3D-Documentation and Modelling of Paracas Settlements in the Highlands of Southern Peru

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Abstract: In the context of a research project of the German Archaeological Institute (DAI) which studies settlement patterns of the Paracas culture (800-200 BC) in southern Peru, modern methods and techniques of remote sensing and 3D modelling were employed by the ArcTron3D company for the documentation of extended settlement and terrace systems in the highlands of the Andes of Peru. In this contribution we focus on the ongoing work for the documentation of the settlement of Collanco.

The 3D documentation of Collanco in 2013 took four days on site and produced a three-dimensional record of a 4.5 sqkm area - including archaeological terrace structures on about 2.5 sqkm. The airborne image documentation (SFM - Structure from Motion) was carried out from a paraglider. Additionally, a high-resolution landscape model including the terrace structures was recorded using a long-range terrestrial 3D laser scanner (Riegl VZ-400). The complementary SFM-photogrammetry data was combined with the laser scanning data using best-fit-operations.

Finally photogrammetry and laser scanning were deployed in combination as well for a very detailed record of a selected small settlement area with subcentimeter accuracy. Excavations in this area were carried out subsequently.

During data processing, an extensive 3D GIS system (Global mapper) was built up. All 3D landscape models and detailed models were brought together in the archaeological 3D information system aSPECT 3D. The data set can now serve as a basis for further landscape surveys, mappings and excavation.

1. Introduction

During the first milenium BC the Central Andean Area in Peru experienced a first period of cultural flowering, which found its manifestation in a more or less homogeneous style horizon, the so-called “Chavín Horizon”. The Paracas culture (800-200 BC) is the regional tradition on the south coast of Peru that incorporates the influences of the Chavín style in its cultural manifestations. The center of the Paracas culture is supposed to be located on the Paracas peninsula, in the Pisco valley, where the first remains of the Paracas culture were documented in the 1920’s (fig. 1)(Tello 1959). Despite of nearly 100 years of investigation of the Paracas culture, the knowledge about the settlements of the Paracas period is very limited. In recent years, however, many new Paracas sites were discovered, not only further south of the assumed central region of the Paracas culture in the department of Ica, but also in the highland regions of the Andes. This new situation makes it necessary to reformulate the question about settlement patterns, territory and the socioeconomic conditions of the time when the Paracas culture flourished on the south coast of Peru.

The research project of the German Archaeological Institute, which is financed by the German Research Foundation (DFG) in the framework of a French-German Cooperation¹, aims at the systematic documentation and investigation of Paracas settlements, in order to create a database of settlement patterns and architectural features for interregional

¹ The Paracas project is realized in cooperation with the Ecole des Hautes Etudes en Sciences Sociales (EHESS), Centre de Recherche sur L’Amérique Préhispanique (CeRAP), Paris, under the direction of Christian Duverger, and with the archaeologists Aicha Bachir Bacha and Oscar Daniel Llanos Jacinto.
comparisons. The focus of the German part of the project is on the highland regions of the valleys of Palpa, which constitute the northern part of the Nasca drainage, on the south coast of Peru (fig. 1). A typical feature of this region are the extended terrace systems, used in pre-hispanic times for settlement purposes as well as for agriculture. In the course of the systematic study of these settlements we discovered hitherto unknown settlement patterns, consisting of circular or oval plazas and patios surrounded by D-shaped structures. The documentation of these extended terrace systems, together with their associated settlements, are a challenge for modern systems of surveying techniques and 3D documentation. In this contribution we present the preliminary results of the application of remote sensing technologies and 3D modelling, especially our fruitful cooperation with the company ArcTron 3D at the Paracas site Collanco.

Fig. 1. Map of the south coast of Peru with the locations and archaeological sites mentioned in the text. Map: DAI/V. Soßna.

