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THE MIRAFLORES EL NIÑO DISASTER:
CONVERGENT CATASTROPHES AND PREHISTORIC AGRARIAN CHANGE
IN SOUTHERN PERU

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Introduction

This article describes a severe El Niño-induced paleoflood episode, the Miraflores Catastrophe, that produced flood deposits that currently overlie late prehistoric occupation surfaces in the Osmore River region of southern Peru (17° South Latitude; Figure 1). This El Niño event is pertinent to problems of change in agrarian subsistence patterns between A.D. 1100 and 1500. We first summarize these patterns. Second, we model change as a response to convergent catastrophes produced by collateral flood and drought disasters. Third, we describe and date evidence of the Miraflores Catastrophe. Fourth, we conclude with an assessment of implications of Osmore data for other Andean areas.

Problematic Change in Subsistence Patterns

Archaeological surveys and excavations in the Osmore River (also called the Moquegua River) extend from its headwaters through the river mouth to nearby littoral areas. Therefore, changes in coastal and sierra subsistence and settlement patterns can be interrelated. Open channel irrigation agriculture has sustained the indigenous economy for more than three millennia (Stanish 1985). In the sierra the principal source of agricultural water is surface runoff from seasonal precipitation averaging 400 mm at elevations above 3000 meter above sea level

(masl). Because the lower two thirds of the basin is arid to hyperarid (less than 250 mm/yr), river flow diminishes and normally disappears at 1200 masl adjacent to the site of Yaral (Figure 1). Here the drainage enters a deep, narrow canyon that transects the Clemenś Desert, the c. 1000 meter-high Coastal Cordillera, and its western escarpment where the Osmore River exits to the sea. Below 500 masl seeps and springs are the principal water sources for farming in the coastal valley and in normally dry drainages, called *quebradas*, such as Miraflores, which descend the Coastal Cordillera along short, steep courses that parallel the river.

Throughout the study area, farming formerly extended to large tracts of land that are no longer in production. The reclamation, use, and abandonment of planting surfaces can be dated with varying degrees of resolution by their canal associated settlements, construction techniques, furrow patterns, relative preservation, cultural superpositions, and geological superpositions (Clement and Moseley 1991; Owen 1993b; Stanish 1992; Williams 1997). Abandoned planting surfaces and their dependent settlements document a major shift from low elevation to high elevation farming between AD 1000-1500.

Coastal agriculture, including that practiced in the Osmore Valley and the *quebradas*, is inferred to have reached its maximum extent

around AD 1000-1100 because planting surfaces have their greatest spatial expansion at that time both in the valley and in the coastal quebradas. Early agrarian expansion around A.D. 1000 is associated with the rise of the coastal Chiribaya culture (Jessup 1991; Owen 1993a), which spread into the arid sierra between Yaral and the modern city of Moquegua prior to collapsing shortly before A.D. 1400. This Chiribaya collapse was abrupt (Jessup 1991), and it entailed the permanent abandonment of more than 80% of all coastal settlements (Owen 1993b) and an inferred population decline of equal magnitude. By A.D. 1400 all preserved prehistoric surfaces in this area had been abandoned, and hydrological models suggest that productive coastal farmland had declined by 80% or more (Ortloff and Kolata 1993). Cultural reorganization ensued, but coastal population levels remained depressed until A.D. 1500 or later (Reycraft 1997). Limited recovery of farmland is not evident until the Spanish introduced olive tree cultivation around A.D. 1575 (Clement and Moseley 1991; Satterlee 1993).

Large scale reclamation of the high sierra above 2250 masl began after A.D. 1300. By A.D. 1500 planting surfaces on canal-irrigated terraces reached their greatest spatial expansion and the majority of the Osmore population resided in the sierra headwaters (Conrad and Webster 1989; Owen 1994; Williams 1997). Highland expansion is associated with the Estuquifña and Estuquifña-Inca archaeological culture that endured into the Colonial Period (Burgi 1993; Stanish 1985). High elevation irrigated terracing was, in part, de-emphasized by the Inca policy of resettling indigenous communities at lower altitudes (Van Buren 1993, 1996; Van Buren *et al.* 1993), and it further declined with the Spanish introduction and expansion of viticulture at elevations between 1200 and 2250 masl (Rice 1997).

In overview, we estimate that more than 80% of all prehispanic farming and settlement in the Osmore drainage shifted from the coast and dry sierra below 2000 masl into the humid sierra above 2250 masl between A.D. 1000-1500. This

major change in economic and demographic conditions has not been previously explained.

Convergent Catastrophes

We propose that the transformation of the Osmore subsistence and settlement patterns was a response to "convergent catastrophes" — crises produced by two or more collateral natural disasters. The nature of convergent catastrophes can be illustrated by an analogy between human disease and natural disasters. Suffered individually, a disease or a disaster is generally survived by a healthy population. Yet, when a population is first struck by one malady and then is afflicted by two or more disorders, the likelihood of recovery is reduced. The potency of multiple natural disasters lies in the compound stress that they exert upon populations. Some may collapse, while others can respond adaptively. In late prehistoric times Osmore River populations experienced two catastrophes. The first, protracted drought, gradually exerted pressures favoring high altitude reclamation, while selecting against low altitude farming. The second catastrophe, the Miraflores flood, triggered intense pressure for rapid change from an agrarian-based economy.

Collateral Drought

The A.D. 1100-1500 drought exacerbated the impact of the Miraflores El Niño. Precipitation is estimated to have declined by 10%-15%. However, the decline in runoff was disproportionately greater because headwater soils always absorb a fixed amount of moisture, 260 mm, before saturation allows runoff. Because annual precipitation averages 360 mm between 3900 and 4900 masl, there is only 100 mm available for runoff in a typical year. When rainfall declines from 360 mm to 324 mm or even 306 mm during a 10% or a 15% drought, runoff is reduced to 64 mm or to 46 mm, respectively. Thus, the relationship between loss of rainfall and loss of runoff is nonlinear. Factoring in water from above 4900 masl, we estimate that runoff from the moist sierra was at least 20% to 30% below normal during the attenuated

drought of A.D. 1100. This decline was compounded by the fact that river flow loses 4% of its volume per kilometer to seepage and evaporation at elevations of 2000 to 3000 masl (Williams 1997). At lower elevations increasing aridity, greater evaporation, and longer transport distances magnify forfeiture of moisture.

Rainfall in the wet sierra and stream flow supply subsurface runoff that eventually charges the coastal aquifer. Much of this moisture never resurfaces in the lower valley or coastal quebrada springs that are the primary mainstay of farming. Subsurface runoff passes through fine grained deposits of the Moquegua Formation that absorb fixed amounts of moisture. Similar to soil absorption, this action magnifies drought-induced loss of subsurface runoff. Thus, 10% to 15% declines in mountain rainfall result in highly amplified spring flow declines. Mathematical modeling suggests a minimum decrease in spring flow of 80% at Quebrada Carrizal during the nadir of the A.D. 1100 drought (Ortloff and Kolata 1993).

Based on our geoarchaeological observations, we concur with Ortloff and Kolata (1993) that irrigation agriculture in short, steep drainages of the arid Pacific watershed is highly responsive to depressed highland rainfall. Therefore, drought stress was most severe at the distal, lower end of the Osmore Basin. The impact of the A.D. 1100 drought on the Carrizal Quebrada spring-fed canal systems, in the lower Osmore Drainage, is calculated to have reduced arable land by more than 80% (Clement and Moseley 1991; Figure 2). This reduction is compatible with the large scale abandonment of planting surfaces after A.D. 1000 and with marked reductions in the size of residential settlements at the spring (Bawden 1989; Clement and Moseley 1991; Reyecraft 1997). We consider Carrizal land loss to be symptomatic of reduced moisture in the coastal aquifer and therefore indicative of concomitant stress on other areas of spring-dependent farming, including the large prehistoric Osmore Canal System in the coastal valley (Satterlee 1993).

