

THE GEOGLYPHS OF NASCA: 3-D RECORDING AND ANALYSIS WITH MODERN DIGITAL TECHNOLOGIES

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Résumé

Depuis longtemps, les investigations archéologiques entreprises au sujet des géoglyphes aux environs de Nasca (Pérou) ont été perturbées en raison de l'absence d'une méthode d'enregistrement efficace. Dans le présent article, il est décrit l'utilisation de procédés photogrammétriques qui permettent d'enregistrer deux importantes concentrations de géoglyphes à Palpa situé au nord de Nasca. L'utilisation de la photogrammétrie digitale ainsi que d'autres techniques de mesure et de modélisation modernes permettent pour la première fois un enregistrement complet, tridimensionnel et de très haute qualité de plus de 1 000 géoglyphes, lesquels seront intégrés dans un SIG d'analyses archéologiques. Les récents développements effectués dans le domaine de la visualisation permettent de survoler et de naviguer en temps réel, même en présence de très grandes quantités de données.

Abstract

A serious archaeological investigation of the famous geoglyphs of Nasca (Peru) has for a long time been obstructed by the lack of an adequate recording of the ground drawings. In this article we describe photogrammetric mapping procedures employed to record two important geoglyph concentrations at Palpa, to the north of Nasca. The use of digital photogrammetry and other modern tools for measurement and modeling allowed for the first time the complete, highly accurate, and three-dimensional recording of more than 1 000 ground drawings which will later on be integrated on a GIS platform for archaeological analysis. The recent stormy development in the area of visualization allows us to fly over and navigate through even very large data sets in real-time.

INTRODUCTION

The geoglyphs of Nasca in the desert of coastal Peru (450 km south of Lima) have been called "the eighth wonder of the world" (Aveni 2000). Over an area of several hundred square kilometers, on ridges and flat plateaus called *pampas*, an array of thousands of lines, trapezoids, biomorphic figures, and other motifs of varying size and precision has been carved into the desert surface. Today these ground drawings – commonly assigned to the Nasca Culture (200 B.C. - 600 A.D.) – are among the most attractive touristic destinations of Peru.

In spite of their great importance, the function and meaning of the geoglyphs is still poorly understood. The more serious interpretations range from an astronomic-calendaric function to artistic expressions or kinship indicators, although recently most investigators argue for a basically ritual function in the framework of a water and fertility cult (Aveni ed. 1990; Reinhard 1996; Lumbreras 2000). However, there are so far two important limitations to Nasca geoglyph research. Firstly, published results of archaeological investigations at Nasca settlements, cemeteries or geoglyph sites are remarkably scant, so that even basic questions about the social and historic development of the Nasca culture still remain unsolved. Secondly, the geoglyphs have never been documented adequately. The available aerial photographs, partial maps and sketches of the ground drawings do not show all the geoglyphs and are of varying scale, precision, and quality.

Therefore, in 1997 the Swiss-Liechtenstein Foundation for Archaeological Research Abroad (SLSA, Zürich/Vaduz) initiated and funded an interdisciplinary research project which aimed at the complete 3-D recording of two major geoglyph concentrations around the town of Palpa, in the northern part of the Nasca drainage, in connection with an exhaustive settlement pattern study of the Palpa and adjacent valleys and extensive excavations at two important Nasca settlements (fig. 1). During five field campaigns, more than 500 pre-hispanic sites were recorded, ranging in time from the Early Formative Period to the Late Horizon (800 B.C. – 1532 A.D.). The results indicate that in Nasca times the Palpa valley was densely settled and highly productive. The excavations at Los Molinos and La Muña, the most important settlement centers of Early and Middle Nasca times, revealed a well organized and socially stratified society which made optimal use of the natural resources and produced highly developed craft goods. Finally, more than 1 000 geoglyphs were photogrammetrically recorded and described in detail, showing that the ground drawings were an integrated part of the Nasca society. While preliminary results of the archaeological fieldwork have been presented elsewhere (Reindel, Isla, Koschmieder 1999; Reindel, Isla 2001; Reindel, Lambers, Grün *in press*), in this article we focus on the photogrammetric mapping procedures which allowed for the first time the complete and highly accurate 3-D recording of two of the most important geoglyph concentrations of the Nasca area (see also Grün, Bär, Beutner 2000; Grün, Beutner 2001).