2. Geography of the south coast of Peru

Peru is divided in three major ecological regions: the desert coast along the Pacific Ocean, the high mountain ridges of the Andes and the tropical lowlands to the East of the Andes. The extremely arid conditions on the desert coast are caused by the cold waters of the Humboldt current, which in connection with the specific pressure conditions of the southern Pacific result in an inversion of atmospheric layers and in consequence in a deficit of precipitation and extreme aridity. The Peruvian desert coast, which can be considered as a northern extension of the Atacama desert of Chile, is one of the driest deserts in the world.
At the East of the desert coast are the mountain ranges of the Andes, which over a short distance of 50 to 100 kms rise to altitudes of almost 7000 m. The ecological parameters of the landscape change according to the altitude, resulting in an extremely varied mosaic of different life zones that were used by human societies in the course of prehispanic history in the most varied manners.

The tropical lowlands to the East, which can be considered as part of the Amazon basin, play a minor role for the considerations of our investigations presented in this contribution. But it can be assumed that the inhabitants of the coast and the highlands maintained relations with these regions already from the earliest times of human occupation of the Central Andean Area.

3. The Paracas culture

The Paracas culture developed between 800 and 200 BC on the south coast of Peru. The existing literature indicates that the territory of the Paracas culture is mainly confined to the modern department of Ica (fig. 1). Few investigations have attempted so far to define the exact political and cultural sphere of influence of the Paracas culture. In the same way, there are few studies that investigate the interaction between coastal and highland populations during the time of existence of the Paracas culture. The great majority of studies of the Paracas culture so far concentrated on the artifacts from a point of view of art history or technical history. The most investigated objects of the Paracas culture are the famous polychrome textiles, which in many cases proceed from grave looting activities without proper scientific documentation (fig. 2)(O’Neale 1942, Tello 1959, Wallace 1962, 1985; Dwyer 1971). An exception are the spectacular findings of mummy bundles excavated by the Peruvian archaeologist Julio C. Tello in 1924 on the Paracas peninsula (Tello 1959, Tello/Mejía Xesspe 1979).

The ceramic artifacts recovered during excavations, surface surveys and museum studies in the first half of the 20th century served as a base for the development of a style chronology of the Paracas ceramic, consisting of 10 phases (Ocuaje 1-10)(Menzel et al. 1964). During the few excavations in Paracas settlements, architectural details and settlement features have been described so far only superficially (Wallace 1962; Massey 1983, 1986; Canziani 1992). Nonetheless, during surveys realized especially in the Ica valley, settlements have been discovered which can be assumed to have been major political centers (Tello 1959; Wallace 1971; Cook 1999; Massey 1983, 1986, 1990). Of special importance are the extended sites with monumental architecture in the lower Ica valley, discovered in the 1940’s by Julio C. Tello and currently investigated by our French cooperation partners (Tello 1959: 59; Bachir Bacha/Llanos Jacinto 2012).

![Fig. 2. A typical Paracas textile. Phtoto: MNAA-H, Lima.](image)
4. The Paracas culture in the Nasca region

The Nasca region lies immediately south of the Ica valley. In 1996 the archaeologist Helaine Silverman, a specialist in archaeology of the south coast of Peru, described the archaeological knowledge about the Paracas culture in Nasca as follows: "... the valleys of the Río Grande de Nazca drainage were essentially outside the Paracas tradition [...]
(Silverman 1996: 131). Silverman by herself had registered numerous sites with evidence of Paracas occupation in her surveys in the Ingenio valley in the Nasca region. Due to the few surface findings and architectural remains with clear affiliation to the Paracas culture she concludes that the occupation of the Nasca valley during Paracas times was only very scarce (Silverman 1993, 1994).

Since 1997 the German Archaeological Institute is carrying out archaeological research in Palpa, in the northern part of the Nasca region. During the archaeological settlement surveys an unexpected number of sites of the Paracas culture were detected (Reindel et al. 1999). In the first phase of the project 120 Paracas sites were identified in an area between the foothills of the Andes and an altitude of 1200 masl. Most of the visible sites were located at the dry margins of the valleys. One of the best preserved site, however, called Jauranga, was located on the valley floor, where it was covered by deep layers of riverbed sediments (fig. 3). In 2003 the remains of a completely undisturbed settlement dating to the middle and late Paracas period (600-200 BC) were excavated (Isla et al. 2003). With the excavations in Jauranga it became clear that the Paracas culture was firmly established in the Palpa and Nasca region.

