

Bordos and Boundaries: Sustainable Agriculture in the High Altitude Deserts of Northwest Argentina, AD 850-1532

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Abstract

Bordos were essential for the long-term sustainability of agriculture in the high altitude desert of Antofagasta de la Sierra in Northwest Argentina during the Late (AD 850 – 1480) and Inca Period (AD 1480 – 1532). Bordos were lineal humps of soil that stimulated the pedogenesis of the predominantly sandy soils of the area. Furthermore, they served as boundaries delimiting irrigation and cultivation fields. Therefore, bordos alongside other technologies were an efficient means by which viable farming was possible in an otherwise marginal agricultural zone. Besides explaining the role of bordos in the context of Northwestern Argentine agriculture this article describes the irrigation systems in place at Antofagasta de la Sierra throughout this period and compares it to the present state of affairs. Our results demonstrate that these late Prehispanic bordos and irrigation networks were well set out and organized such that use of water and soil was efficient, proportional and fair. The Inca do not seem to have disrupted these systems or local autonomy over them. In contrast, modern water and soil is characterized by a household-level decentralized management system. This situation leads to serious conflicts over water use allocations, wastage and flawed irrigation resulting in rising ground salinization.

Keywords: Prehispanic Andean agriculture, desert environment, bordos technology, hydraulic management, irrigation networks, Northwest Argentina

In the last few decades researchers in the Andes have shown how areas currently considered suboptimal for agriculture were, in Prehispanic times, exploited sustainably and productively creating high yield zones in supposedly marginal areas (Beresford-Jones, Arce, Whaley, & Chepstow-Lusty, 2009; Erickson, 2000, 2002; Flores Ochoa & Paz Flores, 1986; Flores Ochoa, Paz Flores, & Rozas, 1996).

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One such area is the high altitude Andean desert known as the Puna de Atacama, where agriculture is considered difficult at the short, medium and long-term scale due essentially to water scarcity and the inherent risks to its sustainability. Factors that impact particularly on the viability of agriculture in the Puna de Atacama are soil and water degradation – salinization – and the harshness and limitations of the climate – night frosts and high velocity winds.

Geographically, the Puna de Atacama constitutes the arid southern portion of the Andean High Plateau that in turn covers Northern Chile and Northwestern Argentina. It has similar environmental characteristics to southwestern Bolivia, although the name has geopolitical connotations rooted in Nineteenth Century territorial disputes (García, Rolandi, & Olivera 2000).

The issue of agricultural sustainability and modern marginality is best encapsulated by the archaeological sites located in the lower Punilla River Basin of the southern desert portion of the Puna de Atacama (*c.* AD 850-1532), Department of Antofagasta de la Sierra, Catamarca Province, Argentina (Figure 1). In this paper then we apply an interdisciplinary approach that includes paleoenvironmental, hydrological, soil studies, archaeological and modern proxies in order to demonstrate how agriculture was both viable and sustainable in these areas through the twin mechanism of technology and embedded social practice.

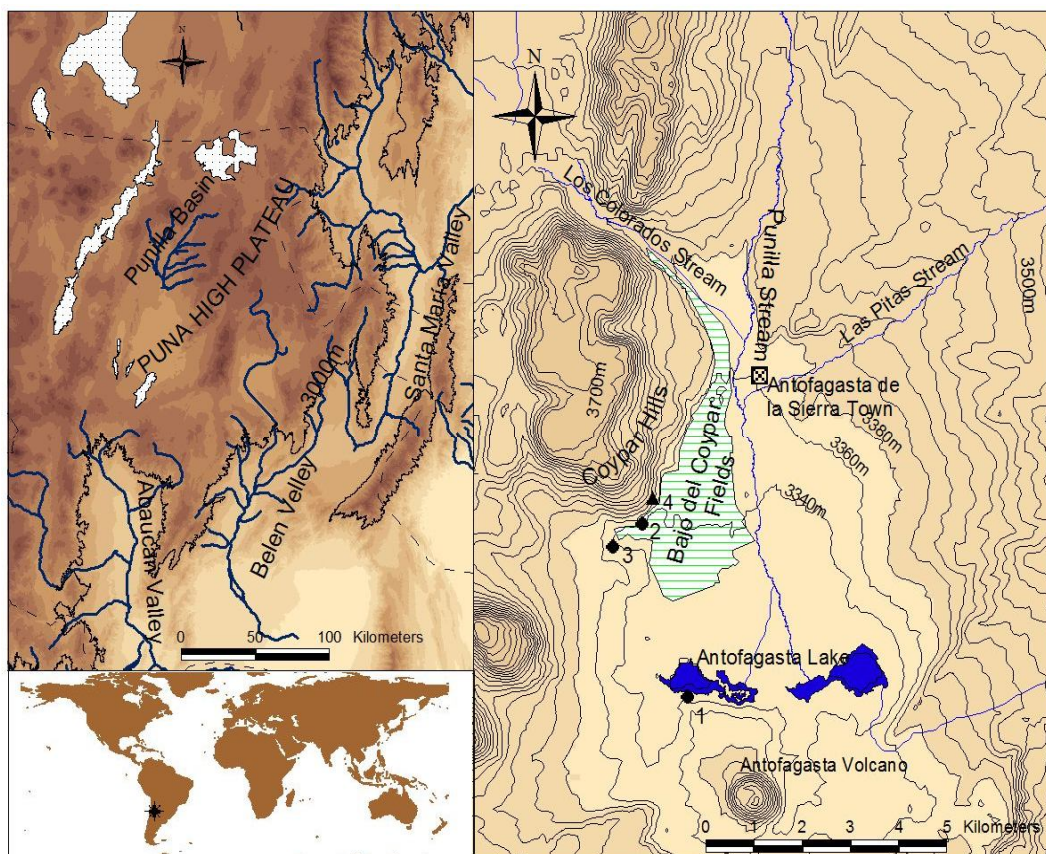


Figure 1. Maps showing the area of the Punilla River Basin in relation to the intermontane valleys of Northwestern Argentina (Above Left), and detailed map of the Punilla River Basin (Right) showing the Bajo del Coypar agricultural fields and sites mentioned in the text: (1) La Alumbreira; (2) Bajo del Coypar II, (3) Quebrada de Petra; (4) Coyparcito

In particular we center on two main themes; firstly, we describe the Prehispanic hydraulic technology known as *bordos* and how this relates to local environmental conditions. *Bordos* were a technological innovation comprising the deliberate accumulation of soil into humps. These served as field boundaries while also facilitating the retention of irrigated water and stimulating pedogenesis. This in turn helped maximize yields in an agriculturally low productive area, through a combination of add-on benefits including temperature regulation, lessened exposure to the elements, among others.

Secondly, we deal with the social implications evoked by the maintenance and management of such a labor-intensive technology. In particular we examine the case for state elite management of the system (Billman, 2002; Stanish, 2001; see also, Steward, 1955; Wittfogel, 1957) versus communal or non-elite organization of the same (e.g. Erickson, 2006; Lane, 2009; see also, Lansing, 1987; Netting, 1993), whilst also analyzing the role of single domestic unit management (Quesada, 2006) – especially in the present-day – in relation to agricultural productivity and hydraulic engineering in the Andes.