THE USE OF AERIAL PHOTOGRAPHY IN NASCA ARCHAEOLOGY

There are several reasons which account for the lack of an adequate map of the Nasca geoglyphs: the sheer number of ground drawings, the vastness and inaccessibility of the plateaus and ridges where they are found, and the enormous amount of labour investment required to map them using traditional surveying means like theodolite and measuring tape. Since the 1940s, the *Servicio Aerofotográfico Nacional* (SAN, Lima) has produced several sets of aerial photographs (at different scales) of the valleys of the Nasca drainage for agricultural purposes. These photographs usually cover the valley floors, so that just the geoglyphs near the irrigated fields are visible on them. Only some areas of archaeological interest, like the northern edge of the Pampa de Nasca, were flown especially to take photos of the ground drawings. The SAN photos were used by Maria Reiche (1993) and other investigators as reference to locate the geoglyphs in the field and to compile sketch maps. Still, the actual mapping work was usually done on the ground. As this is very time consuming, in many cases only the most important geoglyphs were mapped.

Hawkins (1974) was the first to try to overcome these difficulties by employing photogrammetry, as it allows to accurately record the ground drawings on the base of aerial photos without the need to map them in the field. He documented the famous concentration of geoglyphs on the Pampa de San José, on the south bank of the Ingenio river. In cooperation with SAN, a special series of 30 aerial images designed for stereoprocessing was produced and analysed. However, Hawkins' effort suffered from several shortcomings: the scale of the aerial photographs used was not very detailed (< 1:10 000), the mapping was done largely without archaeological expertise, and the published maps were of poor quality.¹

Another attempt to make use of the advantages of aerial photography was the production of a photo set of the southern portion of the Pampa de Nasca in 1984 (Johnson *et al.* 1990). The photographs were taken at a scale of approx. 1:24 000 and combined into a photo mosaic which covers the northern bank of the Nasca river well into the pampa. However, due to their limited overlap, most of the photos taken were not suitable for stereoprocessing, and no systematic mapping of the visible geoglyphs was undertaken.

