Holocene Coevolution of the Physical Landscape and Human Settlement in Northern Coastal Peru

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Humans are constrained by the hyperarid environment of the Peruvian Desert, which they have occupied throughout the Holocene Epoch. Habitats amenable to human occupation are limited to the riparian oases and the high-productivity coastal zone. Dramatic cultural and technological evolution was coincident with landscape evolution that responded to climatic and sea level variability. Occupation sites of hunter-gatherers older than 8,000 years are rarely found, as much of the landscape from this period is drowned and unexplored. Seven-thousand years ago, sea level stabilized and coastal middens of this age attest to exploitation of the now stationary marine resource. In response, rivers backfilled and the population became progressively more dependent upon terrestrial resources. The shift to an agricultural economy resulted in a migration of settlements inland along the river valleys. Extreme events (sea level stabilization, droughts, El Niño floods) have likely facilitated periods of rapid technological and cultural innovation. © 1999 John Wiley & Sons, Inc.

INTRODUCTION

The Peruvian coastline is characterized by extreme environmental juxtapositions: a hyperarid desert with annual rainfall of 5 mm/yr or less crossed by lush riparian oases that parallel the rivers draining the west face of the Andes and adjacent to one of the world's most fertile marine ecosystems fed by strong coastal upwelling (Figure 1). In addition, the region is episodically impacted by large subduction-zone earthquakes and by the regional impacts of the El Niño/Southern Oscillation phenomenon. The archaeological history of the region is, thus, usually interpreted in light of environmental constraints. Unfortunately, the focus of these interpretations has been on the catastrophic events, with little appreciation of Holocene geomorphologic evolution. Whereas some archaeologists have been accused of viewing the landscape as static (for example, see the debate published in American Antiquity: Farrington, 1983; Ortloff et al., 1982, 1983; Pozorski and Pozorski, 1982), the interpretations of others are an interesting combination of an effectively static landscape only intermittently impacted by large-magnitude catastrophic events (e.g., Moseley, 1987, 1992:25–48; Shimada, 1994:35–60). Thus, almost all environmental change has been attributed to either earthquakes or El Niño,

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Figure 1. Map of the research area.

with little appreciation of the landscape response to climate change, sea level rise, or sediment transport. This article seeks to paint a gradualistic perspective of the backdrop of the Holocene environmental history of the region as a setting for cultural evolution while still recognizing the importance of the short period events. Rather than painting an environmentally determined picture of cultural evolution, we attempt to paint a coevolutionary picture whereby environmental constraints provide the canvas on which archaeological history is painted. We will focus on the northern coastal region of Peru. This area combines a rich and reasonably well-known archaeological history with sufficient Quaternary geology to allow us a correlative analysis.

A Brief Archaeological History of Northern Coastal Peru

A number of schemes subdivide Peruvian prehistory, and the interpretation of that prehistory colors the various schemes (Table I; see also Moseley, 1992:22–23). Put simply, the story is of an early Holocene habitation by hunter-gatherers, followed by the development of sedentism uniquely founded on maritime resources, an expansion of these communities inland with the development of agriculture, and a slowly, perhaps punctuated, increasing societal complexity combined with warfare, strife, and the formation of regional states with time. The story described below relies on the published archaeological record, and the chronology is based on uncalibrated radiocarbon age estimates unless otherwise noted.

Little is known of occupations in the region prior to about 10,000 years ago. Presumably, there were hunter-gatherers migrating down the coast, whose occupational remains have largely been buried below the floodplain or submerged below sea level (Sandweiss et al., 1998). By 10,000 ^{14}C yr B.P., during the Early Lithic Period, there is clear evidence for a hunter-gatherer population living in what is

Table I. Relevant terminologies for Peruvian prehistory.

Traditional Andean Period	North Coast and Highland Periods	Casma Period	Casma Chronology (approx. ^{14}C yr)
Lithic	Paijan	Early Lithic[1]	9–8 ka
		Mongoncillo[2]	8–5 ka
	Preceramic	Tortugas[3] or	
Preceramic		Coastal Lithic[1]	
	Cotton Preceramic	Cotton Preceramic[1]	5–4 ka
Initial Period	Initial period	Moxeke[3]	4–3.1 ka
	Cupisnique	Pallka[3]	3.1–2.3 ka
Early Horizon	Salinar		
	Chavin		
		Patazca[3]	2.3–2 ka
Early Intermediate Period	Gallinazo	Cachipampa[3]	2–1.5 ka
	Moche	Nivin[3]	1.5–1.3 ka
Middle Horizon	Wari	Choloque[3]	1.3–1.1 ka
Late Intermediate Period	Chimu	Casma[3]	1.1–0.6 ka
Late Horizon		Manchan[3]	0.6–0.4 ka
	Inca		

The terminology used here is a synthesis of that used by Malpass (1983; those followed by a 2), Moseley (1992), Wells (1988; those followed by a 1), and Wilson (1998; those followed by a 3).

now the coastal desert (Chauchat, 1975, 1978; Malpass, 1983). These populations appear to have been migratory, living along the valley oases and the coastal zone (Malpass, 1983). The primary record of this occupation is lithic scatters, and occupational sites are few (Ossa and Moseley, 1972; Ossa, 1978; Chauchat, 1988). Chauchat (1988) observes that there is a clear absence of stratigraphic overlap between the Pleistocene megafauna and the Paijan sites, indicating that the Paijan people postdate the mega-fauna in coastal Peru. He therefore interprets the long thin blades typical of Paijan projectile points as the adaptation of an earlier terrestrial tool kit to the exploitation of a marine fishery. Alternatively, Sandweiss et al. (1998) and Keefer et al. (1998) argue for the migration of a population already adapted to a maritime-based subsistence pattern into southern Peru by 12,000 cal. yr B.P. (about 10,000 14C yr B.P.). The abundance of land snails (*Scutulus*) in the rare Paijan occupational sites (Ossa and Moseley, 1972; Ossa, 1978; Chauchat, 1988), and their contextual association with extinct Lomas (a xerophytic fog-drip woodland; Lanning, 1963; Malpass 1983), suggests that this resource was more abundant at the Pleistocene-Holocene transition.

Around 8,000 years ago the transition to a more sedentary lifestyle began. We refer to this period as the Coastal Lithic to distinguish it from the earlier lithic period, although both periods are usually grouped together terminologically as the Lithic. The most common archaeological remains of this period are shell mounds, often isolated from the modern coastline or fresh water resources. Only a few of these locations have been excavated (Pozorski and Pozorski, 1979, 1995; Sandweiss et al., 1996) or have firm geochronologic control (Table II). We have identified a number of these sites in the field, and temporally classify them based on the following characteristics: (1) shell midden deposits; (2) a distinctive lithic tool kit (predominantly unifacial choppers, cobble cortex flakes, and simple knives); (3) lack of ceramic or cotton industrial materials; and (4) proximity to the early Holocene shoreline. Most of the sites that confidently group into this period are small, low relief shell mounds with no obvious architectural remains.

With the transition to the Cotton Preceramic (c. 5,000 to 4,000 yr B.P.), cultigens (cotton, gourd, pepper, squash, lucuma, potatoes, guava, and bean; S. Pozorski, 1987) become a common component of the archaeological record. While there is a clear reliance on agricultural resources, most occupational sites are still located in a coastal setting that is commonly remote from perennial river valleys. The architectural complexity of the sites increases dramatically during this period (S. Pozorski, 1987; Pozorski and Pozorski, 1990a, 1990b). Moseley (1975) was the first author to clearly point out that, for coastal Peru, maritime resources serve as the initial foundation for a complex society in contrast to the agriculturally based civilizations of Mesopotamia and Mesoamerica.

The boundary between the Initial Period and the Cotton Preceramic has become less clear as an abundance of geochronologic control is gathered. Pozorski and Pozorski (1990b) show that there was contemporary occupation of coastal aceramic sites and fluvial ceramic-bearing sites during the transition. Thus, they question the common assumption of antecedence when discussing aceramic and ce-

Table II. Geochronologic control for early coastal lithic sites from northern coastal Peru.

Laboratory Sample No.	Location	Material	Depth (cm)	Radiocarbon Age (yr B.P.)[a]	Calibrated Age Range[b] (Cal. yr B.P.)
Casma Embayment[c]					
SMU-1915	North Bay[1]	Charcoal	Surface	6890 ± 70	7670 ± 60
SMU-1916	North Bay[1]	Charcoal	Surface	6130 ± 210	6980 ± 240
UGa-4519	Almejas[2]	Charcoal	Burial at 40–120 cm	7220 ± 70	7980 ± 75
UGa-4539	Almejas[2]	Junco fiber	Burial at 40–120 cm	6875 ± 105	7625 ± 80
Santa Embayment[c]					
SMU-1960	Bosqueron[3]	Shell	Surface	5870 ± 40	6280 ± 25
SI-4955	Ostra collecting station[4]	Shell	Test pit: middle	5160 ± 60	5520 ± 60
SI-4954	Ostra collecting station[4]	Charcoal	Not reported	5680 ± 90	6490 ± 135
BGS-1552	Ostra Base Camp[4]	Charcoal	Not reported	5450 ± 110	6250 ± 140
BGS-1541	Ostra Base Camp[4]	Charcoal	Not reported	6250 ± 250	7100 ± 285
Chao Embayment[c]					
Not reported	Mound Site[4]	Charcoal	Not reported	4010 ± 85	4000 ± 122
Not reported	Mound Site[4]	Charcoal	Not reported	4660 ± 60	5380 ± 80

[a] List includes only the maximum and minimum radiocarbon age estimates for each site.

[b] Ages calibrated using the University of Washington Radiocarbon Calibration Program Rev. 3.0.3c (Stuiver and Reamer, 1993). No reservoir correction was used, as experiments with contemporary shell-charcoal pairs suggest that estuarine fauna are in equlibrium with the environment here (DeVries and Wells, 1990).

