Sudan & Nubia

The Sudan Archaeological Research Society

Bulletin No. 17 *2013*


ASWAN
1st cataract
Egypt
RED SEA
Wadi el- Allaqi
2nd cataract
Batn el-Hajar
Akasha
Wadi Gabgaba
Sedeinga
Jebel Dosha
Tinare
Jawgul
3rd cataract
Sudan
ABU HAMED
Nile
El-Ga'ab
Basin
Kawa
Sudan Military
Railway
Fifth
Cataract
KAREIMA
4th cataract
el-Kurru
Usli
Dangeil
Berber
ED-DEBBA
Gala
Abu Ahmed
Wadi Howar
ATBARA
es-Sour
Atbara
el-Metemma
Wadi el- Melik
Wadi Muqaddam
6th cataract
OMDURMAN
KHARTOUM
KASSALA
Eritrea
Blue Nile
MODERN TOWNS
Ancient sites
WAD MEDANI
Atbara/Setiet
GEDAREF
White Nile
Aba Island
KOSTI
SENNAR
N
Ethiopia
South
Sudan
0
250 km

Sudan & Nubia

The Sudan Archaeological Research Society — *Bulletin No. 17* — *2013*

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Front cover: The descendary of Tomb IV T 1 near Sedeinga under excavation (© V. Francigny / SEDAU).

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Creating a Virtual Reconstruction of the Seti I Inscription at Jebel Dosha

Susie Green

Introduction

This paper describes the process used to create a high resolution orthographic image of a stela at Jebel Dosha using only previously existing photographs. The result is achieved through the creation of a virtual reconstruction of the inscription in the form of a 3D model, which allows different techniques to be used to enhance and clarify the hieroglyphs.

The model is created using a process called Structure from Motion (hereafter referred to as SfM). This uses the principle that movement through a scene allows an understanding of the shape of the scene in three dimensions, in the same way that walking through a room allows someone to visualise how all the furniture is laid out within it. In SfM the movement does not need to be continuous and can be represented by a series of photographs taken from different angles.

SfM is a type of photogrammetry. It uses a technique called bundle adjustment which requires at least three images of each part of the subject, but these can be taken from any unknown position and the cameras do not need to be calibrated. In fact they can be taken with different cameras at different times, as this paper demonstrates. A computer is used to automatically select distinctive points in the photographs, and thousands of these points are matched together. A least squares algorithm is used to calculate the location from which the images were taken. In this process, first an intelligent guess is used to approximate the camera positions, then as each point is added to the equation the position is recalculated a number of times, and the best result is kept. Eventually the locations reach an equilibrium, as we rule out all the incorrect points (Lowe 2004; Snavely 2009). This technique can also let us estimate the errors due to lens distortion without having to calibrate the camera.

The inscription at Jebel Dosha was processed using a command line program called Bundler, which was developed as a way of organising huge online image collections such as flickr. It forms the basis of the Photo Tourism project (Snavely *et al.* 2006), which takes thousands of pictures by different users and arranges them in space to correspond to the positions from which they were taken. This allows a user to browse through the collection as if looking through the cameras. As a result of this process a 3D pointcloud is built up composed of all the points that were matched across the photographs. This gives an idea of the shape of the subject but there is not enough detail to reconstruct it.

This detail is filled in by another program called Patch-based Multi-view Stereo, or PMVS2, which takes the results of Bundler, and in a technique closer to traditional photogrammetry, uses the now known camera locations and calibration to fill in the gaps (Furukawa *et al.* 2010). The result is a highly detailed pointcloud that is similar to the pointclouds produced by laser scanning.

In many ways SfM is an ideal technique for recording archaeology. It does not require expensive equipment or software. It allows photographs to be freely taken from any position and without camera calibration, which means that changing surfaces can be quickly recorded during excavation. Being able to use a light camera without a tripod means work can be carried out under difficult conditions. It even allows photographs taken by different people at different times using different cameras to be combined. The results can have slightly lower accuracy than other techniques such as laser scanning and photogrammetry, but this is not necessarily a concern in archaeology, where millimetre accuracy is not as important as the interpretation of the features which can be seen in a detailed pointcloud. SfM has another important advantage over laser scanning in that it allows the capture of surface colour.