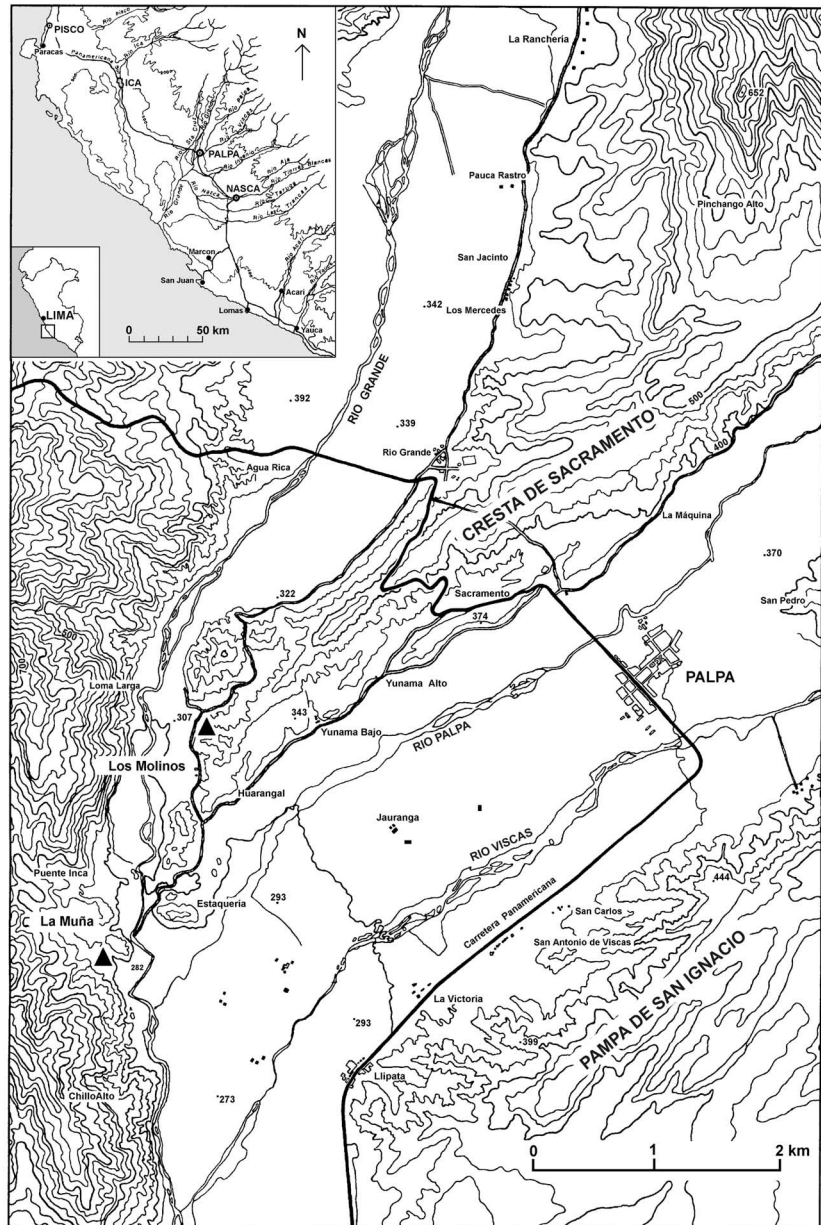


Fig. 1: Area of investigation around Palpa (Ica, Peru)

PHOTOGAMMETRIC MAPPING PROCEDURES

As for the Palpa area, at the start of our project there were two series of SAN aerial photographs available (taken in 1944 and 1970, resp.). Although they showed a good part of the ridge north of Palpa, the plateaus to the south of Palpa were not covered completely, the image scale was too small, and the limited overlap of the images did not allow for 3-D processing. Therefore, we decided to produce a new set of high resolution aerial photographs especially designed for stereoprocessing (fig. 2). The photogrammetric mapping was done in close coordination with the archaeological work and was complemented by a thorough recording of most geoglyphs in the field.



Fig. 2: A part of an aerial image (with fiducial marks) showing the central part of Cresta de Sacramento

The middle and lower parts of the Grande, Palpa and Viscas valleys, especially the alluvial plain where the three rivers merge, are the principal area of our archaeological investigations (fig. 1). The ground drawings are carved in the vegetationless surface of the ridges and plateaus between these fertile river oasis: the *Cresta de Sacramento*, to the north of Palpa, and the *Pampa de San Ignacio*, to the south. For image acquisition, special photoflights were performed by Horizons, Inc., Rapid City, SD, USA which covered the above mentioned ridges and the adjacent valleys, a total of approx. 100 km². A Zeiss RMK A15 camera was used during the flights. There were two missions: 30.04. and 01.05.1997 for the block Sacramento (in colour) and 23.05. and 27.05.1998 for the blocks Sacramento and San Ignacio (in B/W).² Table 1 gives an overview of the project characteristics. In total we produced about 600 aerial images, both in colour and B/W at nominal scales 1:5 000. The image scale was chosen such that the smallest possible lines, which in our area of investigation have a width of about 10 cm, could still be distinguished. The image overlap is 60 % in both directions.

Table 1: Project parameters for Sacramento and San Ignacio image acquisition

Area	photoflight	altitude above ground	number of images*	nominal image scale	colour or B/W	control points
Sacramento	April/May '97	750 m	212 (in 8 strips)	1:5 000	colour neg.	8 (signalised)
	May '98	750 m	169 (in 8 strips)	1:5 000	B/W pos.	0
San Ignacio	May '98	750 m	215 (in 11 strips)	1:5 000	B/W pos.	9 (natural)

* These numbers represent all images exposed during the photoflight and are not identical with the net coverage of the areas.

During the photoflight in April/May 1997 over Sacramento, kinematic GPS observations were carried out. Also, signalised control points were used (fig. 3). The additional flights of May 1998 did not have signalized control points, neither did they carry GPS observations. Thus, in summer 1999 we organized a terrestrial GPS field campaign in order to put 9 natural control points into the block of San Ignacio. The 1998 images of Sacramento however had to be connected via triangulation to the control supported blocks of 1997. All GPS coordinates have been transformed into the Peruvian system UTM Zone 18, which is also the basis of the national topographic maps 1:50 000. Our photographs constitute the first complete set of aerial images over these areas at the right image scales that can be used for stereo processing.

