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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 unsubtle 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, by the early 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 book *Sociobiology* (Wilson 1976). 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, as "anti-social."

One unfortunate outcome of this controversy has been a marked move by social anthropology 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 allying themselves with ecologists, demographers, and natural scientists, many social anthropologists now consider their work to have greatest affinity with literary criticism, with the critique 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 polemic), the sociology of science has generated a veritable cottage industry of science deconstruction, some of which purports to demonstrate that the products of scientific investigation are merely arbitrary social constructs. The tenor of the debate, now irretrievably enmeshed in politicized rhetoric, positions 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 stage sets 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 overweening 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 analysis? Or is each instance of interaction a historically contingent and particular event? Understanding 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, representation, 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 belief 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 Condominas'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 include 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 328 individual shrines, which were conceived as places or objects imbued with spiritual and instrumental power, along a total of 41 directional sight lines, or *ceques*. Different sets of related lineages *(ayllus)*, or larger social groups *(parcialidades)*, were charged with the responsibility for maintaining and offering ritually prescribed sacrifices to the shrines along the *ceque* line designated to that group. About one-third of the *ceque* shrines related directly to springs, streams, rivers, and pools that are actually or symbolically sources of flowing water for irrigating adjoining lands. These water-related *ceque* shrines can be interpreted in one sense as boundary markers, delimiting and sectioning arable land among the various *ayllus* and *parcialidades* (Sherbondy 1992; Zuidema 1990). In this case, a highly abstract belief system tied to fundamental religious concepts constituted the underlying social framework of a complex land tenure and water rights system. These belief systems, encoded in religious practice, have direct impact on social reproduction, on the mode and intensity of economic production, on the distribution of economic goods, and therefore on the suite of natural resources upon which these production systems depended.

The articulation of a general theory of human-environment interaction is well beyond the scope of this paper: such a treatment will require monograph-length treatment. More to the point, the full realization of a general theory of human-environment interaction will require substantial programs of focused empirical research and the development of new methodological tools and interpretive concepts. Therefore, for the remainder of this paper I will concentrate on defining and presenting an empirical case study of one conceptual element that I believe will be an important component of this newly emerging body of theory: the concept of *environmental thresholds.* This concept eloquently demonstrates that human-environment interaction theory will emerge from an intellectual engagement with the research agendas of multiple disciplines, and from a temporal perspective that specifically focuses on the *longue durée.*

ENVIRONMENTAL THRESHOLDS AND THE LIFE HISTORY OF AN ANDEAN CIVILIZATION

Environmental Thresholds

Human cultures can adapt to changing environmental conditions within a range of normal variation. Concepts of "normal variation" are usually defined by recent and short time scales, rather than by long-term variability during which thresholds at environmental extremes can constrain cultural adaptability. In commonly defined "normal" periods, environmental thresholds can be exceeded a few times for short periods without seriously affecting the viability of a society. However, in the longer term, lower-frequency environmental variations with larger amplitudes 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 normal (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 extended regimes of normal environmental variation and then experience a relatively sudden economic and cultural collapse in the face of an extreme (long-term and/or high-amplitude) environmental impact. This latter scenario of structural transformation triggered by an extreme environmental impact is more likely when a society has become profoundly dependent upon a specialized technology linked to the dominant production system. In this case, "structural rigidities" emerging from a successful, but highly specialized and narrow, economic base may render a society more vulnerable to serious external shocks, including extreme environmental impacts at threshold intensity. For instance, during the Depression era, extended drought conditions in the American Southwest, coupled with a severe national economic downturn, generated massive regional migrations of populations that could no longer sustain themselves on the land as farmers or ranchers. The demographic, social, and cultural reverberations of the "Dust Bowl" phenomenon can still be felt in the Southwest and in regions such as California that received the bulk of these environmental refugees.

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 regionally 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 impedes analytical clarity. This complexity is even more daunting in the globalizing social and economic landscapes 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.

The "Natural" History of an Andean Civilization

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 (Kolata 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 masl) and climatic harshness of its environmental setting renders it a particularly good source of information about human-environment interactions.

