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A B S T R A C T

This paper reports new data on Qocha ponds from the Rio Pucará–Azángaro interfluvial zone, northern Lake Titicaca Basin, Peru. Qocha are a little known form of Andean agriculture that developed around 800–500 B.C. and remain in use today. Prior estimates suggested that in the study area, there were more than 25,000 Qocha. While most Andean sunken beds are excavated to reach groundwater, Qocha are rain-fed ponds. How these rain-fed ponds functioned has been an open question, but one that is answered in part by research presented in this paper. We suggest that a thick impermeable stratum of clay that was possibly deposited by paleolake “Minchin” created a perched water table that makes rain-fed Qocha reservoir agriculture possible. Field geology shows that within the study area, this stratum only exists under Terrace E. Based on this model, we hypothesized that persistently used Qocha should only be found on Terrace E. To test this hypothesis we used remotely sensed data to inventory Qocha and to determine their distribution by each terrace present. We identified 11,737 Qocha. By area 93.77% and by count 94.33% of the Qocha are located on Terrace E. These results strongly supported our hypothesis. This case study illustrates that the long term viability of this form of agriculture is made possible by a physical context that is beyond human control.

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1. Introduction

This paper reports new data from the northern Lake Titicaca Basin regarding a type of poorly understood precolumbian agricultural infrastructure that remains in use today—the rain-fed Qocha reservoir. Cultural processes such as the development and long term use of agricultural infrastructure must be considered in light of how they are permitted and constrained by spatio-temporally variable physical contexts that are beyond human control. We provide an example of this relationship through a case study from the Pucará–Azángaro interfluvial area of the northern Lake Titicaca Basin. We hypothesize that in this area, lacustrine clays formed by paleolake “Minchin” create a perched water table, and this geologic phenomenon makes rain-fed Qocha pond agriculture hydrologically possible. Given this model, we hypothesize that persistently used Qocha are restricted to those areas where the paleolake clays are extant. We test this hypothesis by using remote sensing to inventory Qocha and evaluate their distribution in relation to the extent of the paleolake clays. First we introduce relevant background information that highlights the anthropological importance of the region under study and summarize the relevant prior knowledge regarding Qocha. We then continue by presenting our geologic model and specifying the hypothesis that derives from it. Following this we present our methods and results. These data are then brought to bear on the hypothesis that derives from our model.

2. Background

With respect to geography, high resolution climate reconstructions, the origins of agriculture, and the development of socio-political complexity, the Lake Titicaca Basin—and the northern basin in particular—is an extremely important region. By volume of water, Lake Titicaca is the largest lake in South America (WWDR 2003). Laminated sediments from the main basin of Lake Titicaca provide a high resolution, long term, multi-proxy climate record.
Five major rivers drain into Lake Titicaca. Located in the northern basin, and formed at the confluence of the Ríos Pucara and Azángro, the Río Ramis has the greatest discharge of any of these five drainages (Fig. 1).

Recent studies indicate that the northern basin is a probable location for the domestication of potatoes and chenopods (Bruno, 2006, 2008; Rumold, 2010; Spooner et al., 2005). Considered as a whole, the Lake Titicaca Basin is a largely autonomous area of ancient state formation (Stanish, 2001, 2003). Within this region, the earliest evidence for sustained socio-political complexity comes from the archaeological site of Pukara (Klarich, 2005, 2009), located in the northern basin to the west of the Río Pucara. Immediately to the south of the site of Pukara, in the area between the Ríos Pucara and Azangaro, lies the system of intensified agriculture that consists of reservoirs or ponds that are known as qochas. Qochas from this area were initially described as occurring in the “mesopotamia” or chapwimuyu of the Ríos Pucara and Azángaro (Flores Ochoa and Paz Flores, 1983a: 69, 72, 1984: 68, 88, 93). In Quechua, chapwi means middle, center, or between and mayu means river. This chapwimuyu is host to the single largest concentration of qochas known anywhere in the Andes (Erickson, 2000: 341), and this concentration of qochas has been linked to the rise of the Pukara polity. This interfluvial zone, from the confluence of the Ríos Pucara and Azángro northward past the town of Pucara, forms our study area (Fig. 2).

