

THE BAMIYAN VALLEY: LANDSCAPE MODELING FOR CULTURAL HERITAGE VISUALIZATION AND DOCUMENTATION

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ABSTRACT

In this paper we present the modeling and visualization of the cultural heritage area of Bamiyan, Afghanistan. The region is situated ca 200 km north-west of Kabul and it was one of the major Buddhist centres until the ninth century AD. The two standing Buddhas belonged to some of the most famous Buddhist monuments world-wide. In 2001 they were destroyed through an act of vandalism by the Taleban militia. In our previous reports we have already presented the 3D computer reconstruction of the Great Buddha of Bamiyan while in this contribution we will demonstrate 3D visualization products generated with different software packages and a first attempt at generating a spatial information system.

1. INTRODUCTION

The region of Bamiyan, ca 200 km North-West of Kabul, Afghanistan (Figure 1), was one of the major Buddhist centres from the second century AD up to the time when Islam entered the area in the ninth century. For centuries, Bamiyan lay in the heart of the famous Silk Road, offering rest to caravans carrying goods across the area between China and Western Empires. Strategically situated in a central location for travellers from North to South and East to West, Bamiyan was a common meeting place for many ancient cultures.



Figure 1: The map of Afghanistan and the welcome sign before entering Bamiyan village.

In the region, many Buddha statues and hundreds of caves were carved out of the sedimentary rock. In particular, near the village of Bamiyan, at approximately 2500 meters altitude, there were three big statues of Buddha carved out of a vertical cliff (Figure 2).



Figure 2: Panorama of the Bamiyan cliff with the three Buddha statues prior to demolition.

The larger statue of Bamiyan was 53 metres high while the smaller one measured 38 m. They were cut from the sandstone cliffs and they were covered with a mud and straw mixture to model fine details such as the expression of the face, the hands and the folds of the robe (Figure 3).



Figure 3: The two big standing Buddhas of Bamiyan.

The invasion of the Soviet army in December 1979 started a 23-year long period of wars and barbarity that left Afghanistan as a heavily hurt and damaged country, with little hope for quick infrastructure reconstruction, economic improvements, political stability and social peace. Moreover, at the end of the 1990's the extremist Taleban regime started an internal war against all non-Islamic symbols. This led in March 2001 to the complete destruction of the two big standing Buddha statues of Bamiyan (Figure 4), as well as other small statues in Foladi and Kakrak. In 2003, the World Heritage Committee has decided to include the cultural landscape and archaeological remains of the Bamiyan valley in the UNESCO World Heritage List [<http://whc.unesco.org/>]. The area contains numerous Buddhist monastic ensembles and sanctuaries, as well as fortified edifices from the Islamic period. The site symbolizes the hope of the international community that extreme acts of intolerance, such as the deliberate destruction of the Buddhas, are never repeated again. The whole area is nowadays in a fragile state of conservation as it has suffered from abandonment, military actions and explosions. The major dangers are the risk of imminent collapse of the Buddha niches (Figure 5) with the remaining fragments of the statues, further deterioration of

still existing mural paintings in the caves, looting and illicit excavation.



Figure 4: The explosions of March 2001 that destroyed the Buddha statues (Image Source: CNN).

In our previous reports we have already presented the 3D modeling of the lost Great Buddha statue and the two empty niches by using old and recent photographs (Gruen et al., 2004a,b) (Figure 6).



Figure 5: The two empty niches, where the Buddha once stood, as seen in August 2003.

In this work we mainly present the modeling of the entire UNESCO cultural heritage site using high-resolution satellite imagery. The final goal is the production of virtual flights over the area, the extraction of cartographic vector features around the village of Bamiyan and the documentation of the protected area with a tourist and cultural information system.



Figure 6: The 3D computer model of the Great Buddha, as reconstructed from existing images (left, Gruen et al., 2004b) and the 3D model of its actual empty niche (right, Gruen et al., 2004a).

