KEYWORDS: ***PhotoScan – Altai Mountains – Three-dimensional recording – Petroglyph***

THE DETERIORATING PRESERVATION OF THE ALTAI ROCK ART: ASSESSING THREE-DIMENSIONAL IMAGE-BASED MODELLING IN ROCK ART RESEARCH AND MANAGEMENT

Gertjan Plets, Geert Verhoeven, Dimitry Cheremisin, Ruth Plets, Jean Bourgeois, Birger Stichelbaut, Wouter Gheyle and Jeroen De Reu

Abstract. The unique rock art of the Russian Altai is increasingly suffering from human and natural processes. Without well-directed action and documentation it will be practically impossible to establish conservation initiatives and, eventually, many of these sites will be lost. This paper presents an overview of the different processes affecting this rock art, based on fifteen years of observations in the region and recent three-dimensional (3D) photorealistic documentation. A cost-effective 3D workflow for rock art recording and research is discussed as a possible way to tackle this worsening situation. The application of 3D documentation in rock art research has seen an explosive growth during recent years, but its use is still maturing and a strategy on how to deal with the models is still lacking.

1. Introduction

The transitional setting between the major steppe regions of Mongolia and Kazakhstan make the Altai Mountains (southern Siberia) one of the richest and most varied archaeological regions of inner Asia (Fig. 1). Thousands of surface sites and countless petroglyphs on both rocky outcrops and stelae are silent witnesses of the important role this region played since the late Neolithic (3200 BCE). Although there have been some effective surveying projects (e.g. Okladnikov et al. 1979; Kubarev and Jacobson 1996; Jacobson-Tepfer et al. 2010), a large number of rock art sites remained undocumented or were registered inadequately during Soviet times. Moreover, nearly all sites are located in areas with limited protection and are subject to uncontrolled vandalism and environmental processes (Plets et al. 2011a). A limited budget for in-situ conservation and restoration means that time is running out for Altai rock art. Every year this situation is worsening and important scientific data are being lost. Therefore it is of the utmost importance that the existing petroglyphs are documented objectively and in great detail for future conservation and research purposes.

Most recordings in the Altai are still obtained using traditional techniques such as wax and latex rubbing, freehand drawing, photography, casting and tracing (e.g. Martinov et al. 2006; Cheremisin 2008; Kubarev 2011). These techniques are in various aspects insufficient to document the endangered rock art in a detailed and non-intrusive way (Simpson et al. 2004; Cassen and Robin 2010: 2–3). Furthermore, many petroglyphs are finely incised figures which are impossible to detect with these techniques. Three-dimensional (3D) techniques based on image modelling (i.e. traditional photogrammetry) (Simpson et al. 2004; Chandler et al. 2005; Alyilamaz et al. 2010) and range-based methods (i.e. terrestrial laser scanning) (Farjas et al. 2009; Escarcena et al. 2011; Gonzalez-Aguilera et al. 2011) have proven to fill this gap. Besides their high detail, the almost real-life virtual representation of the heritage makes these techniques less abstract than the traditional techniques. Unfortunately, working with these techniques is often not straightforward for the systematic surveying of vast areas. Heavy, purpose-specific and expensive equipment is often needed, slowing down the data collection. Furthermore, processing demands a certain technical background, including costly software, making it difficult to implement these approaches in the daily workflow.

However, recent developments in the area of computer vision-based photogrammetry show great potential for fast, flexible and detailed documentation of heritage, without specialised and expensive instruments (Simpson et al. 2004; Sanz et al. 2010; Doneus et al. 2011; Verhoeven 2011; Verhoeven et al. 2012; Plets et al. 2012).

The aim of this paper is to describe the worsening

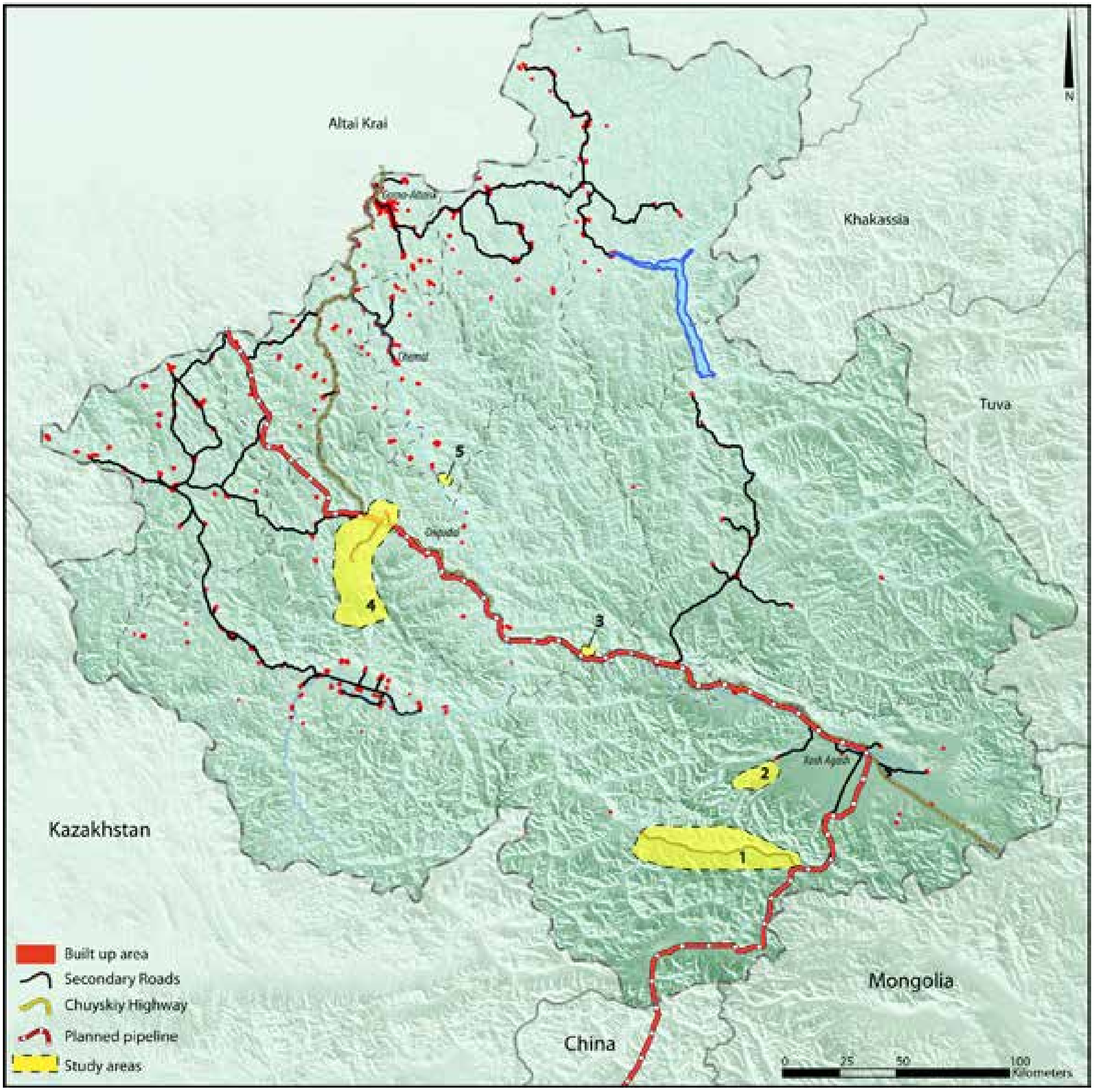


Figure 1. *Map of the Altai Republic indicating the planned pipeline and study areas. 1. Dzhazator valley; 2. Elangash valley; 3. Kalbak Tash I; 4. Karakol Park; 5. Kuyus.*

preservation state of the Altai rock art and how the use of a cost-effective 3D methodology can be a first step towards both safeguarding the scientific information and planning future preservation and conservation initiatives. The preservation will be assessed based on fifteen years of observations in the region and recent three-dimensional photorealistic documentation work. The effectiveness of the 3D methodology, using a commercial computer vision-based package (PhotoScan Professional), will be assessed, based on the results of its extensive use during fieldwork in the summer of 2011, when over 300 individual panels (ranging from small panels with single figures to complex multi-period panels measuring over 20 m^2) were successfully documented. The straightforwardness, flexibility and cost-effectiveness of this approach did not only allow a fast and detailed documentation of the rock art for scientific purposes (Plets et al. 2012), but the presentational strength of the outcomes also has a huge potential for public outreach projects. Apart from the advantages of the methodology, the numerous produced 3D models are also an impetus for a discussion about their management and the possibilities they offer in visualising and studying rock art. Firstly, the increasing use of cost-effective 3D documentation techniques in rock art research contrasts with current practices where 3D models are reduced to 2 (orthophotos) or 2.5 dimensions (digital surface models or DSM) for means of representation and interpretation, losing one third of the information originally provided by the 3D model. Therefore, an entirely 3D-based procedure will be presented. Secondly, the photorealistic 3D models present us with some interesting perspectives for ex-situ virtual preservation of endangered or soon to be destroyed rock art sites — although there are some elements that have to be taken into account.

