Topographical Research in Shahr-i Sokhta: Preliminary Report

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The research conducted in Shahr-i Sokhta by the Laboratory of Ancient Topography and Photogrammetry of the University of the Salento began in 2017 with the aim of reconstructing the ancient landscape of the valley of the Hirmand and establishing the organisational layout of the entire upland on which the protohistoric site lay, using both traditional and innovative methods of investigation. Advanced non-invasive instruments and technologies were employed to enrich the framework of archaeological knowledge that could be gleaned from the terrain, making it possible to tackle the main historical and archaeological issues regarding the transformation of the site and its internal organisation in the most effective way.

The investigations were however affected by two factors concerning the topographical documentation of the site: the lack of an archaeological map containing all the archaeological and geo-environmental information relating to the upland and the total absence of an archive of aerial photographs.

The initial activities conducted by the research group consisted mainly of retrieving the relevant published documentation, with the aim of ascertaining the main characteristics of the site, assessing the cartography thus far produced (topographical maps, excavation plans, thematic maps) and conducting brief instrumental surveys to support the positioning of the excavation areas and vertex points of the general grid of the upland (Fig. 1).

Although the available maps of Shahr-i Sokhta were helpful during the initial attempts to orient ourselves within an unknown site, it proved to be unsatisfactory in various ways. For example, there was no archaeological data showing the correct position of the excavation areas and the visible traces of the ruins on the ground, and the altimetric data was insufficiently detailed, which are both fundamental features of archaeological cartography. The need to create an archaeological map thus arose in response to the lack of fully-fledged digital topographical cartography that could be managed in a GIS environment and thus updated over time.

However, the difficulty of obtaining the base maps that usually provide the starting point in the drawing up of archaeological documentation represented a considerable obstacle. As seen in similar situations, one way to resolve this lack is the acquisition and processing of satellite images. This remote sensing tool has been widely used in areas of the Middle East for the creation of high-scale maps of the exact geographical location of archaeological sites and for positioning the archaeological investigations conducted there (Di Giacomo *et al*. 2011).

However, the use of satellite images is not limited to providing cartographic support. The absence of (or the difficulty of obtaining) aerial images of zones belonging to nations where access to this type of material is considerably difficult represents a severe obstacle to the systematic study of the landscape and topographical and geo-archaeological investigations. For this reason, since the 1980s, but especially since the beginning of the century (Campana 2004), the use of satellite images for the observation of the earth has grown considerably. Such images make it possible to discover and investigate not just archaeological sites,

