Peter Fux – Martin Sauerbier – Janine Peterhans – Thomas Kersten – Maren Lindstaedt

Documentation and Interpretation of the Petroglyphs of Chichictara, Palpa (Peru), Using Terrestrial Laser Scanning and Image-Based 3D Modeling

Abstract: In Chichictara, southern Peru, petroglyphs cover the surface of around 150 rocks, located in a small valley. The goals of the Chichictara Project are the documentation of the petroglyphs, the dating of them and an understanding of the original social function of the site and its components. The presented research methodology is determined by two properties of petroglyphs: Firstly, they are an artificial intervention into the natural environment. That means their natural and archaeological environment must be decisively included into the interpretation. Secondly, their iconographic value is very high, which means that similarities with other archaeological findings have to be made evident. Thus, the site of Chichictara was documented in 3D by means of laser scanning and photogrammetry. The results will be included into a 3D model of the entire Palpa region and connected with a GIS database containing spatial and archaeological information – the rocks will tell us about the past.

Introduction

For some ten years, archaeological and multidisciplinary research has been conducted in the Nasca-Palpa region of the coastal desert of southern Peru. The multidisciplinary research project "Nasca-Palpa", situated in the small city of Palpa and coordinated by Markus Reindel [1] and Johny Isla Cuadrado [2], was initially inspired by the desire for a complete documentation of the famous geoglyphs — often simply called the "Nasca lines" — in this region in order to understand their cultural associations and their original social functions. From the beginning it was clear that these objectives could never be achieved using only traditional archaeological methods. Therefore, archaeologists, geodesists, physicists, geologists, anthropologists and geographers are working together.[3] The geoglyphs and the topography of the Palpa region are now accurately documented in 3D using data acquired by aerial photogrammetry. Approximately 800 archaeological sites have been registered and analyzed and many settlement sites, graves and ceremonial places excavated. We now have an extensive knowledge of the cultural development of this region from the Initial Period (1800–800 BC) to the arrival of the Spanish (16th century). This huge dataset enabled a profound analysis of the geoglyphs by means of GIS-based analysis (Lambers 2006). Due to these research activities it has become obvious that the mainly geometrically shaped and large scaled geoglyphs, situated in the desert plateaus, which have been dated to the archaeologically defined Nasca Culture (200 BC – 650 AD), have their main anthropomorphic and zoomorphic predecessors in the Paracas Culture (800–200 BC). These Paracas predecessors are typically situated on hill slopes. Beside the geoglyphs, there are even more and presumably older relics of prehistoric artificial interventions into the natural environment, showing similar iconographic expressions: the petroglyphs.

Although in the Nasca-Palpa region many petroglyph sites have been well known to archaeologists for a long time, the site of Chichictara for example was already mentioned in 1983 (Orefici 1983), none of them were archaeologically analyzed. The Chichictara petroglyphs were almost completely recorded by Matos A. Valos as freehand sketches (Valos 1987). Moreover, the site has been numerously mentioned (Silverman/ Proulx 2002; Orefici / Drusini 2003; Hostnig 2003). Until now, only selected petroglyphs

[1] German Archaeological Institute, Commission for Archaeology of Non-European Cultures (KAAK), Bonn, Germany.

[2] Instituto Andino de Estudios Arqueológicos (INDEA), Lima, Peru.

[3] For an introduction into the research activities in Palpa, see: Reindel 2004, Reindel/Cuadrado 2005 or Fux 2006.

