ENVIRONMENTAL THRESHOLDS AND THE "NATURAL HISTORY" OF AN ANDEAN CIVILIZATION

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HUMAN-ENVIRONMENT INTERACTION AS A SUBJECT OF ANALYSIS

HUMAN POPULATIONS AND THE PHYSICAL ENVIRONMENT interact through dynamic ecological processes that are mediated by social institutions. Manipulation of water and nutrient cycles, energy flow, and interactions with other organisms constitute the foundations of a society's exploitation of natural resources. The precise nature and form of that exploitation depend on the particular institutional frameworks and technological capacities possessed by a given society. But the instrumental need to develop and deploy natural resources at a scale sufficient to satisfy the needs of human populations and reproduce the social order is common to all societies. Human populations at all spatial and demographic scales, from the dispersed villages of horticulturalists in the diminishing rain forests of Amazonia to the hyper-aggregated, technology-mediated megalopolises of the developed nations, are ineluctably embedded in the material world. All human societies, not simply those of the vanished preindustrial world, are conditioned and constrained by physical processes. Of course, the nature, spatio-temporal characteristics, and social impacts of these constraints are relative to the technological capacities of a given society, but they remain constraints nonetheless.

In turn, large-scale human activities, such as urbanization and its economic corollary, the intensive exploitation of regional hinterlands, significantly alter ecological processes. Human activities on long-term and global scales have altered the natural world to such an extent that when we investigate human-environment interactions we must speak of a "second nature": that is, the interaction of humans with a natural environment that is profoundly anthropogenic, transformed by humans, and no longer the "pristine" nature of our collective imagination (Cronon 1992). This human--second nature interaction operates constantly, changing environmental constraints and creating new challenges and opportunities for the reproduction of the biological and cultural bases of human society. The long-term result of such processes is reflected in a variety of potential human responses to environment-related crises: population aggregation or dispersal, shifts in production strategies, increase in the incidence of conflict, radical restructuring of political structures, warfare and environmental refugeeism, and, in some instances, even urban abandonment and social collapse (Binford et al. 1997; Kolata 1993; Ortloff and Kolata 1993; Tainter 1989; Yoffee and Cowgill 1988).

Although these statements seem commonplace, perhaps even self-evident, the theoretical stance that asserts a mutual embeddedness of the material and the cultural has long fallen into disfavor in one sector of the academic world: the social sciences, and, most particularly, in social anthropology. The dominant perspective of current social anthropology is that cultural systems encapsulate, mediate, and translate natural systems so thoroughly that the properties of the physical world are, in essence, irrelevant to our understanding of human societies. From this perspective, culture is an infinitely flexible artifact of the human mind and of collective social praxis capable of complete intermediation of the natural world. Any kind of natural catastrophe, massive shift in the availability of natural resources, abrupt or long-term environmental change is perceived and socially processed as "background noise" from the frame of reference of culture. If human societies create or contribute to environmental catastrophes, culture can just as readily unmake them, instrumentally and symbolically, most likely through deploying clever technologies. Such catastrophes are viewed merely as grist for the adaptive capacities of humans armed with the innovative force of culture, human societies are capable of decoupling themselves from the surrounding matrix of their physical environment.
The intellectual rejection of an active role for this "environmental matrix" in the culture-nature relationship may have first emerged from a principled dismissal of the unsurable excesses and racialized notions of nineteenth-century geographic and environmental determinism. For a time, the popularity of cultural analyses grounded in "cybernetic" or "systems" models and the kind of cultural ecology prominent in the 1960s and 1970s stimulated intellectual interest in the physical environment among social scientists. However, in the 1980s, an increasingly strident opposition to social analyses that emphasized the material dimensions of the culture-nature dialectic within anthropology congealed in acerbic, public attacks on various hypotheses that human behavior could, in great part, be explained in terms of biological principles. Perhaps the most controversial and certainly the most widely distributed consideration of these hypotheses was advanced in E. O. Wilson's Sociobiology (Wilson 1975). Wilson's expansive claims for a new, integrative discipline which he called, perhaps unfortunately, "sociobiology" catalyzed opposition to biological models of human behavior in anthropology. Heated rhetoric concerning free will, individuality, cultural creativity, and the human capacity to transcend environmental constraints polarized the discipline and, among most social anthropologists, generated an extreme bias against materialist, biological, or environmental analyses of the human condition, whether "sociobiological" or not. These models, particularly in the form advanced by Wilson and his followers, were viewed by many social scientists (with considerable justification) as irredeemably reductionist and, in some sense, "anti-social."

One unfortunate outcome of this controversy has been a marked move by social anthropologists from a conception of itself as a "science of humanity" to one in which the methods of science have been substantially devalued. Most social anthropologists now consider anthropology and themselves to be situated within the humanities. Rather than aligning themselves with ecologists, demographers, and natural scientists, many social anthropologists now consider their work to have greater affinity with literary criticism, with the critiques of popular culture, and with various (often ill-defined) forms of "cultural studies."

