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# **Cultural impacts of severe droughts in the prehistoric Andes: application of a 1,500-year ice core precipitation record**

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## **Introduction**

The Central Andes of South America, roughly corresponding to the highland and Pacific coastal regions of Peru, is a land of unparalleled climatic and physiographic complexity and extremes, largely derived from its tropical location, cold Humboldt (Peru) Current and geologically young, active Andean range. While archaeologists working in the Central Andes have been well aware of the creative and dynamic interplay between climate and culture, it has been difficult to ascertain archaeologically whether observed cultural changes were due to human factors or some combination of human and environmental factors. Part of this difficulty has stemmed from poor environmental data and dating of relevant events, the latter potentially obscuring the cause and effect relationship between the climatic and cultural changes under study.

Recent analyses of deep ice core samples from the Peruvian Andes have established a lengthy, precisely dated record of annual precipitation and proxy temperature that allows archaeologists effectively to assess the impact of climatic factors. Two ice cores drilled in 1983 at the summit of the Quelccaya ice cap in the Cordillera Oriental of the southern highlands of Peru (Fig. 1) preserve a record of annual precipitation for the past 1,500 years. These data reveal not only local highland precipitation amounts, but, by exploring modern climatic relationships between the southern highland region around Quelccaya and the northern Peruvian Andes, can also be used to construct an approximate record of precipitation amounts falling on the headwaters of the northern coastal rivers that drain the western slopes of the Andes.

The prehispanic cultures of the northern Peruvian coast are particularly well-suited for assessing archaeologically the impact of major anomalies in highland precipitation. The coast as a whole suffers from severe aridity, with substantial rains only occurring perhaps several times during one's lifespan. These dry desert conditions have helped preserve archaeological remains and evidence of prehispanic environmental changes, and, more importantly, created inevitable dependence on large-scale irrigation using river runoff from the adjacent highlands. With its heavy dependence on large-scale irrigation agriculture, the prominent prehispanic culture of Mochica (also known as Moche), which

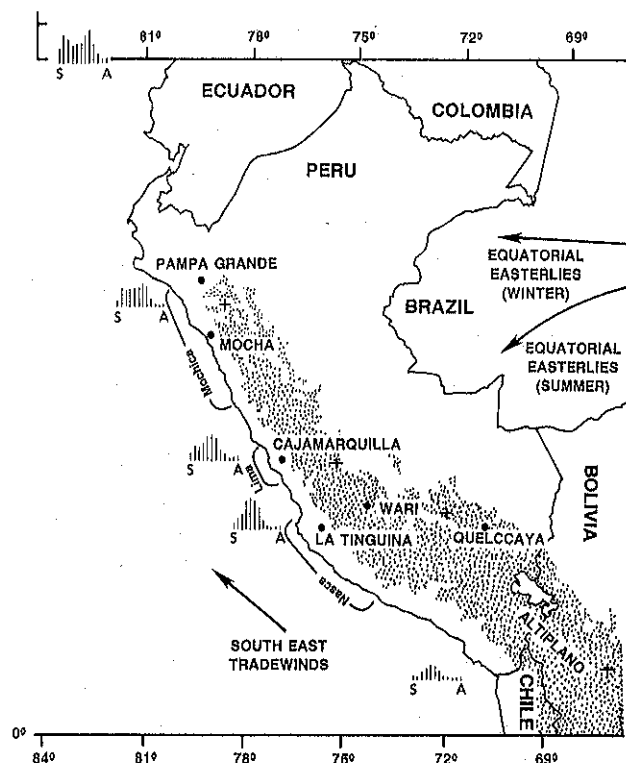


Figure 1 Map showing major archaeological sites and cultures of the early sixth-century Central Andes discussed in text. Topography is delineated at 2000m. Wind vectors are from Taljaard (1972). Average annual rainfall at the highland sites of (from north to south) Quito, Ecuador, Cajamarca, Huancayo, and Cuzco, Peru, and Oruro, Bolivia (located at crosses) is depicted by bar charts. Charts are on a 200mm scale running from September to August. The rainfall peaks show the double wet season of the equator, the low precipitation amounts of the altiplano wet season, and the migration of the equatorial trough and the wet season at three Peruvian sites (January, February and March, respectively).

dominated the north coast of Peru from about the time of Christ to AD 700 or 750 (Fig. 2), would have been quite sensitive to any climatic changes in the adjacent northern highlands that affected the amount of water reaching the coast.

This study focuses on a 100-year period between AD 500 and 600 when the Mochica and its contemporaneous cultures in various other regions of Peru (Fig. 1) underwent rapid and far-reaching internal transformations. By comparing the geophysical record from Quelccaya with archaeologically documented or inferred cultural and environmental changes, it is possible to assess the impacts of climatic anomalies during this complex period.

#### The Moche IV-V transformation

The Mochica culture is widely known for its painted ceramics, sophisticated metallurgy, and monumental adobe brick mounds. Based on changes in ceramic form and style, its chronology is subdivided into five phases (Moche I-V; Table 1). During the height of its power in late Moche III to early Moche IV (c. AD 300 to 500), the Mochica polity controlled essentially all of the northern Peruvian coast (Fig. 2). The site of Moche,

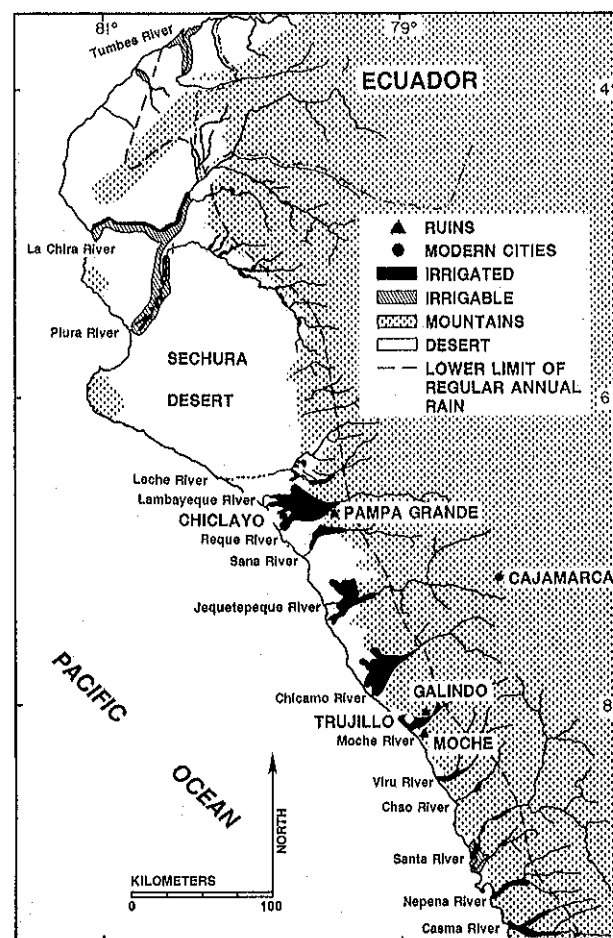


Figure 2 Map showing irrigated agricultural lands in north coast river valleys. The receding Andean foothills allow the formation of a massive intervalley irrigation system unifying the contiguous Leche, Lambayeque and Zaña Valleys. Based on Plate XIV in Kroeber 1930.