Many physical and social facets of qocha agriculture are documented in the pioneering work of Flores Ochoa and Paz Flores. Yet, in 1999, qocha were still described as “poorly studied infrastructure” “infraestructura muy poco estudiada” (Valdivia et al., 1999: 149; authors’ translation). To the best of our knowledge, since 1999, no new empirical studies of qocha agriculture in the northern Lake Titicaca Basin have been conducted or published. As of the year 2000, the origin and history of qochas agriculture in the northern Lake Titicaca Basin remained largely unknown, and a comprehensive inventory of qochas in the Pucara–Azángaro interfluvial did not yet exist (Erickson, 2000: 341). In this paper, we report an inventory of qochas that considers their distribution in relation to landscape evolution. In doing so, we provide a refined understanding of how natural and cultural processes interact with this agricultural technology. First we briefly review relevant prior research on qocha. This review both highlights earlier results that our study refines and identifies the fact that how qocha ponds are capable of holding water remains, up until now, an un answered question. This question is answered by our new geologically oriented model for qocha distribution.

2.1. Temporal context

It has been suggested that within the Lake Titicaca Basin, associated, temporally diagnostic artifacts indicate that all of the major
agricultural techniques, including *qochas*, appear to have developed by as early as 800 B.C., and probably before (Stanish, 2007: 130, 2006: 390). *Qocha* agriculture was first formally reported in the early 1980s by Flores Ochoa and Paz Flores, (1983a,b). In the area where they examined *qochas*, they found few pieces of pottery but those recovered were generally diagnostic Pukara type fragments. Near Llallahua, where there is a major concentration of *qochas* (Fig. 2), researchers have reported the presence of a Pukara style carved monolith located on top of Mount Kojra (Flores Ochoa and Paz Flores, 1986: 103; Rowe, 1942: 72). Flores Ochoa and Paz Flores suggested that all the *qocha* in the Pucara–Azángaro interfluvial are located within a day to a day and a half walk from the site of Pukara (Flores Ochoa and Paz Flores, 1983a: 75, 1983b: 139, 1984: 95, 1986: 103–104, 1987: 95–96, 1992: 264; Flores Ochoa et al., 1996: 256; Washington and Alvarez, 1991: 171). The close spatial association of the *qochas* to Pukara, the presence of Pukara style polychrome pottery in direct association with the *qochas*, and the location of a Pukara style carved monolith near the *qochas* led these investigators to suggest that *qochas* helped to supply the growing needs of the newly emerging urban center at Pukara (Flores Ochoa, 1987: 286–287; Flores Ochoa and Paz Flores, 1983a: 74–75, 1983b: 139, 1984: 95, 1986: 103–104, 1987: 95–96, 1992: 264; Flores Ochoa et al., 1996: 256; Washington and Alvarez, 1991: 171).

Limited sub-surface testing was undertaken at two sites that are directly associated with *qochas* (Alenderfer and Flores Blanco, 2008): Tulani (RM621–622) and Laroqocha (RM1190, 1192, 1194–1195). Tulani is a 1 ha dense surface scatter that contains pottery, chipped stonedebitage, obsidian, and stone hoe fragments. Following the typology of Chávez Justo (2008a,b), the surface pottery assemblage from the site consists of Formative (ca. 800 B.C.–A.D. 400), Early Huaña (ca. A.D. 100–600), Altiplano (A.D. 1100–1475), and Inca (A.D. 1475–1532) styles. Three 1 × 1 m sub-surface test pits were excavated in Tulani. These excavations revealed the presence of stone hoe fragments, burned camelid bone, obsidian projectile points, temporally diagnostic pottery, and numerous small ash filled pits. Following the typology of Klink and Aldenderfer (2005), the projectile points are Type 5B and 5D forms. Excavations recovered a single Qaluyu sherd; Qaluyu–Pukara transitional and Pukara were the dominant pottery styles (Table 1). Early Huaña and Altiplano style fragments were present, but in much lower abundance than either Qaluyu–Pukara or Pukara materials.

Laroqocha is a 3.2 ha scatter of artifacts that is composed of pottery, chipped stone debris, and stone hoe fragments (Fig. 3). Surface pottery consists of Middle–Upper Formative (ca. 800 B.C.–A.D. 200), Early Huaña, Altiplano, and Inca styles. Three 1 × 1 m sub-surface test units were excavated into Laroqocha. This sub-surface testing revealed the presence of fragments of burned camelid bone, concentrations of burned clay, chipped stone debitage, hoe fragments, and pieces of temporally diagnostic pottery. Excavations recovered eight Qaluyu sherds but the pottery assemblage is again dominated by Qaluyu–Pukara and Pukara sherds; Huaña and Altiplano style materials were much less abundant (Table 1). Excavations also exposed an earth oven in association with Pukara pottery. Together, Tulani and Laroqocha reveal that significant amounts of Middle Formative pottery and agricultural implements are found in direct association with *qocha* ponds (Fig. 3). Both Tulani and Laroqocha are located on river Terrace E (see below).