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, fluorescence, 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

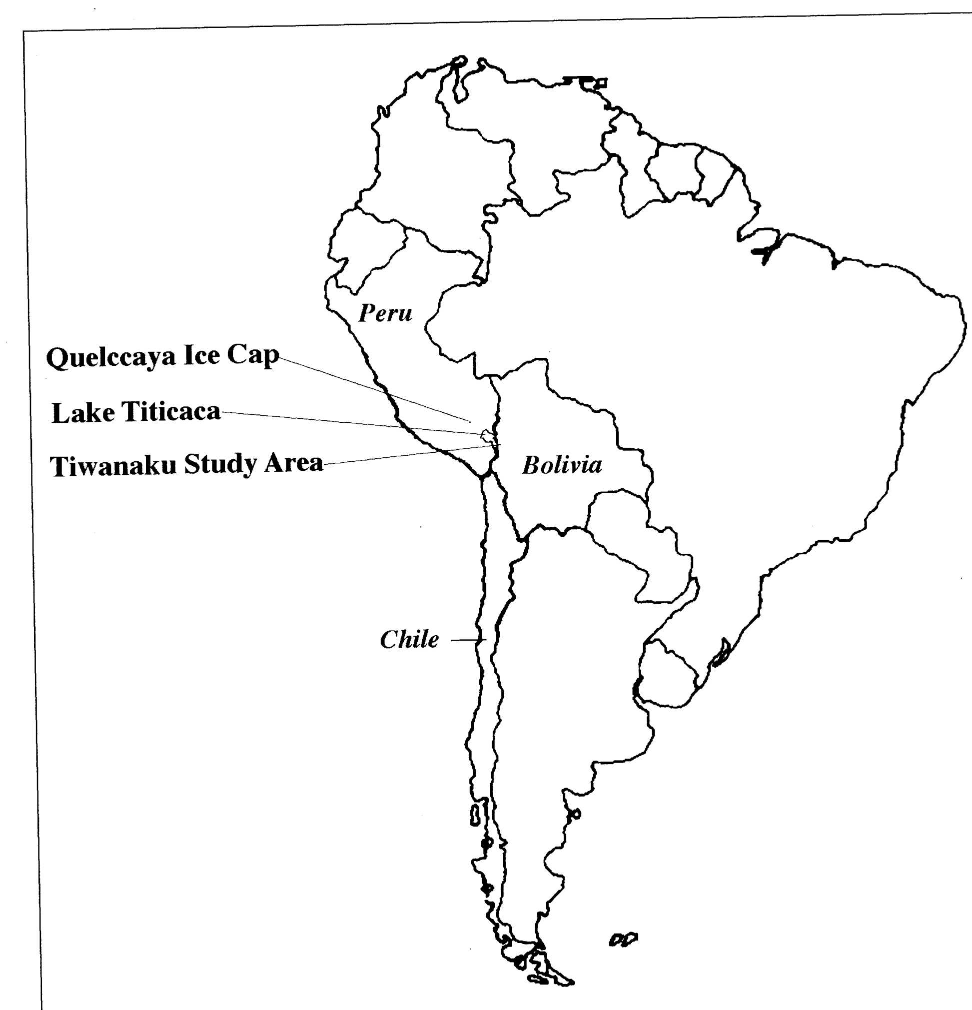

Figure 66. Map of South America showing location of Tiwanaku study area and Quelccaya ice cap.

civilization's core area (Figure 67). The basins lie in the high, intermontane altiplano with a mean elevation above sea level (masl) between 4,200 m at El Alto and 3,808 m (the twentieth-century mean dry-season elevation of Lake Titicaca). The floors of the basins are perennially marshy and subject to inundation during the wet season. Modern climate is cool (9° C annual mean), but tropical mean day-night temperature fluctuation is ±13° C and the annual variation of monthly mean is ± 3° C. 85% of annual precipitation falls between December and March. Long-term average monthly precipitation is nearly always less than monthly potential evapotranspiration so that the soil would always have a moisture deficit were it not for ground water sources. On average during the twentieth century, the lake rises 80 cm during the rainy season and falls 78 cm during the dry season. The lake's mean elevation has been as low as 3,805.2 masl in 1943, and as high as 3,811.6 in 1986. Lake-level fluctuations are statistically significantly but poorly correlated with annual net precipitation. Negative correlations between annual rainfall and the El Niño Southern Oscillation (ENSO) are suggestive but not statistically significant.