2. TERRAIN MODELING FROM SATELLITE IMAGERY

For the 3D modeling and visualization of the area of interest, an accurate DTM is required. We had the contours of

Russian maps 1:50 000 digitised, but when we tried to map an IKONOS image onto the derived DTM we realised that it did not fit. Aerial images were not available to us and the idea to acquire them was unrealistic, due to the absence of any surveying company operating in that area. So space-based image acquisition and processing resulted as the only alternative to the aerial photos or any other surveying method. Nowadays space images are competing successfully with traditional aerial photos, for the purpose of DTM generation or terrain study in such problematic countries, as Afghanistan is. Also the resolution and availability of worldwide scenes taken from satellite platforms are constantly increasing. Those scenes are available in different radiometric modes (panchromatic, multispectral) and also in stereo mode.

2.1 The satellite images

The HRG sensor carried on SPOT-5 since May 2002 was suitable for our tasks [<http://www.spotimage.fr>]. The sensor can acquire stereo images in across-track direction at 2.5m ground resolution in panchromatic mode. The time difference between two successive acquisitions in stereo mode of the same area depends on the incidence angle, with a minimum of one day difference. The satellite flies at a mean height of 832 km, along a quasi-polar and sun-synchronous orbit.

Due to the scientific, social and cultural interest of the project, a B/W stereo pair over Bamiyan was provided at special conditions by the ISIS Program [<http://medias.obs-mip.fr/isis/>]. The two scenes have been acquired on 18th December and 19th December 2003, at 10:40 a.m. and 10:20 a.m. local time respectively. The scenes are 24000 x 24000 pixels large and cover a mountainous area of approximately 60x60 km, centered at (34°50' N, 68° 7' E) and (34°50' N, 67° 48' E). The cloud cover was zero and the ground resolution is 2.5 m.

Furthermore, a colour Geo level IKONOS image mosaic over the Bamiyan area was provided by Space Imaging [<http://www.spaceimaging.com>] (Figure 7). The scenes were acquired on 15th December 2001 and covers an area of 13x20 km, centered at (34°46' N, 67°49' E). The image size is 13957 x 21118 pixels and the ground resolution is 1m.



Figure 7: The two empty Buddha niches as observed by IKONOS (courtesy of Space Imaging, Inc.). Left: Great Buddha. Right: Small Buddha.

2.2 GPS measurements

For the georeferencing of the satellite images, seven GPS points were measured (Figure 8) during our field campaign in

August 2003. Two Trimble GEO Explorer receivers logging carrier phase data (C/A code) were used; one receiver was set as 'master' (fix position) and the other served as 'rover'. The points were identified on the IKONOS image and then measured in C/A mode.

After the data collection, the observations were post-processed to generate more accurate positions. It was not possible to perform absolute differential corrections as the closest master station was ca 1500 km away. Table 1 summarises the GPS measurements.

Table 1: GPS measurements and related parameters.

No. of Points	Average satellites	Average PDOP	Horiz. Accuracy	Vert. Accuracy
7	6	2.78	0.11 m	0.3 m



Figure 8: The distribution of the GPS ground control points on the IKONOS image mosaic. In the centre the master station position.

2.3 Scenes orientation and DTM generation

The DTM was generated from level SPOT5 1A scenes (radiometrically but not geometrically corrected) using SAT-PP (SATellite Precision Positioning) software developed at our Institute. SAT-PP includes different modules for the precise processing of high-resolution satellite image data and allows image pre-processing, orientation, matching, DTM/DSM generation and object extraction. For more details, see [Zhang and Gruen, 2004; Poli et al., 2004]. The IKONOS mosaic orientation was based on a 2D affine transformation. On the other hand, the SPOT scenes orientation was based on a rational function model. Using the camera model, the calibration data and the ephemeris contained in the metadata file, the software estimates the RPC (Rational Polynomial Coefficients) for each image and applies a block adjustment in order to remove systematic errors in the sensor external and internal orientation. The

scenes' orientation was performed with the help of the GCPs measured with GPS. Table 2 shows the image orientation results.

Table 2: Image orientation results.