As such, this paper represents a first preliminary insight into the, past and present organization of hydric resources in this area. We therefore analyze both Prehispanic and modern irrigation networks of the lower Punilla River Basin highlighting in both cases differences in water and soil sustainability, use and misuse of local resources, and social complexity amongst past and present agro-pastoralist economies. A first section presents a brief overview of the archaeology and history of agricultural development in the area. We follow this with details on the environment, paleohydrology, geomorphology and pedology of the region before moving onto a description of the agricultural and irrigation networks in the area. Finally, we juxtapose past and present organization and use of water resources and its implication for future agricultural viability and sustainability.

1. Agriculture at Antofagasta de la Sierra: Archaeology and History

The southern sector of the Puna de Atacama, including the lower Punilla River Basin, is a high-altitude desert plain dominated by xerophilous shrubs near one of the largest lakes – Antofagasta Lake – in this area of the of the southern puna eco-zone of Argentina. The first evidence for food production in this area was that of camelid husbandry during the Third Millennium BC, agriculture was a later introduction and it never totally supplanted pastoralism, in effect creating a modified form of agro-pastoralism (Olivera, 1988; Olivera & Grant, 2008). Regional-level survey data places the first evidence for agriculture at *c.*1000 BC, during the phase known as the Formative Period (*ca.* 1000 BC – AD 850). Social organization at this moment emphasized dispersed residential settlements with a high degree of sedentism (Olivera, 1988; Olivera & Vigliani, 2000/2002).

During the earlier part of the Late Period (AD 850-1480), a new social reality emerged in Antofagasta de la Sierra.

This situation mirrored similar developments across the rest of Northwest Argentina, northern Chile and southern Bolivia and involved the consolidation and spread of intensive agriculture. This intensive agriculture was based around large-scale irrigation systems; concomitant population growth and demographic concentration in densely populated fortified towns. There was also increased evidence at this stage for widespread conflict and warfare (Williams, Villegas, Arechaga, & Gheggi, 2010; Wynveldt & Balesta, 2009), although, perhaps paradoxically, this occurred alongside evidence for extended llama caravan traffic and goods circulation (Elías & Escola, 2010; Nielsen, 2009; Salminci & Gheggi, 2012). New polities emerged at this time, reflected regionally by the appearance of particular art styles – especially in mortuary vessels (Nastri, 1999, 2008; Quiroga, 2003). The political organization of these groups has been posited variously as chiefdoms (Sempé, 2005; Tarragó, 2000), segmentary egalitarian communities (Acuto, 2007) or local-level corporative hierarchies (Nielsen, 2006).

It is during this period (*ca.* AD 850, see ¹⁴C dates in Table 1) that in the lower Punilla River Basin in Antofagasta de la Sierra a small settlement – Bajo del Coypar II – was founded at the foot of the Coypar Hills (Vigliani, 2005). The site was closely associated to the nearby agricultural fields – *bordos* – known as Bajo del Coypar I, and the Quebrada de Petra food storage site (Olivera & Vigliani, 2000/2002), at this latter site a substantial quantity of maize cobs from several subspecies were found inside pits carved into the cliffs rock face (Oliszewski & Olivera, 2009).

N° Lab.	Site	Sample description	Years BP (not calibrated date)	Years BP (corrected date)	13 C (0/00)
UGA 7374	BAJO DEL COYPAR II	charcoal, bonfire, structure b, sector III, Level V a	790± 60	840± 60	-21,9
UGA 7375		charcoal, bonfire, structure b, sector III, Level VI a	700± 60	780± 60	-19,81
UGA 7315		charcoal, bonfire, structure b, sector III, Level VI	1020± 60	1090± 60	-20,69
UGA 7517		charcoal, bonfire, structure b, sector IV, 2nd extraction	650± 50	690± 50	-22,63
UGA 7519		charcoal, bonfire, structure b, sector IV 3rd extraction	630± 60	670± 60	-22,72
UGA 7520		charcoal, bonfire, structure b, sector IV, 4th extraction	660± 60	720± 60	-21,32
UGA 7518		charcoal, structure b, sector IV.	880± 80	920± 80	-22,52
UGA 8626	QUEBRADA DE PETRA	sweet corn shafts	710 + 30	940± 30	-10,12
AA 78543	LA ALUMBRER A	charcoal, west-central sector, structure 1, Level II		981±39	-21
AA 82550		wood, llama caravan gear, west- central sector, tomb A.		534±59	-22,3
AA 78542		charcoal, west-central sector, structure 2, Level III		536±42	-20,6
AA 82551		charcoal, west-central sector structure 2, Level II		1007±50	-18,5
AA 82552		charcoal, east-central sector, structure 1.		916±50	-22,3

Table 1. Radiocarbon dates from archaeological sites associated to agricultural fields. UGA: Center for Applied Isotope Studies (University of Georgia, EEUU); AA: NSF-Arizona AMS Laboratory. AA does not provide original C14 date

In this period further settlements appeared, located along the base of the Late Quaternary basaltic flows in the landscape near to Bajo del Colpar I and II. One such site was situated along the nearby shore of the Antofagasta Lake, known as La Alumbreira (Olivera & Vigliani, 2000/2002). As the largest settlement in the area, La Alumbreira comprised a 20 ha. fortified settlement with a dense concentration of sunken stone buildings, *pucarás*, gates and a defensive perimeter wall (Salminci & Gheggi, 2012). Recent research at La Alumbreira revealed two major zonal moieties encompassing minor spatial units formed by groups of buildings. These spatial units were archaeologically visible in terms of increasing restrictions of movements and interpersonal space in the path system existent within the site. Although there are marked differences in size and construction quality between the buildings of La Alumbreira they are not significant enough to suggest the presence of a specialized elite group. Rather, the symmetrical and repetitive types and location of buildings within the two moieties and minor spatial units would suggest some form of communal political organization probably based around segmentary groups (Salminci, 2010, 2011). This has major implications for how we view organization and maintenance of hydraulic resources in the area during this time.

State intrusion into the region came only with Inca expansion into Northwest Argentina during the fifteenth century, related primarily to mining exploitation, but also with a heightened emphasis on intensified agricultural and pastoralist production (D'Altroy, Williams, & Lorandi, 2007). Agricultural intensification can be gauged through increased construction of terraces and hydraulic infrastructure (González, 1983), whilst the case for increased pastoralist production has also been made (Olivera & Grant, 2008). The Inca state tended to exert physical, ideological and cosmological control through state infrastructure such as roads, (Hyslop, 1984), settlements (Gasparini & Margolies, 1977; Hyslop, 1990), storage and redistribution facilities (LeVine, 1992), ritualized landscapes (Meddens, Wills, McEwan, & Branch 2014) and propaganda (Ogburn, 2004). Nevertheless, Inca presence was not homogenous and the whole plethora of state institutions were not necessarily present in all provinces.

In Antofagasta de la Sierra, the Inca state was present in the *pucara* – hill fort – of Coyparcito located on an elevated point in the Coypar Hills, Inca ceramic, and also crucially, the expansion of the zones agricultural area (Olivera & Vigliani 2000/2002).