[c] References: (1) Wells 1988; (2) Pozorski and Pozorski (1995, in press); (3) DeVries and Wells (1990); (4) Rollins et al. (1986).

ramic sites. As the Initial Period progresses, the major population centers move inland (ca. 4,000–3,000 yr B.P.; Pozorski and Pozorski, 1987; Fung Pineda, 1988). A mixed dependence on marine and agricultural resources develops during this time and continues to the present day. The exploitation of agricultural resources expands with the introduction, or development, of ceramic and irrigation technology. During this window of time, however, debate continues regarding whether the population base and level of societal complexity warrants the term "statehood" (S. Pozorski, 1987; Pozorski and Pozorski, 1987, 1992; Wilson, 1998).

By the Early Horizon (ca. 3,100–2,200 yr B.P.), we see the broad dissemination of artifacts of the Chavin Phenomenon throughout northwestern Peru. Chavin de Huantar is thought to be a cult worship site and is located east of the continental divide in central Peru. Roads were built to connect the highlands and the coastal zone documenting the establishment of significant regional trade networks (Wells, 1988). The iconography at Cerro Sechin and Chavin, respectively, document invasive warfare and the development of a regional culture or art style that may have started during the Initial Period (Tello, 1956; Pozorski and Pozorski, 1987; Wilson, 1998). During the subsequent periods of Peruvian history (see Table I), the population expands to the environmental limitations of the agricultural and maritime resources. Coincident with this are increasing cultural complexity, attempts at large scale engineering structures to expand the agricultural land (Moseley and Deeds, 1982), and a recurrence of the growth and demise of city-states over centuries (Wilson, 1988; Moseley, 1992).

Beginning during the Early Horizon, attempts to expand the irrigation network beyond the limits of the river floodplains are made (Moseley and Deeds, 1982). The most extensive studies of the canal systems have been made in the Rio Moche and Rio Reque (Chiclayo) regions (Farrington and Park, 1978; Moseley and Deeds, 1982; Shimada, 1994, Craig and Shimada, 1986). Ancient canals in these areas were extended onto the desert piedmont adjacent to the river valleys, and canals were constructed to move water from larger to smaller drainages (Shimada, 1994). On the basis of over 500 excavations of engineered structures in the Moche Valley, Moseley (1983) interprets the irrigation chronology as follows: major expansion after A.D. 500, reaching its most extensive network by A.D. 1000, and reduced by 30–40% to nearly its modern size by A.D. 1350. Thus, nearly all of the canal expansion occurred during the Moche and early Chimu Periods, and the collapse was effectively complete during the Chimu Period. Moseley and colleagues (Ortloff et al., 1982, 1983; Moseley et al., 1983) attribute the abandonment of canals predominantly to river incision resulting from tectonic uplift or tilting and from direct fault displacement of the canals. However, in earlier articles (Moseley and Deeds, 1982; Moseley, 1983), a stronger emphasis was made on the impacts of large scale flooding to the engineered infrastructure. A long debate has focused specifically on the La Cumbre-Intervalley Canal, a $>$ 54-km-long structure constructed to bring water from the Chicama River south to the city of Chan Chan on the piedmont north of the Moche River. The failure of this canal has been variously attributed to tectonic displacement (Ortloff et al., 1982, 1983), human error or technological inadequacies (Farrington, 1983; Pozorski and Pozorski, 1982), or to political vagaries (Kus, 1984).

Environmental Constraints of the Peruvian Coastal Desert

Habitable Regions of the Landscape

The north coast of Peru is a land of extreme contrasts. The desert region is a stark landscape of exposed bedrock, alluvial fans, and extensive dune fields. Evidence for prehistoric occupation in the desert is rare, but the region is crisscrossed by ancient roads and abandoned canal networks. With rare exceptions, life in this desert is restricted to narrow valley oases. In most instances, the boundary between the vegetated and barren land surface lies precisely at the edge of the outermost irrigation canal. This canal commonly traces the contact between fluvial deposits and bedrock, dune sands, or tributary alluvium. The temperate climate allows for year-round agriculture, and the valleys are lush with corn, sugar cane, cotton, and a variety of market crops. Both modern and ancient occupations are concentrated in the valleys of these perennial rivers, or along the coastline near the river mouths.

Adjacent to the terrestrial desert is one of the world's most productive marine ecosystems. Extremely fertile surface waters associated with the Peru–Chile current and upwelling zone support one of the world's richest fisheries. The ocean here provides an abundance of shellfish, estuarine and open water marine fauna that have been exploited throughout prehistory (Moseley, 1975; Pozorski and Pozorski, 1979; Sandweiss et al., 1983, 1998; Arntz, 1986).

Climate and Climate History

With a mean annual precipitation of 5–40 mm, the Peruvian coast is one of the world's driest deserts. In spite of its aridity, the desert is habitable due to its cool temperatures (mean annual temperature of 10–25°C at Lima; SENAMHI, unpublished data), high relative humidity (mean monthly range of 80–90%; SENAMHI, unpublished data), and the perennial rivers. Orographic precipitation is, during normal years, generally restricted to the high seaward mountain slopes and provides the fluvial discharge. This arid condition is broken once every 7–20 years when a major El Niño event brings torrential rainfall and warm sea surface temperatures to the coastal zone. The 1997–1998 El Niño event far exceeded the 1982–1983 event in the magnitude of its impacts on the desert environment: rivers had record-breaking flood discharges (for example, Rio Piura's 1998 peak of 4300 m^3/s is compared to 2473 m^3/s in 1983 and a normal mean of 340 m^3/s); sea level peaked 23–30 cm above average; sea surface temperatures peaked 6–8°C above average; and precipitation was an order of magnitude above the long-term mean (Instituto Geofísico del Peru, unpublished data). Large expanses of the northern deserts of Peru, normally salt pans and dune fields, were transformed into lakes and estuaries during the winter of 1998.

The Holocene history of El Niño has remained a matter of some controversy.

Sandweiss et al. (1996, 1997) have argued, based on a thermally anomalous molluskan assemblage (TAMA) found in stranded estuaries, that El Niño events did not occur during the time window from 5,000 to 8,000 ^{14}C yr B.P. However, conflicting data from the same time period, a mixed fauna of cold open water and warm lagoonal mollusks (Wells, 1988; DeVries and Wells, 1990; DeVries et al., 1997), and interannual isotopic anomalies from *Trachycardium procerum* shells, indicating SSTs anomalies of +7 to +8°C (Perrier et al., 1994), suggest that the TAMAs flourished in ephemeral lagoons, which formed as sea level stabilized ca. 8,000 cal yr B.P. (DeVries and Wells, 1990). Sedimentary records of episodic rainfall in the Galapagos (Steinitz-Kannan et al., 1997), catastrophic floods in the Peruvian valleys (Wells, 1990; Wells and Noller, 1997), and clastic deposition in glacial lakes in Ecuador (Rodbell et al., 1997), all indicate that the region was under the influence of a climate with high interannual variability, presumably driven by El Niño. There are limited data suggesting changes in the frequency of El Niño through the Holocene (Steinitz-Kannan et al., 1997; Andrus et al., 1998; Keefer et al., 1998; Rodbell, 1999). Lake cores from highland Ecuador indicate significant changes in the frequency of El Niño during the last 15,000 cal yr, with an apparent increase in the frequency of events ca. 5,000 cal yr B.P. (Rodbell et al., 1999). El Niño events are also observed to have occurred throughout the last 6,000 years at Bainbridge Island (Galapagos), but the frequency of events increases markedly both at 4,000 ^{14}C years B.P. and 2,000 ^{14}C years B.P. (Riedinger et al., 1998; Steinitz-Kannan et al., 1997). A summary of the early Holocence (>5.3 ka) fluvial record of Keefer et al. (1998) with the later Holocene (< 6 ka) lacustrine record of Steinitz-Kannan et al. (1997) suggests a high frequency of El Niño events between 12,500 and 8,700 cal yr B.P., followed by a period of reduced frequency between 8,700 and 5,300 cal yr B.P., and finally a general increase in the frequency of events over the last 6,000 years. However, recent isotopic analysis of biannual growth increments in Ariidae otholiths from the same sites analyzed by Sandweiss (1996, 1997) appear to indicate an increased frequency of El Niño between 5,200 and 6,600 ^{14}C yr B.P. (Andrus et al., 1998).

Longer period, millennial-scale, climatic change is less well-documented here. Thompson et al.'s (1985, 1986, 1992) data from the Quelccaya ice cap indicate longer periods of alternating drought and increased rainfall in the Southern Peruvian Andes, and Rodbell's (1992) work in the Cordillera Blanca documents at least three periods of Holocene glacial expansion. The data from the Huascaran Glacier, a combination of isotopic, dust and pollen studies, indicate that, in the Cordillera Blanca, climate was cool and dusty during the late Glacial Stage, that climate warmed considerably during the mid-Holocene (ca. 8,400–5,200 cal. yr B.P.), subsequently cooled gradually until the Little Ice Age (ca. 200–500 cal. yr B.P.), and has warmed substantially during the last 200 years (Thompson et al., 1995). These climatic changes in the highlands must also have resulted in changes in fluvial discharge to the river valleys of northern coast valleys (Moseley, 1987; Wells, 1990). Contrary to the interpretations of Rollins et al. (1986) and Moseley (1987), there is no terrestrial evidence for a significantly moister "tropical" climate during the first half of the Holocene. Early Holocene and latest Pleistocene paleosols exposed in the early Holocene seacliff between Rio Casma and Rio Moche are comprised of a vesicular A Horizon, a salic/gypsic B horizon, and an oxidized or salic C horizon (Wells, 1988; Noller, 1993; Noller et al., 1998). Given that even small changes in precipitation with elevation (200 m rise to adjacent described soils) result in the translocation of silt and clay into B horizons, one must conclude that precipitation to the coastal zone has been extremely rare throughout the Holocene. Additional evidence is found in the impressively thick (>1 km) early Holocene dune sequences exposed in sea cliffs north of Lima, in the hypersaline lake deposits of the Galapagos Islands (Steinitz-Kannan et al., 1997), and in the highland Ecuador lake records (Riedinger et al., 1998). Hence, Holocene climatic change in northern coastal Peru is probably a result of variations in the frequency and intensity of El Niño, combined with changing river discharge from the highlands.