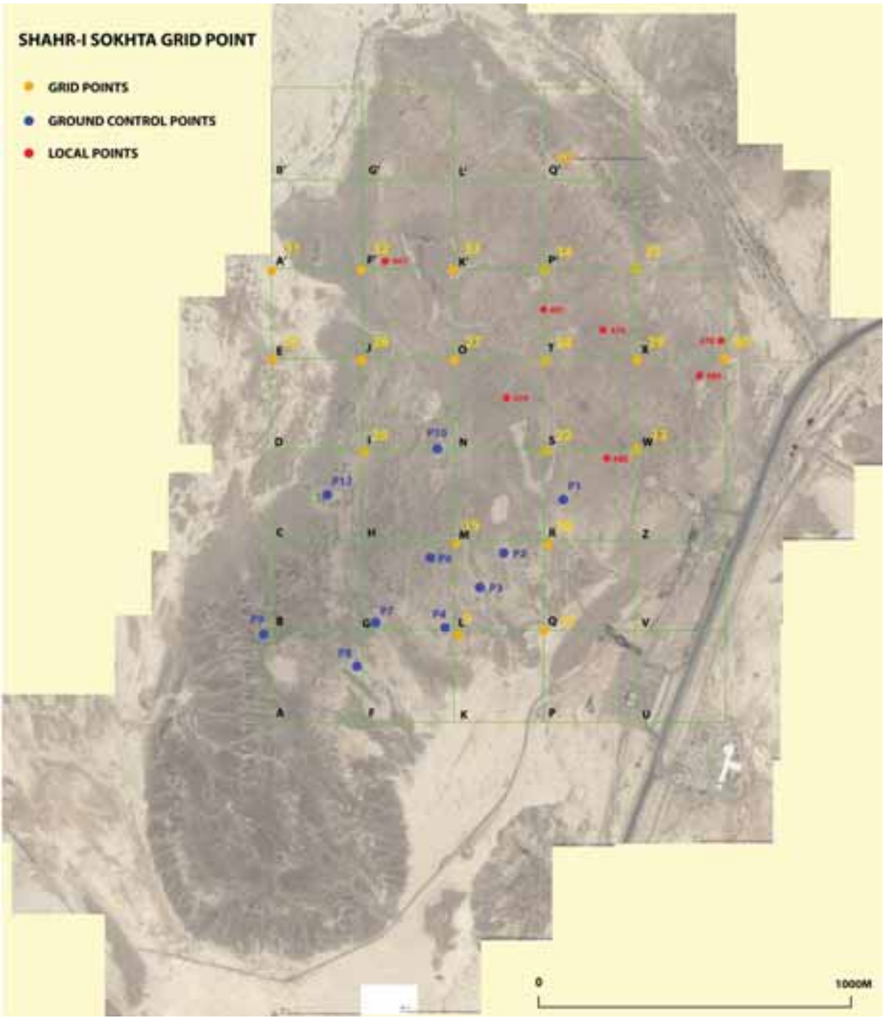

Fig. 1: general grid of the upland of Shahr-i Sokhta, currently being updated.

but also entire regions, with the aim of studying the dynamics of the landscape in question in terms of its history, pattern of settlement and evolution.

For the site of Shahr-i Sokhta and the surrounding area, this obstacle was perceived from the very start of the archaeological research conducted by the Italian mission in the region of Sistan. For this reason, in order to be able to conduct a thorough study, in morphological as well as archaeological terms, of the valley of the Hirmand and southern Sistan in general, in the late 1990s (Forte *et al*. 1998) Landsat TM optical satellite images were obtained. Despite their modest spatial resolution, these provided a promising base for an initial geo-archaeological reconstruction of the region. Roughly 30 years later however, the rather precarious state of the cartographic and aerial-photographic documentation prompted the researchers to seek new satellite images.

The first step was to ascertain and assess the satellite documentation available for the area of Sistan and the valley of the Hirmand in particular. This entailed consideration of all the obtainable resources, starting with material that was free, including the Landsat 8, Landsat 7 ETM+ and 4-5 TM images.[1] Also considered were Sentinel 2 optical satellite images, of which only two datasets are currently available,[2] and Sentinel 1 radar satellite images. The review of the available satellite documentation obviously also took account of the images provided by the American spy satellites of the CORONA missions, of which two strips from the KH-4A mission (with a resolution of 2.80 m on the ground)[3] and two strips from the KH-4B mission (with a resolution of 1.80 m on the ground)[4] are available.

In terms of commercial satellite images, numerous images provided by Quickbird, GeoEye 1, WorldView 1 and WorldView 2, the property of Digital Globe, are available for the area in question.[5] Lastly, the Airbus France catalogue has high-resolution Pléiades images and a SPOT 6 stereopair. Of this range of

1. The images were provided by the earth explorer site of the USGS.
2. The dates of acquisition of the Sentinel 2 images are 5/10/2018 and l'8/10/2018. At the time of writing, Sentinel 2 scenes for southern Sistan were not available.
3. One acquired on 03/05/1965 and the other on 24/05/1965.
4. Both acquired on 26/05/1972. This historic satellite material is still in the procurement phase.
5. This group of images is currently being analysed in view their purchase and processing.

material, it was decided in this first phase to use two high-resolution Pléiades images and the SPOT 6 stereopair.[6]

The high-resolution Pléiades images, already used for archaeological purposes (Malinverni *et al.* 2017), are particularly effective thanks to the sensitivity of the sensor in distinguishing objects in the shade and identifying pale elements in particularly brightly lit environments.[7] In addition, their high resolution (0.5 m) means we have two highly detailed images not only of the site of Shahr-i Sokhta but also of the surrounding area, unheard of for this geographical context and useful for identifying places of interest not just within the ancient city but also in the area around it.

Specifically, two scenes, provided by Pléiades sensor 1A, dated 16/08/2012, and Pléiades sensor 1B, dated 25/08/2017[8] (Fig. 2) were purchased in bundle mode. Both are composed of a panchromatic image[9] and a multispectral image[10] with spatial resolutions of 0.5 m and 2.0 m respectively. The preliminary study of the satellite material began with the scene provided by the Pléiades 1B satellite. The first step was to create a pansharpened image to join the spatial information of the panchromatic image with the spectral resolution of the multispectral image. Among the various algorithms available for the creation of such images, the following methods were used: Brovery, Gramschmidt, IHS and Principal Component Analysis (Lasaponara - Masini 2012) (Fig. 3). Each of these provides different information that can accentuate the resolution on the ground and the multispectral data depending on the case.[11] The preliminary processing also sought to combine the bands to form a colour composite, thereby emphasising elements that can indicate the presence of archaeological evidence (Fig. 4).

