provides the greatest amount of land suitable for agricultural production. From this point, the Moquegua River continues along a narrow linear course through the desert before it ceases to flow on the surface approximately 50 km from the coast. It then continues only as underflow for the next 20 km or so, creating a virtually uninhabitable hyperarid zone between the middle and lower sectors of the drainage. Finally, the Ilo River (as it is called in the lower valley) emerges approximately 25 km from the coast, cutting deeply through the Clemesí Desert before emptying into the ocean (Rice, 1989).

North of the mouth of the Ilo River is a coastal plain bordered by the Pacific Ocean on the west and a series of inland coastal hills to the east that reach a maximum elevation of approximately 1200 m.a.s.l. (Figure 2). This cordillera runs north-northwest, thereby narrowing the coastal plain until it ultimately disappears about a half kilometer south of Wawakiki. Dry quebradas (ravines or gorges) descend from the adjacent Clemesí Desert, pass through these coastal hills, and intersect an aquifer at about 100–150 m.a.s.l., creating a series of freshwater springs across the coastal desert (Bawden, 1989; Clement and Moseley, 1991). Because of the narrowing coastal plain, springs emerge from the desert much closer to the coastline in the north than they do in the south; consequently, local topography surrounding them can vary considerably. As the only source of fresh water outside of the river valley, these springs were focal points for localized agricultural production among small communities. The largest of these systems was Pocoma, which approached 30 ha of cultivated area during the pre-Hispanic era (Satterlee, 1993). Today, Pocoma continues to irrigate the largest amount of land among the coastal springs, though it encompasses only about 15 ha of cultivated terrain.



**Figure 2.** Three-dimensional map of the lower and coastal sections of the Osmore drainage showing the relationship of the coastal springs to the local topography. Vertical scale is exaggerated three times (X:Y:Z = 1:1:3).

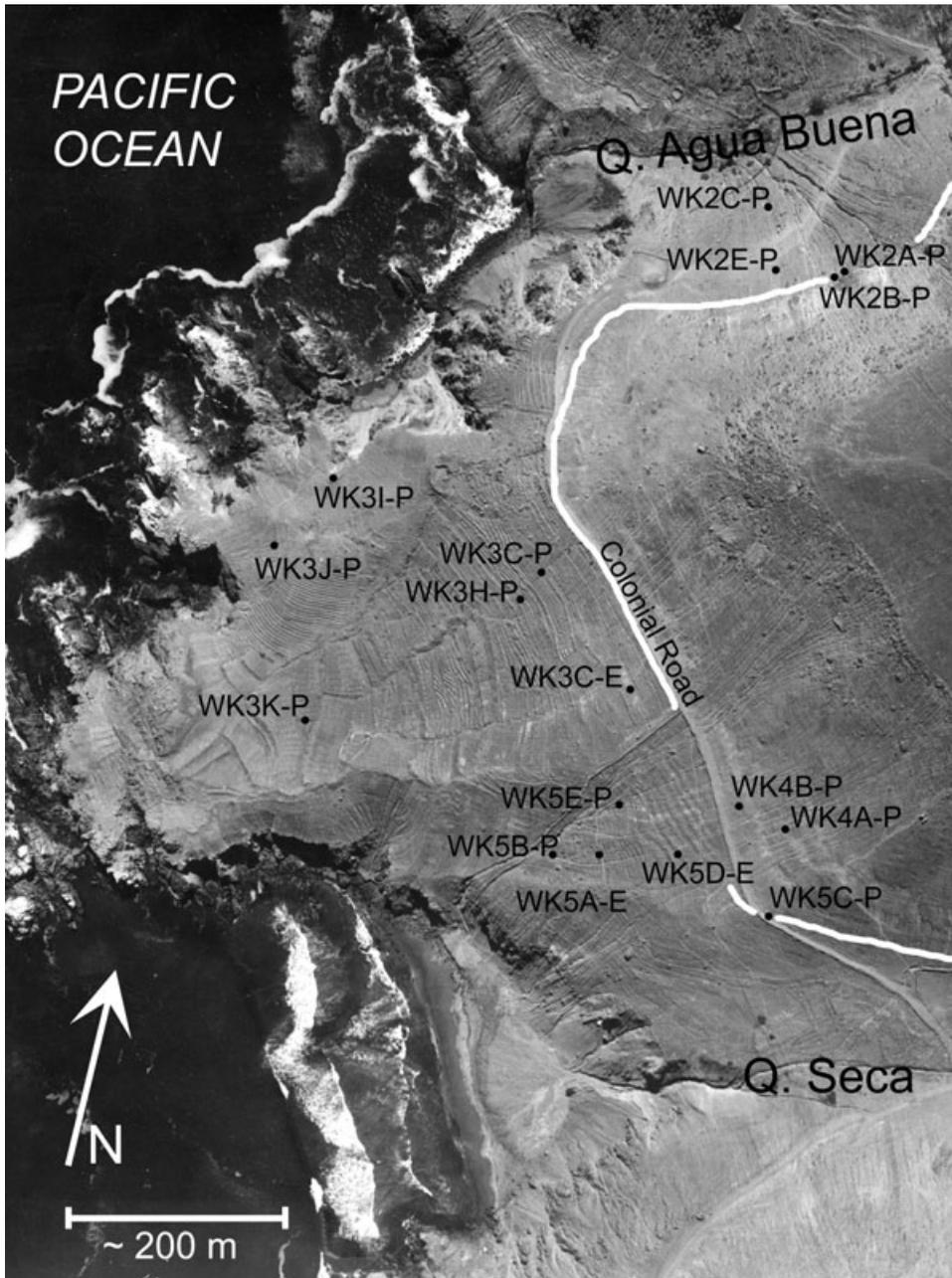
Low volume and slow flow characterize all of the springs in this area, and to improve the productivity of low-discharge springs, both ancient and modern farmers constructed tanks around the source of each spring in order to capture water. After a tank is filled, water is released through a small sluice gate to irrigate prepared fields (Clement and Moseley, 1991). Today, local farmers note that spring discharge generally correlates with mountain rainfall 40–60 km inland and northeast of the Clemesí Desert (Clement and Moseley, 1991:430), suggesting that the Ilo River does not directly replenish the coastal aquifer. Thus, while farmers in the main river valley must contend with water consumption practices of upstream neighbors, coastal-spring farmers remain virtually unaffected by irrigation practices of the main valley. Water flow does, however, vary from one spring to the next, and location and/or rate of discharge can change dramatically, especially following seismic activity. Following the M 8.4 earthquake that struck the Moquegua region of southern Perú in June 2001, farmers working around the coastal olive groves of Pocoma, Miraflores, and Alastaya noted a number of changes in spring discharge rates. Of the eight independent springs that irrigate these three groves, several increased in discharge while others decreased, and yet others remained relatively unchanged (José Jiménez, personal communication, 2003). This example demonstrates that spring flow along the coastal cordillera is very dynamic, and it would have been so despite the declining runoff from highland rainfall during the late Chiribaya period.