Science as a self-correcting, truth-seeking enterprise with explicit rules of engagement is no longer a method for social anthropology; rather it has itself been subsumed as a subject of social analysis. Although science as a social subject has a rich intellectual history, at its worst (that is, when it has turned into a palaism), the sociology of science has generated a veritable cottage industry of science reconstruction, some of which purports to demonstrate that the products of scientific investigation are merely arbitrary social constructs. The tenor of the debate, now irrevocably enmeshed in politicized rhetoric, poses a significant element of contemporary social anthropology as "anti-scientific."

The theoretical stance adopted by social anthropologists to counter positions they perceive as biological reductionism has resulted in an extraordinary irony. If, in essence, the environment and its biological processes are merely passive stages set upon which humans act out their lives, then what need concern us is only the social networks and cultural products of humans, and not their environmental matrix. By promoting a thoroughgoing cultural determinism, many anthropologists now find themselves in an anomalous position of devaluing the natural world, and of downplaying, consciously or not, the importance and impact of ongoing, global environmental degradation. As a result "techno-fixes" to environmental degradation may become more acceptable because they are ultimately products of culture. If they paused to think through the full implications, this strange outcome should lead these anthropologists to reconsider the theoretical underpinnings of their radical culture-centric approach which is, to be blunt, little more than a posture of supreme self-regard.

But what theoretical alternatives are there to the dilemma of environmental reductionism on the one hand and overarching cultural determinism on the other? If we accept that humans interact with their environment, rather than merely act upon it, how do we specify the nature, intensity, and mutual impact of this interaction? Are there general principles of human-environment interaction that can frame our analyses of human-environment interaction? I believe that what frames the interactions between humans and their environment is an extraordinarily difficult, if not intractable, problem because different disciplines (archaeology, ecology, geography, natural resource management, and regional planners, among others) take the subject as their purview, and each of them has its own ideology and temporal frame of reference. I believe that when examined from multiple disciplinary perspectives, and with a sufficiently long time depth to encompass a society's entire life history, the relationships between environmental variation and cultural adaptation can be studied in a more comprehensive manner. The general outlines of a theory of human-environment interaction are more likely to emerge from such a comprehensive approach rather than from disparate, unconnected, disciplinary-based research alone.

A general theory of human-environment interactions will require the development of explicit concepts that reciprocally link behavior with human perception, reproduction, and utilization of the environmental matrix. That is, the purview of a general theory of human-environment interactions is not simply the analysis of modes of economic production and the physical impact of human societies on natural resources. This is and should be a major element of human-environment interaction studies, but this is not the full story. The entire fabric of how human beliefs and knowledge systems, aspirations, and cultural products interact within and with the environmental matrix must also receive due consideration in any comprehensive analysis. For, as a central insight of anthropology emphasizes, it is through the mediating lens of these belief and knowledge systems that humans interact symbolically and instrumentally with the physical world.

Some concrete examples of what I mean here will drive this essential point home. Georges Condorcum's eloquent ethnography (1994) stresses that the complex spatial and temporal patterns of Vietnamese Montagnard ritual life serve in a truly instrumental sense as technologies of production. Such rituals, although arbitrary social and cultural products, perform significant social work by organizing the daily and periodic congregation of Montagnard peoples. Shared ritual acts occur within and structure a broader framework of social exchange that includes activities of economic production: horticulture, hunting, gathering, all activities that significantly transform nature. That is, belief and ritual praxis have a direct, and transformative, impact on both Montagnard social life and their relations with the natural environment. Similarly, Jeanette Sherbondy (1992) and Tom Zuidema (1990) have convincingly demonstrated that the complex belief and knowledge system of the Inka referred to as the ceque system ordered social life in tangible ways that directly affected the exploitation of critical natural resources, specifically land and water. The ceque system was a social landscape of Cuzco, the Inka capital, and by extension the Inka Empire itself, organized in a complex collection of shrines arrayed along lines of sight. The Inka recognized 338 individual shrines, which were conceived as places or objects imbued with spiritual and instrumental power, along a total of 41 directional sight lines, or ceque. Different sets of related lineages (ayllus), or larger social groups (parcialidades), were charged with the responsibility for maintaining and offering ritually prescribed sacrifices to...
may exceed the limits of human adaptability. Furthermore, cultural dependence on highly specialized technologies that cannot be adapted rapidly enough to environmental variations may change the relative level, or sensitivity, of an environmental threshold and negatively affect economic development, demographic growth, and social stability. In sum, as I use the concept here, environmental thresholds refer to long-term, high-amplitude environmental variations that, at the extremes of variation, significantly and permanently alter or constrain the socioeconomic development of human societies.

