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Reviewed work(s):
Source: *Latin American Antiquity*, Vol. 2, No. 2 (Jun., 1991), pp. 99-125
Published by: Society for American Archaeology
Stable URL: http://www.jstor.org/stable/972273
Accessed: 13/02/2012 07:56

THE TECHNOLOGY AND ORGANIZATION OF AGRICULTURAL PRODUCTION IN THE TIWANAKU STATE

Alan L. Kolata

Utilizing data from six seasons of field research, this article focuses on the question of the technology and social organization of intensive agricultural production in the Andean state of Tiwanaku. Recent literature in Andean archaeology and ethnohistory asserts the dominance of local kin groups in the organization of agicultural production rather than supracommunity state authority. The analysis presented here takes issue with this perspective as applied to the core territory of the Tiwanaku state during the period from ca. A.D. 400 to 1000 (Tiwanaku IV–V). I conclude that in this period: (1) the technology of Tiwanaku intensive agricultural production turned on the creation of an artificial regional *hydrological regime of canals, aqueducts, and groundwater regulation articulated with massive raised-field systems, and (2) the organization of agricultural production in this core territory entailed structured, hierarchical interaction between urban and rural settlements characterized by a substantial degree of political centralization and the mobilization of labor by social principles that reached beyond simple kinship relations.*

Utilizando información arqueológica de seis temporadas de campo, este artículo centra su atención en aquellos aspectos tecnológicos y de organización social asociados a la producción agrícola intensiva del estado andino de Tiwanaku. Una posición actual en la literatura arqueológica y etnohistórica andina sostiene que la organización asociada a la producción agrícola estuvo basada en grupos de parentesco local, en lugar de que el manejo planificado de la autoridad estatal actuaba sobre la comunidad. El análisis que aquí se presenta polemiza esta perspectiva en su aplicación al desarrollo del estado Tiwanaku en su área nuclear aproximadamente desde 400 a 1000 D.C. (Tiwanaku IV–V). Concluimos que en este período: (1) la tecnología de la producción agrícola intensiva de Tiwanaku generó la creación de un régimen hidrológico artificial y regional de canales, acueductos y regulación de aguas subterráneas articulado con los sistemas de campos elevados, y (2) la organización de la producción agrícola en este territorio nuclear mantuvo una interacción estructurada y jerarquizada entre los asentamientos urbanos y rurales. Además se caracterizó por tener un grado de centralización política y por la mobilización de mano de obra que utilizó principios sociales que fueron más alla de simples relaciones de parentesco. Un aspecto complementario pero significativo para la investigación que presentamos aquí es la rehabilitación de algunos campos de cultivo prehispánicos (camellones o campos elevados) de la Pampa Koani y del valle de Tiwanaku, y los resultados de su implementación después de los tres primeros años consecutivos. Se subrayan las propiedades térmicas de los campos elevados para la protección contra las heladas, y la alta productividad por superficie sembrada, que es varias veces superior al promedio regional y nacional. Estos resultados evidencian que este régimen de intensificación agrícola fue la estrategia principal de producción intensiva del estado de Tiwanaku.

The organizational principles that govern intensive agricultural production have been a central concern of several influential theoretical formulations regarding the origin and maintenance of state societies (Boserup 1965; Coward 1979; Downing and Gibson 1974; Hunt 1988; Mitchell 1973, 1977; Sanders and Price 1968; Steward 1955; Wittfogel 1938, 1957; among others). The Wittfogel (1957) hypothesis, which postulated that large-scale irrigation requires centralized management of the hydraulic infrastructure and explained the origins of agrarian state societies in arid lands in terms of increased political integration resulting from the need for centralized control of irrigation, has generated a particularly passionate body of literature (see Mitchell [1973] for an excellent summary of that literature).

The current consensus on the Wittfogel hypothesis rejects both the assumption that large-scale hydraulic works presuppose the presence of centralized authority and the causal inference that links

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Latin American Antiquity, 2(2), 1991, pp. 99–125.

the emergence of state societies with the organizational requirements of such hydraulic infrastructures (Hunt 1988; Mitchell 1973, 1977). Justifiably, contemporary scholars of early state societies view the degree of centralization in intensive agricultural systems as highly variable, and demonstrate, in many cases, that the organization of such systems lies outside the purview of state bureaucracies (Netherly 1984), or even excludes political structures from the decision-making apparatus altogether (Lansing 1987). Rather than looking to the central authorities for the principles that structured intensive agricultural production in these states (the "top-down perspective"), these scholars emphasize the importance of recognizing the organizational initiatives of local farmers (the "bottom-up perspective"). In general, the latter perspective seems to accept that intensive systems of agricultural production require some form of (weakly) hierarchical organization, but that there was a tendency to use the minimum amount of organization necessary to maintain the hydraulic infrastructure, while retaining a mechanism for seeking higher levels of organization when necessary (regional dispute resolution, disaster response, and the like).

Certain recent literature in Andean archaeology and ethnohistory closely follows this new orthodoxy, asserting the dominance of local kin groups rather than hierarchical, supracommunity state authority in the organization of agricultural production (Erickson 1988; Graffam 1990; Netherly 1984; see also Schaedel [1988] who extends this analysis to Andean cosmology and worldview). Although this perspective provides a necessary corrective to a rigid, Wittfogel-like formulation, uncritical application can lead to an equally dogmatic position that overlooks, or even denies, the reality of centralized state action on local communities in Andean societies. Neither a categorical top-down or bottom-up frame of reference alone can account for the multiple forms of social linkages that produced intensive systems of agricultural production and provided for the reproduction of society as a whole. Bureaucratic and nonbureaucratic, centralized and uncentralized forms of organization of intensive agricultural production can, and probably always did, coexist in time and space in most agrarian states. Therefore, at any given point in the history of a state society, it is likely that both frames of reference can provide essential insights into the dynamic interaction of local communities and centralized authorities.

In this paper, I argue that the essential geopolitical core of the Andean state of Tiwanaku consisted of a politically and economically integrated agricultural heartland reclaimed from the flat, marshy lands that ring Lake Titicaca (Figure 1). The fields in this core area were shaped into a system capable of sustained yields that provided the bulk of the state's considerable subsistence needs and accommodated the natural expansion of its demographic base (Kolata 1983, 1986; Kolata and Graffam 1989; Kolata and Ortloff 1989; Ortloff and Kolata 1989). The technology of intensive agricultural production in the Tiwanaku state turned on creation of an artificial *regional* hydrological regime of canals, aqueducts, and groundwater regulation articulated with raised-field systems. The organization of agricultural production in this core territory entailed structured, hierarchical interaction between urban and rural settlements characterized by a substantial degree of political centralization and the mobilization of labor by social principles that reached beyond simple kinship relations. This argument does not imply that the Tiwanaku state wielded despotic power in the Wittfogellian sense, or even that it created a formalized, central bureaucracy. Rather, it assumes that Tiwanaku urban elites had a compelling interest in establishing a dedicated landscape of intensive agricultural production in the core territory around the southern shores of Lake Titicaca, and that the organizational principles they instituted to manage this landscape were of regional, rather than local scope.

TIWANAKU RAISED FIELDS: TECHNOLOGICAL DIMENSIONS AND IMPLICATIONS

Systems of raised-field agriculture, if not quite ubiquitous in the ancient Americas, are nevertheless broadly distributed throughout Central and South America, and, to a lesser degree, in North America as well. This type of paleohydraulic system occurs in different climatic regions ranging from the humid tropics of the South American lowlands to the middle-latitude, temperate zones of the upper Midwest in the United States. This wide geographic variation in raised-field technology is matched by high diversity in morphology and function. In certain ecological contexts, such as in perennially

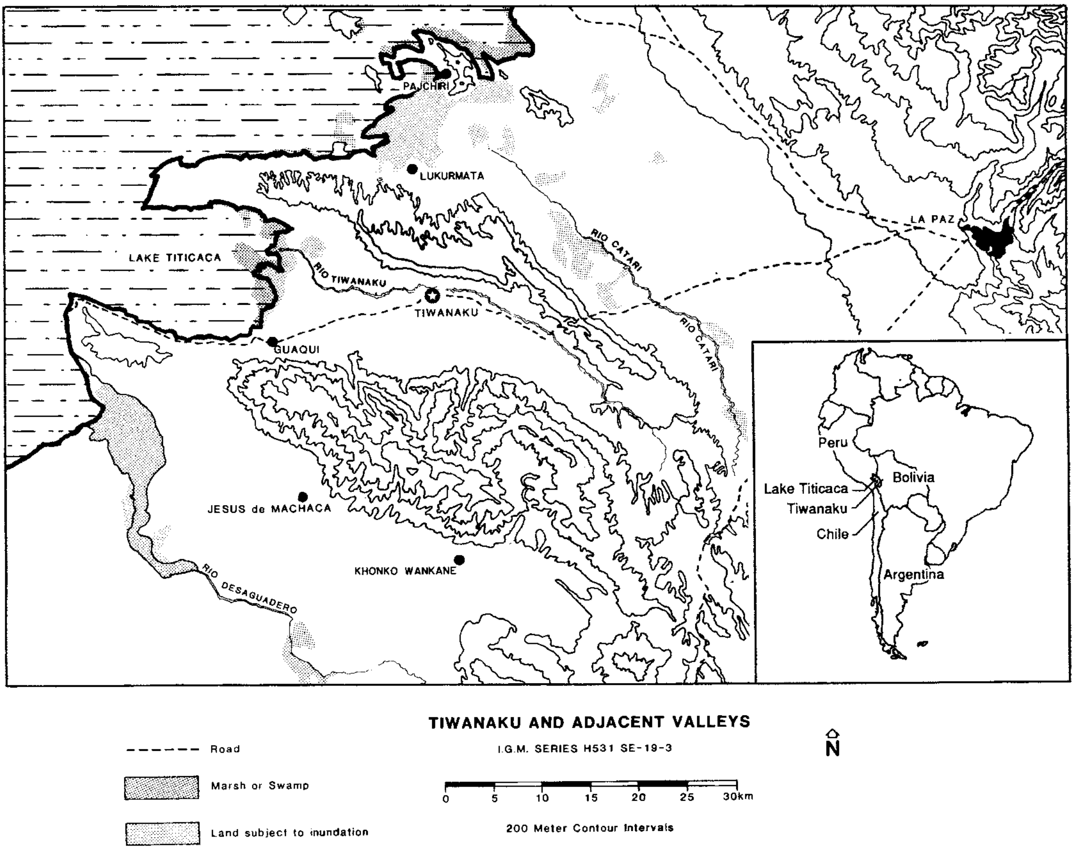

Figure 1. Tiwanaku and adjacent valleys illustrating the location and general topographic and hydrological features of the subbasins of the Río Tiwanaku and the Río Catari, and portions of the Machaca-Desagüadero region discussed in the text. This map locates the principal Tiwanaku urban settlements of Tiwanaku, Lukurmata, Pajchiri, and Khonko Wankané. Major Tiwanaku sites also exist under the modern settlements of Guaqui and Jesus de Machaca illustrated on this map.

inundated landscapes, the primary function of raised fields is to promote drainage and lower local water tables to reduce the potentially disastrous conditions of root rot. In other settings, raised fields mitigate the hazard of killing frosts, thereby enhancing local yields (Gallagher et al. 1985; Riley and Freimuth 1979). Still other systems of raised fields appear to promote the conservation of water and the recycling of essential nutrients. The raised-field complexes of the circum-Lake Titicaca region in Peru and Bolivia, which are of principal concern here, represent the largest, virtually continuous expanse of this cultivation system in the world. This specialized, intensive form of agricultural production was the cornerstone of Tiwanaku's agrarian economy.

