Ground Based Lidar of Ancient Andean Agricultural Systems

By: Ana Cristina Londoño, Megan Hart, Patrick Ryan Williams, Megan Hente, Donna J. Nash, and Sofia Chacaltana C.

Londoño, Ana Cristina, Megan Hart, Williams, P. Ryan, Megan Hente, Donna J. Nash, & Sofia Chacaltana C. 2013. Ground Based Lidar of Ancient Andean Agricultural Systems. In *Proceedings of the 2013 Digital Heritage International Congress, Volume 2* edited by Alonzo Addison, Livio De Luca, Gabriele Guidi, & Sofia Pescarin, pp. 507-510. Institute of Electrical and Electronics Engineers, New York.

Made available courtesy of the Institute of Electrical and Electronics Engineers, Inc.: https://doi.org/10.1109/DigitalHeritage32292.2013

Abstract:

The geomorphology of arid southern Peru has been sculpted by an impressive anthropogenic landscape: kilometers of desert transformed into agricultural terraces abandoned for the past 500 and 1000 years; these include the Inka (1450-1532 CE) agricultural systems at Camata and the Wari (600-1000 CE) agricultural systems at cerros Mejia and Baúl. Initial survey of these Andean agricultural landscapes indicates that processes of water erosion and degradation of constructed features have started, compromising the preservation of this important archaeological legacy. In this paper, we evaluate the use of ground based lidar for subcentimeter resolution surface mapping of terraced Andean agricultural systems, as well as its suitability for fine-scale surface mapping for reconstruction of micro-elevation models of past anthropogenic landscapes and for the understanding of erosion processes in arid lands. A major source of soil loss in dryland areas is the abandonment of agricultural fields. The lack of maintenance of the infrastructure of these once productive agricultural systems accelerates the loss of productive soil, and causes land desertification. Erosion patterns can be used for estimation of erosion rates on disturbed areas under development or intense agricultural use in dryland environments. These rates give a sense of the magnitude of degradation of poorly maintained earthworks in dryland regions. The documentation and quantification of the pattern and rate at which these constructed landforms degrade is of paramount importance for finding a balance between preservation of the delicate arid landscapes and the sustainable development of these impoverished regions.

Keywords: archaeological prospection | archaeological mapping | laser scanning | Andean Prehistory

Article:

I. INTRODUCTION

Erosional dynamics are important for understanding drylands susceptibility to degradation. Moreover, determination of the rates and patterns of erosion in arid regions is essential for the establishment of sustainable arid agricultural practices and design of infrastructure in these generally poor and fragile areas. Erosion studies encounter complications when rates and processes are extrapolated from plot-scale to hillslope and basin scales studies [1]. In order to avoid scale errors, soil removal can be quantified through alternative field techniques, such as micro-topographic surveys (basin and hillslope scale), erosion pins, and rainfall simulations (plot scale). In order to test the effectiveness of micro-topographic surveys in determining rate and patterns of erosion, we used ground based LiDAR to detail the eroded anthropogenic surfaces of archaeological sites in southern Peru for use as proxies for natural environments. Detailed surveys using LiDAR based scanning provide important information about the accurate depiction of erosional features, the characterization of dominant geomorphic processes responsible for landform modifications in arid areas, and variations in erosion rates in agricultural terrace systems. Using data from micro-topographic surveys further delineates long term erosional evolution and morphologic dating under arid climatic regimes. This paper fully integrates the disciplines of geology and archaeology in order to further define the effects of erosional processes in drylands through the finely detailed survey of pre-Columbian agricultural systems. This study is fundamental to advancing our understanding of soil removal and its distribution from plot to basin scales in order to provide appropriate information for environmental management of drylands.

II. PREVIOUS WORK

The Moquegua Valley has been actively researched for over two decades [2,3,4]. Studies have documented the history and construction of the extensive and elaborate Wari and Inka agriculture terrace systems that occurred during the expansion of pre-Columbian colonies in the Andean region (Fig. 1). Large amounts of soil and rock were mobilized for these projects, creating land for cultivation through terracing [5]. In the Moquegua Valley (Fig. 1), the Wari (600 AD-1000 A.D) [3] and Inka (1450 to 1532 A.D.) [6] colonies occupied both the lowlands and the high sierra, developing irrigation systems to divert water from the nearby streams to the terraced agricultural fields [7]. After the collapse of the colonies in ~1000 A.D. and ~1532 A.D., respectively, most of these agricultural terraces were abandoned. Today, the study area remains sparsely populated which may be, at least in part, due to the rugged terrain and extreme aridity (ca. 5 mm/yr). Extreme aridity contributes to the lack of biological activity, with more than 95% of the surface area being lightly vegetated.