2. Petroglyphs of the Altai Mountains

The many cultures that have dwelled in the Altai have

Figure 2. *2D version of 3D model of panel petro 46 of the Turai site. Large presumed Bronze Age representation of a bull carting a load guided by an anthropomorphous figure.*

expressed themselves in a continual tradition of rock art. There are literally thousands of panels, varying from small compositions of a single figure to enormous complex panels packed with images and different cultural layers (Fig. 2). The Altai features a long tradition of rock art where the oldest petroglyphs date back to the late Neolithic (late 4th to early 3rd millennium BCE) and which continues until today. 'Scenes' include a high variety of styles and purported subjects such as hunting, warfare, domestic migrations, more recent supposed shamanistic rituals, and many others. While some sites contain epigraphs (i.e. Turkic runic inscriptions), compositions are mostly figurative representations of various animals and humans. A broad variety of petroglyphs can be found, ranging from heavy peckings of large zoomorphs to centimetre-size fine incisions representing ethnographic or recent 'scenes' (Fig. 3).

Initial documentation of the rock art commenced in the beginning of the 20th century by different researchers, amateurs and artists (Khroroshikh 1949; Kubarev and Jacobson 1996; Erkinova and Kubarev 2004; Martinov et al. 2006). Proper documentation by rock art specialists began in the 1960s (Toshakova 1970; Separinski 1974). Especially the surveys by the Institute of Archaeology and Ethnography of the Siberian Branch of the Russian Academy of Sciences (IAE SBRAS), under the guidance of Okladnikov and Oklanikova, were crucial for the development of rock art research in the Altai Mountains and provided a much welcomed overview of the spatial variety of their rock art (Okladnikov et al. 1979, 1980, 1981, 1982; Okladnikova 1981). Despite their elaborate work, the numerous inventories are rather sketchy and not accurate. Moreover, most unpatinated engravings (i.e. contemporary and ethnographic) were not included in the inventories. Recent work by Kubarev (Kubarev and Jacobson 1996; Kubarev 2011), Miklashevich (2000, 2003, 2006, 2011) and Cheremisin (2002, 2008) provides more detailed insights into the rock art of the region. Unfortunately, the methodologies they used are far too slow to document large areas and

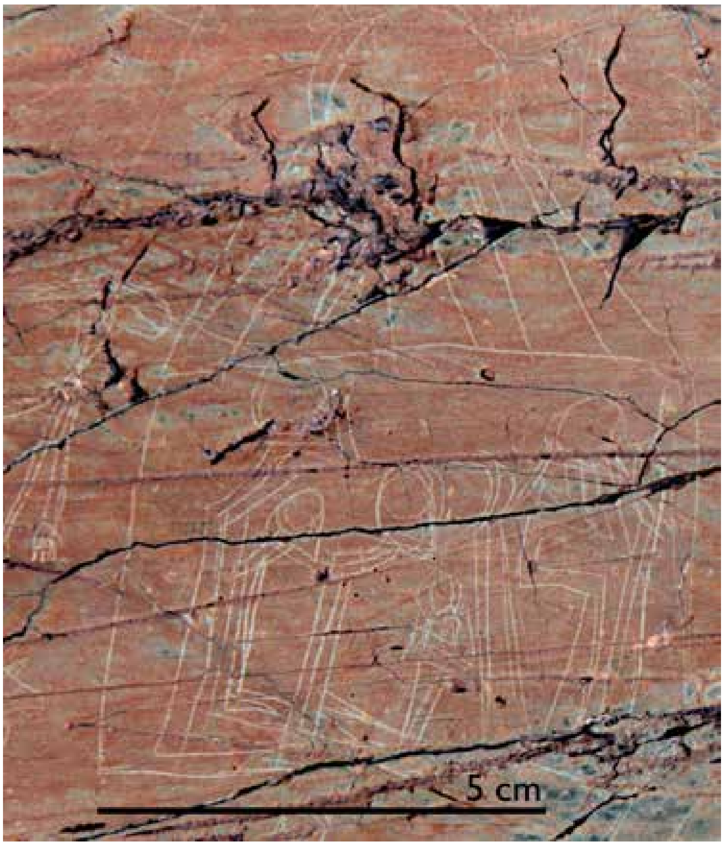


Figure 3. *Orthophoto of a part of panel petro 285 of the Turai site (Elangash valley) apparently showing an ethnographic image of a yurt with its inhabitants.*

Figure 4. *2D version of 3D model of part of the main vertical panel of Kalbak Tash I showing the deteriorating state of the panel. Large flakes have already exfoliated and the large fractures in the rock are widening because of erosion.*

are still largely based on traditional techniques.

To test our 3D methodology, rock art of five study areas (Karakol Park, Elangash Valley, Kalbak Tash I, Dzhazator valley and Kuyus) was documented during thirteen days of fieldwork in the summer of 2011. The different study regions were chosen because of their high variation in size and shape of the panels and morphology of the petroglyphs. Furthermore, because of their representativeness and worsening preservation state, these areas (except the Dzhazator valley) are under some form of local supervision, which we aim to scientifically support. A thorough documentation and assessment could be a major step forward.

3. The worsening preservation state of the rock art of Altai

More than ever, the gradual natural and human impact is affecting the unique rock art of the Altai Mountains. Besides the above-mentioned sites, the long-term future for the rock art across the Altai does not look bright. Environmental processes, visitor pressure, intrusive documentation methods and infrastructural development are placing increasing pressure on the numerous panels and need to be countered.

3.1. Environmental processes

Since most petroglyphs are found on polished foliated rocky outcrops, abiotic processes such as natural erosion by wind and water and degradation caused by freeze-thaw cycles are having a major impact on many sites in the Altai. Because of the predominance of foliated substrates, which are particularly vulnerable to the frequent freeze-thaw cycles (Potts 1970), many cases are known where small flakes of panels are gradually peeling off the rock (Fig. 4) or where complete 'scenes' have exfoliated. This gradual exfoliation is a serious problem as it exposes more and more cracks in the foliated rocks, enabling an accelerated deterioration of the sites.

Biotically induced pressure by the percolating roots can be easily countered by removing all intrusive vegetation from the near vicinity. Minimising abiotic weathering is less easy. Although reinforcing and consolidation of cracks is the most effective measure, no agreed sustainable strategy exists to fix loosening rocks. Past interventions have proven to do more harm than good (Bednarik 2001: 96–98; Bakkevig 2004), caused by the lack of testing before consolidating. Such testing is needed to determine the ideal fixing material (Bakkevig 2004; Hygen 2006; Doehne and Price 2011: 58–63).

Figure 5. 2D version of 3D model of part of panel petro 54 (Elangash valley) showing the impact of traditional documentation using intrusive techniques. The two largest images, the upper one in a typical style similar to the 'deerstone art', are completely disturbed by traces of wax.

The procedure presented by Fernandes (2008), in which specific consolidation mortars are first tested on non-decorated rocky outcrops similar to the decorated rocks, is a viable option as it allows to assess the sustainability and aesthetic impact of the applied conservation techniques and used material. In the interim, however, applying protective covering (Hygen 2006: 24–25; Ernfridsson et al. 2010) would hold decomposing panels together and reduce panel weathering resulting from the freeze-thaw cycles.