Morphology and Structure

The raised fields of the Titicaca Basin are essentially large, elevated planting platforms ranging from 5 to 20 m in width and up to 200 m in length. Within a given segment of a raised-field system, approximately 30–60 percent of the area of a segment is given over to the planting surface itself (Figure 2). The remaining portion is occupied by intervening canals that derive their water from local fluvial networks, natural springs, or percolating ground water (Kolata and Ortloff 1989). At times, the flow of water from natural sources that fed Tiwanaku raised-field systems was enhanced and regulated by massive hydraulic projects designed by the agroengineers of Tiwanaku: dikes,

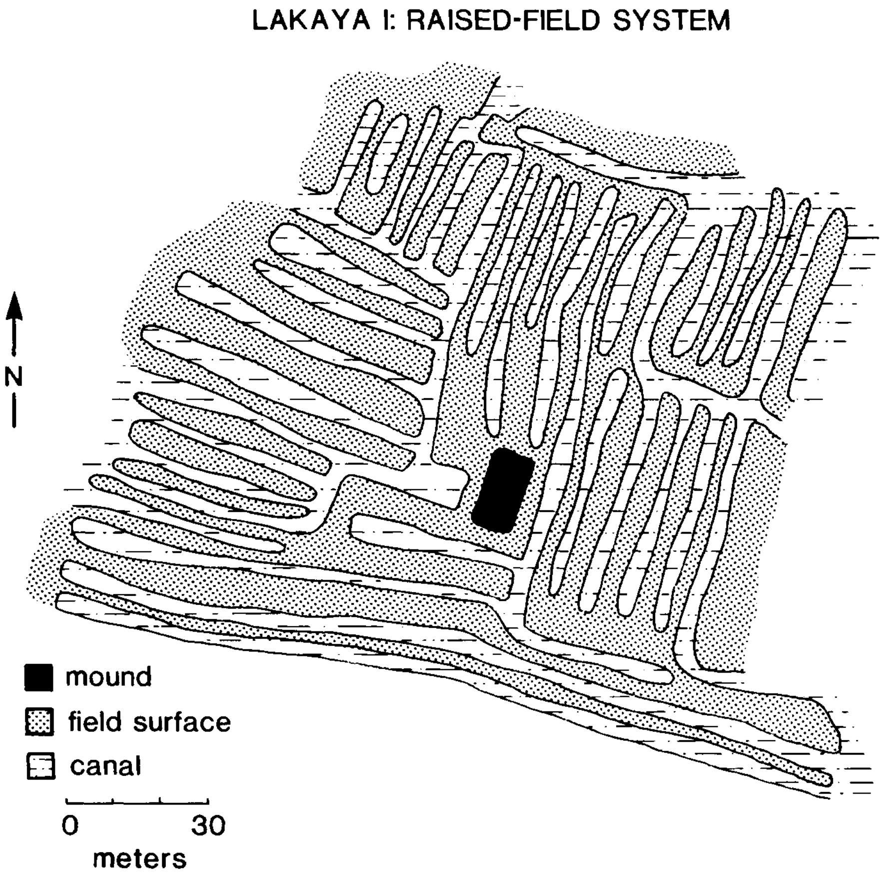

Figure 2. Plan of representative raised-field system in the Lakaya sector of the Pampa Koani illustrating proportion of canal:field surface area. Note central location of house mound dated to Tiwanaku V phase ca. A.D. A.D. 800-1000. This mound most likely represents repeated seasonal occupation by *kamani*, or field guardians.

aqueducts, primary canals and canalized springs, *quebradas*, and rivers (Ortloff and Kolata 1989). Comprehensive descriptions of Titicaca Basin raised-field morphology and structure can be found in Erickson (1988) and Lennon (1982, 1983).

An essential property of the Lake Titicaca raised-field systems stabilized and enhanced their productivity and sustainability. Recent experimental work in restored Tiwanaku raised fields (described in greater detail below) indicates that the canals adjacent to the elevated planting surfaces were rapidly colonized by a diverse range of aquatic macrophytes, such as *Azolla*, *Myriophyllum*, and *Elodea*. These aquatic macrophytes trap suspended, water-borne particulates and thereby sequester nutrients in the agricultural environment (Binford et al. 1990). Plants were probably harvested directly from the surface of the water and incorporated into the planting bed immediately before sowing, or their decayed products were dredged from the muddy sediments of the canals and redistributed over the surface of the field. The high nutritive content of the decomposed aquatic plants would have greatly ameliorated the nitrogen deficit that characterizes most altiplano soils (Unzueta 1975; Winterhalder et al. 1974:99). Excavations in the agricultural sector at the site of Lukurmata (Figure 1) indicated that Tiwanaku farmers did in fact periodically clean the sediments from canals between raised fields (Kolata and Graffam 1989; Kolata and Ortloff 1989:Figure 7). These nitrogen-rich sediments were then used to resurface and revitalize the planting platforms of the raised-field system.

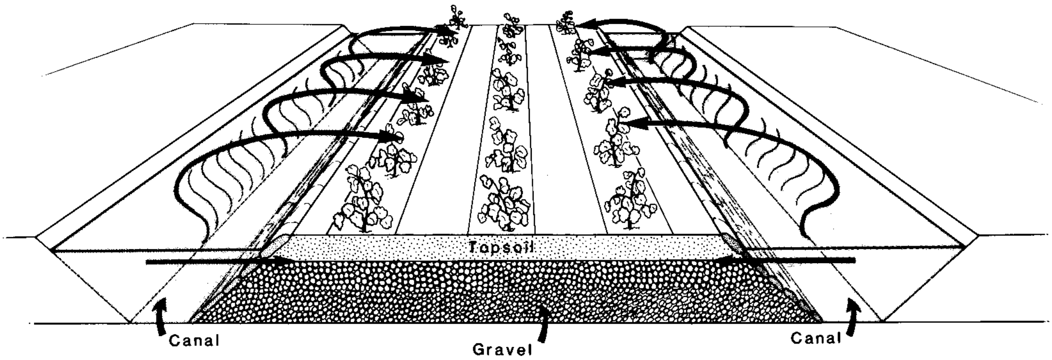

Figure 3. Specific vectors of heat storage and transfer in Tiwanaku raised fields in the Lake Titicaca Basin as described in the text. Illustration based on research discussed in Kolata and Ortloff (1989).

Apart from their capacity to sustain aquatic plants that could be exploited as forms of natural fertilizer, the canals between fields played a second, vital role in maintaining the productivity of raised fields in the specific environmental context of the Andean high plateau. Perhaps the greatest risk that altiplano farmers face on a daily basis during the growing season is the potential for devastation wrought by killing frosts. A number of scholars examining ancient raised-field technologies have advanced the general hypothesis that raised fields in high-altitude (Brookfield 1961; Denevan 1970; Erickson 1985, 1988; Smith et al. 1968; Wadell 1972) and middle-latitude (Riley and Freimuth 1979; Riley et al. 1980) environments served to mitigate frost damage. Erickson (1985) describes the general thermal and microclimatic effects of raised fields in the Huatta district of the Department of Puno, Peru. In experiments undertaken in restored Tiwanaku raised fields during 1987 and 1988, my colleagues and I examined the specific heat-storage pathways and potentials within these systems (Figure 3). The results of this work demonstate that the design of raised-field systems absorbs heat from solar radiation efficiently, promotes heat conservation, and functions effectively to protect both seedlings and maturing plants from frost damage during subfreezing altiplano nights (Kolata and Ortloff 1989). As implied above, the canals surrounding the raised fields are the key to this frost-mitigation effect.

Experiments in Raised-Field Rehabilitation

During the 1987–1988 agricultural season, we obtained graphic empirical confirmation of these heat-conservation effects. In that year, approximately 2.5 ha of ancient Tiwanaku raised fields were reconstructed near the native Aymara village of Lakaya in the Pampa Koani, situated on the southern shores of Lake Titicaca some 10 km to the north of the site of Tiwanaku itself (Figure 4). These well-preserved Tiwanaku raised fields were reconstructed by Aymara from local communities around Lakaya between August and September 1987 and were planted in a variety of indigenous (principally potato) and introduced crops. Organic fertilizer in the form of green manure and animal waste (but no commercial fertilizer) was applied to the rehabilitated fields, and cultivation and weeding proceeded in a normal manner.

On the nights of February 28–29, 1988, the Bolivian altiplano in the Pampa Koani region suffered a killing frost with temperatures in the Lakaya sector dropping to -5°C in some areas. Substantial zones of potato and quinoa cultivation on plains and hillslopes along the southern rim of Lake Titicaca were severely damaged by this heavy frost. Many traditional dry-farmed potato fields within a few hundred meters of the experimental raised-field plots experienced crop losses as high as 70–90 percent. One control plot cultivated in the traditional manner without benefit of raised-field technology lost every maturing potato plant. In contrast, losses in the experimental raised fields of Lakaya were limited to superficial frost damage of foliage on potato plants. Barley, broad beans, quinoa, *cañiwa*, onions, and lettuce on the raised fields also exhibited only superficial damage and

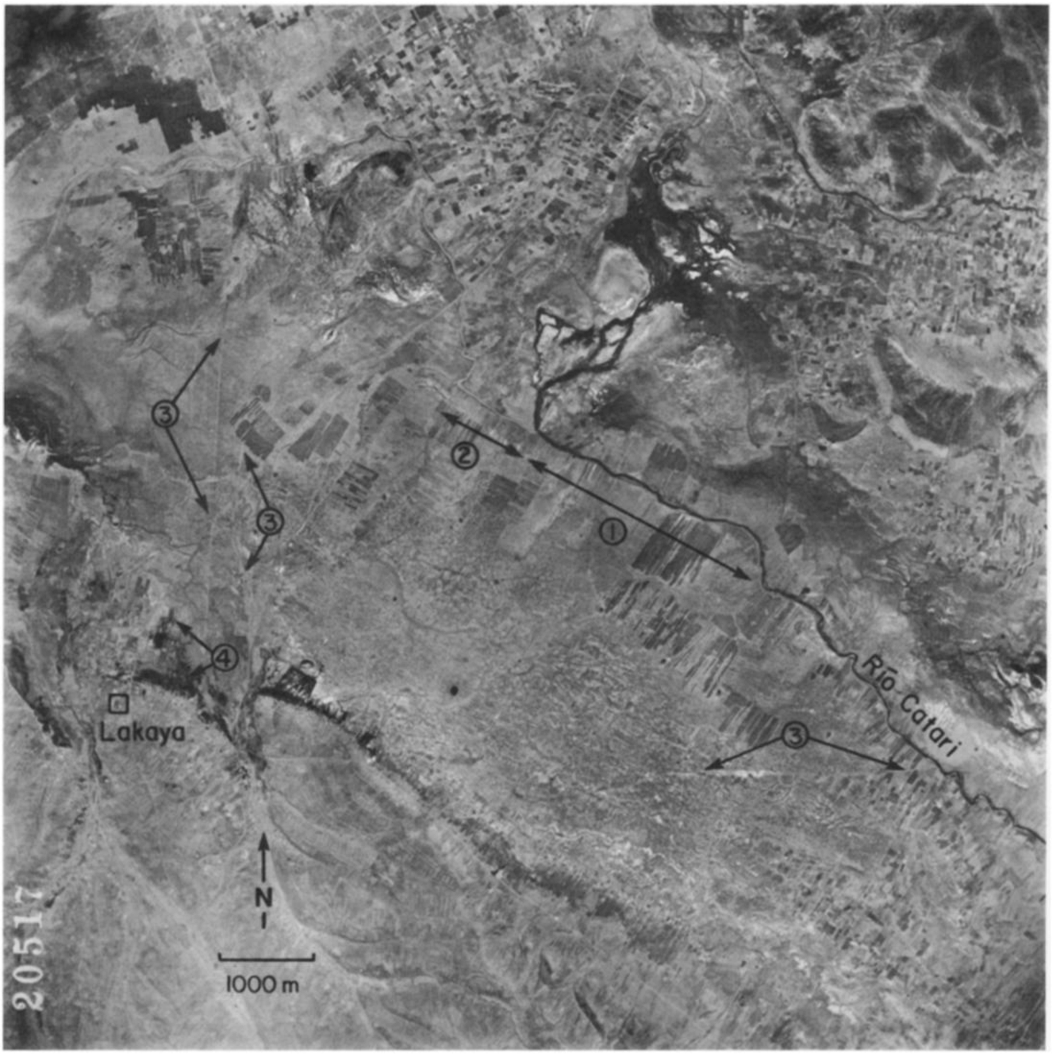

Figure 4. Aerial photograph of southern portions of the Pampa Koani raised-field system study area with regional artificial hydrological features emphasized: (1) artifically canalized section of the Río Catari; (2) intake of the river-by-pass system, or river "shunt"; (3) causeways—the causeway on the west side of this photograph [trans-pampa causeway] may have served as a dike, as well as an elevated roadbed; (4) Lakaya rehabilitated raised fields (from Instituto Geográfico Militar, sheet 20517, 10 August 1955).

low loss rates from the frost. We attribute this substantial differential in plant survivability to the heat-storage properties of the saturated raised fields and their surrounding canals. In effect, these experiments demonstrate that Prehispanic systems of raised-field cultivation in the altiplano possess much higher thermal efficiency than traditional forms of dry farming practiced by the indigenous peoples of the area since the early Spanish Colonial period. Not surprisingly, given the high risk of crop loss through frost damage, the higher thermal efficiency of the raised fields, when combined with the forms of natural fertilization available to the raised-field cultivator, translates into substantially higher yield performance in comparison with dry farming.

In addition to demonstrating the superior thermal properties of raised fields, our experiments in rehabilitating Tiwanaku raised fields indicated substantial yield differentials between traditional,

Table 1. Potato Yield of Rehabilitated Raised Fields: Pampa Koani.