Pollen is poorly preserved in this environment, and attempts at pollen analysis have yielded very limited results. Eight pollen samples from flood sediments in the Quebrada Sanjon and Rio Casma valleys were described for us by K. Graf (personal communication). The sediments represent overbank events over the last 2,200 years (age constrained by correlating fluvial sections with radiocarbon-based geochronologic control). These samples indicate that the modern range of ecosystems (montaña, desert, mattoral, and coastal wetlands) have all contributed to the pollen rain throughout this period (Table III). There is a small increase in wetland species near the base of each individual section, perhaps documenting the proximity of the riparian wetlands. As expected, cultivars are present throughout the sections. Their abundance is higher in the Quebrada Sanjon than in the Rio Casma, probably reflecting the larger irrigable land area in that drainage. These pollen data suggest that the ecosystem has been relatively stable over the last 2,200 years, with perhaps an increase in the production of chenopodium pollen through time.

Changes in Relative Sea Level

Worldwide, the early Holocene was a time of rapid changes in the coastline due predominantly to deglaciation in the Northern Hemisphere. While the general trend of sea-level change during the Holocene is widely agreed upon, the details of the Holocene sea-level curve, both globally and locally, have entailed much debate (e.g., Fairbridge, 1961; Shepard, 1963; Pirazzoli and Montaggioni, 1988; Isla, 1989; Bard et al., 1990, 1996). Wells (1996) developed a relative sea-level curve for northern coastal Peru based on the geomorphology of the beach ridge complex north of the Rio Santa. Sea-level was interpreted to have risen rapidly prior to 7,000 cal yr B.P., and to have stabilized at an elevation within 1 m of present mean sea-level sometime between 7,000 and 6,000 cal yr B.P. Relative sea level then peaked about 1 m higher than present and remained at that level between 6,500 yr B.P. and 500 yr B.P. Relative sea level appears to have dropped approximately 1 m to its current level during the last 500 years.

Short-period variability in sea-level results from tidal and wave cycles. Local tides

Table III. Summary of pollen counts from fluvial sediments in the Rio Casma and Quebrada Sanjon valleys.

	River	Rio Casma					Que, Sanjon		
	Locality	A8195		B81985		A6286	B72588		
	Sample Depth	0.1–0.2	1–1.2	0.1–0.2	1.4–1.5	3–4.5	0.4–1.6	1.6–2.8	6.5–8
	Estimated Age	<100	<500	<100	<500	200	<1000		2200
Montaña/riparian	Ferns	1	2	3	24	1	2	1	45
	Alnus	1	6	5	5	3	1	0	2
	Podocarpus	1	0	0	1	0	0	0	2
Cultivated land	Geraniaceae	0	0	0	0	0	0	9	0
	Phaseolus (beans)	1	6	0	2	2	62	37	0
	Gossypium (cotton)	0	0	0	3	0	11	36	13
	Zea mays	4	4	3	0	2	0	0	9
Matorral/desert	Other Graminae	1	2	8	3	2	0	1	5
	Compositae Tub.	4	16	13	30	14	10	9	14
	Compositae Lig.	0	0	1	12	0	0	0	0
	Caryophyllaceae	1	0	1	1	0	0	0	0
	Chenopodium	84	64	62	14	61	0	1	2
	Ephedra	0	0	0	3	0	0	0	0
Wetlands	Cyperaceae	1	2	6	2	2	1	1	1
	Lycopodium	1	0	3	18	1	0	1	9
	Fungi	7	73	7	24	50	5	0	2

are a mixed semidiurnal microtide with a mean tidal range of 0.76 m (Johnson, 1962). The morphology of the preserved beach faces led Wells (1996) to conclude that tidal range varied between about 1 and 2 m during the Holocene. The modern wave climate is a combination of swell and local sea from the S and SW, with 90% of the sea less that 1.5 m in height, and 95% of the swell is less than 3.65 m in height (Johnson, 1962). A gradual decrease in the height of beach ridges with time suggests a gradual decrease in peak wave height. Declines in peak wave height could result from a climatic change in the region of wave generation, or from offshore sedimentation that decreased offshore slopes, or both. The absence of unconformities in swash-aligned ridges indicates that the dominant swell direction has been from the SSW for at least the last 6,500 years (Wells, 1996).

Tectonic and Geologic Setting

The imposing front face of the Andes and the offshore subduction zone have lead many archaeologists to assume that the entire Peruvian coastline is undergoing rapid tectonic uplift (for example, Moseley, 1983; Moseley et al., 1983; Ortloff et al. 1982, 1983, 1985; Wilson, 1988; Shimada, 1994). However, geomorphological evidence for Holocene uplift along the central Peruvian coastline is absent. Stepped flights of Quaternary marine terraces are present in far northern and southern Peru (DeVries, 1988a, 1988b; Hsu, 1988; Sandweiss et al., 1989; Noller, 1993), whereas, between 6°S and 14°S, no pre-Holocene coastal or marine sediments are present, and tectonic studies indicate a nearly neutral state of stress (Wells, 1988; Mercier et al., 1992; Noller, 1993; Noller and Sebrier, 1998). A variety of neotectonic studies of coastal landforms document either stability or slight subsidence in this region since Pliocene time (Goy et al., 1992; Machare and Ortlieb, 1993; Ortlieb et al., 1994; Zazo et al., 1994). In the adjacent western Andes, active normal faults form an extensive summit graben between the Andean Cordilleras Blanca and Negra. This graben is believed to be the result of gravitational collapse of the Andes due to crustal thickening (Schwartz, 1988; Deverchère et al., 1989). The floors of paleovalleys on the Andean west slope, locally filled with late Miocene ash-flow tuffs, are about 50 m above the floors of the modern drainages, indicating relatively low incision rates. Most of the relief of the north-central coast drainage basins must predate the Miocene tuffs (Myers, 1976; Farrar and Noble, 1976; Noble et al., 1990).

QUATERNARY GEOLOGY AND GEOMORPHOLOGIC HISTORY

The following discussions are based on the mapping and stratigraphy of Wells (1988; 1:10,000 8°45′ to 9°46′S), Noller (1993; 1:500,000 scale maps from 4° to 16°S), and Wells and Noller (unpublished maps at scale to 1:10,000 extending intermittently from 5°90′ to 9°S). Within the context of this article, Noller's (1993) stratigraphic units for the lower coastal desert are described below: Santa Alloformation (beach and nearshore deposits); Sechin Alloformation (fluvial deposits); Colorado Alloformation (alluvial deposits); and eolian deposits.

Santa Alloformation

Rocky eroding shorelines make up over 90% of the coast. Both steep seacliffs and marine platforms are common. The seacliffs separate embayments where sediments of the Santa Alloformation have accumulated. The Santa Alloformation is comprised of the Holocene marine, fossil-bearing, sand and cobble gravel that are stratigraphically positioned between today's shorelines and that of the early Holocene maximum transgression. Morphologically, the Santa Alloformation is comprised of dunes, beach ridges and littoral drift deposits, fan deltas, and salinas. The maximum Holocene transgression has been dated at various localities at c. 7,500 cal yr B.P. (Wells, 1988, 1996), which places a maximum age on this formation. The size and age of the littoral complexes are directly related to sediment discharge from the source river, as the shift from transgression to progradation occurred earlier in the Holocene where the sediment flux was higher. Fan-delta complexes fill the mouths of all major river valleys. Because of the strong and persistent littoral currents, a cuspate delta forms parallel to the dominant wave crests, and sediment is worked north from the rivers into classic zetaform beaches (Zenkovich, 1967). These littoral deposits are concentrated on the north side of the river mouths, indicating that there has been no change in the predominant direction of littoral drift during the Holocene. The widest of the littoral drift deposits form beach ridge complexes up to 6 km wide (Ortlieb et al., 1993).

Sechin Alloformation

The Sechin Alloformation consists of Holocene, coarse, clastic fluvial sediments in vertical accretion, and migrating braid bar deposits, commonly with poorly developed soils, forming floodplains that grade downstream into the fan-delta complexes of the Santa Alloformation. The channel gravels and overbank fluvial sediments are commonly intercalated with thin eolian sand sheets. These deposits overlie a disconformity that is laterally traceable to a geomorphic surface with little to no rock varnish ($\leq$ 10YR hue), no stone pavement, and a poorly developed soil. These deposits contain archaeological sites dated to as early as 3,000 yr B.P., and radiocarbon ages place basal sediments as early as 9,400 cal yr B.P. (Table IV; see also ages for Casma flood sediments in Wells [1990]).

When this formation was described (1984–1988) the uppermost layer was the result of flooding during the 1982–1983 El Niño event. The 1982–1983 deposits in the Casma and Sechin Valleys were described in detail to characterize an El Niño depositional unit (Wells, 1988): The sediments are generally 0.5–1.5 m thick layers of graded sands, silts, clays, and local debris flows overlying channel gravels. Similar sediments were observed to comprise the majority of the floodplain deposits in all river valleys between Piura and Lima. The flood layers are commonly separated by incipient soil horizons (Wells, 1988; Noller, 1993) and/or thin eolian sands, both of which reflect the hiatus in floodplain deposition between El Niño events. Detrital ceramic fragments are common within the gravel fraction, and these, combined with radiocarbon analysis, provide temporal constraint on the sediments.