3.2. Research

Research itself is harmful too, even if the research is done with the best intentions by rock art specialists. Most recordings in the Altai are still carried out using traditional methods such as freehand drawing, tracing, rubbing and casting. While tracing, rubbing and casting have the advantage of representing the petroglyphs in an orthogonal and more accurate way (Cassen and Robin 2010), they are invasive (Fig. 5), affecting the preservation (Simpson et al. 2004; Cassen and Robin 2010) — especially on more weathered panels or sites where lichen have been removed. These methods have now been phased out widely elsewhere in the world. In addition, the final drawings of the petroglyphs are often wrong since the sheet used for rubbing or tracing is distorted to fit the irregularities of the stone surface. Although freehand drawing may be a non-invasive technique, it is not able to reproduce the engravings and other petroglyphs in a realistic way and does not give information about the natural relief of the rock (Cassen and Robin 2011; Plets et al. 2011a).

Many panels are densely overgrown with lichen and very often local and Russian researchers remove lichen to document the underlying figures (Miklashevich and Muhareva 2011). With regards to these lichen, there is an international discussion whether or not these should be removed (Bednarik 2001: 91–93; Bjelland 2002, 2005; Bakkevig 2004; Dandridge 2006; Doehnoe and Price 2011: 58–63). Recent research has pointed out that lichens have an intrusive impact on the underlying rock (Bjelland and Thorseth 2002; Bjelland 2005; Dandridge 2006) but that there are many factors (i.e. type of lichen and rock) that have to be taken into account to evaluate the specific impact. Bakkevig (2004) pointed out the consolidating capacities of lichens, protecting the rock from weathering, but at the same time destabilising the underlying rock. When removed, the affected rock will crumble at a much faster rate than rock that has never been overgrown with lichen. Only treatment of the rocks can counter this accelerated degradation (Dandridge 2006: 89).

Therefore, lichen cannot simply be removed for the sake of documenting Altaian rock art and a well-thought out balance between data acquisition and the preservation consequences is imperative (Hygen 2006: 19).

3.3. Visitor pressure

The tourist sector of the Russian Altai is increasing (Kohler and Byers 1999) and recent large investments aim to improve the infrastructure for the tourism sector (Ovcharov 2008: 64). Although the growth in tourism may offer many interesting financial opportunities for this under-developed region, the increasing presence of tourists also threatens the physical preservation, authenticity and context of the archaeological heritage (Gheyle 2009: 329; Plets et al. 2011a). Especially the much visited rock art is known for its vulnerability

Figure 6. Top: 3D model (2D version) of petroglyph panel in Kalbak Tash I, badly damaged by an attempt to steal it from the rocky outcrop. Bottom: Representation of a 'horse' before and after disturbance. The left picture was taken in 2003 and shows the entire 'horse'; the recent picture (2010) shows the 'horse' without a head and clear chisel marks.

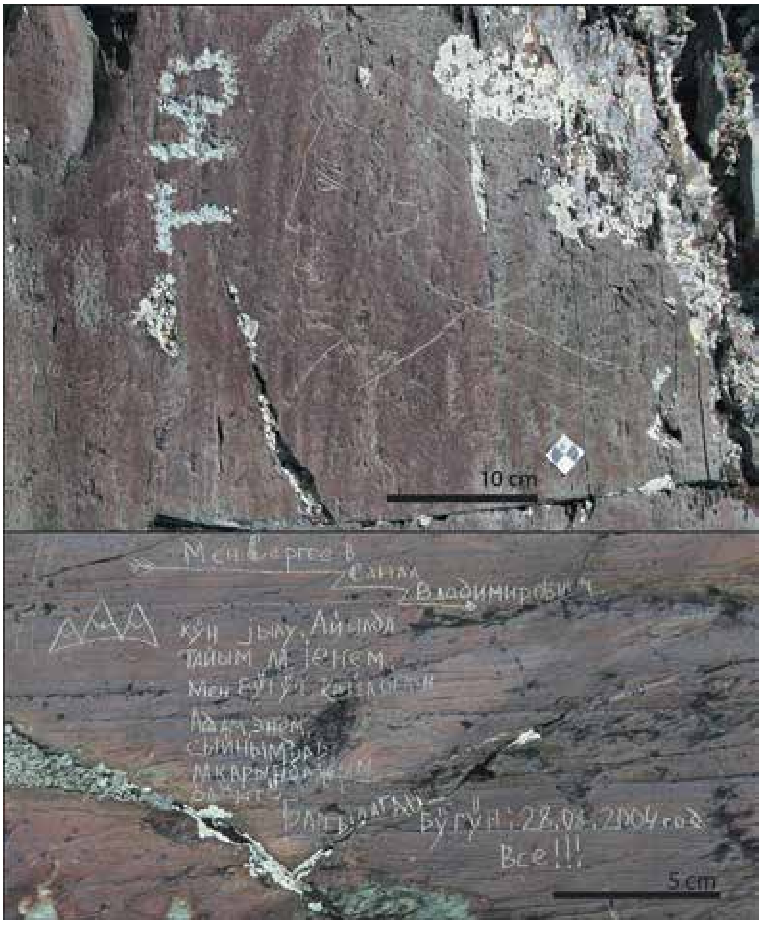


Figure 7. Top: 2D version of 3D model of part of panel petro 63 of the Turai site (Elangash valley). This recent engraving is an example of a historically relevant scene as it depicts cosmonaut Yuri Gagarin, one of the most important symbols of Soviet propaganda. Bottom: orthophoto of part of panel petro 248 of the Turai site showing recent graffiti of a schematic representation of mountain peaks; this correlates with the traditional belief in which mountains play an important role.

to increased visitor pressure (Cheremisin 2002; Fernandes 2009; Berger 2010; Plets et. al 2011a). Most rock art complexes can be freely visited without any form of control or informational infrastructure. Consequently, numerous cases are known where increasing local and international tourism directly and indirectly resulted in vandalism ranging from graffiti (i.e. recent additions to existing panels) and littering to cases where chemicals are rubbed on the petroglyphs to enhance their visibility. Even situations where fragments of the panels are removed to be sold on the black market are common (Fig. 6).

However, the graffiti are not only caused by tourists. Through the last century locals, too, have engraved texts, drawings or made additions to existing rock art. This can especially be met at the Elangash site, where numerous representations were added in the last 100 years, apparently representing both religious and everyday scenes. These compositions underline the long temporal span of rock art manifestations and make these recent additions historically relevant and a potential information source for future generations (Fig. 7): today's graffiti can become tomorrow's rock art (Bednarik 2001: 103–104).

This problem poses the interesting question whether these recent additions should be seen as a continuation of a millennia-old tradition, or as intrusive actions that destroy the panels. Cheremisin (2002) and Fernandes (2009) touched on this issue and underlined the relevance of more recent additions, and made a clear differentiation between vandalism and a continuation of a tradition of producing rock art. Making the distinction between pure vandalism and new relevant additions that are or will become heritage is not straightforward and depends very much on personal interpretation. This difficult assessment can only be made *after* the additions are made. Reversibility is not an option, as all additions are permanent and impossible to remove. So, the question is, can recent additions be tolerated? Would it be better to halt all additions, because a 'wait and see' policy is too risky?

Still, most graffiti are caused by tourists and are one of the most important impacts deteriorating the sites. As graffiti breed more graffiti (Jacobs and Gale 1994: 12), a sound rock art management is urgently needed. The most effective actions would be contracting on-site guards and guides. But for a vast and underdeveloped area like the Altai, more cost-effective actions like visitor brochures and books, ancillary infrastructure such as information panels and fences, and keeping the location of sites undisclosed are actions that could be a big step forward (Gale and Jacobs 1986; Sullivan 1991; Hygen 2006; Fernandes 2009; Franklin 2011). Subtle actions like the latter will not prevent deliberate vandalism, but give the impression that the rock art is important and managed. This could make the visitor aware of the intrusiveness of adding graffiti.

3.4. Infrastructural development

Another major threat are what are known as the Russian 'big projects', government funded projects to boost the economy of the Altai Republic. Amongst them are a planned winter resort (Russia Climbing 2009), a hydro-electric dam on the Katun (Pacific Environment 2011) and a scheduled pipeline through Altai to China (Plets et al. 2011b). Unfortunately, the preservation of cultural heritage is only considered at the end of the long planning phase. Despite lobbying and reactions of the heritage sector, local administration and indigenous interest groups, little can be done to change the advanced state of these plans.