While stylistically diagnostic pottery reveals associations between Qaluyu–Pukara transitional (ca. 800–500 B.C.) and the *qochas* of the Pucara–Azángaro interfluval, somewhat later Pukara (ca. 800 B.C.–A.D. 200) style pottery is far more abundant. The presence of Qaluyu and Qaluyu–Pukara pottery, both earlier Middle Formative styles, in association with these *qochas* indicates that in the Pucara–Azángaro interfluval this agricultural technology likely predates the apogee of the Pukara polity. However, the greater abundance of Pukara pottery in association with these *qochas* indicates that the ponds were probably used more intensively during the height of the Middle Formative Period (ca. 500 B.C.). Material from later traditions including Huaña, Altiplano, and Inca are also found in direct association with the Pucara–Azángaro *qochas*. These associations with later temporally diagnostic styles indicate that *qocha* infrastructure remained in use well after the decline of the Pukara tradition. However, the lower abundance of post-Pukara forms suggests that after the decline of Pukara the intensity of *qocha* use probably declined.
maps (Flores Ochoa, 1987: 282–283; Flores Ochoa and Paz Flores, 1983a: 69; 1983b: 134; 1984: 88–89; 1986: 97; 1987: 87; Flores Ochoa et al., 1996: 254). They estimate that the study region has a total area of 528 km², and that about 384 km² of this is suitable for cultivation and pasture. According to their classification scheme: larger qocha are >200 m dia and >31,400 m² in area; the smaller and more numerous qocha have a mean area of 6500 m². Based on a 0.5 km² sample, Flores Ochoa and Paz Flores estimated the total number of qochas present in the chapwimayu of the Ríos Pucara and Azángaro (Flores Ochoa, 1987: 283–284; Flores Ochoa and Paz Flores, 1983a: 71; 1983b: 135; 1984: 91; 1986: 98; 1987: 89; 1992: 262; Flores Ochoa et al., 1996: 254). They counted close to twenty qochas in 0.5 km², and from this count they estimated that there are 80 qochas in 1 km². They assumed that qochas are circular, and modeled qocha size as 60 m dia. This gave each qocha an area of approximately 2863 m² (We note that the correct solution is 2827 m². However, we also observe that given a rounding operation that these authors later applied to the estimated total number of qocha, the difference in area is insignificant). Based on this estimate, there are 0.226 km² of qocha area per km². They assumed that the study area was 256 km², and from their 0.5 km² sample they calculated a regional total of 57.88 km² of qocha area. Dividing this by the estimated area of a single qocha (2863 m²) produced an estimated 20,215 qochas. The authors rounded this figure up to 25,000, and suggested it served as a conservative estimate of the total number of qochas in the study area (Flores Ochoa, 1987: 284; Flores Ochoa and Paz Flores, 1983a: 71; 1983b: 135; 1984: 91; 1986: 98; 1987: 89; 1992: 263; Flores Ochoa et al., 1996).

Based on estimates of the density of qochas per km², Flores Ochoa and Paz Flores defined three different zones (Fig. 2; Flores Ochoa, 1987: 283; Flores Ochoa and Paz Flores, 1983a: 69–70, Map 3; 1983b: 134, 151, Fig. 14, 1984: 89 Mapa 3; 1986: 97; 1987: 87, 89–90; 1992: 262; Flores Ochoa et al., 1996: 254, Fig. 122; Valdivia et al., 1999: 147, 148, Fig. 1):

1) Disused or Damaged
2) Spaced
3) Numerous.