![Excavations at the Paracas settlement of Jauranga. Photo: DAI/J. Isla.](image)

In the surroundings of Palpa the remains of the early phase of the Paracas culture were found at two more sites, Mollake Chico and Pernil Alto. In Mollake Chico we discovered a tomb with ceramic, stone and metal offerings which show close relations to other cultures of the Chavin horizon of the Central Andean Area (fig. 4)(Isla/Reindel 2006). In Pernil Alto we excavated remains of the early Paracas culture, which were located above a settlement of the preceding Initial period (1800-800 BC) (Reindel/Isla 2008). These findings demonstrated that the Paracas culture not only was present in Palpa, but that the Paracas culture in Palpa was the result of a long-lasting local tradition.
Motivated by the rich findings on the coast, the research area was expanded to the East into the highland region of the Western cordillera of the Andes. There we located important Paracas sites in the middle reaches of the valleys and even in high altitudes, above 4000 masl (Reindel 2008, 2009). The sites described in this paper, Cutamalla and Collanco, were discovered and registered for the first time in the context of these settlement surveys.

Following the results of the investigations in the northern Nasca region, the traditional concepts of the territory of the Paracas culture had to be revised. In contrast to earlier concepts, the Paracas culture had deep roots in the Nasca region and obviously Palpa in all periods was a strong pole of development. On the other hand it became evident that the Paracas culture was not a merely coastal culture. It rather span all ecological levels of the western slopes of the Andes, from the Pacific coast, up to the highest peaks of the cordilleras. The exchange of economic goods between the different ecological zones seems to have played a crucial role for the development of the Paracas culture. The material manifestations of these economic relations are the different types of settlements that can be interpreted as installations for the exploitation of the resources of the different ecological zones.

5. The Paracas archaeological project

The current DFG project “Center and Periphery: the Territory of the Paracas Culture (800-200 BC) in Southern Peru” (in German: „Zentrum und Peripherie: der Siedlungsraum der Paracas-Kultur (800-200 v. Chr.) im Süden Perus“) aims at the characterization of the territory and the internal structure of the Paracas culture through the study of settlements and architectural remains. On a regional level it is intended to register the inventory of Paracas settlements as complete as possible. Two representative settlements, Cutamalla and Collanco, were chosen for a detailed 3D-modelling and excavation of the existing architectural remains. Architectural remains are found in form of settlement structures and agricultural terraces. Specific areas were selected for archaeological excavation.

In all settlements the enormous size of the sites is a serious challenge for documentation purposes. While the settlement areas are more or less suitable for surveying, the terrace complexes use to cover several square kilometers. These terraced landscapes, however, in our perception are crucial for the understanding of the whole question of settlement patterns of the Paracas culture. In order to satisfy our needs for a detailed and complete documentation of the available architectural evidence, we employed state of the art methods of surveying and 3D modelling.

The site of Cutamalla is located at an altitude of 3300 masl. This settlement can be regarded as typical for this ecological level, where sufficient water is available to practice intensive agriculture. The site of Cutamalla comprises an area of more than 100 ha, with extensive terrace systems, where in two clusters settlement clusters of different characteristics are located (fig. 5).
In Cutamalla we discovered settlement structures, which so far are unknown in the Central Andes. The basic settlement units of these structures may be described as D-shaped structures, grouped together in varying numbers, thus forming settlement clusters of different sizes. Major complexes are grouped around oval or circular patios. In their most regular layout circular sunken patios are surrounded by D-shaped structures. These circular complexes in some cases have diameters of more than 40 m. Inside the D-shaped structures excavations revealed deep shafts, carefully veneered with stone slabs. At the site of Cutamalla we found so far 16 of these circular complexes with sunken patios.
The function of the components of these newly discovered Paracas settlements so far are unclear. Initial hypotheses of the use of the circular complexes for agricultural purposes must be rejected on the ground of the results of the analysis of soil and pollen samples. The findings of different types of artifacts instead point to the production of some kind of articles that were later transported to distant regions, probably textile products. In the ecological zone immediately above the settlement of Cutamalla, which is located at 3300 masl, lie the grazing lands of the camelids (Lama, Alpaca), the most important fiber producing animals in the Andes.