In many cases, a popular option is to 'protect' the rock art ex-situ after documentation (Bednarik 2008). However, a rock art site is more than the representations alone, and the interdependency of the site and cultural context dictates the cultural meaning of the location, and the location gives meaning to the rock art (Bradley 1991; Bradley et al. 1994; Bednarik 2008: 8). Such a removal 'robs the rock art of its site and the site of its rock art' (Bednarik 2008: 11) and makes the rock art a 'dead artefact' (Bednarik 2008: 8). We have to conclude that this option is one of the worst things that could happen to the rock art and is diametrically opposed to all international conventions promoting the in-situ sustainable preservation of heritage (e.g. English Heritage 1990; Australia ICOMOS 1999; IFRAO 2000). But the sad reality is that removal is sometimes the only choice between destruction and preservation. This post-modernistic position is certainly applicable for the rock art endangered by the Altai Pipeline. The region is so rich in rock art that it would be impossible to change the route around every rock bearing rock art.

3.5. Towards a sustainable solution

The suggested options for preventing the worsening preservation prospects of the rock art of the Altai should be a starting point for a thorough interdisciplinary and community-based conservation program. This would encompass a significant investment, both financially and in time, which is difficult for a less-developed region like the Altai.

However, good management starts with a detailed and systematic mapping and documentation of the site and the surrounding context in its present state. This information is also imperative for official inclusion on the Russian cultural heritage register, defined by the 2002 federal law *On the objects of cultural heritage (monuments of culture and history)*. This recognition guarantees protection and funding by the Federal Government (Federal Service for Monitoring Compliance with Cultural Heritage Legislation 2002). Moreover, the more this documentation reflects the current reality of the rock art in detail, the more it allows heritage managers to understand the rock art and its preservation needs. Furthermore, by re-documenting the same rock art at a later stage the exact impact can even be better understood. A documentation that approximates the reality can also virtually safeguard the informational, visual and dimensional (i.e. 3D) aspects of this heritage, before the site undergoes more damage while waiting for proper management.

4. Methodology

To document the rock art of the study areas for research and conservational purposes, an appropriate methodology had to be sought. Local institutes and universities see the shortcomings of their traditional recording techniques and acknowledge the necessity of detailed documentation and geo-localisation of these sites. Aiming to participate with the local stakeholders, this methodology (both acquisition and processing) should be cost-effective and straightforward in use. In collaboration with these actors a procedure was developed based on the inherent characteristics of PhotoScan Professional.

PhotoScan Professional is a bilingual (i.e. English and Russian) 3D modelling software application, developed by the Russian company AgiSoft LLC. Just like the commercial software platform Photomodeler Scanner (Karauguz et al. 2009; Sanz et al. 2010; Eos Systems Inc 2011), and the free web-service Autodesk 123D (Autodesk 2011) and various open-source packages like Bundler (Snavely 2010) and Photosynth (Microsoft Corporation 2011), PhotoScan allows the extraction of 3D information from 2D images taken from different vantage points, based on a combination of a structure from motion (SfM) approach and a variety of dense multi-view stereo (MVS) algorithms (Ullman 1979; Seitz et al. 2006; Doneus et al. 2011; Verhoeven et al. 2012). For an elaborate description of the methodology and technical background program and used algorithms, see Doneus et al. (2011),

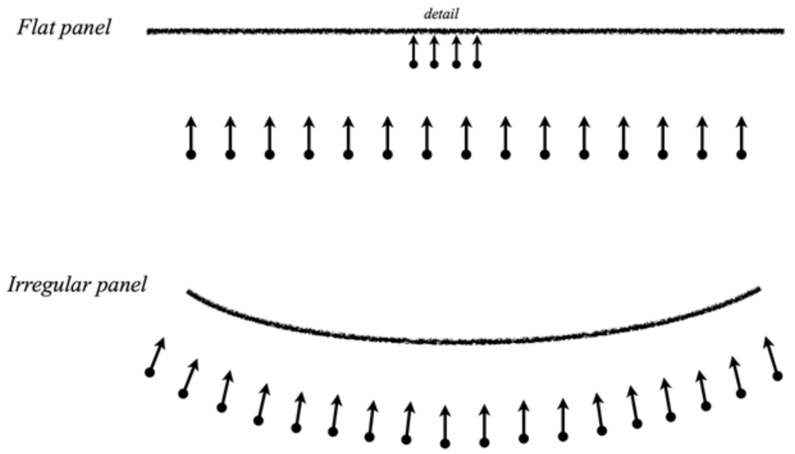


Figure 8. *Best and fastest results are obtained when a series of overlapping pictures are taken from different vantage points, ensuring that the camera is positioned as parallel as possible to the subject. As for irregularly shaped outcrops the same workflow is valid. When details have to be captured in more detail (e.g. fine engravings) a series of closer images can be taken.*

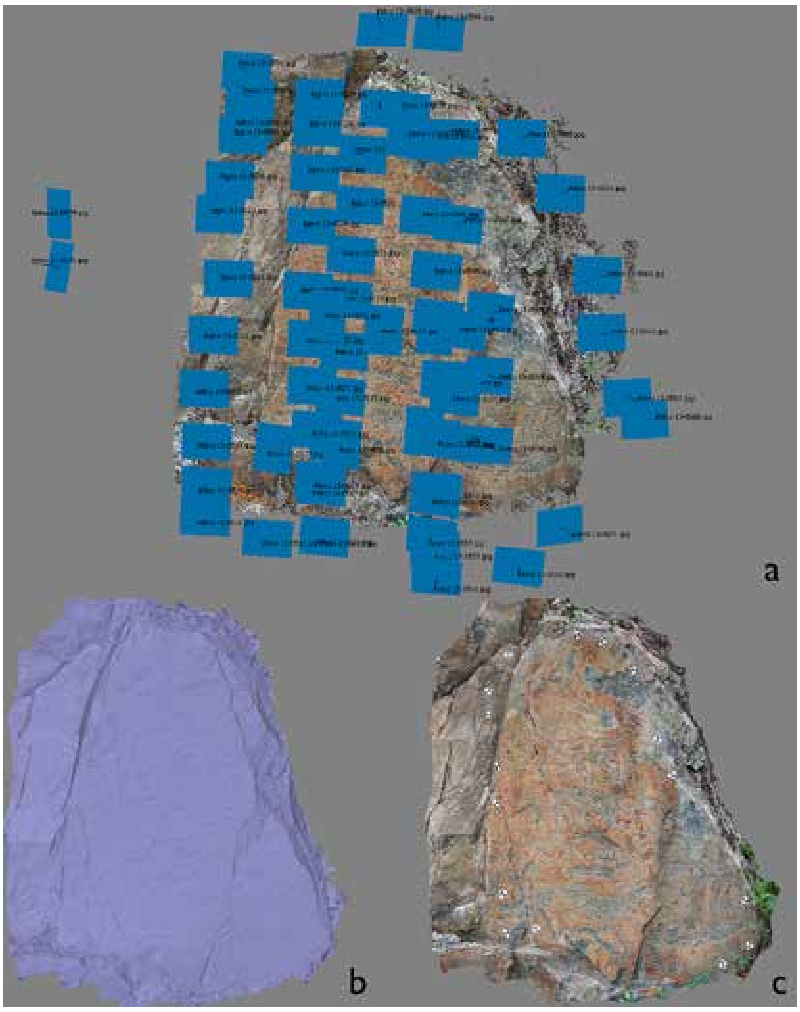


Figure 9. *Based on a set of overlapping images, PhotoScan calculated a dense point cloud and the orientation of the cameras at the time of acquisition (a), a meshed 3D surface model (b) and a textured model (c).*

Verhoeven (2011) and Verhoeven et al. (2012).

Next to its computational performances, the strength of PhotoScan lays in its fast, straightforward and cost-effective data processing. Besides, only a series of overlapping images produced by any decent still camera are needed. The nearly automated processing using the affordable (US$549 for an educational licence) software is very user-friendly. In the end, even users without any technical background are able to generate accurate 3D representations in an unambiguous manner.

For the data acquisition, a commercially available 21 megapixel Canon 5D Mark II full-frame reflex camera was used. Accurate metric information could be deduced from the model, since it was linearly scaled using reference distances measured with a millimetre ruler and a calliper (sub-millimetre resolution).

First, multiple reference points were randomly mounted across the panel using biodegradable and washable glue, limiting preservation impact. Mostly, 6–8 reference points per square metre were mounted on smaller panels (up to 1–2 square metres); for medium sized and large panels 2–4 reference points were used per square metre. Afterwards, the rock art was sketched and all its characteristics as well as acquisition parameters were briefly described (i.e. preliminary interpretation, lithology, dimensions, date, weather conditions and camera metadata and reference point spacing).