Parcel Number	Dimensions (m) Length/Width	Surface area (in m^2)	Number of Furrows	Number of Plants	Weight per Parcel (in kg)	Total Weight per Hectare (in kg (Estimated))	% Exhibiting Frost Lesions[a]
1	3.57/2.90	10.35	4	39	40.80	39,420	10
2	4.00/3.00	12.00	4	49	45.80	38,166	20
3	3.00/3.54	10.62	4	39	39.00	36,723	10
4	2.80/3.17	8.88	4	33	38.30	43,130	0
5	2.70/7.70	20.79	4	84	82.25	39,562	10
6	3.20/3.20	10.24	4	31	43.20	42,187	25
7	2.90/2.90	8.41	4	36	44.70	53,151	10
8	2.80/3.50	9.80	4	43	38.18	38,959	20
9	2.80/2.90	8.12	4	33	29.15	35,899	0
10	3.00/5.00	15.00	9	70	70.50	47,000	10
11	3.00/5.00	15.00	9	75	63.50	42,333	10
12	3.65/3.20	18.25	5	45	57.50	49,229	0
Total		132.41		577	592.88	505,752	
Average		11.03		48	40.40	42,146[b]	10.41

[a] Percent of plants exhibiting frost lesions refers to the specific event of February 28–29, 1988, referred to in the text.

[b] To obtain average yield in kilograms per hectare in the raised-field system as a whole, rather than the platform surfaces alone, this figure must be halved to reflect the approximate proportion of noncultivated canal surfaces. Effective yield per hectare becomes ca. 21 metric tons/hectare.

dry farming and raised-field cultivation. Table 1 illustrates the yields of potato, the principal tuber planted in 12 individual control parcels in the reconstructed raised fields, along with supplemental data on the surface dimensions of the control parcels, number of planted furrows and individual plants per parcel, the achieved weight and number of tubers per potato plant, and the incidence of frost damage.

The yields from the experimental raised fields compare favorably with those obtained from control plots of two traditional variants of altiplano agriculture cultivated for purposes of direct comparison. The two traditional forms of agricultural plots were: (1) shallow-furrow, seasonal rain-dependent plots, cultivated without the benefit of irrigation, or the use of chemical fertilizers or pesticides, but with small quantities of organic fertilizer, principally dried cattle manure, incorporated into the fields prior to seeding, and (2) shallow-furrow, dry-cultivated plots with added chemical fertilizers and pesticides applied both to the soil and to foliage throughout the growing season. The first control plot was established on a previously cultivated, gentle hillslope in the community of Lakaya approximately 120 m south of the reconstructed raised fields on the pampa (Figure 4). The specific plot chosen for cultivation had been in fallow for about five years (the landowner was unable to provide a precise date for the last previous planting of the field, but he did mention that the last crop planted was barley). The second control plot was established in the community of Achuta Grande in the valley of Tiwanaku, 4 km west of the village of Tiwanaku. This plot was cultivated on long-fallowed, flat land near the Río Tiwanaku, which had been used for the past 15 years exclusively for pasturage. This second control plot lies approximately 200 m southwest of 4 ha of rehabilitated raised fields in the Achuta Grande pampa.

The first form of traditional cultivation has been the dominant mode of peasant agricultural production in the Bolivian altiplano for nearly five centuries even though it is patently inefficient. As indicated by the yield and supplemental production data in Table 2, this form of nonfertilized dry farming achieved an average of 2.5 metric tons (t)/ha of potato (the index plant of our experimental work) on five cultivated parcels. During the 1987–1988 growing season, 100 percent of the maturing plants on these parcels exhibited lesions from frost, with the bulk of the damage occurring during the hard freeze in February, 1988. Depending on the individual parcels of cultivated land,

Table 2. Potato Yield of Traditional Agriculture Lacking Commercial Fertilizers.

Parcel Number	Dimensions (m) Length/Width	Surface area (in m²)	Number of Furrows	Number of Plants	Weight per Parcel (in kg)	Total Weight per Hectare (in kg (Estimated))	% Exhibiting Frost Lesions[a]
1	5.00/3.60	18.00	5	60	4.00	2,222	100
2	5.00/3.50	17.50	5	63	4.50	2,571	100
3	5.00/3.65	18.25	5	61	4.60	2,520	100
4	5.00/3.70	18.50	5	61	5.00	2,703	100
5	5.00/3.56	17.80	5	62	3.80	2,135	100
Total		90.05		307	21.9	12,151	
Average		18.01		61.4	4.38	2,430	100

[a] Percent of plants exhibiting frost lesions refers to the specific event of February 28–29, 1988, referred to in the text.

approximately 10–30 percent of these plants were superficially damaged by frost, but the remaining 70–90 percent were destroyed and yielded no edible tubers.

Predictably, the addition of commerical fertilizers (N, P, K: nitrogen, phosphorous, and potassium) on traditional fields (control plot 2) increased production substantially to an average of 14.5 t/ha on eight cultivated parcels (Table 3). Despite the expected enhanced performance of traditional agricultural fields treated with commercial fertilizers, it is clear from a comparison of the data in Table 1 that the experimental raised fields significantly outperformed both the nonfertilized and the fertilizer-treated fields constructed in the traditional fashion. On 12 cultivated parcels of experimental raised fields, potato yields reached an average of 21 t/ha, or nearly twice the yield of traditional fields treated with chemical fertilizers and over seven times the yield of unimproved traditional cultivation. Furthermore, the percentage of the crop planted in raised fields that was affected by frost lesions averaged only about 10.5 percent, a radically different, and much smaller proportion of frost damage than experienced in the two types of traditional cultivation.

Similar experiments in raised-field rehabilitation were conducted in the altiplano of Peru on the northern side of Lake Titicaca by a team of archaeologists and agronomists during the early and mid-1980s (Erickson 1988). Their results are instructive and are generally consonant with ours (Table 4). The Peruvian team apparently did not plant control plots of traditionally cultivated fields for direct comparison, but rather relied on regional averages for the Department of Puno derived

Table 3. Potato Yield of Improved Agriculture With Commercial Fertilizers.

Parcel Number	Dimesions (m) Length/Width	Surface area (in m²)	Number of Furrows	Number of Plants	Weight per Parcel (in kg)	Total Weight per Hectare (in kg, (Estimated))	% Exhibiting Frost Lesions[a]
1	5.00/3.68	18.40	5	45	26.0	14,130	100
2	5.00/3.40	17.00	5	40	26.5	15,588	100
3	5.00/3.60	18.00	5	40	23.0	12,777	100
4	5.00/3.80	19.00	5	40	26.0	13,685	100
5	5.00/3.20	16.00	5	41	14.0	8,750	100
6	5.00/3.30	16.50	5	46	22.5	13,636	100
7	5.00/3.30	16.50	5	51	30.5	19,062	100
8	5.00/3.50	17.50	5	44	32.1	18,342	100
Total		138.40		347	200.6	115,970	
Average		17.30		43.3	25.1	14,496	100

[a] Percent of plants exhibiting frost lesions refers to the specific event of February 28–29, 1988, referred to in the text.

Table 4. Potato Yield on Rehabilitated Raised Fields in Huatta, Peru.

Field Name	Surface Area (m^2)	Yields in kg/ha 1981–1982	 1983–1984	 1984–1985
Machachi	110	6,760		
Candile	73	10,119		
Chojñocoto I	702		13,652	8,573
Chojñocoto II	2,025			5,186
Chojñocoto III	1,449			11,036
Viscachani Pampa	1,405/1,625		12,536	12,309
Pancha Pampa	815			10,990
Average Yield per Hectare per Year		8,440	13,094	10,441
Combined Average Yield per Hectare		10,658 kg/ha		

Note: Adapted from Erickson (1988:Table 8).

from statistics compiled by the Peruvian Ministry of Agriculture. These averages of regional potato production on traditionally cultivated plots range from 1.5 to 6 t/ha, which compares well with our own result of 2.4 t/ha. The higher average production figures for the Puno area (>3 t/ha) probably reflect fields treated with natural or chemical fertilizers and should be compared with our result of 7.25 t/ha for improved traditional agriculture (Table 3). On raised fields that were not treated with fertilizers over a three-year production cycle, the Puno group generated an average of 10.65 t/ha with a range from 8.3 to 13.0 t/ha.

As can be seen in Table 4, production figures varied considerably over time and space. Some areas did particularly well in a given year, and even within individual blocks of reclaimed raised fields there was considerable variability in yield depending on placement of seed in the center or along the edge of a cultivated plot (Erickson 1988), an experience replicated in our own work on the Bolivian side of the lake. The average yields of potato on raised fields achieved by the Puno group are lower than those obtained on the Bolivian side in the Pampa Koani region, although the pattern of dramatically enhanced production on raised fields in comparison to traditional fields is identical. The higher yields obtained on the Bolivian side may relate to slight climatic differences between the northern and southern sides of Lake Titicaca. The area around Puno is at a higher altitude and consequently is somewhat more prone to frost damage than the area of the Pampa Koani. Moreover, the planting and cultivating protocols practiced by the Puno group appear to have differed from our own. The Aymara villagers rehabilitating fields in the Pampa Koani routinely incorporated organic fertilizer (green manure, or animal waste) into the fields during field construction, tilling, and sowing activities.

Despite the differences in average raised-field potato production between the Puno and the Pampa Koani experiments, the general trend of significantly enhanced yields on reclaimed raised fields appears established beyond a reasonable doubt. At a minimum, cultivation on reclaimed raised fields results in production from two to three times greater than that obtained by traditional methods. Moreover, as Erickson (1988:245) points out, raised fields are remarkably efficient in terms of the ratio of seed to producing plant: "in comparison to traditional fields, only half the seed is necessary for planting a hectare of raised fields since half the area is uncultivated canal. [T]hese high production rates are even more impresssive when considering that a hectare of raised fields has only half the number of plants of a traditional potato field." If the experiments of both research groups are correct, raised fields represent a prime example of continuous, efficient, and potentially sustainable cultivation: a system of intensive hydraulic agriculture that required no extended periods of fallow.

But, these experimental results, however provocative, cannot be taken uncritically and at face value. They must be placed in a specific experimental and ecological context that explains at least part of the difference in performance between raised fields and traditional dry farming. In accounting for the differential in yields between these forms of cultivation, two cautionary notes must be factored into the equation.

First, the Bolivian results are based on only three cycles of agricultural production (one cycle reported here in Tables 1–3 plus two additional cycles that have not yet been completely analyzed but which demonstrate similar yield results). Although the Peruvian results are based on additional production cycles, much longer periods of production comparison will be required to statistically confirm a sustained, superior performance of raised fields against traditional forms of agriculture.

Second, the experimental raised fields are constructed on land that has not been in intensive cultivation for over 800 years, and we might anticipate higher than average production in this exceptionally long-fallowed area. Moreover, land in this area of the altiplano has been given over to pasturage for sheep and cattle during the past century, resulting in increased nutrient inputs.

Even with these two caveats, the differences in yield are so dramatic that a significant, although unquantified, proportion of the yield differential between raised fields and traditional forms of agriculture must be attributed to the superior frost-mitigation attributes of the raised fields. If the heat- and nutrient-conservation effects in raised fields described here are further verified, then our perception of the subsistence base of Tiwanaku civilization will be radically altered. If these assumptions and empirical observations are correct and replicable, we must consider the possibility that the physical and thermal properties of Tiwanaku raised-field agriculture in the circum-Titicaca Basin permitted a regime of double cropping of potato, *ulluco*, *cañiwa*, quinoa, and other indigenous staples of the altiplano.

During the 1988–1989 and 1989–1990 agricultural seasons, two crops of potato (as well as a potato–barley) rotation were successfully achieved in the rehabilitated fields of Lakaya (Pampa Koani) and Achuta Grande in the Tiwanaku Valley. The average potato yield for each harvest in the Lakaya raised fields was approximately 20 t/ha. Knapp and Ryder (1983:211) argue for a similar double-cropping regime on Prehispanic raised fields in the altiplano (2,855 m asl) around Quito, Ecuador. They conclude that the frost-control properties of raised-field canals made "potato double-cropping or potato–maize double-cropping" feasible in the Quito altiplano (Knapp and Ryder 1983: 215). Other double-cropping regimes in the context of the Andean highlands are known ethnographically (Mitchell [1977:46–47], for instance, describes such an agricultural regime for an area between 2,859 and 3,400 m asl around Quinua, in the Department of Ayacucho, Peru, that was dependent upon irrigation water to extract a dry-season crop), but these are generally restricted in area and constrained severely by frost hazard. The experimental results from Lakaya constitute prima facie evidence for the feasibility of double cropping in the Pampa Koani region using raised-field technology. However, the key issue of the sustainability of continuous double cropping in this area remains unresolved. Additional experimental production cycles, perhaps extending over two or more decades, will be required before this issue can be settled with a reasonable degree of confidence. Moreover, these results do not, in themselves, demonstrate that Tiwanaku farmers actually did double crop (like many propositions in archaeology, this is currently not directly demonstrable). But the preliminary results from Lakaya demonstrate that a double crop can be achieved using raised-field technology, and that the success of a double-cropping regime in this area is directly dependent upon a consistent, adequate water supply to the raised-field canals.

