# PRELIMINARY REPORT ON THE SUMMER 2012 SEASON OF THE WĀDĪ ḤAFĪR PETROGLYPH SURVEY

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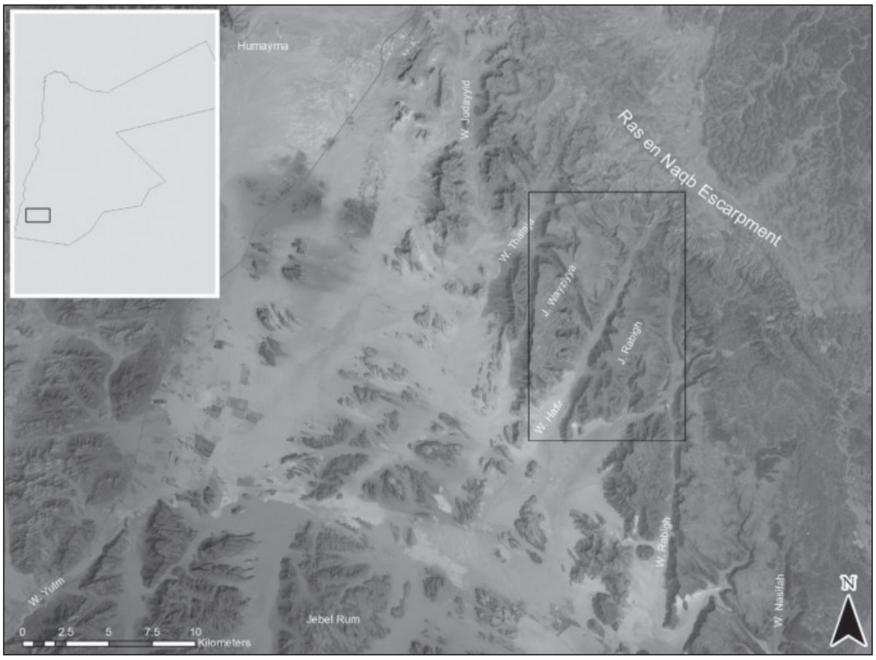
## Introduction

In the summer of 2012, the Wādī Ḥafīr Petroglyph Survey (WHPS) returned to the field for ten days (7–16 July), to photograph specific inscription and rock art sites within the Wādī Ḥafīr of the Ḥisma/ Wādī Ramm desert of southern Jordan (**Fig. 1**). The narrow, boulder-strewn Wādī Ḥafīr canyon, previously surveyed by the WHPS over a six-week period during 2005–06 (Corbett 2011), is home to thousands of inscriptions and drawings carved during various periods of Jordan's history, from the Neolithic to the late Ottoman period. Perhaps the most well-known are the so-called "Thamudic E" (or, more recently, Hismaic) carvings, which date to around 2,000 years ago, and preserve the names, short prayers, simple musings, and signed drawings of the innumerable shepherds, farmers, and traders who lived in or passed through this region.

The 2012 field season aimed to use the latest in digital photography methods and equipment to accomplish three primary objectives:

1) To provide better photographic documentation of select sites, Inscriptions, and drawings that were poorly or insufficiently photographed during the original 2005–06 campaign;
2) To evaluate the effectiveness and usability of various three-dimensional photographic methods for recording worn, abraded, and/ or faintly-carved inscriptions and drawings; and
3) To evaluate the effectiveness and usability of ultra-high-resolution panoramic Gigapan photography for documenting and analyzing select petroglyph sites and landscapes.