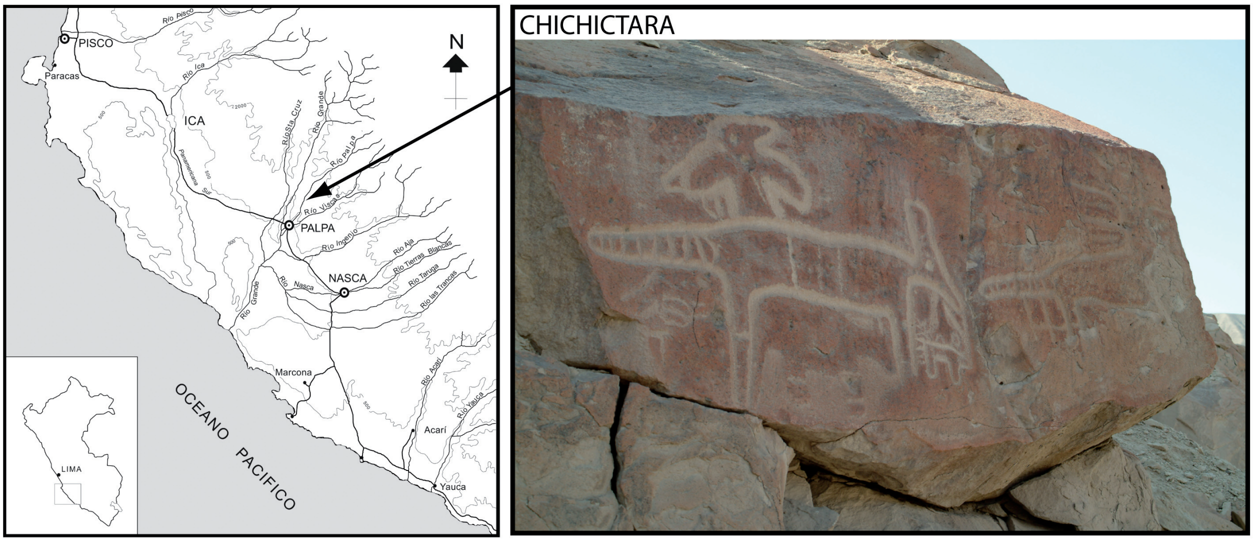

Fig. 1. The map of the southern Pacific coast of Peru (left) with the petroglyph site of Chichictara and a petroglyph (right).

were depicted for iconographic studies, whereas an accurate documentation of the site and an interpretation of the iconography related to the natural and cultural context are still missing. The petroglyphs of Chichictara have a high iconographic value not only due to singular figures, which bear resemblance to other findings like textiles, ceramics or geoglyphs, but also because some exhibit entire scenes. Thus, they are a valuable source for archaeology, which aims to tell us stories about the past. It's high time to analyze them!

The Chichictara Project

Along the eastern slope of the lower valley of the Palpa river there are several accumulations of petroglyphs within a range of about 2.5 km. The largest of them is Chichictara, situated 11 km to the northeast of Palpa and at an altitude of around 550 m above sea level. It is the largest petroglyph site of the Nasca-Palpa region. Approximately 150 sculptured rocks are covered with anthropomorphic, zoomorphic and geometric figures or with depictions of activity such as hunting. The rocks are mostly located on the bottom of the Chichictara valley and its rocky slopes. Because of iconographic similarities with other archaeological findings, these petroglyphs can be roughly dated to the late Initial Period (1800–800 BC) or the Paracas Period (800–200 BC).

The following questions are of particular interest: (1) Can one realize a more accurate temporal and cultural delimitation for the formation of these petroglyphs? (2) Why did men create petroglyphs at this particular site, i.e. what was the social importance of the site? And: (3) What was the meaning of the petroglyphs themselves?

Questions one and three are linked with the intrinsic property of petroglyphs in that they have a highly figurative expressiveness. Thus, they should be compared iconographically with other archaeological findings like textiles, ceramics or geoglyphs, mostly by taking into account their archaeological and topographical context. Following this approach, one can expect answers to questions one and three.

Question two stems from the fact that petroglyphs are an artificial intervention into the natural environment. Their topographic location is surely not caused by accident, which means that the specific petroglyph site very likely had a social function. Something else was occurring there. From analysis of the topographical and archaeological environment of a petroglyph site, good results regarding question two may be expected. Furthermore, it is very likely that the social context of the location has implications for the iconography of the petroglyphs, i.e. answers to question two will have an impact on the analysis of question three.