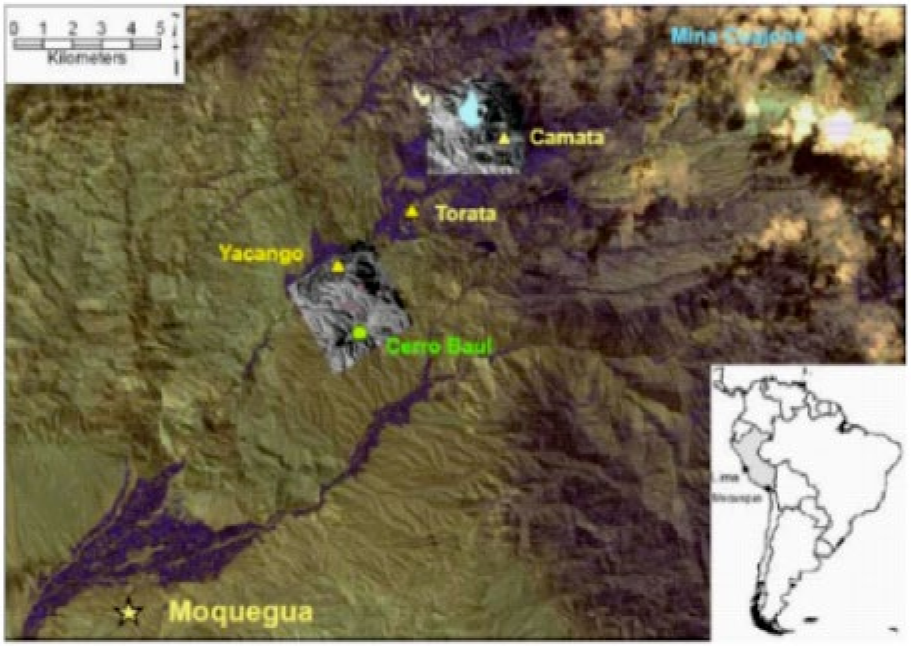


Fig. 1. Location of the Moquegua Valley in Southern Peru

Londoño [8, 9] previously mapped similar undisturbed, abandoned agricultural terraces in southern Peru to study and determine measurements for wash processes over a five century period. The results of this survey found that evidence of wash processes is visible in the agricultural systems through the development of rills and gullies and by a redistribution of terraced fill material on the hillslope. Inka systems present as spoon-shaped notches and channels; these notches are incised and/or bifurcated as piracy of the channels expands upslope and erosion progresses. In addition, erosional features are more pervasive in the older Wari systems, in these terraces, rills and gullies are present and elevation of the terrace tread has diminished considerably. In the most severe cases, only the base stone lining of the terraced wall is preserved.

With the advent of ground based LiDAR survey techniques, larger areal extents of surfaces can be mapped at higher resolutions resulting in greater detail than those performed previously by Londoño [8, 9]. Higher resolution and more accurate point cloud detail renders a more comprehensive and systematic documentation and measurement of the erosion processes that operate in the area, the architecture and layout of the agrarian systems, their construction methods, and their connectivity with irrigation systems. In addition, detailed mapping of the agricultural terraces allows for quantification of the material mobilized during terrace construction in these arid lands. This yields a measure of the geomorphic impact on the landscape imprinted by the pre-Columbian cultures that inhabited this area in southern Peru. We present this paper as documentation of the micro-topographic survey technique of ground based LiDAR scanning in pre-Columbian Wari and Inka agricultural systems of southern Peru as compared to previous efforts. Further, we measure and determine a detailed pattern and rate of hillslope processes under arid climatic regimes. Archaeologists will use this data to establish computer algorithms for building hydrological models of irrigation distribution systems. These models will examine the number and placement of administrative decision points within the irrigation system. By examining administration of irrigation systems, archaeologists are better poised to analyze centralization of control in agricultural decision making.