During the initial research in Cutamalla we realized a terrestrial measurement of the settlement areas. Based on Quickbird satellite images with a resolution of 60 cm, we produced sketch maps for the later measurement of the architectural features. On the ground we complemented the sketch map by eyewitness. Then we realized the topographic measurement with a total station (Leica TCR 705). The data were processed in the field with Surfer and later converted in AutoCAD format.

In 2011 a team of the Institute of Geodesy and Photogrammetry (IGP) of ETH Zurich under the direction of Henri Eisenbeiß performed photogrammetric surveys with an octocopter, as well as laser scans with a Riegl scanner (Riegl VZ 400). The complex photogrammetric analysis is still in process. From the Laserscans we have first results that show clearly the surface of the terrain as well as the structure of terraces and buildings (fig. 5).
In the course of the different activities for the 3D-Modelling of Cutamalla it became clear that the remote sensing procedures delivered promising results. For a deeper understanding of the architectural structure of Cutamalla, however, it was necessary to intensively survey on the ground the detailed architectural features, consisting in many cases of rows of stones pertaining to an individual structure, and being covered in many places by vegetation. Only with the combination of the different methods of remote sensing and verification on the ground it was possible to completely map the different circular complexes and settlement structures of Cutamalla.

The site of Collanco is located at an altitude of 1700 masl, at the right margin of the Rio Palpa (fig. 1, 7-11). Extended terraces cover an area of approximately 2 square kilometers. Collanco can be regarded as a typical site for this ecological level. The valleys in these middle reaches of the Palpa river are deeply cut into the landscape. Agriculture is only possible at the irrigated bottom of the valley. The valley slopes are completely dry, with a vegetation of cactus and occasional shrubs. Climatic conditions, however, must have been different in the past. Palaeoclimatic studies in the course of previous investigations in Palpa revealed that the climate in the Paracas period must have been much more humid (Eitel et al. 2005; Mächtle/Eitel 2013). This may explain the extended agricultural terraces visible at the site. Because of the lack of water only the lowest of these terraces, close to the valley bottom, are in use still today.

In several sectors of Collanco, clusters of structures are located within the terrace complexes. These clusters were interpreted as settlement structures. The largest cluster of this type were found in the northeastern part of the settlement, on a slope with a slight inclination. The architectural cluster is composed of oval-shaped patios which are surrounded by D-shaped structures. These structures resemble in a certain way the circular structures of Cutamalla. But the structures in Collanco are less formalized and not as complete and symmetric like the ones in Cutamalla. Furthermore it has to be born in mind that the complexes in Collanco were built on slopes and were therefore adapted to the existing terrain, meanwhile in Cutamalla the terrain was artificially modified, in order to provide a even platform for the construction of the symmetric circular structures.

Collanco is a major settlement within an extended system of numerous other settlements of different sizes. The other settlements are located in the lower parts of the valley slopes, but also at higher altitudes, on the ridges of the surrounding hills and mountains. These ridgetop settlements are connected with the hinterland by transport routes, which in turn relate these valley locations with the sites of the high mountain area, like for example Cutamalla. Through the documentation of Cutamalla and Collanco it is therefore possible to gain a representative overview over the settlement system of the Paracas culture.

