

**SIGNALS IN THE SAND:
3-D RECORDING AND VISUALIZATION OF THE NASCA GEOGLYPHS**

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ABSTRACT

The geoglyphs of Nasca, Peru are considered one of the world's major mysteries. Despite the fact that many efforts have been made in the past 70 years to record and analyze the geoglyphs no convincing explanation has emerged yet which would explain the purpose of these drawings in the sand beyond any doubt. Many hypotheses have been put forward and each author will find a certain number of lines and figures in support of his/her opinion. The huge number of lines, trapezoids, star centers, biomorphical figures, etc. has up to now defied any comprehensive recording and analysis.

We are currently conducting an ambitious project which aims at the complete 3-D recording of the geoglyphs of the areas of Nasca, Palpa and San Ignacio (a total of about 300 km²) with photogrammetric means. This is done in cooperation with a group of archeologists who will try to relate their excavation results to the geoglyphs in order to get a more complete picture of the overall cultural and social background of the Nasca people (200 B.C. - 600 A.D.).

We are using the latest digital photogrammetric technology for the recording of the geoglyphs and some of the most advanced visualization software. Finally, all data will be integrated on a GIS platform, which will require the efficient management of both vector- and extensive raster image data.

One of the final aims is to make the vector data available to the international community of scientists who show a serious interest in contributing towards the solution of the Nasca mystery. In this process we have produced over 1000 aerial photographs at scales 1:5 000 and 1:10 000 both in color and B/W. In addition we have collected existing, older photographs which can give us an indication of the damage that has been done to the geoglyphs in recent years.

At present the block Palpa has been fully processed and visualization results have been shown to the public on a SGI Onyx2 in an interactive mode at the Nasca exhibition in the Rietberg Museum, Zürich and in the VisDome of ETH Zürich as stereo projection on a large 4x12 m² screen. We report here about the current stage of the project.

1 INTRODUCTION

In the sandy desert of the coastal region of Peru, 400 km south of Lima, lies one of the great mysteries of mankind - the Geoglyphs of Nasca. Over an area of several hundred square-kilometers, on flat plateaus called "pampas", ancient civilizations have carved an array of over thousand geometrical and biomorphic figures of varying size and precision into the earth for no apparent reason. Although it is commonly assumed that most of these earth drawings have been produced by the Nasca people between 200 B.C. and 600 A.D., the purpose of the geoglyphs still remains a mystery. As always in such cases, the very few scientists that approach this problem with serious and sound research concepts are outnumbered by far by the hordes of self-proclaimed experts who voice their opinions in all available media (for example: check the Internet for webpages under "Nasca Lines" or similar terms). Therefore we count today more than 2 dozens of hypotheses offering explanations. The most popular and at the same time the most improbable refers to the lines as landing and starting sites for extraterrestrial spaceships (Däniken, 1997).

The more serious ones may be classified into the following categories: (a) solar, star or moon calendar and astronomy, (b) indicators for underground water, irrigation and agriculture, (c) ceremonial practises, mountain or fertility cult, shamanism, (d) geometry and artistic expression, (e) movement, transportation, communication. It is hard to believe that these geoglyphs did serve just one specific purpose. Too large is the variety of different patterns and figures. We distinguish long straight lines, star-shaped arrangements, geometrical elements like triangles, trapezoids, rectangles, spirals, double spirals, zigzag lines, meandering lines, biomorphic figures (human-likes, animals, plants), and patterns which are hard to interpret as anything realistic.

Although these geoglyphs, which are commonly and for simplicity termed the "Nasca Lines", were known already to the early Spanish explorers, it was until 1926 before the western world took notice again through a report of the Peruvian archeologists Julio Tello and Toribio Mejia Xesspe (Mejia Xesspe, 1927). However, it was the work and the lifelong ded-

ication of Maria Reiche (Reiche, 1969), a German teacher and mathematician, which made them famous, together with the books of Däniken.