Source	RMSE East (m)	RMSE North (m)	RMSE Height (m)
IKONOS	0.56	0.48	-
SPOT Image Pair	1.22	2.01	1.50

The oriented SPOT stereo pair was then subjected to the automated DTM/DSM generation, using the module of SAT-PP. A 20 m raster DTM for the whole area and 5 m raster DTM for the area covered by the IKONOS image were interpolated from the original matching results (Figure 9), using also some manually measured breaklines near the Buddha cliff. The matching algorithm combines the matching results of feature points, grid points and edges. It is a modified version of MPGC (Multi Photo Geometrically Constrained) matching algorithm [Gruen, 1985; Zhang and Gruen, 2004] and can achieve sub-pixel accuracy for all the matched features.

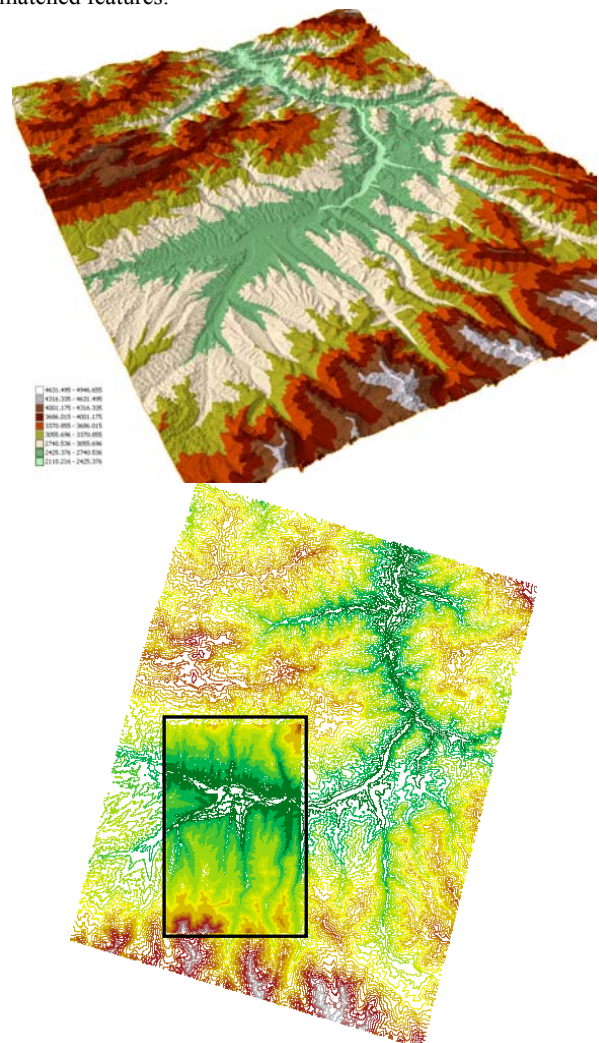


Figure 9: The SPOT derived DTM of the Bamiyan area displayed in colour coding mode (above). The two overlaid DTMs (below).