Continuous cultivation on fixed, permanent fields, short or no fallow periods, and two episodes of sowing and harvesting within the same agricultural year are inconceivable in the contemporary agrarian landscape of the high plateau. Yet these may have been standard features of Tiwanaku agricultural practice. If the farmers of Tiwanaku engaged in double cropping, the estimates of production on raised fields described here may be too conservative and may themselves require substantial upward revision for greater accuracy. The experimental and empirical evidence as it currently stands suggests that such a regime of agricultural intensification was a principal strategy of Tiwanaku agricultural production. This conclusion, in turn, brings us inevitably to a reconsideration of the possibilities and limits of surplus production in the heartland of the Tiwanaku state. Reconstructing these limits offers critical insights into the questions of demographic potential and the structure of local food supply in Tiwanaku's immediate hinterland.

Carrying Capacity, Population, and Food Supply

Perhaps the most perilous enterprise undertaken by archaeologists is that of estimating the population size of prehistoric cities and states and the functionally related concept of regional carrying capacity. By carrying capacity I mean the number and density of people that can be supported at a minimal subsistence level by the resources contained within a given area and with a given production technology. Even under the best of circumstances, population projections and calculations of prehistoric carrying capacity are fraught with uncertainty. Carrying capacity, in particular, is a slippery, highly context-specific concept, bound as much to the social world of cultural beliefs, values, and practice as to the physical world of natural resources. An accurate determination of carrying capacity would require detailed knowledge of what a given culture accepts as an exploitable natural resource, or as a desirable foodstuff. Few human societies were ever completely isolated in a cultural sense, or encapsulated within rigid physical boundaries, and so determining carrying capacity in its fullest sense also entails mapping out the net flow of goods and services into and out of the region of interest.

Given the elasticity and uncertainty of the concept, the estimates of carrying capacity generated here are intended solely as a projection of boundary conditions for population size. In other words, they are not realistic estimates of precise carrying capacity or population size for Tiwanaku and its near hinterland. However, the experiments in raised-field production provide us with an empirical tool for calculating the range of demographic possibilities in the Tiwanaku sustaining area.

The three central valleys that were the setting for Tiwanaku's heartland of cities contain approximately 190 km^2 of fossil raised fields, or some 19,000 ha (Figure 1: Pampa Koani [Catari subbasin] 7,000 ha, Tiwanaku 6,000 ha, Machaca [Desagüadero] 6,000 ha).[1] This estimate of raised-field distribution in the sustaining hinterland of Tiwanaku reflects those fields that have been identified from aerial photographs, surface investigation, and an unsystematic coring program undertaken in the Pampa Koani region between 1979 and 1981. In these three valleys, huge areas of wetlands intricately crisscrossed by small streams fed by perennial springs and rivers show no evidence of raised fields on the surface. Yet geological coring in such wetlands in the Pampa Koani revealed rich organic sediments that may represent agricultural soils deposited under clay, gravel, and sand up to 2 m thick. The active river systems of these wetlands carry enormous quantities of sediments eroded from surrounding uplands. During the intense altiplano rainy season, these rivers often breach the natural levees that contain them, redepositing their sediment loads across the adjacent flood plain. As a result of this inexorable geological process, many raised fields lay undetected, buried deeply beneath the modern surface of the pampa. Other fields have been effaced through erosion, triggered by wind and rain and by rivers that meander across the flood plain, cutting and reshaping the unconsolidated sediments of alluvium. Cultural processes have also contributed to the physical disappearance of ancient field systems. Centuries of cattle herding across the broad plains that once were the setting for intensive cultivation and the introduction of metal plows and mechanized farming have obliterated the traces of abandoned raised fields. Despite the evident loss of some ancient raised fields, the 19,000 ha that are documented in the Tiwanaku sustaining area most likely represent a substantial proportion of the fields that existed in Tiwanaku times, and we can use this figure as a baseline for projections of demographic potential.

Approximations of carrying capacity and demographic potential of the Tiwanaku hinterland based on its agricultural productivity are dependent on certain simplifying assumptions concerning crop type, minimal daily caloric intake per capita, and percent of fields planted:

1. All of the following calculations are based on a single index crop—potato. Clearly a wide variety of high-altitude-adapted plants were grown on Tiwanaku raised fields, but the tubers, particularly numerous varieties of small, frost-resistant "bitter" potatoes, were probably the principal food crop for the people of Tiwanaku. Because all other cultivated and wild food resources are excluded from consideration, the calculations should reflect a measure of conservatism with respect to total potential caloric yield of the region under consideration.

2. For the purpose of comparability, Denevan's (1982) empirically determined figures of 1,460 for minimal daily caloric intake per person, and an average energy yield of 1,000 calories per

Table 5. Carrying-Capacity Estimates for Tiwanaku Sustaining Area Assuming 100 Percent Utilization of Raised Fields.

Maximum Potential Population Under Assumptions Stated in Text		
Region: Raised Fields in Hectares	20 Persons/ ha/Annum (Peruvian Group Estimate)	39 Persons/ ha/Annum (Bolivian Group Estimate)
Single Crop Estimate		
Tiwanaku Valley: 6,000 ha	120,000	234,000
Pampa Koani: 7,000 ha	140,000	273,000
Machaca/Desagüadero: 6,000 ha	120,000	234,000
Total Population	380,000	741,000
Double Crop Estimate		
Tiwanaku Valley: 6,000 ha	240,000	468,000
Pampa Koani: 7,000 ha	280,000	546,000
Machaca/Desagüadero: 6,000 ha	240,000	468,000
Total Population	760,000	1,482,000

kilogram of potato developed for previous carrying-capacity estimates in the ecological context of the Andean highlands will be used. In accordance with these figures, a person on the high plateau requires a yearly minimum intake of approximately 533,000 calories, which can be extracted from 533 kg of potato.

3. Finally, since the objective is to establish boundary conditions, or general parameters of production and population in the Tiwanaku sustaining area, I make an initial assumption of successful utilization of 100 percent of the raised fields in the area to generate population-density estimates. Given potential effects of annual localized crop loss from hail, frost, pests, and spoilage, lake-level fluctuations that would have inundated and taken out of production local areas of raised fields, temporal variability in the use of fields under raised-field cultivation during the several hundred years of Tiwanaku occupation, and other such variables, this expectation is not entirely realistic. The variables that reduced gross production are not easily quantified. Therefore, to account for crop attrition, I will arbitrarily adjust for the cumulative effect of these loss variables by recalculating the population-density estimates a second time, assuming 75 percent utilization of the fields.

Given this set of assumptions, what sort of carrying capacity and population densities can be generated for the Tiwanaku region using the two experimentally determined raised-field production figures of 10.65 t/ha (the Peruvian group) and 21 t/ha (the Bolivian group)? If the average annual yield of potato per hectare is divided by the annual requirement of 533 kg of potato per capita, then 1 ha of raised fields planted in potato will support approximately 20 persons for one year according to the Peruvian experiment, and 39 persons per year according to the Bolivian experiment. Applying these figures to the 19,000 ha of preserved raised fields in the Tiwanaku sustaining area, the carrying capacity for the region ranges between 380,000 and 741,000, assuming a single annual crop and 100 percent utilization of the fields. If a regime of double cropping and 100 percent utilization is assumed, the population figures range between 760,000 and 1,482,000 (Table 5). Recalculating these population figures by changing the assumed field utilization to 75 percent, population ranges of 285,000–555,750 result for a single annual crop, and 570,000–1,111,500 for a double crop (Table 6).

The two most probable ranges from these four sets of maximum supportable population are the options that assume 75 percent utilization of the fields. The rationale for choosing these ranges is straightforward. The farmers of Tiwanaku never simultaneously utilized or achieved productive harvests from 100 percent of the 19,000 ha of preserved raised fields, therefore some level of attrition

Table 6. Carrying-Capacity Estimates for Tiwanaku Sustaining Area Assuming 75 Percent Utilization of Raised Fields.

Maximum Potential Population Under Assumptions Stated in Text		
Region: Raised Fields in Hectares	20 Persons/ ha/Annum (Peruvian Group Estimate)	39 Persons/ ha/Annum (Bolivian Group Estimate)
Single Crop Estimate		
Tiwanaku Valley: 6,000 ha	90,000	175,500
Pampa Koani: 7,000 ha	105,000	204,750
Machaca/Desagüadero: 6,000 ha	90,000	175,500
Total Population	285,000	555,750
Double Crop Estimate		
Tiwanaku Valley: 6,000 ha	180,000	351,000
Pampa Koani: 7,000 ha	210,000	409,500
Machaca/Desagüadero: 6,000 ha	180,000	351,000
Total Population	570,000	1,111,500

must be factored into these calculations. The 25 percent attrition value, although arbitrary, is a historically plausible cumulative estimate of crop loss from frost, spoilage, fields left in fallow, and the like. On the other hand, the experimental work in the Pampa Koani and that of Knapp and Ryder (1983) in the Quito altiplano suggest that double cropping in the high plateau was feasible with raised-field technology. Whenever possible Tiwanaku farmers would have exploited the opportunity to produce substantial surpluses through double cropping. Almost universally, small farmers choose planting strategies that reduce risk over those that hold out the possibility of high return but with a substantially increased chance of total loss. Small farmers, like most small investors in the stock market, are risk adverse (Garnsey 1988:47–49). Successful double cropping represents the rare and attractive case in which the potential for high return is matched by a property of substantial risk reduction. If farmers experience total loss from frost or hail in one planting cycle, they can still recoup losses by planting and harvesting in the second cycle. If both cycles of planting yield bumper crops, the farmer, of course, can expect substantial, storable agricultural surplus. In other words, there was a powerful incentive for Tiwanaku farmers to employ a regime of double cropping. Moreover, as argued below, the Tiwanaku state itself was engaged in organizing substantial estates of agricultural production, particularly in the Pampa Koani district. In order to finance public projects, the elite interest groups that constituted the command hierarchy of Tiwanaku urban society also would have had an interest in extracting maximum, sustainable yields from their agricultural estates through double cropping. Given these considerations, the most likely maximum range of supportable population for the Tiwanaku hinterland is the double-cropping option of 570,000–1,111,500.

The indigenous technology of raised-field agriculture clearly had the capacity to support large and concentrated human populations. The figures in Table 6 indicate that in Tiwanaku times the Pampa Koani region alone had the potential of supporting from 210,000 to 410,000 people on a sustained basis (again assuming the benchmark of double cropping and 75 percent field utilization). Even if we calculate carrying capacity using a single annual crop, the range of supportable population remains impressive: 105,000–205,000. Today, in the absence of raised-field technology, the carrying capacity of the Pampa Koani is enormously reduced, and the entire region supports only about 7,000 people at a level slightly beyond bare subsistence. Similar radical differences between past and present carrying capacity and absolute population levels can be demonstrated for the Tiwanaku Valley and the Machaca/Desagüadero area as well.

Comparing the high population potentials generated by these calculations with actual population estimates for the Tiwanaku sustaining area during Tiwanaku IV and V times (ca. A.D. 400-1000), what conclusions may be drawn with respect to carrying capacity and the structure of food supply to urbanized populations? First, it is clear that, based on the component of agricultural production alone, the carrying capacity of the Tiwanaku metropolitan zone exceeded peak estimated population throughout the period from A.D. 400 to 1000. That is, Tiwanaku core populations never approached an absolute level that was sufficient to put stress on the agricultural capacity to absorb and sustain demographic growth. Elsewhere, I have estimated overall peak population for the immediate Tiwanaku core area (the three-valley system of Pampa Koani–Tiwanaku–Machaca) during this period as approximately 365,000, distributed into a concentrated, urbanized component of some 115,000 and a dispersed rural component approaching 250,000 (Kolata 1989). Taking into account other sources of food supply available to these populations, such as the enormous quantities of high-quality meat stored on the hoof in llama herds or the rich aquatic resources of the lake-edge environment, it is even more apparent that Tiwanaku population levels never approached the calculated ceiling of population potential. Any plausible estimate of the carrying capacity in the three-valley system comes to the same conclusion. In Tiwanaku times, there was always a substantial margin of productivity that was never extracted from Tiwanaku's sustaining hinterland. In short, stress brought on by absolute population pressure against a fixed resource base never played a significant role in precipitating social change among the people of Tiwanaku.