The Disused or Damaged zone is located to the west of the study area, and they suggest that this area has an extent of about 128 km². Interpretation of aerial photographs led them to suggest that in this zone, salinization may have led to the deterioration of the qochas. They also note that several haciendas are present in this area including Qoa (Ccoa), Pichacani, and Cojempati. This led Flores Ochoa and Paz Flores to offer the alternative hypothesis that agricultural intensification on the part of the haciendas and the use of mechanized agriculture may have contributed to the deterioration of qochas in this zone. By flattening and leveling the ground surface,
mechanized agriculture can physically damage qochas. The Spaced zone is defined by areas where there are < 100 qochas per km². They estimate that the Spaced zone has an extent of approximately 96 km². It is located on the eastern side of the Río Azángaro in the areas known as Tuturco, Juyacache, Huayrapata, and the ex-hacienda Corpa in front of the town of Achaya and in the general area of Calapuja. The Numerous zone has a density of > 100 qochas per km², and this zone covers an estimated 160 km². The Numerous Zone is found around the communities of Iquilo, Mataro Grande, Llallahua, the former hacienda of Sullata, and in the Larco and Characayaca pampas. Having reviewed prior attempts to count and estimate the distribution of qocha we now turn to relevant aspects of the geologic setting of the region.

3. Geologic setting and expectations for Qocha location

Fluvial geomorphological research in the interfluvial or chap-wimayu of the Ríos Pucara and Azángaro indicated the presence of five river terraces and three major facies associations (Farabaugh and Rigsby, 2005). Termed A—E, A is the lowest terrace above the active floodplain and E is the highest (Fig. 4). The entire modern surface of the area between these two rivers is covered by a combination of braided and meandering fluvial sediments that form two of the region’s three major facies associations. The deposition and erosion of these two fluvial deposits is strongly correlated with periods of high and low precipitation respectively (Baker et al., 2001a). The third facies association is only found underlying Terrace E, and it is always found directly below the aforementioned fluvial deposits. This third facies association is composed of a meter-thick accumulation of thinly laminated gray to blue—gray clays that bear gastropods, ostracods, and abundant organic material (Fig. 5; Farabaugh and Rigsby, 2005: 19). These clays were deposited by the settling of fine particles suspended in a lacustrine environment (Farabaugh and Rigsby, 2005: 20). Carbon from this clay stratum dates to 40,170 ± 430 cal B.P. Although near the limit of finite radiocarbon dating, we trust that this single radiocarbon date corresponds to a wetter period from 46,000–36,000 cal yr B.P (Clapperton, 1993; Clapperton et al., 1997; Fritz et al., 2004) during which paleolake “Minchin” extended across vast areas of the Andean altiplano (Baker et al., 2001a; Fritz et al., 2004). The blue—gray lacustrine clay stratum underlying Terrace E is today found 40 m above the current level of the Rio Ramis and about 150 m above the modern level of Lake Titicaca (Farabaugh and Rigsby, 2005: 25). This implies that the water level of paleolake “Minchin” was at least 150 m above the modern level of Lake Titicaca (Fig. 1). We believe that subsequent tectonism, tilting due to folding and faulting, differentially elevated the northern shores of the Lake Titicaca basin since the original deposition of the lacustrine clay.

We hypothesize that the extent lacustrine clays deposited in paleolake “Minchin” are responsible for creating a perched water table, and it is this geologic phenomenon that makes rain-fed qocha pond agriculture hydrologically possible. If our model is correct, then the large majority of qochas should be located on Terrace E where the paleolake “Minchin” clay is present. Experimentation and attempts to expand this agricultural infrastructure may have resulted in the presence of a few qochas on lower terraces.

4. Methods for inventorying Qocha and evaluating geologic expectations for their location

To determine 1) the total number and density of qochas and 2) whether or not they are restricted spatially to Terrace E, the entire lower interfluvial zone of the Ríos Pucara and Azangaro was examined by inspecting satellite and aerial remote sensing imagery. In any remote sensing survey, the ability to detect features is a function of the size of the targets of interest and the spatial resolution of the imagery (Craig and Chagnon, 2006; Jensen, 1996; McGwire et al., 1996: 102–105, Fig. 6.2; Sabin, 1987). In addition to prior publications, field survey and GPS data that we collected from the interfluvial region indicated that qochas were generally larger than 30 m. We had access to 0.5 m spatial resolution aerial photographs that covered the entire study area. Thus, the size of the features and the resolution of the imagery rendered qocha reservoirs well suited for mapping with satellite and aerial remote sensing imagery.

Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) level 3 orthorectified imagery covering the study area was obtained from the Land Process Distributed Active Archive Center (LP DAAC). An image captured on 15 August 2007 covered the entire study area in a single cloud-free scene. From this multispectral dataset, a VNR 1,2,3N band false color composite image was created and inspected. Declassified CORONA imagery was obtained from the USGS as a film positive. The CORONA image
was captured 30 June 1979 (mission number 1215-5, Ops designation 00473). The image was taken with the KH-9 film camera, which has a reported spatial resolution of 20–30 ft (6–9 m). The film was scanned at 3000 dpi and georeferenced to the orthorectified ASTER false color composite. We purchased 1 m spatial resolution IKONOS-2 satellite image that was captured on 20 June 2001 (Fig. 3). Printed paper aerial photographs covering the study area from August of 1979 that are available through Programa Especial de Titulación Tierras (PETT) were scanned at 3000 dpi and georeferenced to the ASTER and CORONA images. Examination of the scanned PETT imagery indicated that the aerial photographs had a spatial resolution of 0.5 m. This resolution is more than sufficient to detect qochas (e.g. McGwire et al., 1996: 104). Field checking showed that anomalies interpreted in these air photos were in fact qochas.

The georeferenced IKONOS-2 scene and the PETT images were visually inspected and all detectable qochas were digitized into a geographic information system (GIS) as polygon features. In the imagery, qochas were identified based on two primary criteria: 1) the anomaly appeared to be a basin and 2) canals were visible either entering or exiting the basin-like anomaly. In most cases, the basin-like anomaly bore evidence of recent cultivation. In some cases, the basin-like anomalies appeared to be no longer under cultivation. These anomalies were interpreted as qocha which are
no longer in use. Some of these basin-like anomalies were extremely faint, and a conclusive identification could not be made. Field checking confirmed that these features likely represent abandoned and badly eroded qochas. These extremely faint basin-like anomalies were not inventoried.

River terrace breaks were identified and defined through field geology (Farabaugh and Rigsby, 2005). These terraces are large features that are easily observed in the satellite and aerial imagery. The terraces were digitized from inspection of the ASTER, CORONA, IKONOS-2, and PETT images.

From the GIS polygon coverages we determined: qocha count, qocha area, terrace extent, and terrace area. This allowed us to calculate: qocha count by terrace, qocha area by terrace, and mean qocha area. These calculations provide a test of the hypothesis that persistently used qochas should only be located on Terrace E where the paleolake “Minchin” clay is present. We also provide revised density calculations that are based on both qocha count and qocha area.

5. Results of the inventory

Within the survey area, a total of 11,737 qochas were remotely identified and digitized as polygons (Fig. 6 and Tables 1 and 2). In terms of the area of these polygons, 99.5% of the qochas fall within two standard deviations of the mean. 57 or 0.49% of the qochas have areas that are larger than two standard deviations of the mean. We characterize these as exceptionally large qocha (area >2s). In terms of either counts or proportions of the total survey area, it is useful to retain the exceptionally large qochas in the sample. Outlier removal helps to reduce skew, and this operation is important for equations that assume a normal distribution. We present both transformed and untransformed data since they provide distinct insights into qocha size.

Removing outliers, the mean declines by 178.43 m and it shifts towards the median (Table 2). Outlier removal decreases the standard deviation by 4903.92 m; the untransformed value is 3.45 times this figure. Outlier removal reduces the skewness from 81.99
to 2.41. Even with outlier removal, the distribution remains positively or right-skewed.

All of the qochas are located on Terraces C–E (Table 3). Together these terraces constitute half (50.6%) of the total survey area. Terrace E is a little more than a third (34.7%) of the total survey area, but the limits of this terrace contain 94.33% of the total qocha count and 93.76% of the total qocha area. Thus, 35% of the study area contains 94% of the qochas.

Considering qocha counts by terrace area, densities ranged from 0.6–62 qochas/km². Qocha density is highest on Terrace E (Table 4). With respect to their area, qocha constitute 6% of the study area. In terms of their area, qocha comprise >1% of Terrace C, 8% of Terrace D, and 17% of Terrace E. Exceptionally large qocha (area>25) are found on each of these three terraces.