Table 1 Relative chronological correlations of the Mochica, Lima and Nasca styles.

North coast (Shimada n.d.)	Central coast (Patterson 1966)	Ica Valley (Menzel 1977)	Nasca Valley (Silverman 1990)
C	Lima 9		
Moche V B		Nasca 9	Nasca 5
A	Lima 8		
		Nasca 8	Nasca 4?
B	Lima 7		
Moche IV	Lima 6	Nasca 7	Nasca 3
A	Lima 5		

situated on the southern bank close to the mouth of the Moche Valley, has been regarded as the capital of the polity at least for Moche III and IV (e.g., Schaedel 1972; Topic 1982; Fig. 3). The site boasts the enormous Huaca del Sol and Huaca de la Luna mounds. The former is the largest adobe construction in the New World (Hastings and Moseley 1975: 186) and was built over several centuries (ibid.: 197; Moseley 1975). It has been argued that Moche III and IV regional centers contained at least one sizable monument built in the architectural canons expressed at Sol and Luna (Moseley 1983a: 219).

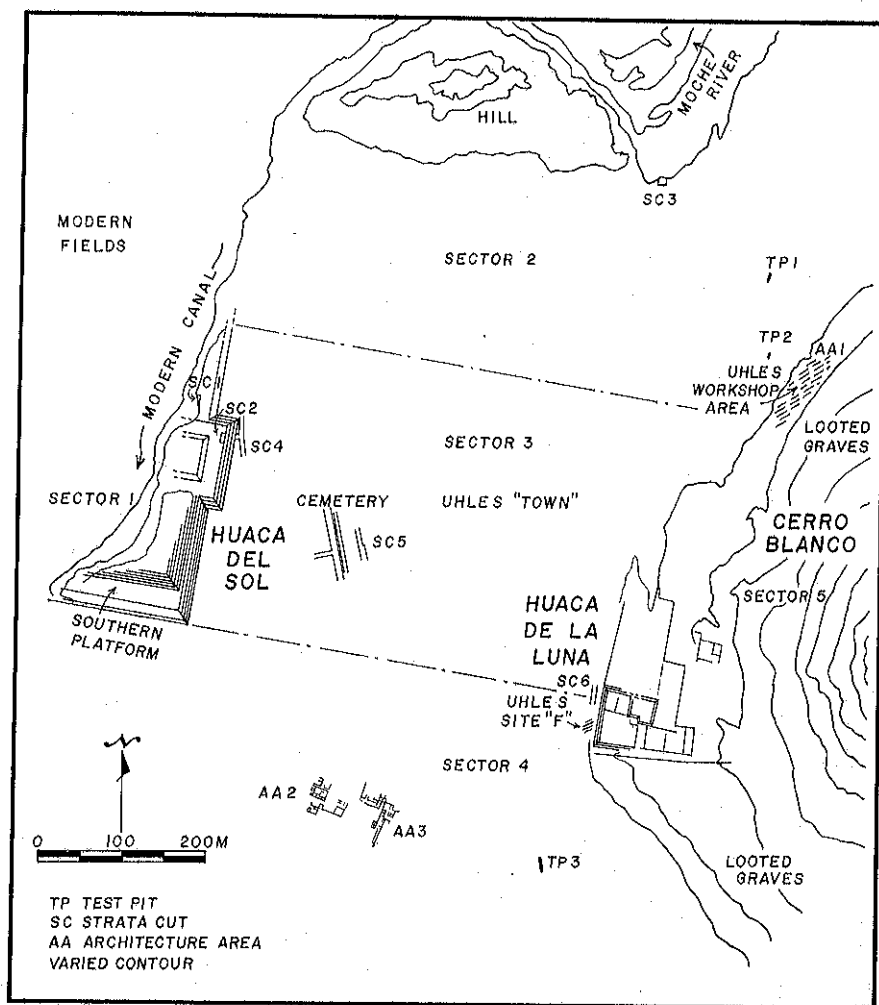


Figure 3 Map of the site of Moche. The sand-filled area between Huaca del Sol and Huaca de la Luna contains largely unexplored cemeteries and architecture. Based on Map 5 in Donnan and Mackey 1978 and Fig. 11.1 of Topic 1982.

Sometime late in Moche IV, a number of serious environmental disturbances appear to have occurred at the site of Moche. The base of the Huaca del Sol was extensively water damaged and several meters of soil from the surrounding area were stripped away (Moseley and Deeds 1982: 38). This destruction was apparently caused by a major flash flood (ibid.). Shortly after the flood damage was repaired, southern portions of the site were invaded by sand dunes which eventually cut off the main irrigation canals to nearby cultivation fields and the water supply to the capital (ibid.; also see Moseley, Feldman and Ortloff 1981). The site was essentially abandoned at the end of Moche IV (Donnan and Mackey 1978: 211). It is significant that the Mochica polity appears to have concurrently lost control of (or simply abandoned) its realm south of Moche (e.g., Proulx 1973: 48; Wilson 1988: 333).

The above was accompanied by a major northward and inland shift in Mochica geopolitics and population. Mochica occupation of the northern realm continued, although with major organizational changes. Within the Moche valley, settlements and agricultural land in the lower valley were abandoned in favor of inland locations on the north bank. During Moche V the urban site of Galindo (Fig. 2; c. 6km<sup>2</sup> in extent, 12km further inland from Moche) emerged as the regional center (Bawden 1982: 318-19). No major new irrigation or architectural projects were undertaken during this time span (ibid.). It appears that the Mochica polity at Galindo could no longer command labor forces from neighboring valleys. In fact, the Moche valley was no longer the stronghold of the Mochica culture.

Concurrently, in the adjacent Chicama valley, the Mochica regional center of Moccollope was abandoned at the end of Moche IV (Russell and Leonard in press). Farther north in the contiguous Leche, Lambayeque, Zaña and Jequetepeque valleys, in contrast to relatively rare Moche I-III and early IV settlements, those dating to late Moche IV and V are widespread (Shimada 1987: 131-3). The Moche IV-V transition in the northern realm can be inferred from radiocarbon dates to be sometime between AD 500 and 600 (Table 2). Eleven internally consistent radiocarbon dates from secure primary contexts at four sites place Moche V occupation in the northern realm spanning c. AD 600-700 to 750 (Table 2; Bawden 1977: 410; Shimada 1976: 377-8; 1978: 571; in press; n.d.).