Table IV. Radiocarbon age estimates s from flood sediments in the Sechin Alloformation in the Chiclayo Area.

Laboratory No.	Location[a]	Lat/Lon	Material	Depth (cm)	Radiocarbon Age (yr B.P.)	Calibrated Age Range[b] (Cal. yr B.P.)
CAMS-1507	Que. Sanjon-1	79°30′E 6°30′S	Charcoal	140	650 ± 50	660–560
CAMS-1877	Que. Sanjon-2		Charcoal	40–60	220 ± 90	310–0
CAMS-1544	Que. Sanjon-3		Charcoal	645–795	2160 ± 100	2310–1950
CAMS-1531	Rio Reque-1	79°40′E 6°45′S	Charcoal	110–320	3010 ± 50	3320–3350
CAMS-1885	Rio Reque-1		Charcoal	320–420	7820 ± 70	8640–8440
CAMS-1880	Rio Reque-2		Charcoal	420–550	240 ± 60	310–150
CAMS-1528	Rio Reque-2		Bulk sed.	420–520	220 ± 50	300–0
CAMS-1530	Rio Reque-2		Charcoal	520–290	400 ± 50	510–330
CAMS-1884	Rio Reque-3		Charcoal	320–360	200 ± 70	300–0
CAMS-1529	Rio Reque-3		Charcoal	460–750	360 ± 50	500–310
CAMS-1539	Rio Reque-3		Charcoal	960–1030	8490 ± 60	9490–9440
CAMS-1879	Rio Lambayeque	79°35′E 6°45′S	Soil (MRT)	170–280	2170 ± 60	2300–2050
CAMS-1545	El Algorrobal	79°35′E 6°45′S	Charcoal	60–220	1630 ± 50	1560–1420
CAMS-1878	El Algorrobal		Charcoal	220–280	2530 ± 60	2740–2380
CAMS-1882	El Algorrobal		Charcoal	220–280	2580 ± 70	2760–2400

[a] This list gives data from four different river valleys in N. Coastal Peru. Three different stratigraphic sections yield datable material in Quebrada Sanjon and Rio Reque. Each stratigraphic section is given a unique number.

[b] Ages calibrated using the University of Washington Radiocarbon Calibration Program Rev. 3.0.3c (Stuiver and Reamer, 1993). Range reflects the 1σ error estimates.

The frequency of sedimentation events was expected to vary both between and within river valleys. A combination of geomorphologic, hydrologic variables (channel proximity, lateral channel migration, avulsion events), and human interference (building of check dams and canal intakes) all have the potential of filtering the record of flooding at any given place. Composite stratigraphic columns were, therefore, generated for sets of valleys around Casma (9°30′S, see Wells, 1988, 1990) and Chiclayo (6°40′S). The record of El Niño sedimentation events generated by this method is not exclusive, but should be considered a minimal listing of major flood events to have impacted coastal Peru during the Holocene. The composite stratigraphy (Figure 2) suggests that a minimum of 18 major El Niño events sufficient to produce a stratigraphic record have occurred during the last 9,500 years. This results in a mean frequency of about one large event every 525 yr. The apparent decrease in frequency through time is, in part, a result of the increased preservation potential for the youngest deposits (Wells, 1990).

Colorado Alloformation

The Colorado Alloformation consists of poorly stratified, clast supported, angular to subrounded, coarse, bouldery gravels that comprise Holocene to early Pleistocene alluvial fans and fill terraces of ephemeral drainages of most of the Peruvian desert. Sequences of the nested alluvial fans and terraces are differentiated into Lower Colorado and Upper Colorado Allomembers, based on relative age criteria. The alluvial fan surfaces of the Colorado Alloformation have been subdivided into up to seven terraces 2–190 m above the modern stream channel (Wells, 1988; Noller, 1993). With increasing age, the terraces: (1) are stranded higher and higher above the most recent thalweg of the proximal fan; (2) have increasingly darker rock varnish (oldest: 5YR3/2; intermediate: 10YR4/3; youngest: 2.5Y6/4); (3) have increased development of desert pavement (except for the oldest terraces which are actively eroding); (4) have decreased surface roughness (again except the oldest where new roughness is imposed by erosion); (5) gradually lose their fine-scale depositional morphology (i.e. channels, bars, and overbank regions lose their distinctiveness) as a result of (3) and (4); and (6) develop deeper, finer-textured, salt-enriched soil profiles. The oldest terrace is preserved as a ballena surface or as isolated remnants of a dissected pediment on spur ridges of the local peaks. The Lower and Upper Colorado Allomembers are early Pleistocene to middle Pleistocene and middle Pleistocene to early Holocene, respectively, on the basis of stratigraphic position, ages of correlative marine terraces, ages of overlying archaeological sites, and relative age criteria (Noller, 1993). Depositional lobes of Colorado Alloformation prograde into the channels of perennial rivers, in the process diverting thalwegs into their opposite bank. The sediments of the Upper Colorado Allomember interfinger with sediments of the Sechin and Santa Alloformations.

Along the coastline, deposits of the Lower Colorado Allomember coalesce to form an alluvial piedmont with a bajada surface whose distal edge has been eroded

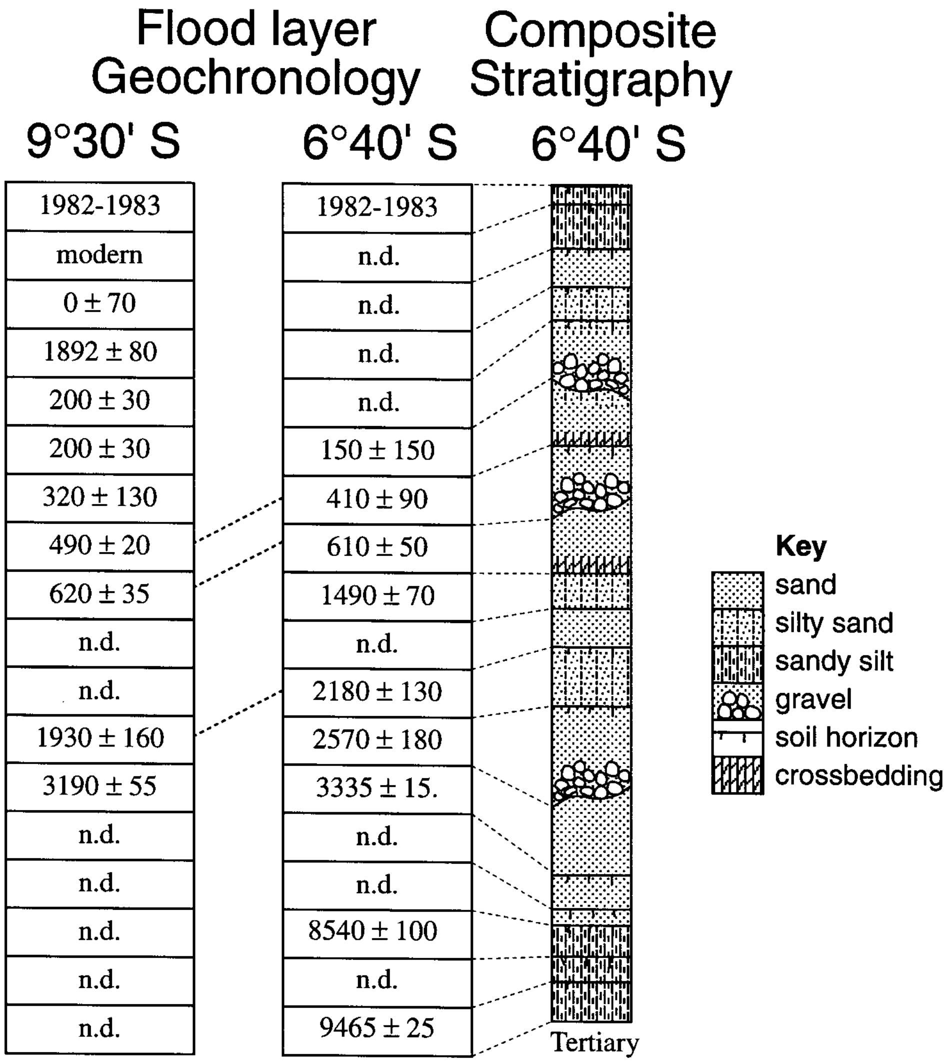

Figure 2. Diagrammatic representation of the stratigraphy of the Sechin Alloformation in the Casma (9°30′) and Chicama (6°40′) regions. Composite stratigraphy is a diagrammatic representation of 14 individual stratigraphy columns from the Rio Reque, Quebrada Sanjon, and Rio La Leche. More detail on the sedimentology of the Rio Casma Region can be found in Wells (1987, 1988, 1990).

by the Holocene rise of sea level. These eroded alluvial fans have been locally misidentified as uplifted marine terraces (Nials et al., 1979:8; Ortloff et al., 1982: 575), whereas their sedimentology (poorly sorted pebble and cobble conglomerates in a silty sand matrix) indicates that they are subaerial debris flow units and alluvial sediments.

Younger and Older Eolian Deposits

Both active eolian material and ancient stable dunes are common here. The dunes take many forms: small erg, longitudinal, transverse, barchan, climbing, and falling dunes, to name a few (see also Grolier et al., n.d.). In addition to the depositional landforms, yardangs and wind-eroded hillslopes are common (McCauley et al., 1977). Active dunes overlie landforms of all types, and eolian sand sheets are intercalated in all depositional packages. Eolian sediments range in size from silt to granules, and bedforms range from small ripples (≤20 cm thick) to seif dunes 200 m high. Oblique convergence of the south-southwest onshore winds foster the growth and movement of sand dunes from beach and river sources. These dune fields extend inland, turn easterly, and typically end on the southern bank of the next Andean river north of the source (Wells, 1988; Noller, 1993). Soils are rare, and poorly developed if present.