THE SOCIAL ORGANIZATION OF AGRICULTURAL PRODUCTION

We may conclude, then, with reasonable certainty that raised-field technology in combination with extensive herding and fishing activities formed the pivot of Tiwanaku's endogenous economy (Browman 1978, 1981; Lynch 1983; Núñez and Dillehay 1979). This powerful troika of productive systems ensured the autonomy and self-sufficiency of food supply in the Tiwanaku core area and provided the touchstones for supporting sustained demographic and economic growth. But several important issues remain: How was the system of raised-field agriculture organized and managed? What was the unit of agricultural production in the Tiwanaku hinterland, and did this fundamental unit of production change over time and space? What were the economic and social relationships between the rural inhabitants of Tiwanaku's hinterland and those residing in urban centers?, and, To what extent was an elite bureaucracy of the Tiwanaku state actively engaged in managing and intensifying these systems of production?

First, we must recognize that these issues have an implied structure of space/time variability. Simply put, it is unlikely that a single configuration describes and explains the social organization of agricultural production as this was worked out once and for all by the people of Tiwanaku. The ways that arable land, labor, agricultural produce, and people were interrelated at the local level, and how these, in turn, formed a nexus with physically and socially distant political authorities constitute a series of shifting and evanescent patterns. We cannot expect or falsely create uniformity. There never was a once and for all. Rather we can conjecture with some confidence that there existed multiple structures of local organization revolving around the social, economic, and ritual acts of farming that were formed and reformed in the variegated textures of local history. By their nature as products of the interaction of people now long disappeared, the precise character and meaning of these organizational forms are forever lost to us. Yet, we know that certain social institutions, such as the *minka* and the *mit'a* forms of labor exchange, were constituent elements of the cultural systems conjoining land (both state and local), work, and agricultural production that have demonstrable antiquity and centrality in the autochthonous Andean world (Erickson 1988; Hastings and Moseley 1975; Moseley 1975). It is from these perduring social principles that we begin reconstructing the basic contours of the organization of agricultural production at various periods in the long history of the people of Tiwanaku.

The Ayllu*/Local-Level Organization Hypothesis*

After a decade of intensive archaeological research on raised fields in the Lake Titicaca Basin, we now know that these specialized agricultural systems have considerable time depth. The earliest documented raised fields were uncovered in excavations on the northern, Peruvian side of Lake Titicaca in the district of Huatta (Erickson 1987, 1988). Here, raised fields associated with small Formative-period habitation sites have been dated between 850 and 600 B. C., principally through thermoluminescent dating of ceramics incorporated in field-construction fill (Erickson 1987). Erickson (1988:438) speculates that this marshy, wetlands environment may have been colonized and exploited by farmers as early as 3000 B.C. This inference, although entirely plausible, has yet to be confirmed archaeologically. Excavations in raised fields on the Bolivian side of the lake in various sites throughout the Pampa Koani and other areas in the Tiwanaku hinterland have recovered Chiripa ceramics associated with the period from 800 to 200 B.C. (Graffam 1990; Kolata 1986). However, these ceramics were not recovered in direct associations with the raised fields themselves, and therefore cannot be used definitively to date the agricultural works. Nevertheless, given the pattern of early reclamation of land for agricultural purposes on the northern side of the lake, it is reasonable to assume that the lacustrine-oriented Chiripa and pre-Chiripa peoples of the southern side were engaged in similar efforts to enhance their productive base through intensive raised-field agriculture. How did these pioneering agriculturists of the high plateau organize the process of constructing and maintaining raised-field agriculture?

We can conjecture that the initial experimentation with raised-field agriculture involved relatively small groups of related families who developed and elaborated this technology of cultivation along the marshy shores of Lake Titicaca. The maximal unit of social organization of these early farmers was probably the *ayllu*, based territorially in small villages and hamlets (in the range of approximately 10 to a few hundred people). The effective unit of production within these *ayllus* was the individual household, minimally a married couple and dependent children, as it remains today in the rural reaches of the high plateau. In other words, the agriculturists who pioneered the raised-field system in the Titicaca Basin during the first millennium B.C. organized themselves as small, kin-based corporate groups. The clusters of related families were not differentiated sociologically beyond the level of the structural hierarchies embedded within the *ayllu* itself. These were quintessential prestate social formations that functioned by community consensus without political positions defined by ascribed statuses or the intervention of civil bureaucracies. The social landscape of these groups did not incorporate distinctions drawn across class lines, nor was there a complex structure of political command. However, this is not to say that the cultural universe of these kin-based corporate groups was primitive or parochial. Judging from contemporary ethnographic accounts from the altiplano, such rural *ayllus* enjoyed substantial communication and social exchange over considerable distance, and conceived of their interaction in terms of elaborate, cyclically expressed ritual actions grounded in a shared ideology (Abercrombie 1986; Bastien 1978).

Erickson (1988) has argued that such small corporate groups, organized along the lines of traditional Andean principles of kinship, were capable of constructing the immense configuration of raised fields in the Titicaca Basin. In essence, he speculates that this agricultural system was originated by, and remained the province of, a wetlands-adapted cluster of ethnic groups that he associates with the ethnohistorically documented Uru- and Pukina-speaking peoples. Erickson (1988:348) concludes that Andean raised-field agriculture was *never* under the direct control of centralized state governments: "[I]n the Lake Titicaca Basin, the raised fields were associated with relatively small cooperative groups, while the dominant political organization in the basin was at the level of a state. It is unlikely that this highly productive system which functioned efficiently under local management would have been tampered with by the state."

If we pose the question whether the enormous raised-field systems of the Titicaca Basin could have been constructed by relatively small corporate groups in a piecemeal fashion over long periods of time, the clear answer, drawn from the broadest cross-cultural perspective on analogous systems of hydraulic agriculture, is yes. The massive irrigated terrace systems of Sri Lanka described by Leach (1959) are a classic ethnographic example of this kind of gradual physical accretion of hydraulic works organized and constructed according to decentralized principles of local decision making. Similarly, Lansing (1987) provides a fascinating description of the organization of irrigation on rice terraces in Bali through a system of "water temples." In this system, a complex hierarchy of temples controls the schedule of water distribution by managing the performance of rituals perceived to be essential to the growth cycle of the rice plant. The temple hierarchy itself begins (or perhaps more aptly from the perspective of the productive cycle, ends) with small family shrines erected by each farmer at the distal points of the irrigation canals where water first flows into individual plots. Farther upstream, collectivities representing clusters of families organized into small irrigation communities (*subaks*) establish communal temples at the heads of field systems. Continuing up the hierarchy, *Ulun Swi* regional temples shared by a cluster of *subaks* were erected to manage water distribution and maintenance of the hydraulic system at the heads of terraces. Virtually every water source had a corresponding temple, and all temples were subordinated to and overseen by a supreme water temple. Temple priests were responsible for performing three tasks fundamental to successful operation of any regional irrigation system (Coward 1979): managing the allocation of water, organizing the physical maintenance of canals and terraces, and resolving conflicts among competing farmers. The priests of the water temple also were charged with authorizing new additions to the interlinked canal and terrace network.

The striking features of the Balinese water-temple system are its hierarchical design and its virtually complete disengagement from a strictly political form of organization. Each farmer is responsible for the maintenance of his portion of the irrigation canals up to his family's shrine. The *subak* is responsible for the maintenance of communal irrigation lines up to the *Ulun Swi* regional temple, and so on upstream in increasingly more inclusive social units to the supreme water temple. In this sense, there is no tightly centralized authority charged with construction and maintenance of this system. The inevitable conflicts over water rights were frequently resolved at lower levels of the temple hierarchy than at the symbolic apex represented by the supreme water temple and its coterie of priests. Furthermore, the procedure for allocating irrigation water among the *subaks* is the end product of intensely conservative, traditional decisions made locally. Accordingly, there is rarely any need to consult the temples for guidance because most aspects of water scheduling and sharing are routinized and anticipated as predictable events in the agricultural cycle. In short, the Balinese water-temple system represents one instance in which relatively complex networks of hydraulic structures were constructed and maintained by locally autonomous social groups that reinforced community cooperation through the working out of shared beliefs expressed publicly in the repetitive performance of agricultural rituals. In the Balinese case, religious ideology performs considerable social work, obviating the need for centralized or formal political forms of organization.

The dialectical interplay of local autonomy and central authority in the management of complex irrigation systems recurs in a particularly trenchant ethnohistorical example from the Chicama Valley of Peru during the sixteenth century. According to Netherly's (1977, 1984) reconstruction of social structure in Prehispanic societies on the north coast of Peru, all complex polities there

> were characterized by what may be called a dual corporate organization in which bounded, named, social groups at lower levels of organization were integrated into higher levels by means of a series of ranked moieties, headed by personages we may term headmen, lords, or paramount lords according to their hierarchical position. . . . At every level in this organizational structure, each unit can ideally be subdivided into two unequal, subordinate groups [Netherly 1984:230].

Each layer in this social system, characterized by principles of duality and hierarchy, was governed not by a single soverign but by two political rulers, one of whom maintained a higher status than the other. This status distinction is reflected in the Spanish terms for these two kinds of local, indigenous lords: *cacique* or *kuraka principal* (paramount ruler) and *segunda persona* (lieutenant). Each of these pairs of local lords could call upon the subjects of their own group to perform labor related to agricultural production, such as canal construction and periodic cleaning. Moreover, each of these lords could also mobilize labor for tribute payments to paramount rulers of higher status in this nested hierarchy. Netherly (1984:233) concludes that this organizational structure was "infinitely subdivisible and could accomodate an extremely large population without reorganization," accordingly, "[T]here was no need for a large body of supervising bureaucrats to manage such labor."

As in the case of the Balinese water temples, this system maintained local autonomy and partitioned responsibility for labor among its constituent groups. Each cluster of farmers maintained the irrigation canals that fed their own land holdings. They also contributed labor for the upkeep of essential common elements of the system, such as principal water intakes and the maximum elevation canals that provided water to the network of smaller feeder lines radiating out among the agricultural fields. Conflicts over labor obligations and water rights were resolved by the *kurakas* at the next highest political level in the hierarchy of governance. In Netherly's view, the only managerial role assumed by central state authorities was in responding to catastrophes (such as periodic torrential rainfall generated by El Niño events) that threatened to destroy the irrigation system as a whole.

It is abundantly clear, then, that relatively small, autonomous social groups are capable of managing sophisticated systems of hydraulic agriculture without the intervention of state authority. We can conclude that local control of agricultural production embedded in an organizational structure similar (if perhaps somewhat simpler) to that proposed by Netherly for north-coastal Peru represents the most plausible scenario for the context of the pioneering raised-field agriculturists of the Titicaca Basin during the period from about 800 B.C. to A.D. 300. However, in the period after A.D. 300, when the mature Tiwanaku state had coalesced and begun a strategy of territorial expansion (Kolata 1983; Ponce Sangines 1972, 1980), our research in the Tiwanaku Valley and its adjoining areas indicates that, in at least some sustaining zones, the paramount lords of the state promoted different and more centralized principles of organizing agricultural production than those portrayed by Netherly.

Regional Hydraulics and Settlement Patterns: Implications for the Organization of Tiwanaku Intensive Agriculture

I have argued elsewhere (Kolata 1986) that settlement patterns in the Pampa Koani indicate that agricultural production in the period from ca. A.D. 400 to 1000 (Tiwanaku IV and V) in this region was directed explicitly toward the generation of crop surpluses, and not with an eye toward local consumption. The patterns that emerge from the distinctive nature, distribution, and elaboration of sites and their associated material culture suggest the following general interpretation of settlement function and hierarchy on the Pampa Koani. Small house mounds physically associated or structurally merged with raised-field segments were the residences of rural families engaged in primary agricultural production. A more ephemeral or rather seasonal function for many of the smaller house mounds, such as the base of the huts used by *kamani* (an Aymara term for youths who guard growing crops) is probable. The larger platform mounds, on the other hand, housed a corps of administrators and their household retainers charged with organizing the seasonal cycle of agricultural activities and accounting for the produce that flowed from the state fields of Pampa Koani during harvest time (Kolata 1986:754–756). A monumental dual platform-mound complex represented the ritual and administrative apex of settlement hierarchy on the Pampa Koani, distinguished in status from both the small habitation mounds and the other, less architecturally elaborated platform mounds. In demographic terms, there are simply insufficient numbers of human settlements on the Pampa Koani proper to account for the virtually continuous expanse of raised fields and associated hydraulic structures in the region.

The distribution and function of these settlements on the Pampa Koani implies that the labor to construct and maintain the extensive field systems must have been drawn from a wider, nonlocal region in a pattern attuned to the agricultural cycle of the seasons. This labor was most likely extracted by the centralized authorities of the Tiwanaku state in the form of corveé through a mechanism similar to the Inca *mit'a* labor-tax system. New evidence concerning the nature and regional function of massive public construction projects that were designed to promote large-scale reclamation and productivity of arable land on the Koani plain and in the valley of Tiwanaku reinforces these conclusions and points to a managerial hand beyond that of locally autonomous village or *ayllu* groupings.