III. METHODOLOGY

The basis for such a systematic topographic study of the pre-Columbian agricultural terraces is complete three-dimensional documentation of point cloud renderings of the plan view and sections of the abandoned agricultural terraces. A characteristic feature of the terraces is their remote nature and association with archeological sites. They cover a large portion of the landscapes in mountainous southernmost Peru, and are expansive; they do not follow a consistent master plan other than extreme changes in topography, and are expressions of a once vivid and productive agricultural community which makes creating a three-dimensional rendering an extensive project.

We performed detailed rendering of agricultural surfaces using a Leica ScanStation 2 ground based LiDAR. We carried out scans on grids of approximately 100 x 100 m on terraced surfaces with vertical and horizontal resolutions of 25 and 30 cm; the resolution varied depending on the local topography and extent of the site. In each site, we scanned the surfaces from three different stations to obtain an accurate rendering of the terraced surface. Geographic coordinates for each target and stations were collected with a differential GPS for georeferencing of the scans and accurate locations. Subsequently, we performed scan registration with tools of Leica's Cyclone version 7.2 processing software to obtain an accurate 3D rendering of the surface.

IV. RESULTS

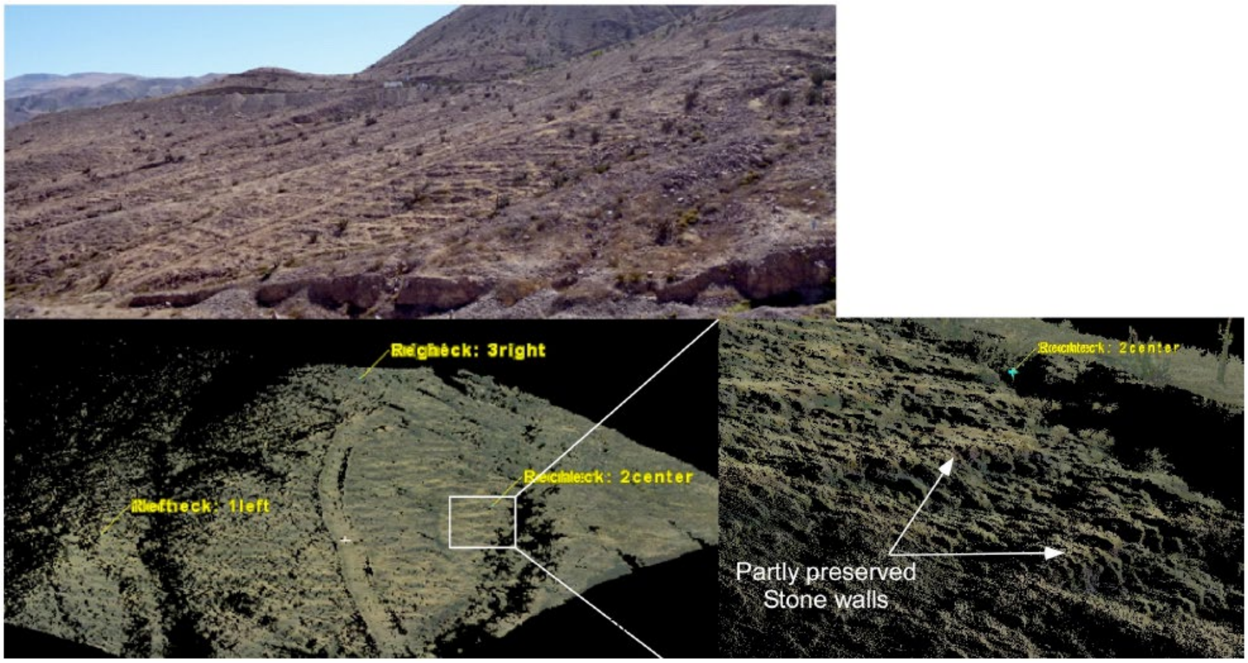
We present two case studies in Wari and Inka agricultural terraces. Their degree of preservation varies, Wari agricultural systems are characterized by more pervasive erosion in walls and the whole thread surfaces. In Inka systems erosion is less intense, and is concentrated in certain sections of the terraced walls, but better preservation is present.