*1. The Northern Ḥismā of southern Jordan (with Wādī Ḥafīr highlighted).*

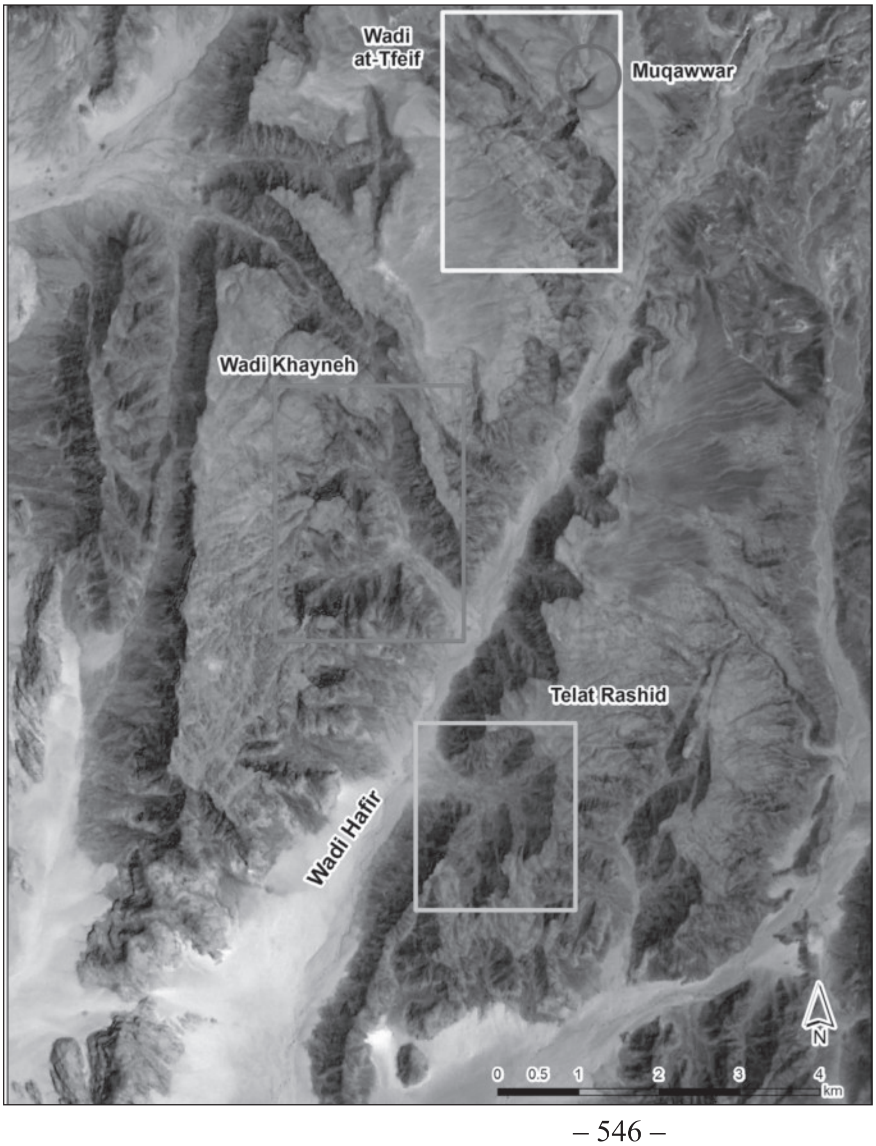
In addition, the project had the secondary objective of visiting and photographing a handful of exceptional Thamudic carving sites that had been recorded in the Ḥafīr during the earlier survey work of William Jobling (‘Aqaba-Ma‘an Archaeological and Epigraphic Survey, 1980–1990; Jobling 1983, 1985a, 1988, 1989), but had not been identified during the first season of the WHPS.

The 2012 survey focused almost all of its efforts on re-photographing individual stones and rock faces already identified by the WHPS in the three major tributaries of the Ḥafīr (Telat Rāshid, Wādī Khāyneh, Wādī at-Ṭfeif) and the seasonal cascade pools of Muqawwar located in the heights above at-Ṭfeif (**Fig. 2**), although a selection of other petroglyph-rich areas were also visited.

**Improved Photo Documentation of WHPS Sites**

The project’s first goal for 2012 was to re-photograph select Hismaic inscription and drawing sites that were poorly photographed during the first session of the WHPS in 2005–06. In these limited but often significant cases, the existing digital photographs did not capture the complete inscriptions and/or drawings in a single frame, were shot in full sun or heavy shadow, or were photographed at insufficient resolution. The poor quality of the photographs made full reading, analysis, and interpretation of the carvings unnecessarily difficult or impossible, not to mention the fact that they were often not of publication quality.