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 core 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. 7700–3500 B.P.) is consistent with earlier results reported by

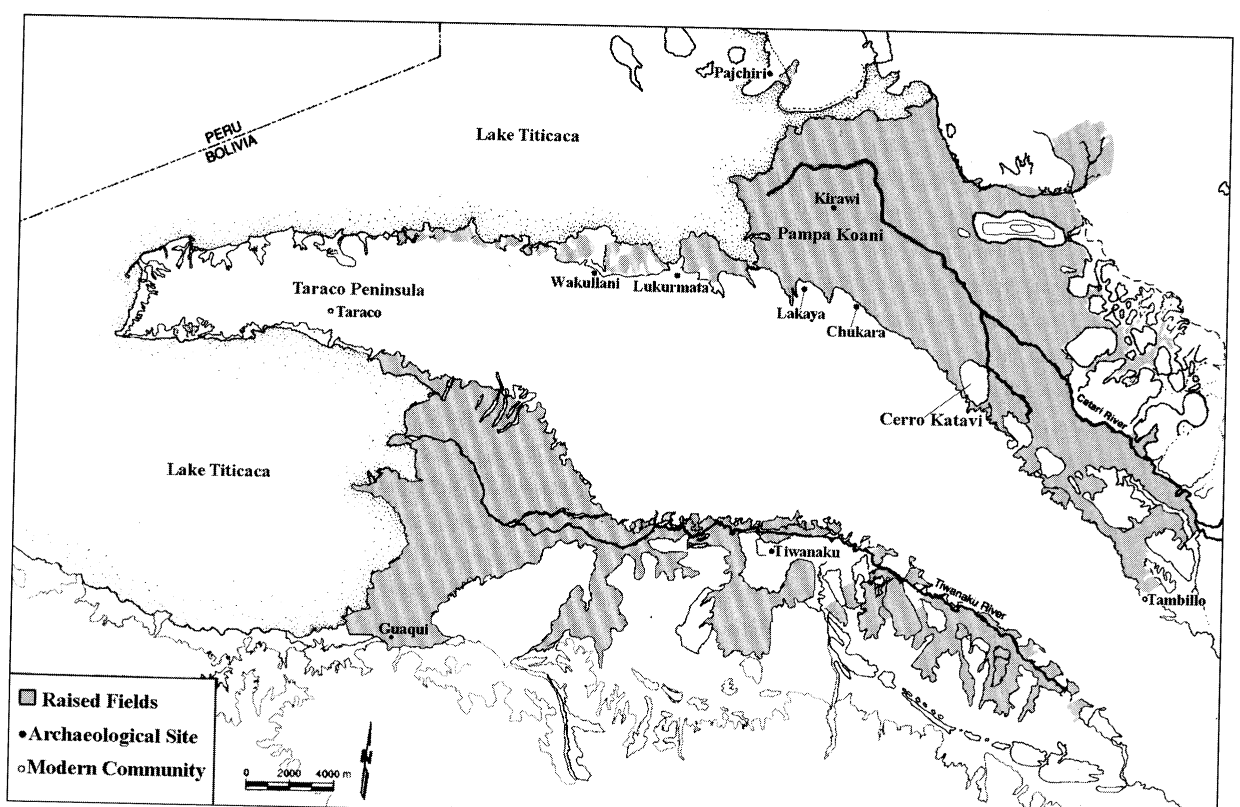

Figure 67. Distribution of raised fields, archaeological sites, and selected modern communities in the Tiwanaku and Catari River basins.