The potential social impacts of environmental thresholds are relative, context-dependent, and linked to the demographic, institutional, and technological profiles of a given society. Contemporary human societies, particularly those in the developed world, may possess the demographic scale, institutional flexibility, and technological capacity to mitigate the social impacts of extreme environmental variation without experiencing significant structural change (at least at the temporal scale of several decades). Most human societies have the social capacity to smooth the impacts of more relatively short-term, low-amplitude environmental variation without experiencing permanent disruption in production systems, or occasioning dramatic ruptures in belief systems. However, some societies may flourish for long periods of time under structural change (at least at the temporal scale of several decades). The relative simplicity of this case, from the perspective of preindustrial, state-level society that flourished for approximately 600 years in an extreme environment. I refer here specifically to the indigenous Andean civilization of Tiwanaku that was centered in the altiplano, or high plateau of southern Peru and northwest Bolivia (Kalata 1993, 1996; Figure 66). The relative simplicity of this agrarian society (when compared with contemporary societies) in tandem with the extreme altitude (ca. 3,800–4,200 msl) and climatic harshness of its environmental setting renders it a particularly good source of information about human-environment interactions.

Such instances of environmental refugeeism are decidedly not the product of a less socially complex past, or of the twilight of traditional agrarian societies alone. Environmental refugeeism is just as trenchantly an issue of the contemporary industrial (and postindustrial) world. One prime example of this is in the extreme land degradation and desertification currently being experienced in the Mediterranean basin of southern Spain, Italy, and Greece. Here thousands of hectares of formerly cultivated land are being converted each year to near-deserts and badlands as the result of a complex interplay of climatic and anthropogenic causes that are regionally variable and not yet well understood. Secular climate variation, accelerating soil erosion, crop choices driven by global market forces, availability and distribution of capital, massive demographic flows from rural to urban milieus, cultural shifts from agrarian to information-based economies, shifting social aspirations, among other factors, combine in differing degrees and in locally distinctive patterns to generate an unstable human-environment relationship that has intensified land degradation and abandonment on locally significant scales. The macro-regional pattern of desertification may have different proximate causes in different local contexts, but both short- and long-term environmental changes are generalized elements implicated in the causal chain. Isolating all the links of this causal chain, specifying the precise causal sequence, and weighting the effects of social, natural, and “second nature” components in this sequence demand a powerful dynamic modeling process that has not yet been adequately developed.

The inordinate complexity and recursiveness of the relationship between human societies and their environmental matrix implies analytical clarity. This complexity is even more daunting in the globalizing social and economic landscape of contemporary life, characterized by societies with virtually instantaneous communication, global markets, borderless capital and labor flows, and startling inequalities in access to natural resources. The global communities of social, cultural, and economic interaction have expanded exponentially, and with them so has the complexity of understanding the trajectories of change in the sphere of human-environment interactions. To begin developing concepts that may be useful for modeling human-environment interactions, we must first seek to simplify the variables to be considered.

Given the evident complexity of treating these interactions in contemporary societies, my strategy here will be to explore the concept of environmental thresholds in the much less differentiated social and economic context of a preindustrial, state-level society that flourished for approximately 600 years in an extreme environment. I refer here specifically to the indigenous Andean civilization of Tiwanaku that was centered in the altiplano, or high plateau of southern Peru and northwest Bolivia (Kalata 1993, 1996; Figure 66). The relative simplicity of this agrarian society (when compared with contemporary societies) in tandem with the extreme altitude (ca. 3,800–4,200 msl) and climatic harshness of its environmental setting renders it a particularly good source of information about human-environment interactions.

The "Natural" History of an Andean Civilization

Tiwanaku developed a state-level agrarian society with relatively high population densities in an environment that has been consistently portrayed as marginal for intensive agricultural production. Tiwanaku populations occupied a social landscape of considerable complexity (in premodern terms) and lived in an arduous environment in which small or subtle environmental change could have disproportionate effects on human adaptations. In other words, Tiwanaku populations lived in a social and physical landscape that was close to environmental thresholds. Therefore, an analysis of human-environment interactions over the "longue durée" of Tiwanaku emergence, fluorecence, and political disintegration should offer insight into the role of environmental thresholds in shaping or constraining cultural adaptations. The drainage basins of the Tiwanaku and Catari rivers near Lake Titicaca are the local ecosystems of the Tiwanaku people.
A decade of new research in the Tiwanaku core area has demonstrated that, despite the rigors and risks of its environmental setting, this civilization developed a complex agricultural infrastructure based on a technically specialized form of raised-field cultivation that supported dense human populations for more than half a millennium (ca. A.D. 500–1100). The principal contours of changing human-environment relationships in the Tiwanaku region over the past 3,500 years are detailed in a series of publications by our research group (see particularly Abbott et al. 1997; Binford et al. 1997; Kolata 1986, 1991, 1993, 1996). Readers interested in the full exposition of the evidence for the conclusions we have drawn may refer to these publications.