The royal stela, dedicated to King Seti I at Jebel Dosha

Jebel Dosha sits on the west bank of the Nile between the Second and Third Cataracts a few kilometres north of Soleb, and south of the island of Sai. At the *jebel* there is a rock-cut chapel and several smaller monuments. The subject of this paper is a royal stela, dedicated to King Seti I. It is rectangular and has a high quality inscription with a scene above showing Seti I offering to the deities of the cataract region, with the kneeling figure of the viceroy of Kush who commissioned the stela underneath. There are 15 lines of text, which are well preserved on the left of the stela, but badly damaged on the right (Davies 2004a; 2004b).

Given the inaccessibility of the monument, there are no detailed photographs of the entire inscription. Plate 1 makes it clear why it is so hard to take a good photograph of the stela. It can only be reached by balancing a ladder precariously on the small platform below, and it is impossible to pull back any distance horizontally. If there had only been one set of photographs of the inscription it would have been very unlikely it could have been recreated, but luckily there were two. These sets are very similar because they were taken by two different people who were both trying to achieve the same thing: full coverage across the surface of the stela. It is the duplication that makes it possible to create a high density pointcloud. The images overlap, so most of the surface is visible in at least three photographs. Both sets were taken without a tripod, so although the images are similar, the positions of the cameras are different, allowing us to triangulate to find the surface points.

Creating a high resolution orthographic image

Figure 1 shows the high resolution pointcloud and the camera positions found by Bundler. These clearly show how the

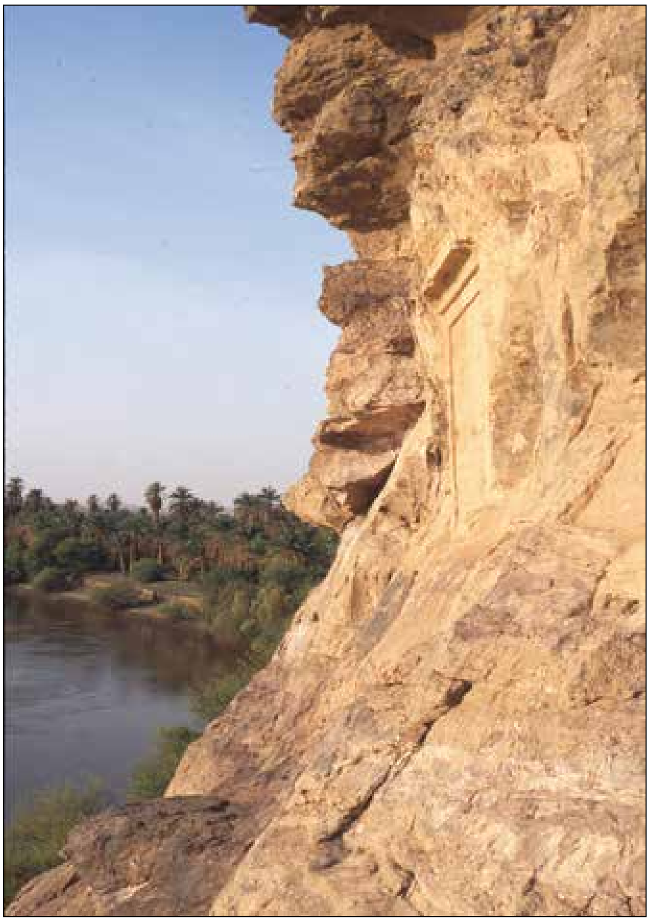

Plate 1. The siting of the royal stela, dedicated to King Seti I at Jebel Dosha (photo courtesy of Vivian Davies).

pictures were taken. There are a few distant photographs taken from the platform below, but most form a grid near the surface. At the lower part the photographs are facing directly onto the surface, but the higher part is only covered by cameras angled upwards because the ladder was not high enough to reach the top. In the pointcloud you can make out the parts of the inscription which are enhanced by the colour of the points, which is taken from the photographs.

The quality of the pointcloud is dependent on several factors. There must be enough detail in the subject matter to find and match features across the images, the features must be distinguishable in the images, and there must be good coverage by at least three photographs. The combination of the hieroglyphs and the changing pattern of the rock underneath mean that surface detail is not a problem here. The areas in shadow are too dark to match the features well so part of the bar at the top of the inscription is missing and the area in shadow under the bar is also patchy. The biggest problem is the low density of points at the corners. This is due to the way the pictures were taken. A series of overlapping images across a surface will have the best coverage at the centre of the surface because two or more images will always overlap. The poorest coverage will be at the corners because the outermost pictures have nothing to overlap with. There is nothing that can be done to solve this problem in the pointcloud, but this is not necessarily a problem for our orthographic image as will be demonstrated.