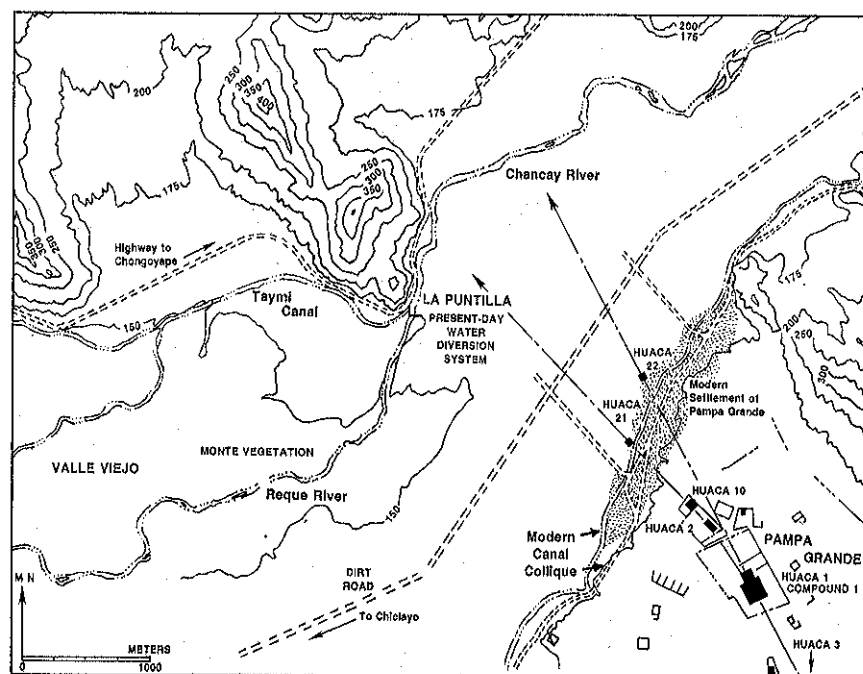
Clearly, the paramount Moche V settlement was the planned city of Pampa Grande built at the neck of the Lambayeque Valley, approximately 55km inland from the Pacific and some 165km north of Galindo (ibid.). In contrast to the frontier settlement of Galindo, many Mochica traditions and institutions persisted at Pampa Grande, including monumental platform mound building (Huaca Fortaleza close in size to Huaca del Sol (ibid.)).

Galindo and Pampa Grande shared some critical features. Their valley neck locations reflect an explicit, high-level concern with control of the main intakes of all major regional canals (Fig. 4). Another key feature observed at both Pampa Grande and Galindo is population nucleation of unprecedented scale and rapidity. The sand-filled area with intermittent architectural remains at Moche that Uhle (1913) identified as a 'town' is only about 1,000m × 300m in extent (Fig. 3). In contrast, both Galindo and Pampa Grande have densely built architecture covering an area c. 6km<sup>2</sup> in extent. At Pampa Grande, the overwhelming portion of the architecture dates to Moche V and some of the stone structures in the upper peripheries of the site seem to have been unfinished. At its height, it

**Table 2** Radiocarbon dates for Moche IV–V transition and Moche V culture. The calibrated dates in this table were computer-generated at the Radiocarbon Laboratory, Institute for the Study of Earth and Man, Southern Methodist University, on the basis of the Belfast Laboratory results on Irish Oak chronologies. The calibration program used here was designed and written by Steven Robinson of the US Geological Survey Radiocarbon Laboratory in Menlo Park, California.

Context and material	Lab. no.	C-14 age (BP $\pm$ 1 $\sigma$ ; ad)	Calibrated date (AD)
<b>Pampa Grande (Lambayeque Valley):</b>			
Burnt wooden post atop platform mound (Huaca 18), Sector H; Moche V	A-1704	1280 $\pm$ 70 BP; ad 690	AD 740 $\pm$ 80
Charred cotton, floor of elite compound ('Deer House'; Unit 14); Moche V	SMU-399	1300 $\pm$ 60 BP; ad 650	AD 710 $\pm$ 60
Charred cotton, floor of burnt platform mound in rectangular enclosure (Unit 16); Moche V	SMU-644	1250 $\pm$ 50 BP; ad 650	AD 770 $\pm$ 70
Burnt cane, roof of <i>Spondylus</i> workshop, rectangular compound (Unit 15); Moche V	SMU-682	1380 $\pm$ 40 BP; ad 570 f	AD 650 $\pm$ 20
Carbonized corn kernels in an urn placed in the floor of Structure 43, Unit 45, Sector H; Moche V	A-1705	1380 $\pm$ 70 BP; ad 570 not corrected for C-12/13 fractionation	AD 650 $\pm$ 50
<b>Huaca Soledad (Leche Valley):</b>			
Charcoal from a firepit, Test Pit 3, Cut A, Southern Cemetery stratigraphically pre-Moche IV intrusion associated with late Gallinazo-like sherds.	SMU-897	1570 $\pm$ 40 BP; ad 380 f	AD 490 $\pm$ 60
Charcoal from 'protective organic layer' covering Phase I construction, Mound II; associated with Moche V (?) burnished blackware bowl fragments	SMU-833	1410 $\pm$ 60 BP; ad 540	AD 630 $\pm$ 40
<b>Huaca del Pueblo Batán Grande (Leche Valley):</b>			
Trench 1/2-79 charcoal from firepit near the sterile sand, Stratum XII, Level N; late Moche IV	SMU-873	1540 $\pm$ 60 BP; ad 410	AD 520 $\pm$ 70
Charcoal from firepit in the sandy Stratum XII, Level D/E Moche V	SMU-901	1430 $\pm$ 60 BP; ad 520 f	AD 620 $\pm$ 40
Charcoal from buried, discolored and sooted vessel near the top of Stratum XII Moche V	SMU-876	1410 $\pm$ 60 BP; ad 540	AD 640 $\pm$ 40
<b>Galindo (Moche Valley):</b>			
Wood charcoal from 'pre-primary' room in the south court razed in order to construct the foundation of the Huaca Galindo; end of Moche IV or the onset of Moche V	GX-3256	1415 $\pm$ 185 BP; ad 535	
Wood charcoal from 'post-primary' squatter occupation at the Huaca Galindo compound – immediately after Moche V	GX-3257	1325 $\pm$ 165 BP; ad 625	
Ash level, ceramic workshop; Moche V	K4649-RC14-5	1260 $\pm$ 140 BP; ad 690	
Hearth, Structure 18; Moche V unacceptably old	K4649	2335 $\pm$ 175 BP; bc 385	

is believed to have had a population of 10,000–15,000 (Shimada n.d.). Both sites are believed to have included resident farmers who commuted to the prime cultivation fields below the valley necks (ibid.). In addition, both sites feature tightly controlled large-scale



**Figure 4** Map showing the valley neck location of Pampa Grande that afforded ready control of the main intakes of all major regional canals. The Taymi Canal, the north bank 'maximum elevation canal' draws water from the Chancay River at La Puntilla and less than 2 km downstream gives rise to the Lambayeque River (artificially canalized ancient river). The ancient Collique canal, the south bank maximum elevation canal, had its intake some 4 km inland from Pampa Grande.

storage of food (beans and maize kernels) and inferred craft goods (ibid.; Anders 1977; 1981; Bawden 1982: 304–7). Further, these and other Moche V sites manifested a diminished repertoire and use of traditional religious iconography, new ceramic forms, and a shift from extended to flexed burial position, as well as in ritual activities and paraphernalia (Bawden 1983; Shimada n.d.).