## **AGRICULTURAL LAND USE AT WAWAKIKI**

### **Wawakiki**

Wawakiki is located on a small sea-cliff promontory approximately 27 km north of the mouth of the Ilo River (Figure 3). It is bordered by Quebrada Agua Buena to the north and by Quebrada Seca to the south, both of which extend some 2–3 km inland. Both quebrada channels are deeply incised (at times exceeding depths of 4 m), and the adjacent flanks to the north and south of both are very steep and unstable, creating highly constricted canyons along their entire course. The Quebrada Agua Buena channel empties directly into the sea, dropping some 40 m over an escarpment, while Quebrada Seca spills over a similar height onto a 200-m-wide sandy beach enclosed by rocky outcrops rising from the sea. A coastal road constructed in the past decade to connect the Osmore and Tambo drainages crosses both quebradas, unfortunately destroying many of the terrace and canal features located on the steep slopes just below the road cut.

Past and present research along the coast has documented a long, though probably intermittent, history of occupation and land use at Wawakiki during the Early Ceramic period (ca. 100 B.C.–A.D. 400; Ó Donnabáain et al., 1991), the Late Chiribaya period (A.D. 1200–1375; Bawden, 1989; Umire and Miranda, 2001), the early Spanish colonial period (ca. A.D. 1600–1750; Kuon Cabello, 1981:139; Adiazola Flores, 1998:61), and the early 20th century (Paernio, 1908:6). Historic aerial photographs confirm that cultivation of the canyon walls and coastal promontory of Wawakiki had ceased by 1951 (Figure 3).



**Figure 3.** Historic aerial photograph of Wawakiki showing the locations of principal excavations and profiles mentioned in the text. White lines designate the remains of primary canals extending onto the coastal promontory from quebradas Agua Buena and Seca. Spanish colonial property wall can be seen south of excavation WK3C-E and extending toward the southwest from the colonial road (photograph taken by the Servicio Aereofotográfico Nacional del Perú, 1951).

## **Identification of Late Pre-Hispanic Agricultural Infrastructure**

To investigate agricultural land use at Wawakiki, two kinds of field techniques were employed: isolated profiles (-p) and excavations (-e). Isolated profiles targeted natural rills and other erosional cuts that are scattered across the site and run perpendicular to the slope. At least one wall of an erosional cut was straightened and cleaned down to sterile sediments, and a detailed profile was drawn to document depositional pattern, field technology, and chronological evolution of field systems. Sediments removed from these erosional trenches were not screened nor were artifacts collected, but observations were noted in profile descriptions. Isolated profiles ranged from less than 2–27 m in length, with an average of nearly 7 m.

Excavations, on the other hand, targeted field areas with little erosional disturbance. All excavations were 1 m wide and ranged from 2 to 5 m in length, and all were excavated by depositional stratigraphy or by 10-cm levels. Sediments were sifted through a 0.5-cm mesh screen, and all artifacts were collected and catalogued. Profiles were drawn of at least one long wall of each excavation, and at times two or even all four walls were profiled. A total of 31 isolated profiles and 10 excavations were performed throughout the site, yielding profile data from 41 unique locations (Figure 3).