A. Case Study: Lower Cerro Mejia

The oldest proposed study area is the Wari terrace network around cerros Baúl and Mejía. Radiocarbon dates and archaeological superposition place the construction of the system to the 7th century AD, with agricultural contraction beginning by 900 A.D. and complete abandonment by 1100 A.D. [3, 10]. The average slope of this system is 22 percent [11] with an irrigation canal length of over 14 km and an irrigation area of 325 hectares [4]. The administrative center for the Wari settlement was on the summit of the great mesa at Cerro Baúl.

Ground based LiDAR mapping shows that the hillslope is covered by rock fragments and gravel (Fig. 2). Cobbles are scatter throughout the terrace threads product of the collapse and failure of the risers above. Risers show different levels of preservation, some of the risers have been completely removed so that the terrace system resembles a planar slope and in other areas, risers range between 20 and 60 cm in height. Some of the risers have been breached, and spoon-shaped notches are formed; in this case, the mobilized material is deposited as fans. Preliminary results indicate that in the lower slopes of Cerro Mejía, erosion is primarily by diffuse slope wash.

Sediment removed from the slope is carried downslope, accumulating at the base of the risers and further down slope onto the treads.



In addition, microelevational data demonstrate a highly regular irrigation pattern on these terraces, with a central administrative decision point located near the head of the system, and no further subdivisions of irrigation administration within the sample except for the water diversion onto each terrace from the drop canal. Terraces were constructed via a cut and fill technique, with additional soil inputs from irrigation silts. Overall, this preliminary sample suggests a relatively centralized system of irrigation water distribution.

B. Case Study: Camata

The Camata agricultural system was abandoned by the Inka 450 years ago. Archaeological constraints and ethnohistoric data indicate this system was used for less than 100 years, and was abandoned shortly after the Spanish conquest [10]. The system has an average slope of ca. 31 percent [11], a canal length of 6.7 km, and an area of 341 hectares [4]. Analysis of micro-topographic surveys using ground based LiDAR show that the dominant erosional processes in these agricultural terraces consist of spoon-shaped notches that have destroyed sections of the terrace walls (Fig. 3). Continuous processes progress into development of small channels, some of which show initiation of bifurcation at their heads. Eroded material is deposited in several forms, small fans may form at the base of the terrace risers or may further extend, accumulating sediment as channel fill down the slope. In addition, LiDAR imagery depicts sections of terrace systems that have good preservation of their risers.