As such, the 2012 survey re-photographed approximately 100 inscription and drawing

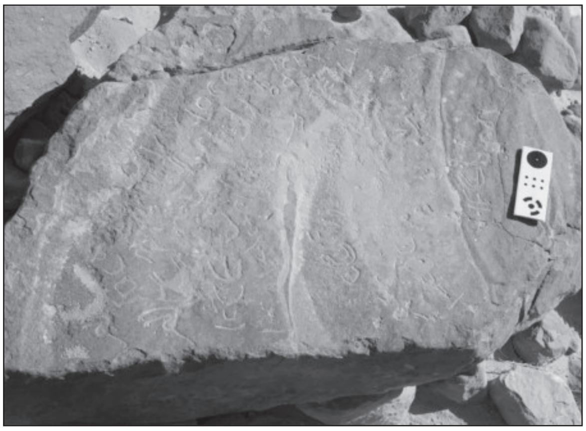



*2. The Wādī Ḥafīr, with its main tributaries highlighted.*

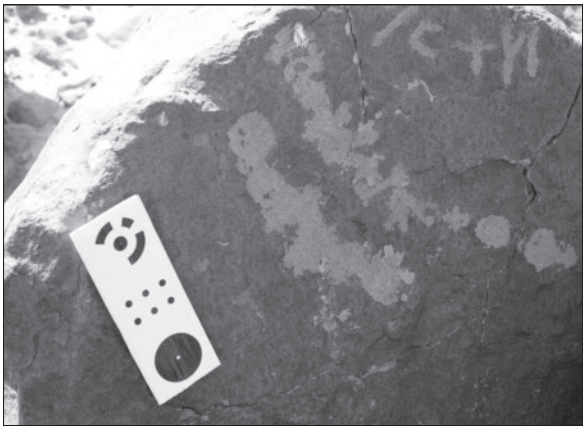
sites originally surveyed in 2005–06. In most cases, the new photographs were taken from different angles or perspectives, or with the scale or white board placed in a different location, allowing for a clearer view of the entirety of an inscribed surface. For most sites, the new photograph simply provides better visual context for the location of a carving relative to the stone surface, while in other cases, re-photographing the stone has helped clarify textual readings or even identify new inscriptions.

### Advanced Digital Photography

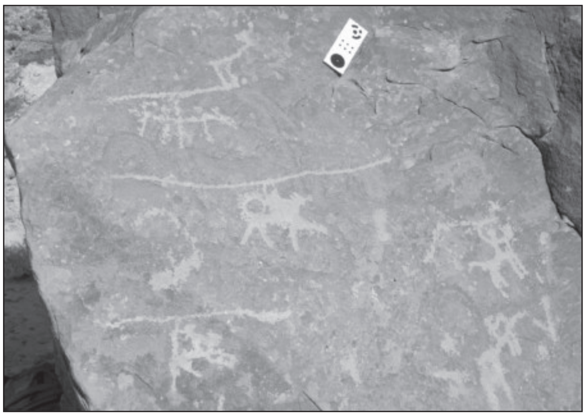
The project's second major objective was to re-photograph specific petroglyph sites, first recorded by the WHPS in 2005–06 and to evaluate the field practicality, and ultimate effectiveness, of various computational photographic methods. These methods, which are increasingly used in rock art and petroglyph studies to reveal carving elements that are difficult to discern in standard digital photographs, or are even invisible to the naked eye, help improve the contrast in images of inscriptions and drawings that have suffered various weathering processes and/or severe damage. These weathering processes, the mechanisms and typology of which have been extensively discussed in the rock art literature (Bednarik 2012; Dorn *et al.* 2008; Siegesmund *et al.* 2002), reduce readability by either effacing the carving entirely (**Fig. 3**), or should the carving be of sufficient age, producing a dark patina that makes the inscribed surface virtually indistinguishable from the undisturbed, natural stone (**Fig. 4**). In addition to natural weathering processes, ancient erasures (e.g. deliberate human attempts to disturb or "erase" texts) have made some inscriptions unreadable (**Fig. 5**). In other cases, the density and complexity of multiple carvings from various periods inscribed on the same panel can often lead to a layering effect, that itself reduces readability (**Fig. 6**).



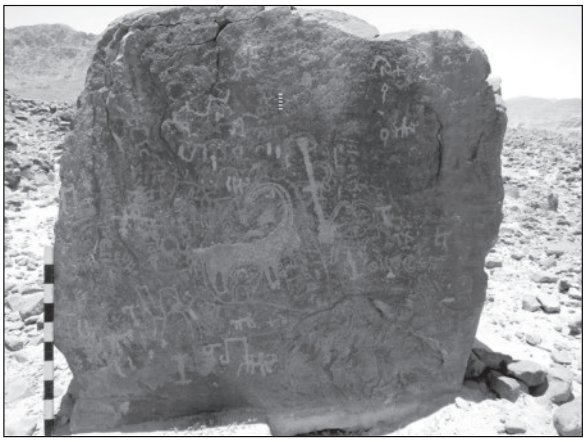
*3. An inscribed boulder that suffers from heavy weathering, obscuring the details of inscriptions and drawings.*