Overall, the Moche IV–V transformation was unprecedented, not only in its impressive scope, scale and rapidity, but also in the fact that many of the observed changes could not be anticipated from the preceding 500 years of Mochica cultural evolution.

#### Comparative data

It is significant that other coastal regions of Peru also witnessed roughly coterminous, major settlement shifts favoring the valley neck or other locations with secure access to water. In the Rimac Valley on the central coast, the site of Maranga, a major ceremonial-civic center of the Lima culture was depopulated sometime around Lima 8 (see

Table 1; Canziani 1987; MacNeish, Patterson, and Browman 1975: 54; Patterson 1966: 112). Concurrently, rapid population nucleation unprecedented on the central coast was seen at the site of Cajamarquilla (c. 6km<sup>2</sup>) situated farther inland near the valley neck (ibid.) and significant population aggregation also occurred around the valley neck in the adjacent Lurín Valley to the south (Earle 1972: 476).

Relevant information from the coast farther south is tantalizing, but surrounded by ongoing chronological debate. At sites in the upper and middle Ica Valley on the south coast of Peru (Fig. 1), Menzel (1971: 86–9) encountered evidence of a drought and concurrent Nasca 7–8 settlement shift (Table 1). Changes observed in the plant remains recovered from a midden at La Tinguña (Fig. 1), the principal Nasca 7 site in the valley, are of particular interest. From lower to upper strata, Menzel (1971: 90) observed that maize (*Zea mays*) and beans (*Canavalia* sp. *Phaseolus lunatus*) became rare and *aji* peppers (*Capsicum* sp.) disappeared, while calabash (*Cucurbita moschata*) increased over time, representing the single largest category of cultivated plant found in the excavation. Among these crops calabash has the shortest growth period and requires the least water overall. Today, calabash is grown in areas or times of water shortage on the coast.

It is not a simple matter to determine the relative economic significance of cultivated plants or prevailing climatic conditions from their preserved remains in archaeological contexts. However, this general reduction in quantities and variety of plants was accompanied by a decline in craftsmanship of associated ceramics and followed by a major settlement shift (ibid.: 91). Further, while the favored location for Nasca 7 sites was dry alluvial fans or plains well above modern cultivation and habitation limits, Nasca 8 and later sites are found in lower areas closer to water sources (ibid.).

Overall, Menzel (ibid.) argues that unusually favorable conditions at the onset of Nasca 7 allowed occupation of valley margins well beyond limits of modern cultivation and habitation, but water availability decreased over time, eventually forcing permanent abandonment by the end of Nasca 7 (ibid.).

However, recent fieldwork in the adjacent Nazca drainage (Fig. 1) to the south has documented some major cultural changes between Nasca 4 and 5 that deserve our attention. Following its apogee and expansion during Nasca 3, construction at the principal Nasca site of Cahuachi ceased in Nasca 4 and the site was abandoned by Nasca 5 (Proulx 1968; Silverman 1986; Strong 1957). Concurrently, Nasca art underwent a notable transformation. During Nasca 5, the 'Monumental' substyle that characterizes Nasca 3 and 4 (Proulx 1968) loses its naturalism with the rather abrupt intrusion of a new substyle termed 'Proliferous' with seemingly excessive details and fillers (Roark 1965: 2). During Nasca 5 and 6, mythical themes are replaced by military themes, including association of trophy heads and human warriors (ibid.).

In addition to these changes, Schreiber and Lancho (1988: 62) argue that the shift in settlement focus from upper Nazca valley in Nasca 2–4 to mid-valley in Nasca 5 through 8 relates to the construction of ingenious *pukios*, artificial galleries for tapping underground filtration water for irrigation. Due to the peculiar geological condition, the Nazca drainage water flows underground in the mid-valley necessitating *pukios*, which offer a more stable and reliable source of water than the seasonal surface flow.

Available radiocarbon dates from the south coast are still too few to reliably bracket the span of various critical Nasca phases. Silverman (1988: 25, 26) suggests a date of AD 550

for Nasca 5 on the basis of a single radiocarbon determination (1430 ± 90 BP [L-335E]; Rowe 1967: 23; Strong 1957, Table 4). There is no date directly associated with Nasca 6 materials. One determination of a sample associated with a Nasca 7 burial from Chaviña is 1320 ± 60 BP (Y-126; Lothrop and Mahler 1957: 47; Rowe 1967: 23). Nasca 8 has been dated to 'c. AD 700–800' on the basis of three internally consistent, uncorrected radiocarbon dates (Silverman 1988: 25). Comparison of relevant radiocarbon dates suggest that the Moche IV–V transformation is coeval with that seen between Nasca 4 and 5.

### Explanations

One possible explanation for these apparently coeval and abrupt settlement shifts is that coastal cultures were responding to the threat of or actual intrusion by the Wari polity centered in the Ayacucho basin in the central highlands of Peru (cf. Collier 1955; Menzel 1964; Schaedel 1951; 1966; Willey 1953). The northward shift of the Mochica capital would be viewed as seeking safe refuge away from the encroaching Wari forces. The large intervening Jequetepeque Valley, a principal route linking the north coast and highlands, would have been a poor choice for the Moche V capital due to the presence of the Cajamarca polity, an inferred Wari ally centered in the Cajamarca Basin at the headwaters of the Jequetepeque River (Shimada n.d.). Also, a survey has shown that the extensive sand sheet that today covers much of the south bank of the river had begun inland movement before the Moche V occupation there (Eling 1987: 458).

This model does not adequately account for the population nucleation at valley necks and attendant concern over control of water. Further, the Wari or local Wari-derived features documented thus far on the north coast appeared during or immediately after Moche V (e.g., Donnan 1972; Menzel 1977; Shimada in press; n.d.). At present, there is nothing concrete to indicate Wari involvement in the Moche IV–V transformation. Rather, Wari expansion appears to have been a major contributing factor in the subsequent demise of the Moche V polity around AD 700–750 (ibid.).

A number of alternative explanations have invoked climatic anomalies. Building on her inferences regarding changing climatic conditions derived from the use or abandonment of wells on the Santa Elena peninsula of Ecuador, Paulsen (1976) has argued that an Andean interpluvial that began about AD 600 was a factor in the Nasca 7–8 settlement shift and the rise of the Wari 'empire'. This long distance (c. 1,500km) extrapolation is based on the premise of a global pattern of drastic simultaneous changes (ibid.: 124).