For instance, Figure 4 illustrates two kinds of public construction projects on the Koani plain that served functions related to the operation of raised fields, not as bounded, independent bundles of field plots, but as interdependent *regional* system of production. The first of these public constructions is a network of elevated causeways and dikes. The principal route of the largest elevated roadbed, the trans-pampa causeway, together with its major branch connected the marshy, low-lying zone of raised fields in the western end of the Pampa Koani with roads running along mountain terraces forming the northern and southern boundaries of the pampa, respectively. These contour roads running along the base of the mountain slopes lead directly to the important regional Tiwanaku urban settlements of Lukurmata and Pajchiri, as well as to the smaller towns of Yayes and Lakaya (Figures 1 and 4). The trans-pampa causeway itself was possibly paved with cut stone in its southern extremity as it approached Lakaya. Several smaller elevated roadbeds radiate out laterally from the trans-pampa causeway to articulate field segments with the larger platform mounds in the central ritual and administrative settlement cluster. The formal causeways on the Pampa Koani were designed to facilitate travel and presumably the transport of agricultural goods from the production zone to consuming and processing centers of population. Transport of bulk produce along the causeway and road network was most likely facilitated by organized packtrains of llamas.

The north–south-trending trans-pampa causeway may have served another function besides that of transport. The elevated bed of this causeway runs astride the maximum-elevation contour in the western end of the Pampa Koani. To the west of the causeway, the land slopes upward gradually from the shores of Lake Titicaca to this maximum elevation (3,824 m asl); east of the causeway, the land slopes gently downward such that 11 km inland from the shore absolute elevation is only 3,820 m asl. During the catastrophic flood that affected the Andean altiplano between September 1985 and April 1986, this ancient causeway acted as an effective dike, impounding the rising waters of Lake Titicaca for a time. However, once the lake had risen over 2.75 m, the entire stretch of the pampa to the east of the causeway was rapidly inundated with brackish waters to a depth of nearly 1 m, destroying houses, pastures, and potato fields. When the flood waters finally receded by late 1988, salt deposits that still depress local crop yields were left behind in thick, patchy crusts. Tiwanaku engineers may well have been aware of this natural elevation feature and sited the trans-pampa causeway along it to enhance the capacity of this linear feature to impound water. The causeway/dike, in short, may have been a disaster-control device that prevented destruction of the raised fields in the eastern reaches of the Koani plain during years when rainfall did not reach the catastrophic proportions of the unusual 1985–1986 event.

The second Tiwanaku construction project on the Koani plain illustrated in Figure 4 represents a definite regional hydraulic-control device. At some point in the history of land reclamation on the Pampa Koani, a long segment of the Río Catari, the principal river bisecting the pampa, was artificially canalized. The canalization of the river was achieved by diverting the natural course of the flow at a point approximately 12 km inland from the lake shore (Figure 5, note meander scar of the ancient river bed) into a new bed furnished with massive earthen levees. This diversion and canalization of the natural river achieved two important goals for the efficient operation of a regional agricultural system: (1) It opened up huge stretches of land to raised-field reclamation in the southern portions of Pampa Koani, and (2) it permitted some measure of human control over potentially disastrous fluvial inundations of the reclaimed landscape.

A previously unrecognized facet of the Río Catari canalization was discovered during the 1990 field season. The hydraulic engineers of Tiwanaku were apparently unsatisfied with a simple diversion and canalization of the Río Catari. Excessive rainy-season flow can result rapidly in bed erosion, river excursions, and potentially disastrous inundation of adjacent land. In order to augment its capacity to handle periodic flooding, Tiwanaku hydraulic engineers constructed a canal by-pass system paralleling the banks of the canalized sections of the Río Catari to shunt excess flow away from critical reclaimed lands toward Lake Titicaca. The southern bank of the canal by-pass (the side facing the bulk of the raised fields in the Pampa Koani region) was reinforced by a levee, averaging ca. 3 m high and 5 m wide (Figure 5). This river shunt effectively extracted substantial quantities of seasonal flow and redirected that flow away from areas critical to agriculture.

The artificial canalization of the Río Catari and subsequent construction of a river-shunt system is not unique in the annals of Tiwanaku hydraulic engineering. In fact, river and stream canalization is a distinct and rather audacious strategy of water control common to the rural and urban landscapes of Tiwanaku society. A virtually identical shunt system was identified as a crucial feature of the recently recognized canal that bisects the middle and lower Tiwanaku Valley (Figure 6). In this case, the artificial canal serves as a shunt for excess flow in the Río Tiwanaku in addition to irrigating downstream raised-field complexes (Figure 7). As in the Río Catari system, this canal has substantial, reinforced earthen levees to stabilize extracted river flow.

Figure 5. Artificial earthen levees designed to stabilize extracted river flow on the Río Catari canal by-pass (see Figure 4, Feature 2). These reinforced earthen banks are also characteristic of the Waña Jawira River shunt in the valley of Tiwanaku.

The Tiwanaku Valley canal (which we have designated by the local Aymara term *Waña Jawira*) illustrates a sophisticated principle of Tiwanaku regional hydraulic engineering: designed multifunctionality. The canal, together with its shunt system, was capable of implementing either a water-distribution or a water-extraction strategy. That is, in the dry season, or in times of drought, the canal was capable of carrying river water from its intake on the Río Tiwanaku to secondary canals downstream, for distribution to adjacent raised-field complexes (Figures 6 and 7). During the rainy season, or in an inundation event, the intakes of the secondary distribution canals could have been blocked with some form of formal or informal sluice gates and excess river flow extracted and redirected away from the downstream agricultural landscape. In the case of the Waña Jawira, the principal canal rejoins the Río Tiwanaku at a point some 4 km downstream from its intake. Interestingly, there appears to be evidence from aerial photographs of a "second loop" to the Waña Jawira system that takes off from the Río Tiwanaku immediately west of the point at which the first section of the canal rejoins the river; this segment of the canal eventually terminates at the shoreline of Lake Titicaca. However, this presumed second loop is inadequately investigated, and we cannot yet confirm that it is an artificial feature, rather than, for instance, an ancient river meander.

Designed multifunctionality of hydraulic structures integrated into a regional regime of water control was clearly a key empirical principle in the organization of Tiwanaku agricultural production and not an aberrant or unique occurrence. If the latter were the case, one could argue, as Netherly (1984) does for the Chimu Moche–Chicama intervalley canal, that the state only rarely invested in capital- and labor-intensive projects to enhance agricultural production, preferring a laissez-faire approach to managing its agrarian affairs. However, repeated and consistent occurrence of major Tiwanaku hydraulic structures in both rural and urban zones vitiates application of the laissez-faire hypothesis to the Tiwanaku system.

Recent investigations at Lukurmata and Pajchiri resulted in discovery and detailed analysis of aqueducts: the first open-channel, surface-water transport structures to be definitively associated

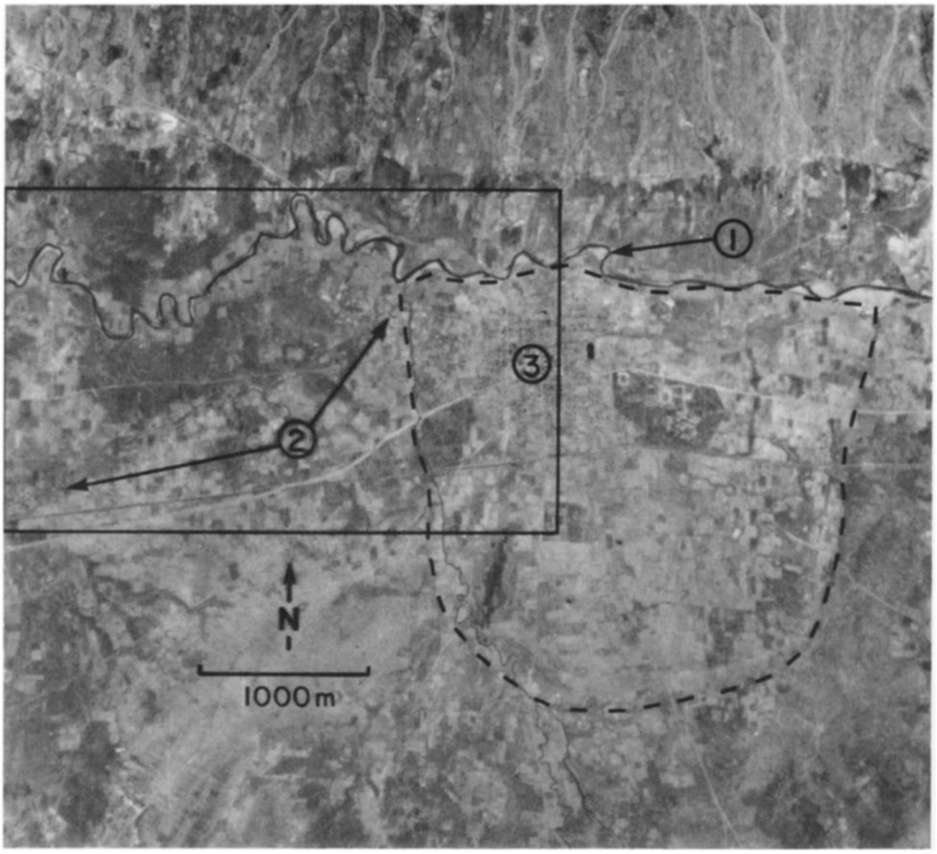

Figure 6. Aerial photograph of the site of Tiwanaku and the adjacent Waña Jawira canal system immediately to the west. Dashed lines denote the boundaries of the archaeological site: (1) Río Tiwanaku; (2) segment of the Waña Jawira canal system. The intake of the Waña Jawira canal, destroyed by river incision and migration, was originally on the Río Tiwanaku. The Waña Jawira canal rejoins the Río Tiwanaku approximately 4 km downstream (west). As indicated in Figure 7, this canal functioned as a water-delivery network to raised agricultural fields and as a river by-pass, or shunt. Box illustrates area mapped in figure 7; (3) modern village of Tiwanaku.

with Tiwanaku urban sites (Ortloff and Kolata 1989). Six aqueducts were documented for these two sites, and at Lukurmata one of these was radiocarbon dated to 1085 ± 90 B.P. (corrected), A.D. 950 ± 100 (calibrated) (ETH-3178), or the Tiwanaku V phase (Ortloff and Kolata 1989).

There are several more uninvestigated aqueducts channeling water into and away from raised-field systems dated to the Tiwanaku IV and V phases throughout the Pampa Koani zone. The Lukurmata and Pajchiri aqueducts share certain structural features of great interest. The entire drainage systems of which these aqueducts were key components entailed construction or modification of two components: (1) an upper channel that was formed by an artificially modified, natural *quebrada*, or dry stream bed, and (2) a lower channel that consists of a constructed, elevated aqueduct that provides passage for water over an open field for eventual discharge into Lake Titicaca. The external retaining walls of the aqueducts are cobble lined throughout their entire length, providing an outermost stable skin infilled with earth, gravel, and stone (see Ortloff and Kolata 1989:Figures 4–8). The uppermost modified *quebrada* channels of these aqueducts reach into high montane catchment basins where they were charged by precipitation runoff and by permanent springs and subterranean seeps. One of the aqueducts at Pajchiri, which crosses a sector of raised fields constructed on a series of massive terraces dropping down to a bay in Lake Titicaca, was furnished with cut-stone drop structures and secondary feeder canals. Such drop structures (consisting of small

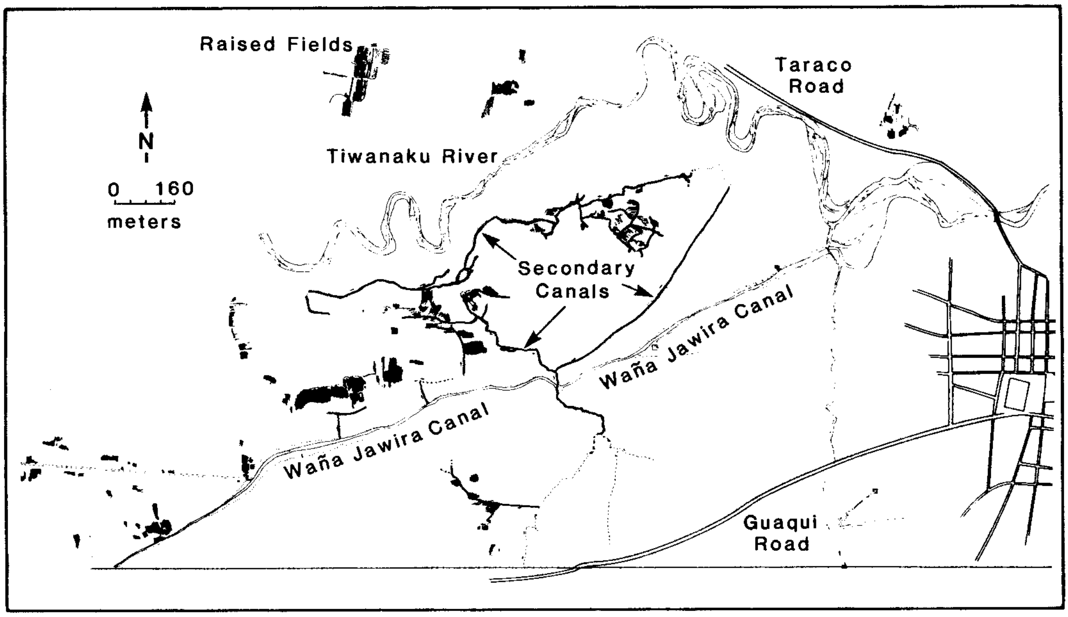

Figure 7. Map of the investigated portions of the Tiwanaku Valley canal (Waña Jawira system) illustrating intake near the current bed of the Rio Tiwanaku and articulations with secondary irrigation canals and raised fields. All secondary canals are indicated by solid lines.

lateral canals of cut stone that diverted water from the aqueduct to lower-lying raised fields) may have been incorporated into some aqueducts to mitigate the effects of periodic droughts that afflict the Andean altiplano. Fresh water from the montane basins frequently flows continuously (if at a reduced rate) even during the most pernicious drought, and these precious sources of perennial water were improved by the people of Tiwanaku through elaboration of efficient distribution networks.