*5. An example of an ancient erasure, where the original text was obliterated by a later carver.*



*4. An example of a stone where old, heavily patinated glyphs disappear into the background, whereas newer glyphs are clearly visible.*



*6. A large boulder face featuring multiple layers of inscriptions, drawings, and markings carved during various periods.*

Many earlier studies (Mudge *et al.* 2012, 2006; Plets 2012; Matthews and Noble 2008; Landon and Seales 2006; Chandler *et al.* 2007; Sanz *et al.* 2010) have shown that two photographic techniques (Digital Photogrammetry and Reflectance Transformation Imaging [RTI]), can dramatically improve the reading, analysis, and interpretation of ancient inscriptions and rock drawings. In Jordan, a recent study also showed the efficacy of Photogrammetry to improve the interpretation of petroglyphs carved on basalt (Yorke and Austin 2014). In addition to RTI and Digital Photogrammetry, the 2012 survey also deployed a robotic Gigapan camera-mount to obtain high-resolution panoramic imagery (>200 megapixels) of both large rock-panels and the broader landscape context of inscribed boulder fields.

In order to test the relative effectiveness and usability of each method, specific carving sites from Wādī Ḥafīr were re-photographed, using one or more of the above mentioned techniques. Although such methods are most immediately useful for extracting better readings from the wadi's worn or faintly-carved Hismaic, Nabataean, and Kufic inscriptions, they were also applied to select examples of blackened, heavily-patinated prehistoric rock art panels, where three-dimensional models may help identify "hidden," worn, or obscured dimensions to the drawings.

*Reflectance Transformation Imaging*

RTI is a photographic technique that allows one to extract dense surface-normal information from a rock face, by taking between 16 and 60 photographs with a strobe light placed in different random but evenly distributed positions around an "invisible" hemisphere surrounding the rock face (Malzbender *et al*. 2001; Mudge *et al*. 2006). This technique is often effective for the extremely detailed recording of the incisions in the rock, as surface normal information can be provided for each pixel, which can often measure under 1 mm depending on the camera, lens, and distance to the object. The RTI files are relatively small, and can easily be viewed in the freely available RTIV iewer software. Several filters are also available to enhance faint features (Earl *et al*. 2010a, 2010b; Gabov and Bevan 2011; Bevan *et al.* 2013).

For the WHPS, however, only a few RTI captures were attempted in the field, because of problems in effectively deploying the equipment (**Fig. 7**). Large, high-powered strobe lights (Alien Bees B1600, 640 watts maximum output) were required to provide sufficient illumination to overcome the sunlight and, as a consequence, very dark neutral density filters were required to reduce the exposure time (the remote flash triggers could only synchronize under 1/400 of a second). The neutral-density filters can make camera set-up difficult, as they are almost opaque to the naked eye. Several portable batteries were also required to power the flash system. As such, the technique was found to be time consuming in the field, while another restriction was the requirement that the flash be positioned at a distance of at least 2.5 times the diagonal dimension of the rock panel. If a rock panel exceeded a diameter of 1 m or if it was too high up (above 1 m) or too low to the ground, it could not be illuminated in enough positions to produce high-quality data.

*Photogrammetry*

Photogrammetry, in contrast to RTI, seeks to keep the lighting scene of the rock face constant, but uses overlapping pairs of images (60–100% overlap) to generate a highly accurate 3D model of the surface. Recent studies have demonstrated that models generated by dense stereo matching can easily achieve sub-millimeter accuracy (Koutsoudis *et al.* 2014; Remondino *et al.* 2014) and are, as a consequence, more than adequate to record most glyphs encountered in Wādī Ḥafīr in 3D.