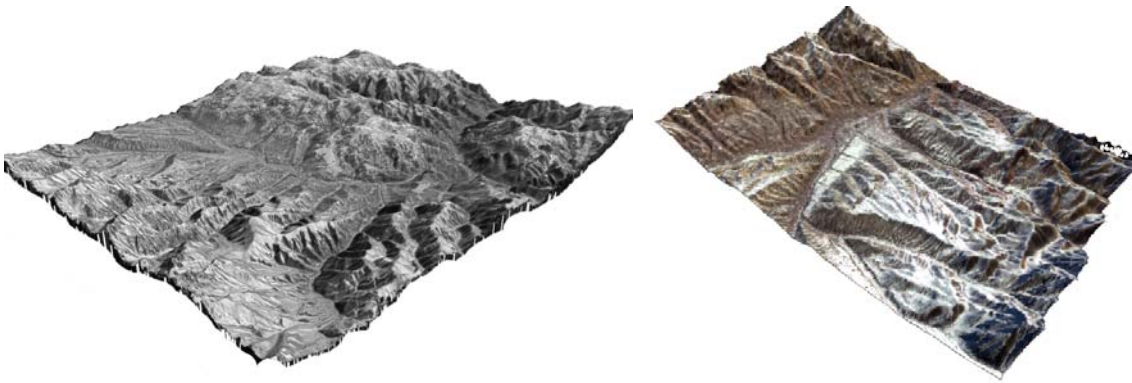


Figure 10: The DTM of the Bamiyan area generated from satellite images and textured with a SPOT5 (left) and a colour IKONOS ortho-image (right).