For my purposes here, the most salient results of this sustained research may be summarized as follows:

1. During the mid Holocene our lake coring data indicate that the Andean altiplano experienced extremely dry conditions during which the level of Lake Titicaca was more than 20 m and perhaps as much as 50 m below the current level. This middle Holocene dry period (ca. 7700–5500 B.P.) is consistent with earlier results reported by Mouguiai et al. (1986) and Wilmann and Oliveira Almeida (1997).

2. The emergence of complex, Formative period (pre-Tiwanku) societies in the Lake Titicaca basin and the initiation of widespread agriculture coincided with a rapid increase in available moisture ca. 3500 B.C. (1500 B.C.). This increase in moisture drove a greater than 20 m rise in lake level within a period of approximately 200-400 years. All of our dated lake cores show an erosion surface on a basal stratum of inorganic, mineralized soil followed by an aggregation of biologically based sediments that are preserved in a stratigraphic sequence that indicates that altiplano cultures were able to sustain an agricultural production that was sufficient to support the complex agricultural culture of the Formative period in the southwestern Lake Titicaca basin.

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Nevertheless, the controlling biological resource for effective cultivation is water. Therefore, widespread and sustained cultivation in the altiplano (a risk-prone environment for farmers even under the best climatic circumstances) only became feasible when the climate became significantly wetter.

3. Subsequent to the 3500 B.P., climate amelioration, the level of Lake Titicaca has fluctuated significantly, but the climate regime has not returned to the hyperarid conditions characteristic of the middle Holocene. In the period from 200-400 B.C. to A.D. 1500, short-term sedimentation hiatuses, low-level lake stands, and inferred lower net precipitation in the Lake Titicaca basin, as well as evidence of extended periods of high lake levels and greater net precipitation, occur throughout our cores (Figure 68; detailed exposition of this evidence appears in Abbott et al. 1997). Throughout this period, archaeological evidence indicates that altiplano cultures were able to sustain an effective mixed subsistence economy of agropastoralism. Formative period agriculture appears to have consisted primarily of dry-land (that is, unirrigated, seasonally flooded canals alternating with platform plantations), seasonal flooded canals alternating with platform plantations, were first described as ancient, pantropical agricultural systems by Denevan and Turner (1974). Erickson (1993) reports results from the northern Lake Titicaca basin around Puno, Peru, suggesting that raised-field cultivation flourished there in the Formative period, and there is indirect evidence that Chiripa populations may have experienced significant small-scale raised-field cultivation on the southern side of the basin as well. Certainly post-1500 B.C. (post-threshold) climatic conditions would have permitted the development of this water-intensive form of cultivation. Raised-field cultivation was probably part of the total economic repertoire of altiplano populations from at least the late Formative, but it does not appear to be the dominant component of production systems until the period conventionally referred to as Tiwanaku IV (ca. A.D. 400–750). In the Tiwanaku core area, large-scale raised-field cultivation (Kolata 1996). Raised fields, consisting of seasonally flooded canals alternating with platform plantations, were first described as ancient, pantropical agricultural systems by Denevan and Turner (1974). Erickson (1993) reports results from the northern Lake Titicaca basin around Puno, Peru, suggesting that raised-field cultivation flourished there in the Formative period, and there is indirect evidence that Chiripa populations may have experienced significant small-scale raised-field cultivation on the southern side of the basin as well. Certainly post-1500 B.C. (post-threshold) climatic conditions would have permitted the development of this water-intensive form of cultivation. Raised-field cultivation was probably part of the total economic repertoire of altiplano populations from at least the late Formative, but it does not appear to be the dominant component of production systems until the period conventionally referred to as Tiwanaku IV (ca. A.D. 400–750). In the Tiwanaku core area, large-scale raised-field...
cultivation on wetlands emerged after A.D. 600, expanding to a maximum regional scale of ca. 190 km² by A.D. 800-1000 (Binford et al. 1997; Kolata 1993; Seddon 1994). From intensive survey and excavations in one sector of the Tiwanaku core region (the Rio Catari basin), we estimate that approximately 80% of this maximum area (or about 150 km²) was under cultivation during these two centuries (Binford et al. 1997; Seddon 1994). Expansion of raised fields in this area coincided with several centuries of elevated lake-level stands reflective of high regional precipitation. Palynological and sediment records from our cores indicate that the level of Lake Titicaca was higher than today in the period from A.D. 350 to ca. 500 (Binford et al. 1997). Average ice accumulations measured in the Quelccaya ice cap approximately 200 km north of Lake Titicaca record wetter periods from A.D. 610-650 and 760-1040 (Thompson et al. 1985; Thompson 1992). Within the three millennia from 1500 B.C. to A.D. 1500, in addition to these periods of high lake stands and wetter conditions we have identified a series of four major hiatuses in organic sedimentation resulting from low lake levels that are indicative of significantly lower net precipitation in the Lake Titicaca basin. Similarly, the paleoclimate record from Quelccaya indicates drier periods in A.D. 540-610, 650-760, and 1040-1450. Our own paleolimnological research complements the highly-resolved paleoclimate record from Quelccaya, although, as might be expected, the temporal concordance and inferred intensity of climatic conditions are not always completely identical in these two independent paleoclimate records. Here I will concentrate on the most prominent unconformity in the lake cores which commences ca. A.D. 1100 and exhibits a strong concordance with the extraordinary period of low ice accumulation at Quelccaya recorded in the period from A.D. 1040 to 1450 (Figure 69). These two paleoclimate records of low precipitation correlate with the abandonment of regional-scale raised-field agricultural systems, and with the political and cultural disintegration of Tiwanaku civilization.
...postabandonment sediments, occur in the interval from cal A.D. 1150 to 1300. These dates indicate that effective abandonment of the regional scale raised-field system occurred before 1150.