The most important step is the image acquisition (Fig. 8). Successful processing is guaranteed when the site is captured in a standardised way. Most important, an overlapping series of pictures from various viewpoints is needed (AgiSoft LLC 2012: 3–5). The best and fastest results are obtained if the rock art is shot as vertically as possible (Verhoeven 2011: 71). For irregular-shaped outcrops the same workflow is valid, but the outcrop has to be photographed in a way so each picture is taken equidistant and vertically to the surface. An overlapping series of more zoomed-in photographs can be taken to document certain details.

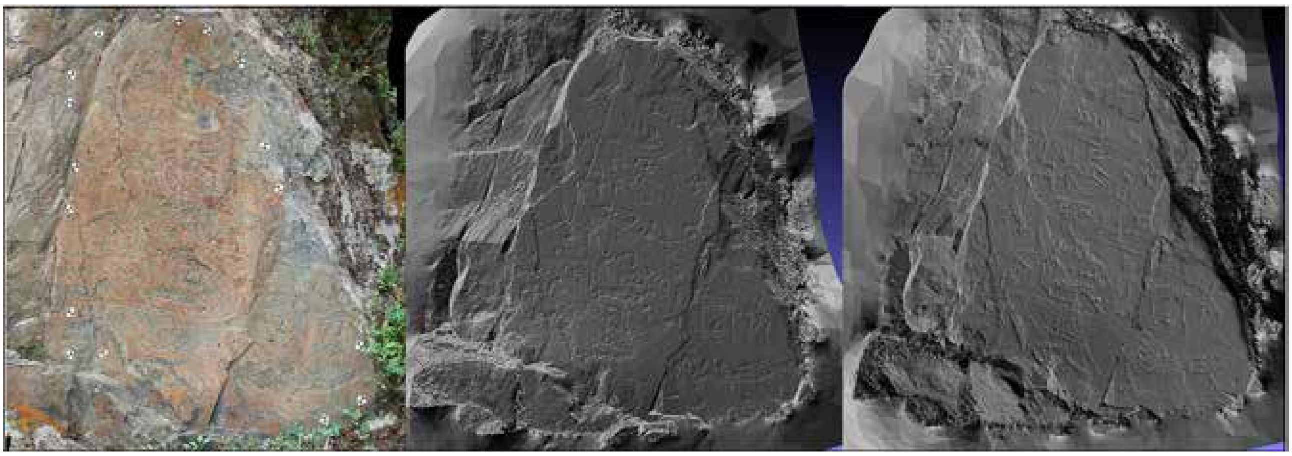


Figure 10. Images show petroglyph panel petro 13 not far from the village of Bichiktu-Boom (Karakol valley). Due to slight erosion the peck marks are difficult to distinguish (left image); when changing illumination setting in MeshLab several otherwise difficult to distinguish relief details become visible on the meshed 3D surface.

Once a good image collection is created, the semi-automated image processing can be commenced. First the image set has to be aligned. Since the final result largely depends upon textural variations in the imagery, it is sometimes necessary to mask areas lacking this information (e.g. sky and water) before starting with the actual alignment (AgiSoft LLC 2012: 3–6).

In this step the program uses a SfM approach to detect correlating feature points between overlapping 2D images and uses these correspondences to calculate the position and orientation of the camera at the moment of image acquisition (Ullman 1979) and builds a 3D sparse point cloud (Fig. 9) (AgiSoft LLC 2012: 7). There is no need for calibrated optics, as the interior camera calibration parameters are computed automatically (Verhoeven 2011: 68). In a next step, an MVS approach calculates a meshed 3D model. Afterwards, this 3D model can be texturised based on a selected photograph or a blend of various (selected) photographs.

At this stage, the reconstructed 3D scene still lacks absolute dimensions. By defining the distance between two reference points the model is rescaled to an absolute model from which correct metrical information can be extracted. A comparison of the remaining reference distances with those deduced from the 3D model enables the assessment of its accuracy.

This absolute model can be exported to different exchangeable formats which can be accessed outside PhotoScan. The 3D scene can be exported to common formats (Wavefront OBJ, 3DS, VRML, Stanford PLY, COLLADA DAE, Autodesk DXF, U3D and Acrobat PDF) which can be accessed and visualised in various software packages (e.g. freeware packages like Blender and MeshLab). In addition, orthophotos and 2.5D digital surface models (DSM) can be calculated.

5. Results

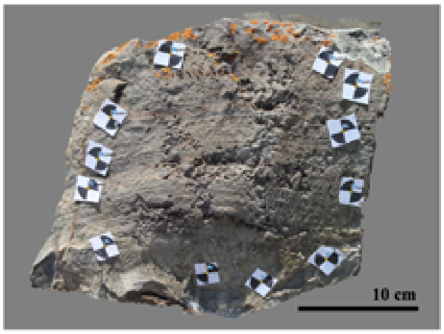
In total, over 10 000 photographs were taken over thirteen working days to document 323 petroglyph panels in the five study areas. The outcomes of the acquisition and the technical and practical advantages of this methodology are as follows:

First of all, the methodology is able to represent all visible morphological features of the rock art panel. Interestingly, the morphology of the underlying rock is modelled, even for the most irregularly shaped panel. Furthermore, also invisible details of the site might become visible when studying the 3D model completely stripped of any colour and texture information (Fig. 10). Through this visualisation, all pecked petroglyphs are clearly disclosed, giving information about the structure and relief of each representation. Moreover, just as Cassen and Robin (2010) were able to accurately map unclear pecked petroglyphs by physically altering the light, the virtual illumination of the exported 3D models can be altered in a variety of programs, allowing to discern otherwise invisible relief details.

Importantly, all this detail goes hand in hand with a high metric accuracy, both for large and small panels. A thorough comparison of the measured reference distances set with the reference distances deduced from the 3D model, for both small and large panels, showed that there was only a minimal discrepancy (in the order of a few millimetres or even sub-millimetres) between both sets (Fig. 11). This comparison showed that one reference distance is sufficient to obtain a highly accurate model. However, it is advised to measure more reference distances in the field to assess the relative accuracy of the model.

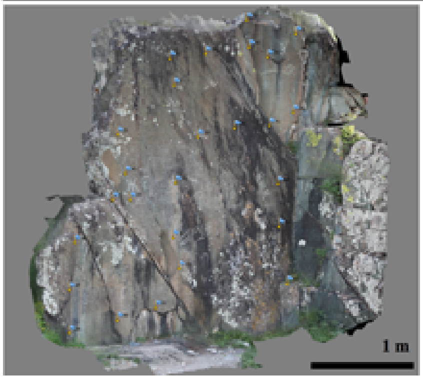
Other photogrammetric (e.g. Photometrix and iWitness) or computer vision (e.g. Eos Systems PhotoModeler) packages allow similar outcomes based on image modelling (Sanz et al. 2009). The strength of PhotoScan, however, is its straightforwardness of image processing and the variety of imagery it can handle.

Control points	*Field measurement (cm)*	*Measurement on model (cm)*	*Difference (cm)*	*Absolute difference (cm)*
1 - 2	4.8	4.8125	0.0125	0.0125
1 - 3	7.1	7.0588	-0.0412	0.0412
1 - 4	10.4	10.3515	-0.0485	0.0485
1 - 5	16	16.0141	0.0141	0.0141
2 - 3	2.7	2.6164	-0.0836	0.0836
2 - 4	6.1	6.0676	-0.0324	0.0324
2 - 5	12.4	12.3855	-0.0145	0.0145
5 - 6	11.7	11.6324	-0.0676	0.0676
5 - 7	13.85	Reference distance	Reference distance	Reference distance
5 - 8	14.1	14.0323	-0.0677	0.0677
6 - 7	2.6	2.6419	0.0419	0.0419
6 - 8	5.1	5.2107	0.1107	0.1107
6 - 9	10	10.0623	0.0623	0.0623
11 - 12	4.5	4.4591	-0.0409	0.0409
1 - 12	8.5	8.4359	-0.0641	0.0641
			Sum	0.7021
			Average deviation	0.0501



a. Model: Petro-12 Tuekta site (Karakol park, Ursul valley), 0.0562 square metre; distances measured with caliper.