The next step is to create a polygon mesh from the pointcloud which can be done automatically using a process called Poisson Surface Reconstruction (Kazhdan *et al*. 2006), which can be performed in an open source program called Meshlab (MeshLab). The points in the pointcloud hold information about the direction they are facing, and this is used to create a surface made up of small triangles. The surface can be coloured using the points, and the result is easier to read than the original pointcloud. Unfortunately the areas where the points are thin are not very good quality and this is particularly apparent at the bottom left, and in the shadow along the top. The quality of the mesh will never be as good as the original photographs because information is lost at each step. However we are able to get most of this information back by using Meshlab to project the photographs onto the mesh using the original camera positions as virtual projectors.

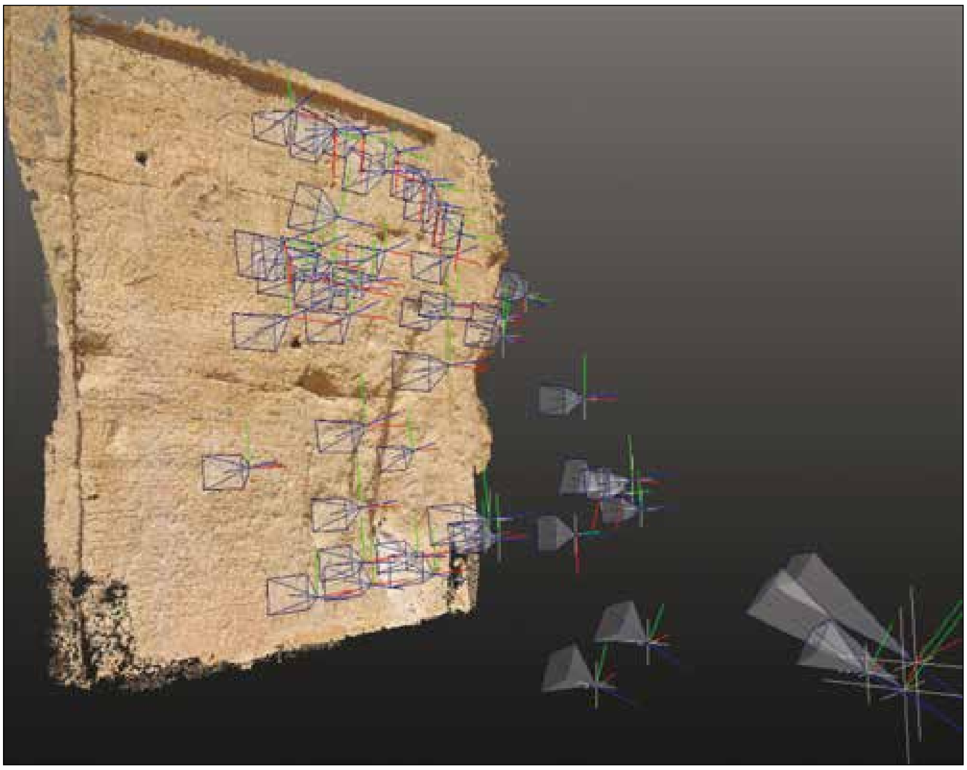

Figure 1. The high resolution pointcloud and camera locations.

The result is a mosaic of the original photographs, with each photograph aligned correctly with its neighbours. This is not only because the camera locations and angles are accurate, but most importantly the shape of the surface is exactly the same. If the photographs were projected onto a flat surface they would not match correctly because the cameras would all be slightly different distances from the surface. Meshlab weights the parts of each photograph used. The centres of the images are favoured over the edges, which allows them to blend together seamlessly, and the areas that are perpendicular to the mesh are chosen over those that are oblique, so each photograph is used where the quality is best. The colours are matched across all the images.

The final orthographic image is created by recording the projected photographs as if from an orthogonal camera that is perpendicular to the mesh. This is done using a Meshlab filter *(Project active raster's colour to current mesh, filling the texture, using basic weighting)* and the result is the creation of a new image file shown in Figure 2. This file is a highly detailed orthophotograph of the inscription. Any variations in the angles of the sides are real representations of the shape of the stela. The resolution is only limited by the resolution of the original photographs, and the image shown has a full resolution of 6500 by 7500 pixels as shown in the enlarged area depicting the kneeling figure of the viceroy of Kush. The areas where the pointcloud was thin are of much better quality in the orthophoto because only a few points are needed to build a surface on which to project the photographs.