At the opposite end of the river basin, we model the expansion of high altitude farming as

a drought response that maximized the use of scarce rainfall and runoff. Osmore headwater reclamation relied principally upon canal-irrigated agricultural terraces. Their adaptive advantage lay in capturing moisture at or near its source, thereby minimizing runoff flow loss. Reclamation of the upper sierra spread after A.D. 1300 and peaked between A.D. 1400 and A.D. 1500 (Owen 1994; Stanish 1992; Williams 1997). Disadvantages of high altitude irrigated terraces include high construction and maintenance costs, high earthquake vulnerability, and reduced crop variation at high elevation. These factors were of greater relative importance after the A.D. 1500 advent of the Little Ice Age, which is associated with two centuries of 20-25% above normal precipitation (Binford *et al.* 1997; Thompson *et al.* 1986). Greater rainfall allowed re-establishment of sierra farming at lower elevations, recharging of the coastal aquifer, and re-expansion of littoral spring-fed farming.

Catastrophic El Niño Flooding

During strong El Niño-Southern Oscillation (ENSO) events the Osmore rainfall regime reverses. Drought prevails at altitudes above 2000 masl, and rainfall occurs in the lower watershed (Caviedes 1984; SPCC 1985). Moquegua City experienced several showers during the very strong ENSO event of 1982-83, and torrential rain and limited flooding occurred in the Cumesí Desert. The steep Pacific escarpment of the Coastal Cordillera orographically influenced cloud cover moving off the ocean and intensified precipitation along the mid and upper slopes of the maritime range, resulting in three separate incidents of coastal flooding during the 1982-83 event. During the minor 1992 event, we observed no rain below 200 masl, but some quebradas with affluents high in the maritime range discharged small mud flows into the sea. The very strong event of 1997-98 was generally similar to that of 1982-83. There were showers, but no flooding in the vicinity of Moquegua City. Some Cumesí quebradas flooded and inundated sections of the Pan American highway, while episodes of strong

flash flooding transpired along the Pacific escarpment of the Coastal Cordillera.

Below 2250 masl, most slopes of the watershed are covered with loose, weathered rock and unconsolidated sediment. This material can be entrained by runoff from ENSO precipitation. For exceptionally severe rainfall events, we define, based on our observations, three stages of runoff: entrainment, debris-flow, and flood generation below 1500 masl (Figure 3). First, during deluges, sheetfloods and debris flows composed of sediment and water wash down hill slopes (1 in Figure 3). Some material comes to rest on the lower slopes and hill bases. More typically it flows into small channels that carry moisture and sediment to larger quebradas. Here additional matter is commonly entrained from the drainage channels, creating flash floods and large debris flows of viscous mud and coarse sediments (2 in Figure 3). Quebrada floods discharge into the sea or into the Osmore drainage. Third and finally, a high flood surge descends the Osmore River valley carrying runoff and debris from the interior basin (3 in Figure 3). Flood surges descending large and small channels splatter mud and deposit coarse debris. Surges are followed by low flows of relatively clear slack water, which deposit fine sediment. With the cessation of rainfall, debris flow and flood deposits dry and harden, thus providing a geologic record of the event. For example, deposits produced by the 1982-83 ENSO event remain well preserved, as do deposits of some earlier events.

Our studies indicate that the Miraflores flood episode was the most severe El Niño catastrophe to occur in the study area during the last millennium. It destroyed much of the Chiribaya cultural landscape along the deeply incised Osmore drainage. Most farming transpired in valley bottom land only slightly higher than the active river channel. Settlements were typically strung along steep valley sides above canals that provided potable water. Escaping the Miraflores deluge would have been difficult because the valley-side settlements were the first to be inundated by sheetfloods and debris flows descending

hill slopes. Lateral movement was then cut by flash floods cascading down quebradas. Finally, a very high flood surge plunged down the Osmore river channel spilling over its lower banks.

High fatalities are inferred because some settlements were entirely washed away, and others were completely buried by debris flows. Yet, some sites on high, well drained promontories escaped destruction. Flooding wreaked exceptional havoc on low lying irrigation systems. The Osmore Canal, the highest, longest reclamation system ever built in the lower valley, suffered extensive damage. The intake and lead-off channel were swept away. The canal was breached and cut at every quebrada crossing, washed off every steep slope, and completely buried along every gentle slope (Satterlee 1993). Damage to spring-fed irrigation systems in coastal quebradas was variable. Although intakes and quebrada crossings were destroyed, distal planting surfaces and canal sections on high ground survived at Chuza, Carrizal, and Pocoma (Figure 2). However, the entire irrigation system at Miraflores Quebrada was washed away. Pervasive damage to the agrarian infrastructure must have contributed to post-disaster famine. The spread of pestilence and disease can be reasonably inferred because these conditions have accompanied historic El Niño disasters (Beck and Davies 1976; Caviedes 1984; Murphy 1926; Satterlee 1993).

The 1982-83 ENSO event was associated with pronounced drought at high altitudes that affected both pasture and farmland and led to famine in the altiplano. In contrast, desert precipitation sustained extensive blooms of *lomas* vegetation that provided pasture for domesticated animals (*lomas* are dispersed communities of wild plants normally sustained by winter fog condensation; Dillon 1985). We also observed limited farming in *lomas* areas. However, returns from *lomas* exploitation were minor in comparison to El Niño-induced losses. Presumably, similar conditions prevailed during the Miraflores disaster. Elevated ocean temperatures accompanying the ancient ENSO event also must have affected normal marine re-

sources, but fishing certainly recovered faster than did farming.

Consequences of Drought and Flood Catastrophes

Prior to the Miraflores catastrophe, two and a half centuries of drought led to the gradual agrarian contraction of spring-fed irrigation systems in the lower valley and in coastal quebradas (Ortloff and Kolata 1993). Upstream expansion of Chiribaya culture from the coast into the mid-valley sierra can be modeled as an adaptive response, particularly if highland settlements were exporting agricultural produce to the lowlands. Dietary diversification may represent another drought response. In the lower valley there was a long-term increase in the variety of plants used and consumed by Chiribaya populations (Dendy 1991). Sustained by ocean fog, *lomas* vegetation supported intensive llama herding (Wheeler 1991), and there was also substantial exploitation of seafood (Bawden 1989; Jessup 1990).

Although catastrophic loss of life is inferred for the Miraflores disaster, the meager demographic recovery in the study area is particularly noteworthy. In addition to the Osmore valley, Carrizal Quebrada also exhibits a comparable decline in population with poor post-flood recuperation (Bawden 1989; Reycraft 1997), and we have found scant evidence of post-flood occupations in other coastal quebradas. We hypothesize that demographic recovery was tied to agrarian recovery which, in turn, was hindered by continued drought. There was simply insufficient water to warrant reconstructing the Osmore Canal System or to reactivate coastal spring-fed farming, other than on a very minor scale. Consequently, once Chiribaya was impaired by an El Niño disaster, it could not recover its former cultural preeminence in the Osmore drainage.

We postulate that between A.D. 1200 and 1400 there was insufficient rainfall and runoff to support intensive farming in either the upper or the lower sierra. During drought, high altitude farming draws off stream flow needed to sustain lower elevation irrigation. With the exception of

one high altitude farmstead (Stanish 1992), the Chiribaya sierra occupation focused exclusively upon the use of river runoff below 2000 masl. This focus facilitated interchange with the lower valley and perhaps helped to charge the depleted coastal aquifer. Yet, arid sierra irrigation is hydrologically inefficient during drought because runoff flows long distances with significant loss before reaching planting surfaces. A major consequence of the Miraflores catastrophe was the removal of cultural constraints on high sierra agrarian reclamation. Although efficient, headwater farming drew down runoff supplies, and, consequently, downstream the Yaral section of the Osmore River remained out of production until the Colonial Period.

Systematic survey and excavation of settlements in the Otoro River headwaters indicate that this area was colonized before the flood by small groups of people living in open farmsteads. They constructed very long canals to reach gently sloping land that did not require large investments in terrace construction. This was a labor-saving, but water-expensive irrigation strategy. The strategy was reversed to one of shorter canals irrigating steep, terraced slopes during the Estuquiña occupation, when the number and size of settlements increased dramatically (Stanish 1985, 1992). Throughout the Osmore headwaters all major Estuquiña settlements were fortified (Borstel *et al.* 1989; Owen 1994; Rice *et al.* 1989; Stanish 1992). However, warfare and physical conflict are not evident in Estuquiña mortuary populations that have received study (Buikstra 1995; Williams 1990). Nonetheless, we suggest that settlement fortification reflects concern with maintaining claims to scarce water resources and arable land. Conquest was involved in the Inca and Spanish intrusions into the Osmore drainage. We propose that their policies of resettling indigenous people and re-expanding agriculture at lower elevations were made tenable by increasing rainfall that exceeded long-term norms after A.D. 1500.