This last point is important as it served to demonstrate that, as in other regions (e.g. D'Altroy, 1992), the Inca Empire fomented the intensification and expansion of the agro-pastoralist resource of a given area, as happened further North in the Calchaquí Valley (Williams, Korstanje, Cuenya, & Villegas, 2010). This would have had obvious implications for local relations with the incoming Inca elite concerning exploitation, maintenance and ultimately ownership of the areas irrigation networks.

No Inca structures or modifications were uncovered at La Alumbraera (Salminci, 2010), but Bajo del Coypar II does have evidence for Inca re-use, as seen in architecture and ceramic (Olivera & Vigliani, 2000/2002; Vigliani, 2005). The deliberate placing of an Inca site close to, but not within, the main local site – La Alumbraera – of an area, is a common feature of imperial strategy which was replicated across the empire (e.g. Acuto, 2008; Astuhamán, 2008; Conrad, 1977; Lane, 2011).

Spanish conquest of Northwest Argentina started in AD 1550 when colonial town of Del Barco was founded. Nevertheless, the mountainous regions of the area – including the Puna de Atacama – were only finally subjugated towards the mid-Seventeenth Century after the conflict known as the Calchaquí Wars (Lorandi & Boixados, 1987-88; Schaposchnik, 1997). The effect of Spanish conquest on Antofagasta de la Sierra is still poorly understood given the paucity of archaeological and historical evidence for this period.

There are only two known historical documents from this period that specifically mention Antofagasta, one from AD 1633, concerning a colonial territorial delimitation under the jurisdiction of the town of Londres de Pomán, Belén Valley, and a second from AD 1766 concerning a land grant known as a *merced* (García et al., 2000). This last does not mention local populations or agriculture, rather it talks about a low-valley location used for fattening bovine herds during the winter months and mining activities carried out at Incahuasi located some 90km away from Antofagasta.

After this period, there are a few additional details that can be gleaned from description by travellers and military men sent by the Bolivian, Chilean and Argentine governments in the mid-Nineteenth and early Twentieth Centuries. It should be noted that Antofagasta de la Sierra and the Puna de Atacama belonged alternatively to Bolivia (AD 1831-1879), Chile (AD 1879-1899) and Argentina (AD 1899 to the present).

These documents and diaries strongly suggest that a cultural and demographic collapse has occurred in the area, given that they describe low density populations of scattered and dispersed human groups settled near to, and around, the lower Punilla River Basin. These people mainly practiced llama, goat and cattle herding; agriculture was a minor pursuit focusing on alfalfa cultivation (García, Rolandi, López, & Valer, 2002). In the present-day, the inhabitants of Antofagasta exploit only 10% of the Prehispanic fields for agriculture.

As we shall subsequently see, later Prehispanic and modern water management, insofar as irrigation networks are concerned, differ significantly such that their modern use is considerably less productive than that of the past. Aside from a better-organized irrigation network the key to past agricultural productivity was astute use of *bordas* technology.

2. Climate, soil and water at Antofagasta de la Sierra

Detailed knowledge concerning hydrology and climate are essential to understanding past and present water management of agricultural fields. In Antofagasta de la Sierra annual rainfall is below than 130mm and 97% of it occurs during the Summer months (September-March). Evapotranspiration, at 552mm, is superior to rainfall and water balance is therefore negative throughout the whole year (Figure 2B). Mean annual temperature is 10°C, the warmest month being January (21°C) and the coldest being August (0°C) (Figure 2C). Night frosts severely affect crop growth making agriculture unfeasible during the colder months. Frequent, high velocity winds augment evaporation and aridity rendering agriculture even harder.

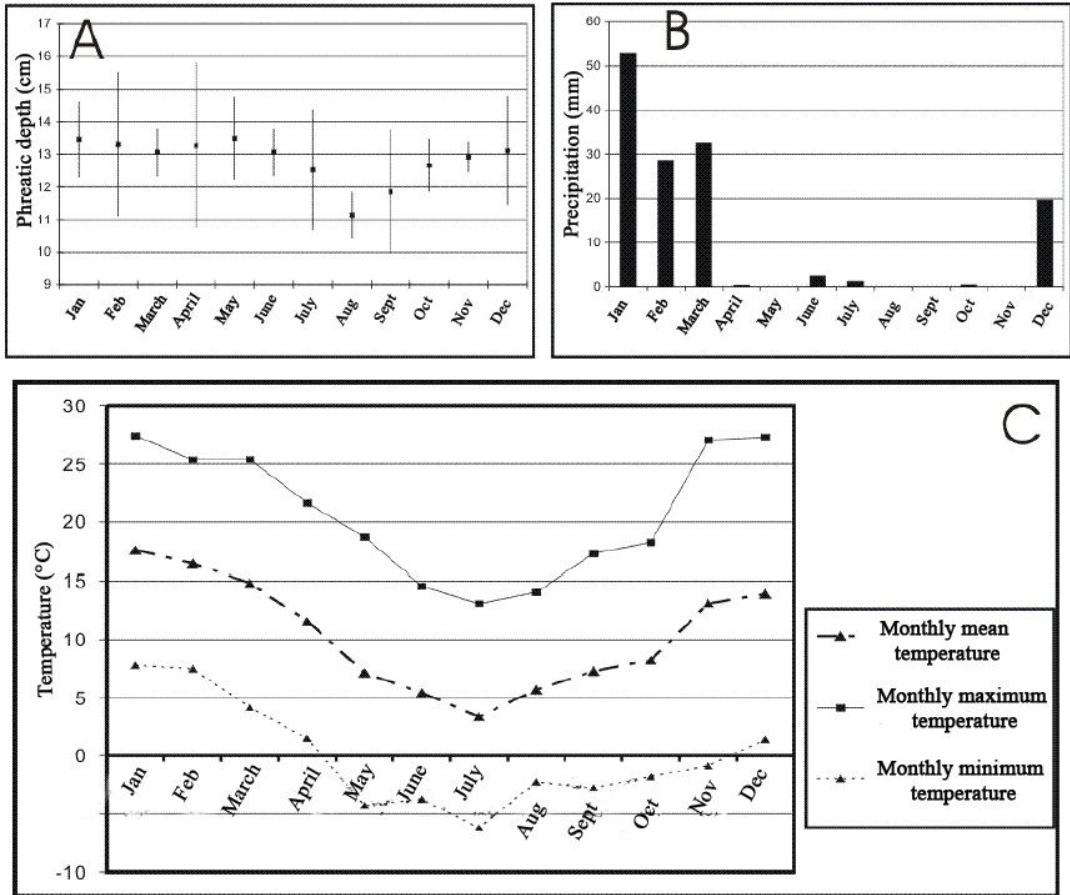


Figure 2: A – Depth of Phreatic Layer; B – Precipitation; C - Temperature

Yet, although Antofagasta de la Sierra is considered a desert environment, orographic rainfalls recharge high Andean aquifers creating springs and streams that provide year-round perennial water flow. This aquifer system comprises the Punilla River (1800-2000 l/h [liters per hour]) and its main tributaries the Las Pitas River (800 l/h) and springs located in the Los Colorados Ravine (1200 l/h). Total amount of available water therefore totals 4000 l/h for the lower Punilla River Basin. The phreatic stratum record, for the period 2000-2007 (Figure 2A), shows that the Punilla River stream has little seasonal (10%) or annual (15%) discharge variation, which means that water volume does not diminish significantly at anytime during the year (Tchilinguirian, 2008).