When raised-field chronology, lake-level fluctuations (Abbott et al. 1997), and snow accumulation at Quelccaya (Thompson et al. 1985) are displayed on a common time scale, a striking concordance emerges (Figure 69). Snow accumulations declined beginning at 1040. The drier period reflective of this decline in precipitation peaks around 1300 and persists, although with lesser intensity, until 1450. Our lake cores demonstrate a major hiatus in organic sedimentation in all cores except one which was taken at a deep site covered by water at the lowest lake level. However, seven dates, six of which are from postabandonment sediments, occur in the interval from cal A.D. 1150 to 1300. These dates indicate that effective abandonment of the regional scale raised-field system occurred before 1150.

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### Table 7. Radiocarbon Dates from Raised-Field Excavations Grouped According to Archaeological Contexts (from Binford et al. 1997:245, Table 2)

<table>
<thead>
<tr>
<th>NOSAMS No.</th>
<th>Material</th>
<th>Location (provenience)</th>
<th>Context</th>
<th>Calibrated years (All A.D.)</th>
<th>Calibrated one-sigma age range (All A.D.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>OS-2541 Mollusc 6</td>
<td>(86-4-2) Construction/use</td>
<td>1040 ± 35</td>
<td>1010</td>
<td>990-1020</td>
<td></td>
</tr>
<tr>
<td>2540 Mollusc 7</td>
<td>(86-2-1) Construction/use</td>
<td>820 ± 30</td>
<td>1230</td>
<td>1220-1280</td>
<td></td>
</tr>
<tr>
<td>2538 Mollusc 8</td>
<td>(109-2-3) Construction/use</td>
<td>1070 ± 30</td>
<td>990</td>
<td>970-1010</td>
<td></td>
</tr>
<tr>
<td>2539 Mollusc 10</td>
<td>(88-3-3) Construction/use</td>
<td>1070 ± 30</td>
<td>990</td>
<td>970-1010</td>
<td></td>
</tr>
<tr>
<td>2564 Mollusc 11</td>
<td>(111-2-3) Construction/use</td>
<td>1030 ± 35</td>
<td>1010</td>
<td>990-1020</td>
<td></td>
</tr>
<tr>
<td>2561 Mollusc 11</td>
<td>(111-2-4) Construction/use</td>
<td>930 ± 30</td>
<td>1050,1090,1120,</td>
<td>1040-1170</td>
<td></td>
</tr>
<tr>
<td>2569 Mollusc 12</td>
<td>(112-3-2) Construction/use</td>
<td>1290 ± 50</td>
<td>710,750,760</td>
<td>670-780</td>
<td></td>
</tr>
<tr>
<td>2557 Carbon 13</td>
<td>(113-3-2) Construction/use</td>
<td>950 ± 30</td>
<td>1040,1150</td>
<td>1030-1160</td>
<td></td>
</tr>
<tr>
<td>2565 Mollusc 13</td>
<td>(113-3-3) Construction/use</td>
<td>690 ± 30</td>
<td>1300</td>
<td>1290-1300</td>
<td></td>
</tr>
<tr>
<td>2544 Mollusc 14</td>
<td>(134-4-2) Construction/use</td>
<td>980 ± 30</td>
<td>1030</td>
<td>1020-1150</td>
<td></td>
</tr>
<tr>
<td>2562 Mollusc 16</td>
<td>(114-5-3) Construction/use</td>
<td>990 ± 30</td>
<td>1030</td>
<td>1020-1040</td>
<td></td>
</tr>
<tr>
<td>2559 Carbon 17</td>
<td>(35-1-7) Construction/use</td>
<td>1220 ± 40</td>
<td>790</td>
<td>780-880</td>
<td></td>
</tr>
<tr>
<td>2563 Mollusc 18</td>
<td>(89-3-4) Construction/use</td>
<td>1440 ± 45</td>
<td>640</td>
<td>600-660</td>
<td></td>
</tr>
<tr>
<td>2542 Mollusc 18</td>
<td>(183-2-1) Postabandonment</td>
<td>775 ± 60</td>
<td>1280</td>
<td>1220-1290</td>
<td></td>
</tr>
<tr>
<td>2563 Carbon 2</td>
<td>(62-1-3) Postabandonment</td>
<td>840 ± 45</td>
<td>1220</td>
<td>1170-1260</td>
<td></td>
</tr>
<tr>
<td>2558 Carbon 3</td>
<td>(CC33-1) Postabandonment</td>
<td>875 ± 35</td>
<td>1190</td>
<td>1160-1220</td>
<td></td>
</tr>
<tr>
<td>2650 Mollusc 9</td>
<td>(110-3-1) Postabandonment</td>
<td>955 ± 30</td>
<td>1040</td>
<td>1030-1160</td>
<td></td>
</tr>
<tr>
<td>2561 Carbon 9</td>
<td>(110-3-2) Postabandonment</td>
<td>910 ± 30</td>
<td>1160</td>
<td>1050-1180</td>
<td></td>
</tr>
<tr>
<td>2566 Carbon 15</td>
<td>(147-2-5) Postabandonment</td>
<td>840 ± 35</td>
<td>1220</td>
<td>1180-1250</td>
<td></td>
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<tr>
<td>2576 Carbon 16</td>
<td>(114-5-1) Postabandonment</td>
<td>860 ± 40</td>
<td>1210</td>
<td>1170-1230</td>
<td></td>
</tr>
<tr>
<td>2537 Mollusc 4</td>
<td>(63-3-1) Problematic</td>
<td>1410 ± 30</td>
<td>650</td>
<td>630-660</td>
<td></td>
</tr>
<tr>
<td>2560 Carbon 4</td>
<td>(63-3-1) Problematic</td>
<td>615 ± 30</td>
<td>1320,1340,1390</td>
<td>1310-1400</td>
<td></td>
</tr>
<tr>
<td>2543 Carbon 5</td>
<td>(65-3-5) Problematic</td>
<td>1140 ± 30</td>
<td>890</td>
<td>890-970</td>
<td></td>
</tr>
<tr>
<td>2542 Carbon 6</td>
<td>(65-3-5) Problematic</td>
<td>425 ± 45</td>
<td>1450</td>
<td>1440-1480</td>
<td></td>
</tr>
</tbody>
</table>