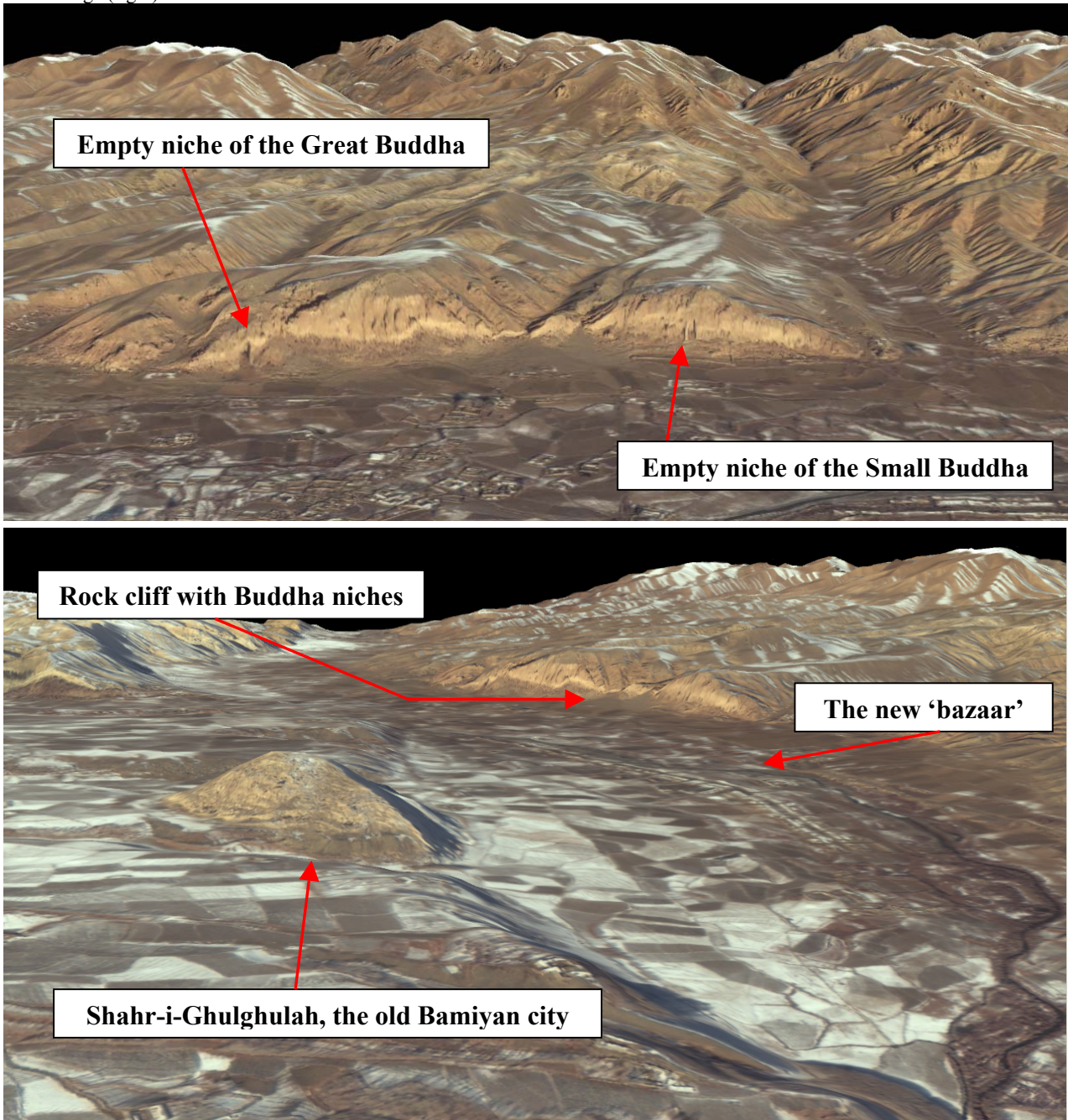


Figure 11: Zoom into the 3D Bamiyan terrain model textured with colour IKONOS ortho-image. The rock cliff with the two empty niches (above). The pyramid-type hill (Shar-i Ghulghulah) where the old city was located, the Bamiyan cliff and the new 'bazaar' of the village (below).

3. DTM DATA VISUALIZATION

The visualization of the produced DTM is a very important element, as for the external world it is usually the unique and possible contact with the 3D model. For the photo-realistic visualization of the whole Bamiyan area, a 2.5 m resolution B/W ortho-image from SPOT images and a 1 m resolution RGB ortho-image from the IKONOS image were generated. The textured 3D models (rendered with Erdas-Virtual GIS) are shown in Figure 10 and 11, where two closer views on the 3D IKONOS textured model of the Bamiyan cliff and the old Bamiyan city (the pyramid-type hill to the left) are presented.

Table 3: DTM geometry and texture data

	Area [km]	Grid [m]	Points [Mil.]	Geometry file *	Texture file *
SPOT	49x38	20	4.6	215 MB	432 MB
IKONOS	13x20	5	12	550 MB	858 MB

* *uncompressed format*

Visualization packages and tools are available in different forms. For DTM visualization (often called ‘geovisualization’), more than 500 packages are available, while many other developed software are not known and public. The packages can be classified according to their real-time performances, the rendering quality of geometry and texture, the anti-aliasing function, the input data, the level of detail (LOD) properties, etc. The Bamiyan dataset has a size of ca 640 MB (SPOT data) and 1.4 GB (IKONOS data) and it requires very powerful visualization software for an interactive use. We employed Skyline (IDC AG), Erdas-Virtual GIS and ESRI ArcGIS-ArcScene for data rendering, real-time demos and video generation and in the following section a short comparison is reported. All packages allows interactive or user-defined flythrough animations.

3.1 Erdas–Virtual GIS 8.6

The package works with its own internal file format (IMG), reducing considerable the file size. The LOD can be only statically applied to the whole scene. A dynamic LOD can be applied generating a ‘Virtual World’ (as it is called in the software): the model is divided in different sectors and, for each sector, the software constructs a pyramid of detail for the geometry and the texture data. In the generated virtual world, the user can easily navigate through the scene while the details are automatically adapted according to the model’s distance from the viewer.

3.2 Skyline–Terra Builder

The software converts all the data (geometry and texture) in its own internal and binary file format (MPT), which can reduce the total data size by a factor 4. The interactive and offline navigation is very easy, due to the dynamic LOD. Unfortunately different aliasing artefacts are present in the rendered model and the LOD resampling produces a noticeable reduction in the image texture quality, even in the foreground.

3.3 ESRI ArcGIS – ArcScene 8.3

ArcScene is mainly a 3D GIS tool of ArcGIS. The DTM data is imported as regular grid and then a TIN is generated in an internal binary format. The software cannot perform real-time rendering of big data sets, it has a static LOD control but it can easily display different vector information without aliasing

effect. The ‘extrude’ function can display features from 2D vector data sources and generate lines, walls or solids in 3D.