In contrast to traditional methods of petroglyph documentation, which were conducted mostly using 2D approaches, a 3D documentation and modeling of the petroglyphs was used. For the Chichictara project a methodology was selected that takes into account all above-mentioned considerations: Each rock with petroglyphs was documented in 3D using photogrammetric methods. From these models vector graphics for iconographic studies can be extracted. To cope with the natural environment the petroglyph site of Chichictara was recorded in 3D using terrestrial laser scanning. The goal of the project was the integration of each singular rock-model with its petroglyphs in high resolution into the derived digital terrain model (DTM) of Chichictara. Additionally, the integration of the whole Chichictara model into a digital terrain model is planned, which covers the Palpa region with its river valleys, derived from ASTER satellite imagery. Finally, it is supposed to integrate the entire DTM into a GIS database containing spatial and archaeological information, collected during ten years of multidisciplinary research activities. The presented approach allows a comprehensive analysis of the petroglyph site of Chichictara and its components.

In the following, the fieldwork conducted in 2006 is summarized including on-going work. Finally, examples of the initial results of archaeological interpretation are presented.

Photogrammetric 3D Reconstruction of the Petroglyphs

Image Acquisition

The recording of the photogrammetric images of Chichictara was carried out from the end of August to the middle of October 2006. 66 sculptured rocks were documented by 20 to 80 images per photogrammetric block, depending on the complexity and size of the object, at an average image scale of about 1:100. A digital CMOS camera Canon EOS 10D with an image format of 3072 x 2048 pixels was used for image recording. In order to ensure that a sufficient number of tie points could be measured for relative image orientation, targets were affixed to the rocks. Additionally, scale bars were placed on the rocks to enable the definition of a scale for the arbitrarily oriented and located coordinate systems after relative orientation. Two classes of sculptured rocks were distinguished. While a larger part is situated on the valley floor, a second group of petroglyphs can be found on the vertical rock façade in the upper part of the valley. The first group was documented using a radial camera network configuration, with camera positions around the object, whereas the second group was documented using approximately parallel viewing directions towards the rock façade. Considering the documentation process in terms of image scale, object distance and base length as well as the capacity of the camera, an accuracy of $s_{X,Y} \approx$ 0.8 mm in X and Y (planimetry) and of $s_Z \approx$ 2mm in Z (viewing direction) can be expected (Luhmann 2000), given that well-defined tie points can be measured on the rock surface.

Image Orientation

For image orientation the close-range photogrammetry software package PhotoModeler 5.0 was used. The measurement of tie points for relative orientation was conducted manually. In addition to the signalized points, further well-defined points on the rock surface were measured. Finally, by means of a bundle block adjustment including self calibration, the parameters of image orientation and camera calibration were determined simultaneously. For the seven completed blocks, containing ten petroglyphs, a standard deviation of the image coordinates of σ_{xy} = 0.9–3.2 pixels was achieved, which corresponds to 0.7–2.4 mm in object space.

3D Modeling of the Rocks and Petroglyphs

The 3D modeling is conducted by means of two approaches. Currently, the automated generation of digital surface models of the rocks is investigated by image matching. Furthermore, the geometrically shaped rocks are modeled manually. Both approaches can be combined, e.g. in case of partial failure of the automated procedure.

The automated surface generation is conducted using the software SAT-PP (Satellite Imagery Precision Processing), which was developed at ETH Zurich (Zhang 2005). SAT-PP, originally developed for satellite image processing, was already applied successfully in close-range photogrammetry projects (Remondino / Zhang 2006).

In a first step, the parameters of interior and exterior image orientation are exported from PhotoModeler into a SAT-PP conform file format automatically by means of a Python script. The digital images are filtered using the Wallis filter, in order to enhance the local contrast and brightness by preserving the edge information. After the project setup including epipolar image and image pyramid generation, seed points for the automated surface generation procedure are measured manually. Matching masks defining the image areas to be considered during image matching are also generated. The image matching procedure follows the Multiple Primitive Multi-Image (MPM) matching approach and aims for the generation of a dense point raster based on three different primitives: interest points, grid points and line features. The extracted features first are matched pair-wise through the image pyramids, and in a second step matched by means of Multi-Photo Geometrically Constrained Matching (ZHANG 2005) in all suitable images. As a result, a dense point raster was obtained representing the surface of a sculptured rock.

Manual 3D modeling is conducted in PhotoModeler. The rock surface is modeled by means of spatial triangles (meshes) and textured automatically after radiometric adjustment and target removal from the images. The manual approach is mainly applied to the geometrically shaped rocks *(Fig. 2)*.