6. The Pléiades satellite images and the SPOT 6 stereo images were provided by ESA (European Space Agency), as Third Party Missions Data.
7. This is the result of the 12 bit pixel depth.
8. The Pléiades satellite group is composed of two satellites equipped with high-resolution sensors: Pléiades 1A, launched in 2011 and Pléiades 1B, launched in 2012. They follow a heliosynchronous orbit and have a temporal resolution of 26 days.
9. The panchromatic image has a single greyscale band covering wavelengths of 0.47 to 0.83 mm.
10. The multispectral image has four spectral bands with the following wavelengths: B0 (blue): 0.43-0.55 mm; B1 (green): 0.50-0.62 mm; B2 (red): 0.59-0.71 mm; B3 (near-infrared): 0.74-0.94 mm.
11. The best processing method is still being evaluated.

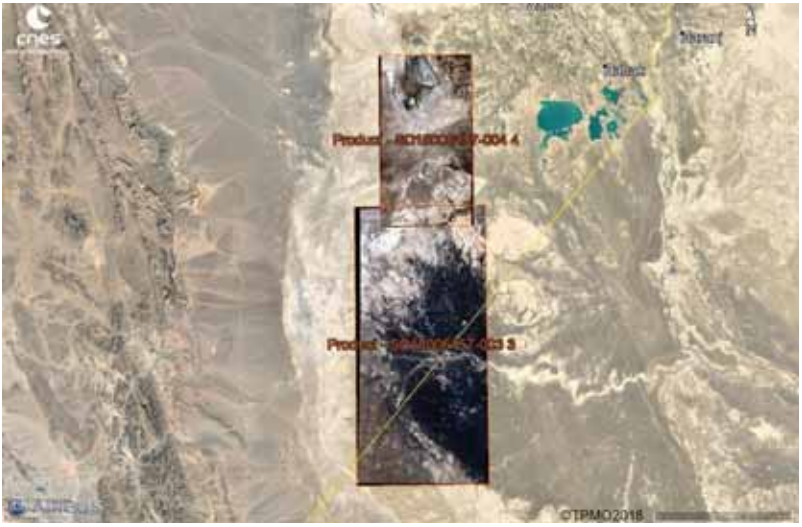

Fig. 2: positioning of the Pléiades images.

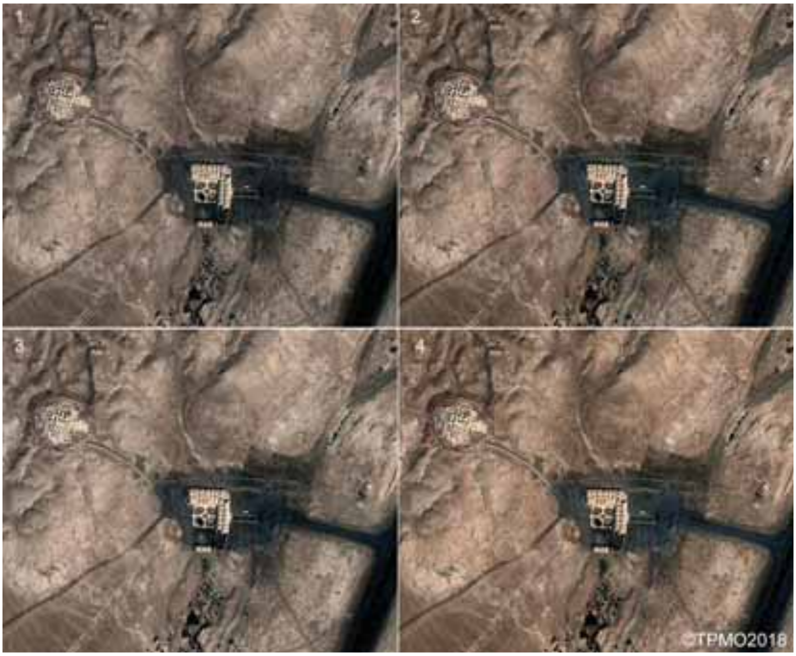

Fig. 3: Pan-sharpening. (1) Brovery; (2) IHS; (3) Gram Schmidt; (4) Principal Component.