Very thick, old inactive dunes make up much of the coastal plain and are commonly exposed in the modern sea cliff. These ancient stable dunes range from a few meters to more than 300 m in thickness. The surface of these dunes has a stable soil mantle and is commonly covered with a thin lag gravel or the remains of lomas (fog drip) vegetation. In the smaller valleys near the coast, eolian processes are generally more active than fluvial processes and the landforms are transitional in character. The sediments are dominantly eolian, although their surface form is closer to that of an alluvial fan. Stable discrete climbing and falling dunes are also common in this context.

CASE STUDY: THE CASMA VALLEY

The description below focuses on the Rio Casma Valley, where Wells (1988) completed the region's most detailed survey of geomorphology, as well as a cursory survey of the archaeology. A more detailed settlement pattern study of Casma is in process (Wilson, 1998). Subsequent reconnaissance geomorphology in the Supe, Moche, Chicama, and Reque valleys supported the general findings of this survey.

History of the Research

The goal of this research was to document the impacts to the physical landscape of at least 5,000 years of agriculture. To that end, the river valley and adjacent desert and coastal zones were mapped using aerial photographs and 1:10,000 scale planimetric maps as a base. Both surficial geology and archaeological structures and cemeteries were recorded and a stratigraphic framework developed. Only a few of the archaeological structures have age estimates, based on either published information (Malpass, 1983; Pozorski and Pozorski, 1986; Pozorski and Pozorski, 1987; Tello, 1956; Wilson, 1998), or field collaboration with Tom and Shelia Pozorski (personal communication).

The region studied extends along the coast from Huaynuna in the north to Quebrada Rio Seco in the South (Figures 3 and 4), and upstream along the Casma and Sechin Valleys for a distance of about 22 km. The focus of the mapping was a strip roughly 2 km wide adjacent to the hydrologic resources (coastline, river channel). The only open desert region mapped was that between the Sechin and Casma Rivers.

Settlement History

The Casma region has had nearly continuous occupation for probably the last 10,000 ^{14}C years and artifacts are ubiquitous across the landscape. The 10,000 year age is based on five Paijan lithic workshops in the region, three on extinct lomas south of the valley (Malpass, 1983), and two unpublished sites with poorly defined context (Chauchat, 1988). The earliest dated occupation is from a lithic shell midden on the south side of the Casma paleo-embayment. Materials from a burial within the midden yielded a calibrated radiocarbon age estimate of c. 8,000 cal yr B.P. (see Table II). The valley contains some of the largest early architectural re-

Figure 3. Map of the Casma Study Area. Areas in gray were mapped at a scale of 1:10,000 by Wells (1988).

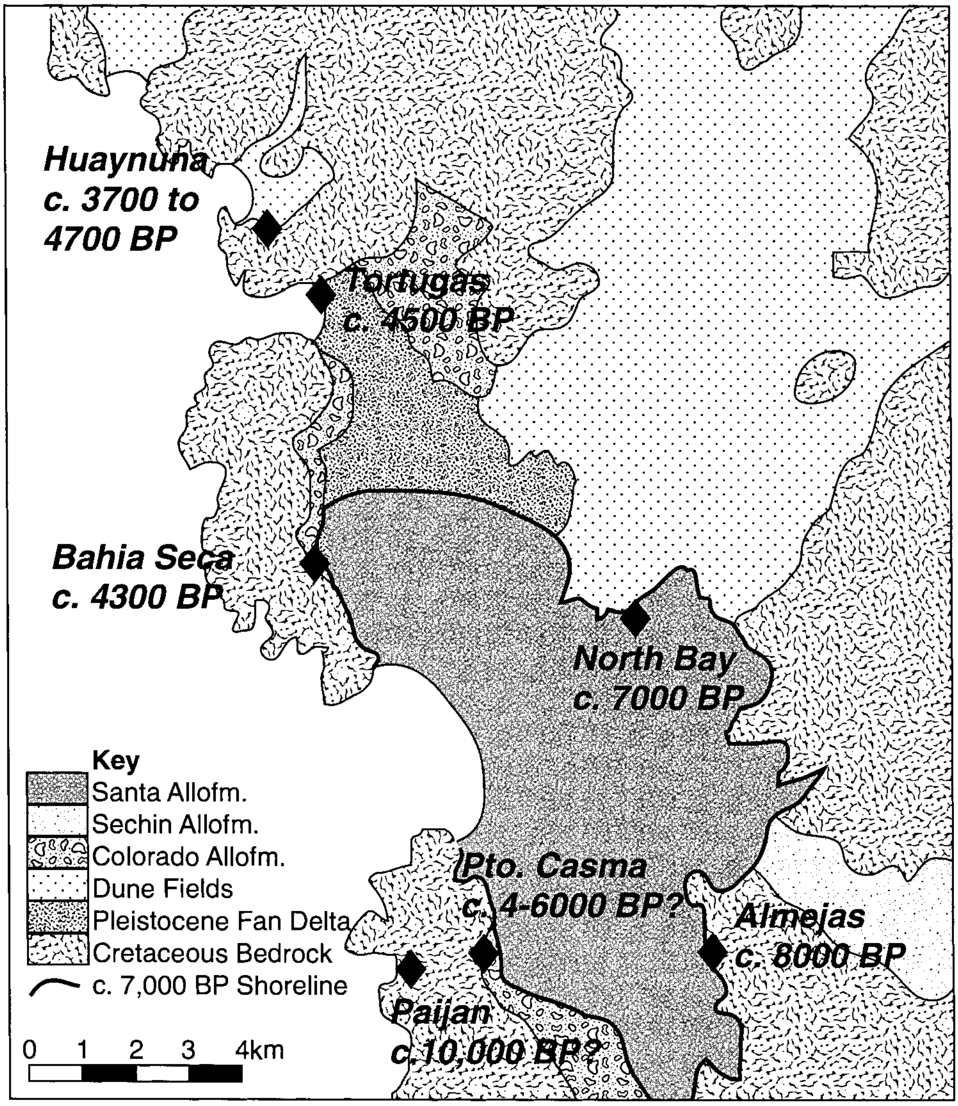

Figure 4. Location of Lithic and Preceramic Period archaeological sites along the Casma Paleo-shoreline. Dates for the Pto. Casma site and the Paijan site are by correlation with similar sites; dates for all the other sites are based on radiocarbon geochronology. Dates for Huaynuna, Tortugas, Bahia Seca, and Almejas from Pozorski and Pozorski (1990a, 1992, 1995, in press).

mains in the New World. For example, the Las Llamas/Moxeque complex (ca. 4,000–3,100 yr B.P.) covers 185.6 ha (Wilson, 1998), and the contemporaneous central pyramid at Sechin Alto has a base area of 9 ha.

For this study, the distribution of obvious architectural remains, roads, mines, and cemeteries were mapped from aerial photograph interpretation (Wells, 1988). This was not meant to be a comprehensive archaeological survey, and no attempt was made to map the distribution of discrete artifacts in the field. The site chronology has been developed from published sources and occasionally supplemented by field visits with T. and S. Pozorski. Only in a few instances was site chronology determined by Wells. In these cases, emphasis was placed on the recognition of the coastal lithic sites that have a very distinctive tool kit (predominantly unifacial choppers, cobble cortex flakes, and simple knives). Also, a few locations yielded surficial charcoal that was sampled for radiocarbon analysis.

There have been a number of archaeological surveys of the Casma Valley, beginning with Tello (1956), followed by Fung Pineda and Leon (1977), Malpass (1983), Pozorski and Pozorski (1986, 1987, 1992), and most recently by Wilson (1998). A summary chronology is presented in Table V. Malpass' survey focused on finding lithic sites in a fairly small area outside the valley proper. The majority of Malpass' Mongoncillo sites are located around Lomas Las Aldas, some 15 km south of Casma. Wilson's investigation is a comprehensive archaeological survey documenting the distribution of roads and architecture throughout the lower Casma/Sechin Valleys. Wilson documented ten times more occupations than Wells (1988) because (1) The area surveyed was larger, (2) many sites were recognized to have multiple occupations, and (3) sites were subdivided more discretely. Wilson (1998) has also revised the chronology of many of the sites. For example, many of the sites that Wells (1988) classified as Early Horizon (using the chronology of Tello, 1956) Wilson considers to be Patazca (Early Intermediate Period) occupations.

Based on Wilson's (1998) preliminary data, we can make the very general observation that population in the Casma Valley has increased with time, with the apparent exception of a decreased number of occupations during the Nivin (Moche) and possibly during the Manchan (Chimu/Inca) Periods. The drop in numbers of occupations is marked during the Nivin, and most likely represents a real decrease in the population of the valley during this time. The drop in number of sites during the Manchan period is small (from 399 sites representing 450 yr during the Casma Period to 154 sites representing 181 yr for the Manchan Period), and population levels could easily have been accommodated by small changes in the number of occupants per site.

Integration of Physical and Cultural Landscape Change

During the early Holocene, sea level was west of and below its present location and rising rapidly. The lower reach of the river valley was more entrenched than it is today, and the floodplain was less extensive and sediment grain size was coarser (Wells, 1988). It is likely that there was a riparian corridor along the stream

Table V. Site distribution as a function of chronology, Casma.