Mourguiart et al. (1986) and Wirrmann and Oliveira Almeida (1987). The severity and protracted character of this period of hyperaridity precluded intensive agriculture and inhibited the development of large, sedentary human populations. Populations may have lived around the shores of a much-diminished Lake Titicaca, but the relative lack of water precluded the emergence of effective agricultural systems. If sedentary settlements existed, their resource base was not predominantly agricultural; rather, during this period in the altiplano, the principal social adaptation to chronic dry conditions most likely took the form of small-scale, dispersed and mobile pastoralism (Aldenderfer 1998). An ancient (and, in vestigial form, still practiced) pattern of transhumance between the altiplano, the humid tropical lowlands of the Amazonian drainage, and the Pacific coasts of Peru and Chile may have been established during this time. Despite speculations to the contrary (cf. Erickson 1993), prior to ca. 1500 B.C. there is no empirical evidence from Lake Titicaca for sedentary village life based primarily on agricultural production. In fact, the consistency of the paleoecological data enable us to propose a predictive model that no archaeological sites indicative of effective, sedentary agricultural villages will ever be found for this period. Although sedentary villages based principally on pastoral lifeways may have existed, aggregated populations were probably not numerous, and certainly did not achieve the demographic scale of the agriculturally based villages of the Formative period in the southwestern Lake Titicaca basin.

2. The emergence of complex, Formative period (pre-Tiwanaku) societies in the Lake Titicaca basin and the initiation of widespread agriculture coincided with a rapid increase in available moisture ca. 3500 B.P. (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 abrupt transition to laminated organic sediments (Abbott et al. 1997). We interpret these laminated sediments as evidence of rapid infilling and lacustrine deposition within the lake basin. Coincident with this increase in available moisture, the archaeological record for the Lake Titicaca region reveals the presence, for the first time, of numerous agricultural villages associated with Formative period cultures such as Chiripa. In effect, climate amelioration eliminated an environmental threshold that had constrained the emergence of effective agricultural systems. This improved climate regime created the physical conditions for the development of a new system of resource exploitation (intensive agriculture) that ultimately underwrote an increase in demographic scale and social complexity of altiplano populations. Primary archaeological evidence for the initial domestication of plants in the altiplano and surrounding areas is not extensive, so it is difficult to document the regional spatio-temporal patterns of the emergence of cultivation systems. 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 1500 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 these results 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, seasonal rain-fed) cultivation with low total production relative to subsequent forms of intensive agriculture, such as raised-field cultivation (Kolata 1996). Raised fields, consisting of seasonally flooded canals alternating with platform planting surfaces, were first described as ancient, pan-tropical agricultural systems by Denevan (1970) and 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 experimented with 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