Table 3: Comparison of geometry and texture data reduction after the conversion to the different software internal format. Note how Skyline can reduce the whole file size of a factor 4

	SPOT geometry/texture	IKONOS geometry/texture	TOT size SPOT/IKONOS
Erdas	28 / 434 MB	47 / 865 MB	462 / 912 MB
Skyline	28 / 397 MB	47 / 598 MB	177 / 268 MB *
ArcScene	27 / 432 MB	46 / 858 MB	459 / 904 MB

* *Final size of the binary project file*

4. TOURIST INFORMATION SYSTEM

A GIS is a software used to map, collect, manage and analyze geographical and other related kinds of attribute data. GIS records the geometry and location of features in layers and the combination of layers of information related to a place gives a better understanding of the area. The GIS technology allows database operations like queries and statistical analysis together with the visualization and geographic analysis of maps.

The use of GIS in heritage management has been also underlined by UNESCO, as a GIS allows (1) historical and physical site documentation, (2) the assessment of physical condition, cultural significance and administrative context, (3) the preparation of conservation and management strategies, (4) the implementation, monitoring and evaluation of management policies [<http://www.unescobkk.org/culture/gis/index.html>]. Furthermore, a GIS tool generates permanent records of heritage sites, including also text documentation, virtual flight-over and 3D models.

The information recovered from the high-resolution satellite imagery is imported in GIS software (ArcView and ArcGIS) for further analysis, data visualization and topographic information generation.

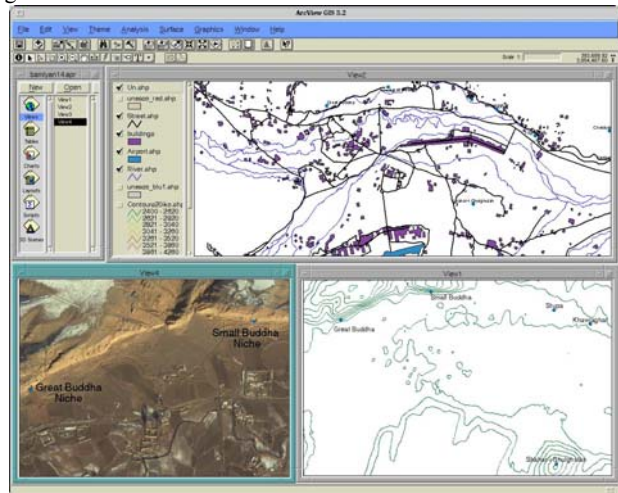


Figure 12: A view of the GIS data edited in ArcView.

The ‘cultural landscape and archaeological remains of the Bamiyan valley’, as defined by UNESCO [<http://www.whc.unesco.org/sites/208rev.htm>] includes 8 locations, identified with an area of interest and a buffer area:

1. Bamiyan Cliff including niches of the 38 meter Buddha, seated Buddhas, 55 meter Buddha and surrounding caves;
2. Kakrak Valley caves including the niche of the standing Buddha;
3. Qoul-I Akram Caves in the Fuladi Valley;
4. Kalai Ghamai Caves in the Fuladi Valley;
5. Shahr-i-Zuhak;

6. Qallay Kaphari A;
7. Qallay Kaphari B;
8. Shahr-i-Ghulghulah.

Man-made objects (e.g. streets and buildings) and rivers were measured manually from the ortho-images. A total of 243 objects were extracted and then overlapped onto the recovered DTM and ortho-image, using the extrude function of ArcScene (Figure 13). For visualization reasons, an exaggeration of 5 m was given to the extracted buildings.

From the DTM raster grid, the contour lines of the area can be computed and displayed together with the man-made objects for the new cartography of the Bamiyan village. Until now only Russian maps from the 70's are available, but, as shown in Figure 14, the morphology of the village is changed.