The chronology of the agricultural infrastructure and associated features at the site was assessed using radiocarbon dates from a variety of contexts in conjunction with a number of relative chronological markers. These relative indicators include diagnostic ceramics associated with terrace walls and nearby domestic sectors, stratigraphic positioning of buried field horizons, and relative degree of preservation of agricultural fields and planting surfaces. In addition, historical records report the eruption of the Huaynaputina volcano of southern Perú on February 19, 1600, which projected tephra over a large area of the southern highlands and coast. Tephra depths along the Tambo-Ilo coastline are 1–2 cm near Ilo, and up to 5 cm at the midpoint between the Tambo and Ilo rivers (Thouret et al., 1997:436). Tephra thickness at Wawakiki ranges from 1 to 3 cm, and its preservation depends on a number of variables, including local topography and both natural and cultural post-depositional activities. Undisturbed deposits of tephra typically have sharp contacts and are well defined in profile, while significantly disturbed or reworked deposits either exhibited considerable mixing with surrounding strata or were no longer visible in profile. Intact and well-defined lenses of tephra allow for precise chronological assignment of planting surfaces, terrace walls, and sediment strata to pre- or post-1600. Finally, characteristics of agricultural features more securely dated to the Chiribaya phase were used to identify Chiribaya agricultural technology and land use in other areas, where conditions did not permit such rigorous temporal control.

## **RESULTS**

### **Maximum Elevation Canals**

Two maximum elevation canals associated with Chiribaya construction are known to have extended from both quebrada channels, transporting water along steep

**Table I.** Radiocarbon dates mentioned in the text.<sup>a</sup>

Field Sample # Excav/ Profile	Lab Sample # Geochron Lab. (GL) U. of Arizona (AA)	Type	Material	Uncalibrated Radiocarbon yr B.P.	Calibrated 1 $\sigma$ cal A.D. Age Ranges (Relative Probabilities)	Calibrated 2 $\sigma$ cal A.D. Age Ranges (Relative Probabilities)
1-WK5B-P	GL30458	Conv.	Charcoal	700 $\pm$ 60	1286–1323 (0.455) 1346–1390 (0.545)	1233–1243 (0.012) 1267–1409 (0.988)
4-WK3C4-E	AA56760	AMS	Charcoal	575 $\pm$ 31	1399–1427 (1.000)	1324–1341 (0.074) 1391–1442 (0.926)
5-WK3C5-E	AA56761	AMS	Charcoal	651 $\pm$ 32	1317–1356 (0.750) 1383–1397 (0.250)	1298–1370 (0.734) 1376–1404 (0.266)
6-WK3C-E	AA56762	AMS	Charcoal	685 $\pm$ 33	1298–1322 (0.404) 1348–1372 (0.384) 1376–1388 (0.211)	1291–1393 (1.000)
8-WK2E-P	AA56764	AMS	Charcoal	1793 $\pm$ 33	240–264 (0.261) 270–340 (0.739)	140–152 (0.012) 175–193 (0.020) 212–398 (0.968)
15-WK4B-P	AA56771	AMS	Charcoal	592 $\pm$ 35	1325–1333 (0.117) 1392–1425 (0.883)	1319–1352 (0.262) 1385–1439 (0.738)
16-WK4A-P	AA56772	AMS	Charcoal	627 $\pm$ 30	1322–1348 (0.656) 1388–1403 (0.344)	1304–1360 (0.605) 1380–1416 (0.395)
17-WK4A-P*	GL30460	Conv.	Charcoal	640 $\pm$ 50	1305–1306 (0.019) 1315–1360 (0.644) 1380–1405 (0.338)	1293–1421 (1.000)
18-WK4A-P	AA56773	AMS	Charcoal	727 $\pm$ 30	1284–1305 (0.487) 1313–1315 (0.049) 1360–1380 (0.464)	1276–1321 (0.558) 1349–1387 (0.442)
19-WK4A-P	AA56774	AMS	Charcoal	480 $\pm$ 30	1434–1460 (1.000)	1419–1497 (1.000)
20-WK4A-P*	GL30461	Conv.	Charcoal	720 $\pm$ 90	1273–1392 (1.000)	1184–1199 (0.014) 1206–1429 (0.986)

\* Samples have been measured with extended counting time.

<sup>a</sup> Dates were calibrated using CALIB REV4.4 Radiocarbon Calibration Program (Stuiver and Reimer, 1993) made available by the University of Washington, based on southern hemispheric data sets described by McCormac et al. (2002).

canyon walls to the coastal promontory of Wawakiki (Figure 3). The Quebrada Seca canal can be traced for a distance of 215 m at an average gradient of nearly 4%. Profile WK5C-p confirms that the canal most likely had only one major period of use, and that its base had been at least partially chiseled into bedrock. It passes just below a series of domestic terraces, and diagnostic ceramics and radiocarbon dates associated with shallow and more deeply buried floor surfaces confirm there was substantial occupation during the late Chiribaya phase (Table I, field samples 15–20). Unfortunately, the canal disappears under slope debris and talus from the modern