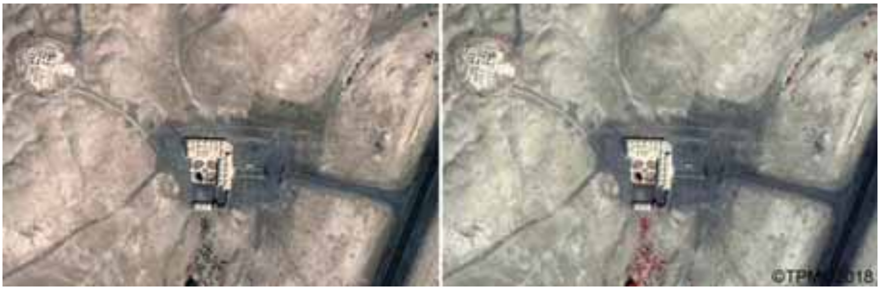

Fig. 4: Colour Composite. Left: natural colours (RGB 321); right: false colours (RGB 432).

In addition to the preliminary processing of the high-resolution images, a DEM of the plateau of Shahr-i Sokhta and the surrounding area was created from the SPOT 6 stereo images of 14/02/2016. This material is in bundle format and includes a panchromatic image and a multispectral image with spatial resolutions of 1.5 m[12] and 6 m[13] respectively. They were acquired in stereo mode and the two images (StereoA and StereoB) were processed using ERDAS IMAGE© and ERDAS eATE© software. In order to obtain a DEM with a reliable spatial resolution, the panchromatic image was used. The autocorrelation of the images with the terrain was performed using Rational Polynomial Coefficients (RPCs),[14] which are included as accessory information in the dataset of the images. After creating the tie-points between the two images, the software produces an initial output (an anaglyph) that shows the superimposition of the stereo images with the signalled tie-points (Fig. 5). The subsequent phase involved the creation of the DEM (Fig. 6), which, with a resolution of about 5 m on the ground, is the best DEM currently available for both the protohistoric site and the surrounding area, helping to accurately reconstruct the transformation of the landscape in the valley of the Hirmand.[15]

12. The panchromatic image has a single greyscale band covering wavelengths of 0.450 to 0.740 mm.
13. The multispectral image has four bands covering the following spectra: Blue (0.455-0.5225 mm); Red (0.530-0.590 mm); Green (0.625-0.695 mm); infrared (0.760-0.890 mm).
14. RPCs contain information on the way in which the satellite images were acquired. These data were used as it was not possible to obtain all the Ground Control Points on the ground needed for this operation.
15. The DEM generated and presented here represents an initial attempt to provide a reliable geomorphological support that will be revised and improved as the research moves forward.

As well as the use of satellite images, part of the work concerns the post-processing of aerial photographs taken by Unmanned Aerial Vehicles (UAVs).[16] The UAV-acquired images used in the present study were obtained from video footage of the upland of Shahr-i Sokhta: in addition to the residential and craft areas already excavated, numerous archaeological traces of buried structures are visible (Fig. 7).

Specifically, some stills show traces of broad areas of the ancient city that have not yet been investigated near the excavated sectors, such as those arranged around Area 26, which has been interpreted as a market, or near the Central Quarters. What is seen in these traces is the alteration of the composition of the terrain arising from the disintegration of the mud bricks and hence the clay of which they are composed (Fig. 8). Identification of the numerous archaeological traces, identified in aerial photographs acquired by drones, is helping to update and enrich our knowledge of the general plan of the site.

The post-processing of the UAV images involved first and foremost selecting still photographs from the video footage with sufficient overlap to allow them to be arranged in sequence. However, it was also possible to perform image-based 3D modelling, which makes it possible to generate measurements and 3D models from digital images. In the first place, the stills obtained from the video footage were tiled with the use of photomerging software, which makes it possible to develop a three-dimensional model of the area in question, in this case the excavation sector known as the "Monumental Area", from the overlapping images.

The procedure for generating a 3D model consists of three fundamental steps:

mesh: after generating the dense points cloud the next step is to join up the vertices, edges, corners and faces that determine the shape of an object, creating a mesh of polygons that together form the surface of the digital volume.