Techniques to enhance and clarify the inscription

The second part of this paper looks at ways of using the 3D model of the inscription to enhance the orthophotograph and clarify the inscription. The model has been set up so that surface information can be read using an orthogonal camera. It is also possible to use this camera to read height information. Each point on the mesh is given a colour value based on its elevation (z value), using Meshlab's *Per Vertex Colour* Function, and this is written to a new image, as shown in Figure 3a. The values are clamped at the highest and lowest extents of the carvings. Variations in height across the surface mean that the colours vary and the inscriptions are not very clear. While these variations can be interesting in themselves, it is possible to eliminate them to enhance the inscription using a low pass filter in Photoshop. A copy of the image is filtered using a gaussian blur until the inscriptions are no longer visible. This ensures that any changes are applied at a scale

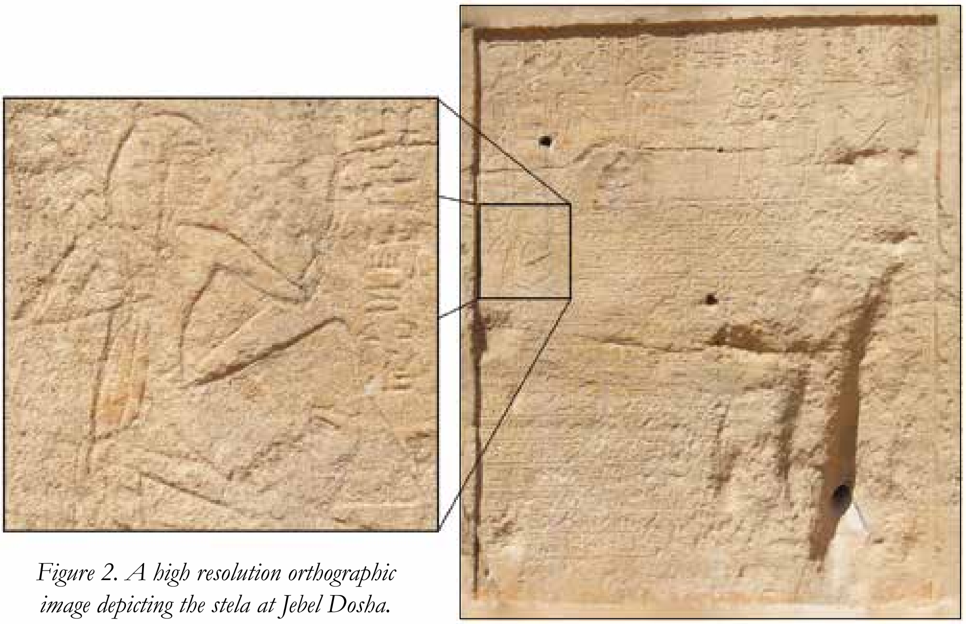

Figure 2. A high resolution orthographic image depicting the stela at Jebel Dosha.