Cardich (1980, 1985) phrases his explanation in terms of the rise and fall of ambient temperature. He sees the first several centuries of our era as warm and 'benign', allowing agricultural expansion into higher elevations and secure and plentiful agricultural production overall (Cardich 1980: 23). Starting around AD 500, however, he sees the onset of a cold era that eventually brought about an 'agro-climatic crisis' in the Central Andes and coastward expansion by the Wari population during the seventh and eighth centuries (ibid.: 23–4). His arguments are based on such evidence as contraction and expansion of Andean glaciers, changing upper limits of human occupation in high altitudes of the Central Andes, as well as tree-ring data from California and historical records from Europe.

MacNeish, Patterson and Browman (1975), on the other hand, rely on pollen and soil data collected in the Ayacucho basin to account for the observed Lima settlement shift in the Rimac valley. Importantly, they treat the settlement shift as analytically detached from and chronologically preceding the Wari expansion. They see it as a response to a series of major fluctuations in the precipitation pattern between c. AD 450 and 550 (ibid.: 52–4). During the early part of this time span, they believe that central coast populations reached maxima largely due to a sustained period of increased availability of irrigation water resulting from greater precipitation levels (ibid.). However, with the inferred return to normal or subnormal precipitation levels starting around AD 500 and significantly less water reaching the coast, coastal agricultural production underwent a corresponding decrease with abandonment of marginal and lower valley farmlands and settlements (ibid.). Population nucleation at the valley neck would be a logical response as the location provides ready access to the best-cultivable land and water reaching the coast. Further, the presence of the main intakes for intra- and inter-valley canals at the valley necks would have provided Cajamarquilla with the political upperhand over lower valley populations.

For the Nasca 4–5 settlement shift, Schreiber and Lancha (1988: 62) argue that the concurrent construction of *pukios* may have been the 'most appropriate response of the Nasca culture' to adverse effects of droughts around AD 500 seen in the decadal precipitation records from Quelccaya ice cores previously published by Thompson et al. (1985).

As a whole, these climatic explanations present similar scenarios. At the same time, their explanatory power is seriously weakened by the fact that characterization and dating of relevant natural and climatic events and forces are imprecise or uncertain. For example, the interpluvial era that Paulsen speaks of spans several centuries without any indication of how abruptly it began or how its intensity fluctuated over time. The critical 'bridging arguments' demonstrating the appropriateness of using Quelccaya or other highland climatic data to the coast are missing in the other explanations.

On the other hand, annual precipitation records from the Quelccaya ice cores offer temporally precise, direct indications of water availability for the past 1,500 years. In addition, a review of Peruvian meteorology and climatic factors is presented to show the appropriateness of using the Quelccaya data to infer the amount of precipitation falling on the watersheds of the northern Peruvian Andes.

### Climate

The climate of Peru is largely dictated by its equatorial position, the presence of the high Andean eastern and western cordilleras running parallel to the long Pacific coast (3°S–18°S), and the presence of the cool Humboldt Current offshore. The arid coastal plain is quite narrow with the western Andean cordillera rising above it rather abruptly. The Moche Valley, for example, rises to an elevation of 4,000m within 102km of the coast. Most of the Pacific water vapor in the prevailing southeasterly tradewinds, which parallel the coastline, is transported toward the equator rather than precipitated locally. Coastal precipitation is infrequent, suppressed by the atmospheric subsidence characteristic of subtropical eastern ocean areas. The only available surface water is carried across the arid coast by rivers fed with runoff from highland precipitation.

East of the Andes, the equatorial easterlies prevail. The position of the subtropical Atlantic anticyclone governs the curvature of the flow, with a northerly component bringing Amazonian water vapor to all of the high Peruvian cordilleras in the southern hemispheric summer (Hastenrath 1977; Johnson 1976; Taljaard 1972; van Loon 1972). Most of this water vapor is precipitated in the high windward escarpment of the Andes and little crosses the ridges and highlands to fall as precipitation on the western slopes. It is important to note that the majority of highland precipitation originates from the Amazon to the east rather than from the nearby Pacific. In the winter, strong easterly winds continue to occur in the tropics, though the stable flow around the Atlantic anticyclone now brings northwesterly and westerly winds to the subtropics and the upper level winds even reach northward to affect the higher mountain elevations of the southern tropics (ibid.).

The southeast tradewinds and equatorial easterlies dominate the windflow in this tropical region and any seasonal variation in precipitation is brought about by the annual northward and southward migration of the equatorial trough (ibid.; Fig. 1). The equatorial trough is the zonal band of relatively low pressure lying between the northeast and southeast tradewinds and along whose axis occur areas of atmospheric convergence, convection, and resultant precipitation. The latitudinal passage of the equatorial trough dominates the large-scale atmospheric circulation and signals the onset of the southern hemisphere wet season (Snow 1976). North of Peru, near the equator, two wet seasons and two dry seasons occur as the trough moves northward and later southward during the year (Fig. 1). However, along the entire extent of the Peruvian Andes, there is only one pronounced wet season occurring during the southern summer (Nov.–Apr.), and one dry season occurring during the southern winter (May–Oct.; Fig. 1). Although Andean physiography can cause variable local surface winds and rain amounts, the majority of the annual precipitation occurs during the southern summer wet season when the prevailing easterlies carry Amazonian water vapor high up onto the highlands interacting with the equatorial trough (Johnson 1976).

The greatest amount of precipitation in the northern Peruvian highlands occurs in March as the equatorial trough passes overhead (ibid.; ONERN 1976). In the north, the eastern ridge is a more punctuated chain and it is the western cordillera that acts as the major barrier to moist summertime winds off the Amazon Basin. Occasionally, however, vapor-laden air does travel across the entire Andes. Additional low level water vapor, originating from the Pacific, can be channelled inland by low-level seabreezes and upvalley winds and initiate convection which then builds into the upper level Amazon moisture source. If the easterly tradewinds are stable, convection is contained and only cloudiness occurs. If however, the easterlies are unstable, large thunderclouds build up over areas of extreme orographic uplift, triggering infrequent showers over the headwaters of the northern coastal rivers. Despite the importance of diurnal and orographic effects and the proximity of onshore Pacific water vapor, it is the character of the easterlies that determines the amount of precipitation that falls on the western slopes of northern Peru (Howell 1954).

In the southern Peruvian Andes, the heaviest rains occur in January, the month when the equatorial trough reaches furthest south (Fig. 1). Since the eastern cordillera is more of a continuous high chain in the south, it is the range that acts as the major barrier to the prevailing vapor-laden easterlies and the western sierra and slopes of southern Peru are

even drier than in the north. Fundamentally therefore, the eastern barrier in the south and the western cordillera (the source of coastal rivers) in the north are both affected by the same moisture-bearing equatorial easterlies from Amazonia.