Maria Reiche, who spent a large part of her life (1942 to 1998) on the harsh desert plateaus in the vicinity of the small town of Nasca, was inspired by her mentor Paul Kosok, a historian, who, in 1941, after a flight over the pampa of Nasca, came up as the first with the idea of these lines being pointers to star and sun constellations in the ancient sky, used by the farmers to predict the arrival of the yearly flow of water from the Andes. As such they would have served as a huge graphical calendar, similar to a sundial. There are many attempts to explain the geoglyphs (Kosok, Reiche, 1949; Hawkins, 1969; Morrison, 1978; Hadingham, 1987; Aveni, 1990; Reinhard, 1996) and a vast amount of popular literature on the subject is available (Rohrbach, 1992; Däniken, 1970, 1997).



Figure 1. Geoglyphs of Palpa and San Ignacio. The image up left shows a line of minimal width (pocket-knife in the center of the image shows the dimensions)

However, the many investigations and attempts to verify particular hypotheses are of only fragmentary character. They lack an element which is crucial for any scientific attempt to come up with an all-encompassing and convincing explanation: A complete recording of the geoglyphs. Up to now, scientists were always concerned with only those parts of the whole set of geoglyphs that seemed to support their individual hypotheses. This is understandable if one uses only traditional surveying equipment and techniques like theodolites and tapes. Modern technologies, like digital photogrammetry, digital visualization and GIS enable us for the first time not only to record in 3-D all geoglyphs completely and precisely in a joint coordinate system within a reasonable timeframe, but also provide for new analysis tools, which allow for a more objective assessment with unbiased quantitative approaches. At the same time it is obvious that many of the geoglyphs suffer from destruction, both through natural and human interference.

Although the pampa of Nasca is in the meantime included in the UNESCO World Heritage List and thus fairly well protected, other areas of high geoglyph concentration are totally open for human vandalism. Therefore it is high time for a comprehensive recording of whatever is left over to the current day.

In cooperation with the Swiss-Liechtenstein Foundation for Archeological Studies Abroad (SLSA) a project was defined that aimed (a) at the complete recording of the main geoglyph sites and (b) at the support of a team of archeologists who, for the first time, would do excavations in the areas of geoglyphs in order to learn more about the ancient Nasca cultures and their relations to the geoglyphs. There have been already three archeological campaigns with significant findings, which also triggered great interest in the public (Reindel, 1997; Reindel, et al., 1998; Scagnet, 1998; Reindel, Isla Cuadrado, 1999; Schulz, 1999; Rehländer, 2000). Also, early results of the photogrammetric processing and visualization have been presented to the public on occasion of an exhibition in the Rietberg Museum, Zürich (Grün, 1999).

This presentation consisted of two parts: An interactive display of textured 3-D models on a SGI Onyx2 and a 3-D stereo flyover on a 4x12 m² screen in the VisDome of ETH Zürich. In this paper we will report about the photogrammetric part of the project, including image acquisition, data processing and visualization of the results. This project comprises all the elements and products of a modern project of digital photogrammetry, including

- Aerial image acquisition with kinematic GPS
- Ground control points with static GPS
- Scanning of aerial images

- Aerial triangulation, both in manual and automated mode
- DTM generation, both in manual and automated mode
- Extraction of geoglyphs in 3-D vector form
- Generation of B/W (black/white) and color digital orthoimages
- Texture mapping and integration of vector geoglyphs
- Generation of synthetic views and flyovers
- Design of a datamodel and implementation on a GIS platform
- Development of GIS-based analysis functions

Some of these steps have to be performed in close cooperation with the archeologists. The project is not completed yet, therefore this is just an intermediate status report. The GIS-related issues will be presented in another publication.

2 PROJECT AREA AND IMAGE ACQUISITION

The ancient culture and the geoglyphs are named after the small town of Nasca, situated within the valley of the Nazca river, about 60 km from the Pacific ocean. The landscape of this region is dominated by vegetationless extensions of the western slopes of the Andes.