6. 3D documentation and modelling in Collanco

The ArcTron 3D GmbH², an engineering company specializing in archaeological 3D documentation, was commissioned by the German Archaeological Institute to carry out a 3D documentation of the larger settlement area of Collanco including its extensive terrace structures (Fig.7). The following objectives were defined for the mission:

- Documentation of the settlement areas and the widespread terraces
- Generating a 3D model of the entire belonging area (approx. 4,5 km²)
- Generating a contour lines map
- Surveying selected areas in high detail resolution for terrace measurements (slant)
- High-resolution documentation of the designated excavation area (approx 1.650 m²)

² ArcTron 3D Ltd. For more information about the range of services in the field of archaeology and heritage conservation visit www.arctron.de (German and English internet homepage. Current update 04.11.2013)
In cooperation with Markus Reindel, Martin Schaich realized an initial fundamental project layout prior to the field study. It included free and generally available satellite data (Google Earth / SRTM - Shuttle Radar Topography Mission).

In order to be able to adapt the workflow of the local situation and in accordance with the given project budget, a variety of combined technological equipment was transported to Peru (fig. 8). This effort was necessary to guarantee at least a basic level of documentation even if problems with customs or other challenges (e.g. bad weather conditions etc.) would occur.

For the 3D documentation in sub-centimeter accuracy we used a terrestrial 3D laser scanner (Riegl VZ-400)\(^3\) with a maximum surveying distance up to 600m. A variety of cameras with special lenses (i.a. Nikon D700, Nikon D5100) were employed for the photogrammetric aerial photo documentation. Other surveying devices included a GPS (Leica GPS 1200) for georeferencing and a Leica total station for surveying reflectors.

During this short surveying campaign a total area of approx. 4,5 km\(^2\) has been surveyed (Fig. 9). The prehistoric terrace structures expanding over an area of approx. 1,7 km\(^2\) were located within. The respective studies on site were carried out by the archaeologists and 3D surveying specialist Martin Schaich (CEO - ArcTron 3D GmbH). The time limit to complete the 3D survey including longer driving times and preparation time was 5 days altogether (30.01.-03.02.2013)\(^4\).

\(^4\) Johny Isla and his Peruvian team provided manifold support and assistance with transportation, help on site and various other issues.
The topography of Collanco is characterized by many difficulties. The terrain is partially very difficult to access (river crossing, ravine-like canyons - so-called „Quebradas“, slopes, etc.) and is expanded across a large area. It is overgrown with cacti - in some parts with a “forest-like” density from ground-level perspective - and reaching heights of up to 6m (Fig. 8). This vegetation occludes much terrain, therefore the approach of using the terrestrial 3D lasercans as solely method of documentation did not seem effective.

The concept called for a combination of 3D photogrammetry with vertical photos taken from an octocopter. Unfortunately the difficult weather conditions did not allow this method. The generally very windy conditions in this area with gusts well above 25 km/h required an alternative in order not to jeopardize the equipment incl. camera. Therefore, a paraglider was used. The pilot (Martin Schaich) navigating the solo glider in very windy conditions had to simultaneously take the photogrammetric pictures. This was not an easy task. Initially the pilot intended to use a powered (motorized) paraglider for this project. But because the motor could not be shipped to the location due to financial and logistic reasons the pilot had to take-off without motor from the top of the surrounding mountains. Extensive picture series were taken during both the time-intensive ascents and each relatively short flight. These photo sequences were later processed with SFM (Structure from Motion) technologies. A complete detailed documentation of the terrain with high resolution vertical photographs was not

Fig. 9. Collanco. Coloured elevation overview of the total area documented in 3D as DTM (Digital Terrain Model). The map was generated by a data fusion of aerial photogrammetry and terrestrial 3D laser scanning. Map data: © ArcTron 3D GmbH & DAI (2013).
feasible due to the circumstances described above. This is planned to be accomplished during future surveying campaigns.