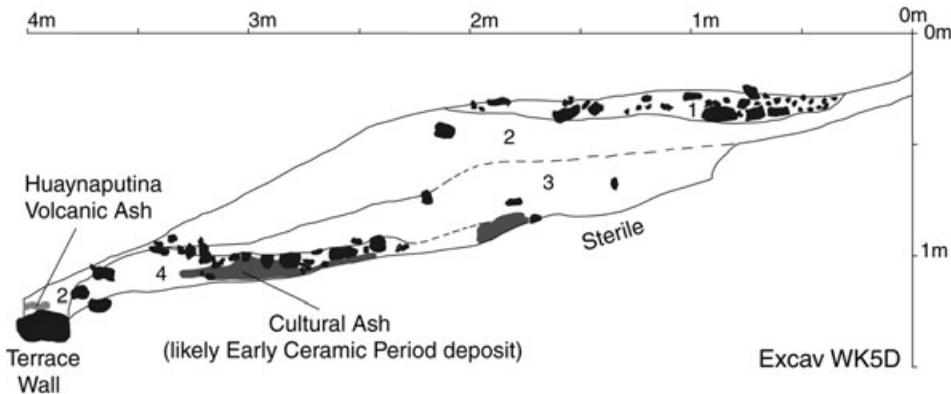
road cut long before intersecting the main channel of Quebrada Seca, rendering it impossible to positively identify its spring source.

The Quebrada Agua Buena canal can be traced intermittently for a distance of at least 430 m at an average gradient of 3%, but given its position high up on the canyon wall, it likely extended inland for at least another 300 m or so before intersecting with the quebrada channel. Like its Quebrada Seca counterpart, this too disappears under slope debris and talus from the modern road as it approaches the quebrada channel. Profiles of natural rills that cut through this canal along the steep canyon wall of Quebrada Agua Buena revealed two thin alluvial deposits of laminated silt and sand, separated by several layers of loose colluvium, suggesting that it was renovated at least once during the Spanish colonial era subsequent to its initial construction during the Chiribaya period. Identified in profiles WK2A-p and WK2B-p, these colluvial deposits consist of coarse gravels and small angular stones originating from the steep, unstable hillsides above (see Figure 3). Farmers during the Spanish colonial era excavated into these deposits to reactivate the canal. Surface examination along the entire course of the canal also suggests that the degree to which colluvium buries particular sections varies considerably. The initial construction of this canal is dated by the association of its distal end with the Chiribaya domestic area and with buried pre-A.D. 1600 agricultural terrace features that are discussed below. Its renovation during the Spanish colonial era is supported by its association with linear sediment furrows overlying both Huaynaputina tephra and stone terraces.

These two primary canals extended from their respective quebrada channels, transporting water across steep canyon walls and onto the coastal promontory where they nearly overlapped at similar contours near the southern edge of the coastal promontory. As an integrated hydrological system, they irrigated an area of at least 11 ha, though modern road construction along canyon walls has most certainly destroyed evidence of additionally cultivated terrain of the pre-Hispanic era. While calculated gradients of these canals are quite steep (see Doolittle, 1990), they are not surprising given the low spring discharge. As mentioned above, the Quebrada Agua Buena canal may have extended for a total distance of nearly 750 m. Local rates of evaporation and infiltration would require rapid transport as distances increase from spring source to cultivated terrain.

### **Quebrada Seca Agricultural Land Use**

Agricultural terraces in this area include those of the steep canyon wall of Quebrada Seca as well as the area immediately south of the Spanish colonial stone property wall (Figure 3). Labor-intensive hillside terraces faced with stone are evident throughout this sector, though it shows no indication of cultivation after the pre-Hispanic era. This area exhibits well-preserved lenses of Huaynaputina volcanic tephra. Tephra was noted in both excavations and profiles in very shallow contexts, as well as in many other unexcavated rills that course their way through the hillside. In addition, there is a notable absence of Spanish colonial and modern-era furrows that dominate the surface elsewhere at the site, further suggesting pre-Hispanic abandonment.



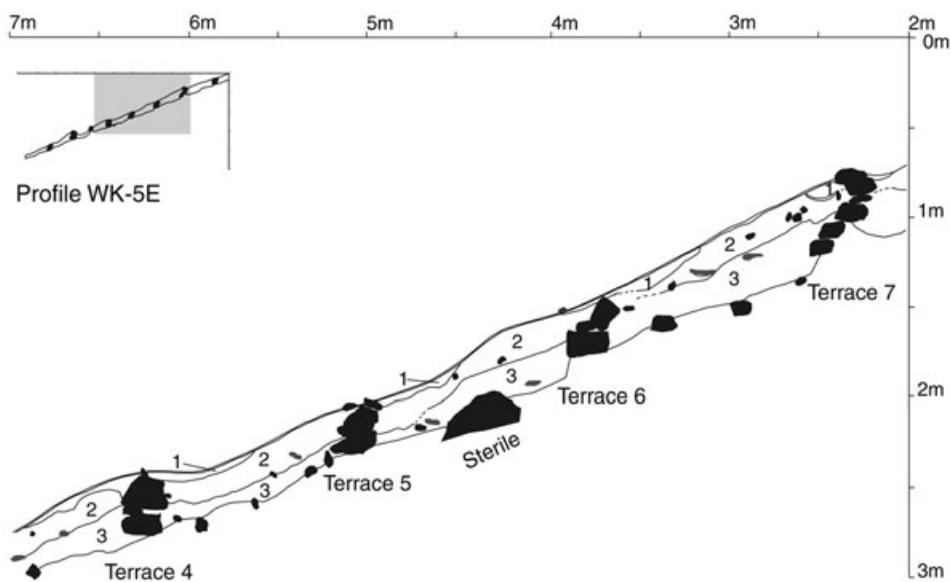
- 1 Alluvial deposits consisting of silt, sand, medium-to-coarse gravels, and coarse angular stones
- 2 Terrace fill composed of medium sand mixed with small and medium gravels and stones; small marine shell and ceramic fragments are scattered throughout
- 3 Very similar to layer 2, though shell fragments increase in size and density
- 4 Matrix of silt, sand, burned rock, and shell fragments that overlay sterile; density increases with depth, and marine shell fragments are large, sometimes whole; possible Early Ceramic period occupation

**Figure 4.** North profile of excavation WK5D-e. Note the presence of Huaynaputina ash superimposed over the basal layer of a collapsed terrace wall. Huaynaputina ash was also identified in the south profile of this excavation as well.