Casma Period[a]	Estimated Chronology	Number of Sites (Malpass, 1983)	Number of Occupations (Wells, 1988)	Number of Occupations (Wilson, 1998)
Early Lithic[1]	9–8 ka	3		
Mongoncillo[2]	8–5 ka	38	6	
Tortugas,[3] or Coastal Lithic[1]				
Cotton Preceramic[1]	5–4 ka		4	10
Moxeke[3]	4–3.1 ka		8	65
Pallka[3]	3.1–2.3 ka		8	45
Patazca[3]	2.3–2 ka			196
Cachipampa[3]	2–1.5 ka			194
Nivin[3]	1.5–1.3 ka		2	31
Choloque[3]	1.3–1.1 ka		3	249
Casma[3]	1.1–0.6 ka			399
Manchan[3]	0.6–0.4 ka		7	154
No temporal information			68	
			108	1343

[a](1) Wells (1988); (2) Malpass (1983); (3) Wilson (1998). Because of differences in their schemes for lumping or subdividing the chronology, not every period is represented in each of the surveys. For example, Wilson does not subdivide the Preceramic periods, and Wells did not subdivide the Early Intermediate Period.

channels that supported large and small game (Chauchat, 1988). No sites that corresponding to this time (the Lithic Period: 10–8,000 yr B.P.) have been found in the Casma valley proper. However, in the course of the geomorphic survey, a small site with Paijan-like blades was found on a high alluvial fan in the Quebrada Rio Seco south of Casma, and Malpass (1983) has described two similar sites from the coastal headlands just south of the Casma Valley. If these sites indeed correlate with the Paijan sites to the north, they record a small occupation of the region prior to the stabilization of sea level. The paucity of artifact finds of this period indicates that either sites from the early Holocene are submerged offshore or buried under Holocene sediment, or that there was only very minor and probably transient use of the region prior to 7,000 yr B.P.

Shoreline transgression continued until sometime ca. 7,000 yr B.P., when the rate of sedimentation outpaced the rate of sea level rise such that coastal progradation began (Wells, 1996). In the window of time surrounding this shift from transgression to progradation, the shoreline was occupied by coastal lithic communities who left evidence for their presence as shell middens. Along the Casma bayshore, three small early coastal sites are each separated by about 10 km of shoreline, suggesting that each site exploited the resources along a discrete stretch of the coast (Figure 4). The smaller embayments directly to the north, Tortugas and Huaynuna, each supported a single lithic community on their respective 2.5 and 5 km of protected coastline. There appears to be some spatial stratigraphy between the sites, with the earliest sites (Almejas and North Bay) located on the most easterly shoreline, and the later Cotton Preceramic Sites (Bahia Seca, Tortugas, and Huaynuna) located on paleo-shorelines farther to the west. This is suggestive of substantial sedimentation between the two occupation phases. Regardless of the controversy surrounding the water temperature of the adjacent oceans during this time (Sandweiss et al., 1996, 1997; DeVries et al., 1997; Wells and Noller, 1997), there is little doubt that the primary protein resource for these early occupants was nearshore and estuarine fauna. The inhabitants of these sites also made use of riparian plant resources (Pozorski and Pozorski, 1987), and the absence of local freshwater sources or paleo-spring deposits suggest that they must have traveled to the river valleys for fresh water. However, like the preceding period, no valley sites are known to correspond to this time. If there was occupation in the valley, it either is buried below the Holocene floodplain or has been eroded away.

Shortly after sea level stabilized (ca. 5,000 yr B.P.), the coastal valleys began to back fill with finer-grained sediment. Sedimentation in these valleys changed the substrate of the valley floor from a predominantly coarse gravel fill to finer-grained gravel and sand fill (Wells, 1988). Coincident with this change in fluvial substrate is an increased reliance on agricultural resources (Pozorski and Pozorski, 1987, 1992). Over the course of the next two millennia, as the rivers backfilled and the floodplain grew, there was concomitant increase in reliance on agricultural resources. Coastal sites become more complex between ca. 4,000 and 3,500 yr B.P., and by about 3,000 yr B.P. the population base had largely moved inland (Pozorski and Pozorski, 1992). Although marine protein continued to be an important resource, the focal point for occupation clearly centered around agricultural resources by 3,000 yr B.P. Thus, the technological developments that resulted in a change from a maritime focus to an agricultural focus occurred coincidentally with an evolution of the river valley, such that an appropriate substrate was available on which agriculture could flourish (Stanley and Warne, 1997).

While the occupants moved inland, they largely chose not to build monumental architecture on the floodplain. The great bulk of archaeological sites (79%) in the Casma Valley are located on stable geomorphic surfaces: alluvial fans, older dunes, coastal deposits, or the older ($>$ 500 yr B.P.) floodplain. A smaller, but significant, number (14%) are located on erosional bedrock surfaces. Sixty-seven percent of the sites are located on the Colorado Alloformation in small tributary channels or on the higher terraces of the Santa Alloformation. Collectively, these sites are constructed on the surfaces adjacent to, but largely outside, the irrigable floodplain. Wilson's (1998) preliminary maps confirm these observations. Detrital artifacts and buried agricultural soils are common in the deposits of the Santa Alloformation, indicating that the floodplain has been utilized throughout the later Holocene. The observed settlement pattern suggests that people largely chose to occupy space outside of the prime agricultural land and beyond the reaches of El Niño flooding.

No intervalley irrigation networks have been found in the Casma area, but “abandoned” canals do extend into the desert in first- to third-order tributaries. These canals frequently contour near the contact between the Colorado Alloformation and bedrock. In 1985, we observed the remains of modern “abandoned” canals adjacent to the Sechin branch of the Rio Casma. These canals had been dug by backhoes or other heavy equipment in attempts to reclaim land during the 1983 El Niño. Local farmers, displaced from their farmland by flooding, attempted to harness the flood discharge into these canals. The canals were abandoned, due to recession of the floodwaters, before any agricultural land was actually reclaimed. Thus, even in modern times, people are building and abandoning canals into the desert margins.

Humans have cleared the desert pavement from alluvial fan surfaces for many generations. While not as spectacular as the Nasca geoglyphs to the south, a variety of roads, geoglyphs, and other cleared features are present in the Casma area (Pozorski et al., 1982). Cross-cutting relationships show that most of the prehistoric road networks were cleared during the time that the sediment beneath the youngest three terraces of the Upper Colorado Allomember was being deposited. Circular depressions have been excavated into the terrace surfaces of the Lower Colorado Alloformation. These depressions are most likely borrow and levigation pits for mining clay from the older, reddened, clay-rich Bt, soil horizons.

Only four other valleys on the north coast of Peru have comparable published archaeological surveys: Rio Nepeña, Rio Santa, Rio Viru, and Rio Moche (Willey, 1953; Proulx, 1985; Wilson, 1988; Billman, 1996). While there are nuances to the archaeological history in each valley, the gross general patterns parallel those observed in the Casma Valley. The earliest extant occupations are shell middens located along the shoreline cut by the early Holocene marine transgression. Sometime between 3,000 and 5,000 years ago, there is a movement of the population inland contemporaneously with a shift to dependence upon agricultural resources. The great majority of sites in all valleys are located on alluvial fans or bedrock along the valley margins, and sites on the floodplain are rare. Wells (1992) interprets the settlement patterns on the delta of the Rio Santa to reflect the progradation of that delta.

DISCUSSION: THE COEVOLUTION OF LANDSCAPE AND CULTURE IN NORTH COASTAL PERU

The physical landscape of northern coastal Peru has evolved in response to river incision, changes in sea level, and climatic variability during the Holocene. Wells (1988) concluded that, in this hyperarid desert, human impacts to the landscape were small compared to these natural occurrences. The limitations of this harsh environment, and changes in that environment through time have, however, impacted the cultural history of the region. Figure 5 provides a summary of Holocene environmental variability and the archaeological chronology for this region. The discussion below focuses on the ways in which these natural environmental changes underscored cultural history.

Sea Level Rise and the Onset of Sedentism

The stabilization of sea level during the early Holocene was fundamentally important to providing a physically immobile resource base. Shoreline stability resulted in stationary marine resources that could be counted upon to provide a daily protein supply. Large protected embayments were created as ocean waters flooded river mouths (Wells, 1988). Adjacent to the mouths of some of the larger rivers, riverine sediment was reworked into beach ridges behind which protected lagoonal environments were created (DeVries and Wells, 1990; Wells, 1996). Within both of these types of embayments was a rich estuarine resource that was relatively easy to access and exploit.

Nearly all of the early coastal lithic sites are located adjacent to both the early Holocene shoreline and a protected bay (e.g., Willey, 1953; Cardenas, 1979; Wells, 1988; Wilson, 1988; Sandweiss et al., 1996). In many instances, subsequent sedimentation has resulted in the paleo-seacliff and bay floor being located many kilometers inland of the modern shoreline. The earliest middens are small mounds deposited on the alluvium or bedrock into which the seacliff was cut. The spacing of the middens suggests that each community accessed a discrete stretch of shoreline. While shell debris dominates the midden deposits, the inhabitants were also exploiting both estuarine fish and open marine fauna (Sandweiss et al., 1996; Pozorski and Pozorski, 1987), as well as terrestrial plant resources. In the transition from the Paijan to the Coastal Lithic Period, the tool kit drops most of the large intricate bifacial tools in exchange for hammers, simple knives and unifacial cobble core tools (Malpass, 1983). This changing tool kit reflects the industrial shift associated with dependence upon a stationary maritime resource base.

Episodic El Niño events undoubtedly would have impacted these local inhabitants as the ecosystem they were dependent upon is heavily impacted (Moseley, 1975; Wilson, 1981; Arntz, 1986). However, during El Niño events, tropical species replace the temperate species, and a different fauna is available for exploitation. The question remains as to how adaptable the local populations would have been to exploiting an El Niño fauna and the lomas resources. Given that the populations were still small during this time period, it is likely that fluctuations in the marine ecosystem associated with El Niño would not have caused widespread famine.