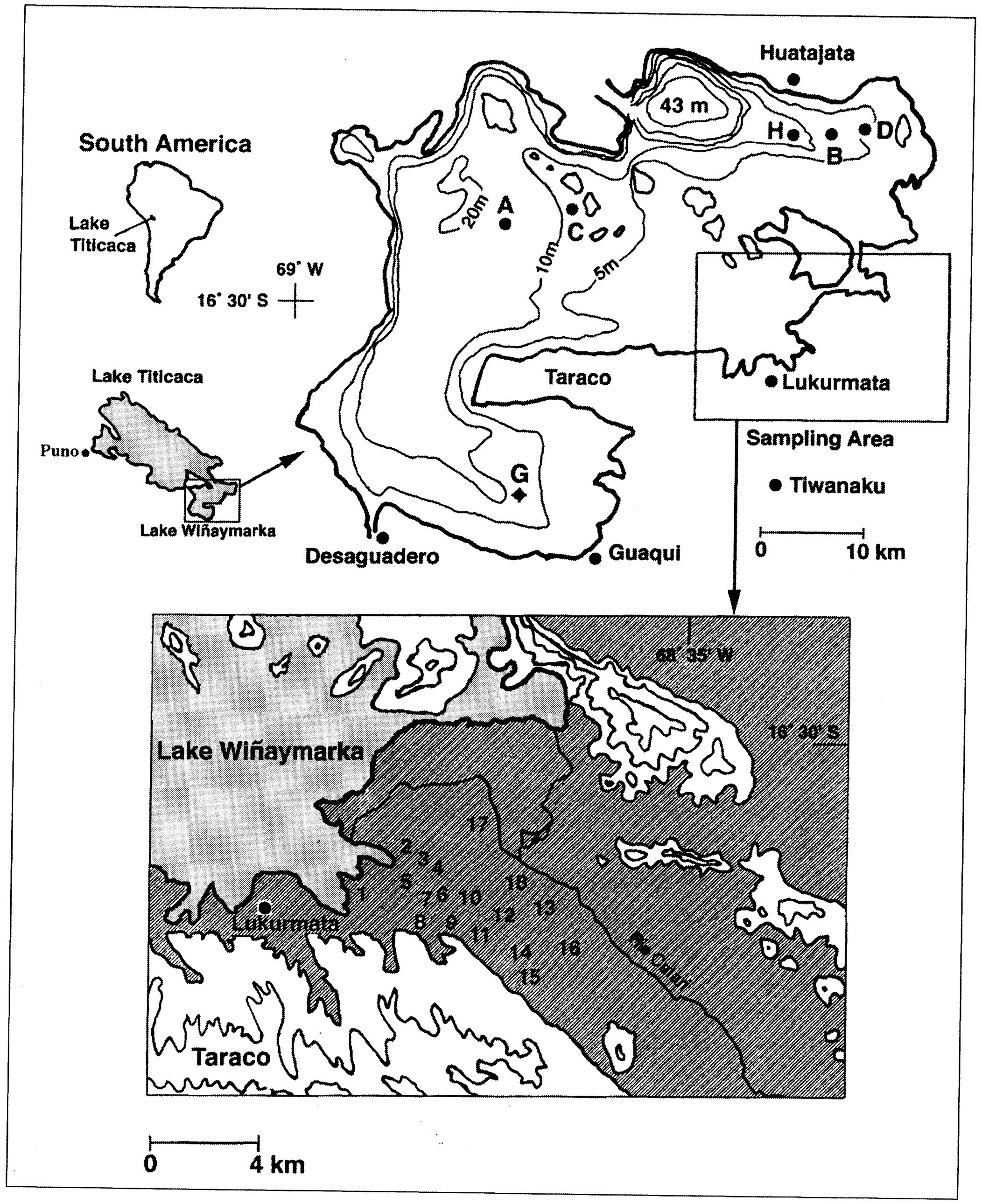

Figure 68. Map of Lake Wiñaymarka (Titicaca) and the Catari River basin showing 1977 bathymetry, coring locations, selected archaeological sites, extent of abandoned raised fields (shaded area in the lower map), and radiocarbon-dated raised fields (numbered points) (after Binford et al. 1997:236, fig. 1).

cultivation on wetlands emerged after A.D. 600, expanding to a maximum regional scale of ca. 190 km^2 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 km^2) 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.