The Miraflores Unit

Flood deposits that overlie Chiribaya cultural remains comprise the Miraflores Unit of the local Holocene geological column, which has a partially dated "Basal Sequence" of earlier deposits (Keefer *et al.* 1998). Miraflores sediments are often overlain by: the A.D. 1600 Huayna Putina Unit of tephra (Thouret *et al.* 1999); the Chuza Unit of earthquake and flood debris tentatively dated to A.D. 1607; and flood deposits from the 1982-1983 and the 1997-98 El Niños. The tephra unit is securely dated to the February A.D. 1600 violent eruption of the Huayna Putina volcano located about 120 km northeast of Ilo. This is the only late Holocene as well as early historic period tephra to be identified in the entire Osmore drainage, and samples from the Moquegua region have been chemically identified in and cross-dated to the Quelccaya ice cores (Thompson *et al.* 1985).

The Miraflores Quebrada

With affluents high in the Coastal Cordillera, the incised Miraflores drainage is the coastal type locality for the Miraflores Unit. The quebrada exits the range through a constricted canyon, where a number of springs fluoresce. The canyon opens onto a short coastal plain that the drainage crosses in a narrow, incised channel more than 2 m deep (Figure 4). In the canyon, mud and debris flows produced by the 1982-1983 ENSO event resulted in deposits that buried springs and inundated grove areas. Downstream from the canyon in the coastal plain area, the flows were largely contained within the incised quebrada channel. The 1982-1983 deposits are typically a few centimeters thick, with a maximum observed thickness of 20 cm. They are composed mostly of sand and silt with a few pebbles and rock fragments less than 4 cm in diameter.

Deposits of the Miraflores Unit are of a much greater order of magnitude, with a thickness ranging up to 1.0 to 1.2 m. They extend up the canyon walls and expand laterally out of the quebrada channel, across the coastal plain down to the sea (Figure 4:1). Miraflores flooding also

transported large clasts and boulders up to 3 m in diameter across the coastal plain. There are no subsequent flood deposits of comparable scale in the sedimentary record preserved at the Miraflores Quebrada, including the historic Chuza Unit.

A measured section through the Holocene sedimentary sequence is shown in Figure 5. This section is in the bank of a tributary to the main Miraflores quebrada (Figure 4:2). The uppermost unit exposed in the section is the 0.005 m thick deposit from the 1982-1983 El Niño event that consists of grayish-brown silty sand, containing some grit up to 0.002 m in diameter. Below this deposit is .3 to .7 m of dark yellowish-brown aeolian sand, containing a little silt. Underlying this stratum is the Chuza Unit, a 0.15 to 0.2-m-thick layer of very compacted silty sand, that is dark yellowish-brown in color and contains much grit and some rock fragments up to about 0.07 m in diameter. Below the Chuza Unit is another layer of aeolian sand with a little silt, which is 0.0025 m thick. Below this sand lies the Miraflores Unit deposit consisting of 0.66 to 1.00 m of well-compacted silty sand, pinkish gray in color and containing rocks up to 0.08 m in diameter. Underlying the Miraflores deposit is a 0.01-m-thick layer of brown aeolian sand containing little silt. The lowest unit, the base of which is not exposed, is 0.45 to 0.8 m of the pre-Miraflores Basal Sequence that consists of brownish-yellow coarse sand, containing a little silt and gravel, and rocks up to 0.8 m in diameter.

The Miraflores event swept away the local Chiribaya occupation in a torrent of water, mud, and huge boulders, leaving the characteristics of this culture to be inferred from better-preserved Chiribaya remains in adjacent quebradas. At Miraflores, the indigenous irrigation system presumably extended from the springs down the canyon onto the upper margins of the coastal plain. This system was operational when spring flow was greater than it is today and distal fields extended somewhat farther downslope than the confines of the Colonial olive grove that was enclosed by a large stone wall (Figure 4:3). The

Chiribaya settlement was situated on the south side of the quebrada immediately below the irrigation system. Residential structures extended for at least 100 m along the quebrada channel and for an equal distance inward across the coastal plain (Figure 4:4). The habitation area was large because the Miraflores spring flow was high and could support a large agricultural system in comparison with the 10 other irrigated quebradas that we have investigated.

Chiribaya residences typically occupy long residential terraces, cut into the natural substrate and back-filled along retaining walls that may be faced with mortarless stonework. Rectangular rooms and compartments are of cane construction, with bound canes set vertically in narrow trenches and vertical posts supporting mat roofs of plant material. Quebrada settlements occasionally include special purpose buildings in the form of large, semisubterranean, one-room structures. Occupational refuse is common, and midden with plant debris often occurs in terrace fill.

Surface traces of the Miraflores settlement are now limited to low irregularities in the overlying Miraflores deposits produced by remnants of domestic terraces and two semisubterranean structures. Exploratory tests in the area include 12 shallow 1 x 1 m probes, a 2 x 2 m probe in the east wall of the northernmost sunken structure, 1 m trenches across both sunken structures, and a 1 m wide x 2 m deep x 8 m long profile cut from the quebrada channel into the settlement (Satterlee 1993). These probes revealed the heavily eroded outlines of structural features, such as terraces, that were originally cut into the consolidated substrate. Architecture of cane or masonry built atop the substrate was gone. Similarly, refuse and midden had been swept away prior to the deposition of at least 0.68 m and possibly as much as 1.2 m of fine debris. Excavated artifacts from the trenches were limited to three shards and several fragments of cane.

However, the walls and the depth of the north sunken structure had allowed for the

entrapment and subsequent preservation of more cultural materials. The 2 x 2 m test in the east wall of this sunken structure produced seven Chiribaya shards, one unidentifiable shard, spun alpaca threads, four textile fragments, a fragment of corn stalk and cob, and a few guinea pig bones. There is no evidence of post-flood farming or settlement by indigenous people. However, surface evidence of reoccupation close to the springs would be obfuscated by later centuries of olive farming.

Olive trees were first planted in the Miraflores flood sediments before the deposition of thin, intermittent accumulations of tephra from the February A.D. 1600 eruption of the Huayna Putina volcano, located about 120 km northeast of Ilo. Shortly after this eruption, the Chuza Unit was deposited, and at a number of points along the quebrada the Miraflores Unit is overlain by tephra, by the Chuza Unit, and by the 1982-1983 mud flows.

The Osmore Canal

The river type locality for the Miraflores Unit is the Tomb Site on the prehispanic Osmore Canal System (Figure 6: site 266; all site numbers are from Owen 1992), the largest irrigation system ever erected in the lower drainage. Apparently built by A.D. 900 or 1000, the system was operational when Chiribaya people shared the lower valley with an ethnically distinct populace called the Ilo-Tumilaca/Cabuza (I-T/C) population. Over time the latter population diminished; whereas the Chiribaya population grew. Occupying hillsides above the second planting surface (Figure 6: site 215), the IT/C site of Loreto Alto is one of the larger settlements potentially associated with the irrigation system. Loreto Alto produced four calibrated ^{14}C dates that fall between A.D. 1000 and 1250 (Owen 1992), and we presume that the irrigation system was operational at this time.

Historic and recent farming have taken place along the river floodplain and on sections of very low fluvial terraces. Irrigated by short

canals, this accessible land was presumably reclaimed early in antiquity. Other potentially arable land is much less accessible to river water because it is limited to remnants of a high (5-15 m) fluvial terrace that survives discontinuously, primarily along the north side of the canyon. Designed to irrigate three widely separated northern remnants of the high terrace, the Osmore Canal originated in a bedrock constriction in the valley that forms a hydrologic choke, forcing underflow and ground water to surface (Figure 6). The canal pursued an inclined contour course along the canyon side. To reach arable terrace surfaces, it traversed many near-vertical bedrock faces along a course cut into the mountain side and supported by masonry suspension structures. The Osmore system was water costly because it transported water over such long distances between irrigated terraces, and earth bank canals of this length typically lose more than 50% of the water they transport. Therefore, we infer that the canal was originally constructed when spring and stream flow were substantially greater.