Note: Refer to Figure 68 for site locations. The four problematic assays reflect two pairs of dates from identical stratigraphic contexts that returned highly divergent dates.

This consistent sedimentation hiatus reflects a major lake-level decline of between 12 m and 17 m. In effect, most of Lake Wistiyamarka (the smaller basin of Lake Titicaca) evaporated during this sedimentation hiatus (Figure 66). Calibrated dates of A.D. 1030 and 1280 generally bracket this hiatus (Binford et al. 1997), placing the lake-level decline precisely within the extended period of lower snow accumulation and lower regional precipitation recorded in the Quelccaya ice cap. These data indicate a period of reduced net precipitation that can be characterized as a severe, protracted drought. Binford et al. (1997) calculate that a 10–15% decrease in net precipitation from the modern rate could cause the measured 12–17 m lake-level decline. Raised fields in the Tiwanaku core area were used only on a small scale after these precipitation and lake-level declines, and even these, dated between 1100 and 1300, were located in the lowest-lying areas, suggesting that they may have been the last to dry. Furthermore, their calibrated, one-sigma age ranges extend prior to 1100, and all but one of the raised-field dates from postabandonment contexts were during the driest of periods. Based on these combined archaeological and paleoecological observations, our interpretations are straightforward: a regional, long-term decline in net precipitation on the order of 10–15% severely reduced available moisture which, in turn, induced abandonment of the water-intensive form of agriculture upon which the Tiwanaku civilization had become dependent. A decline of this magnitude and duration would have led first to significant decrease in annual rainfall, then to decreased spring discharges and loss of ground water resources as aquifers were not recharged. The lack of water simply made the complex physical and biological functions of the raised fields impossible. In sum, the onset of severe drought conditions created a new environmental threshold that had profound effects on local human activities. The interpretation of human response to this environmental threshold will occupy the remaining portion of this paper.

**HUMAN RESPONSE TO ENVIRONMENTAL CHANGE: THE CASE OF TIWANAKU**

In the absence of eyewitness testimony and textual documentation (of which we have none from the precolombian Andean world), we must seek an adequate proxy line of evidence for understanding human response to major periods of environmental change. One such method that can establish at least the broad contours of human response derives from the analysis of settlement patterns: that is, the spatial, temporal, and material patterns through which humans inhabit their social and physical landscapes. Human settlement patterns are closely linked with, if not determined by, underlying production systems. Large-scale changes in natural resources, such as the conversion of rain forest to agriculture or pasture land, can open up landscapes to human exploitation and occasion major demographic shifts as populations migrate to take advantage of new resources. Equally, the regional depletion of essential natural resources, such as potable lake, or fresh water, can undermine human production systems and induce rapid (expressed in decadal terms) out-migration. These demographic shifts and changes in production systems can be identified archaeologically through space and time with intensive settlement pattern survey and excavations.