Evidence for Chiribaya construction and use of these terraces (as opposed to a possible later Estuquiña-Inka period use) stems from several excavations. Excavation WK5D-e is a 1 × 4 m unit whose western limit overlies a terrace wall. The northern profile of the unit identified a thin lens of Huaynaputina tephra superimposed over the basal stones of the collapsed terrace wall (Figure 4). The preserved height of the terrace near the unit's eastern end is approximately 1 m above the basal layer, and thus the overall degree of decay exhibited by this terrace suggests that a substantial period had elapsed between its abandonment and the time of tephra deposition (A.D. 1600).

Data from isolated profile WK5B-p also support a Late Chiribaya construction and cultivation period for this area (see Figure 3). WK5B-p is located near the distal end of this sector in a deep (~1 m) rill, and remains of at least two terrace walls spaced 1.5 m apart are noted. The profile also identified a 5–10-cm-thick lens of burned material underlying the base of one terrace wall and at a very abrupt contact between cultural terrace fill and sterile colluvium. This lens contained pellets of camelid dung and remains of maize cobs, which yielded an uncalibrated radiocarbon age of 700 ± 60 yr B.P., and calibrated age ranges of A.D. 1286–1390 (1σ) and A.D. 1267–1409 (2σ) (Table I, field sample 1), confirming terrace construction at this most distal end of the irrigation system during the late Chiribaya period.

All excavations and profiles in this area identified agricultural terraces constructed of stone facing. While several units noted preservation of terrace walls to be only one



- 1 Thin alluvial deposits consisting of laminated silt and sand with scattered medium-to-coarse gravels
- 2 Upper strata of terrace fill; fine silt and sand with scattered medium gravels, fairly homogeneous along with strata 3; small scatters of rootlets throughout much of this strata; it exhibits light-to-medium compaction
- 3 Lower strata of terrace fill; silty sand, scattered gravels, underlying strata 2 for the entire length of the profile; primary difference between 2 and 3 is level of compaction, with 3 being much more compacted

**Figure 5.** North profile of WK5E-p showing regular spacing of terrace walls in this sector.

course high, other units documented terrace walls still standing as high as 65 cm, associated with fairly homogenous deposits of terrace fill, and stratigraphically below Huaynaputina tephra. On a 40% slope, isolated profile WK5E-p best illustrates the labor and technology the Chiribaya invested in agriculture on this coastal promontory. The profile is almost 11 m long, and it documents a total of eight stone terrace walls spaced at approximately 1.5-m intervals. Each terrace is constructed of stacked uncut/unshaped stones preserved to heights of 25–50 cm (Figure 5). Sediments associated with the terrace walls are fairly homogenous, and contacts between sedimentary deposits are gradational with only minor differences in compaction. Stone walls visibly extend laterally across much of the hillside, as well as both up- and downslope from the profile.

Also important is the use of stone footer walls in front of some principal terrace walls. These basal walls were typically smaller than, and located within 20–30 cm of, the main terrace wall, and they may have provided strength at the bases of terraces where the greatest pressure is exerted. Isolated profiles from Quebrada Agua Buena and the coastal promontory document a number of footer walls in those areas as well.

Though footer walls have not been documented elsewhere along the coast, low stone-faced terrace walls at Wawakiki generally conform to descriptions of Chiribaya

agricultural infrastructure recorded farther south at Carrizal Spring. There, Chiribaya stone-faced terraces average 35 cm in height, contain sediment fill with scatters of domestic refuse such as marine shell and ceramics, and they contrast sharply with field technologies of the later Spanish colonial and modern eras (Clement and Moseley, 1991:433). The contrast is just as striking at Wawakiki, which, among other things, allows for identification of buried Chiribaya agricultural terraces beneath colonial fields in both Quebrada Agua Buena and on the coastal promontory.