There is a gradually increasing complexity to the architecture and layout of the sites with the shift to the Cotton Preceramic Period. Most of the sites dating to this time period are still located along the seacliff (e.g., Huaca Prieta in the Chicama River valley, Bird and Hyslop, 1985), but a gradual movement to inland occupation begins (Pozorski and Pozorski, 1987). Locally, these younger middens overlie the sea cliff (Figure 6), documenting the fact that shoreline had already prograded oceanward by the time of their final occupation. Although the maritime resources continued to be a rich, abundant, and important economic base, the filling of the shoreline embayments resulted in a loss of some of the most easily exploited environments. This change in habitat, from estuary to fluvial-deltaic, was coincident with the next major cultural shift.

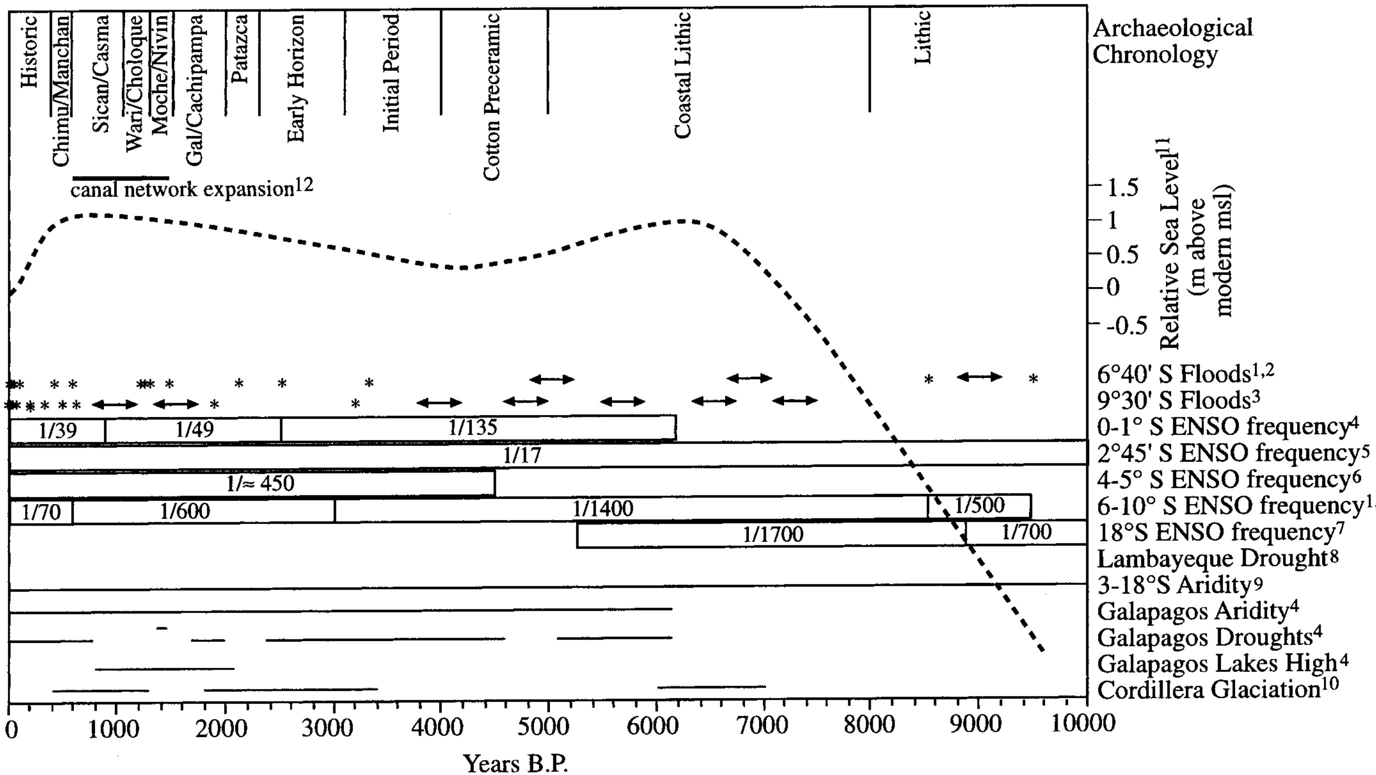

Figure 5. Summary of the data that records environmental variability during the Holocene. Individual flood events are denoted by stars (timing constrained by radiocarbon analysis) or arrows (timing constrained by stratigraphy). ENSO frequency is in events per year. Data sources: (1) this article; (2) Schaff, 1988; (3) Wells, 1990; (4) Steinitz-Kannan et al., 1997; (5) Rodbell et al., 1997; (6) Ortlieb and Machare, 1993; (7) Keefer et al., 1998; (8) Shimada, 1994; (9) Noller, 1993; (10) Rodbell, 1992; (11) Wells, 1996; (12) Moseley, 1983.

Figure 6. Photograph of the Chao Mound overlying the maximum transgressive shoreline at Salinas de Chao. This mound clearly overlies the sea cliff and must, therefore, have been built after shoreline had receded from this locality, contrary to the implications of Rollins et al. (1986). This mound is a U-shaped structure, covered with human artifacts (shell, stone tools, stone bowls, and stone stelae), that is similar in scale and alignment to the barchanoid dunes that now cross the region. There have been no excavations at this site, but it seems likely that the structure is an occupied sand dune that has been stabilized by the surface scatter of coarse debris.

Sea Level Stability and the Onset of Agriculture

During the time window of 5,000–6,000 yr B.P., when the sea level curve becomes flat, sedimentation in the major rivers outpaced sea level rise and rapid progradation began. This resulted in the formation of deltas that filled the estuaries at the river mouths, and littoral complexes filling embayments north of river mouths. Additionally, rivers that had been entrenched and typified by coarse-grained channel gravels began to back fill, and a fine-grained floodplain formed in the lower river valleys. Thus, a new environment was created of low, relatively moist land with a fine-grained substrate both in the deltas and in the lower reaches of the river valleys.

This new floodplain environment would have been more amenable to tillage and irrigation than the valleys prior to 6,000 yr B.P. Beginning ca. 5,000 years ago, during the Cotton Preceramic Period, the exploitation of this environment was initiated, although the focal point for occupation remained along the coastline (Bird, 1948; Strong and Evans, 1952; Willey, 1953; Proulx, 1973; Pozorski and Pozorski, 1987; Wilson, 1988). The exception to this is a number of upper valley sites that Wilson

(1988) documents in the Santa Valley. However, the chronology of these upper Santa valley sites is not particularly clear—they are aceramic windbreaks and could date to a much later period of time.

This new landscape niche was rapidly occupied as humans moved from the shoreline into river valley settlements during the Initial Period (Pozorski and Pozorski, 1987). Irrigation agriculture was possible once this environment was well established, and people appear to have exploited the floodplain shortly after it was formed. Wells (1988) and Noller (1993) document buried plowed (Ap) soil horizons in the upper three-quarters of the Holocene section, documenting the long history of floodplain tillage. With the shift to an agricultural focus and inland occupation, site layouts and architecture became gradually more complex. Pozorski and Pozorski (1987) have argued that the foundations for Andean statehood were laid during this period.

In some valleys, the archaeological record of the Initial Period is scant or nonexistent (Strong and Evans, 1952; Proulx, 1973; Wilson, 1988). Given that there has been at least a few meters of fluvial sedimentation after the Initial Period, sites may be buried in the floodplain sediments. If this is the case, occupations in these valleys were probably small structures rather than the larger architectural styles observed in the Casma or Chao valleys (Alva, 1986; Pozorski and Pozorski, 1987).

Cultural Responses to River Evolution

The combination of high Andean relief and low annual rainfall has resulted in steep, straight, deeply incised, V-shaped river channels. In all but the lowermost reaches of the rivers, the thalweg is eroding into bedrock. The sediment in transit is predominantly a mix of coarse channel gravels and debris flow deposits. In the lower stretches of the rivers, below what Moseley (1983) refers to as the “river neck,” or what would be geomorphologically referred to as the fan or hydrographic apex, the rivers have deposited large fan delta complexes.

Downstream of the fan apex, the river thalwegs are commonly set anywhere from 2 to 8 m below the highest floodplain surface. Radiocarbon ages on this surface place it at 500 yr B.P. (Casma Valley; Wells, 1990) to 200 yr B.P. (Quebrada Sanjon). This incision has been previously interpreted to have resulted from tectonic uplift or tilting of these drainage basins (Moseley, 1983). Between perennial river valleys, the alluvial fans of the Colorado Alloformation have coalesced into a bajada surface.

A number of fluvial processes combine to produce the relief in the perennial valleys without any tectonic uplift. These rivers are subject to intermittent flash floods during El Niño years when the river levels are raised substantially. It is during these events that the rivers avulse and deposit sediment on the floodplain. During the intervening years when discharge falls, the rivers incise and cut laterally into the floodplain sediments, resulting in thalwegs inset well below the most recently flooded surface. The oldest terraces of the Sechin Alloformation are a manifestation of channel entrenchment at the fan head (the hydrographic apex). While fan head entrenchment can result from climatic change or tectonic movement in the source basin (e.g., Bull, 1991), here it is most likely the result of fan elongation and a decrease in the slope of the channel (Denny, 1967; National Research Council, 1996). During the past 7,000 yr, river delta deposition has moved the distal edge of the fans anywhere from 4 to 8 km westwards. As the river elongates in this process, slope decreases, and this decrease in slope is manifested upstream as fan head entrenchment.

Once the floodplain was established, local society became dependent upon agricultural resources. Populations grew rapidly as the development of irrigation technology allowed for the exploitation of larger and larger areas of the floodplain. All of the larger drainages have excess discharge that could be harnessed for irrigation, but which is unused because of the limited floodplain area within the river valleys (Moseley, 1983). Thus, in spite of the aridity, agricultural resources are limited by the land area available, not by river discharge. Numerous attempts, throughout prehistory, have been made to extend the irrigation networks outside of the floodplain (Moseley, 1983; Ortloff et al., 1983; Shimada, 1994).