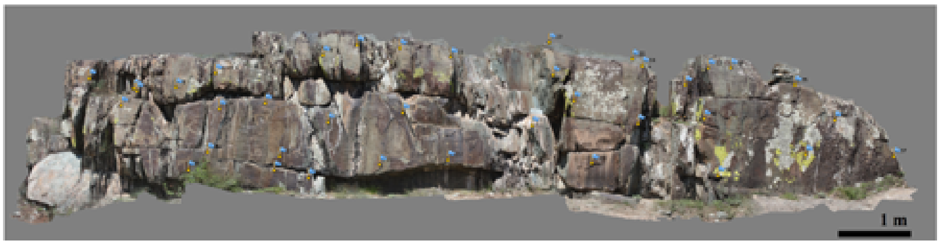
Control points	*Field measurement (cm)*	*Measurement on model (cm)*	*Difference (cm)*	*Absolute difference (cm)*
7 - 1	24.6	24.5683	0.0317	0.0317
7 - 10	53	53.006	-0.0060	0.0060
21 - 7	73.2	73.0617	0.1383	0.1383
21 - 43	35	34.9852	0.0148	0.0148
15 - 43	23.6	23.6552	-0.0552	0.0552
2 - 15	16.5	16.49	0.0100	0.0100
15 - 26	46.9	46.9216	-0.0216	0.0216
12 - 15	53.8	53.858	-0.0580	0.0580
10 - 26	50.4	50.4039	-0.0039	0.0039
11 - 49	36.5	36.373	0.1270	0.1270
16 - 49	42.2	42.188	0.0120	0.0120
49 - 47	52.9	Reference distance	Reference distance	Reference distance
47 - 16	36.6	38.5193	-1.9193	1.9193
46 - 47	43.1	43.1837	-0.0837	0.0837
36 - 48	59.5	59.4454	0.0546	0.0546
36 - 18	44.4	44.3787	0.0213	0.0213
10 - 39	44.4	44.2853	0.1147	0.1147
40 - 30	50.45	50.5266	-0.0766	0.0766
30 - 39	76.9	76.8751	0.0249	0.0249
41 - 36	42.85	42.9378	-0.0878	0.0878
41 - 18	60.6	60.5443	0.0557	0.0557
34 - 35	62.5	62.3817	0.1183	0.1183
40 - 34	24	24.0987	-0.0987	0.0987
8 - 34	37.1	37.1677	-0.0677	0.0677
8 - 35	80.1	79.9545	0.1455	0.1455
32 - 34	42	41.955	0.0450	0.0450
			Sum	3.3923
			Average deviation	0.1357



b. Model: Petro-25 Kalbak Tash, 13.8297 square metres; distances measured with mm ruler.

Figures 11a and 11b.

Control points	*Field measurement (cm)*	*Measurement on model (cm)*	*Difference (cm)*	*Absolute difference (cm)*
1 - 3	57.1	57.5536	0.4536	0.4536
2 - 3	18.1	18.2114	0.1314	0.1314
2 - 5	48.3	48.6451	0.3451	0.3451
30 - 31	21.7	21.8103	0.1103	0.1103
30 - 29	37.7	37.9857	0.2857	0.2857
5 - 6	36.7	36.9732	0.2732	0.2732
27 - 24	49.6	49.9848	0.3848	0.3848
25 - 27	30.2	30.4562	0.2562	0.2562
25 - 26	29.4	29.5446	0.1446	0.1446
26 - 27	12.2	12.2561	0.0561	0.0561
25 - 24	49.6	50.0734	0.1734	0.1734
25 - 23	30.2	61.7641	0.2641	0.2641
24 - 23	57.1	57.334	0.2340	0.2340
30 - 27	60.6	61.0211	0.4211	0.4211
29 - 27	65.7	66.0807	0.3807	0.3807
9 - 10	36.6	36.738	0.1380	0.1380
12 - 17	47.1	47.1502	0.0502	0.0502
15 - 13	57.7	Reference distance	Reference distance	Reference distance
16 - 15	51.7	51.6402	-0.0598	0.0598
6 - 30	67.1	67.4959	0.3959	0.3959
40 - 15	54.8	54.639	-0.1610	0.1610
14 - 32	48.2	48.2262	0.0262	0.0262
33 - 34	18.4	18.3364	-0.0636	0.0636
39 - 40	48.9	48.9237	0.0237	0.0237
34 - 35	55	54.7964	-0.2036	0.2036
35 - 36	43.8	43.6265	-0.1735	0.1735
38 - 39	74.2	73.9775	-0.2225	0.2225
37 - 38	71.6	71.3564	-0.2436	0.2436
			Sum	5.6759
			Average deviation	0.2102



c. Model: Petro-19b Kalbak Tash, 19.0695 square metres; distances measured with mm ruler.

Figures 11a to 11c. *For small, medium-sized and large panels the average error is very low, showing only a minimal discrepancy (in the order of a few millimetres or even sub-millimetre level) between the measured reference distances set and the reference distances deduced from the 3D model.*

As a result, people with little technical background are able to successfully process photographs to 3D models. Firstly, only a series of overlapping images is needed, so calibrated cameras or specific markers are elementary (like e.g. PhotoModeller). Additionally, a limited amount of equipment is needed (essentially a photo camera), which allows high mobility in the field. Even 'old' images that were not intended for 3D modelling, but taken with sufficient overlap and with some indications of metric dimensions (e.g. scale bar), can be used. In executing the whole process from image alignment to dense 3D reconstruction, PhotoScan allows the user to set a few parameters. Once the correct parameters are found for a specific workflow, the whole process can be batched into an automatic processing chain.

The cost of the software and necessary hardware is very low, even when using a professional camera. In this case a Canon 5D Mark II and professional L-series lens was used, but comparative tests with a consumer-grade reflex camera (Canon 500D 15, 1 MP) showed similar results (the essential difference being the colour quality and detail of the produced texture).

The data collection (i.e. placing and removing the reference points, describing the panel and photography) in the field is remarkably fast and only takes a minimal amount of time, obviously depending on the dimensions of the rock art panel. The acquisition of photos for modelling petroglyph panels (up to 1–2 m²) takes a couple of minutes, whilst larger panels (15–25 m²) can be covered in an hour.

Because most processing steps are automated, preparing the photos for processing in PhotoScan is easy in comparison with PhotoModeller (Sanz et al. 2010: 3165). In all cases, simply importing the pictures into the software was sufficient to start the first alignment step. The only non-automated steps are defining the reference points and setting the reference distances.

Compared to traditional techniques, there is little doubt about the major advantages provided by the

Figure 12. *Comparison between traditional documentation (tracing on plastic sheet) by one of the authors (a) and a detailed CAD drawing derived from an orthophoto (b) produced in PhotoScan Professional. This model of a panel in the Chagan Uzun valley was produced using old images taken in 2009, which were not taken for 3D modelling purposes.*

approach presented here. Importantly, because the contact with the panel is limited, the methodology provides a non-invasive alternative to recording techniques like rubbing and tracing. Secondly, when comparing the outcome of traditional techniques with these image-based techniques, the ability to comprehensively document every detail (e.g. relief and texture) enables us to document petroglyphs ranging from large figures to lines incised with a fine instrument (Fig. 12). However, the most important accomplishment is that the panel is documented in 3D and that the shape of the rock is also integrated in the documentation (see section 6 for a more elaborate discussion). Without a doubt this enables a detailed assessment, analysis and modelling of the preservation of a site.

However, the methodology has some drawbacks. First of all, a multi-core computer with a high-end graphical card and sufficient memory (minimum 6–8 RAM) is recommended to process the large amount of data. Depending on the required output, number of images and pixel count of every image, processing time can take many times longer than the original acquisition time. But as this is a nearly automatically desk-based step that can be batched, the computer can independently calculate the 3D models with limited human input. Secondly, PhotoScan is a program under development. This does not only mean that numerous new features are frequently added, but that bugs and crashes can be encountered. Thirdly, the focus of the field campaign was mainly on testing the potential and possibilities of the program. Because it was thought that colour reference and white balance cards could affect the processing they were not included in the images — as a result the presented workflow is not a colour-accurate one. Recent tests have clearly shown that these cards do not influence the processing. Overall, the speed of the calculations, the flexibility of the data acquisition and the impressive output make such a PhotoScan-based workflow very suitable for a cost-effective and accurate documentation of rock art in high detail.