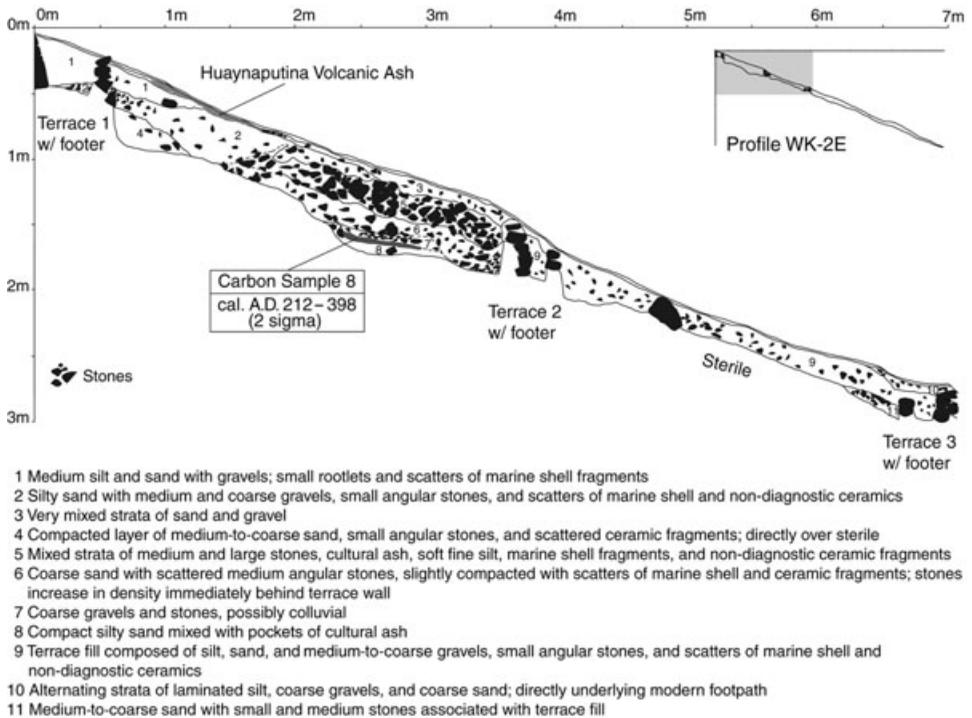
### **Quebrada Agua Buena Agricultural Land Use**

The Quebrada Agua Buena canyon wall angles downward at a 41% slope from the primary canal to the main channel. Data from isolated profiles WK2C-p and WK2E-p confirm that this area was heavily terraced during the Chiribaya period. Stone-faced terrace walls in these profiles range from 40 to 60 cm in height, and are spaced at roughly 3-m intervals. Strata associated with terrace walls are typically composed of dark sediments, scattered small angular stones, and fragments of marine shell and ceramics. Combined, the two profiles reveal five cases where terrace walls are associated with small footer walls, much like those observed in Quebrada Seca (Figure 6). Huaynaputina tephra is present in both profiles as well, clearly post-dating the terrace walls. In the case of profile WK2E-p, Chiribaya terraced fields partially overlie buried Early Ceramic period deposits that yielded an uncalibrated age of  $1793 \pm 33$  yr B.P. and calibrated age ranges of A.D. 270–340 ( $1\sigma$ ) and A.D. 212–398 ( $2\sigma$ ) (Table I, field sample 8).

### **Coastal Promontory Agricultural Land Use**

The coastal promontory lies near the distal end of both primary irrigation canals (see Figure 3). The terrain slopes downward at a 35% gradient from the Quebrada Agua Buena maximum elevation canal, and its surface is largely dominated by well-preserved Spanish colonial and modern-era remains of linear and caracol furrows (Figure 7). Caracoles are a particularly noteworthy traditional Andean technology consisting of sinuous secondary furrow canal systems that rationalize water use by providing moisture to the greatest area of cultivation and by maximizing infiltration to cultivated plants (Rivera, 1987:232). While caracoles were clearly in use during the post-Spanish colonial era, it is unclear whether this technology was employed during the Chiribaya period. Also, a single water impoundment tank lies near the upper northern extent of the area, and excavations to sterile sediments determined it to be of purely Spanish colonial and post-colonial construction and use. A total of 16 profiles and excavations were performed in this area, five of which lend strong support for intensive terracing and land use during the Chiribaya phase.

Isolated profiles WK3C-p and WK3H-p are located within the same rill and separated by only 2 m. Together they provide 24 total meters of profile data, extending downslope from just below the maximum elevation canal (see Figure 3). Despite considerable reworking of this terrain in historic times into linear sediment furrows, buried stone-faced terraces were identified in both profiles. In addition, buried lenses of Huaynaputina tephra are noted in three distinct locations, and by superposition



**Figure 6.** West profile of WK2E-p showing three terraces with associated footer walls just below the maximum elevation canal in Quebrada Agua Buena.

they are associated with strata that post-date terrace walls. Terraces identified in both profiles are constructed of stacked stone, typically preserved to heights of 35–50 cm, and spaced at approximately 2-m intervals. In several instances, footer walls are associated with principal terrace walls.

Farther downslope near the northern sea cliff, remains of similar stone-faced terraces were identified in isolated profiles WK3I-p and WK3J-p, though the terrain in this area is very steep, rocky, and unstable, making for poor preservation of pre-Hispanic agricultural infrastructure (see Figure 3). At WK3I-p, two walls spaced about 3 m apart were identified. The lower wall has been reduced to a linear pile of stones within 2 m of the sea cliff, while the upper wall is preserved to a height of 50 cm and is partially buried by linear furrows. While Huaynaputina tephra was absent here and cultural materials were few, poor preservation and terrace technology approximate much more that of the pre-Hispanic era than that of the Spanish colonial or modern periods.

Because field deposits are deeply buried near the lowermost portion of the coastal promontory, evidence for pre-Hispanic land use in this area is difficult to find. However, isolated profile WK3K-p lends some support for pre-Hispanic land use



**Figure 7.** View to the north of the coastal promontory at Wawakiki, showing pronounced Spanish colonial and modern-era sediment furrows on the surface. Colonial property wall is visible in the foreground (lower right).