16. The authors thank Dr Media Rahmani, of the Iranian research group, for granting us permission to use the aerial photographs taken by her.

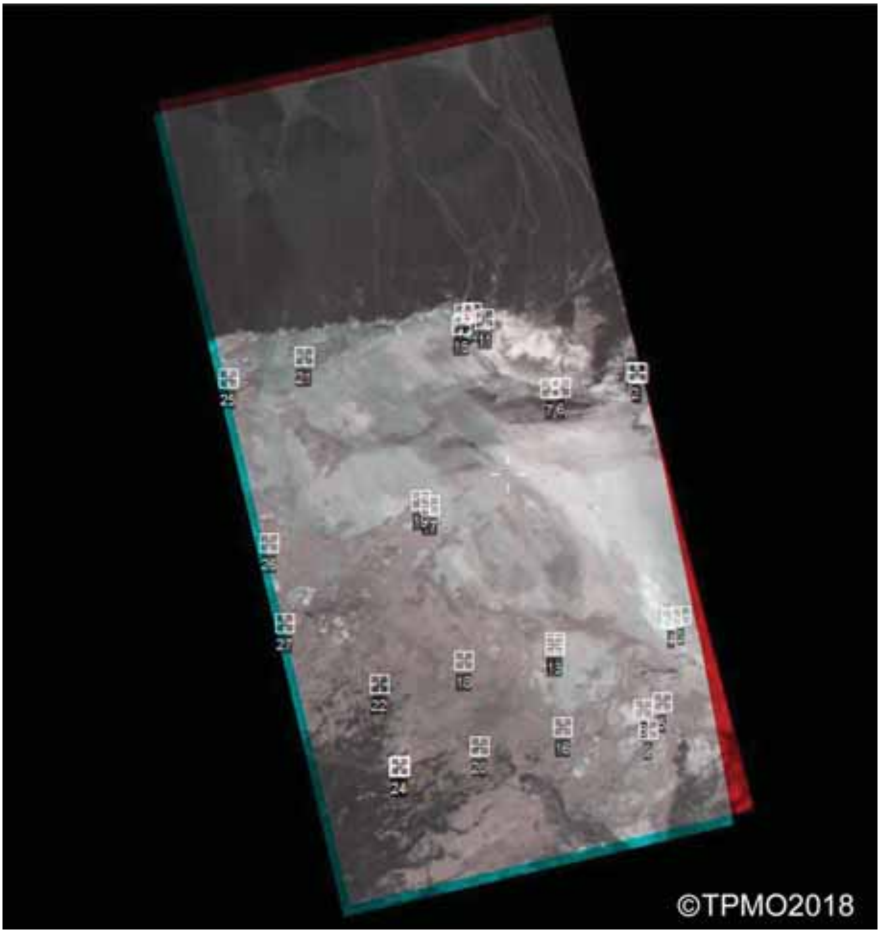

Fig. 5: anaglyph of the SPOT 6 stereo images with the identification of the tie-points.

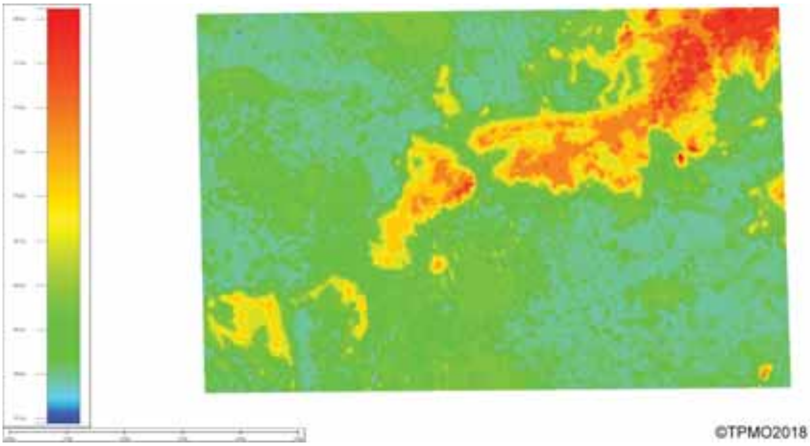

Fig. 6: DEM of the upland of Shahr-i Sokhta.

Fig. 7: upland of Shahr-i Sokhta: the arrows indicate traces of buried structures near excavation sectors.