Fig. 2. Textured 3D model of a geometrically shaped rock, engraved with zoomorphic and anthropomorphic figures.

Generation of a DTM of the Chichictara Valley Using Terrestrial Laser Scanning

For the Chichictara valley it was decided to generate a detailed DTM, which is suitable for the integration of the photogrammetric 3D models of the rocks. A Trimble GS200 terrestrial laser scanner with a maximum range of 200 m and more and with a wavelength of 532 nm for the laser was used. The distance measurement of the instrument uses the time-of-flight method measuring between 1000 and 2000 points per second in practical operations. In order to guarantee power supply for computer and scanner during the fieldwork, a gasoline-driven generator with a power of 1 kW was used. The dimensions of the valley are approximately 250 m in length, 130 m in width and 70 m in height. Investigations into the generation of DTMs by means of terrestrial laser scanning have previously been conducted successfully (HÖNNIGER / KERSTEN 2005).

The scanning of the valley in Chichictara was completed during six days of fieldwork, using 13 different scan positions. 14 spherical tie points (spheres) were distributed in the terrain and used as tie points for registration and geo-referencing of the individual point clouds. The 3D coordinates of the spheres were determined using a Leica TCA 700 total station in a local coordinate system. A mean standard deviation of 6 mm was achieved for the 3D coordinates after geodetic network adjustment. By means of the GPS measurements the resulting local net was transformed to the UTM system, in which the spatial data of the Nasca-Palpa project is available.

For the terrain scans, a resolution of 15 cm at 100 m distance was chosen, so that for each scan position a point density of at least 50 cm could be obtained even for longer distances. Additionally, high resolution scans with 3 mm at 10 m distance were accomplished for certain petroglyphs, aiming for exemplary comparison with the photogrammetrically derived 3D models. In total, an amount of 27 million points was scanned, resulting in 512 MB of data volume.

The first step of data processing was the registration of the point clouds to a common coordinate system. After each day of field work, the measured point clouds were registered using the spherical tie points. Finally, these groups of two to three scan positions were transformed into a common local coordinate system with an accuracy of 1.5–2.5 cm. For the following terrain modeling, the achieved precision can be considered satisfactory.

For the generation of a regular raster DTM, the point cloud was thinned to approximately 2 million points, according to a point distance of about 50 cm, which is sufficient for a detailed modeling of the valley and its important features. A higher point density would cause a rough terrain representation and difficulties on a standard PC due to the amount of data. Terrain modeling was performed using the 3D modeling software Geomagic (Geomagic Inc.), *Fig. 3* shows the DTM of the entire valley.

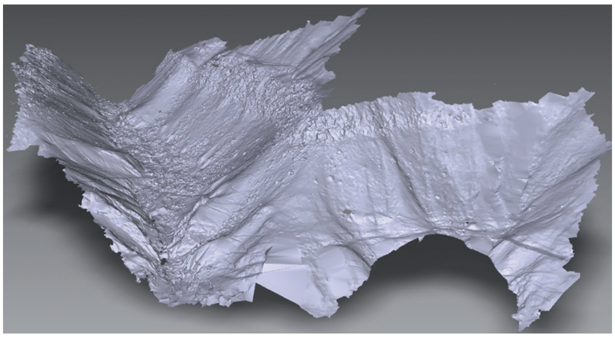

Fig. 3. The digital terrain model of Chichictara derived from terrestrial laser scanning.

Integration of the Photogrammetric 3D Models into the Nasca-Palpa GIS

The textured 3D models derived from photogrammetric processing have to be transformed into the UTM system. This can be carried out using identical points in the laser scanning DTM and in the 3D models of the rocks modeled in Geomagic. In this step it is important to preserve correct texture coordinates. In a second step, it is planned to integrate the laser scanning DTM including the detailed rock models into a DTM derived from ASTER satellite imagery. Finally, the resulting combined model as well as attribute data obtained from the archaeological analysis of the petroglyphs will be integrated into the Nasca-Palpa GIS database. The conceptual UML (Unified Modeling Language) data model (Lambers / Sauerbier 2003) was enhanced by the typological and chronological modeling of the petroglyphs as well as their relation to the acquired spatial data and the archaeological site database.