The Tomb Site

Erosional and depositional features associated with the Miraflores Unit interdict the ancient irrigation system along virtually all of the 9 km canal course and completely obliterate it in many areas. The remarkable height of the paleoflood surge that swept down the canyon is revealed at the Tomb Site (Figure 6: Site 266). This site is located in a short, steep bedrock gully crossed by the intake section of the canal that here was only 5.8 m above the active flood plain. The narrow gully was crossed by a short earthen aqueduct created by infilling behind a two-step, boulder-faced retention terrace (Figure 7). Limited occupation developed in the gully above the canal. Potable water drawn from the canal was stored in a sunken circular cistern, constructed of masonry, beside the channel. After the destruction of the canal, the cistern was used as a tomb for an adult. Because of recent erosional undercutting, some two-thirds of the cistern and most of its burial content had slumped downhill by 1989. Excavation of the remaining fill yielded

human bone and a fragmentary wooden artifact, which was ^{14}C dated to A.D. 900 ± 35 yrs. (PITT 0949, uncalibrated; cal A.D. 983-1154, 2 sigma, using Stuiver and Pearson 1993).

Some 8 m upstream from the cistern, slumping exposed the deposits banked against the canal that are illustrated in the stratigraphic profile, Figure 7. The oldest unit in the profile (except for the canal itself) is a talus deposit, consisting of small, angular rock fragments, weathered from nearby bedrock that slid down the gully, burying the canal and upper terrace face (Figure 7 a). This unconsolidated talus includes a minor admixture of cultural debris from the human occupation immediately upslope. There is no evidence of subsequent occupation in the gully, and the canal did not function after it was buried. Burial may be interpreted as the product of ENSO rainfall and runoff transporting this rocky debris down the gully and over the canal. If this supposition is correct, then significant ENSO-derived flow began in this gully (and, presumably, other nearby gullies) even before the principal Miraflores river flood surge reached this point in the main valley.

The main river flood surge deposited pinkish sandy silt, comprising the Miraflores Unit here, against the masonry support structure of the canal (Figure 7 b). The top of the surviving deposit is 4.3 m above the active river channel. The Miraflores Unit is in turn overlain by thin deposits of the Huayna Putina tephra (Figure 7 c). The tephra is capped by the Chuza Unit (Figure 7 d) which is a compact debris flow composed of talus material from the lateral gully. Chuza river flow material was not exposed in this profile. Loose talus debris partially covers the Chuza Unit. Flood deposits from the 1982-1983 ENSO event occur near the base of the profile, 1.5 m above the active river channel (Figure 7 e).

First Planting Surface

Downstream from the Tomb Site, the Osmore Canal rose well above the river bed and

the Miraflores flood surge. However, the Miraflores-Huayna Putina tephra-Chuza-1982-1983 flood sequence recurs in overbank deposits at many sites along the river course. Figure 8 illustrates the deposits banked against the first irrigated terrace where the cut bank of the terrace is about 3 m high (Figure 6: Site 236). Here, the Miraflores Unit is about 1.45 m thick. The lowermost 1.2 m of the Unit consist of sand and silt containing rock fragments and rocks as large as 0.25 m in diameter; these deposits are interpreted as being derived from a local tributary quebrada. Above these are 0.2 m of fine sands and silts, devoid of rocks, which are interpreted as being deposited by the flood descending the main valley. The upper few centimeters of the riverlaid sediments are a fire-altered pinkish-white color, and the Unit is covered by a 0.03-m-thick layer of carbon that resulted from local burning of cane and vegetable matter. The carbon deposit is, in turn, overlain by 0.02 to 0.03 m of volcanic ash, which is capped by 0.1 m of aeolian sand. The overlying Chuza Unit consists of 0.8 m of coarse colluvial sand with numerous rock fragments and angular clasts up to 0.2 m in diameter. It is capped by 0.02 to 0.04 m of aeolian sand layer overlain by 0.4 to 0.55 m of post-Chuza El Niño debris that is topped by aeolian sand mixed with anthropogenic vegetable matter. River flood deposits from the 1982-1983 El Niño flooding are represented by a splatter of sand and silt plastered against the Miraflores Unit about 4 m above the modern channel.

Other Sites

At the first planting surface, and elsewhere, the exceptional height and thickness of the Miraflores Unit stands out in sharp contrast to the more modest river flood deposits from the 1982-1983 ENSO event. Because most of the Osmore Canal System occupied high ground, it was not destroyed by the main Miraflores flood surge that descended down the river course. Rather, it was destroyed by collateral runoff that descended down the canyon sides and by mud debris flowing out of the tributary quebradas; the canal was completely washed away at every quebrada it crossed. Where the canal ran along

the rear of irrigated terraces it was buried by thick deposits of sediment that washed down adjacent hill slopes. Systematic survey has identified no surface exposures of intact canal and has shown that the destruction of the canal was essentially total (Satterlee 1991, 1993). Traces of the field terraces and planting surfaces do survive on sections of the second (Figure 6: Site 215) and third (Figure 6: Site 208) irrigated terraces. On the second terrace, a post-flood indigenous settlement was established on abandoned planting surfaces that were never farmed again. Nonetheless, there have been no Chiribaya or I-T/C cultural remains found stratigraphically above the Miraflores Unit in the lower valley.

Situated on the south side of the valley about 5 km upstream from the coast, Chiribaya Baja is one of the biggest prehispanic settlements in the lower Osmore drainage (Jessup 1991). Cane-walled structures occupied the tops of large residential terraces that were built along more than 300 m of the lower valley slopes. Examination of numerous looters' pits and a nearby river profile indicates that an extensive flow of colluvial debris swept over the occupation area inundating cane buildings and collapsing others. The flood deposits are overlain by tephra, which is, in turn, capped by another flow of colluvial debris. We interpret the stratigraphic sequence as Miraflores, Huayna Putina, and Chuza Units. Outside the valley proper we have examined a number of Chiribaya sites that occupy high terrain that is not subject to inundation from upslope runoff. These sites are capped by tephra, but not by flood deposits.

Initial geoarchaeological reconnaissance in the upper drainage has not identified the Miraflores or Chuza Units at elevations above 2,000 m. We presume that this absence results from the drought experienced by the high sierra during ENSO events. However, paleoflooding is evident in the lower, usually arid sierra. Sierra farming ends where the middle valley constricts into a narrow gorge, and the large site of Yarl is situated above the last arable land (Figure 1). The Chiribaya occupation was located on the

top of a fluvial terrace remnant more than 7 m above the active flood plain and on steep hill-sides behind and above the terrace. Occupational remains are capped by two separate flood deposits, separated by volcanic tephra, a sequence indicative of the Miraflores, Huayna Putina, and Chuza Units. The Miraflores flood deposits are extensive. They comprise thick sediments that poured down hill slopes into and over the Chiribaya settlement. While the Chiribaya settlement in the Miraflores Quebrada was swept away, the Yaral settlement was simply buried by collateral debris flow, and so domestic terraces and cane wall structures are relatively well-preserved. A three-fold flood-tephra-flood sedimentary sequence is also exposed in the terrace bank below the settlement. The upper flood deposit appears to be Chuza colluvium. Here the Miraflores flood deposits are comprised, at least partly, of fluvial material, suggesting that the river flood surge was about two meters high. A surge of this magnitude would decimate contemporary irrigation agriculture that occupies areas that are little higher than the river flood plain.

Dating

At the Tomb Site, a charcoal sample taken from a plant ash and carbon lens, partly overlying and partially incorporated into the Miraflores deposits, yielded a ^{14}C date of A.D. 1360 \pm 35 yrs. (PITT-0948, uncalibrated; cal A.D. 1314-1437, 2 sigma, using Stuiver and Pearson 1993). This ash and carbon lens, which was capped by Huayna Putina ash, probably slumped down into the moist flood deposits from the pre-flood human occupation material immediately upslope in the gully.