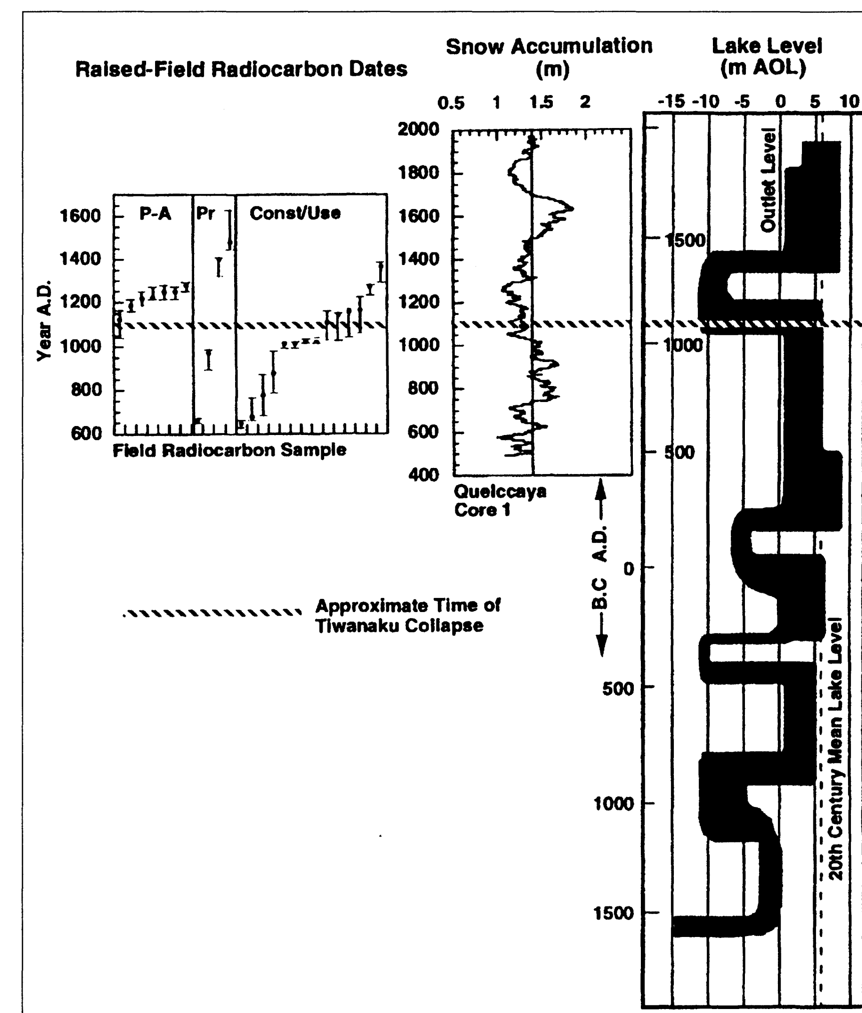

Figure 69. Calibrated radiocarbon dates, snow accumulation on the Quelccaya ice cap (redrawn from Thompson et al. 1985 and smoothed with a 10-year moving mean), and proposed lake-level curve redrawn from Abbott et al. 1977. P-A, Pr, and Const/Use denote material taken from postabandonment, problematic, and construction/use contexts, respectively (Seddon 1994). The cross-hatched line at A.D. 1100 denotes the approximate beginning of reduced precipitation at the Quelccaya ice cap and the beginning of the collapse of the Tiwanaku civilization. The lake-level line is drawn thickly to illustrate century-scale variability; for example, the twentieth-century variation has been about 6 m (after Binford et al. 1997:246, fig. 7).

4. After several centuries of successful hydraulic agriculture, primary archaeological evidence drawn from intensive survey and excavations in the Rio Catari basin indicates that intensive raised-field agriculture in the Tiwanaku core area disappears as a regional-scale production strategy in the period after ca. A.D. 1150. Eleven of 14 dates from raised-field construction and use contexts range between cal A.D. 600 and 1100. These dates bracket the most intensive period of raised-field cultivation in the Tiwanaku area (Table 7). Two dates from use contexts, at cal A.D. 1230 and 1300, suggest that small-scale use of raised fields occurred after cal 1150 A.D., but only in local geomorphological settings of localized high ground water levels. 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.

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.

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

NOSAMS No.	Material	Location (provenience)	Context	^{14}C Age	Calibrated years (All A.D.)	Calibrated one – sigma age range (All A.D.)
OS-2541	Mollusc	6 (86-4-2)	Construction/use	1040 ± 35	1010	990–1020
2540	Mollusc	7 (86-2-1)	Construction/use	820 ± 30	1230	1220–1280
2538	Mollusc	8 (109-2-3)	Construction/use	1070 ± 30	990	970–1010
2539	Mollusc	10 (88-3-3)	Construction/use	1070 ± 30	990	970–1010
2654	Mollusc	11 (111-2-3)	Construction/use	1030 ± 35	1010	990–1020
2564	Carbon	11 (111-2-3)	Construction/use	1360 ± 40	670	650–680
2651	Mollusc	11 (111-2-4)	Construction/use	930 ± 30	1050, 1090, 1120, 1140, 1160	1040–1170
2649	Mollusc	12 (112-3-2)	Construction/use	1290 ± 50	710, 750, 760	670–780
2557	Carbon	13 (113-3-2)	Construction/use	950 ± 30	1040,1150	1030–1160
2565	Carbon	13 (113-3-3)	Construction/use	690 ± 30	1300	1290–1300
2544	Mollusc	14 (134-4-2)	Construction/use	980 ± 30	1030	1020–1150
2652	Mollusc	16 (114-5-3)	Construction/use	990 ± 30	1030	1020–1040
2559	Carbon	17 (35-1-7)	Construction/use	1220 ± 40	790	780–880
2653	Mollusc	18 (89-3-4)	Construction/use	1440 ± 45	640	600–660
2542	Mallusc	1 (83-2-1)	Postabandonment	775 ± 60	1280	1220–1290
2563	Carbon	2 (62-1-3)	Postabandonment	840 ± 45	1220	1170–1260
2558	Carbon	3 (CC33-1)	Postabandonment	875 ± 35	1190	1160–1220
2650	Mollusc	9 (110-3-1)	Postabandonment	955 ± 30	1040	1030–1160
2561	Carbon	9 (110-3-2)	Postabandonment	910 ± 30	1160	1050–1180
2566	Carbon	15 (147-2-5)	Postabandonment	840 ± 35	1220	1180–1250
2758	Carbon	16 (114-5-1)	Postabandonment	860 ± 40	1210	1170–1230
2537	Mollusc	4 (63-3-1)	Problematic	1410 ± 30	650	630–660
2560	Carbon	4 (63-3-1)	Problematic	615 ± 30	1320, 1340, 1390	1310–1400
2543	Mollusc	5 (85-3-5)	Problematic	1140 ± 30	890	890–970
2562	Carbon	5 (85-3-5)	Problematic	425 ± 45	1450	1440–1480