(see Figure 3). This profile was excavated on the side of an early modern-era terrace, but because of time constraints, excavation was abandoned before reaching sterile sediments. Nonetheless, stratified sediment layers up to 1.75 m below the final planting surface were exposed. Noteworthy was the lack of cultural debris (e.g., ceramics and marine shell fragments) in strata 1–7, a characteristic of Spanish colonial and early-modern era fields. These layers exhibit considerable mixing and are largely composed of silt, sand, and gravels of light-to-medium compaction and scatters of small angular stones. However, lower levels 8, and especially 9 and 10, reveal an increase of tiny shards of undecorated ceramics, scatters of marine shell fragments, and medium angular stones, much more characteristic of pre-Hispanic terrace fill noted in other more securely dated contexts at Wawakiki. Boundaries between these lower layers are very gradational, with density of cultural debris being the primary difference. While certainly not as conclusive as agricultural infrastructure identified in other areas of the site, the presence of these deeply buried strata that approximate pre-Hispanic terrace fill encountered in other areas provides some support that late Chiribaya cultivation extended to the lower portion of the coastal promontory as well.

## DISCUSSION AND CONCLUSIONS

Data obtained from both canyon walls and the coastal promontory suggest that upwards of 11 ha were intensively cultivated during the late Chiribaya period, with much of the steeper slopes heavily modified with stone-faced terraces. At times, Wawakiki farmers utilized a technological innovation involving the use of footer walls that may have provided extra support at the base of main terrace walls. Clearly, this canal and terrace technology represents a well-engineered installation, a majority of which seems to have been constructed during the late Chiribaya phase. Sediments associated with stone walls are typically thick and fairly homogeneous, with little evidence of alluvial deposition from gradually eroding topsoil. This suggests that the construction of at least most individual terraces grew in a planned, systematic fashion, rather than incrementally over long periods of use and modification (for incremental construction, see Doolittle, 1984; Smith and Price, 1994). On a broad level, this irrigation system appears to have achieved its most extensive form during the late Chiribaya period, with terrace construction at the most distal end of irrigation canals still occurring in the 14th century. Such a system is often understood to require socially coordinated planning, engineering, and subsequent labor investments to sustain it, though, in this case, these were achieved very much at a local level. With substantial initial investments, the Wawakiki community transformed this arid coastal promontory into a highly productive landscape. Their advanced irrigation technology utilized relatively steep canals and stone-faced terraces and drastically increased agricultural productivity in an area where water is a very limited commodity and steep barren hill slopes are highly prone to erosion.

Agriculturalists along the Ilo River were undoubtedly feeling the combined effects of low highland precipitation coupled with continued water consumption by their upstream neighbors in the middle valley. However, the coastal aquifer is not directly recharged by the Ilo River and, therefore, agricultural systems among the coastal springs are not adversely affected by water consumption of inland valley farmers. Furthermore, while spring-supplied agricultural systems along the coast might respond quickly to fluctuations in highland precipitation (see Ortloff and Kolata, 1993), periodic coastal rains stemming from less-severe El Niño events between the 12th and 14th centuries may, in fact, have been beneficial to local production, since coastal precipitation would have certainly replenished the groundwater aquifer upon which agrarian systems such as Wawakiki were dependent (Magilligan and Goldstein, 2001:434; Dillehay et al., 2004:273). The very fact that such intensive land use occurred in this context of relatively low highland rainfall further testifies to a secure water supply at the site. Importantly, Wawakiki's position between two closely spaced quebrada channels permitted the construction of a multi-quebrada irrigation system that would have allowed farmers to take advantage of the dynamic nature of coastal spring discharge. Because of the overlapping hydrological regimes, farmers could utilize multiple sources of spring water to irrigate much of a single unit of land, principally those terraces located on the coastal promontory. Ultimately, the use of two independent spring sources may have been a response by local farmers to overcome fluctuations in spring discharge and, therefore, maintain a certain degree of stability in agricultural production.

Similarly, agricultural systems like that of Wawakiki may have been in position to withstand the typically detrimental effects of massive floods and debris flows associated with very strong and even rare “mega” El Niño events, such as that documented for the mid-14th century throughout many coastal valleys of Perú (Pozorski, 1987; Wells, 1987; Moore, 1991; Satterlee et al., 2001; Magilligan et al., 2001). Undoubtedly, the 14th-century flooding episode differentially affected lower valley and coastal Chiribaya settlements and production strategies. In the lower valley, widespread destruction of the principal canal by floods and debris flows led to the abandonment of roughly 77% of all Chiribaya sites, and there is no evidence of canal reconstruction until the Spanish colonial period (Reycraft, 2000:106). Similarly, some coastal Chiribaya settlements witnessed equally dramatic effects from the disaster, such as the settlement at Quebrada Miraflores, which was destroyed and deeply buried by massive debris flows that extended laterally across the pampa for distances upwards of several hundred meters from the main channel (Satterlee, 1993; Satterlee et al., 2001). At Quebrada Carrizal, debris flows covered nearly 75% of the available agricultural surfaces (Satterlee, 1993:215), and agriculture there continued at only 50% of its former production after the event (Reycraft, 2000:106). However, the topography in the Wawakiki area is markedly different than that of many of the spring sites to its south. The steep canyon walls of each quebrada, coupled with deeply incised and steep quebrada channels, did not permit excessive overland debris flows like those described at Miraflores and Carrizal.