This data serves to show that the main environmental restrictions on agriculture are the low winter temperatures – the period between April-September – including frost and winds rather than water availability given that this last resource is relatively abundant throughout the year. The end effect of these conditions means that a yearly harvest is possible during the period between September and April.

Paleohydrological reconstructions based on sedimentological and palaeopedological records (Tchilinguirian, 2008) indicated abrupt hydrological fluctuations during the last 2000 years (Figure 3). Despite the differences in local geological and geomorphologic patterns, the records show similar large-scale trends that subdivide into six main paleohydrological phases: (1) a wet phase >450 BC; (2) a dry phase *c.* 450 BC – AD 1250; (3) a wet phase AD 1250 – 1350; (4) a dry phase *c.* AD 1350 – 1650; (5) a wet phase *c.* AD 1650 – 1800; and, (6) a dry phase *c.* AD 1800 to the present.

Wet phase deposits are mostly fine-grained diatom rich sediments and organic detritus with interbedded gravel channels and paleopeat layers. They were interpreted as occurring when perennial groundwater was discharged during low frequency non-storm precipitation in an alluvial plain system. In the more arid phases, wetland sedimentation was interrupted by erosion episodes that occurred when water levels decreased and the surface area of the wetlands began to shrink. Even so it is important to note that agricultural development in the lower Punilla River Basin (AD 850-1532) took place during a predominantly arid period, very similar to modern-day conditions albeit interrupted by a short period of higher water availability during the AD 1250-1350 wet phase (Tchilinguirian & Olivera, 2010).

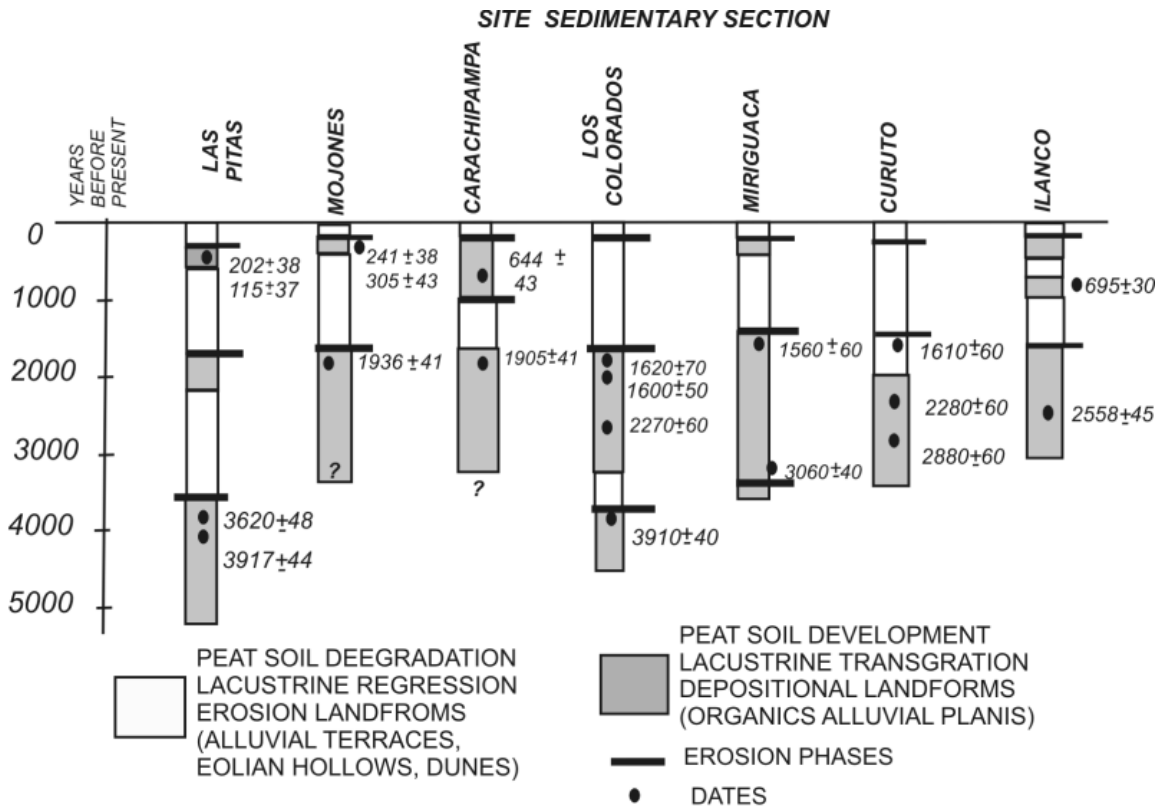


Figure 3: Palaeopedological Samples Taken from Different Valleys within the Punilla Basin

The lower basin landscape has four soil-geomorphologic zones each with different degrees of agricultural potential. These four zones are characterized as; wetlands, fluvial terraces, hills and alluvial fans (Figure 4). The wetlands or moorland, known locally as *vegas* (Cabrera, 1976), or *bofedales* in the Central Andes (Custred, 1977), are located in close proximity to water streams. They constitute poorly drained soils, unfit for crop agriculture, as they are prone to flooding due to shallow phreatic water levels. This makes them fit only as pastureland, albeit prime pastureland (Cabrera, 1968).

Fluvial terraces exist at two different levels, low terraces located 1-2m above the *vegas* level and high terraces located 4-6m above this wetland level. Together they cover an approximate surface area of 1000 ha. The low terraces are currently used for agriculture, as yet no evidence has been found for Prehispanic use of these fields.

The high terraces are located on 0.5°-1° slopes at elevations between 3325 m and 3365 m and are situated in the best available agricultural land – that with the highest productivity potential. Many Prehispanic fields have been identified in this terrace zone.

Hills are located to the southwest and west of the high terrace zone; this geomorphologic unit has steep slopes of between 15° to 20° gradients. The hills are composed of several colluvial blocks and basaltic outcrops set over Tertiary sandstones. Alluvial fans appear between the hills and the high terraces at more moderate slopes of between 1° and 5°. In both these zones agriculture was practiced in the past, while only in the latter is agriculture practiced in the present-day.