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 Wiñaymarka (the smaller basin of Lake Titicaca) evaporated during this sedimentation hiatus (Figure 68). 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 average 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 precolumbian 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 often 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 minerals, arable land, 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 paleoagricultural 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 Lukurmata. During the subsequent Tiwanaku periods, Lukurmata was a major settlement extending from 1.2 to 2 km^2 along the colluvial terraces above the Pampa Koani. The clustering of Formative period sites around Lukurmata 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 raised-field 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 occupations and the agricultural landscapes 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 Kishuarani Pata, the other on the summit of Cerro Katavi. The preferred location for Tiwanaku sites in the southern Rio Catari basin was the colluvial terrace zone along the Taraco Peninsula. The densely populated urban site of Lukurmata, which reached a maximum size of ca. 145 ha, was the principal Tiwanaku period settlement in the basin (Kolata 1989).

Elsewhere I have argued that Lukurmata represents a secondary administrative center of the Tiwanaku polity (Kolata 1986, 1991). Smaller tertiary settlements associated with significant Tiwanaku occupations such as Wakullani, Chojasivi, Lakaya, Chiar Kala, Qeya Kuntu, and Tumuyu are spaced at regular intervals along the same colluvial terrace zone of the Taraco Peninsula. A major cluster of Tiwanaku sites, forming six mound groups, occupied the middle of the southern Pampa Koani. These mound sites, including the large (2.35 ha) dual mound complex of Kirawi (PK 5/6 [Kolata 1986, 1991] or CC65 in our new site designation), are surrounded by extensive raised-field systems, major canal networks, and elevated dike/causeway networks (Kolata 1996).

The Tiwanaku period settlement distributions are highly significant, and clearly hierarchical in character. As I have argued (Kolata 1986, 1991) and Seddon (1994) confirms, there were no substantial Tiwanaku populations resident on the pampa. Habitations are limited to small, probably seasonally occupied house mounds and the larger, centrally located mound cluster around Kirawi. The largest residential sites in the Rio Catari basin (such as Lukurmata and Lakaya) were established along the northern edge of the Taraco Peninsula. These settlements are urban in character and demographic scale with evidence for internal spatial differentiation into distinct ceremonial, residential, and craft sectors (Janusek 1994).

Our current evidence suggests that the construction of raised fields on a regional scale began late in the Tiwanaku IV period and continued into the Tiwanaku V period. This is slightly later than the Tiwanaku IV date originally proposed (Kolata 1986:758, 1991:120). More significantly, as Seddon (1994) has reported, most of these fields were constructed in single events: there is relatively little evidence for reconstruction and reengineering as would be expected if local systems were gradually knitted together by small-scale farmers, as has been argued by Erickson (1993) for the northern Lake Titicaca basin. Rather, in the Rio Catari basin, the single-event construction of the raised fields and the integration of fields with an underlying grid of irrigation canals (documented in Kolata 1996:109–151) implies that this entire system was planned and executed in a coordinated fashion. The few, relatively small and impermanent settlements in the pampa could not have provided the human labor responsible for constructing and maintaining the large, regional expanse of raised-field systems in the Pampa Koani (Kolata 1986, 1993). The labor for this task must have been drawn from outside the pampa zone: from the secondary urban centers, tertiary towns, and quaternary hamlets distributed along the base of the Taraco Peninsula, and perhaps from outside the Rio Catari basin itself.