*7. Setting up to photograph an inscription at the Muqawwar cascades using Reflectance Transformation Imaging (RTI).*

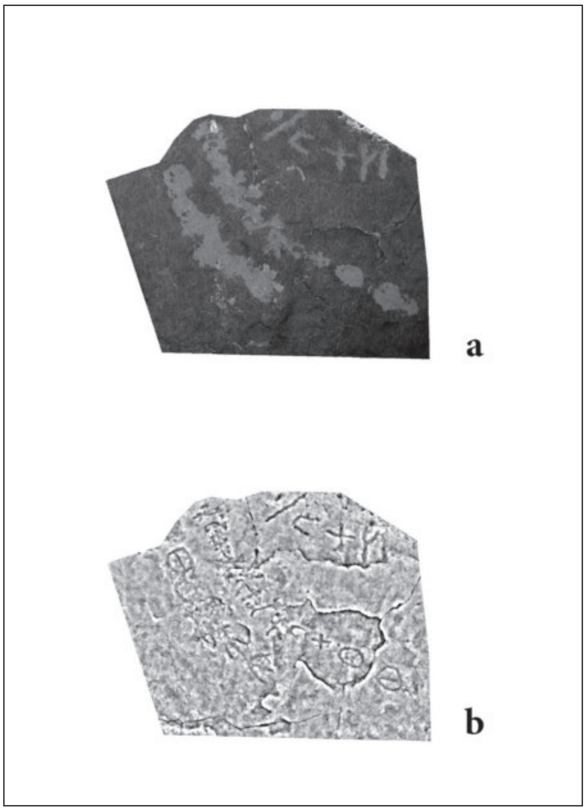
Three types of photogrammetry capture were used in the field. For areas where extremely high detail was required, strips of photos with 66% overlap were taken at close range (30–50 cm; **Fig. 8**). In cases where the entire area of interest could fit in a single camera frame, several photos were taken from several converging angles. Finally, where very detailed models were required of large rock faces, panoramic photogrammetry was employed. For the latter, the camera was fitted with a long focal-length lens (200–300 mm), and set up on a robotic Gigapan in several positions, such that the panoramas "converged" on the rock panel.

Once the photographs were processed in one of two commercial photogrammetry packages (Agisoft Photoscan or ADAMTech CalibCam), the resulting 3D models were enhanced in one of two open-source point-cloud and mesh manipulation software packages: MeshLab or CloudCompare. While good results were obtained by removing the color from the models, and either dynamically relighting the surface to bring out small details, or by applying artificial lighting models such as "radiance scaling" or "ambient occlusion," the most consistent results were achieved by "depth mapping," a technique where the stone surface is compared to a smoothed, average surface of the stone, and the difference between the actual and smooth surface is assigned a gray-scale value.

Three successful cases of depth mapping deserve discussion. WHPS 377 (**Fig. 5**) provides an excellent case, where a text that was deliberately scratched out in antiquity can be at least partially recovered. With normal digital photographs, obtaining accurate readings from such "erased" texts can be difficult, if not impossible, as the "erasures" typically obliterate the distinguishing features of individual letters, causing the text to appear as a jumbled mess with no discernible order (**Fig. 9a**). With depth mapping, however, it becomes somewhat easier to get beneath these relatively shallow scratches, to discern something of the characters of the original inscription (**Fig. 9b**). In WHPS 377, the distinguishing features of many (though certainly not all) of the individual characters are now discernible, allowing us to clearly identify this as a prayer text (Opening with the verb *ns²rt* ["may she release an ill from"]) to the goddess Allat (*'lt*), that was carved (*ẖṭṭ*) by someone whose name is still somewhat unclear (though perhaps *w'l*). In any event, depth mapping allows us to propose a plausible reading for a text that was previously completely unreadable.

A second example, WHPS 864, shows how depth mapping can help discern carvings and inscriptions that are heavily patinated and, as such, largely indistinguishable (Either in standard digital photos or with the naked eye) from the surrounding stone surface. The standard