Outlook

As discussed in the section *The Chichictara Project*, the presented methodology, which was developed to analyze the site of Chichictara with its components, is focused on the following intrinsic properties of petroglyphs: First, they are an artificial intervention into the natural environment. The derived high resolution 3D model of the valley of Chichictara and the precise 3D documentation of the region of Palpa with its river valleys allows the user to deal with this property. Second, they have a high figurative expressiveness. This property, which is mainly a problem of data management, can be handled with the methodological approach of an enhancement of the GIS database of the Nasca-Palpa project containing archaeological and spatial information. The acquired petroglyph data as well as their analyzed results will be integrated into the existing GIS database. In conclusion an illustrative example for each of these two approaches is presented in the following:

(1) As mentioned previously, Chichictara is situated in the lower valley of the Palpa river, just a few kilometers before its confluence with the Viscas and Grande rivers in the wide and very fertile plain of Palpa *(Fig. 4)*. The plain, irrigated from these three rivers which have their source in the highlands to the east, is protected from strong coastal winds by the cordillera in the west and by a small hill range in the north. Nowadays the climatic situation of the Palpa plain is especially advantageous for agriculture and despite of drastic climatic changes during the last three millennia it is very likely that this region had favorable conditions even 3000 years before the present day.[4] After the confluence of these three rivers near Palpa, the Grande river crosses the desert westwards and winds its way through the coastal cordillera to the misty and windy Pacific Coast, approximately 65 km away from Chichictara. Following the Palpa river eastwards the valley climbs steeply, crossing different climatic zones, to the more rainy highlands, which have an altitude between 3000 and 4300 meters above sea level.

It is an apparent pattern of Andean people moving up and down the mountain, crossing multiple ecological zones (Moseley 1992, 25–51). The

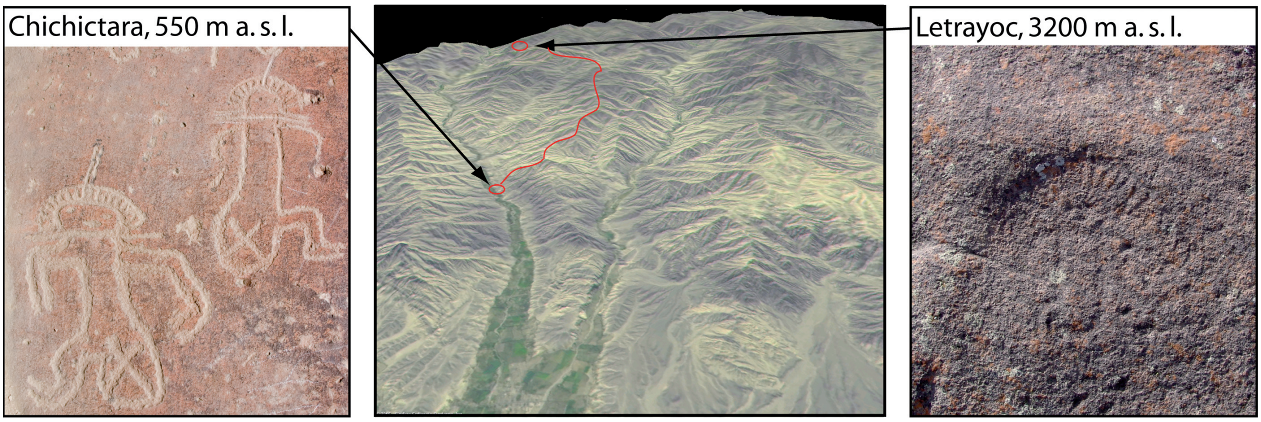

Fig. 4. The centre image shows the footpath between Chichictara and Letrayoc, mapped in the textured 3D model derived from ASTER satellite imagery. The left and right images show petroglyphs of similar type found at the two sites.