Ortloff et al. (1983) and Moseley (1983) have attempted to explain the abandonment of the canals by local tectonic tilting or block faulting. Neither of these explanations are viable. Numerous authors (Wells, 1988; Goy et al., 1992; Noller, 1993; Machare and Ortlieb, 1993; Zazo et al., 1994; Ortlieb et al., 1994; Noller and Sebrier, 1998) have pointed out the lack of deformation in Quaternary sediments and landforms in this area of the coast, and it is clearly impossible for engineered structures to have been deformed in the absence of deformation of landforms or depositional units. We must then consider that river incision by the nontectonic processes is more likely to have accounted for abandonment of the canal intakes. Additionally, variability in river discharge may be tied to highland climatic changes (Rodbell, 1992; Rodbell et al., 1997) or changes in the frequency of El Niño events (Rodbell et al., 1999). The canal networks of the Moche and Chicama valleys were initially extended beyond modern limits sometime between A.D. 500 and A.D. 100 during the period of the Moche control of the north coast (Moseley, 1983; Moseley and Deeds, 1982; T. Pozorski, 1987). Schaaf (1988), using the ice core records from Quelccaya, documents what may be a period of increased El Niño frequency (5 events between 600 and 700 yr B.P. = 1 event every 20 yr) while the canal network was expanding. This period of high event frequency occurs at a time when the low-resolution flood record suggests relatively low event frequency (long-term average estimates range from 1 in 49 to 1 in 600 yr; see Figure 3). Canal contraction may regionally occur as early as A.D. 1000, but in the Moche Valley postdates a major flood ca. A.D. 1300 (T. Pozorski, 1987). The time of canal contraction is contemporaneous with the medieval warm period. Flood frequency may have been even lower during this time (only three events are recorded in the flood records of Nials et al. [1979], S. Pozorski [1987], and Wells [1990]), and continued wind and aridity is indicated by canals infilled with eolian sand and dust (T. Pozorski, 1987). T. Pozorski (1987) suggests that the cost to maintain marginal canals during a period of low river discharge exceeded the agricultural benefits such that the canals were abandoned subsequent to the A.D. 1300 flood. After this date, Chimu focused their resources on territorial expansion rather than on the restoration of engineering works. These data suggest that canal expansion was an attempt to harness excess moisture followed by contraction when water resources became scarce.

Climate History and Cultural Evolution

The prehistory of episodic flooding in north coastal Peru is remarkably similar between the Chicama and the Casma regions. The composite stratigraphy at both locations results in a minimum of 18 large El Niño events after 9,500 yr B.P. The flood stratigraphy is extended some by Keefer et al. (1998), who document five large flood events between 8,900 and 12,500 years B.P., so that the combined stratigraphic record results in a minimum of 20 major El Niño events during the last 12,000 years, yielding an average recurrence interval of 600 yr. As noted earlier, preservation potential probably accounts for at least part of the apparent increase in event frequency with time. However, a variety of records (Wells, 1990; Steinitz-Kannan et al., 1997; Keefer et al., 1998) now suggest that there was a decrease in event frequency between ca. 8,500 and 3,000 yr B.P. This period of decreased El Niño frequency may in part account for Sandweiss et al.'s (1996) interpretation of no El Niño prior to 5,000 yr B.P. Contrary to Sandweiss et al.'s (1996, 1997) reconstructions, however, the other paleoclimatic records indicate continuous background aridity through this window of time (Wells, 1988; Noller, 1993; Ortlieb and Machare, 1993; Steinitz-Kannan et al., 1997; Keefer et al., 1998).

At least three of the archaeological period boundaries are coincident, within the geochronologic uncertainty, with significant flood events. Wilson (1998) places the Initial Period–Early Horizon (Moxeke-Pallka) boundary at 3,100 yr B.P. (flood age 3190 $\pm$ 55 yr B.P.), the Patazca–Cachipampa boundary at 2,000 yr B.P. (flood ages 1930 $\pm$ 160 and 2180 $\pm$ 130 yr B.P. in Casma and Chiclayo, respectively), and the Middle Horizon–Late Intermediate Period (Casma–Manchan) boundary at 600 yr B.P. (flood ages 620 $\pm$ 35 and 610 $\pm$ 50 yr. B.P. in Casma and Chiclayo, respectively). Moseley (1992) and Shimada (1994) have proposed that the Moche IV to Moche V transition occurred subsequent to a major El Niño event (ca. A.D. 550 or 1,400 yr B.P.) that occurred in the middle of a long period of drought. However, Uceda and Amico (1993) document thin layers of flood sediment preserved throughout the stratigraphy of this time period at the Moche capital, thus indicating that El Niño events continued to occur during the hypothesized drought. Moseley (1987) hypothesizes that major El Niño events create a "punctuated equilibrium" in cultural evolution, whereby periods of extreme environmental stress are also periods of marked cultural change. The physical impacts of a major El Niño event, river flooding and changes in maritime resources, could certainly result in economic and cultural vulnerability. Thus, as suggested by Moseley (1987), we posit that the rate of cultural evolution was enhanced after major El Niño events due perhaps to infrastructure demise, technological innovation, or governmental vulnerability resulting from El Niño's impact on a constrained resource base. We also concur, however, with Uceda and Amico's (1993) assertion that prehistoric cultures in coastal Peru must have been well adapted to dealing with recurrent El Niño events and that cultural evolution is not wholly dependent upon a climatic phenomenon.

It is important to remember that not all El Niños are equal. Events of the magnitude of 1983 or 1998 most likely occurred only once or twice each century, and even a larger event may occur at a longer recurrence interval (Nials et al., 1979; Craig and Shimada, 1986; Moseley, 1987; Wells, 1988, 1990). Duration, intensity, extent, and frequency of events all change through time (Dunbar et al., 1994). The Little Ice Age may have been a period of reduced frequency or intensity (Thompson et al., 1986; Steinitz-Kannan et al., 1997), and it appears that, as we enter a period of warmer atmospheric temperatures, the frequency and intensity of events is increasing. Likewise, the cultural response to individual events will vary both spatially and temporally. In only a few instances is the temporal control sufficient to unequivocally tie cultural or technological response to an individual El Niño event. For example, Moore (1991) documents the establishment of a small agricultural community in the lower Casma valley to reclaim water-logged land following the ca. 600 yr B.P. El Niño event. Flood sediments are also observed to partially bury many archaeological sites, even in the small tributary valleys. The fill stratigraphy at Cerro Sechin (near the confluence of Rio Sechin and Rio Casma) contained numerous flood layers, at least one of which had preserved human footprints on its surface (Samaniego et al., 1985:179–182). Most of the flood sediments trapped within Cerro Sechin must have washed down the very small first-order catchment that is upslope of the site. El Niño's impacts on the archaeological record are therefore at least twofold: (1) the cultural implications of dealing with very large intermittent flooding and maritime ecosystem transformations, and (2) the geomorphological implications of burial and reworking of archaeological materials.

Long-period climatic variability, which is well expressed in the highlands but not in the desert, has also affected on the coastal populations. Shimada et al. (1991a, 1991b) interpret the ice core data from the Quelccaya icecap to record what they believe to be "one of the harshest droughts in the past 1,500 years," between A.D. 562 and A.D. 594 (1,356–1,388 yr B.P.). They suggest that this drought ended nearly a century of extremely dry conditions (Shimada, 1994:122–128). Shimada (1994) attributes the cultural changes from Moche IV to V largely to this specific drought following on the tails of a long dry period. Moseley and Deeds (1982) blame the demise of the Moche IV Capital (Huacas del Sol and Luna in the Moche Valley) to the incursion of eolian sands during this time, although recent excavations (Uceda and Amico, 1993) indicate that the site continued to be occupied into the Moche V period. Concurrently, the Casma Valley was experiencing a marked decrease in the numbers of settlements (Table V) and probably in the total population in the valley. If there was indeed a marked drought ca. A.D. 500–600, it is not surprising that the Casma Valley, with its relatively low annual discharge, would be hard hit. But what is a drought in a hyperarid desert where rain is so rare? Given that the geological data supporting this drought (Thompson et al., 1985) are based on changes in highland precipitation, it is likely that droughts on the coast are a result of decreased highland rainfall, resulting in lower levels of river discharge to the coastal lowlands.

CONCLUSIONS

The environmental constraints of life in the hyperarid desert of coastal Peru have influenced cultural adaptations throughout prehistory. The resource base of this desert is extremely limited and focused along the coastlines and riparian oases. These two environments have evolved during the Holocene in response to sea level change, climatic variability, and sediment flux. Although commonly cited as a driving force for Holocene geomorphologic evolution, no evidence for catastrophic tectonic uplift has been found in this region. The large littoral complexes deposited adjacent to the mouth of large rivers are the result of sedimentation during a period of relative sea level stability. During this same period of time, the lower valleys have filled with a sequence of floodplain sediments, largely deposited during El Niño events, resulting in the gradual formation of an extensive fine-grained floodplain.

Human history reflects the changing environments. When the coastline became stable ca. 7,000 yr B.P. the first sedentary communities were founded along its shoreline. As rivers backfilled and a fine-grained floodplain formed, there was a concomitant increase in reliance on fluvial resources and an eventual shift toward reliance upon irrigation agriculture. Irrigation agriculture expanded to the physical limits of the floodplain, and numerous attempts have been made to use excess river discharge from the larger drainages to irrigate the adjacent desert regions or smaller drainages.

In summary, the environment of coastal Peru has set limits on cultural and technological development. Evolution of the environment means that the limitations have changed through time. The formation of stationary, easily accessible resources necessarily preceded the exploitation of those resources. The rapidity with which the resources were exploited suggests that the local populations were able to adapt quickly with technological and cultural innovations into new environmental niches. Extreme environmental and economic stress associated with the largest El Niño events or with drought cycles may have helped to cause or to promote short periods of more rapid cultural and technological change.

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