*8. Capturing strips of photos on a large rock panel using a macro-lens.*



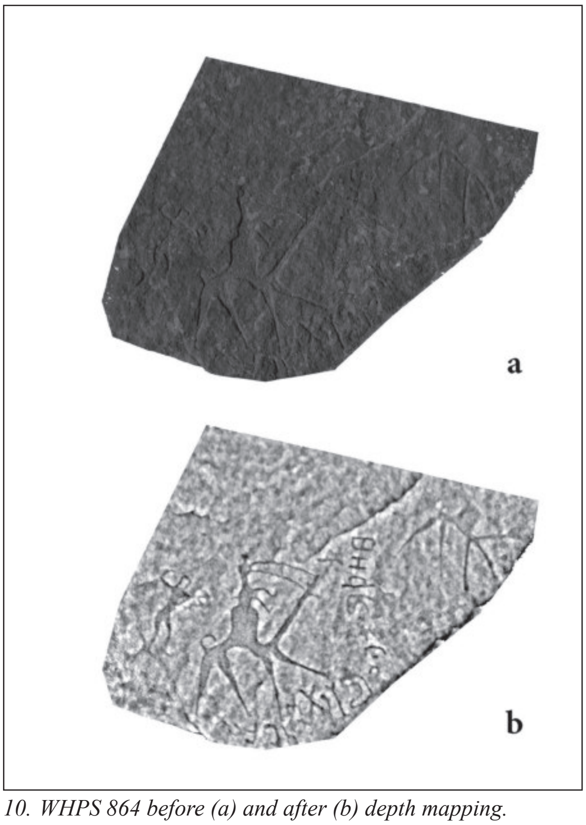
*9. Before (a) and after (b) enhancement of WHPS 377 using depth mapping.*

color image (**Fig. 10a**) allows us to see only the vague outlines of a camel and rider drawing, and perhaps the presence of an inscription, with few details of either discernible. Using depth mapping (**Fig. 10b**), however, many more aspects of this rather elegant drawing are now clearly visible (a she-camel with rider, legs outstretched, holds the camel's reigns, while a figure armed with a bow attacks both from behind) and the Hismaic inscription that signed the drawing is almost completely readable (w zdmnt bn rm'l *ḫṭṭ h-bkrt = "and zdmnt son of rm'l carved this she-camel"*).

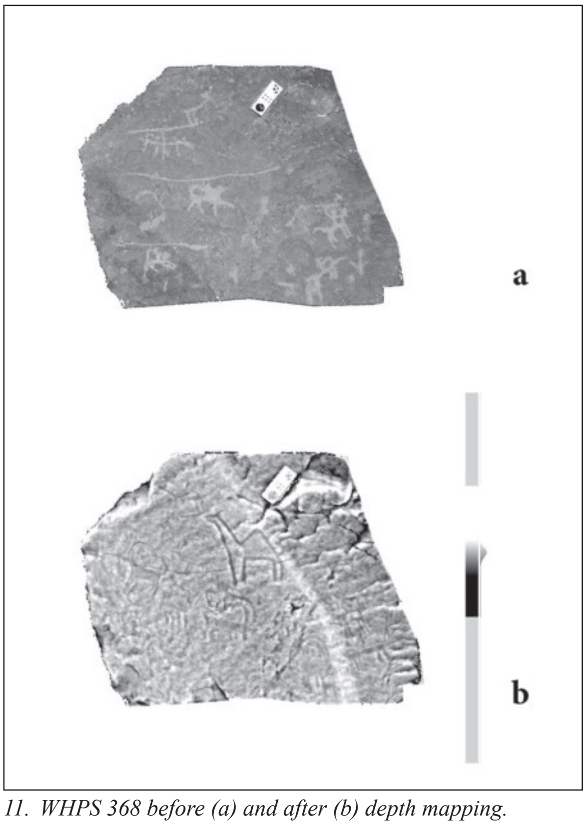
Finally, WHPS 368 presents an example of a stone where not only are earlier carvings heavily patinated, but they are also covered and hidden by drawings from a later period. In the standard color image (**Fig. 11a**), all one can clearly make out are several stylized horse and rider figures (armed with long lances) carved across the stone surface. Using depth mapping (**Fig. 11b**), however, an entire layer of earlier, more deeply carved drawings is revealed, including the bold outlines of a camel drawing and several ibex depictions. Depth mapping, therefore, allows us to capture and document an earlier stratum of drawings that would otherwise be likely to go unnoticed. This additional 3D information on the layering of the carvings can be a useful tool, alongside other established methods in rock art dating (Keyser 2001).