[4] See, for example, Mächtle et al. 2006.

exploitation of many different ecological zones, in combination with cultural interactions and material exchange, can be seen amongst others as an adaptation to extreme topographic and climatic situations and a means of reducing a substantial risk. Bearing in mind this cultural pattern, our discovery of an ancient footpath coming from the nearby ridge and entering the slope of the Palpa valley exactly at Chichictara is informative and illustrated in *Fig. 4*. Furthermore, in the highlands at an altitude of 3200 meters above sea level, another petroglyph-site with similar iconography, Letrayoc, was found. This is located where the footpath leaves the ridge and close to a water source.[5] The distance between Chichictara and Letrayoc is around 30 km. It is reasonable to contemplate Chichictara in the context of this footpath and the availability of water.

(2) Iconographic studies on petroglyphs are most promising, taking into account crossover studies between different archaeological findings, such as textiles, ceramics or geoglyphs. The last ten years of research activities in the Nasca-Palpa project have provided a huge data set for such work. This data can be managed by means of a GIS database with the objective of revealing cultural evidence. The following examples should illustrate the potential for success of the presented method:

Fig. 5 (left) shows a ceramic bead from a grave at Mollaque Chico, only a few kilometers away from Chichictara. Because of its ceramic offerings and organic materials, the grave can be dated to the Paracas Period (800–200 BC). The unrolling of the ceramic bead shows a so-called "Chavin head". The same motif appears as a petroglyph at Chichictara. The grave at Mollaque Chico is therefore evidence that may help to date the petroglyph.

But there are also objects in various museums which will be included in the updated database for comparison with the petroglyphs. An example is the textile of *Fig. 5 (right)*. One can see a human being incorporated with snaky animals. These animal depictions regularly occur on textiles and ceramics during both the Paracas and Nasca (200 BC – 650 AD) periods. Most likely the represented animal is a marine bristle worm.[6] Its appearance near the water surface attracts fish and indicates favorable conditions for fishing. Therefore, the motif of the textile can be interpreted as a symbol of the dependency of man on these animals, who bring them food. This interpretation of the textile helps in the understanding of the petroglyph showing the same animal. In addition, this petroglyph emphasizes the high importance of interactions between all the people living between the highlands and the coast.

Acknowledgements

The authors thank the Swiss-Liechtenstein Foundation for Archaeological Research Abroad, SLSA, for financing the project, and Markus Reindel (German Archaeological Institute, Commission for Archaeology of Non-European Cultures (KAAK)) and Johny Isla (Instituto Andino de Estudios Arqueológicos (INDEA)) for their support in Palpa.

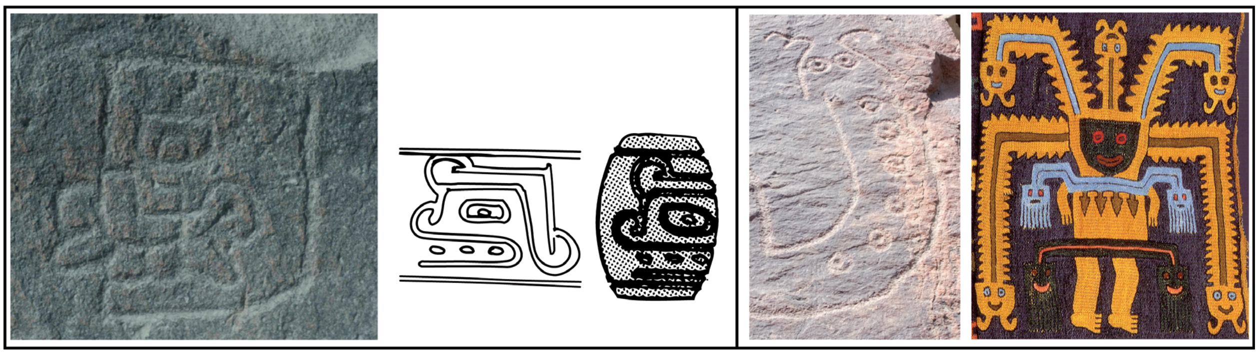

Fig. 5. Left: The petroglyph shows the same "Chavin-head" like a ceramic bead from a grave at Mollaque Chico, dating into Paracas period. Right: A petroglyph showing a bristle worm. The same motif appears on several textiles.

[5] Thomas Stöllner (Bergbaumuseum Bochum, Germany) discovered the petroglyphs of Letrayoc.

[6] See Wickler / Seibt 1998, 14–24.