In the volatile environment of the Andean high plateau, agricultural disaster lurks in many disguises, and one of these, as potentially catastrophic as drought, is torrential rainfall and inundation (the 1985–1986 event being the most recent instance). Inundation can have an exceptionally long-term impact by generating high groundwater conditions and supersaturation of soils that are potentially deleterious to crop growth. Apparently, most of the investigated aqueducts do not possess drop structures and were not articulated with secondary feeder canals. These hydraulic structures supported continuously functioning drainage canals designed to remove excess water from areas of field reclamation, and thereby reduce the incidence of dangerously high groundwater conditions. By diverting excess water from the raised fields, such structures may have helped stabilize the water table at a point below that of the critical zone of crop root development. In other words, like the Río Catari and Tiwanaku Valley canalization and shunt systems, the aqueducts of Pajchiri and Lukurmata can be interpreted as technologically sophisticated examples of designed multifunctionality responsive to the severe inundation–drought cycles that characterize the altiplano. These river canalizations, *quebrada* modifications, aqueducts, dikes, and causeways functionally integrated the agricultural landscape of the Pampa Koani zone into a regional system of production.

CONCLUSIONS

Agricultural production on the Pampa Koani, to some degree, may have served the needs of local consumption. But the archaeologically evident instances of capital investment in expanding reclamation of potentially arable land and in altering and controlling the hydrological regime of the raised-field systems directly implies the action of a regional political authority. The conjoined data from the spatial and temporal distribution of settlements and field systems, from broad demographic patterns (as these can currently be reconstituted), estimates of labor input and caloric yields, and the technological profile of the interconnected aqueduct–reservoir–canal–causeway–field systems in the northern Tiwanaku sustaining area, implicate some forms of extractive and channelizing functions performed beyond the purview of local community leaders or political elites. Although the initial, pioneering construction of raised-field plots was most likely the product of an autonomous, uncentralized social order, the subsequent reshaping of the Koani plain into a regional system of agricultural production under the hegemony of Tiwanaku elites in the period from ca. A.D. 400 to 1000 entailed the periodic mobilization and coordination of a substantial nonresident labor force. The logistic requirements of repeatedly organizing the deployment of a concentrated, nonlocal labor force demanded a political order with powerful regional authority to alienate land and co-opt labor, and at least a rudimentary bureaucratic system to track the extraction of labor service from subject communities and the subsequent flow of produce from state-operated fields.

This interpretation of the organizational framework of production in the Koani zone implies that Tiwanaku established proprietary agricultural estates in which ownership and usufruct rights were vested directly in state institutions, or perhaps more precisely in the hands of the elite, dominant classes. These corporate estates or production zones were bound directly to the capital of Tiwanaku through a network of secondary and tertiary urban, or urbanized formations with administrative functions. Dispersed, rural hamlets and individual households occur in the Tiwanaku area outside the zone of optimal lacustrine agricultural soils. These settlements were probably engaged in small-scale subsistence dry farming and "tethered" herding of camelids, and undoubtedly, along with the commoner populations of the larger secondary and tertiary centers, provided a substantial proportion of the corvée, or perhaps more properly, *mit'a* labor for the state fields.

The population in this sustaining area was not distributed uniformly or broadly across the landscape. Rather, a pattern of nodal population clustering has been documented in large urban centers such as Lukurmata and Pajchiri, and in intermediate-scale settlements such as Chiripa, Chojasivi, Lakaya, and Yayes, arrayed along the combined geological and human-altered terraces that define the northern and southern borders of the Koani plain (Figure 4). The regionally integrated agricultural field systems in this same zone were constructed and maintained during the Tiwanaku III through Tiwanaku V phases (ca. A.D. 300–1000). During Tiwanaku phases IV and V these field systems achieved their maximum spatial reach. The most technologically advanced manipulation of the reclaimed landscape of raised fields in this area, represented by the construction of interconnected spring, reservoir, and aqueduct water-delivery systems was associated with these same two periods of Tiwanaku internal development (Kolata and Ortloff 1989; Ortloff and Kolata 1989).

If local lords, as political leaders of ranked, hierarchically nested corporate groups, were responsible for creating the agricultural landscape of Tiwanaku's northern sustaining area without the control functions of a centralized state bureaucracy, the settlement pattern of the region would look quite different than it actually does. For instance, we would anticipate that relatively substantial settlements would be established at, or associated with, key "break points" in the delivery system that provided fresh water to the raised-field networks. Such strategic break points would include the intakes of principal canals, the origin points of abundant mountain springs that issue from the surrounding terraces of the Lakaya geological formation, or the geographically dispersed, but agriculturally critical zones of high groundwater characteristic of that formation. In short, the politico-administrative and settlement landscape in the Koani zone would reflect a configuration closer to that hypothesized by Netherly (1984) for the late Prehispanic north coast of Peru, in which autonomous sociopolitical groups (*parcialidades*) were arrayed along lands watered by individual canals, or segments of canals. Given the marked absence of substantial habitation centers with the raised-field–canal–causeway system of the Koani zone, and the complete lack of evidence for local control over, or population clustering in strategic areas of structural articulation within the hydraulic system as a whole, there remains little alternative but to consider the organization of Tiwanaku's northern sustaining area as reflecting state action at a distance.

It is premature at present to extend this analysis to the Tiwanaku Valley and Machaca zones. Ongoing research will eventually determine if a similar pattern of centralized extraction apparent in the Koani zone holds for the central and southern sustaining area of Tiwanaku, or if, in these zones, there was a different system of organizing agricultural production. Nevertheless, initial results from intensive survey in the Tiwanaku Valley suggest that, as in the Koani region, agricultural production in this valley during the Tiwanaku IV–V phases was also organized and managed hierarchically (Albarracín-Jordan 1990; Albarracín-Jordan and Mathews 1990; Mathews 1990).

It may well be that some form of organization similar to the recursive, hierarchically ranked sets of moieties that Netherly (1984:230) envisions as the fundamental armature for the management of large-scale irrigation systems on Peru's north coast played a role in the development of Tiwanaku's agricultural sustaining area. But, the principles governing mobilization and control of human labor must have been rather different from the relative local autonomy at the level of the *parcialidades* implied in Netherly's treatment of the north-coast material. In straightforward terms, the data from the Koani region implicate a pattern of purposive state development of a distinct, integrated, rural agricultural-production zone. The organization of production in this zone was achieved by centralized state action that entailed the presence of strategically located installations not under the control of local corporate groups. In great part, the labor to construct and maintain these installations was similarly nonlocal, mobilized from a region much broader than that encompassed by the field systems themselves. By about A.D. 500 (the Tiwanaku IV phase), the Pampa Koani hinterland can best be understood as a constructed landscape of state production. The labor invested in shaping that landscape may have been drawn from taxation of both local and nonlocal corporate groups headed by ranked political leaders who acted as intermediaries and surrogates for the Tiwanaku political elite. But, given what is known of the settlement distribution in the Koani region, the autonomy of these local *kurakas* must have been constrained by the needs and the prerogatives of the more highly ranked nonlocal elites who resided in the network of urban centers in the greater Tiwanaku sustaining area.

I would argue that the paramount elites of Tiwanaku operated with fluid, context-specific strategies of economic development. On the one hand, the group or perhaps class interests of these elites demanded the creation of strategic, directly controlled production zones that ensured long-term stability in access to surplus crops and commodities. Investment in landscape capital (terrace and irrigation systems, aqueducts, and dikes) that served the purpose of expanding or stabilizing regional agricultural production goes hand in glove with this strategy of direct elite (state) intervention. Economic surplus generated from these intensification projects, of course, was the pediment of their political power. It furnished them with the means to sustain personal and group prestige through dynamic public expressions of generosity and abundance during the cyclical calendar of agricultural festivals and ritual events. The opulent lifestyle permitted to them by this surplus product was a kind of essential social theater that tangibly ratified their personal and positional status within Tiwanaku society.

At the same time that social and ideological necessity demanded that Tiwanaku elites carve out corporate estates to ensure a direct supply of agricultural production, political reality dictated that their relationships with most local communities and ethnic groups under their, at times, uncertain dominion follow the path of least resistance. That is, in most instances coercion of local populations and mass alienation of land and labor was not a viable political option for the Tiwanaku elites. The political and logistical costs entailed in dominating a huge, diverse physical territory were too great to sustain, and local resistance to the complete encroachment of an authoritarian regime was too much of a present threat to the social order to justify a posture of unalloyed hostility. Instead, Tiwanaku elites, much like their Inca counterparts some 700 years later, struck a balance between force and persuasion. They established, quite likely with ruthless efficiency, key proprietary estates of production that assured them of a stable fund of product that could be invested in sustaining the social roles demanded of them. At the same time, outside of these core areas of directly controlled production they moved by indirection and subtle attention to the local political context. In the latter circumstance, tributary relationships between the cosmopolitan elites of Tiwanaku and their distant rural counterparts were most likely framed in terms of patron/client exchanges. Such clientage relationships, in which the state confirmed the traditional authority of local *kurakas* in dealing with their own communities, were strategic elements of Inca statecraft, reflecting the remarkable shrewdness and political pragmatism of native Andean elites.

Acknowledgments. The preliminary results of the research discussed here are based on an ongoing project supported by the National Science Foundation (BNS 86-07541, BNS 88-05490), the National Endowment for the Humanities (RO-21368-86, RO-21806-88), the University of Chicago, Division of Social Sciences, Tesoro Petroleum Corporation, and the Occidental Oil and Gas Corporation. In addition, the experimental raised-field rehabilitation project, some results of which are summarized in this article, is supported by grants from the Inter-American Foundation (BO-252, BO-273, BO-374), USAID-Bolivia small grants program, and the Fondo Social de Emergencia (recently renamed the Fondo de Inversión Social), a Bolivian national governmental agency. In Bolivia, the research is authorized through long-term agreements with the Instituto Nacional de Arqueología (INAR), the Instituto Boliviano de Cultura, and the Ministerio de Educación y Cultura. I am particularly indebted to Oswaldo Rivera Sundt, current director of INAR, who acts as codirector of the field research and coordinator of the field-rehabilitation program. Jorge Washington Guzman, project agronomist, collected the data on crop yields presented in Tables 1–3. Leo Ticcla, INAR staff member and project geologist, mapped the Waña Jawira canal system illustrated in Figure 7 and pointed out the possibility of a second loop to the system. Cesar Callisaya coordinated labor and logistics. He performs a critical role as the project's interpreter of Aymara language and politics; the project could not operate without him. Michael Binford, Mark Brenner, and Charles Ortloff, consultants to the project, graciously shared valuable data, graphics, and interpretive insights that are incorporated in this manuscript. Maria Lozada Cerna and Martin Giesso provided key editorial comments and polished the Spanish-language abstract. The communities of Lakaya, Achuta Grande, Chukara, Quiripujo, Korila, and Tiwanaku generously granted us access to their lands for the purposes of the raised-field experiments. We are grateful for their forbearance, friendship, and enthusiasm for the project. Finally, I wish to acknowledge the substantive, constructive critiques of this manuscript proffered by three anonymous reviewers and by the editor, Prudence Rice. Many of their suggestions have been incorporated in the final product.

REFERENCES CITED

Abercrombie, T.
1986 *The Politics of Sacrifice: An Aymara Cosmology in Action.* Unpublished Ph.D. dissertation, Department of Anthropology, University of Chicago, Chicago.