*High-Resolution Panoramas*

Panoramic photography positions the camera on a rotating mount, and is offset from the rotation center by a distance unique to the particular camera and lens combination. This offset, the so-called "no parallax point," ensures that there is no change in perspective as photos at different angles on the mount are taken (Littlefield 2006). To expedite this process, and to ensure that adequate overlap between photos was achieved, a robotic Gigapan head was used, that automatically captures images of an area once the upper left and bottom right corners of the panorama have been set (**Fig. 12**). This technique allows researchers to use conventional Digital SLR cameras and lenses to take extremely high-resolution photos of rock panels much more quickly and accurately than by using image mosaics (e.g., Mark and Billo 2011a, 2011b). The stitching of the individual



*10. WHPS 864 before (a) and after (b) depth mapping.*

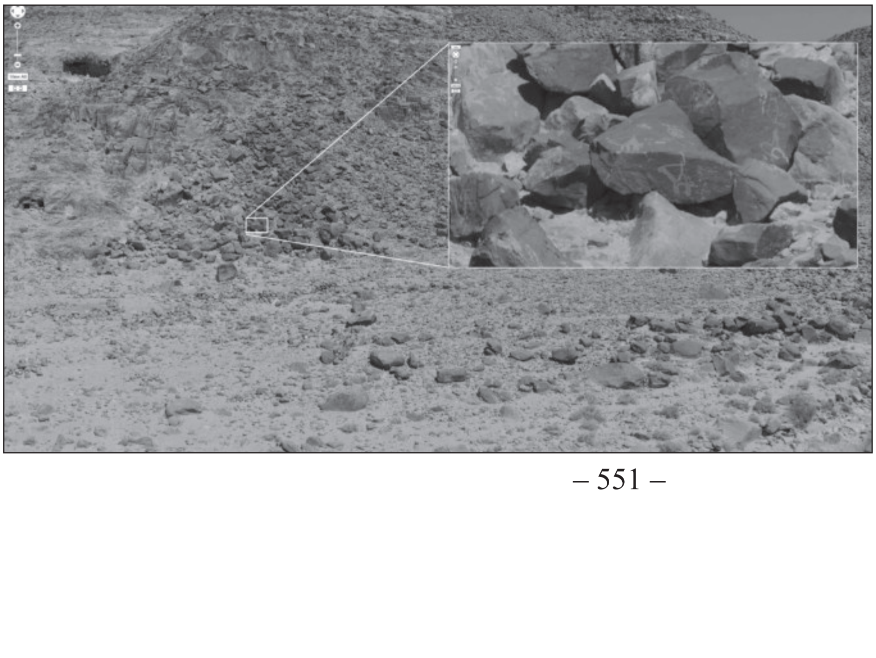


*11. WHPS 368 before (a) and after (b) depth mapping.*

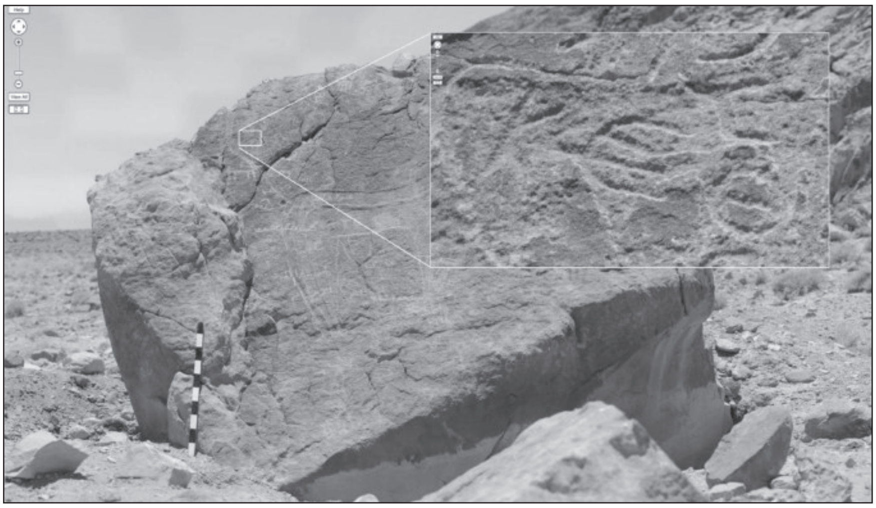
*12. Setting up the tripod-mounted Gigapan robotic head at the "Bull Stone" (WHPS 836).*

photos into panoramas was accomplished with either Gigapan Stitch or with Kolor's Autopano Giga.