It is a harsh, dry land which gets its supply of water only through small rivers carrying the precious wet down from the high Andes. The valleys have all the characteristics of oases and agricultural products can only be grown there. Our area of interest stretches between the rivers Rio Grande and Rio Nasca (compare Figure 2). This area is dominated by very flat plateaus of sand, gravel and small rocks. These "pampas" must have posed a real challenge for the Nasca artists and in fact most of the geoglyphs are located at these ideal drawing tables.

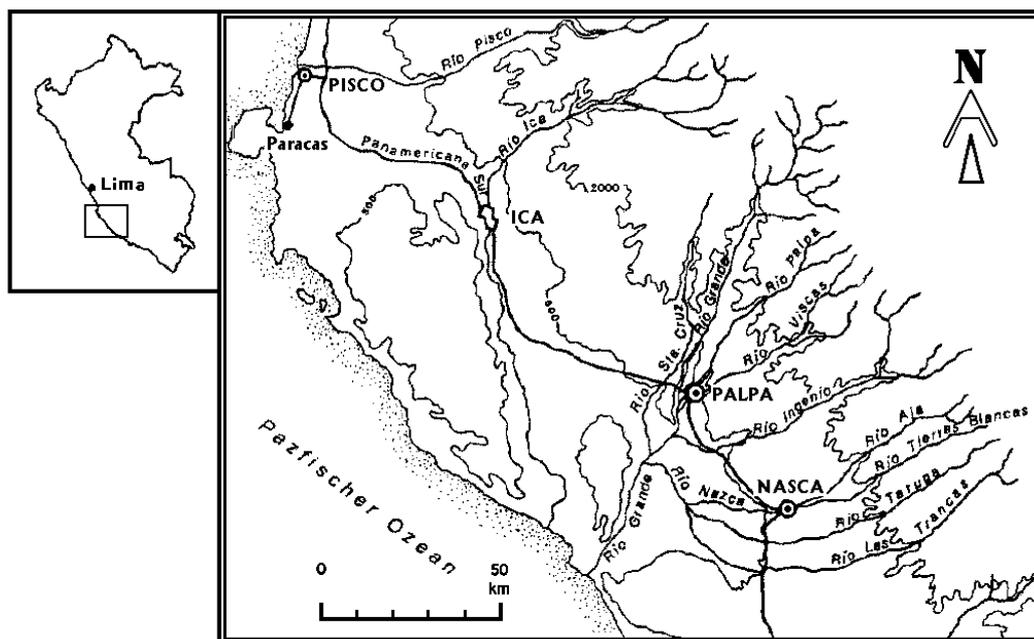


Figure 2. Project region Palpa/Nasca on the Peruvian south coast

We have selected three major geoglyph concentrations, the areas of Nasca, San Ignacio and Palpa, for our work. The pampa of Nasca became famous through the work of Maria Reiche.

The Panamerican Highway cuts right through the northern part and some of the most dense geoglyph sites and its construction has done much damage to those lines and figures. Nowadays it is a restricted zone and one can only travel along the highway. This was one of the reasons why we could set only very few ground control points and why we decided to apply kinematic GPS in addition. Each area has been covered by a separate block and constitutes an independent project by itself.

The photoflights were performed by Horizons, Inc., Rapid City, SD, USA with a Zeiss RMK A15 camera. There were two missions: 30.04. and 01.05.1997 for the blocks Nasca and Palpa, both in color; 23.05. and 27.05.1998 for the blocks Palpa and San Ignacio, resp. Nasca, all in B/W. Table 1 gives an overview of the project characteristics. In total we have produced more than 1000 aerial images, both in color and B/W at scales 1:5 000 for Palpa and San Ignacio and 1:10 000 for Nasca. The image scale was chosen such that the smallest possible lines, which in the Palpa and San Ignacio areas

have a width of about 10 cm (compare Figure 1), could still be distinguished. The image overlap is 60% in both directions. The control points are very sparse and signalized in Nasca and Palpa, while in San Ignacio natural features have been used. 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.