Since it was anticipated (and this was later confirmed by practical tests) that the automated measurement of tie points would cause serious problems because of lack of good texture in many regions, we decided from the very beginning to measure manually on the Analytical Plotters AC3 and S9. The triangulation of the Sacramento colour block was performed with 88 images and 8 control points. Since the quality of the colour images of the 1997 flight was not very good, we ordered a B/W photoflight to be done one year later. At that time, without us being in the area, the signalized ground control points were not available any more. Also, kinematic GPS was not used. Therefore we had to measure the B/W block without any control points and connect it via joint tie points to some images of the colour block. We did a joint bundle adjustment of both the colour and B/W images, including kinematic GPS data for the colour block. Table 2 gives the results of triangulation for both blocks.

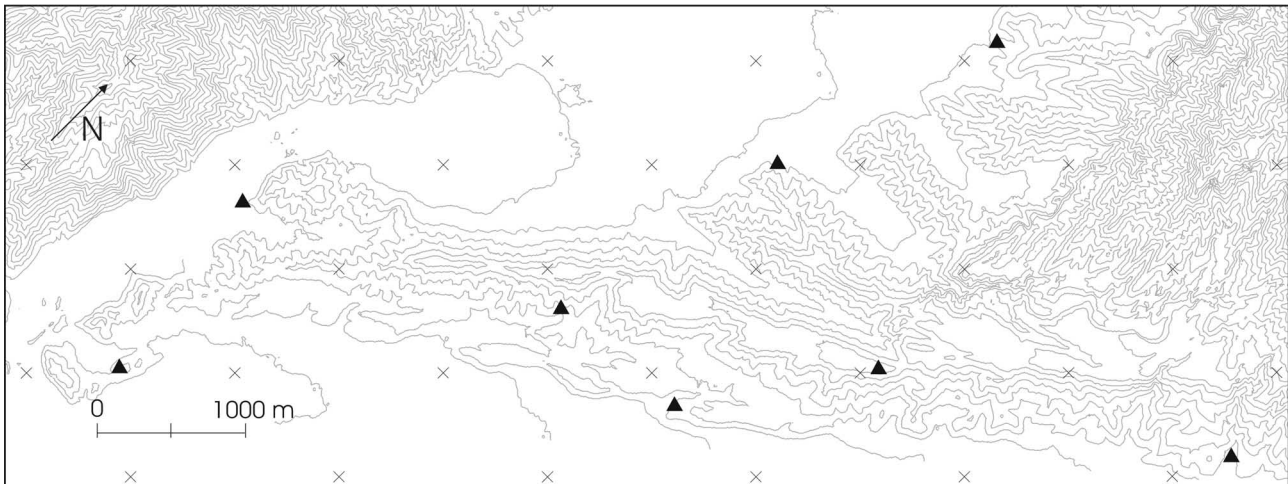


Fig. 3: Distribution of ground control points on Cresta de Sacramento

Although the photoflight was meant to produce a nominal image scale of 1:5 000, the actual scale turned out to be approx. 1:7 000. The overall block accuracy, as given in table 2, was good enough for the purpose at hand. It was clear that at this fairly high noise level self-calibration would not help improving the results and was therefore not used.

Table 2: Triangulation characteristics for Sacramento and San Ignacio

Area	images used	number of images	control points	kinematic GPS	σ_0 [μm]
Sacramento	B/W and colour	211	8	yes	13.3
San Ignacio	B/W	158	9	no	9.5

In order to generate a DTM (digital terrain model) of the area of investigation, 57 B/W stereo pairs for the Sacramento block and 94 B/W stereo pairs of the San Ignacio block had to be measured. We decided to go with manual measurements because we needed a very precise DTM, especially for the integration of the image texture map and vector data of the geoglyphs. Any deviation between vector data and texture would have been noticeable very easily. Our previous experiences with automated commercial image matchers convinced us that these could not give us the required performance. This was actually confirmed by tests, which gave unacceptable DTM results due to poor texture and contrast in large areas of the images. Actually, in a separate investigation we tested the performance of automated matching on three different commercial systems with one model of the Sacramento block and we obtained RMS errors of 0.69, 0.66 and 0.55 m respectively. This does not compare well with the theoretical expectation for manual measurements of 0.2 m (based on 0.015 % of the flying height above ground), and, even worse, produced many unacceptable blunders. We used profile measurements at a profile distance of 20 m with additional breaklines. Later on we also integrated all extracted geoglyphs as breaklines into the DTM.

The wireframe model serves as the basis for orthoimage production and visualization. We produced wireframe models at various resolutions according to the different purposes. Rasterwidths range from 25 m for overview representations down to 1 m for high resolution applications (fig. 4).