Our archaeological research in the Rio Catari basin of the Tiwanaku core area has defined the spatio-temporal distribution and occupational nature of human settlements and the relationship of these settlements to the paleoecological landscape. Full results of this research including the boundaries of the study area, sampling strategies, site distribution and chronological attributions, size hierarchies, and details of project methodology are reported in Seddon 1994 and referenced in Binford et al. 1997. Here I will summarize the essential information bearing on the issue of human response to environmental change, particularly with reference to the critical eleventh-to fourteenth-century period of severe drought that we have identified in the paleoecological record.

The Rio Catari basin survey project registered a total of 214 sites, many of which consisted of clusters of surface mounds on the basin floors, or pampas. The survey revealed six Formative period sites, four of which were of substantial size (>1 ha). These sites were identified by abundant ceramics associated with the Chiripa tradition, and other local Formative period ceramic styles (Albarracin-Jordan and Mathews 1990). All Formative period settlements occupied colluvial terraces overlooking the basin floor. The four largest sites were spaced approximately 4 to 7 km apart along the northern flanks of the Taraco Peninsula (Figure 67). The two smaller settlements, each about 0.8 ha, clustered around the Formative period components of Lukuruma. During the subsequent Tiwanaku periods, Lukuruma was a major settlement extending from 1.2 to 2 km² along the colluvial terraces above the Pampa Koani. The clustering of Formative period sites around Lukuruma suggests that its importance as a center of substantial...
human occupation emerged during this time. As noted above, there is no evidence for a direct relationship between human settlement and agriculture on the pampa during the Formative Period. To date, all evidence for such a relationship is inferential. Nevertheless, excavations during the initial 1978–1979, 1982–1983, and subsequent 1987–1993 field seasons uncovered occupational floors deep below the present surface of the pampa (>2.5 m). Primary evidence for Formative period occupation was found on the agricultural landscape for they could have exploited may be deeply buried. Further research will be required to clarify the distribution and spatio-temporal relationships of Formative period sites in the basin.

Conventionally, the principal Tiwanaku cultural developments (Tiwanaku phases IV–V) have been associated chronologically with the seven centuries from ca. A.D. 400 to 1100. Forty-eight sites in the Catari River basin contain definitive evidence for Tiwanaku occupation. Twelve sites were located on the basin floor. Thirty-four were located along the colluvial terraces at the base of the Taraco Peninsula and around Cerro Katavi. Two sites were located in strategic, elevated positions above the lower colluvial terraces one on Cerro Kiskuranti Pata, the other on the summit of Cerro Katavi. However, the four small Tiwanaku sites in the southern Rio Catari basin was the colluvial terrace zone of the Taraco Peninsula. In the eastern sector of the surveyed pampa, these small Tiwanaku sites show evidence of continued occupation or use as mortuary sites in the Early Pacajes-Inka phase and continued up to the time of the Toleman reforms, that is, ca. 1570. The settlement pattern for this last phase of Pacajes occupation is summarized in Seddon (1994). In sharp contrast with the hierarchical settlement pattern of the late Tiwanaku IV–V period, the Early Pacajes phase is characterized by dispersed sites settled principally in the pampa zone as well as along the colluvial terraces of the Taraco Peninsula. Although sites are numerous (107 sites, or 50% of our total sample, show evidence for Early Pacajes occupation), most of them are very small (<1 ha). In the northern Lake Titicaca basin, Pacajes-Inka occupation is temporally overlapped with both the Early and Late Pacajes-Inka phases. Here I will briefly summarize settlement patterns for the first two Pacajes phase occupations. Albarracin-Jordan and Mathews (1990) define the Late Pacajes phase as one that overlaps chronologically with the Pacajes-Inka phase and continued up to the time of the Toleman reforms, that is, ca. 1570. The settlement pattern for this last phase of Pacajes occupation is summarized in Seddon (1994).