Albarracín-Jordan, J.
1990 Prehispanic Dynamic of Settlement in the Lower Tiwanaku Valley, Bolivia. In *Tiwanaku and Its Hinterland: Third Preliminary Report of the Proyecto Wila Jawira*, edited by A. L. Kolata and O. Rivera, pp. 276–296. Submitted to the Instituto Nacional de Arqueología de Bolivia, the National Science Foundation, and the National Endowment for the Humanities.

Albarracín-Jordan, J., and J. Mathews
1990 *Asentamientos prehispánicos del valle de Tiwanaku*, vol. 1. Producciones Cima, La Paz, Bolivia.

Bastien, J.
1978 *Mountain of the Condor: Metaphor and Ritual in an Andean Ayllu.* West, St. Paul, Minnesota.

Binford, M., M. Brenner, and D. Engstrom
1990 Temporal Sedimentation Patterns in the Nearshore Littoral of Lago Titicaca Menor (Bolivia). In *Le lac Titicaca: Synthese des connaissances actuelles*, edited by C. DeJoux and A. Iltis. ORSTOM, Toulouse, France, in press.

Boserup, E.
1965 *The Conditions of Agricultural Growth: The Economics of Agrarian Change Under Population Pressure.* Aldine Atherton, Chicago.

Brookfield, H.
1961 The Highland People of New Guinea: A Study of Distribution and Localization. *Geographical Journal* 127:436–448.

Browman, D.
1978 Toward the Development of the Tiwanaku (Tiahuanaco) State. In *Advances in Andean Archaeology*, edited by D. Browman, pp. 327–349. Mouton, The Hague.
1981 New Light on Andean Tiwanaku. *American Scientist* 69:408–419.

Coward, E., Jr.
1979 Principles of Social Organization in an Indigenous Irrigation System. *Human Organization* 38(1):28–36.

Denevan, W.
1970 Aboriginal Drained-Field Cultivation in the Americas. *Science* 169:647–654.
1982 Hydraulic Agriculture in the American Tropics: Forms, Measures, and Recent Research. In *Maya Subsistence: Essays in Honor of Dennis E. Puleston*, edited by K. V. Flannery, pp. 181–203. Academic Press, New York.

Downing, T., and M. Gibson (editors)
1974 *Irrigation's Impact on Society.* University of Arizona Press, Tucson.

Erickson, C.
1985 Applications of Prehistoric Andean Technology: Experiments in Raised Field Agriculture, Huatta,

Lake Titicaca: 1981–1982. In *Prehistoric Intensive Agriculture in the Tropics*, edited by I. Farrington, pp. 209–232. BAR International Series 232. British Archaeological Reports, Oxford.

1987 The Dating of Raised-Field Agriculture in the Lake Titicaca Basin, Peru. In *Pre-Hispanic Agricultural Fields in the Andean Region*, edited by W. Denevan, K. Mathewson, and G. Knapp, pp. 373–384. BAR International Series 359. British Archaeological Reports, Oxford.

1988 *An Archaeological Investigation of Raised Field Agriculture in the Lake Titicaca Basin of Peru.* Ph.D. dissertation, University of Illinois at Urbana–Champaign. University Microfilms, Ann Arbor.

Garnsey, P.

1988 *Famine and Food Supply in the Graeco-Roman World: Responses to Risk and Crisis.* Cambridge University Press, Cambridge.

Gallagher, J., R. Boszhardt, R. Sasso, and K. Stevenson

1985 Oneota Ridged Field Agriculture in Southwestern Wisconsin. *American Antiquity* 50:605–612.

Graffam, G.

1990 *Raised Fields Without Bureaucracy: An Archaeological Examination of Intensive Wetland Cultivation in the Pampa Koani Zone, Lake Titicaca, Bolivia.* Unpublished Ph.D. dissertation, Department of Anthropology, University of Toronto, Toronto.

Hastings, C., and M. Moseley

1975 The Adobes of Huaca del Sol and Huaca de la Luna. *American Antiquity* 40:196–203.

Hunt, R.

1988 Size and Structure of Authority in Canal Irrigation Systems. *Journal of Anthropological Research* 44: 335–355.

Knapp, G., and R. Ryder

1983 Aspects of the Origin, Morphology and Function of Ridged Fields in the Quito Altiplano, Ecuador. In *Drained Field Agriculture in Central and South America*, edited by J. Darch, pp. 201–221. BAR International Series 189. British Archaeological Reports, Oxford.

Kolata, A.

1983 The South Andes. In *Ancient South Americans*, edited by J. Jennings, pp. 241–285. W. H. Freeman, San Francisco.

1986 The Agricultural Foundations of the Tiwanaku State: A View from the Heartland. *American Antiquity* 51:748–762.

1989 Introducción: Objectivos y estrategias de la investigación. In *Arqueología de Lukurmata*, vol. 2, edited by A. Kolata, pp. 13–40. Instituto Nacional de Arqueología y Ediciones Puma Punku, La Paz, Bolivia.

Kolata, A., and G. Graffam

1989 Los campos elevados de Lukurmata, Bolivia. In *Arqueología de Lukurmata*, vol. 2, edited by A. Kolata, pp. 173–212. Instituto Nacional de Arqueología y Ediciones Puma Punku, La Paz, Bolivia.

Kolata, A., and C. Ortloff

1989 Thermal Analysis of Tiwanaku Raised Field Systems in the Lake Titicaca Basin of Bolivia. *Journal of Archaeological Science* 16:233–263.

Lansing, J.

1987 Balinese "Water Temples" and the Management of Irrigation. *American Anthropologist* 89:326–341.

Leach, E.

1959 Hydraulic Society in Ceylon. *Past and Present* 15:2–25.

Lennon, T.

1982 *Raised Fields of Lake Titicaca, Peru: A Pre-Hispanic Water Management System.* Ph.D. dissertation, University of Colorado. University Microfilms, Ann Arbor.

1983 Pattern Analysis of Prehispanic Raised Fields of Lake Titicaca, Peru. In *Drained Field Agriculture in Central and South America*, edited by J. P. Darch, pp. 183–200. BAR International Series 189. British Archaeological Reports, Oxford.

Lynch, T.

1983 Camelid Pastoralism and the Emergence of Tiwanaku Civilization in the South-Central Andes. *World Archaeology* 15:1–14.

Mathews, J.

1990 Preliminary Report of the Tiwanaku Mid-Valley Survey Project: The North Sierra Zone. In *Tiwanaku and Its Hinterland: Third Preliminary Report of the Proyecto Wila Jawira*, edited by A. Kolata and O. Rivera, pp. 269–275. Submitted to the Instituto Nacional de Arqueología de Bolivia, the National Science Foundation, and the National Endowment for the Humanities.

Mitchell, W.

1973 The Hydraulic Hypothesis: A Reappraisal. *Current Anthropology* 14:532–534.

1977 Irrigation Farming in the Andes: Evolutionary Implications. In *Peasant Livelihood: Studies in Economic Anthropology and Cultural Ecology*, edited by R. Halperin and J. Dow, pp. 36–59. St. Martin's Press, New York.

Moseley, M.

1975 Prehistoric Principles of Labor Organization in the Moche Valley, Peru. *American Antiquity* 40:191–196.

Netherly, P.
1977 *Local Level Lords on the North Coast of Peru.* Ph.D. Dissertation, Cornell University. University Microfilms, Ann Arbor.
1984 The Management of Late Andean Irrigation Systems on the North Coast of Peru. *American Antiquity* 49:227–254.
Núñez, L., and T. Dillehay
1979 *Movilidad giratoria, armonía social y desarrollo en los Andes meridionales: Patrones de tráfico e interacción económica.* Universidad del Norte, Antofagasta, Chile.
Ortloff, C., and A. Kolata
1989 Hydraulic Analysis of Tiwanaku Aqueduct Structures at Lukurmata and Pajchiri, Bolivia. *Journal of Archaeological Science* 16:513–535.
Ponce Sangines, C.
1972 *Tiwanaku: Espacio, tiempo y cultura: Ensayo de síntesis arqueológica.* Publicación No. 30. Academia Nacional de Ciencias de Bolivia, La Paz.
1980 *Panorama de la Arqueología Boliviana.* 2nd ed. Libreria y Editorial "Juventud," La Paz, Bolivia.
Riley, T., and G. Freimuth
1979 Field Systems and Frost Drainage in the Prehistoric Agriculture of the Upper Great Lakes. *American Antiquity* 44:271–285.
Riley, T., C. Moffat, and G. Freimuth
1980 Campos elevados prehistóricos en el medio-oeste superior de los Estados Unidos. *América Indígena* 40:797–815.
Schaedel, R.
1988 Andean World View: Hierarchy or Reciprocity, Regulation or Control? *Current Anthropology* 29:768–775.
Sanders, W., and B. Price
1968 *Mesoamerica: The Evolution of a Civilization.* Random House, New York.
Smith, C., W. Denevan, and P. Hamilton
1968 Ancient Ridged Fields in the Region of Lake Titicaca. *Geographical Journal* 134:353–367.
Steward, J. (editor)
1955 *Irrigation Civilizations: A Comparative Study.* Pan American Union, Washington, D.C.
Unzueta, O.
1975 *Mapa ecológico de Bolivia: Memoria explicativa.* Ministerio de Asuntos Campesinos y Agropecuarios. Oficina de Información Técnica, La Paz, Bolivia.
Wadell, E.
1972 *The Mound Builders.* American Ethnological Society Monographs. University of Washington Press, Seattle.
Winterhalder, B., R. Larson, and R. Thomas
1974 Dung as an Essential Resource in a Highland Peruvian Community. *Human Ecology* 2:89–104.
Wittfogel, K.
1938 Die Theorie der Orientalischen Gesellschaft. In *Zeitschrift für Socialforschung* VII:90–112.
1957 *Oriental Despotism: A Comparative Study in Total Power.* Yale University Press, New Haven.

NOTE

[1] There are substantial differences in the published and unpublished literature with respect to the areal extent of raised fields on the Bolivian side of Lake Titicaca. Smith et al. (1968:355) published a figure of 30 square kilometers (3,014 ha) for the Catari subbasin, and a total for the entire Bolivian side of 39 km^2 (3,938 ha). They calculate an additional 65 km^2 (6,501 ha) for the Desagüadero region on the Peruvian border with Bolivia. This latter figure corresponds well with the 60 km^2 that I project for the Machaca/Desagüadero region (which, in my definition, includes an area straddling, and on both sides of, the Peru–Bolivia border). Graffam's (1990) dissertation revised the figure for the Catari subbasin (Pampa Koani) upward to 44 km^2 from the Smith et al. estimate, but did not address the extent of raised fields outside of the Catari region. Both of these estimates are based on calculations drawn from aerial photographs. Previously, I suggested that the maximum extent of raised fields in the Catari subbasin was 70 km^2 (Kolata 1986), and here estimate that the total for the three-valley Tiwanaku hinterland approaches 190 km^2. The estimate of 70 km^2 for the Catari subbasin is based on the analysis of aerial photographs, pedestrian survey, and geological coring. Graffam's (1990:311) distribution map does not include raised fields northwest of the Río Catari, southeast of the village of Aygachi, or east and northeast of the community of Catavi. Because of differential preservation, many of these relict fields do not appear on the available aerial photographs, but they are evident in ground survey, sometimes simply as subtle differences in surface vegetation. The estimate of 60 km^2 for the Tiwanaku Valley is based on analysis of aerial photographs and on the results of systematic pedestrian survey in the lower and middle sections of the valley, a portion of which is reported in Albarracín-Jordan and Mathews (1990). Because systematic survey of the upper valley has

not been undertaken to date, this estimate is, in part, conjectural. The projection of 60 km^2 for the Machaca–Desagüadero region is based on analysis of aerial photographs and unsystematic survey, and, as noted above, corresponds with the Smith et al. (1968) estimate for the same area.

Received December 6, 1990; accepted April 3, 1991

The Mesoamerican Ballgame

Vernon L. Scarborough and David R. Wilcox, eds.

Brings together research from field archaeology, mythology, and Maya hieroglyphic studies to illuminate this important yet puzzling aspect of Native American culture. The contributors offer new information on the distribution of ballcourts, new interpretations of mural art, and newly perceived relations of the game with material in the *Popol Vuh*. "This is without any doubt the single most important volume ever written on the hip-ball game of the ancient Mesoamericans . . . which supersedes all previous work on the subject" (Michael D. Coe, Peabody Museum). 404 pp., $45.00.

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Susan Schroeder

Chimalpahin's history of pre-Conquest Mexico is one of very few primary sources of information about indigenous life in central Mexico in pre-Hispanic and early colonial times. Susan Schroeder has reconstructed Chimalpahin's life, synthesized his annals, and interpreted the sociopolitical reality he depicts through an analysis of Nahuatl terminology, reconstructing Chalco political and social units as Chimalpahin perceived them. Her work also offers a key to Nahuatl concepts and terminology through which we can better comprehend the mental organization of the pre-Columbian Indian world. 264 pp., $40.00.

The University of Arizona Press

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