In summary, even though the mountains of Peru stretch across  $15^{\circ}$  of tropical latitude, the majority of the highlands are subject to the same meteorological regime and the annual precipitation totals are remarkably consistent (Johnson 1976). There is no indication of significant shifts in the basic pattern or geographical extent of this regime over the past 1,500 years (Wells 1987: 14,463). The principal variables determining local climate are the altitude and exposure (either windward or leeward of the Andes). There is remarkably little large-scale variation in total annual precipitation in the north/south direction (Johnson 1970) until the subtropics and the high *altiplano* (high altitude plateau) of the extreme south of Peru, northern Chile, northwest Argentina, and western Bolivia are reached. Annual rainfall does decrease noticeably in the dry *altiplano* region south of  $15^{\circ}\text{S}$  (Johnson 1976). However, the Quelccaya ice cap ( $13^{\circ}56'\text{S}$ ,  $70^{\circ}50'\text{W}$ ) is situated on the eastern cordillera, firmly in the tropics, north of the subtropical *altiplano*, and experiences precipitation amounts similar to the rest of Peru.

The precipitation regime at Quelccaya was established by meteorological data collected there from 1976 to 1984 (Grootes et al. 1989; Thompson 1980; Thompson and Mosley-Thompson 1987; Thompson, Mosley-Thompson, and Morales 1984; Thompson et al. 1984; 1985). These data showed that a single annual cycle (one wet season and one dry season) occurs in this region as it does in the rest of Peru. The mid-level easterly tradewinds are the dominant winds during the wet season, bringing moisture from the Amazon Basin to the region. During the winter dry season, strong upper-level westerlies (carrying particulate matter from the western highlands) are more prevalent at these high elevations in the southern tropics.

A 10m ice core drilled from the La Garganta Glacier in the Huascarán Col in the north Peruvian highlands ( $9^{\circ}07'\text{S}$ ,  $77^{\circ}36'\text{W}$  – 900km northwest of Quelccaya) obtained comparable meteorological data and a short ice core record which was similar to the upper portions of the Quelccaya cores (Thompson, Mosley-Thompson, and Morales 1984; Thompson et al. 1984). This similarity increases confidence in using the Quelccaya data to describe the entire tropical Peruvian precipitation regime (*ibid.*).

The meteorological relationships described above are periodically disrupted by the atmospheric and oceanic phenomenon known as El Niño events that can bring torrential rains and flash flooding to the western slopes of the Andes (e.g., Cane 1983; Quinn, Neal, and de Mayolo 1987; Rasmussen and Wallace 1983; Wyrski 1975). Severe El Niños (e.g., 1982–3) have also been tied to intense but short-term droughts in the southern highlands and *altiplano* and because of this, short-term, abrupt drought signatures may indicate certain intense El Niño events (Thompson, Mosley-Thompson, and Morales 1984).

This study, however, focuses on persistent pluvial and interpluvial periods of the record rather than attempting to identify individual El Niños with a belief that long-term droughts and wet periods would contribute to more lasting societal change than the impact of disruptive though transient El Niños.



Plate 1 Fifty-meter ice cliff near the margin of the Quelccaya ice cap. The individual layers, representing annual increments of accumulation, average 0.75 meters in thickness. This marked stratigraphy has allowed the development of the first 1,500 year climatic record from a tropical ice cap. Photo by L. G. Thompson.



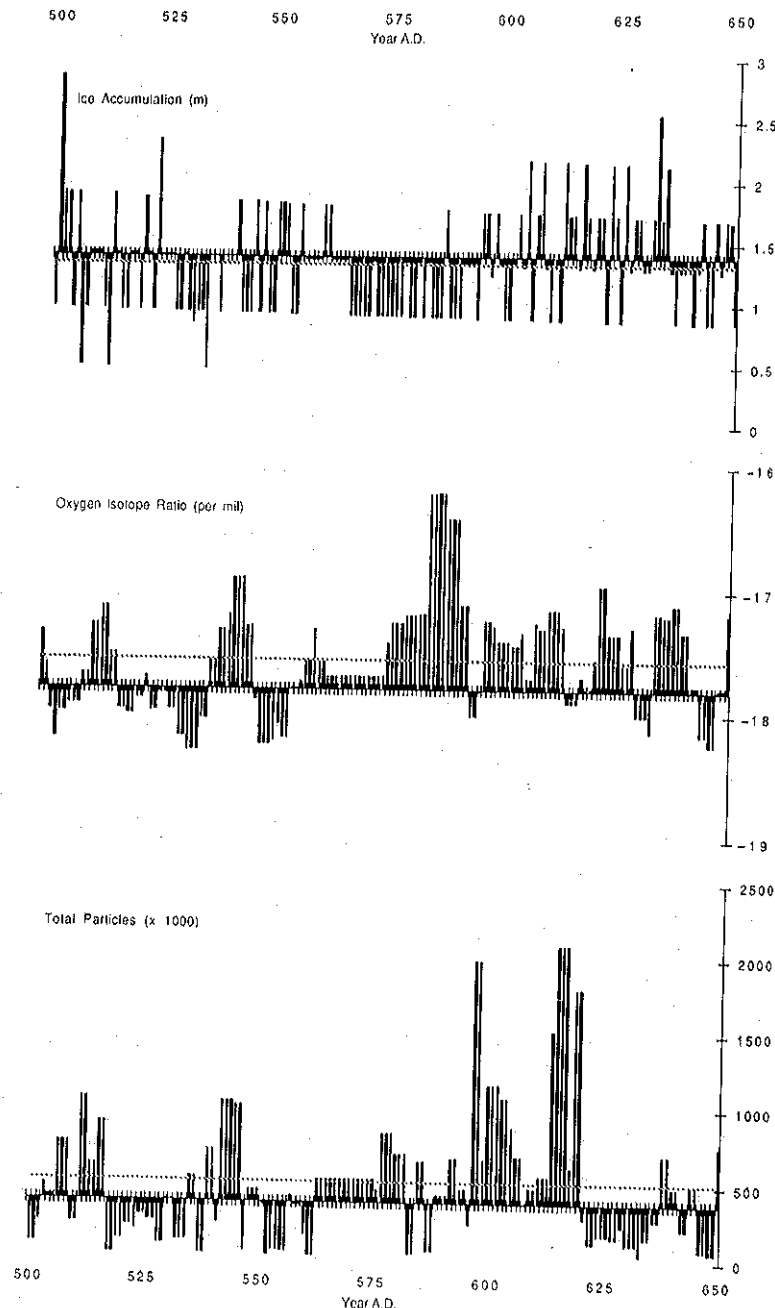


Figure 5 Graphs of annual ice accumulation (meters), oxygen isotope ratio (per mil) and total particles (in the size range 0.63–16.0  $\mu\text{m}$ , X1000 per mil) displayed around the long-term mean (of 1500 years). The dashed lines indicate the short-term means (of 150 years).

### The Quelccaya data

The Quelccaya ice core analyses were conducted by the Byrd Polar Research Center, Ohio State University. The availability of two cores (154.8m and 163.6m, respectively) enabled the accurate dating of the cores and production of an excellent time scale. Microparticle concentrations,  $\delta^{18}\text{O}$ , and conductivity all display annual cyclical variations and these were complemented by the excellent visual stratigraphy (Pl. 1). The visible dust layers reflect the annual wet season/dry season cycle, and make it possible to integrate and refine the dating of the records. Meteorological data obtained at Quelccaya indicate that the mean annual temperature is below freezing (minus  $3^{\circ}\text{C}$ ). Therefore, the glacier is not affected by significant melting and percolation and the ice cores accurately represent annual precipitation. Averaged  $\delta^{18}\text{O}$  records (indicative of relative temperatures) and the consistency between the two cores suggest that this has been the case throughout the 1,500 year-period (Thompson et al. 1985). The annual data used in this study (dating from AD 500–650) are believed accurate to  $\pm 20$  years.