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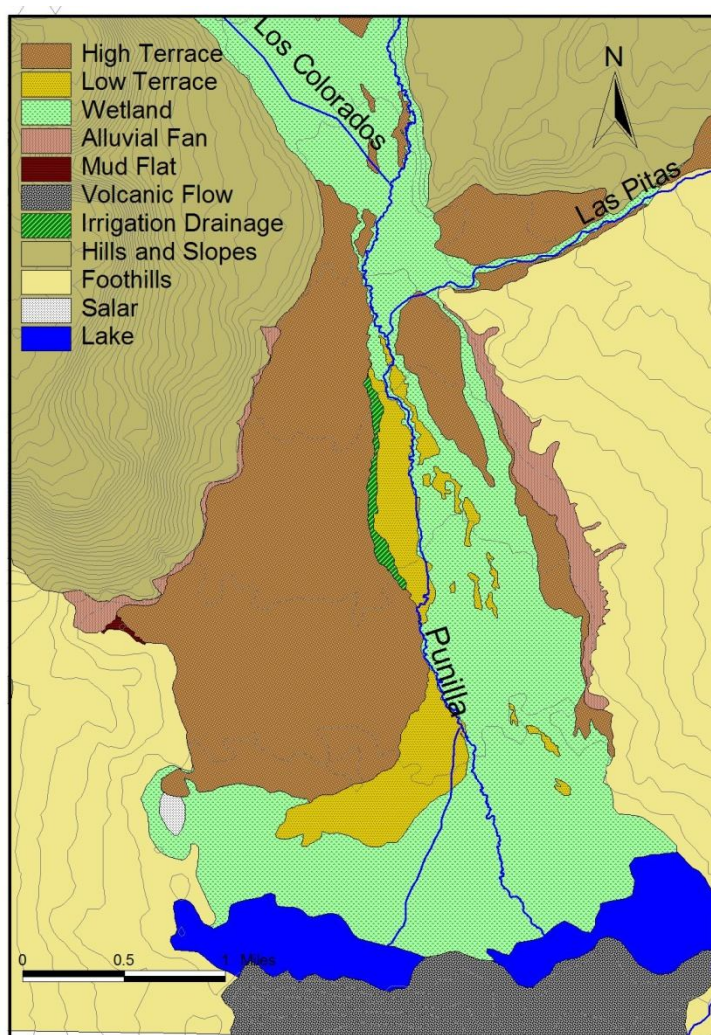


Figure 4: Distribution of Soil-Types and Geomorphs in the lower Punilla River Basin

A chemical analysis of modern cultivated land shows a higher degree of organic matter (0.6-0.5%) and phosphorous (6.4-14 ppm) in relation to that of uncultivated land (Olivera & Tchilinguirian 2000). Potassium, sodium as well as soluble carbon and magnesium also show heightened levels in cultivated vis-à-vis uncultivated areas. This is a crucial distinction, without cultivation the land is rendered poor and marginal, it is the practice of agriculture that gradually raises the farming potential of these areas.

Therefore, sustainable and controlled cultivation can release this potential, indeed the main threat to agriculture in the area is salinity (Tchilinguirian & Olivera, 2010).

Finally, the irrigation water contains very low conductivity levels making it apt for sustained and productive agriculture. Nevertheless, salt in some quantity (300-900 mho/cm) is present in the water. Misuse of water – such as when land is flooded and the water is left undrained to evaporate by itself – will facilitate the retention and crystallization of this salt in the soil leading to a deterioration in the yield and farming potential of the land. This is the case at present.

3. Agriculture, Technology and Irrigation at Antofagasta de la Sierra

The lower Punilla River Basin study area had evidence for various types of Prehispanic agricultural technologies located in different soil-geomorphologic zones (Olivera & Vigliani 2000/2002; Tchilinguirian & Olivera 2011). These technologies date to the Late (AD 850 – 1480) and Inca Periods, (AD 1480 – 1532). There were also post-Hispanic technologies that are currently in use (García et al., 2002).

The major sector of Prehispanic fields in the area, where located in the high terrace zone and were associated to a particular type of agricultural technology known as *bordos*. Gravity irrigation canals were employed to inundate fields, this is a feature common to many Northwest Argentine Late Prehispanic (AD 850-1532) sites (Albeck, 1995; Korstanje, 1997; Quesada, 2006; Tarragó, 2000) and indeed across the Andes (Denevan, 2001). Nevertheless, a notable difference was the use of the local sandy soil from the fluvial terraces rather than stone as the main construction material. These sandy soil channels were used for spreading water and additionally for delimiting plots of land. By these means, people in the past built a regular grid of different plots of land demarcated by elevated areas or humps of soil *ca.* 0.2m high and 0.6m wide known as *bordos* (Olivera & Tchilinguirian, 2000).

Two types of *bordos* enclosures were identified across the high fluvial terrace zone, rectangular checkered shapes of 30-50 m by 30-50 m, and more elongated rectangular checkered shapes of 230 m by 40 m outlined by thinner *bordos* (Figure 5 and 6). In total these two types of *bordos* cover an area of approximately 400 ha.

The smaller bordos are more labor intensive and are set closer to the main irrigation canals, than the larger bordos which are located further away from the main irrigation system especially in the Southern sector of the lower Punilla River Basin. This difference in construction cost and proximity to water sources strongly suggests that the smaller bordos were used more regularly and intensely than the larger ones. It is possible that the larger bordos were only used during years where there was a greater amount of water available in the system.

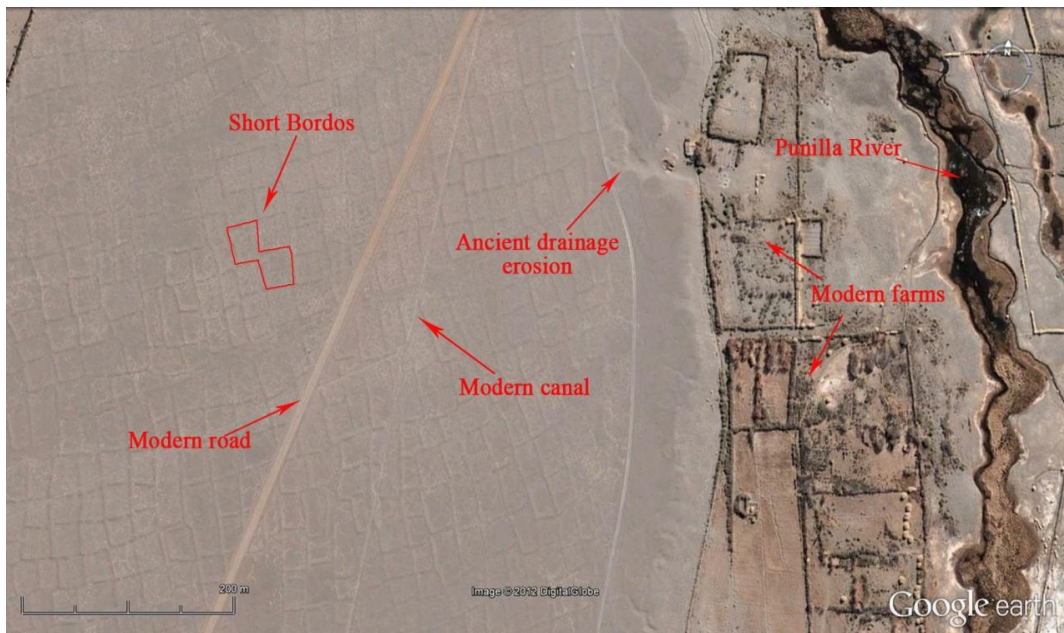


Figure 5: Satellite Images Showing Short Bordos and Other Past and Modern Features (Googleearth)

Bordos were a crucial technology for the area, greatly improving crop yield and thus making agriculture sustainable in what was in effect a borderline area for agricultural production. Furthermore, bordos helped prevent salinization, while creating microclimates that further facilitated high altitude agriculture. This is not unique to bordos, indeed high altitude terraces in the Andes provide the same benefits while also creating a level planting field in the otherwise vertically challenging Andes (Donkin, 1979). Perhaps though a more apt comparison would be the raised field systems, known as *camellones*, of the circum-Titicaca Basin (Erickson, 1986; Valdez, 2006).