Fig. 8: example of a trace arising from alteration of the composition of the terrain.

texture: in the texturing phase, the colour images are mapped on to the polygonal model (mesh), i.e. the geometrical 3D surface (Fig. 9: 2).

The model created is correctly repositioned in space with the help of Ground Control Points (and thus the three coordinates X, Y, Z), located in the field by Total Station. The use of GCPs makes it possible to rapidly extrapolate a perfectly georeferenced orthophoto (Fig. 9.3), which can be managed in a GIS environment. This in turn makes it possible to vectorise the traces identified, or even the excavation area if no site plan of this is available, enabling the rapid characterisation of the structures.

From the georeferenced orthophoto, and thus using the elevation (Z) assigned to each GCP, it is possible to obtain a DEM with contours at manageable distances (in this case 0.5 m between one isoline and the next). In dark red is the highest area, corresponding to the high part of the tepe on which the building was constructed; in blue are the areas with lower elevations. Note that the areas in pale red (to the

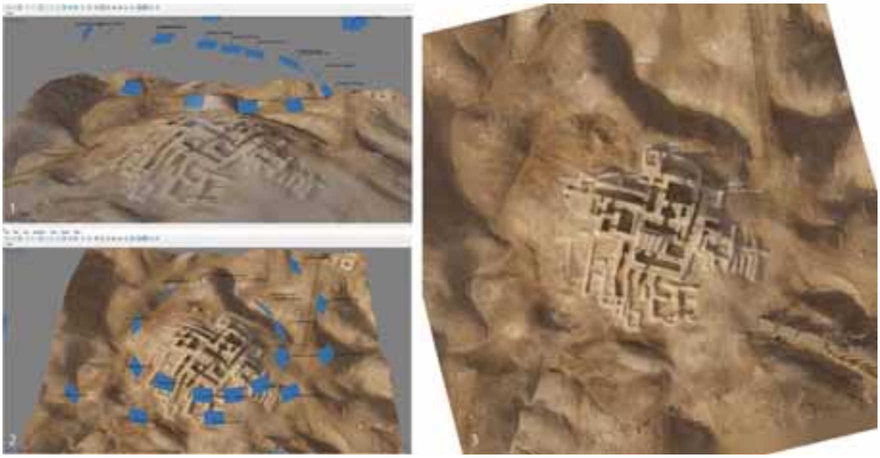

Fig. 9: post-processing of the drone images: from the points cloud (1) to the texturised model (2) and the processing of a georeferenced orthophoto (3).

north of the tepe) are characterised by uniform elevation, favourable to human occupation. This is highlighted by the creation of a path profile, which shows the altimetric profile of the area. Indeed, the aerial photographs of this sector show the traces of buildings that have yet to be excavated (Fig. 10). It emerges that the so-called "Monumental Area" was larger than previously assumed, or was flanked by other structures that occupied the highest flat parts of the tepe.

The images that yielded a high number of soil-marks were processed by applying various photographic filters in order to emphasise the traces (Fig. 11). The traces visible in the vertical photographs were vectorised in a GIS environment (Fig. 12).

Those visible in the diagonal images, which could not be vectorised, were used to document the areas that were richest in traces. In this way, it was possible to map the most interesting areas in which to conduct targeted UAV flights for the acquisition of aerial photographs in the future.

The information from both satellite images and images acquired by drones constitutes the basis of the GIS of Shahr-i Sokhta. Although the work is still in its infancy, it has been possible to map not only the excavated sectors but also the areas that have yielded the most evidence of buried structures. This mapping, currently being updated, provides a starting point for planning and orienting future research activities. These will involve the acquisition of new satellite images, especially a satellite stereopair with greater spatial resolution from which to derive further information on the anthropised area, thereby improving the DEM. In addition, low-elevation aerial-photographic flights will be conducted, since the images used for the considerations set out in this chapter do not contain any of the parameters that are indispensable for the post-processing of the data.