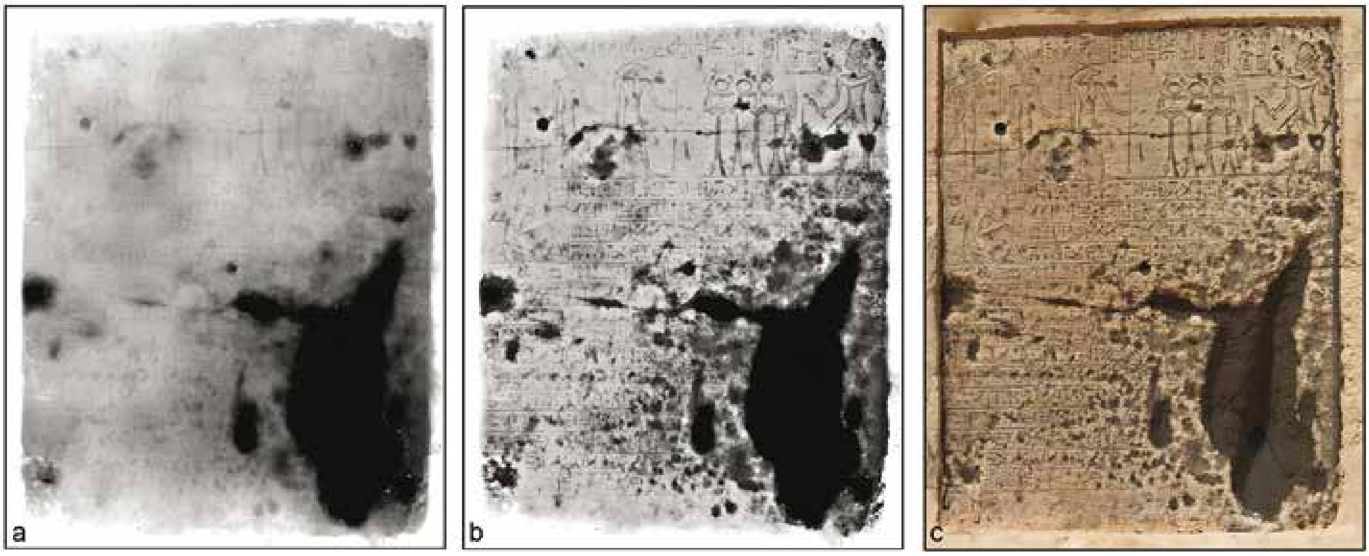

Figure 3. Using a depth map to enhance the inscription.

bigger than the details that are being enhanced. The blurred image is used as a selection mask to divide the image into lighter and darker areas then light areas are made darker and the dark areas are made lighter which balances out the colour variation across the image and allows the inscription stand out better. The process is repeated until the surface of the stela is a uniform colour and the dark areas only represent parts of the surface that have been cut away, as shown in Figure 3b. The depth map can be overlaid upon the orthophotograph which will match it exactly as they were both created from the same model. In Figure 3c the depth map illustrates the quality of the carvings. The edges of the figures are finely graded from the centre and the clothes of the kneeling viceroy of Kush are carved in a way that makes the light seem to be passing through them.

There are still some problems associated with the representation of depth. It is hard to bring out the contrast in areas that deviate from a plane, and subtle changes in the surface are lost. This can be overcome by a process known as ambient occlusion. This is widely used by artists in the visual effects industry to enhance the subtle details of their models. It refers to the shadows cast into occluded areas from an ambient light. The effect is similar to the shadows you would see on an overcast day. In order to calculate ambient occlusion a large number of virtual lights are used to light a scene, as if it was being lit from every direction. Where the surface forms ridges and dips some of the light is occluded and these areas are darker. It is ideal for picking out subtle recesses such as those of an inscription. The ambient occlusion was applied to the model in another open source program called Cloud Compare (Cloud Compare V2) using the PCV plugin (Tarini *et al.* 2003), then returned to Meshlab where another orthographic image was created. Figure 4 shows the result of an ambient occlusion pass on the model with the carvings picked out in shadow. It is possible to enhance the differences more clearly by using red, green and blue to represent the surface occlusion rather than just greyscale, especially if the threshold is set so that the boundary between red and yellow is where the surface is cut away (Figure 5). Using the three colours allows the eye to detect more subtle differences in the shading. This technique is very good for enhancing the hieroglyphs. They are no longer obscured by the shadows cast by the sun, and even the tiniest of variations in the surface are visible as shades of orange.

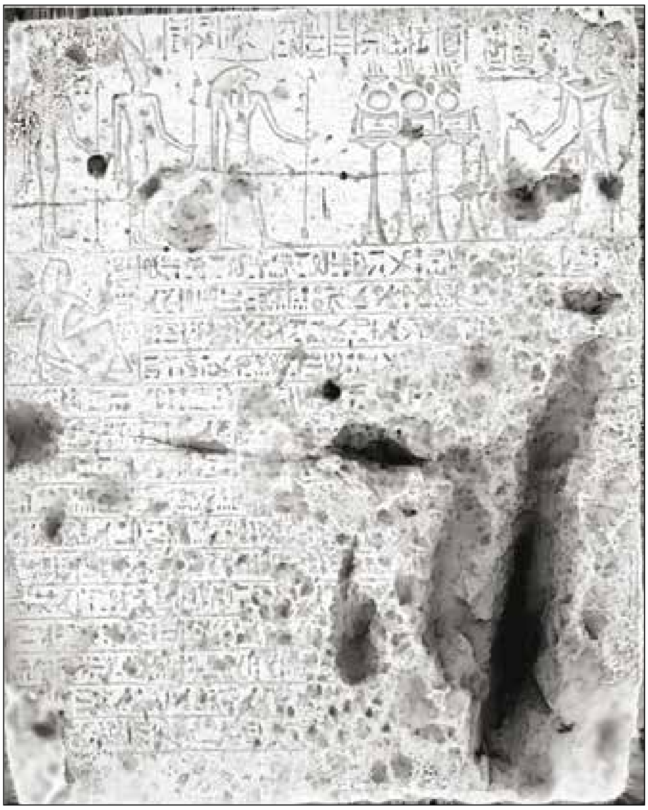

Figure 4. An ambient occlusion filter applied to the model of the inscription.