I have suggested that the Tiwanaku Valley and the Rio Catari basin served distinct functions in Tiwanaku's agricultural economy (Kolata 1996). Raised fields in the Tiwanaku Valley consisted of dispersed and often self-contained pockets, directly associated with significant human settlements. The raised-field systems and hydraulic infrastructures of the Rio Catari basin, on the other hand, constitute an enormous anthropogenic landscape of ca. 70 km^2 associated directly with only a few human settlements. These patterns strongly suggest that the Rio Catari basin was a dedicated landscape of agricultural production under the Tiwanaku polity (Kolata 1991, 1996), that Tiwanaku population and administrative centers were concentrated away from prime agricultural lands, and that the overall settlement pattern was highly structured and hierarchical in nature.

The subsequent post-Tiwanaku, Pacajes phase occupations exhibit a major shift in settlement patterns. The Pacajes occupations have been divided by Albarracin-Jordan and Mathews (1990) into Early Pacajes (ca. A.D. 1150–1475), Pacajes-Inka, and Late Pacajes (ca. A.D. 1475–1570) phases. Rather than considering Pacajes-Inka to be a distinct chronological phase, Albarracin-Jordan and Mathews (1990) conceive it as a culturally significant period of Inka domination in the Lake Titicaca basin that temporally overlapped with both the Early and Late Pacajes 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 Toledan 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 pampas 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 eastern sector of the surveyed pampa, these small sites consisted of low mounds and burials intrusive into Tiwanaku period mound clusters. Thirty-seven of the Tiwanaku sites show evidence of continued occupation or use as mortuary sites in the Early Pacajes phase. The shift to a widely dispersed human occupation of the pampas zone, as opposed to the concentrated, hierarchical pattern of the previous Tiwanaku period, is dramatic.

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 pampas zone and back to the terraces along the Taraco Peninsula. Fifty-four sites, or 72% of 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 hierarchy of settlements differentiated by size, types of artifacts, and function. At this time, the geopolitical landscape of the altiplano consisted of distinct political-territorial formations that have been 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 Chukara in the Rio Catari basin is an example of a significant town within such an urbanized political configuration. Chukara, possibly associated with the Aymara kingdom of Pacajes (Paxaces), is a large site (48.4 ha) with distinct, internally differentiated residential, mortuary, and agricultural sectors. An extensive ring of communities a few kilometers to the southeast, centered around the site of Tumuyu (14.2 ha) on the lower slopes of Cerro Katavi, represents another important regional center along with similar sites located at the contemporary villages of Lakaya, Lukurmata, Chojasivi, 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 of settlements: 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 centralized Tiwanaku state. However, the agricultural landscapes of production of this later prehispanic period are 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 major climatic change that we have identified in the Lake Titicaca basin, and that Thompson (1992) documents at the Quelccaya ice cap. Although limited areas of raised fields may have been cultivated in localities with remnant high ground water until the thirteenth and early 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 km^2 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 declining 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 differed significantly from raised fields 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; Kolata and Ortloff 1989), assuring reliable harvests for generations. The (Malthusian) response to abundant surplus production was a logistical capacity to sustain large populations. The late Tiwanaku period emergence of a settlement pattern characterized by substantial urbanization indicates that this capacity was, in fact, realized.

When environmental conditions began to change significantly by the mid-twelfth century, the stability of this productive, anthropogenic landscape was threatened. The onset of the protracted drought that we have documented established a new environmental threshold in the Lake Titicaca basin. But the nature of this environmental threshold was not a simple meteorological issue of lower precipitation levels. The ability of Tiwanaku populations to adapt to deteriorating climatic conditions was compromised *culturally* by centuries of demographic expansion underwritten by the extraordinary productive capacity of the raised-field systems, and by long-term reliance on a highly specialized technology that required exploitation of a single, abundant natural resource. The most convincing scenario of Tiwanaku political collapse fits the case of a social formation with a highly successful, but inadequately diversified, economy that experiences an 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 render them any 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; Stine 1994; Weiss et al. 1993).

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