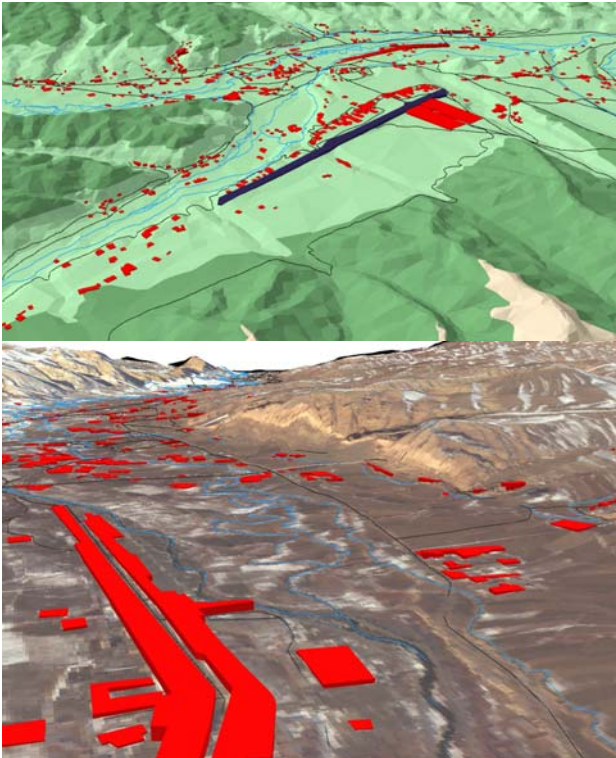


Figure 13: Two views (rendered with ArcScene) of the 3D model of the Bamiyan area with the extracted man-made structures (streets, houses and airport) and the rivers.

With other GIS functions and tools, the 8 protected locations inside the Bamiyan area can be defined (according to their buffer area), and displayed (Figure 15).

Now that these maps are available, further analysis can be performed for administrative, conservation and monitoring management.

5. CONCLUSIONS

In this work we have shown the modeling of the whole cultural heritage site of Bamiyan, Afghanistan, from high-resolution satellite imagery. We have used different types of sensors and produced a detailed terrain model that will be used for visualization, animation and documentation. The satellite images were the only possibility for the mapping of the heritage area because of their instant availability and high resolution.

For the photo-realistic 3D digital models of the entire Bamiyan area different commercial packages have been used, but the management of large terrain data sets is still problematic, in particular for real-time rendering.

In addition, the DTM data has been imported into a GIS software to create a complete information system of the UNESCO protected area, which may serve for technical, scientific and touristic purposes in the future.

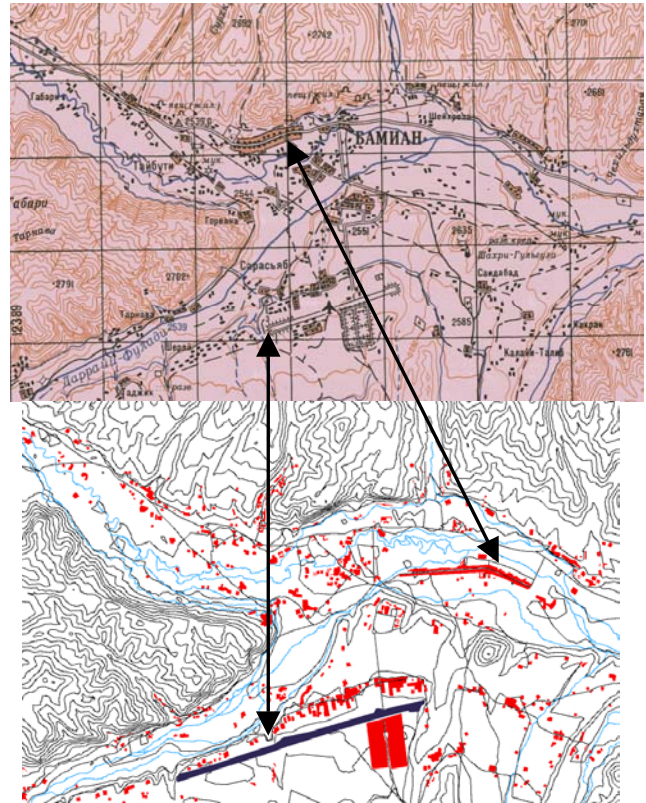


Figure 14: The new cartography of the Bamiyan village generated from satellite imagery (below) compared with an old aerial Russian map (above). Two big changes are signalled: enlargement of the airport and the shift of the city-bazaar.