Polynomial Texture Mapping

The final technique to which the Jebel Dosha stela was subjected is Polynomial Texture Mapping (hereafter PTM). This is usually performed on a real object using a camera and flash rig. PTMs are created from a series of photographs of an object lit from different points. In some ways the setup is similar to ambient occlusion, but instead of all the light coming from all directions at once, only one light at a time is used, and many images are produced. (Malzbender *et al.* 2001) There are a variety of rigs

Figure 5. A detail of the inscription enhanced by ambient occlusion.

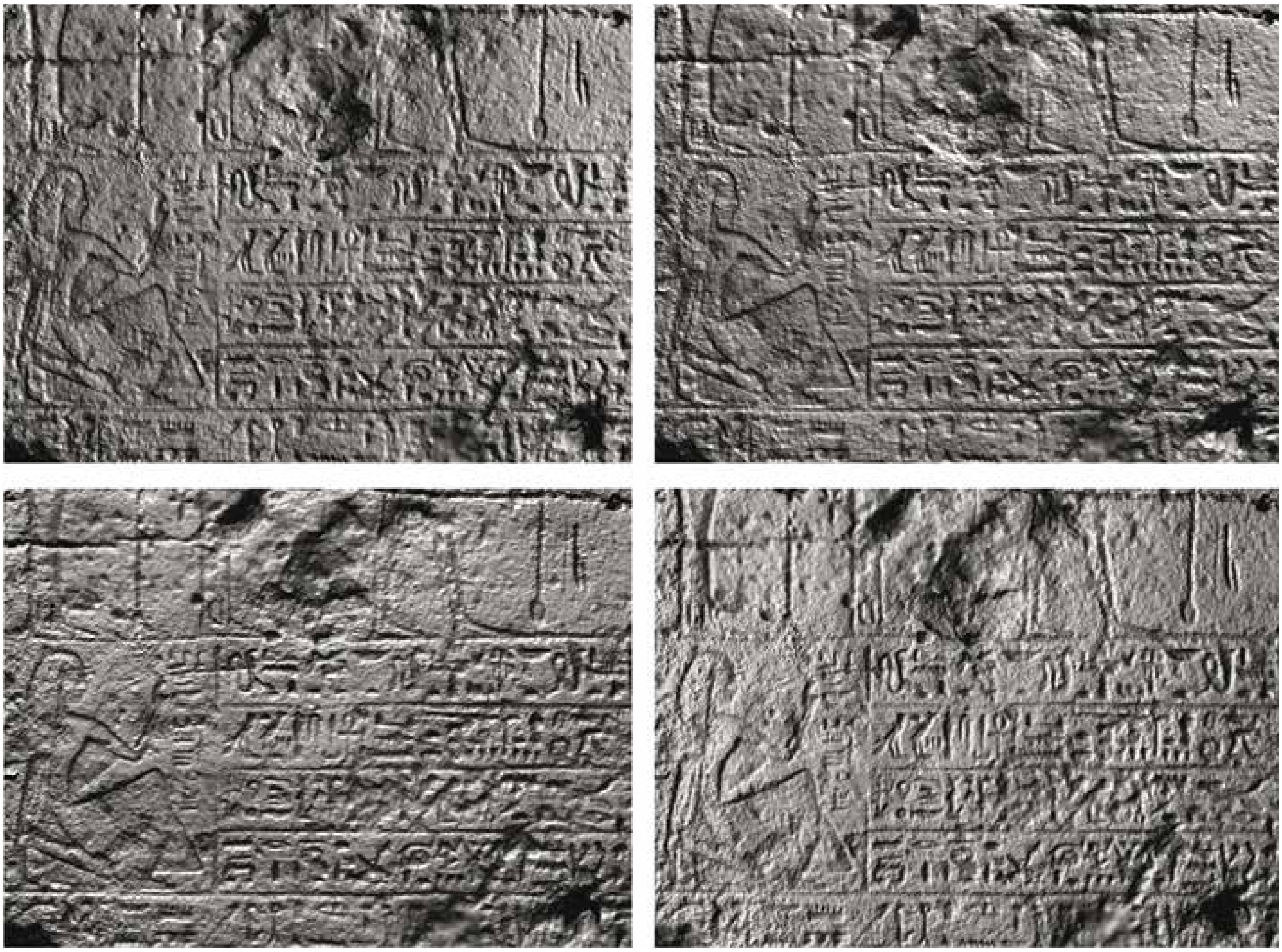

Figure 6. Four of the images created to produce an interactive PTM.