In terms of the regional archaeological sequence for the Osmore drainage, we postulate that the Miraflores Unit dates to the end of the Chiribaya Phase occupation. In the lower valley and in coastal quebradas the Miraflores Unit stratigraphically overlies Chiribaya and I-T/C occupational surfaces. In mid-valley, at an elevation of 1200 m, Miraflores, Huayna Putina, and Chuza deposits overlie a Chiribaya cemetery

and residential architecture at Yaral, where excavations indicate that the extensive Chiribaya occupation was brought to a devastating and abrupt end by Miraflores flooding. Archaeological evidence indicates that no Chiribaya or I-T/C remains have been found stratigraphically above the Miraflores Unit in the Osmore drainage or in coastal quebradas.

In the regional cultural sequence, Chiribaya-style art and architecture are succeeded by the Estuquiña-style and then Estuquiña-Inca materials (Jessup 1990; Owen 1992, 1991; Stanish 1985). In the lower valley, the replacement of Chiribaya by Estuquiña has been characterized as abrupt with no evidence of temporal overlap (Jessup 1991). Surface remains associated with the post-flood settlement atop the second terrace (Figure 6: Site 215) of the Osmore Canal System appear to be of Estuquiña affiliation. At Carrizal Quebrada, late prehispanic burials yield Estuquiña ceramic forms that are also associated with Burro Flaco cultural remains that overlie Miraflores deposits at the mouth of the Pocoma Quebrada (Reycraft 1997).

If the Miraflores Unit were the product of severe El Niño conditions, then these conditions should be reflected in ice-core data from Quelccaya glacier, located about 200 km north of Ilo. The composition of the glacial material is sensitive to climatological perturbations and provides chronological constraints for past ENSO events (Thompson *et al.* 1984). For late prehistoric times the ice core data indicate: 1. below average precipitation from A.D. 1000 to 1500; 2. drought episodes at A.D. 1250-1300 and 1450-1500; and, 3. periods of ENSO activity at A.D. 1270-75, 1350-1370, and 1482-1493, with the A.D. 1350 episode being pronounced (Thompson *et al.* 1985; Thompson, personal communication 1995).

The last of the three periods of ENSO activity is not compatible with the dating of the Miraflores Unit; the 1482-93 date falls within the era of Inca domination and can be eliminated because late pre-Inca remains overlie

Miraflores deposits at several sites. Calibrated radiocarbon dates on Chiribaya remains indicate that this occupation spanned the A.D. 1270-1275 episode of ENSO activity without interruption (Owen 1992). In contrast, Chiribaya remains have not been found stratigraphically above the Miraflores Unit. Therefore, the unit does not appear compatible with this early period of El Niño conditions. Deposition of the Miraflores Unit, however, is compatible with the A.D. 1350-70 episode of pronounced ENSO activity recorded in the Quelccaya cores, based both on these stratigraphic relations and on the ^{14}C data discussed above.

In the Quelccaya glacial cores, the dating of the A.D. 1350-1370 ENSO activity is based upon counting varve-like annual deposits of both wet season snow and dry season dust accumulations (Thompson *et al.* 1984). This method offers more precise chronological calibration than that of the available ^{14}C assays pertaining directly or indirectly to the Miraflores Unit. Nonetheless, the available ^{14}C data conform to the ice core dates, and we therefore postulate that the Miraflores episode of paleoflooding occurred during the A.D. 1350-70 ice core episode of pronounced ENSO activity.

Implications

The Andean paleoflood record must be interpreted with caution. Large flood deposits can result from large quantities of El Niño rainfall. They can also result from smaller quantities of ENSO precipitations that entrain debris dislodged by a preceding earthquake of large magnitude (Moseley *et al.* 1992). We believe the Chuza Unit was produced by A.D. 1607 El Niño runoff that entrained copious material dislodged by the A.D. 1604 magnitude 8.5 earthquake. Therefore, large Chuza flood deposits should be restricted to the region impacted by the earthquake.

Chuza deposits often contain high quantities of large, angular sediments derived from the Coastal Cordillera, and well-preserved plant inclusions. Plants survive only as molds in Mira-

flores deposits which, in the lower valley, contain substantial quantities of fine, red sediment derived from the inland Moquegua Formation. These features suggest large quantities of water. If the deposits resulted exclusively from ENSO rainfall and runoff, then the Miraflores Unit should represent a geoarchaeological horizon marker produced by exceptionally severe El Niño conditions that affected the entire Cordillera. Assessing this possibility is hampered by problems of cross-dating distant paleoflood deposits to one another and to the glacial ice cores. El Niño flooding dated to A.D. 1300 or shortly thereafter has been reported for the Casma and Moche drainages of northern Peru (Moore 1991; Pozorski 1987; Wells 1987). Therefore, the possibility that the Miraflores El Niño episode was a Pan-Andean catastrophe should not be dismissed.

If the A.D. 1100-1500 drought affected the entire central Andean Cordillera, as is probable, then the decline in precipitation at high elevations constituted a water loss that was amplified progressively at successively lower elevations along the arid watershed. Therefore, drought stress was greatest on coastal populations and relatively less severe on sierra populations. In the sierra, agrarian reclamation of high terrain in close proximity to restricted rainfall should prove to be pervasive after A.D. 1100. Decades ago Donald Lathrap (1970) pointed out that along the eastern watershed high altitude terracing underwent unprecedented expansion in late prehistoric times. He saw this as a process that began in the south, moving north from Bolivia through Peru. If altitudinous reclamation did indeed proceed longitudinally, then it can be modeled as a drought response process that began in the south where the Cordillera is driest and advanced north as decreased precipitation began to affect less arid regions of the mountain range (Moseley 1997). Always provocative, Lathrap (1970:179) associated the spread of high elevation reclamation with the radiation of Quechua-speaking peoples and the rise of the Inca Empire. Regardless of linguistic considerations, catastrophe clearly contributed to change in the political landscape of the Osmore

River basin, if not other drainages. By responding successfully to diminished rainfall, high sierra populations grew in size and were positioned to dominate their wan coastal counterparts, who had few means of mitigating their drought-depressed agrarian production.

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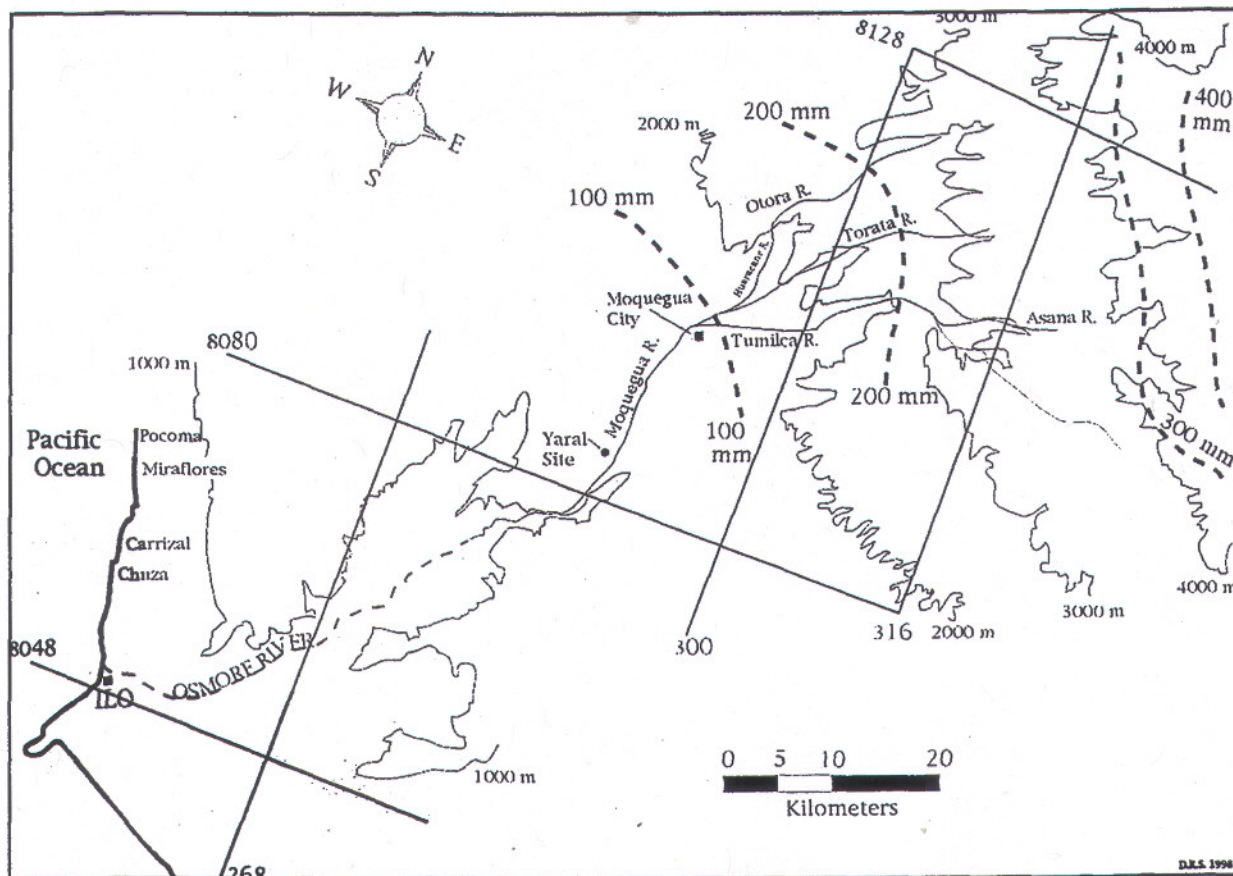