All aerial images (B/W and colour) were scanned at a resolution of 21 μm pixelsize on the Agfa Horizon image scanner (block Sacramento) and on the Zeiss SKAI of the Federal Office of Topography, Wabern, Switzerland (block San Ignacio), respectively. In the case of the Sacramento block this corresponds to a footprint of 15 cm, which ensured that the most narrow geoglyph lines were still visible. For orthoimage generation and mosaicking we used Socet Set on the Leica/Helava DPW 770. The largest mosaic consists of 34 images and requires 1.4 GB storage space. For texture mapping different resolution levels are available (25 cm up to 2 m footprint) (figs. 5, 7).



Fig. 4: Digital terrain model (shaded relief) of Cresta de Sacramento

The 3-D mapping of geoglyphs was done manually on the Analytical Plotter S9. Wherever possible, the heaped perimeter lines of the cleared areas, lines, and figures were marked by polygons. Thanks to the high resolution of the images used, it was possible to record even narrow lines very accurately. To further enhance the quality of the recording, during the 2000 and 2001 field campaigns the resulting maps were revised in the field. All mapped features were stored as 3-D objects in the special xmp format of the mapping software XMAP which was used on the Analytical Plotter. This format was afterwards converted into dxf format for further processing.

COMPLEMENTARY ARCHAEOLOGICAL FIELDWORK

In spite of its high quality, the photogrammetric mapping had still to be revised in the field. On the base of the aerial images alone, many narrow lines are hardly distinguishable from modern footpaths, and ground drawings affected by erosion are sometimes difficult to discern. Besides, there is certain information needed for archaeological analysis which can only be recorded in the field. Thus, maps at scales suitable for fieldwork (1:100 to 1:1 000) were generated using ArcView Release 3.2. All the geoglyphs were located in the fields and revised on the maps. Using a standardized feature sheet, they were also described in detail with respect to form, construction technique, stratigraphic relations to other features, associated buildings and findings, and other attributes. This way we recorded 922 geoglyphs out of the more than 1 000 geoglyphs photogrammetrically mapped in Sacramento and San Ignacio. The corrections on the maps were later integrated into the digital vector data again on the Analytical Plotter S9. On the base of the revised 3-D vector data we produced final 2-D maps of the geoglyphs and their surroundings (fig. 6) as well as synthetic 3-D views with vector overlay (fig. 7). While the work on the Cresta de Sacramento has already been completed (Reindel, Lambers, Grün *in press*), the revision of the San Ignacio data set is still in progress.