used to create polynomial texture maps but they all require some degree of controlled environment which would be very difficult to recreate at Jebel Dosha. However the setup can be created virtually using our model of the inscription. This setup was created in Autodesk's 3D modelling program Maya (Autodesk Maya 2013). A virtual geodesic dome was placed over the model of the inscription and a light was moved to each point on the dome in turn. An image was rendered and the name of the image file and position of the point was written to a text file. This was repeated for over 80 different light locations. Figure 6 shows some of the images created. The text file is used by HP labs PTM tools (HP Labs Research 2013) to build a composite image file that can be loaded into a PTM viewer, and allows the user to change the lighting interactively. The moving lights cast shadows in different places as they move across the surface. Effectively we are recreating the shadows the sun would cast as it moves across the surface of the stela, highlighting different aspects of the relief as it moves.

This paper demonstrates the power of technology to enhance existing archaeological records. Most of the programs used are open source and freely available on the internet, and the use of existing photographs means that the techniques described in this paper were carried out without incurring any financial cost. The results will allow the inscription to be interpreted more clearly as well as creating a high resolution orthographic record of the stela. These techniques are applicable in any situation where a large collection of photographs record surface detail. They have been used to good effect in recording and interpreting landscape features photographed from an unmanned aerial vehicle, and have potential to reconstruct historical landscapes from heritage air photographs.

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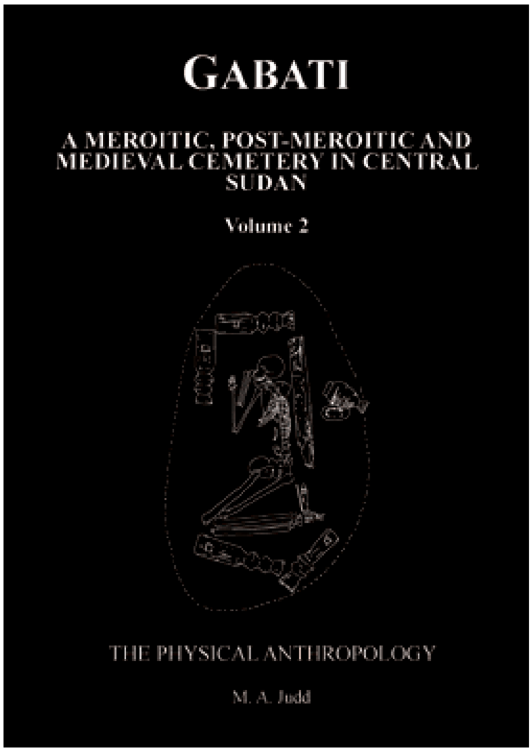
Gabati

A Meroitic, Post-Meroitic and Medieval Cemetery in Central Sudan. Vol. 2: The Physical Anthropology



by Margaret A. Judd,
with a contribution by David N. Edwards
London 2012

xii + 208 pages, 110 tables, 15 figures, 66 maps, 73 colour plates
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The cemetery at Gabati, dating from the Meroitic, post-Meroitic and Christian periods was excavated in advance of road construction in 1994-5, the detailed report being published by SARS in 1998. This complementary volume provides an in-depth analysis of the human remains. A final chapter, a contribution from David Edwards, the field director of the project, in conjunction with Judd, assesses the archaeological results in light of continuing research in the region over the last decade and more.

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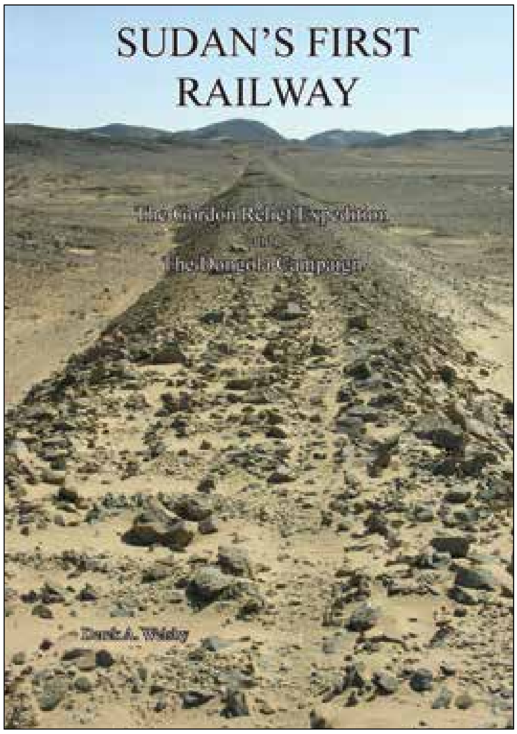
Sudan's First Railway