6. Discussion of the results

The scanned PETT imagery that we used to detect the qochas has a spatial resolution of 0.5 m, thus each pixel covers an area of 0.25 m². Once the exceptionally large outliers are removed, qochas have a mean area of 2672 m². This indicates that typically a qocha is present in the Numerous Zone. The highest density of qochas (62 qocha/km²) is located on Terrace E. Our inventory indicates that qocha density by count is considerably lower than prior estimates. Even on Terrace E, the area of greatest qocha density, the ponds comprise less than 15% of the space. In light of this revised inventory, let us now return to our geologic model and the expectation regarding qocha distribution that derives from it.

In the remote past, palaeolake “Minchin” apparently extended across a large portion of the Altiplano including the interfluviu of the Ríos Pucara and Azángaro (Baker et al., 2001a; Fritz et al., 2004). Within the Pucara–Azángaro interfluviu, palaeoqocha “Minchin” left a thick deposit of laminar blue–gray lacustrine clays (Farabaugh and Rigsby, 2005). This deposit now underlies the highest Terrace E (Farabaugh and Rigsby, 2005: 24–26, Fig. 12). Elsewhere in the interfluvial region, within the mapped boundaries of the surfaces of Terraces D–A, river downcutting and erosion has removed this lacustrine unit.

With respect to our present study area, we believe that the impermeable nature of the lacustrine clay deposit is responsible for creating a perched water table that makes qocha agriculture possible. If this hypothesis is correct, then qochas should be located on Terrace E. Experimentation by early agropastoralists may have led to the expansion of qochas into the lower Terraces D–A, but our hypothesis dictates that the large majority of the qochas should be located on Terrace E.

The distribution of qochas conforms well to our hypothesis. Whether considered by count or by area, more than 90% of the qochas are located on Terrace E. The existence of 553 qocha on Terrace D and 39 qocha on Terrace C might appear to stand in contrast to our expectation that qochas should be located on Terrace E. However, field observations and remote imagery indicate that the qochas on Terraces D and C are largely abandoned. The extremely faint un-definable basin-like anomalies described earlier were located within the limits of Terraces D and C. Notably, these two terrace are within the Disused or Damaged Zone that was defined by Flores Ochoa and Paz Flores (compare Figs. 2 and 6). In light of this, we suspect that qochas were created on Terraces D and C during a period of agricultural expansion. Following this period, qochas within this zone were abandoned. Periodically, people may re-attempt use of qochas on these terraces. Yet compared to Terrace E, use of qochas on Terraces D and C was limited in both scope and duration. Further investigation of this zone is required to more fully understand what we believe represents a fluctuating use of Terraces D and C for qocha cultivation.

7. Conclusions

Qaluyu (ca. 800–500 B.C.; Browman, 1980; Chávez, 1977), Qaluyu–Pukara transitional (ca. 750–200 B.C.; Chávez Justo, 2008a: Fig. 14), and Pukara (ca. 800 B.C.–A.D. 200; Stanish, 2006: 85–89; Klarich, 2005: 242) are the earliest pottery styles found in association with qocha ponds that are located on Terrain E. Near Llallahu, a Pukara style caved monolith was is found in association with qochas (Flores Ochoa and Paz Flores, 1986: 103; Rowe, 1942: 72). Recent pedestrian surface survey located a Qaluyu–Pukara
style stone monolith that was placed inside a large qocha named María Huancaque Qocha which is located near the community of Chiqchipani. Excavations at Tulani (RM621–622) and larroqocha (RM1190, 1192, 1194–1195) produced an abundance of Middle Formative ceramics and stone hoes. Both of these sites are situated on Terrace E and are found in very close association with a dense concentration of qochas. Together, these associations suggest that on Terrace E, use of qochas began by at least 500 B.C. and probably earlier. Within this same area, pottery diagnostic to all major time periods is found in association with qochas (Aldenderfer and Flores Blanco, 2008). Based on pottery styles, Pukara appears to represent the most intense use of qochas. Pottery styles that post-date the Middle Formative are much less abundant. This suggests that qochas were used less intensively after the decline of Pukara. Yet, the qocha on Terrace E are still used today by modern Quechua agropastoralists. On Terrace E, the multiple associations with ancient and modern material culture indicate that qochas have been used, perhaps in different ways and probably with varying degrees of intensity, over a period of 2500 years. Yet the capacity for the success of long term agricultural technology is dictated by geologic intensity, over a period of 2500 years. Yet the capacity for the success of long term agricultural technology appears limited. The viability of this agricultural technology appears limited. The quaternary glacier advances and palaeoalka highstands in the bolivian altiplano. Quaternary International 38–39, 49–59.