Figure 1. Average annual precipitation, in millimeters, occurring in the Osmore Drainage. Changes in rainfall amounts are indicated by the dark, dashed lines. Elevations are given in meters.

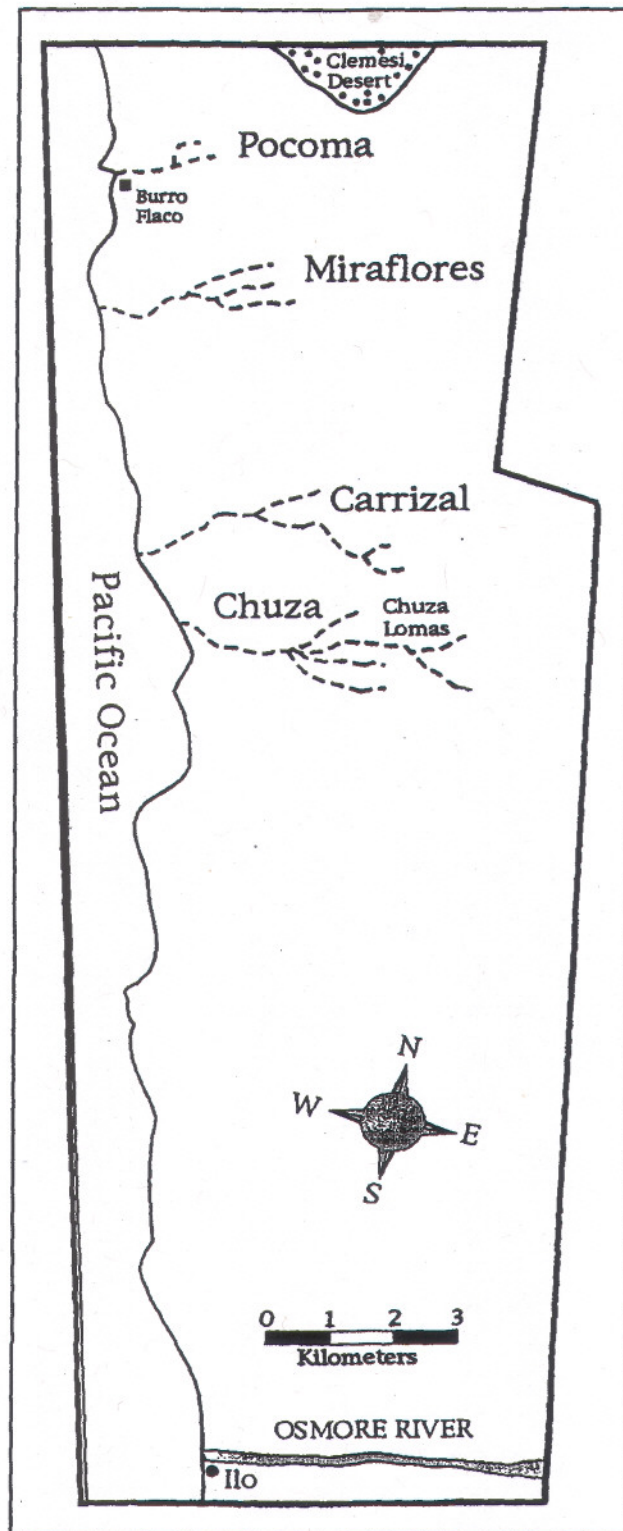


Figure 2. Coastal Quebradas north of the Osmore River.

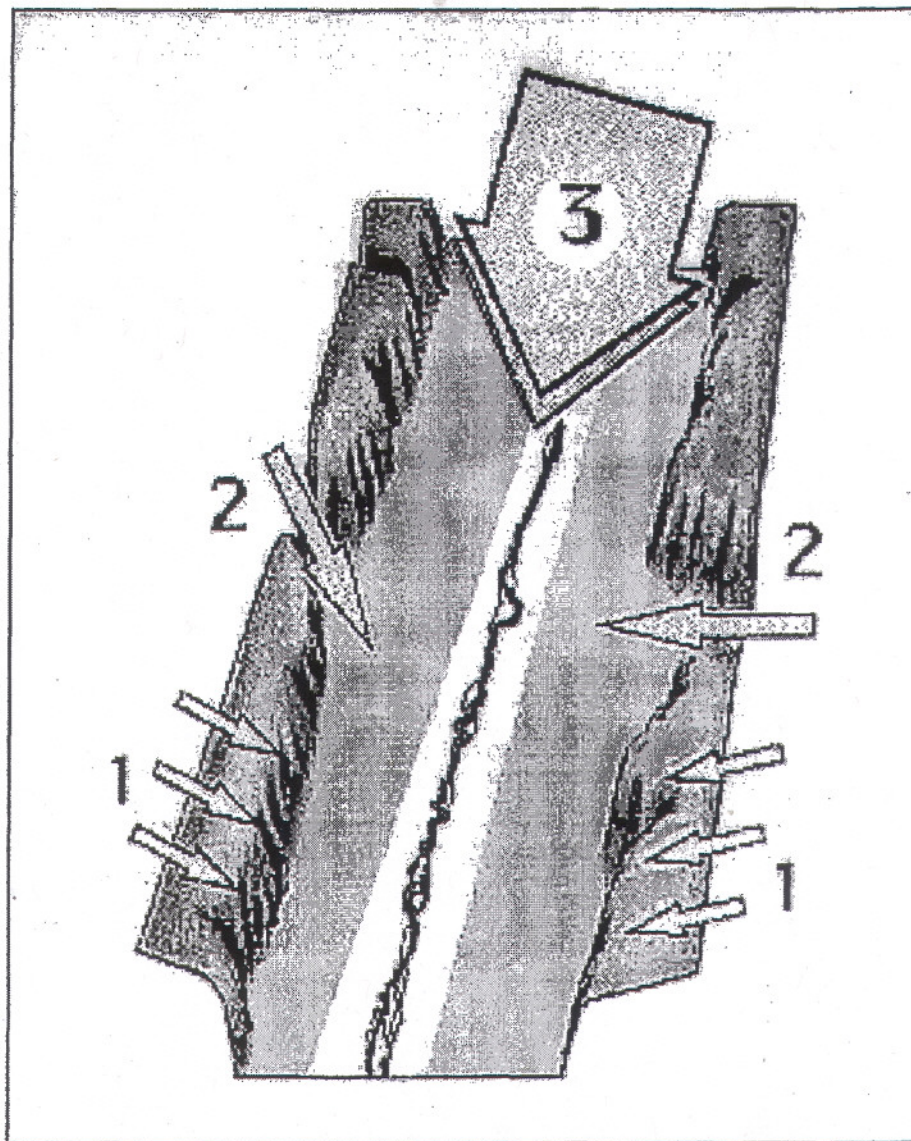


Figure 3: Stages of debris flow and flash flood generation in the coastal valley beginning 1, with hill slope sheet wash, progressing 2, through quebrada flash floods, and culminating 3, in a large flood surge descending the valley.