6. Discussion: needs and perspectives of the 3D models

The cost-effectiveness and straightforwardness of the presented methodology enables every rock art researcher with basically a camera and a computer to produce 3D models of rock art. As 3D documentation is a fast evolving field and similar packages are being developed, 3D modelling will become a standard in rock art research and conservation. However, a more elaborate discussion is needed about implementation of 3D in rock art research, and within this discussion two specific elements will be addressed. First of all, how should we work with 3D rock art from the scientific point of view and how should results be presented? Secondly, in a worst case scenario, can virtual preservation be an option and which issues should be considered?

Currently, representations of panels and 'scenes' are done in 2D or 2.5D. But, as much as the landscape context and rock art are interwoven, the rock art manifestations are also interconnected with the shape and appearance of the underlying rock (Martinez 2001: 11). These aspects are not fully visible on flat 2D images but only through the extra geometrical dimension provided by 3D technology. Moreover, 3D has the visual strength of making information more perceptible for the human eye, which on its

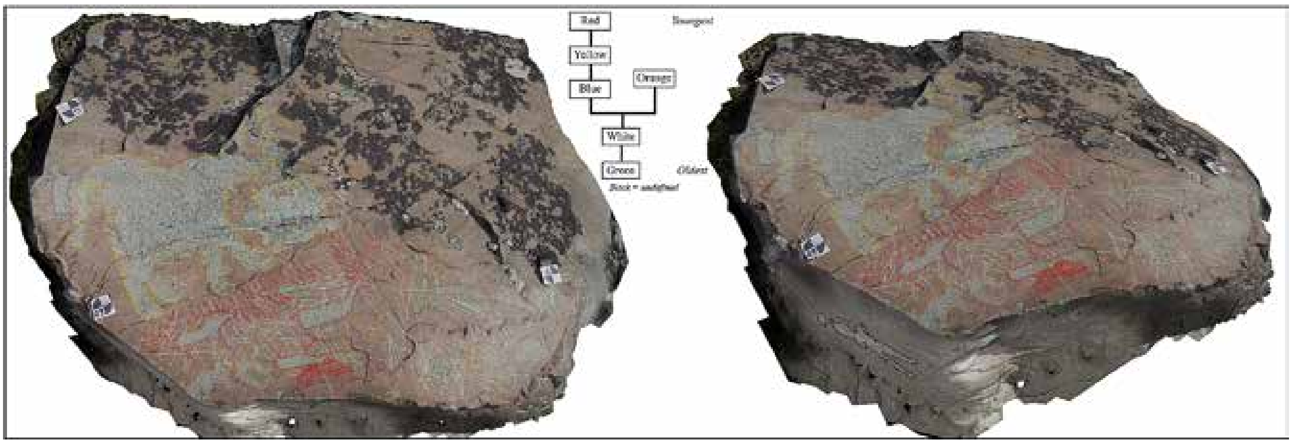


Figure 13. *3D model of panel petro 195 of the Turai site (Elangash valley). With Harris matrix indicating the stratigraphy of the panel.*

own has potential for an informative profit (Friedhoff and Benzon 1989; Hermon 2008). This principle is further underlined by the statement of Hermon when discussing the visual framework provided by VR and 3D visualisation: '... the better the visual tool, the better the explanation and the comprehension of information' (Hermon 2008: 37).

When looking at past 3D rock art documentation practices, the model itself is generally converted into a DSM or orthophoto (e.g. Farjas et al. 2009; Alyilmaz et al. 2010; Gonzales-Aguilera et al. 2011; Riveiro et al. 2011). And although these are much better products than conventional photographs or traditional drawings and copies, they are still 2D or 2.5D products losing all supplementary depth and height information. Moreover, 2.5D surfaces cannot deal with undercuttings, while orthophotos of an irregularly shaped rock do not allow measuring the real dimensions of the rock art because everything is reprojected onto a flat plane. This step backwards from 3D to 2D is an understandable choice; it reflects the choice to keep working within the existing 2D framework. Furthermore, 2D is still more convenient to present in publications, books and talks. This means that 3D methodologies are fitted into an existing 2D workflow solely to facilitate and improve parts of an existing way of working. This conflicting situation in heritage studies has already been discussed by Kalay (2008: 9):

> Rather than how can the new technology assist the practice and how to avoid its pitfalls, the question to be asked is how can the affordances provided by the new technology change the practice itself?

Although this was noted in 2008, at the beginning of the big boom of straightforward 3D documentation techniques, this statement is still relevant and the potential of 3D for scientific interpretation is still not fully employed (Hermon 2012). This hampers the progress of the archaeological practice itself. When Hermon (2008: 37–42; Hermon and Kalisperis 2011) compared the use of 3D and VR as a communication tool for education and heritage communication with a view towards solving archaeological problems, it was clear that 3D and VR was successfully applied in public outreach projects and changed the way to communicate heritage. But the remarkable boom of VR and 3D had not impacted the archaeological reasoning process (Hermon 2008: 42, 2012).

Thus, as for 3D rock art documentation, it is important to engage in a full 3D-based practice. As illustrated by Sauerbier et al. (2008) and Fux et al. (2009), it is possible to establish a full 3D workflow, ranging from digitalisation and data management to interpretation. Unfortunately 3D software allowing visualisation, digitalisation (i.e. CAD tracing of the rock art) and data management is in full development and only costly packages like ArcScene allow to change visualisation of the different layers (i.e. surface model and texture), see the model from different viewpoints and digitise all relevant features and link these digitalisations to a database (Optiz and Nowlin 2012) in a 3D environment. But even these costly packages cannot deal with large files (i.e. big panels with a detailed geometry). Only future developments in the maturing field of 3D documentation and visualisation will lead to straightforward and cost-effective alternatives for rock art digitalisation, management and interpretation of 3D models. Awaiting these developments, a way to digitise and interpret the rock art on the models is through exporting the texture of the model from PhotoScan or MeshLab and import it into editing software similar to Adobe Photoshop where the visible rock art can be traced. Then this edited texture can be imported in PhotoScan or MeshLab and the panel can be further studied in 3D (Fig. 13).

Another reason to favour a 3D output is related to the presentation of these relics. However, more and more literature is electronically accessible, so why would it not be possible to provide 3D models as has been done for decades with 2D photographs and illustrations? The main advantage of some existing file formats like .pdf is that they easily integrate 3D content