In Wādī Ḥafīr, panoramic photography served three main purposes. First, by producing panoramic views of entire boulder fields at sufficiently high resolution within a single image, the technique allows individual carvings to be discerned and studied within the broader landscape context in which they are found (**Fig. 13**). This is a particularly useful technique for both documenting and visualizing the particular areas where Hismaic inscriptions and drawings tend to cluster, such as along elevated wadi banks, and at the confluences of significant wadi tributaries (Corbett 2012: 212). Second, for large densely carved boulders and rock faces, such as the so-called "Bull Stone" (WHPS 836), panoramic photography with long focal-length lenses allows the entire surface of the inscribed panel to be recorded in great detail within a single high-resolution image (**Fig. 14**), allowing for far more efficient documentation, analysis, and presentation / publication. Likewise, in many cases it would be difficult or impossible to take overlapping image mosaics of the same panels at close range. Finally, by using the ADAMTech CalibCam software, we can take the constituent images from panoramas shot at several positions around a rock panel, and build extremely detailed 3D models of the surface, thereby providing a dynamic way of viewing, analyzing, and presenting epigraphic and rock art sites. This application of panoram-



*13. Gigapan image of a boulder field in Wādī at-Tfeif, with magnified view of WHPS 691 highlighted.*



14. *High-resolution panorama image of the "Bull Stone" (WHPS 836), with magnified view of inscribed Hismaic characters.*

ic, gigapixel photogrammetry has already found useful applications in geotechnical engineering of unstable rock slopes (Lato *et al.* 2012).

**Re-Locating Sites from the AMAES**

During the 2012 season, nearly a dozen exceptional Thamudic carving sites first identified by Jobling during the AMAES were re-located and re-photographed, and their coordinates recorded with GPS. These sites, which were not located during the first season of the WHPS, were found by using the AMAES film rolls, together with the locations of Jobling sites previously identified by the WHPS, to isolate the most probable areas for discovery. In this way, several exceptional Thamudic E/Hismaic carvings first recorded by Jobling were re-identified by the WHPS, including an elaborate ibex hunt scene (WHPS 580; Jobling 1985a: 214) carved by *ḥgg* son of *bglt* (**Fig. 15**), a battle with a lion (WHPS 564; Jobling 1988: 429–431), that was drawn by *zdmnt* (**Fig. 16**), and a large boulder (WHPS 178; Jobling 1985b: 398–399) covered with many intriguing Hismaic inscriptions and drawings (**Fig. 17**).

16. *Re-located Jobling site, WHPS 564: A lion battle scene drawn by zdmnt.*

15. *Re-located Jobling site, WHPS 580: An ibex hunt scene carved by ḥgg son of bglt.*

17. *Re-located Jobling site, WHPS 178: A boulder covered with Hismaic inscriptions and drawings.*

## Conclusions

In addition to re-photographing many inscriptions and rock drawings recorded during both the first season of the WHPS and Jobling's original AMAES, the WHPS 2012 season was able to draw several important conclusions regarding the use of computational photographic techniques for epigraphic and rock art survey in Jordan. First, while RTI has impressive capabilities in a studio or museum setting, it is difficult to deploy in very remote and bright, sun-lit locations like Wādī Ḥafīr. What is more, the often poor positioning (e.g., too large, high, low) of the carved stone faces often made proper light distribution for good RTI capture impossible. Photogrammetry, by contrast, allowed for very quick capture in the field (usually not more than 10 minutes per stone) and, after photographic processing and analysis, yielded results that matched or exceeded those typically achieved with RTI. Frequently, software manipulation of the resulting 3D models using rendering tools such as radiance scaling, ambient occlusion or, more often, depth mapping, revealed features in the carvings that were virtually invisible both in digital photographs and even during thorough inspection in the field. The high-resolution panorama equipment was also very successfully employed and produced extremely dense 3D models, as well as very detailed photos that could easily be shared online.

Our experience in 2012 has also led to several recommendations for future epigraphic and rock art surveys employing such photographic methods. First, the volume of data collected from three DSLR cameras in the field was immense (over 15,000 photos). Organizing the images and processing the resulting 3D data, from even a relatively short survey like our 10-day season, has been very time consuming. While handheld GPS was used to locate the position of each stone, in the future we will routinely employ geotaggers on all cameras, to record the position of the photos as well as their direction, using a built-in triple-axis compass. This metadata will allow us to plot the location of all the photos within a Geographic Information System (GIS), thereby allowing image sets to be quickly retrieved and analyzed, while also providing a much better overall picture of what areas of the wadi have (and have not) been documented. Finally, the latest generation of DSLR cameras offers three times the number of megapixels (36 *vs.* 12) as the cameras used in 2012. As such, we could now produce models virtually the same as were achieved in 2012, but with only a third of the photographs taken.

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