There are aerial images around from previous missions of the SAN (Servicio Aerofotografico Nacional), but most of these blocks were flown for agricultural and land development purposes and cover mainly the valleys, which do not contain geoglyphs. Our oldest set of images dates back to 1944 and shows clearly the geoglyphs in a much better condition than today. Also, attempts have been made to take 70 mm format photos from a balloon and a small airplane (Aveni, 1990) over the pampa of Nasca, but these efforts failed because of either uncontrollable conditions for the balloon or too small image scales (1:24 000) for the airplane photos. 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.



Figure 3. Part of an aerial image of the Palpa block

Area	image acquisition	number of images	planned image scale	C (color) or B/W (black and white)	number of control points
Nasca	Apr/Mai'97	309	1:10 000	C neg	11 (signal.)
	Mai'98	309	1:10 000	B/W pos	0
Palpa	Apr/Mai'97	134	1:5 000	C neg	8 (signal.)
	Mai'98	134	1:5 000	B/W pos	0
San Ignacio	Mai'98	189	1:5 000	B/W pos	9 (natural)

Table 1: Project parameters for Nasca, Palpa and San Ignacio

3 PHOTGRAMMETRIC DATA PROCESSING

In the following we will only report about the processing of the block Palpa. This one had priority because all the excavations took place in the Palpa area. Currently the block San Ignacio is in work.

3.1 Aerial Triangulation

Since it was anticipated 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 AC-3

and S9. The triangulation of the Palpa color block was performed with 88 images and 8 control points. Since we were not very happy with the quality of the color images 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 color block. We did a joint bundle adjustment of both the color and B/W images including kinematic GPS data (BW+C). Table 2 gives the results of triangulation.

Version	number of images	number of control points	kinematic GPS	σ_0 [μm]
B/W+C	211	8	yes	13.3

Table 2: Triangulation characteristics for Palpa

Although the photoflight was meant to produce an image scale of 1:5 000 the actual scale turned out to be 1:7 000. The overall block accuracy, as indicated by $\sigma_0 = 13.3 \mu\text{m}$, corresponding to 9.3 cm on the ground, 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.

3.2 DTM Generation

In order to generate a DTM of the Palpa area a total of 57 B/W stereo pairs 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.

We used profile measurements at a profile distance of 20 m with additional breaklines. This gave us about 200 000 points for an area of about 2 km by 9 km. Later on we also integrated all the extracted geoglyphs as breaklines into the DTM. Figure 4 shows the shaded version of a wireframe model of the DTM with the plateau Cresta de Sacramento as the major site of geoglyphs. The flat region is the Rio Grande valley. The major excavation sites La Muña and Los Molinos are indicated.