Here the interspersing of ridge and waterlogged furrow ameliorates the diurnal frosts and harshness of the climate providing a platform for sustainable and productive agriculture (de la Torre & Burga, 1986).

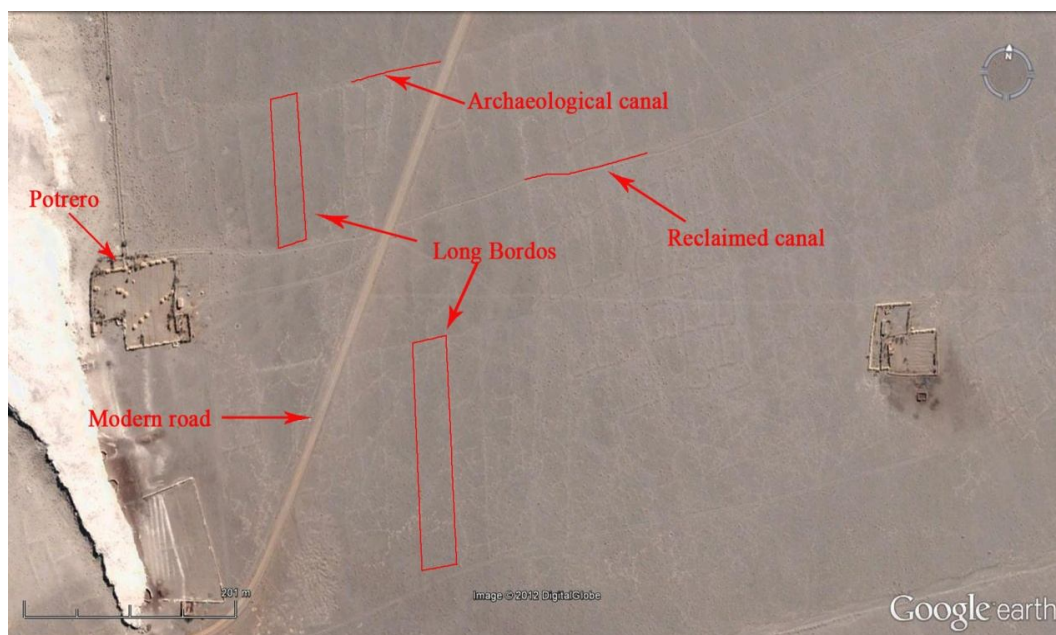


Figure 6: Satellite Image Showing Long Bordo Plots, Reclaimed and Archaeological Canals (Google Earth)

In Antofagasta de la Sierra the accumulation of humidity in and around the bordos could have positively impacted on ground temperature and exposure. Modern day studies show that the planting of certain local plants on the bordos, such as pampas grass (*cortaderia selloana sp.*), has the added effect of creating a dense barrier of vegetation – up to 1.5 m in height – that can greatly reduce the effects of the wind and transevaporation while concomitantly augmenting ground temperature (García et al., 2002). Widespread use of such a technic in the past would also have helped retain humidity by trapping moisture around the pampas grass roots. As mentioned previously, although water quality is good inundation irrigation will increase soil salinization if it is not properly executed. Chemical analysis on soils showed that bordos hampered the over-salinization of soil; instead the salt accumulates on the *bordos* leaving the cultivation area free, or almost free, of salt (Olivera & Tchilinguirian, 2000).

This accumulation of salt on structures similar to bordos has been noted by earlier researchers such as Lyster & Longenecker (1957:9) who stated that, 'With each irrigation event, salt leaches out of the soil under the furrow and build up in the ridges.' Bordos also created a unique microclimate that lessened water evaporation rates by ameliorating wind velocity and reducing night frost intensity on the fields. This in turn helped extend the productive season of the plots in question.

In the hills and alluvial fans of the area there is a more reduced agricultural zone characterized by terraces and squared land plots. These stone walled terrace remains can be found on steep gradients; while amongst the foothills there are square plots of previously cultivation land bounded by stonewalls (Figure 7 and 8).

These two types of field systems probably date to the Inca Period (AD 1480-1532) given that this sector is located on the slopes of the Coypar Hills in association to the Inca fort of Coyparcito and the Bajo del Coypar II settlement that has firm evidence of Inca presence. It is possible that these field systems in conjunction with the Bajo del Coypar II site represented the main administrative and transit node for the Inca Empire in the lower Punilla River Basin (Olivera & Vigliani, 2000/2002).

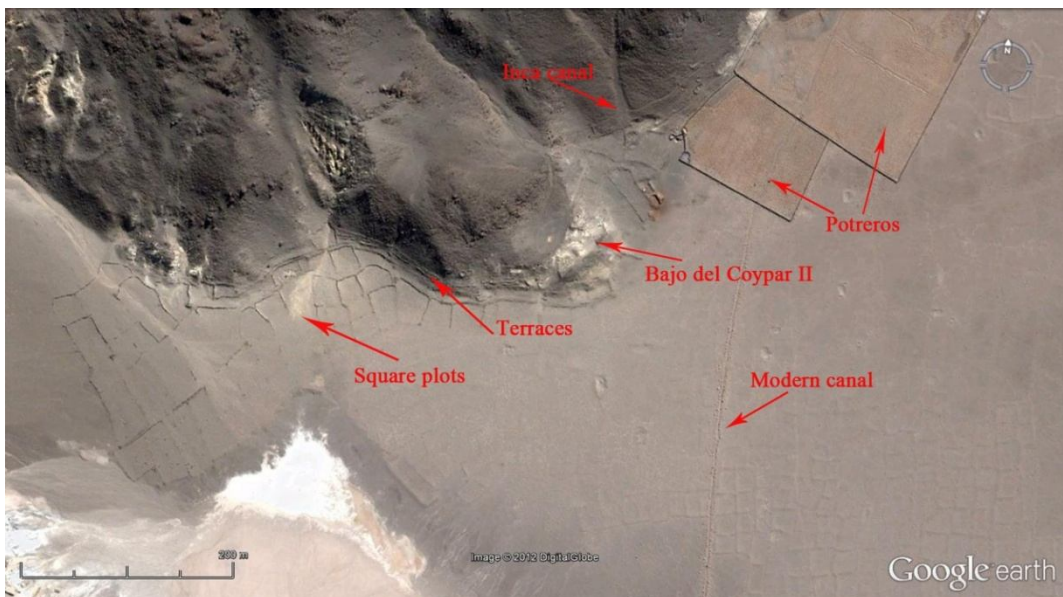


Figure 7: Satellite image showing terraces and square plots. We can also see the modern-day potreros and the course of a modern canal that cuts the Prehispanic bordos fields (GoogleEarth)



Figure 8: Image of Inca Terraces and Square Plots

No water reservoirs or dams have been uncovered in the area, this probably has to do with the fact that water flow is continuous throughout the year, thus negating the need for water storage. Furthermore the high rates of transevaporation would reduce the efficiency of open-air water storage facilities. The natural, gentle gradient of the terrain also makes it unnecessary to have technology that breaks incoming water velocity; likewise the water is relatively clean of sediments making silt traps equally redundant.