There are, however, deposits of a massive debris flow along the banks of both quebrada channels. These units range from 30 to 60 cm in depth and consist of compact matrix-supported deposits of silt and sand containing rounded cobbles as large as 30 cm in diameter. This deposit likely dates to the mid-14th century, as only two massive debris-flow deposits are documented for the late Holocene in the area: The Miraflores unit of the late 14th century and the Chuza unit dated to the early 17th century (Keefer et al., 2003; Moseley and Keefer, in press). The Miraflores unit is generally composed of silty sand containing some coarser material as large as 8–25 cm in diameter or larger, while the Chuza unit is composed of silt, sand, and thousands of 1–5-cm angular rock fragments (Satterlee, 1993; Keefer et al., 2003:49–53). Given the absence of small angular rock fragments, the Wawakiki deposit more closely matches compositional descriptions of debris flows associated with the 14th-century event, rather than the later event of the early 17th century. Furthermore, the deposit noted at Wawakiki is the only debris flow of any size noted on the banks of the quebrada channels. However, this deposit extends beyond the channel margins for a distance of only about 4 m on either side, and it had little impact on the majority of the agricultural features occupying steep canyon walls or the relatively well-protected coastal promontory.

Wawakiki is not completely immune to El Niño events, however. Sheet flow during coastal downpours would have been a principal cause for concern on cultivated hillsides, and even minor coarse sheet-wash deposits are sporadically noted on terraces below the Chiribaya domestic sector. In fact, in all likelihood, the lead-off channels of each canal were completely destroyed by the mid-14th-century event, since they are often positioned near the quebrada channels themselves and thus in the paths of large debris flows. However, it is virtually impossible to determine by

superposition if new canal channels were cut through this debris flow immediately after the event, since the only canal segments preserved are located high up on the adjacent canyon walls. Unfortunately, modern road construction has buried those portions of the canals that would have intercepted flood deposits.

Radiocarbon age ranges from Chiribaya agricultural, marine, and domestic contexts at Wawakiki provide some support for minor occupation beyond the event but to what degree remains ambiguous. Calibrated age ranges suggest that: (1) Systematic terrace construction may have at least partially occurred during the middle of the 14th century (Table I, field sample 1); (2) intense marine exploitation occurred at least from the middle of the 14th century to the early 15th century (Table I, field samples 4–6); and (3) habitation terraces were occupied from at least the late 13th century to the middle of the 15th century (Table I, field samples 15–20). In addition, limited quantities of Terminal Chiribaya period post-flood ceramics were reported at Wawakiki in highly disturbed contexts, further suggesting some degree of post-flood occupation (Reycraft, 1997). In any case, while it appears that Wawakiki did not support an intensive pre-Hispanic occupation beyond the 14th-century flood event, the damage inflicted by massive debris flows would have been greatly limited compared to that of their southern neighbors along the coast and in the main river valley. The fact that Spanish farmers were able to reactivate the primary canal in Quebrada Agua Buena and cultivate much of the same terrain as their Chiribaya predecessors suggests that flood-related damage to agricultural infrastructure was indeed minimal. On a smaller scale, effects of other lesser flooding episodes associated with strong or very strong El Niños that likely occurred with greater frequency prior to this massive event would have also been reduced. In fact, where high-relief terrain characterizes the desert coastline, such as the nearly 20-km stretch midway between the Ilo and Tambo rivers, the lateral extent of debris flows from massive flooding episodes would be minimal.

Both long-term and punctuated environmental shifts—like prolonged drought or periodic flooding episodes—elicit varied agricultural and organizational responses from different sociopolitical levels of society (Dillehay and Kolata, 2004). Along the lower and coastal Osmore drainage, small communities invested heavily in labor-intensive irrigation and terrace systems, often making efficient use of local resources offered by their microenvironmental contexts. Decisions to intensively exploit coastal springs for agriculture during the late Chiribaya period may have, in part, been a regional response to diminishing agricultural potential in the Ilo River valley. On a more local level, however, small agricultural communities along the coast achieved various degrees of success and failure during this period, especially given both topographic variation and fluctuating rates of spring discharge. Multi-quebrada irrigation systems may have permitted increased stability in the face of long-term periods of aridity and fluctuations in spring discharge of an already reduced aquifer, while high relief, hillside-terraced systems may have been better equipped to withstand the punctuated impact of massive flooding episodes. At Wawakiki, colluvial deposits from steep, unstable canyon walls may have, in fact, posed greater concern for canal construction and maintenance along steep slopes than widespread flooding episodes.

Wawakiki is not unique, as remains of other agricultural communities exhibiting similar features lie farther north. The nearby uninvestigated Chiribaya site at Punta Callango (Figure 1) shares many topographical, technological, and production elements as Wawakiki, including its coastal upland position perched on a rocky sea cliff, labor-intensive hillside terraces, and lengthy canal networks. Future research will tell, but Wawakiki is likely only one of a number of small sea-cliff communities whose investment in laborious canal and terrace technologies may have allowed local farmers to flourish during this late Chiribaya period of climatic uncertainties.

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