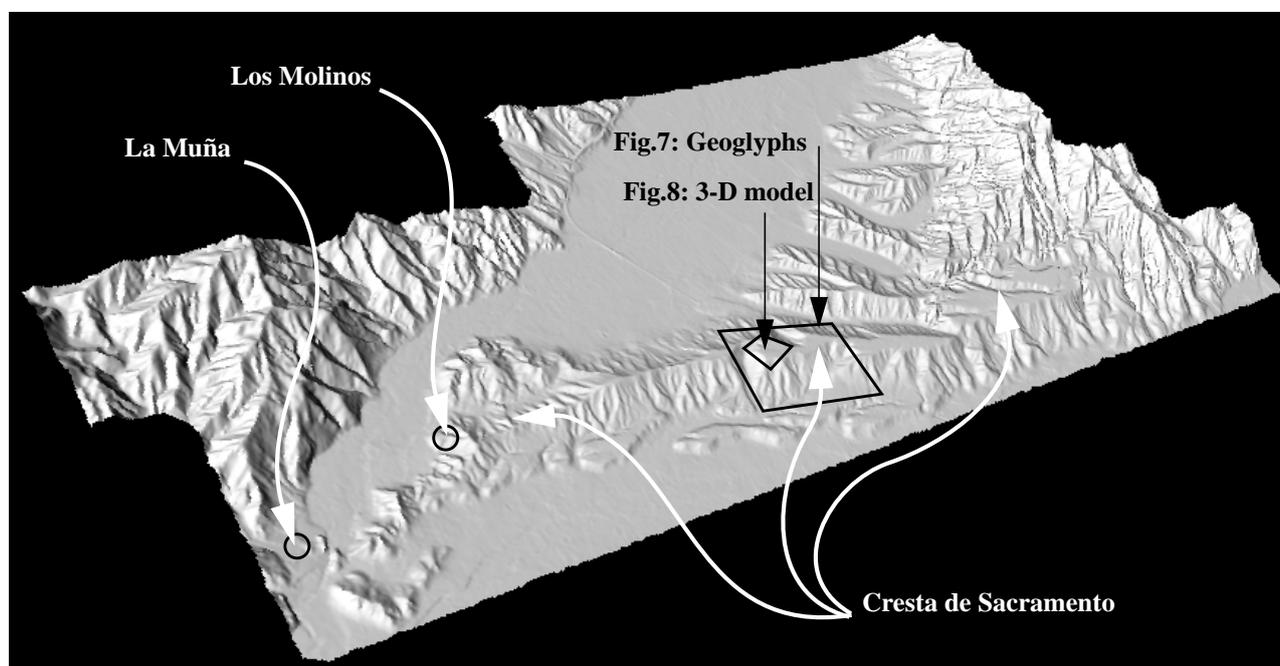


Figure 4: Shaded DTM of the Palpa area

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

3.3 Generation of Orthoimages

All aerial images B/W and color are scanned at a resolution of 21 µm pixelsize at the Agfa Horizon image scanner. In case of the Palpa block this corresponds to a footprint of 15 cm. This is about the size of the most narrow geoglyph lines. For orthoimage generation and mosaicking we used the Leica/Helava DPW 770. The largest mosaick 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).

3.4 Extraction of Geoglyphs in Vector Form

The 3-D mapping of geoglyphs is a very sensitive business and was done manually on the Analytical Plotter S9. Since archeological knowledge is indispensable for correct interpretation the stereomeasurements were done by K. Lambers, an archeologist on the project. For later analysis on a GIS platform we had to develop a system of attributes for the various types of geoglyphs and other items of interest, like ancient settlements, fortification walls, terraces and platforms and the like.

The feature codes 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 converted into dxf format with feature codes. Maps for overview and with detailed content have been generated by using ArcView Release 3.1. The attributes also contain information on stratigraphy and type of generation (negative/positive areas, heaped/cleared/furrowed lines). The classification scheme of the geoglyphs is indicated in Figure 5. Currently the vector map including attribution is verified by archeologists in the field.