In the present-day the areas irrigation network supplies water to around 500 ha. of pastures, 50 ha. of agricultural land and also the population of the nearby town of Antofagasta de la Sierra (Figure 9). These networks comprise reused ancient canals and new ones that frequently crosscut archaeological fields (Figure 7). Sluices for the irrigation grid are located at different points of the river basin and are found in all the streams and springs in the area – Punilla, Los Colorados and Las Pitás. Based on the identification of these sluices a total of ten water networks were recognized across the Punilla River, two across the Los Colorados and another four at Las Pitás. The majority of these sluices belong to single households dispersed across the area. In the past multiple households seem to have shared a single irrigation outlet.

In the past the archaeological evidence suggests that only two networks irrigated the whole of the lower Punilla River Basin (Figure 10). One network took water from the springs in Los Colorados Ravine and the other from the Punilla River.

The height of the hill and alluvial fan sectors only permitted irrigation by the Los Colorados network, while the high terrace sector was able to receive water from both networks.

The Punilla network irrigated the high terrace sector that included all bordos plots. The network started at 3373 m above sea level, at 900 m downslope from this point a southern bifurcation divided the main canal in two – Canal A and Canal B – both of which would run roughly in a north to south orientation. Canal A run parallel to the base of the Coypar Hills and is still in use, Canal B followed the edge of the high fluvial terrace.

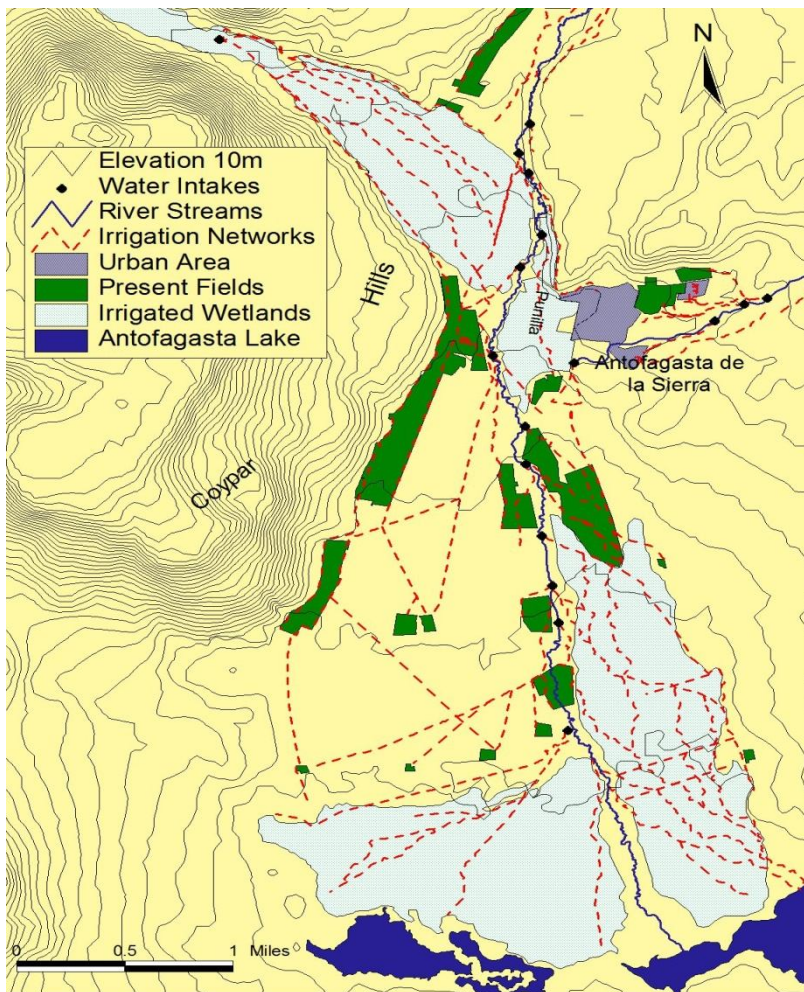


Figure 9: Approximate Distribution of Modern Network of Irrigation Canals

A series of secondary canals distributed water from Canals A and B. Those connected to Canal A were oriented Northwest to Southeast, while those of Canal B went in an East to West direction. The North to South oriented canals took advantage of the maximum slope of the terrain and water flowed at relatively high velocity. East to West canals were oblique to the maximum slope and delivered water to plots at a lower velocity. The irrigation system also used the demarcated land plots to conduct water, these diverted water from plots adjacent to secondary canals to those further removed from these canals along a contiguous path.

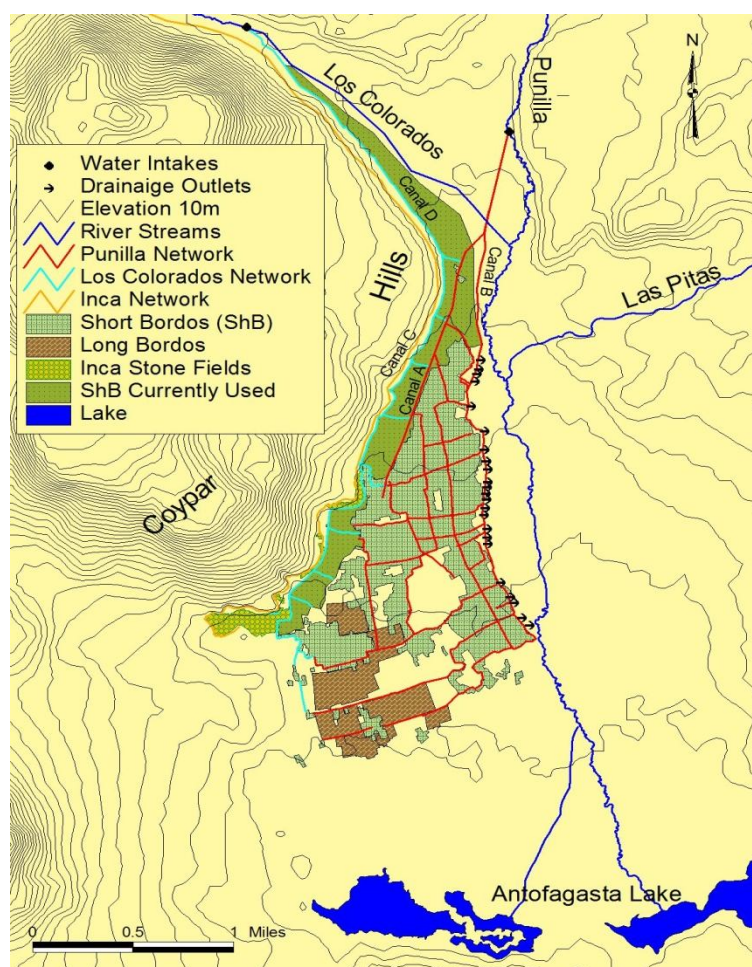


Figure 10: Distribution of Agricultural Technologies and Network of Prehispanic Irrigation Canals

The Los Colorados irrigation network can be divided into two sub-networks, one higher and the other lower similar in general layout to the Canal A Punilla network. The lower sub-network was characterized by a main canal – Canal D – excavated directly into the earth substrate, it seems to have been used during the Late Period (AD 850 – 1480), and started at an altitude of 3380 meters bringing water from a spring located in the Los Colorados Ravine to the high terrace and alluvial fan sectors. The higher sub-network started at 3400m drawing water from another spring and seems to have been constructed and used during the Inca Period (AD 1480-1532). The main canal – Canal C – of this sub-network was 7 km in length and stone-lined. Secondary canals were oriented West to East and transported water from Canal C to the terraces and stonewalled plots. The Los Colorados and the Punilla networks were linked by several interconnected, minor canals (Figure 10).