The use of these annual data was highly desirable for this study, since environmental variations stressful to human cultures could be identified. Previously, only decadal data from Quelccaya had been published and it was difficult to assess the persistence, severity, or abruptness of precipitation anomalies.

The accumulation record (in meters of ice equivalent) is the most direct measurement of the annual precipitation received during a highland wet season (Fig. 5). One unusual episode of subnormal precipitation is immediately evident. A three-decade long drought occurred abruptly between AD 563 and 594. The Quelccaya record has been found to contain good indications of drought (Thompson 1980; Thompson et al. 1985), and this three-decade event conforms to the typical signature of a drought (less accumulation, greater soluble and insoluble particulates, and less negative annual  $\delta^{18}\text{O}$  values). This drought is remarkable for its severity (c. 30 per cent deviation from mean precipitation), duration, and abrupt onset. Sheer length of this drought indicates that we are indeed dealing with a drought rather than merely a series of El Niño events. Other shorter droughts occur between AD 524 and 540 and between AD 636 and 645. A pluvial period seems to have occurred between AD 602 and 635.

The accumulation data can be used to infer relative annual trends in the precipitation amounts. The systematic trends obvious in the ice accumulation record are due to the flow model used to calculate annual accumulations (Thompson et al. 1985). These model-induced trends are more pronounced in these lower layers of the core where the greatest thinning was experienced, but do reflect the precipitation trends over the longer term in this portion of the core. Nevertheless, the abrupt multi-decadal drought identified in the late sixth century qualifies as severe even when compared to other drought periods throughout the 1,500 year record.

### Discussion

It is apparent that the annual Quelccaya ice core data can be used directly as a precipitation record for much of the Peruvian highlands since both the northern and southern highlands experience the same climatic regime and these climatic relationships only change briefly

during unpredictable El Niño episodes (Schaaf 1988). Thus, the ice cores can provide an approximate record of the availability of irrigation water on the coast. The Quelccaya data were compared with the coastal archaeological record of environmental change that was independently compiled. The latter suggests that some level of environmental degradation beginning around AD 500 affected much of the Peruvian coast and that the Mochica settlement shift was part of a broader pattern. This matches the lower half of the Quelccaya accumulation graph, which indicates several droughts of increasing duration.

Of most interest is the three-decade drought's coincidence in time (between AD 562 and 594) with the major Moche IV–V cultural transition (archaeologically dated to c. AD 550–600) which was accompanied by the drastic inland and northward relocation of the capital, as well as population nucleation at valley necks. This drought is remarkable relative to the entire 1,500 year glacial data set in its severity, abrupt onset and relentless persistence for over thirty years.

This thirty-year drought should have resulted in significantly reduced river runoff to the coastal communities. Some idea of the possible impact of this drought on the coast may be gained by looking at the modern situation (Fig. 6). The twenty-nine-year average (1937–65) of water used within the Lambayeque Valley was 88 per cent of the water volume carried by the Chancay River as measured at Carhuaquero c. 29km inland from Pampa Grande; some years literally no water was discharged to the Pacific (Portugal 1966: 38). Modern large-scale cultivation of water-demanding sugar cane in the valley is in part responsible for the above high consumption figure. At the same time, this skewing effect is partly offset by the high discharge volumes of 1939, 1941, 1943 and 1953 when El Niño rains occurred.

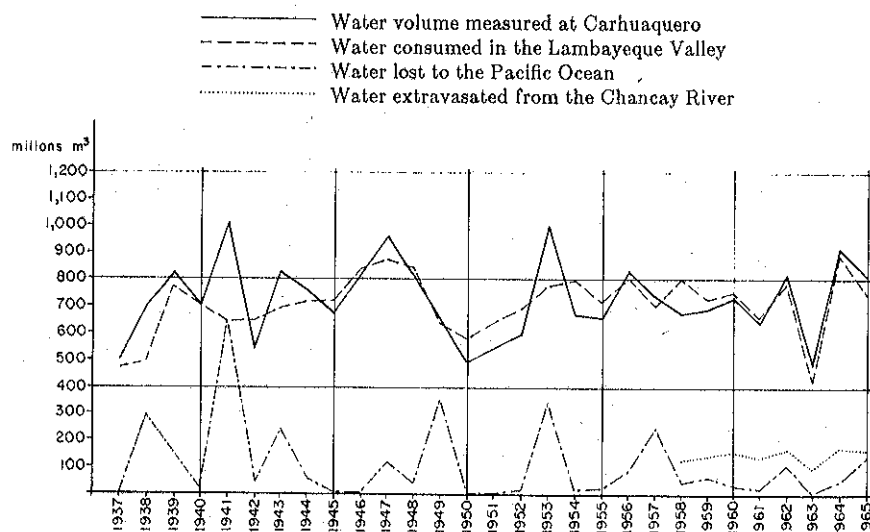


Figure 6 Annual discharge and utilization of the Chancay River water for the span of 1937–65. (Redrawn from Portugal 1966.)

Colonial documents pertaining to prehispanic irrigation on the north coast speak of how the Chimú overlords of the fifteenth century respected the age-old tradition of allowing users at the tail end of the canal to irrigate first (Netherly 1984: 243–8). However, these marginal lands and outlying canals would have been the most immediately or severely affected by long-term droughts. Given the usual problems of evaporation and filtration, these peripheral areas would have been the hardest to maintain. The water table would have been reduced and salinization might have been a problem in areas of low flow. A shift toward drought-resistant cultigens would also be expected. Any torrential El Niño rains on an already hyper-arid north coast would have caused flash flooding and increased soil erosion and would have contributed to new and greater sand dune sources at the mouths of rivers. Overall, Mochica population appears to have faced reduced water and an overall reduction in cultivation and the available archaeological evidence suggests that it opted for intensive cultivation of land below the valley neck with ready access to water and best soil.

The selection of the Lambayeque valley as the Moche V political and population center was likely to have been influenced by the fact that this valley is endowed with ideal conditions for large-scale irrigation agriculture. The Chancay River, its principal river, with a large drainage area of c. 3,375km<sup>2</sup>, has a relatively high elevation of river course and the highest minimum and one of the highest overall discharge volumes (typically around 700–900 million m<sup>3</sup> per year) on the north coast (Kosok 1959, 1965; cf. tables in Kroeber 1930: 76 and Moseley 1983b: 302 with Fig. 6). In addition, this valley has extensive, fertile, low and evenly sloping alluvium that connects imperceptibly into that of the adjacent Leche and Zaña valleys. The interconnected Leche-Lambayeque plain alone has 136,000 hectares of cultivable land, of which some 90,000 hectares are under irrigation today (Delavaud 1984: 85).