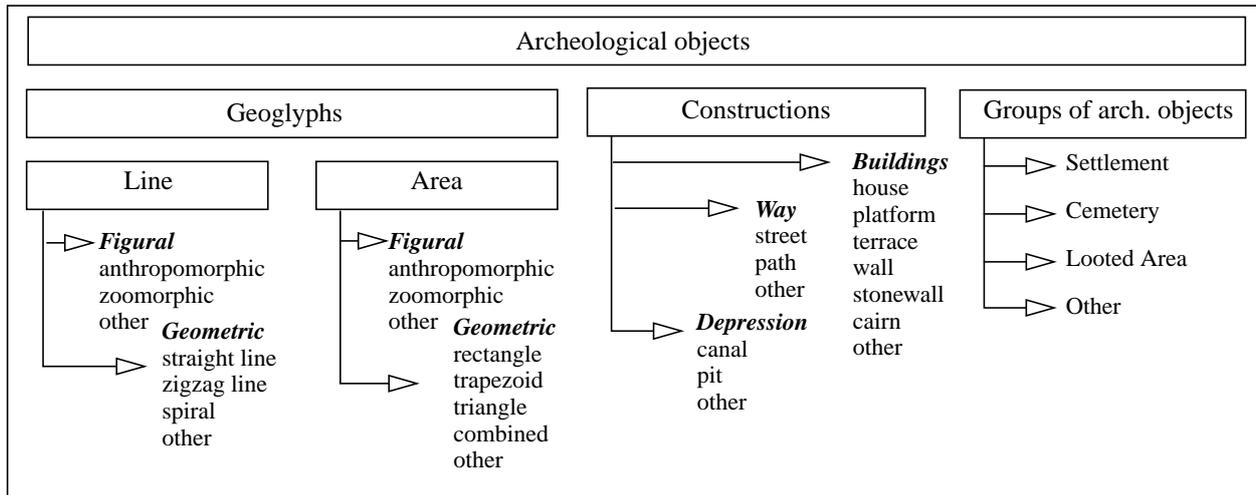


Figure 5. Classification scheme of the geoglyphs. The lowest level (stratigraphy and generation mode) are not shown.

Within the project area of Palpa alone we generated more than 9500 vector segments. Figure 6 shows three particular objects (from left: double spiral, “astronaut”, whale; compare also Figure 1). Figure 7 shows a small section of the whole area.

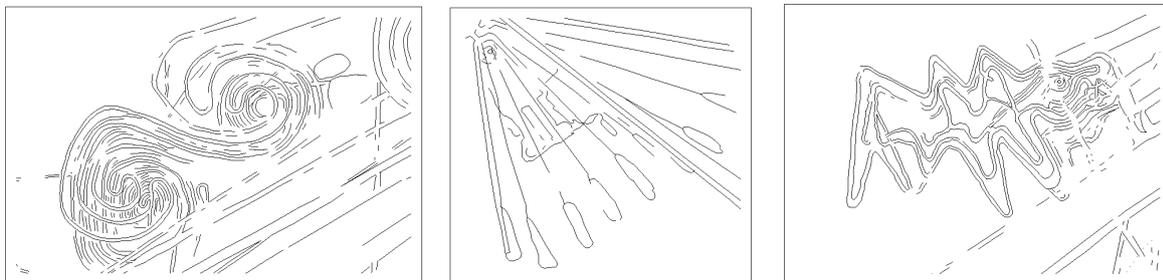


Figure 6. Various Palpa geoglyphs. From left: double spiral, “astronaut”, whale

In general, the pampa of Nasca, San Ignacio and Palpa have a very rich in iconography. Besides many anthropomorphic figures we find zoomorphic objects such as whale, monkey, dog, anteater, condor, hummingbird, parrot, chaucato, flamingo, frigate bird, pelican, snake, spider, lizzard, dragonfly and plantlike species such as tree, flower, spices, etc.