For the 3D documentation of the area a multi-level accuracy and resolution concept was realized. Comprehensive terrestrial 3D laser scans (with numerous small data gaps due to the dense cactus vegetation) built the fundamental data structure. After registration and optimization of the scans for correlation (software packages: RiScanPro, Geomagic, QTSculptr), an average registration accuracy of <3 cm was accomplished for the entire area. Using a “best-fit”-operation, the photogrammetric processed “Structure for Motion”-point clouds could be integrated, scaled and georeferenced into the terrestrial laserscan model (average deviation: <5cm). Poor SFM point qualities were filtered out by photogrammetric criteria. Finally the data was further processed into a comprehensive DSM (= Digital Surface Model incl. vegetation).

The software aSPECT 3D was used for this process (Schaich 2013). It integrated the program package SURE developed by the Institute of Photogrammetry at the University of Stuttgart (Wenzel et al. 2013). SURE delivers „Dense Image Matching“ and allows to specify the photogrammetric accuracy value for each generated point. The accuracy for the entire DSM (software packages: Terra Solid, Global Mapper) was verified through the total station survey of reference markers (target crosses). With a 7-parameter transformation (software package: aSPECT 3D) of 14 reference points, also laid out at the borders of the survey area, a deviation of 2-4 cm to the total station coordinates was recorded. For filtering the cacti, ArcTron developed a semi-automated filtering process which was used only in selected areas. The algorithm for processing the entire area must yet be further developed.

The digital terrain model of Collanco was used as a base for further terrestrial mapping and archaeological interpretation of terraces and settlement structures, as well as for an initial documentation for archaeological excavations. For the field reconnaissance the DSM was plotted on manageable DIN A3 sheets. After ground truthing, the identified structures were added with pencil on the plots. In the laboratory these sketches were transferred as vectors to individual layers in a GIS-Programm (Quantum GIS) over the Digital Surface Model.

During the terrestrial reconnaissance and archaeological interpretation we identified terraces, buildings and pathways, but also parts of an extend system of irrigation and drainage canals (fig. 10). According to our current interpretation, horizontal branches of the irrigation system started at reservoirs that were built with retaining walls in the ravines of the slopes, where water accumulated during the rainy season. From these horizontal canals secondary canals were diverted leading water to the agricultural terraces. On the other hand, inside the settlement clusters canals were used to drain water in order to avoid damage of the structures. The 3D documentation in Collanco can thus be considered as a further example of the effective combination of modern methods of remote sensing and 3D modelling with traditional methods of archaeological reconnaissance and interpretation.
Last but not least, the 3D documentation was an appropriate methodology for the documentation of the excavation area. Based on the detailed modelling of the settlement structures, excavation could start immediately in August 2013, without further documentation of the existing surface. The traditional, time-consuming documentation of the surface evidence by handdrawings, which in Collanco would have been especially complicated due to the great number of building stones, at the start of our excavation had been accomplished already through the laser scanning (fig. 11). Furthermore, 3D modelling was used also during the excavation with the documentation system aSPECT 3D. The remote sensing methods of archaeological documentation were complemented by traditional methods of hand drawing and by use of a pantograph.

The area selected for high resolution survey expanded over a terrain of approx. 1.650 m². Detailed terrestrial scans (accuracy: <1cm) were generated using the Riegl VZ-400 scanner (Fig. 11). In summer of 2013 archaeological excavations took place in this settlement area which has been documented in high resolution. In aSPECT 3D the 3D data was used on site for further archaeological documentation purposes. aSPECT 3D is a database-driven 3D information system. It is designed specifically for archaeological and cultural heritage preservation tasks. In the summer campaign of 2013 archaeologists used this 3D information system for further 3D documentation of archaeological sites and excavation results. The 3D software provides interfaces for standard archaeological documentation equipment like GPS and total station. It includes a complete SFM module (3D ImageScan module) with functions to scale and georeference (Survey module) 3D data allowing an effective documentation of even very complex archaeological features.
Fig. 11. Collanco. Detailed, 3D-modelled settlement area (approx. 1.650 m²) as 3D orthophoto with contour lines. This map was generated by data fusion of airborne photogrammetry data with terrestrial 3D lasercanning data. Map data: © ArcTron 3D GmbH & DAI (2013).

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