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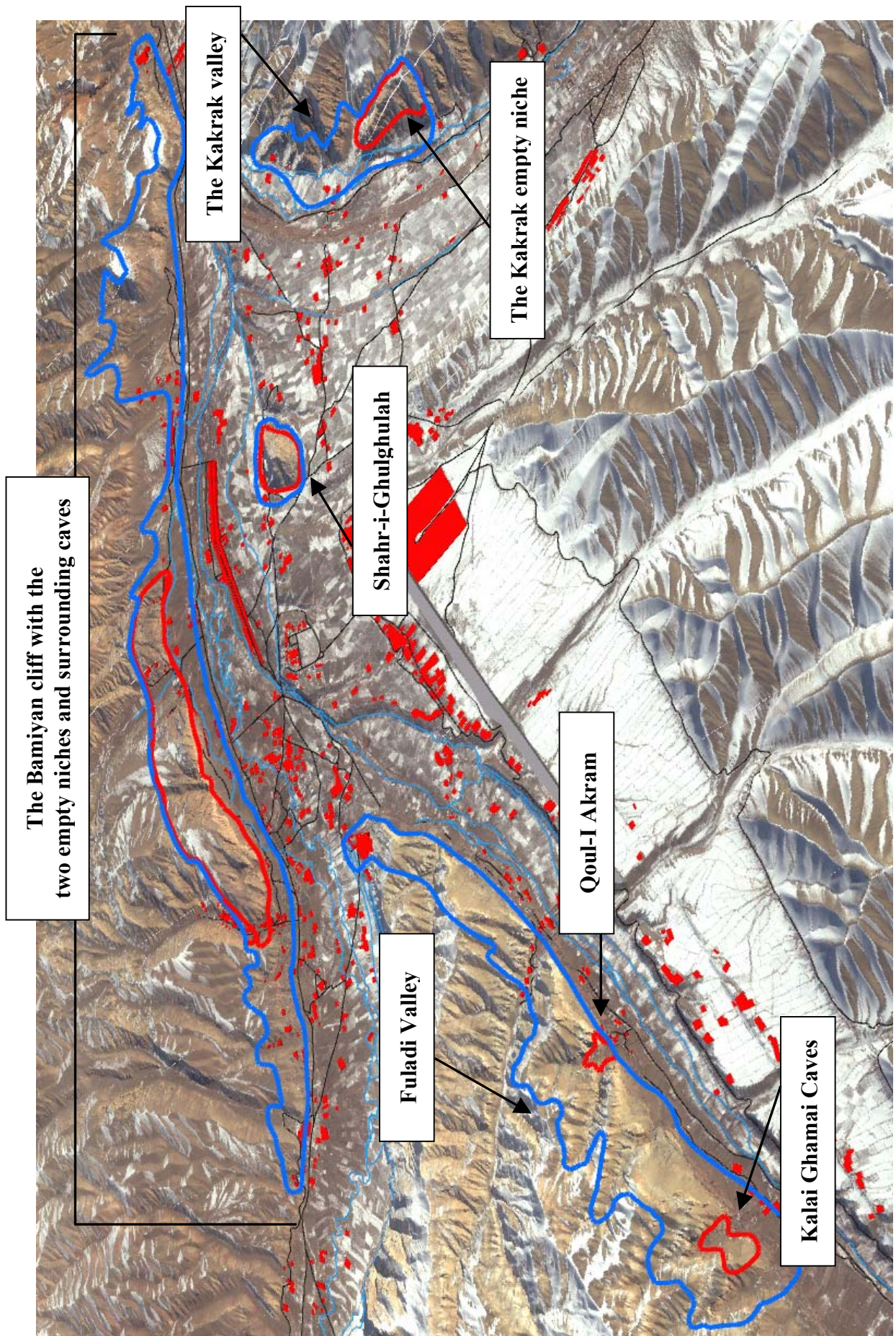


Figure 15: The UNESCO protected areas near the Bamiyan village, with their buffer (blue) zone, displayed within ArcScene.