The selection was also likely to have been shaped by political considerations. The recent discoveries at an adobe platform at Sipán of a cluster of sumptuous Moche III elite burials, as well as Moche I and II looted burials in nearby cemeteries (Alva 1988; Alva et al. 1989) suggest that the Lambayeque valley may have been the home of a powerful polity that participated in a Moche III–IV intervalley Mochica confederation (Shimada n.d.). These burials that are in many ways unmatched by any other excavated Mochica burials in the quantity and quality of funerary offerings (including numerous gold ornaments) clearly attest to the wealth and power of the local leaders. However, there is a conspicuous paucity of late Moche III and early Moche IV settlements or corporate projects in the Lambayeque region in notable contrast to the region farther south that appears to have been dominated by the competing polity centered at the site of Moche. By processes as yet unclear, it seems the latter region gained the paramount leadership of the north coast during late Moche III (c. AD 350–400?; *ibid.*). With the deteriorating environment, the elite at Moche may well have lost prestige and power, allowing the inferred Lambayeque polity to reclaim its former prestige and political leadership of the northern north coast (*ibid.*). Overall, it is suggested here that combined cultural and natural considerations led to the selection of the Lambayeque valley as the Moche V political seat.

The Quelccaya ice core data have sufficient time depth to illuminate general environmental conditions prior to the onset of the three-decade drought. During the first half of the sixth century, the Mochica culture suffered a few shorter droughts (and probably El Niño events). In addition to environmental degradation, the unpredictability

of El Niño events would have posed added stress on the population. Though some of the cultural changes noted earlier may have been direct responses to the three-decade drought, others were likely to have been preconditioned for change during the early sixth century with this later drought acting as the trigger. Some settlements may have been abandoned in response to the seventeen-year drought that began in AD 524, while others survived only to succumb to the later, three-decade catastrophe.

Such a determination would be difficult given the pervasive problem of imprecise archaeological dating. This problem is acute on the south coast. For example, because of the difficulty in the direct dating of *pukios*, their dating has been based on surface ceramics of associated settlements. The critical Nasca 5 has only one pertinent radiocarbon determination from 1956, and some investigators (e.g., Silverman and Browne 1990) believe that Nasca 4 is the product of overly fine stylistic differentiation and should be subsumed in Nasca 5. Not only do Nasca 4, 5 and 7 phases need many more reliable radiocarbon determinations, but also the chronological correlation of Nasca stylistic variation found in the adjacent Ica and Nazca valleys (if not within each valley) must be securely established. Moche IV and Lima 7 through 9 all need reliable, additional radiocarbon determinations. It should be kept in mind that the relevant settlement shifts are contemporaneous only in the sense of cross-dated ceramic phases and not in absolute terms.

There is a clear and urgent need for additional research into the general cultural and natural conditions during the sixth century both on the coast and in the highlands. The debate over the diagnostics and mechanisms of Wari expansion have overshadowed the significance of an apparently coterminous, major settlement pattern shift and urbanism along the coast (apparently in the highlands as well; see Isbell 1986 and Isbell and Schreiber 1978 for the emergence of the city of Wari) that seem to have preceded the first wave of Wari expansion out of the Ayacucho region. Wari expansion or El Niño events do not satisfactorily account for the observed Moche IV–V changes. Instead, settlement shifts, urbanism, and Wari expansion may well be responses to the same drought conditions that beset the entire Peruvian Andes in the sixth century (Paulsen 1976). In this regard, we await advances in archaeological assessment of the cultural significance of past climatic anomalies in the Andean highlands where dry farming on artificial terraces was an important complement to irrigation (W. H. Isbell, D. L. Browman, personal communication, 1989).

On the coast, appropriate excavations have not been carried out, for example, at Moche, to ascertain whether the urbanism at Pampa Grande and Galindo was an institutional response to sixth-century droughts or simply an accentuated form of earlier, Mochica urbanism. If the latter was the case, we may ask whether the large-scale storage at these Moche V sites was a response to the exigencies of emergent cities (i.e., provisioning of non-farming sectors or general redistributive need) or provisioning for future, unpredictable natural catastrophes. Similarly, we do not have adequate pre-Moche V samples to determine whether large-scale coastal herding and breeding of llamas on northern Peruvian coast (Pozorski 1979; Shimada and Shimada 1981; 1985) was initiated during the Moche IV–V transition to augment and stabilize food supply adversely affected by the droughts.

## Conclusion

In this case study from the Peruvian Andes, the possible role of severe droughts in conditioning a drastic, broad spectrum transformation of the prehistoric Mochica culture on the north coast of Peru was assessed using a precisely dated 1,500-year long precipitation record established on the basis of deep ice cores. It suggests that a prolonged period of environmental stress during much of the sixth century (especially a severe three-decade drought) significantly affected north coast agricultural production. This stress was at least partially responsible for aspects of the Moche IV–V societal reorganization, particularly the population nucleation at valley necks with easy access to water and control of the principal intakes for the valley-wide irrigation canals.

It should be recognized that precisely dated, reliable climatic data form a basis for powerful interpretive models for archaeologists. However, they should not be unduly influenced by such data in correlating archaeologically observed but imprecisely dated cultural changes with any of the climatic anomalies found in the data. Imprecise dating may hide significant relationships but by the same token, it may allow unwarranted correlation. Instead, such data should alert us to the ever greater need to give proper weight to the possible role of cultural factors. Cultural responses to the climatic disturbances are highly complex phenomena shaped by a multitude of variables, including the abruptness, duration and severity of the disturbances, as well as the resource base, size and organizational capabilities of the affected populations. They are creative processes that are situation specific. Given the rarity of severe, long-term droughts, there is little modern or historical basis for archaeological modelling of cultural responses (e.g., Guillet 1987).

In general, our study shows the importance of annual regional climatic data and an interdisciplinary approach in identifying environmental variations stressful to human cultures and their responses. Such an approach may eventually shed light on cultural impacts of other severe droughts recorded in the Quelccaya sequence.

## Acknowledgements

We are grateful to D. L. Browman, A. K. Craig, D. Guillet, W. H. Isbell, J. W. Snow, and M. E. Moseley for their valuable comments on an earlier draft.

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# Abstract

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## **Cultural impacts of severe droughts in the prehistoric Andes: application of a 1,500-year ice core precipitation record**

Late in the sixth century, Andean peoples experienced major cultural upheavals, including a notable settlement shift of the classic Mochica culture on the northern Peruvian coast. A recently established annual precipitation record derived from ice cores from the Quelccaya glacier in southern Peru allows assessment of the possible role of climatic disturbances in northern Peru. Both areas are in the same tropical climatic regime. A comparison between the archaeological record and the Quelccaya data suggests the Mochica upheaval was conditioned by a series of severe sixth-century droughts, including one of the severest droughts of the past 1,500 years, spanning AD 562 to 594.