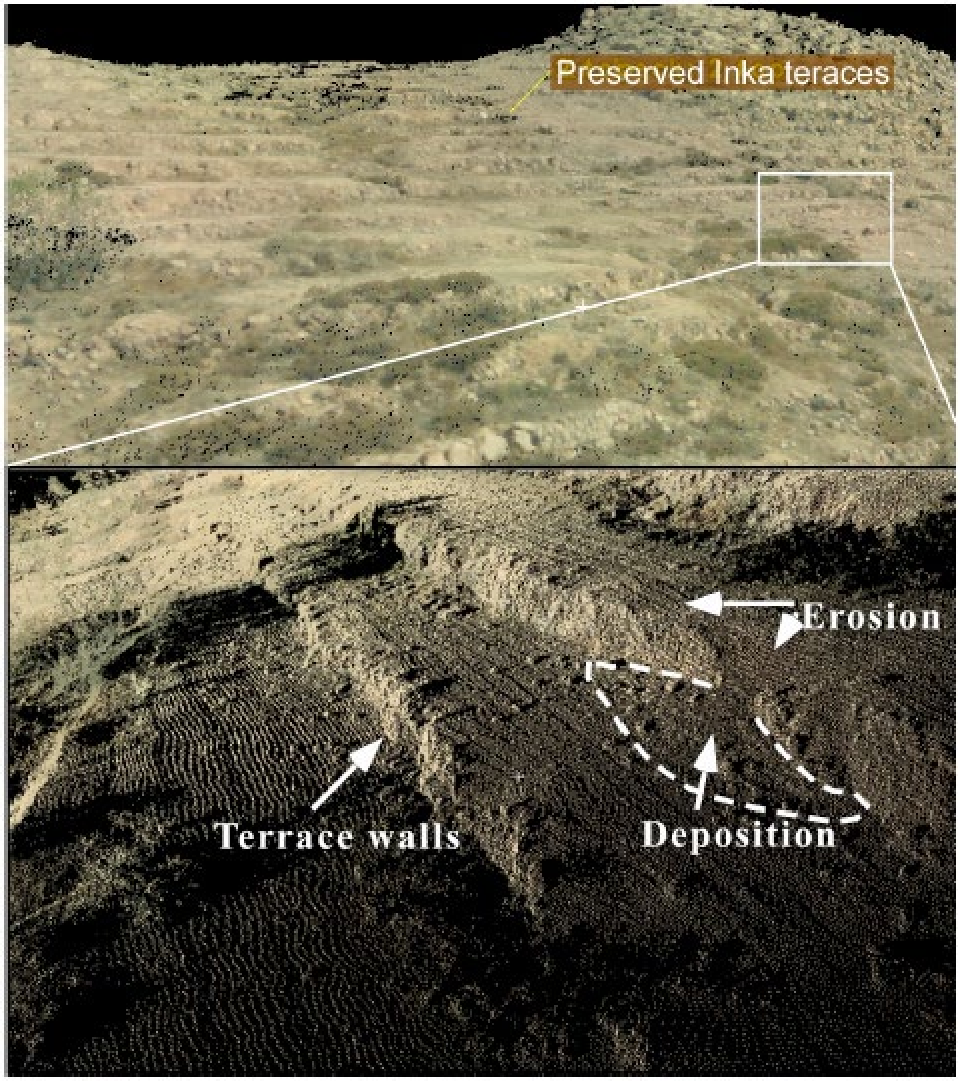


Fig. 3. LiDAR scan of Inka terraces at Camata.

V. DISCUSSION

Sub-centimeter accuracy micro-topographic surveys derived from ground based LiDAR on these terraces contribute to ongoing research on erosion processes on arid lands by providing an accurate depiction of physical baseline surveys. Using this data, the baseline physical survey of the terraced slopes is updated over time to determine erosional rates within the basins. Slope wash processes under arid conditions may be surveyed either by minute observation of modification by extant processes on natural slopes, or experimental hillslopes, by deduction from basin morphology and channel incision, or by observation of dated erosional features [8]. The latter approach requires the initial morphology and age of a slope be known, but these two conditions are rarely found on slopes formed by natural processes. Therefore ancient agricultural systems are ideal for the study of erosional processes: their initial morphology is known which permits accurate comparison of the original and present morphology of the slope. Also, most of the terraced areas have been virtually untouched since they were abandoned decreasing error due to surface disturbance.

Micro-topography derived from ground based LiDAR is ideal for the reconstruction of the post-abandonment topography of these ancient agricultural systems, necessary for erosion rate calculations; in addition, sub-centimeter elevation accuracy allows for mapping of minute erosional features that aid the understanding of the surficial processes acting on the terraced slopes. Ground-based LiDAR is a very efficient means of microelevational mapping due to the rapid acquisition time of millions of data points. What would normally require a week's time to map can be accomplished at higher resolution in less than a day.

These surveys have also improved the knowledge of the baseline level and complemented the existing and ongoing research of the Wari agrarian and irrigation systems. The new high resolution data will be critical to modeling slope stability and agrarian degradation [12], as well as providing high resolution digital elevation models for analyzing hydrological flow and decision making in irrigation systems [13]

In summary, the contributions of ground-based lidar to geoarchaeological research problems can be quite significant. Published studies on monitoring landslide bodies [14, 15, 16] and erosion studies [16, 17, 18] are complemented here by study of minute erosion features on anthropogenic landforms in the south-central Andes. Likewise, high resolution DSMs serve social scientists for modeling hydrological flow in anthropogenic irrigation systems.

ACKNOWLEDGMENT

This research project was made possible by the support of National Geographic GRANT #W259-12. The authors thank E. Calizaya, P. Escontrias, and D. Reid for assistance in the field. M. Moseley provided insightful comments and discussions surrounding the topics in this paper.

REFERENCES

[1] J. Poesen, Nachtergaele, J., Verstraeten, G., Valentin, C.,. Gully erosion and environmental change: importance and research needs. Catena 50, 2003, p. 91–133.