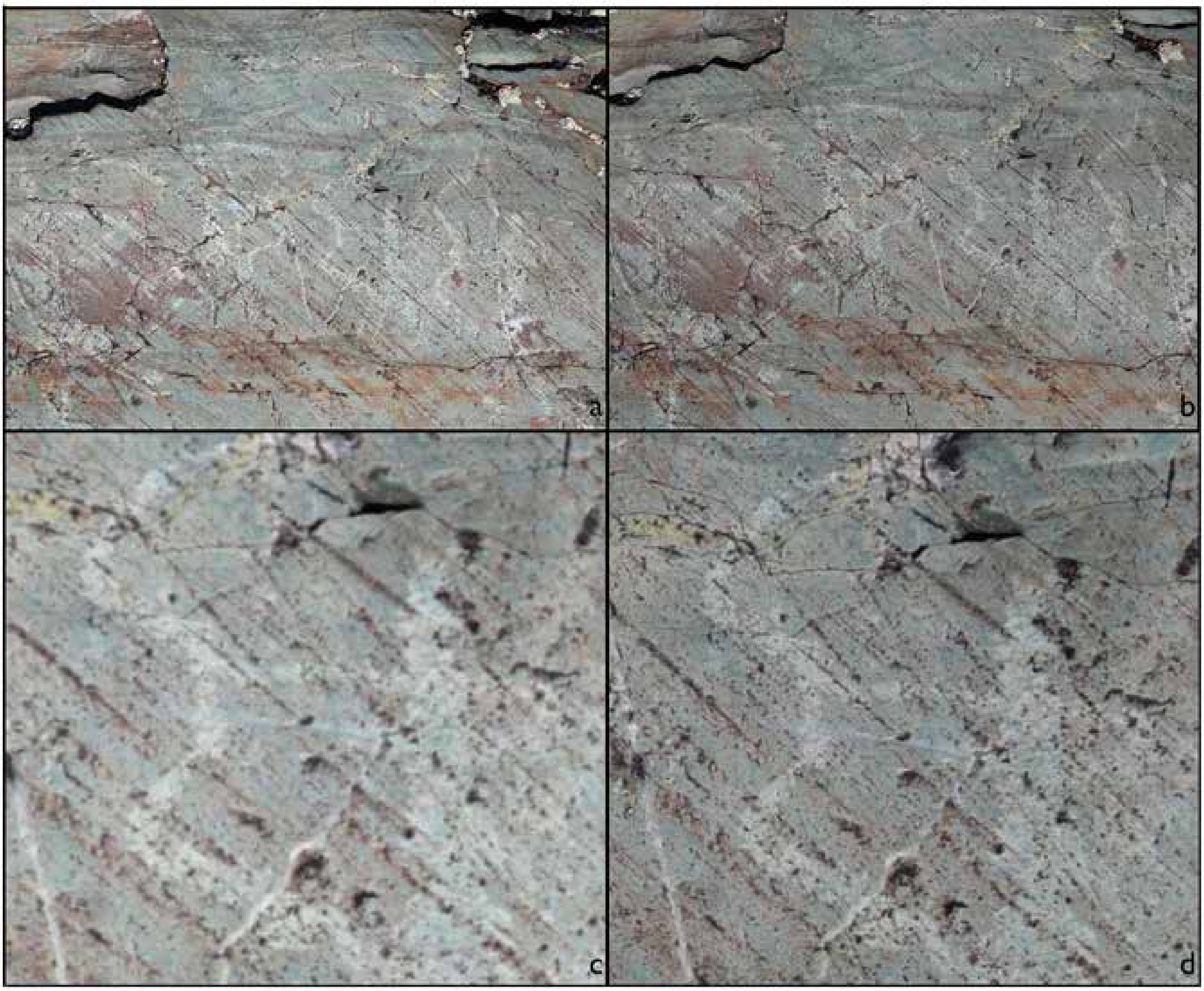


Figure 14. Comparison between a model in a MeshLab .obj compatible format (b and d) and Acrobat compatible .pdf format (a and c) of panel petro 183 of the Turai site (Elangash valley). Both models are derived from the same model in PhotoScan (i.e. same geometry and texture settings).

in electronic documents, making it possible to navigate in the 3D models. This allows rock art researchers to exchange data in a detailed and objective way. User-friendly freeware packages like MeshLab can deal with many 3D formats (e.g. .obj or .ply) and allow 3D exchange with high detail. Unfortunately, the .pdf and .u3d formats are unable to deal with large detailed files. Consequently, only models where the detail of the geometry is brought back below a certain threshold (AGISOFT LCC 2012) can be exported from PhotoScan Professional to Acrobat Reader-supported extensions. Furthermore, the texture loses its quality and is fuzzier than the original when exporting to .pdf or .u3d (Fig. 14), caused by the current technical limitations of Acrobat Reader. As a result, the integrated .pdf models are not as photorealistic and detailed as the original model in PhotoScan or accessible exports in MeshLab. This makes it difficult to integrate elaborate panels (over 6 m^2) and compositions consisting of finely incised engravings.

Nevertheless, consistent with Kalay (2008) and Hermon (2012) and illustrated by recent researches in the field of cultural heritage (e.g. Fux et al. 2009; Grussenmeyer et al. 2010; Scopigno et al. 2011; Sanders 2012), 3D methodologies allow us to change the entire practice instead of fitting the methodology into an existing procedure. This enables researchers to completely assess and present the full semantics of the studied rock art.

As the world of 3D is rapidly evolving, there is no doubt that better techniques and software will be developed, allowing documentation, visualisation, analysis, data management, interpretation and exchange. This makes 3D potentially valuable to 'virtually' preserve endangered sites. Although this could be a major advantage for under-developed regions like the Altai, three key issues should be taken into account when considering virtual preservation for soon to be destroyed sites.

Firstly, the aim of heritage researchers should always be the long-term in-situ preservation of heritage. So, would the suggested type of ex-situ preservation be a right signal? It could be seen by the outside world as an economical alternative, which is furthermore very visual and fancy looking, as opposed to very expensive conservation programs. Owing to the fact that it could be very dangerous to provide this as an option, it should really be presented as a worst-case solution when the harsh reality dictates that there are no substantial sustainable prospects for long-term preservation and it is necessary to document the present state of the rock art as detailed as possible. Even if this will mean converting some rock art of the Altai into so-called 'dead artefacts' (Bednarik 2008: 8).

Secondly, the 3D representations are able to present the rock art of the Altai with affordances that traditional outcomes could never achieve in such detail. But, as stated by Kalay (2008: 6), 3D models are not able to present authenticity. One is not able to either touch the heritage or get a sense of the surrounding landscape and indigenous values. Although elements such as landscape setting can be integrated virtually, this is still far away from the real phenomenology of a rock art site.

Another major issue with virtual preservation is the storing of metadata and paradata. If it were to be decided that temporary (i.e. while waiting for conservation) virtual preservation for a vast and underfinanced area as the Altai could be beneficial, this would mean that thousands of panels would have to be documented. Without decent data management, the large quantity of data will not outlive the degenerating rock art it is meant to preserve digitally. As underlined by Addison (2008) this can only be prevented by paying attention to metadata (data about the data) of the original raw data (i.e. measurements and pictures) and outcomes. Furthermore, 3D models are not 100% objective reproductions of the documented reality. The production of models often requires human involvement (e.g. removing artefacts in the models to enhance the surface quality). However, still more objective than traditional techniques, this human involvement needs to be documented as paradata to enable an assessment to the authenticity of the produced models (Havemann 2012).

7. Conclusion and future work

Based on prior field observations and 3D documentation acquired during the summer of 2011, the various processes that affect this part of the rich cultural heritage of the Altai Republic could be described. It is believed that a first step towards preventing a worsening situation is thorough, objective and consistent documentation. Hence, in close collaboration with local stakeholders (i.e. park managers, universities and institutions) a cost-effective, flexible and straightforward methodology was developed for the documentation of Altai rock art, which was successfully tested on 323 panels. Apart from the presented advantages of the methodology, the numerous produced 3D models were also an impetus for a discussion about their further use and possibilities. Firstly, the use of cost-effective 3D documentation techniques allows changing the workflow of rock art research into a full 3D experience. Secondly, the models allow to 'virtually preserve' sites ex-situ. However, this is a tricky and possibly dangerous possibility, therefore some caution needs to be exercised in its application.

These trials were preliminary tests to evaluate the possibilities of PhotoScan Professional for rock art documentation, but the results exceeded all expectation. Further fine-tuning of the methodology is imperative. Firstly, it is aimed to make the workflow more colour accurate. Additionally, tests with hyperspectral images within the 3D methodology will have to be made to evaluate their value in documenting invisible aspects of the rock art (e.g. traces of pigment). Furthermore, the exchange of the 3D content to .pdf is not ideal yet. These models do not have the same photorealistic detail as the other exports (e.g. for MeshLab or Blender), which seem to present the outcomes in a more abstract way.

In the future it is our aim to set up an on-line portal where the models will be displayed for colleagues, tourists and locals. Based on the presented successful tests, a manual (in Russian) and field school for Siberian students and researchers are being prepared in collaboration with IAE SBRAS for the summer of 2012. Hopefully this will result in a systematic, non-intrusive and more detailed documentation of the rock art by local stakeholders. In addition, systematic documentation of all sites in the Elangash Valley and adjacent valleys will continue, aiming to fully document and understand the ethnographic and recent rock art manifestations.

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Gertjan Plets, Dr Geert Verhoeven, Dr Jean Bourgeois,
Dr Birger Stichelbaut, Dr Wouter Gheyle and
Dr Jeroen De Reu
Department of Archaeology
Ghent University
Sint-Pietersnieuwstraat 35
9000 Ghent
Belgium
gertjan.plets@ugent.be; geert.verhoeven@ugent.be; jean.bourgeois@ugent.be; wouter.gheyle@ugent.be; jeroen.dereu@ugent.be

Dr Dimitry Cheremisin
Institute of Archaeology and Ethnography
Siberian Branch of the Russian Academy of Sciences
Prospect Akademika Lavrenteva
630090 Novosibirsk

Russia
cheremis@archaeology.nsc.ru

Dr Ruth Plets
Environmental Sciences Research Institute
University of Ulster
Coloraine Campus
Cromore Road
BT52 1SA Coloraine
Northern Ireland
r.plets@ulster.ac.uk

MS received 16 May 2012.

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