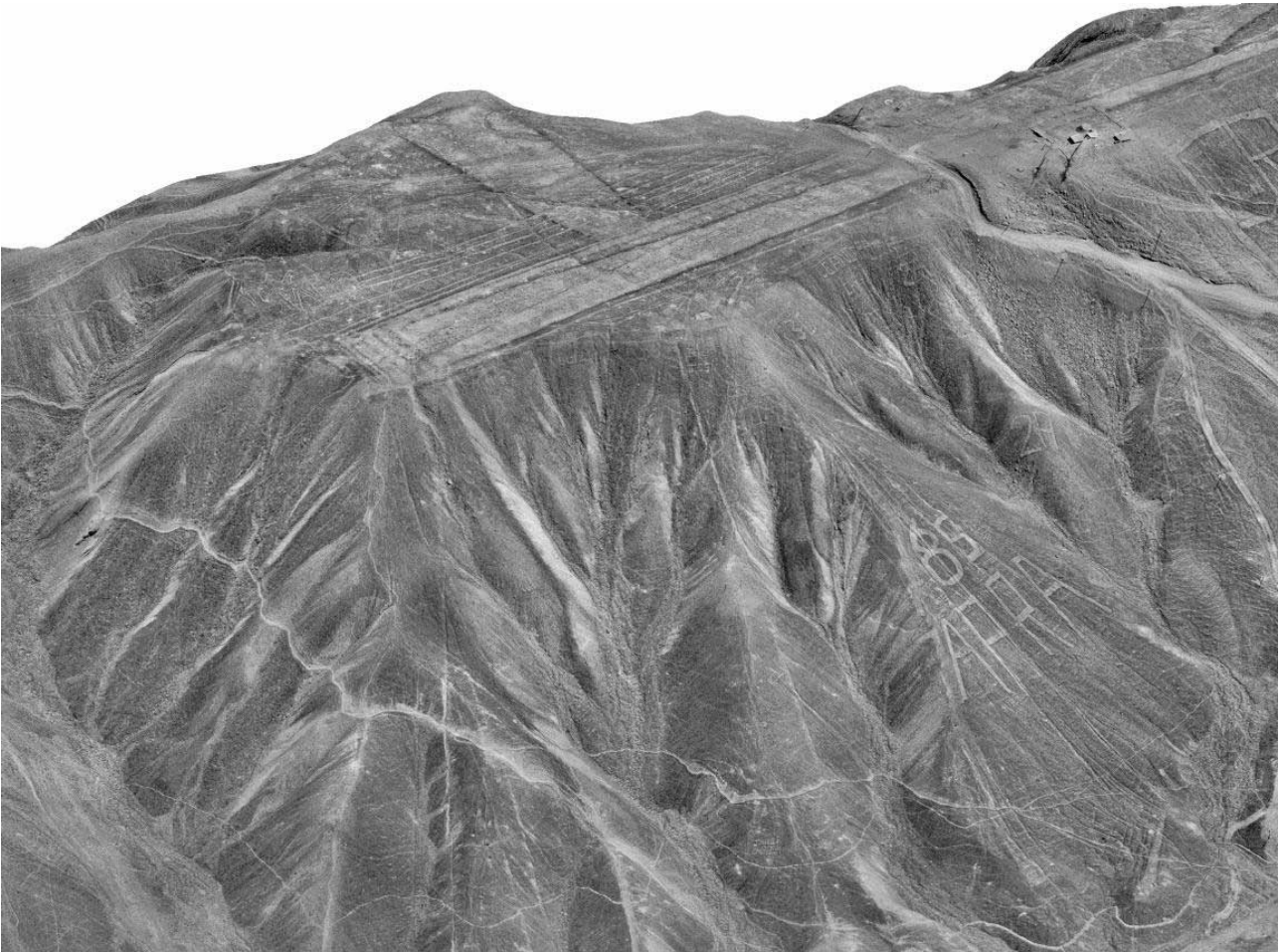


Fig. 5: Synthetic 3-D view (DTM with orthoimage texture) of site PAP 52

VISUALIZATION OF RESULTS

The computer visualization of the produced 3-D models is very often an important element for data analysis and representation. Visualization tools are available in manifold forms, with several hundred commercial software packages on the market and even more in R&D establishments. For the uninitiated user it is very difficult to select a program of choice, and it needs a lot of testing and practical work with different kind of datasets before a critical assessment and acquisition decision can be made. Although the conceptional aspects of computer graphics algorithms are quite straightforward, it is always the implementation and the quality of the key components of the computer platform which define the performance. When analysing visualization software a major consideration is whether real-time performance is required or not. For many analysis applications real-time performance is just a must for the sake of economy and efficiency of operation.

Actually one can classify visualization software on the basis of its real-time performance, given a certain computer configuration. In this context one can distinguish high-end, middle class and low-end systems (e.g. Skyline, IMAGINE VirtualGIS and CosmoPlayer, in this order). While low-end software like CosmoPlayer is increasingly available as freeware (3-D browsers) over the Internet, the other levels of quality can only be reached by paying, in parts dearly, for the product. There are many more quality criteria which can be applied, but since most of these are to be weighted differently according to the varying user requests we will not dig into this issue any further here. Observing that computer power and graphics board performance is increasing dramatically over the last years one can nowadays expect even from laptops a rendering performance which was unheard of only 2-3 years ago. One critical parameter is the Level-of-Detail (LoD) property. LoD capability ensures that at each and every frame of an image sequence only the foreground portion of the 3-D model is represented at highest resolution. Other zones of model depth are represented at lower resolution. This reduces the amount of computations substantially, an advantage which becomes the more prominent the bigger the model is. This LoD property applies both to vector and image raster data.