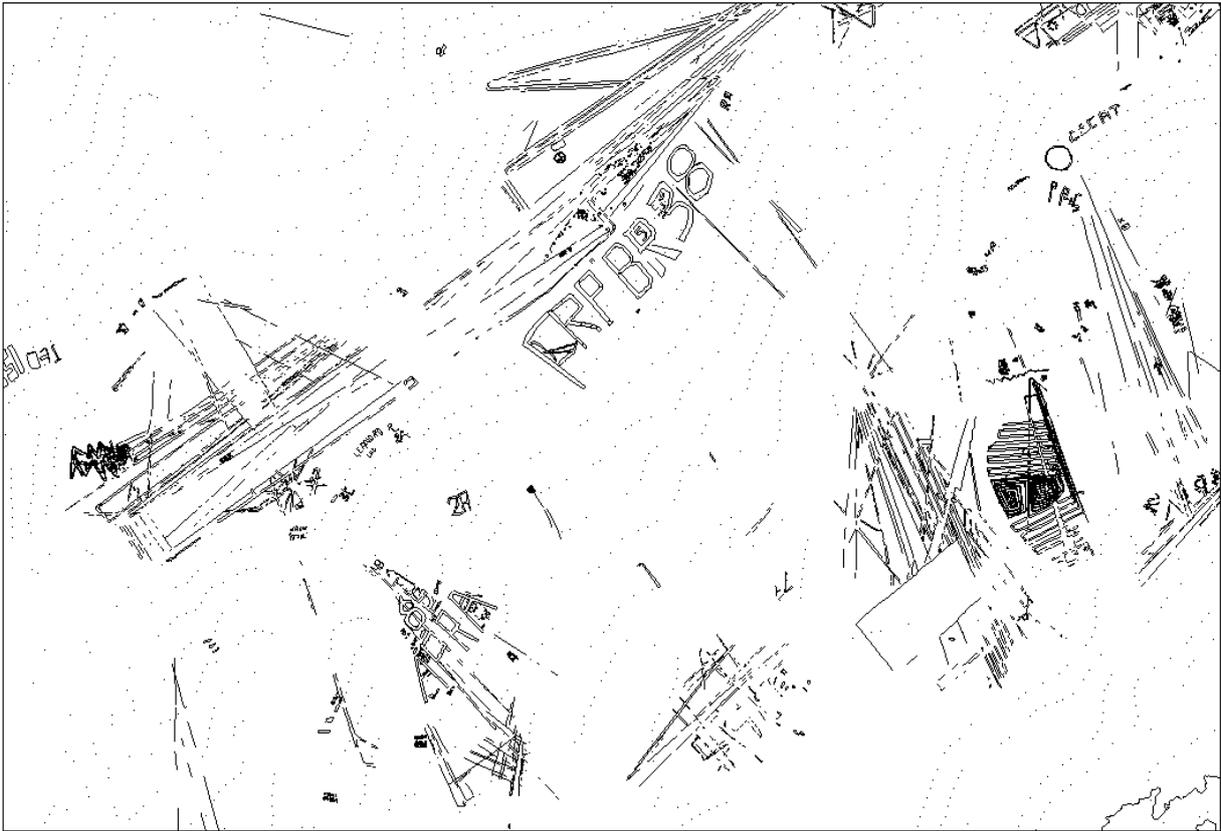


Figure 7. Plot of a section of the geoglyphs of Palpa

4 VISUALIZATION OF RESULTS



Figure 8. 3-D model of the 'WHALE', lines, trapezoids and a star figure - orthoimage mapped onto DTM

5 CONCLUSIONS

We have reported here about the current processing stage of the project. The block Palpa is fully processed, the geoglyphs and other items of archeological interest are extracted and modeled in 3-D. A conceptual data model has been developed which waits for implementation on a GIS platform. Since high quality of the results in terms of accuracy and completeness is required, we could not rely on any automated procedures for processing, neither for triangulation nor for DTM generation or feature extraction. However, we used cutting edge photogrammetric technology wherever feasible. The produced datasets are extensive, the Palpa texture map alone absorbs 2 GB and we find great difficulties with real-time visualization.

The block San Ignacio is currently in work. The pampa of Nasca ranks third on our list of priorities.

It is much too early for any conclusions concerning the purpose of the geoglyphs and we wish to stay away from any speculative statements. A few facts however can already be derived from the existing data:

- In general the geoglyphs are not of very high geometrical precision. Thus the production cannot be considered a great engineering achievement.
- Geoglyphs are overlaying each other. Therefore the builders were not very respectful of previous works. Aveni, Silverman, 1991, state very appropriately that some areas look like an "... unerased blackboard at the end of a busy day of class".
- There is a strong relation between density of geoglyphs and closeness to settlements. Physical convenience was surely an issue for the builders.
- Geoglyphs are located where topography admits. There is a strong correlation between geoglyphs and topography. Geoglyphs are crowded in vast, flat areas and on smooth slopes.
- Where accessible, geoglyphs deteriorate nowadays very quickly through human disrespect, intervention and vandalism.

These facts should be considered when any of the prevailing hypotheses is evaluated. The purpose of the geoglyphs of Nasca, Peru still remains a mystery. These signals in the sand, laid out by ancient civilizations, will continue to puzzle scientists, esoterics and unprejudiced tourists.

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