[2] M. Moseley, The Incas and Their Ancestors: The Archaeology of Peru. 2nd Ed., London: Thames and Hudson, 2001.

[3] M. Moseley, Nash, D., Williams P., deFrance, S., Miranda, A., Ruales, M., Burning down the brewery: Establishing and evacuating an ancient imperial colony at Cerro Baúl, Peru. Proceedings of the National Academy of Sciences 102, 2005, p. 17264-17271.

[4] P. R. Williams, Agricultural Innovation, Intensification, and Sociopolitical Development: the Case of Highland Irrigation Agriculture on the Pacific Andean Watersheds. In Agricultural Strategies, J. Marcus & C. Stanish, Eds. Los Angeles: Cotsen Institute of Archaeology, UCLA, 2006.

[5] J. Treacy, Denevan,W., The creation of cultivable land through terracing. In: Miller, N., Gleason, K. (Eds.). The Archaeology of Garden and Field. Philadelphia: University of Pennsylvania Press, 1994, p. 91–110.

[6] C. Dayton, Late prehistoric and modern irrigation agriculture in Torata, Peru. PhD dissertation, Boston University, 2008.

[7] P. R. Williams, Rethinking disaster-induced collapse in the demise of the Andean highland states: Wari and Tiwanaku. World Archaeology 33, 2002, p. 361–374.

[8] A.C. Londoño, Pattern and rate of erosion inferred from Inca agricultural terraces in arid southern Peru. Geomorphology 99, 2008., p. 13–25.

[9] A.C. Londoño, Arid geomorphic processes revealed by erosion of pre- Columbian archaeological earthworks in Southern Peru. PhD Dissertation, University of Cincinnati, 2008.

[10] P. R. Williams, The Role of Disaster in the Development of Agriculture and the Evolution of Social Complexity in the South-Central Andean Sierra. PhD Dissertation, Department of Anthropology, University of Florida, Gainesville, 1997.

[11] P. R. Williams, Agricultural Hydraulics and the State in the Torata Valley, Perú. MA Thesis, Department of Anthropology, University of Florida, Gainesville, 1995.

[12] P. R. Williams, D. K. Keefer, D. J. Nash, K. Sims, C. Dayton, M. Moseley. Envisioning the Invisible: Reconstructing the Taphonomy of Ancient Andean Agricultural Landscapes through GIS Slope Stability Models. *The Reconstruction of Archaeological Landscapes through Digital Technologies II,* M. Forte, Ed. Oxford: BAR Intl Series 1379. 2005, Pp. 53-59.

[13] P. R. Williams, Hydraulic Landscapes and Social Conflict in Middle Horizon Peru. in M. Forte & P. R. Williams, eds. *The Reconstruction of Archaeological Landscapes through Digital Technologies.* Oxford: BAR Intl Series S1151, 2003, p. 163-172.

[14] G. Bitelli, M. Dubbini, and A. Zanutta. Terrestrial laser scanning and digital photogrammetry techniques to monitor landslide bodies. *International Archives of Photogrammetry, Remote Sensing and Spatial Information Sciences* 35, 2004, p. 246-251.

[15] A. Abellán, J. M. Vilaplana, and J. Martínez. "Application of a longrange Terrestrial Laser Scanner to a detailed rockfall study at Vall de Núria (Eastern Pyrenees, Spain)." *Engineering geology* 88, no. 3, 2006, p. 136-148.

[16] A. Abellán, J. Calvet, J. M. Vilaplana, and J.Blanchard. "Detection and spatial prediction of rockfalls by means of terrestrial laser scanner monitoring." *Geomorphology* 119, no. 3, 2010, p. 162-171.

[17] N. J. Rosser, D. N. Petley, M. Lim, S. A. Dunning, and R. J. Allison. Terrestrial laser scanning for monitoring the process of hard rock coastal cliff erosion. *Quarterly Journal of Engineering Geology and Hydrogeology* 38, no. 4, 2005, p. 363-375.

[18] Milan, David J., George L. Heritage, and David Hetherington. Application of a 3D laser scanner in the assessment of erosion and deposition volumes and channel change in a proglacial river. *Earth surface processes and landforms* 32, no. 11, 2007, p. 1657-1674.