The Gordon Relief Expedition and The Dongola Campaign



by Derek A. Welsby

London 2011

149 pages, 6 tables, 47 figures, 173 colour and 19 b&w plates
ISBN 978 1 901169 1 89

Begun in 1875 by the Egyptian khedive, Ismail Pasha, the railway played an important role during the Gordon Relief Expedition of 1884-5 and Kitchener's Dongola Campaign in 1896. It was abandoned and cannibalised to build other railways in Sudan during the first decade of the 20th century. For much of its course it runs through the desert and in those areas the roadbed, the associated military installations and the innumerable construction camps are extremely well preserved. This book is the result of a photographic survey of these installations together with the detailed archaeological surveys undertaken within them. A report on the artefacts, which includes personal equipment, ammunition, fragments of rolling stock, bottles, tins and ceramics, completes the volume.

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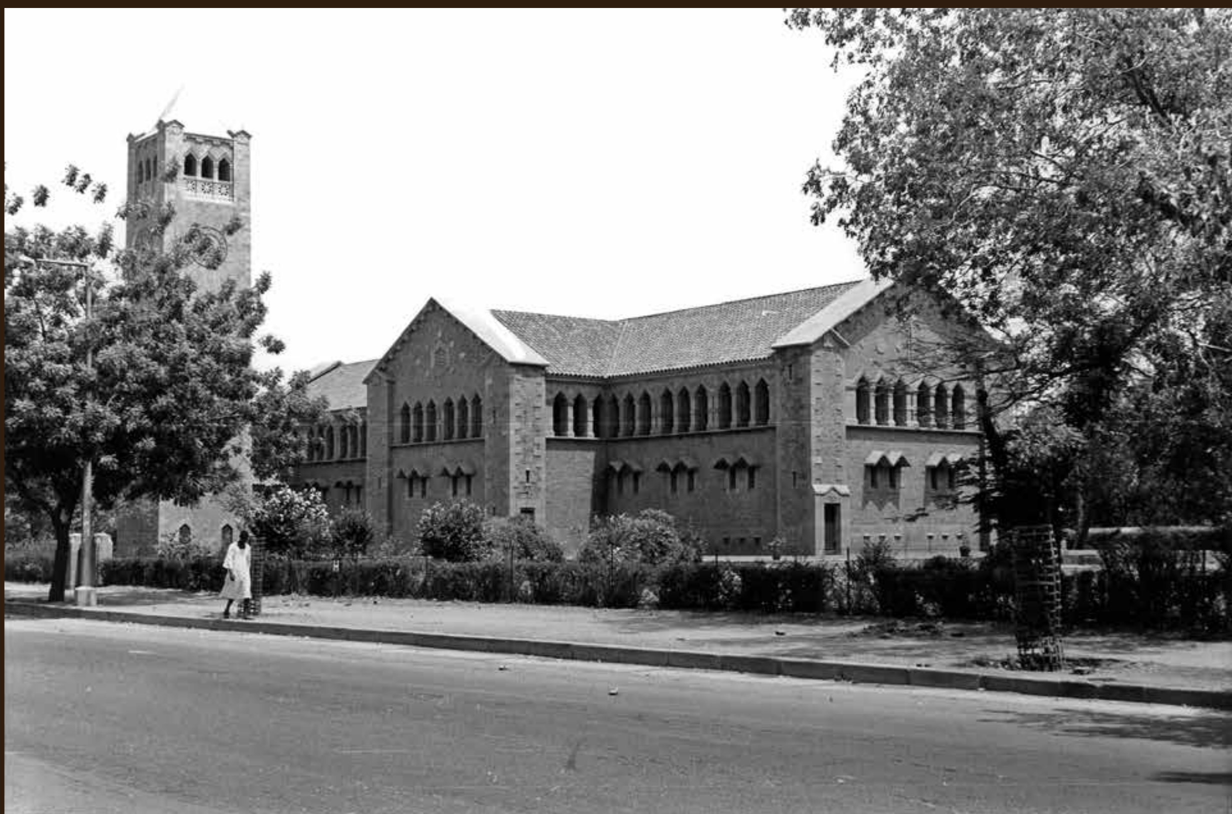
Khartoum. The Republican Palace, once the Governor General's residence, in 1968 (photo SARS Hawkes Archive HAW P091.01).



Khartoum. The Anglican cathedral in 1968. Now minus its bell tower it houses the Republican Palace Museum (photo SARS Hawkes Archive HAW P090.01).

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