Currently our datasets Sacramento and San Ignacio encompass 13 MB of vector data and 3 GB of image raster data at the highest resolution level. After all data is collected we expect about 20 % more. Our hybrid datasets include not only DTM and texture map (fig. 5), but also the 3-D vectors of the geoglyphs, which are integrated as a third layer (fig. 7). This requires high-end visualization software to be used for the successful real-time visualization of the

complete dataset. So far we have used a variety of software, of which not all are real-time capable for large datasets: SGI Scene Viewer, Inventor, ERDAS IMAGINE VirtualGIS, the VisDome installations of ETH Zürich, which are also based on SGI technology, and our own software DTMZ-TexViz, which renders 3-D texture maps in parallel projection. On occasion of an exhibition in the Rietberg Museum, Zürich (Grün 1999), we presented our project in a twofold way: (a) we had an installation of a SGI Onyx2 in the museum, where visitors could interactively navigate through small texture models, and (b) we had once per week a demonstration of a flyover in the VisDome of ETH Zürich on a 4x12 m² screen in polarized stereo projection. Both installations found much interest in the public. We are currently evaluating commercial high-end software with LoD capabilities with the aim to be able to show datasets of several Gigabytes even on laptops in real-time.

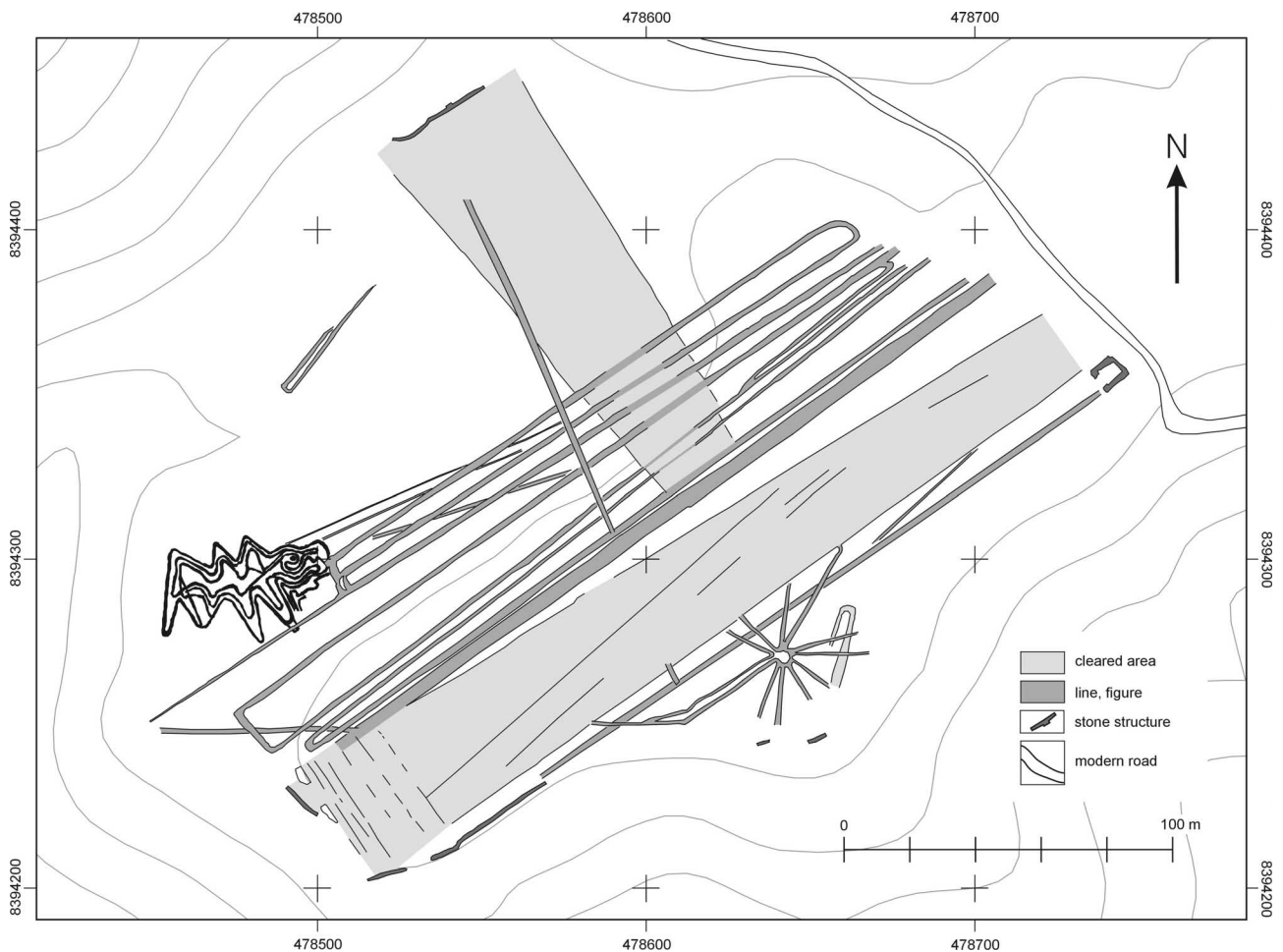


Fig. 6: 2-D map of a whale figure, lines, trapezoids, and a line center at site PAP 52