Figure 4: Aerial View of Miraflores Quebrada indicating: 1) extent of the coastal plain debris flow; 2) canyon and tributary area; 3) Colonial Period walled olive grove; and 4) Chiribaya settlement area.

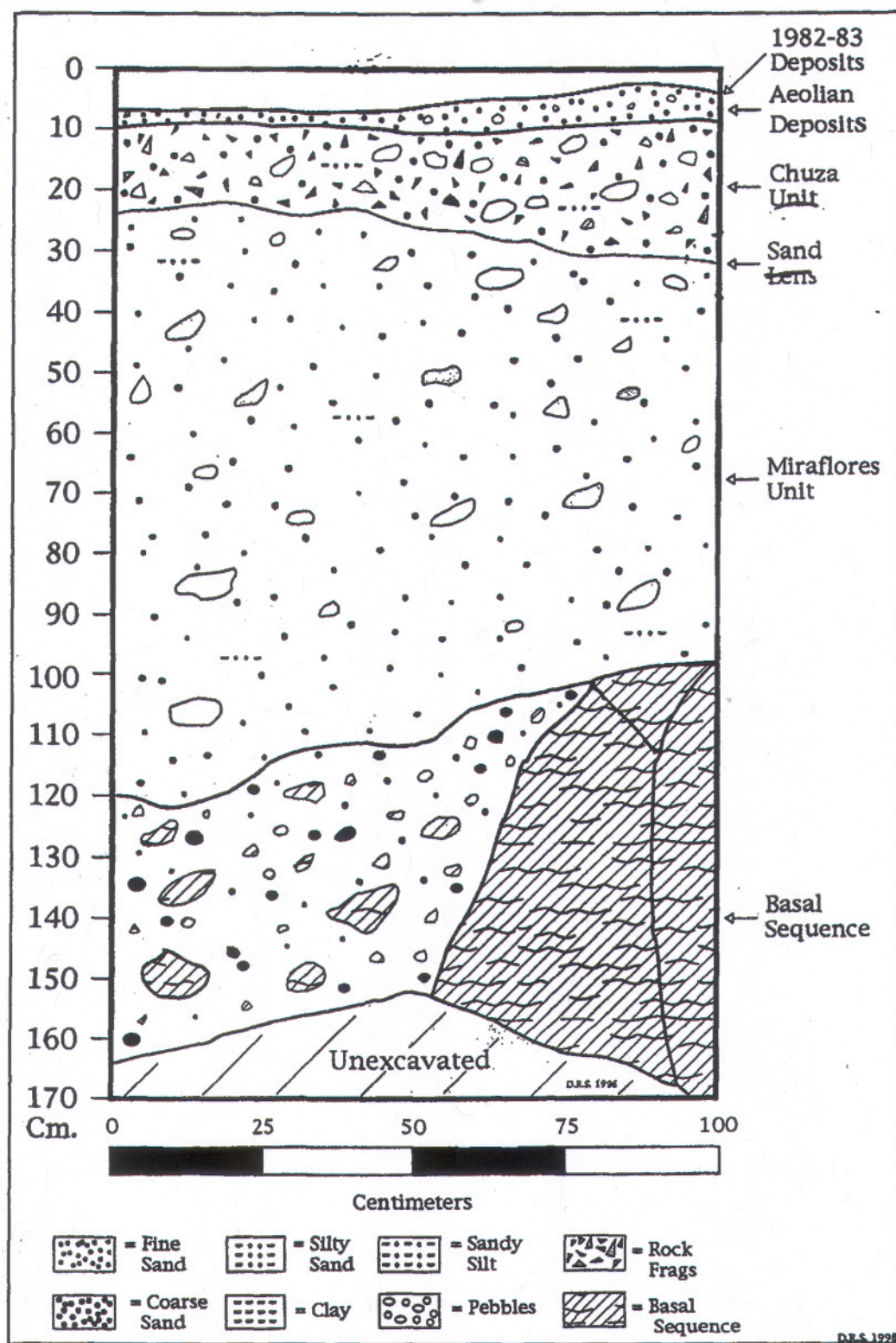
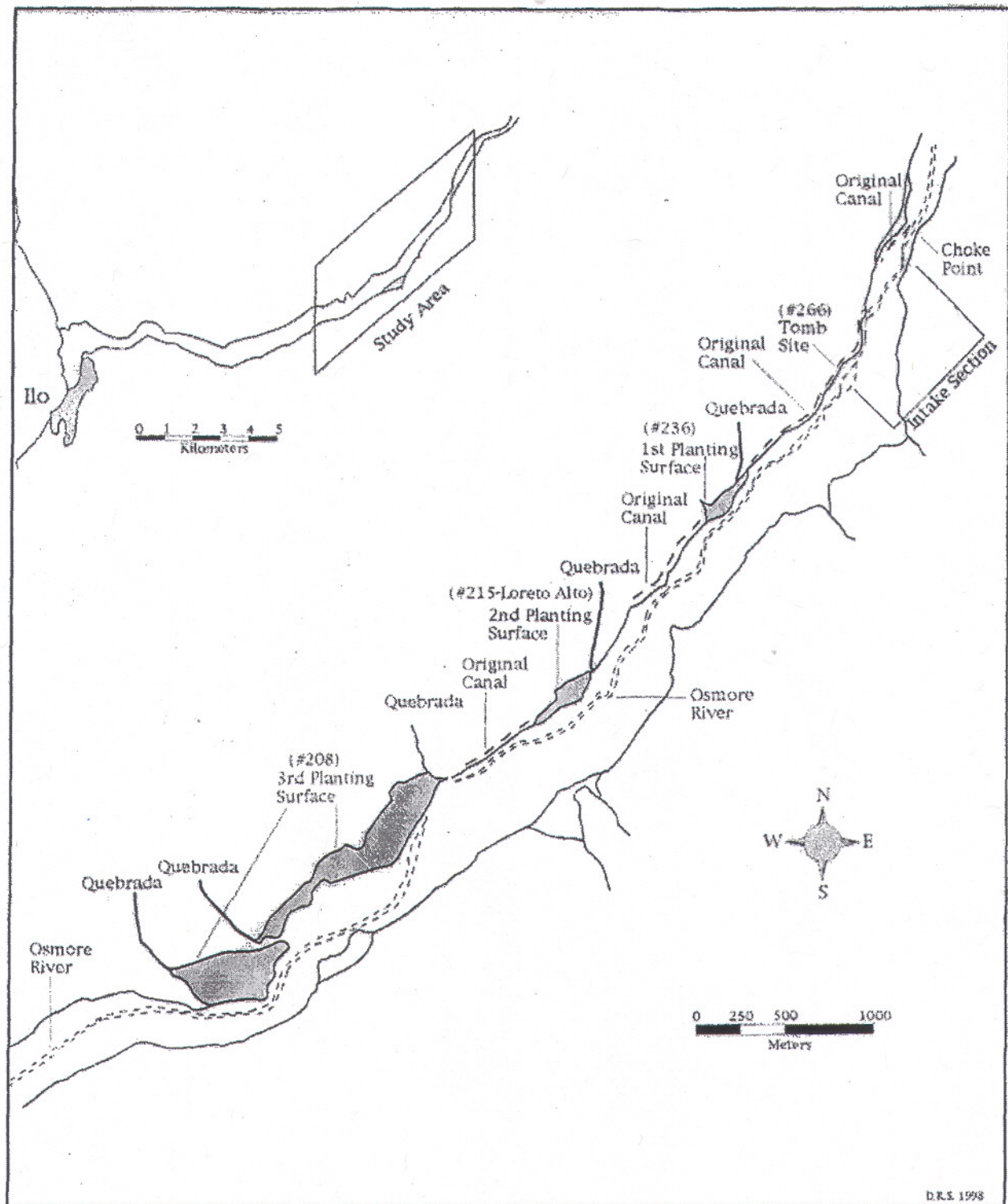


Figure 5. Geologic Column—Miraflores Quebrada.