References

FUX 2006

P. FUX, Das Petroglyphen-Projekt «Chichictara» in Palpa, Peru. Feldarbeiten im Jahr 2006 und Ausblick. Jahresbericht der Schweizerisch-Liechtensteinischen Stiftung für Archäologische Forschungen im Ausland, SLSA (Zürich 2006).

HÖNNIGER / KERSTEN 2005

C. HÖNNIGER / T. KERSTEN, Topografische Aufnahme der sächsischen Ringwallanlage Willenscharen mit dem 3D-Laserscanning-System GS100 von Mensi. In: T. LUHMANN (ED.), Photogrammetrie, Laserscanning, Optische 3D-Messtechnik. Beiträge der Oldenburger 3D-Tage 2005 (Heidelberg 2005) 224–231.

HOSTNIG 2003

R. HOSTNIG, Arte rupestre del Perú: inventario nacional (Lima 2003).

LAMBERS 2006

K. LAMBERS, The Geoglyphs of Palpa, Peru. Documentation, Analysis, and Interpretation. Forschungen zur Archäologie Aussereuropäischer Kulturen 2 (Aichwald 2006).

LAMBERS / SAUERBIER 2003

K. LAMBERS / M. SAUERBIER, A data model for a GIS-based analysis of the Nasca lines at Palpa, Peru. International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences XXXIV-5 / C15, 2003, 713–718.

LUHMANN 2000

T. LUHMANN. Nahbereichsphotogrammetrie. Grundlagen, Methoden und Anwendungen (Heidelberg 2000).

MÄCHTLE ET AL. 2006

B. MÄCHTLE / B. EITEL / A. KADEREIT / I. UNKEL, Holocene environmental changes in the northern Atacama desert, southern Peru, and their impact on the rise and fall of Pre-columbian cultures. Zeitschrift für Geomorphologie N. F. Supplement 142, Stuttgart, 2006, 47–62.

MATOS A VALOS 1987

A. MATOS A VALOS, Los Petroglifos de Chichictara. Instituto Nacionál de Cultura (Lima 1987).

MOSELEY 1992

M. E. MOSELEY, The Incas and their Ancestors. The Archaeology of Peru (London 1992).

OREFICI 1983

G. OREFICI, Los Petroglifos de Chichitara. Proyecto S. José. Informe final de la Campaña 1982. Report to the Instituto Nacionál de Cultura (Lima 1983).

OREFICI / DRUSINI 2003

G. OREFICI / A. DRUSINI, Nasca: hipótesis y evidencias de su desarollo cultural. Documentos e Investigaciones 2 (Brescia 2003).

REINDEL 2004

M. REINDEL, Wüstenzeichnungen und Wasserkulte: Geoglyphen und Siedlungsgeschichte in Palpa (Peru). In: Expeditionen in vergessene Welten. 25 Jahre archäologische Forschungen in Amerika, Afrika und Asien. AVA-Forschungen 10 (Bonn 2004).

REINDEL / ISLA 2005

M. REINDEL / J. ISLA, Archäologisches Projekt „Paracas in Palpa", Peru. Ausgrabungen und Forschungen 2005. Jahresbericht der Schweizerisch-Liechtensteinischen Stiftung für Archäologische Forschungen im Ausland 2005 (Zürich 2005).

SILVERMAN / PROULX 2002

H . SILVERMAN / D. PROULX, The Nasca. The Peoples of America (Oxford 2002).

WICKLER / SEIBT 1998

W. WICKLER / U. SEIBT, Kalenderwurm und Perlenpost: Biologen entschlüsseln ungeschriebene Botschaften (Heidelberg 1998).

Peter Fux

University of Zurich
Department of Pre- and Protohistory
Karl-Schmid-Str. 4
8006 Zurich, Switzerland
peterfux@mac.com

Martin Sauerbier
Janine Peterhans

ETH Zurich
Institute of Geodesy and Photogrammetry
Wolfgang-Pauli-Str. 15
8093 Zurich, Switzerland
msb@geod.baug.ethz.ch

Thomas Kersten
Maren Lindstaedt

HafenCity University Hamburg
Department Geomatics
Hebebrandstraße 1
22297 Hamburg, Germany
t.kersten@rzcn.haw-hamburg.de