GIS AS A TOOL FOR GEOGLYPH ANALYSIS

The 3-D vector data of the Palpa geoglyphs, together with their detailed descriptions, constitute a comprehensive data set designed not to test just one specific, but various hypotheses about the function and the meaning of the geoglyphs. The data acquisition has already been completed, while the data processing is still under way. In the subsequent analysis, emphasis will be placed on the manifold relations of the geoglyphs to their natural as well as cultural environment. These relations are to be analysed largely within a geographic information system (GIS) which is currently being evaluated.

Since their first introduction into the field of archaeology at the end of the 1980s, geographic information systems have proven especially well suited to investigate and to visualize spatial dimensions and relations inherent in many archaeological contexts (Kvamme 1999). Although the investigation of spatial relations is by no means new to archaeologists, only with the introduction of computer-based GIS platforms the effective handling of large quantities of spatially referenced data became possible and resulted in many new insights in archaeological contexts, even if they had been thoroughly investigated before, using traditional archaeological means. As for the Nasca geoglyphs, most hitherto proposed hypotheses about their function and meaning stress their spatial relations to other archaeological objects, to certain landscape features, or even to subterranean water sources or celestial constellations (see overviews of theories in Morrison 1987; Aveni 1990, 2000; Lumbreras 2000). However, up to now the capabilities of GIS to systematically investigate these relations have not yet been exploited in Nasca archaeology.

We are currently evaluating and implementing a GIS for the Palpa area on the base of commercial GIS software which will serve us for data management, as a tool to systematically analyse the spatial relations of archaeological objects to their surroundings, and for the visualization of results. The photogrammetrically recorded 3-D vector data of the Palpa geoglyphs can easily be integrated on a GIS platform, with the DTM serving as geometric reference. The geoglyph attributes recorded in the field are stored in a database linked to the vector data. Data on other archaeological features like settlements or cemeteries will also be included, as will additional information on the geology, geomorphology, hydrology, and land use of the Palpa region. Spatial analysis will primarily address:

- the dependence of the distribution of certain geoglyph types on local topography,
- orientation of geoglyphs towards landscape features (mountain tops, alongside rivers and plateaus, etc.),
- possible correlations between settlement patterns and geoglyph distribution,
- visibility and accessibility of geoglyphs from contemporary settlements and cemeteries,
- correlation of geoglyph distribution to water sources (rivers, ground water).

These questions will be addressed in consideration of the results of the Palpa settlement survey and the excavations at Los Molinos and La Muña, which allow not only new insights in Nasca socio-political organization, but also for the first time the proper placement of the ground drawings in their cultural-historic context.



Fig. 7: Synthetic 3-D view (DTM with orthoimage texture and vector overlay) of site PAP 50 with spirals, lines and anthropomorphic figures

CONCLUSIONS

The current work at Palpa constitutes the first systematic attempt to record, investigate, and interpret the ground drawings of the Nasca culture within their cultural context. The application of digital photogrammetry and up-to-date visualization tools allows us to produce a highly accurate 3-D documentation of more than 1 000 geoglyphs which can be easily visualized on-screen and analysed within a GIS environment. This data set is unprecedented with respect to its quantity as well as its quality. The analysis of the data, intended for the next years, will provide new insights into the function and meaning of the geoglyphs for the people who built them. The project can also serve as a reference example to demonstrate the synergy which results from a good cooperation between archaeology, natural and engineering sciences.

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¹ There are two more published maps of the area investigated by Hawkins (Instituto Geográfico Nacional 1993; Nikitzki 1993) which are possibly based on the same set of aerial photographs used by him, although no clear reference is given on either of them.

² At the same time a complete set of aerial photographs of the *Pampa de Nasca* (between the Ingenio and the Nasca valley) was produced at a nominal scale of 1:10 000. This area is not included in the present project but will be addressed at a later date.

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