By 1475, populations in the Rio Catari basin had come into sustained contact with the expanding Inka state. Seventy-five sites, or 35% of the total sample, are associated with Pacajes-Inka style ceramics. During this period, another reorientation in settlement patterns occurs, reflected in a significant shift of human occupation away from the pampa zone and back to the terraces along the Taraco Peninsula. Seventy-five sites, or 35% of all Pacajes-Inka sites, were located along these terraces. Many of these sites are also associated with major transportation routes that connected with or were integrated into the Inka Empire's road system. The Pacajes-Inka sites demonstrate a clear hierarchical of settlements differentiated by size, types of artifacts, and function. At this time, the geopolitical landscape was the alipu, the clusters of distinct political-territorial formations that we have referred to as the Aymara kingdoms. These kingdoms were complex polities of great territorial scope and political sophistication with an urban character. The principal regional center of residence along with similar sites located at the contemporary villages of Lakaya, Lukurmata, Chojasi and Wakullani. Smaller settlements extended out into the pampa. Overall the settlement pattern of the Pacajes-Inka phase in the Rio Catari basin is markedly hierarchical, minimally reflecting a four-tiered structure: urban political capitals, secondary towns (such as Chukara), tertiary villages, and dispersed quaternary hamlets. In short, this fifteenth-century pattern replicates the hierarchical structural forms of the earlier Tiwanaku periods when the Rio Catari drainage was integrated into a dedicated production zone under the hegemony of the central Tiwanaku state. Ancient agricultural landownership in the Catari basin is thus later prehistoric period is completely different from those of the earlier Tiwanaku period. As noted above, raised-field systems constructed and utilized on a regional scale disappear from the archaeological record ca. 1150, coincident with the onset of a major climatic change that we have identified in the Lake Titicaca basin, and that Thompson (1992) documents at the equatorial ice cap. Although limited areas of raised fields may have been cultivated in localities with remnant high ground water until the thirteenth and fourteenth centuries, they were not sufficient either in spatial scope or in productive capacity to support large populations. In fact, most of the ca. 70 km² area of raised fields cultivated by Tiwanaku from the seventh to the early twelfth centuries in the Rio Catari basin had been abandoned because of incipient ground water by the early twelfth century. By the mid fifteenth century, annual precipitation returned to levels approximating modern conditions; however, raised-field cultivation on lake-edge wetlands was never reactivated. Instead, intensive agriculture during the Pacajes-Inka period shifted to irrigated and rain-fed terrace cultivation on surrounding mountain slopes. This form of intensive agriculture is dramatically different from rainfed agriculture in both technical and spatial terms, and these differences affected the social organization of production. The raised
fields of the Rio Catari basin constituted a virtually continuous, anthropogenic landscape of production with a single, common source of ground water and an integrated system of irrigation canals; terrace cultivation, on the other hand, entailed the construction of discontinuous pockets of production, each of which required its own water source and canal system.

CONCLUSIONS: ENVIRONMENTAL THRESHOLDS AND THE HUMAN-ENVIRONMENT NEXUS

The linkages between settlement organization, raised-field production, and climate regime in the Rio Catari basin reveal much about the changing relationships of humans to their environment. The emergence of intensive raised-field agriculture in the Lake Titicaca basin was inhibited by a clear environmental threshold: the middle Holocene period of hyperaridity. Only with significant climate amelioration after ca. 1500 B.C. could sustained agriculture develop in this high-altitude, risk-prone environment. An extended period of higher precipitation and available moisture removed the biological constraints to intensive agriculture. Early forms of hydraulic agriculture most likely developed coincident with the emergence of effective farming villages in the Lake Titicaca basin during this period of climate amelioration. However, the regional-scale elaboration of raised fields, although environmentally feasible as early as 1500 B.C., did not emerge until relatively late in the Tiwanaku sequence (ca. A.D. 600–700) at a time of substantial transformation in the organization of the site of Tiwanaku itself toward a more centralized social order (Kolata 1993:134, 164). In sum, internal social forces and external environmental conditions combined to promote the development of a stable, integrated landscape of surplus production in the Rio Catari basin by late Tiwanaku times. Raised fields, which converted wetlands to cultivable areas, increased crop production relative to dry-land farming, protected against frost, retained nutrients, and mitigated soil salinization (Biesboer et al. 1999; Carney et al. 1993; Kolata 1996). Assuring reliable harvests for generations. The (Malthusian) response to abundant surplus production was a logistical capacity to respond to the external shock of large amplitude. The complex and technically specialized character of Tiwanaku’s production system rendered it vulnerable to an extreme environmental impact. As Garrett Hardin (1993:101) observes: “Technology is a blessing to be sure, but every blessing has its price. The price of increased complexity is increased vulnerability.” The vulnerability of Tiwanaku’s technically sophisticated agricultural system was acute since it depended on the ubiquity and abundance of a single natural resource: water. When the water was shut off by climate change at threshold intensity, the system failed. The reemergence of complex, territorially expansive political formations in the Lake Titicaca basin occurred only after annual precipitation increased to approximately modern levels by the mid-fifteenth century.

Our research demonstrates that climate changes occurred rapidly and held significant hydrological, ecological, and cultural implications for inhabitants of the Lake Titicaca basin. Environmental thresholds are never absolute. The social impact of environmental change on societies depends on the amplitude of the environmental change, the elasticity of critical natural resources, the technical capacity of society to continuously exploit these resources, the diversity of a society’s economic base, the flexibility of its political system, the degree of connectedness of the social formation with neighboring societies, and other similar sociocultural characteristics. That is, environmental thresholds are relative, “moving values” that are dependent on a complicated interplay of individual social and environmental variables. But the relativity of environmental thresholds, and the inordinate difficulty of tracking their effects on complex, contemporary societies, does not necessarily mean they are less real or less analytically important. The accumulation of recent evidence for climate-culture interactions in other regions of the world similar to those we have documented for the Andean altiplano indicates that environmental components of a cultural analysis are essential for understanding human behavior (Hodell et al. 1995; Stone 1994; Weiss et al. 1993).

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