To summarize, ancient irrigation at the lower Punilla River Basin was dependent on only, two main irrigation networks. The first part of the system transported water at relatively high velocity through single canals that took advantage of the maximum gradients in the terrain. By the second stage at around a distance of 900 m South from the starting point networks fanned out into several more minor branches that covered the entire cultivatable surface. Secondary canals oriented East to West reduced flow velocity to allow for easy irrigation of agricultural plots.

Floodgates were probably improvised, like nowadays, removing *bordos* humps when and where it was necessary. Finally, when it was necessary excess water was diverted back to Punilla River through the use of drainage sluices. This is in sharp contrast to the present-day jumble of multiple mini-irrigation systems usually maintained by individual households.

4. Discussion

Although the Puna de Atacama is a desert environment the lower Punilla River basin is a veritable resource oasis located in the Antofagasta de la Sierra region. Furthermore, archaeological and palaeoenvironmental evidence shows that the Punilla River has always provided water for the area, especially the lower basin sector. This water supply, if well managed, was enough to irrigate the totality of the Prehispanic fields in the area.

Other environmental limitations to intensive agriculture such as night frost, salinization risk and water distribution were ameliorated during the late Prehispanic period (AD 850 – 1532) by a combination of technological innovations that improved soil and water management.

During the Prehispanic period cultivation was conducted mainly on the high terraces where soil with high permeability reduced the risk of salinization. Although the local water has low conductivity values, inundation irrigation does lead to soil salinization as has been observed in large areas of modern-day irrigated pastures, as well as within smaller patches of the fields presently under cultivation (Olivera & Tchilinguirian, 2000; Olivera & Vigliani, 2000/2002). The number of Prehispanic water excess drainage sluices (Figures 5 and 10) testifies to ancient worries concerning the risk of flooding and concomitant salinization. In addition the creation and maintenance of bordos also helped to reinforce and prevent accumulation of salt, thereby enabling the long-term sustainability of these agricultural fields.

Both the high terrace and lower slope soils are inadequate for agriculture without the use of fertilizers. Ethnological examples (García et al., 2002) and indirect archaeological data (Tchilinguirian & Olivera, 2010) – phosphorus soil values – suggest that animal dung, in the past probably from camelids, was the main source of fertilizer and nitrogen used in rendering these fields productive. This underlines the key role that animal husbandry in the area has played in making agriculture sustainable in the long-term (Olivera & Grant, 2008).

The configuration of agricultural space and the pattern of irrigation networks permit us to sketch the social organization of labor and other related activities. Past and present irrigation network designs reveal important aspects of the social management of water use. The regular grids of Prehispanic field plots indicate that ancient settlement grew around a strict adherence to the Punilla and Los Colorados irrigation networks layout and an underlying principle of contiguous and interdependent construction. This regularity juxtaposed to the lack of significant social stratification seen in the settlements would seem to indicate a community-based management of water resources in the lower Punilla River basin. This form of community management of local hydric resources has been inferred for other areas of the Andes (e.g. Erickson, 1993; Lane, 2009; Sherbondy, 1994).

The implication for the lower Punilla River basin is that the community regulated the location of new plots in relation to the existing irrigation networks as well as implicitly the allocation of water perhaps through a system of community water managers.

Further evidence for community, rather than state or household, management of water would seem to be suggested by the gradual accretion of fields and secondary canals that we observed whilst in the field. This type of unified or centralized community management does have modern analogues (Gelles, 2000; Hunt & Hunt, 1976; Mitchell & Guillet, 1994; Trawick, 2001; Treacy, 1994) and in this area it does not seem to have come under excessive scrutiny during the Inca Period (AD 1480 – 1532). Indeed, the Incas seem to have constructed their own independent water supply – Canal C – impacting as little as possible on the pre-existing local network.

Another important factor to note is the regular size of the plots and the similarity in the local conditions of these. This implies that a certain standardized size was used for these plots so that their water requirements would have been roughly similar. Equally, the land plots were regularly patterned in a manner such that water wastage would have been kept at a minimum, an important consideration in an agriculturally marginal area such as this. Again this is an aspect common to how certain modern-day communities organize their space (e.g. Trawick, 2001; Treacy, 1994). Finally, this community enforced regularity, management and redistribution system could well have hampered, in some measure, antisocial activities in the use and abuse of water, such as occur at present.

A comparison between past and present irrigation networks shows that late Prehispanic use and distribution of water in the lower Punilla River Basin followed a more rigid and community centered system than the one currently in use. Indeed, the modern system seems to be both improvised and household oriented. This can be seen by the existence of several independent networks and the large number of associated canals as opposed to the well-organized and rationalized system that existed in the past. An ethnographical study on Antofagasta de la Sierra shows the difficulties that current irrigation authorities have in getting the individual irrigators to observe the pre-established turns of water use (García et al. 2002). The authors suggest that this is due to the lack of resources such as motor vehicles and fuel, but a further and crucial reason for these regulation violations might be the decentralized irrigation network design that exists at present.

Another important aspect of modern water management is the social inequality that exists amongst the agro-pastoralists of Antofagasta de la Sierra. Differences in wealth amongst the individual households in the area create differential access to scarce water resources such that the more prosperous families can usurp with relative impunity water from less well-favored families (García et al., 2002). The intricate and highly personalized irrigation networks in existence today make it very hard to equitably regulate allocations of water. Overall modern water management is singularly ineffective, benefitting individual households rather than the community at large, and in turn contributes to wastage, salinization of fields and lost productivity leading invariably to a significantly lower level of settlement and the increased marginalization of this rural zone.

5. Conclusion

When comparing past and present agricultural production and water management it is apparent that past societies had a more efficient and sustainable approach to use of the zones resources. In effect Prehispanic strategies effectively pushed the boundaries of viable and productive agriculture through a combination of well-regulated irrigation networks and access to water combined with the effective use of technology such as bordos to maximize yields and ameliorate the harshness of the environment. Although some social stratification might well have existed amongst the late Prehispanic communities of Antofagasta de la Sierra this was not sufficient to offset the benefits of a community-based water management system. In large measure the Inca state seems to have accepted local sensibilities in this respect.

In contrast, current hydraulic management misuses water in a variety of different ways, lowering the phreatic water levels, producing soil salinization and causing occasional shortages in distinct zones due to over inundation, as well as other problems derived from an unrestricted and poorly managed use of hydric resources.

To conclude, the lower Punilla River Basin case study not only helps us understand better the prehistoric economic processes and systems in place in the Southern Puna de Atacama area, but also serves as an important alternative vision to what is possible in an area currently considered marginal and inadequate for large-scale agriculture and long-term settlement.

The fact that, under similar climatic conditions, productivity in the past was considerably higher than at present should make us pause and think about what is wrong with the current system and encourage us to alter it. Such a move would benefit not only the human communities in the area but more widely the bio-systems of this high altitude desert.

6. References

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