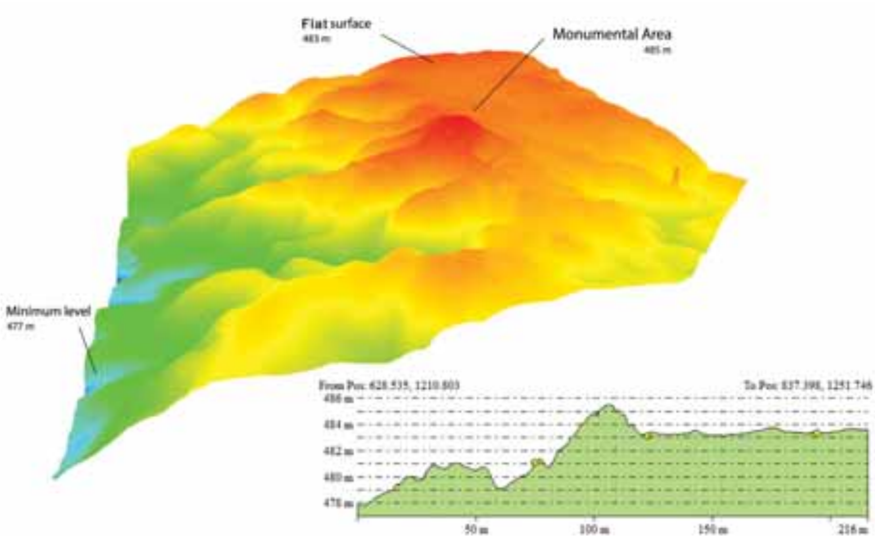

Fig. 10: DEM of the so-called Monumental Area with the relative path profile.

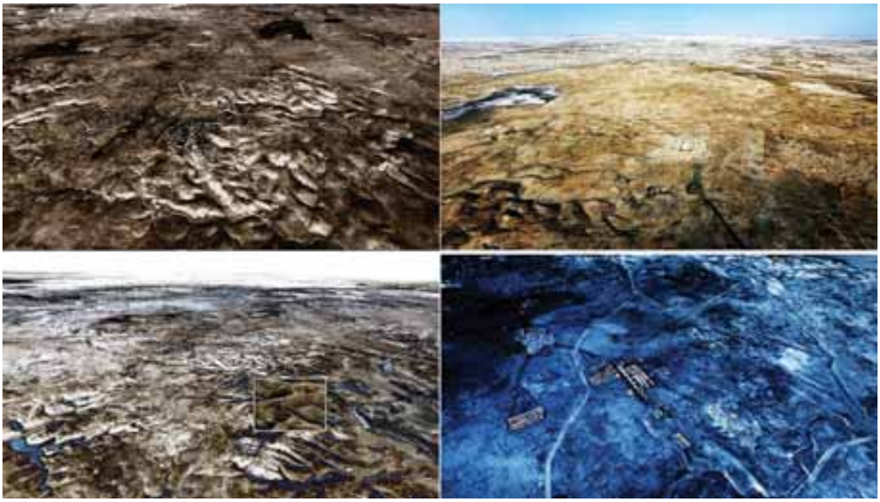

Fig. 11: examples of the application of photographic filters (by G. Murro).

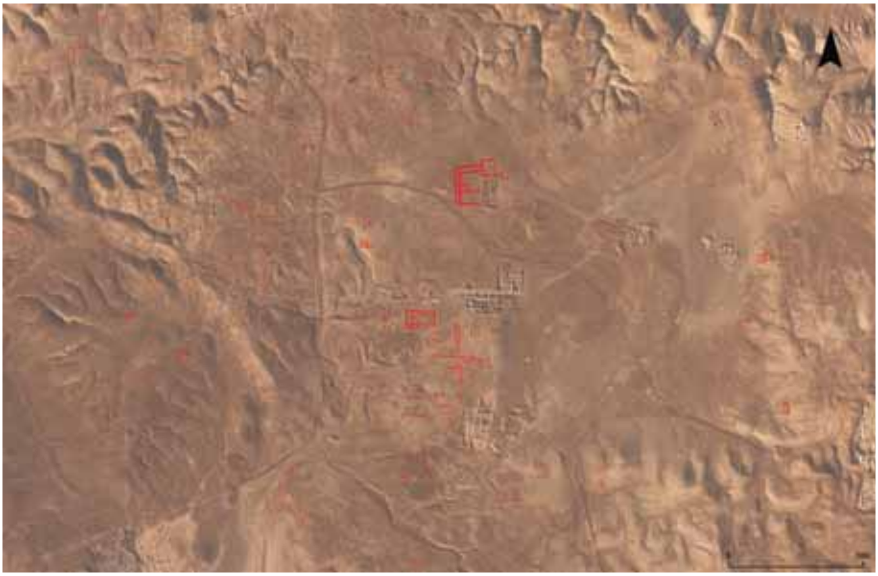

Fig. 12: vectorisation of the traces visible near Area 26.

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