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Figure 6. Osmore Canal System.

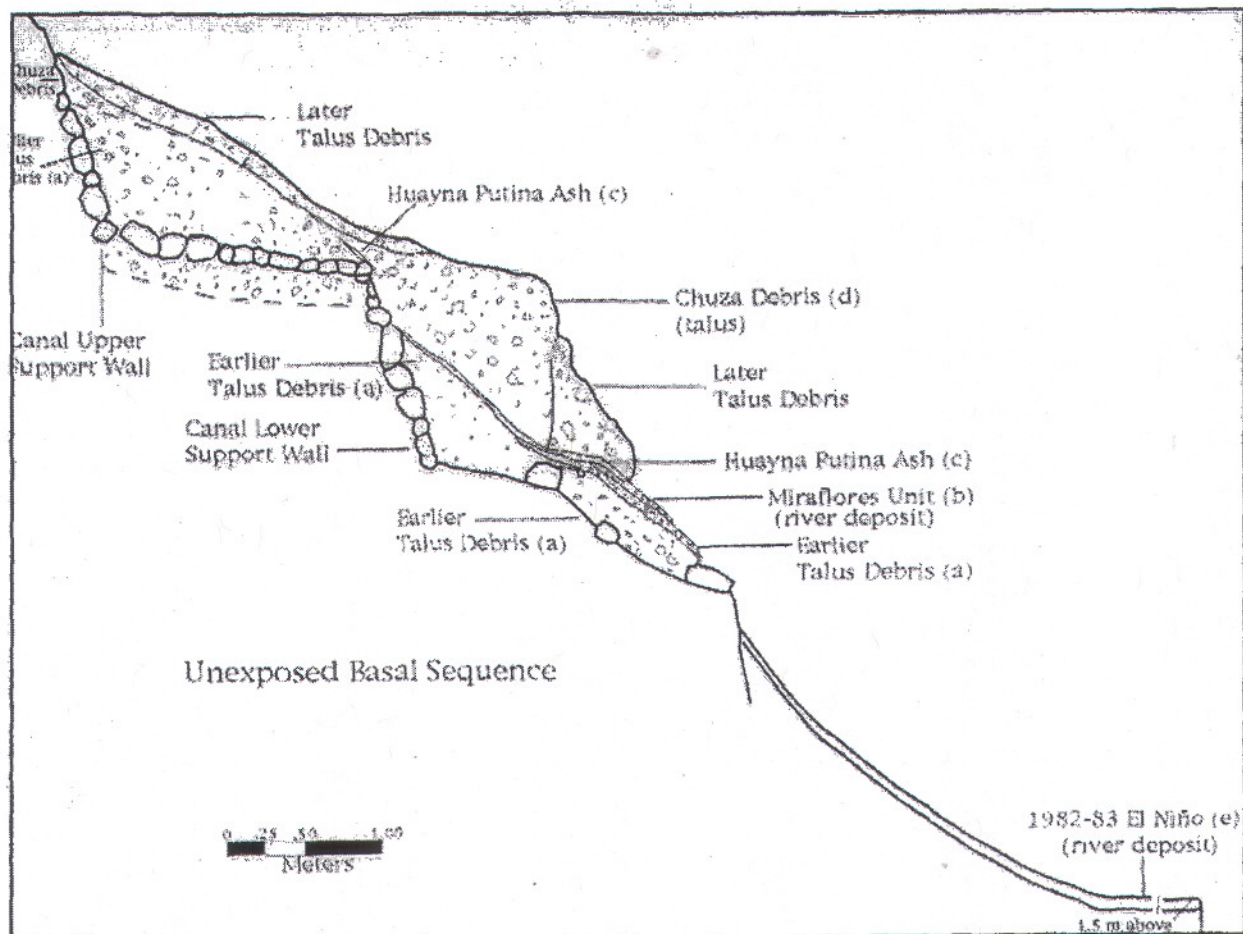


Figure 7. Tomb Site Profile.

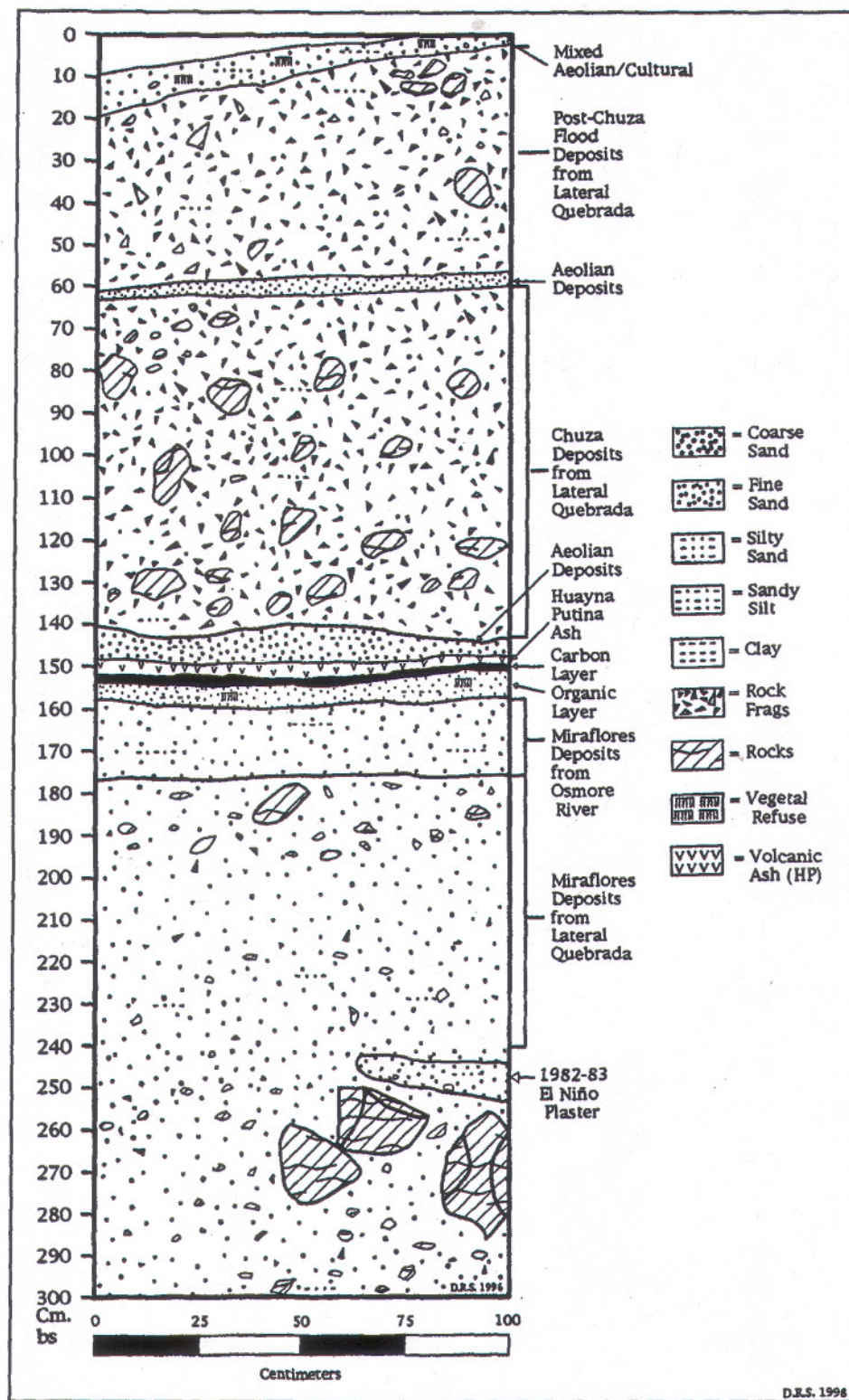


Figure 8. Geologic Column—First Planting Surface.