CAA
2017

http://dx.doi.org/10.15496/publikation-43225

Accessing the Inaccessible: Detailed 'Off-Site' Archaeological Survey Using Satellite Imagery and GIS at the Hatnub Travertine Quarries, Egypt

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Abstract

Archaeological sites, trails, and roads are traced using satellite remote-sensing, but landscape archaeology often requires detailed survey of much smaller features. At the Hatnub travertine quarries in the Egyptian desert, an 'off-site' survey of small diffuse archaeological features was undertaken using high-resolution, pan-sharpened satellite imagery with contrast stretching in obscured areas. Comparison with recent field survey data demonstrated that this remote-survey process was fast, reliable, and generally accurate, with a 93% success rate identifying known features, and false positives estimated at 13%. The resulting digital plans provide an accurate initial record of an imperilled landscape at a level of detail that has not previously been attempted using remotely sensed data. This ensures that future ground-truthing and investigatory fieldwork is targeted at the most important remains and can be combined with mobile recording techniques that modify the remote sensing, survey data during 'on-site' fieldwork.

Keywords: GIS, remote-sensing, survey, satellite imagery, Egypt, mobile-GIS

Introduction

Archaeological investigations of landscape and 'non-site' archaeology have been widely established as a means of answering local and regional research questions and contributing to debates about settlement distribution, transport, and resource procurement (For recent examples see papers in Burgers, Kluiving and Hermans 2016; Campana, Forte and Luizza 2010; David and Thomas 2008). This research depends upon the existence of consistent information concerning sites, anthropogenic features (including archaeological features of all periods and other human interventions in the landscape) and historical traces across the locality or region that is under investigation.

In countries like Egypt, where local or national databases of archaeological remains are non-existent, difficult to access or still in development, or where the nature of the archaeological record predisposes excavators to focus upon certain sites or types of site, it can be difficult to obtain the necessary landscape data to undertake regional archaeological research (Fradley and Sheldrick 2017: 796; Tassie and Hassan 2009; Weeks 2008: 18-19; Wendrich 2010). This places concomitant restrictions upon landscape archaeology and regional analyses in the country (Abu-Jaber et al. 2009: 3; Jeffreys 2010: 106-108; Parcak 2008). This issue, together with the ongoing threat to archaeological remains, has prompted many archaeologists and Egyptologists to begin recording anthropogenic features at the local and regional level using traditional epigraphic and archaeological surveying techniques (see for example Bloxam et al. 2014; Darnell 2013; Darnell and Darnell 2013; Förster and Riemer 2013 ; Förster 2015; Heldal 2009; Heldal et al. 2009; Kelany et al. 2009; Kemp and Garfi 1993; Riemer 2013; Rossi and Ikram 2013; Shaw 2006; 2010; Wilson and Grigoropoulos 2009).

The extent and quantity of archaeological remains that can be recorded using these methods is limited by the length of the fieldwork, the resources of the project, and the size of the concession within which it has permission to work.

Archaeologists working on Egyptian landscapes have been making use of satellite imagery since the 1980s (El-Baz 1984; Wendorf, Close, and Schild 1987). Although these methods were initially limited by the resolution of the imagery (Bubenzer and Bolton 2013: 72-3), more recent work has made use of increasingly high resolution satellite imagery to locate and monitor archaeological sites (Mumford and Parcak 2002; Parcak 2007; 2010; Parcak et al. 2016), record roads (De Laet et al. 2015), and larger anthropogenic features (Ejsmond, Chyla, and Baka 2015; Ejsmond et al. 2015: 619).

This research has repeatedly demonstrated that the resolution of the satellite imagery is of greater importance in the identification of small archaeological features than its multi-spectral component (Bubenzer and Bolton 2013: 66; De Laet et al. 2015: 293-5; Dore and McElroy 2011: 15) and that pan-sharpened imagery is preferable to individual multi-spectral bands because it is higher resolution (De Laet et al. 2015: 289). Research has also shown visual inspection to be more effective in the identification of smaller archaeological features than automatic processing (Dore and McElroy 2011: 16).

With the increasing availability of very high (sub 0.5 m) resolution satellite imagery, it is now cost-effective to record in detail far smaller archaeological features than was previously possible, using remotely-sensed satellite imagery in Geographic Information System (GIS) software. This type of 'remote-survey' should prove substantially faster than 'on-site' field survey and enable subsequent fieldwork to focus upon targeted 'ground-truthing' and the investigation of questionable or interesting features identified during the survey.

This paper describes the methods used in the initial 'off-site' remote-survey of 100 km^2 of the Hatnub desert quarrying landscape using Worldview-3 high resolution (0.4 m) pan-sharpened satellite imagery in ArcGIS 10.4, and assesses the accuracy of the remote-survey in comparison to field survey records of the same area made by Shaw (2010).

The Hatnub Travertine Quarries

The travertine (or 'Egyptian alabaster') quarrying region at Hatnub was the pre-eminent ancient source of that highly prized translucent white stone (Harris 1961: 77). The quarries are located 17 km from the Nile river, southeast of the site of Amarna in Middle Egypt (Figure 1) and were rediscovered in 1891 by Howard Carter and Percy Newbery (Shaw 2010: 3-5). The inscriptions in the three main quarries (named P, T, and R) were first published in Blackden and Fraser (1892) and the definitive publication of the Hatnub texts was undertaken by Anthes (1928), although recent epigraphic work in Quarry P suggests that more is to be found (Enmarch 2015; Gourdon 2014).

The three main quarries and the road leading to them were recorded in Petrie's (1894 3-4: pl. 34) and Timme's (1917: 34-47: pl. 1-8) plans of the nearby site of Amarna, but both of these maps were small in scale and neither researcher made any attempt to comprehensively record individual archaeological features. Harrell (2001) recorded the quarries at the north end of the Amarna plain (Figure 1), but did not extend his survey further south. The most extensively investigated area is the concentration of tracks, huts, shelters, windbreaks and cairns around Quarry P, 890 m^2 of which was surveyed by Shaw (2010) between 1985 and 1994. This was an exhaustive survey, which produced detailed plans, but Shaw was only able to record a small fraction of the landscape. A short visit to the site or cursory review of satellite imagery shows that the tracks, shelters, and cairns extend over at least 100 km^2 in a diffuse pattern around all the travertine quarries and along the c. 17 km road between them and the Nile valley (Figure 1).

The Hatnub landscape and its many unrecorded quarries, hut-clusters, trails, paths, cairns, and shrines forms what has been called a 'quarry complex' (Bloxam 2011: 152). The study of this complex has the potential to reveal new logistical, practical, and cultural aspects of quarrying and to contribute to international debates about the procurement of resources and the role of peripheral landscapes in ancient societies. To address these complex archaeological questions and undertake detailed analysis, it is necessary to first record all the visible archaeological features across the entire 100 km^2 study area.

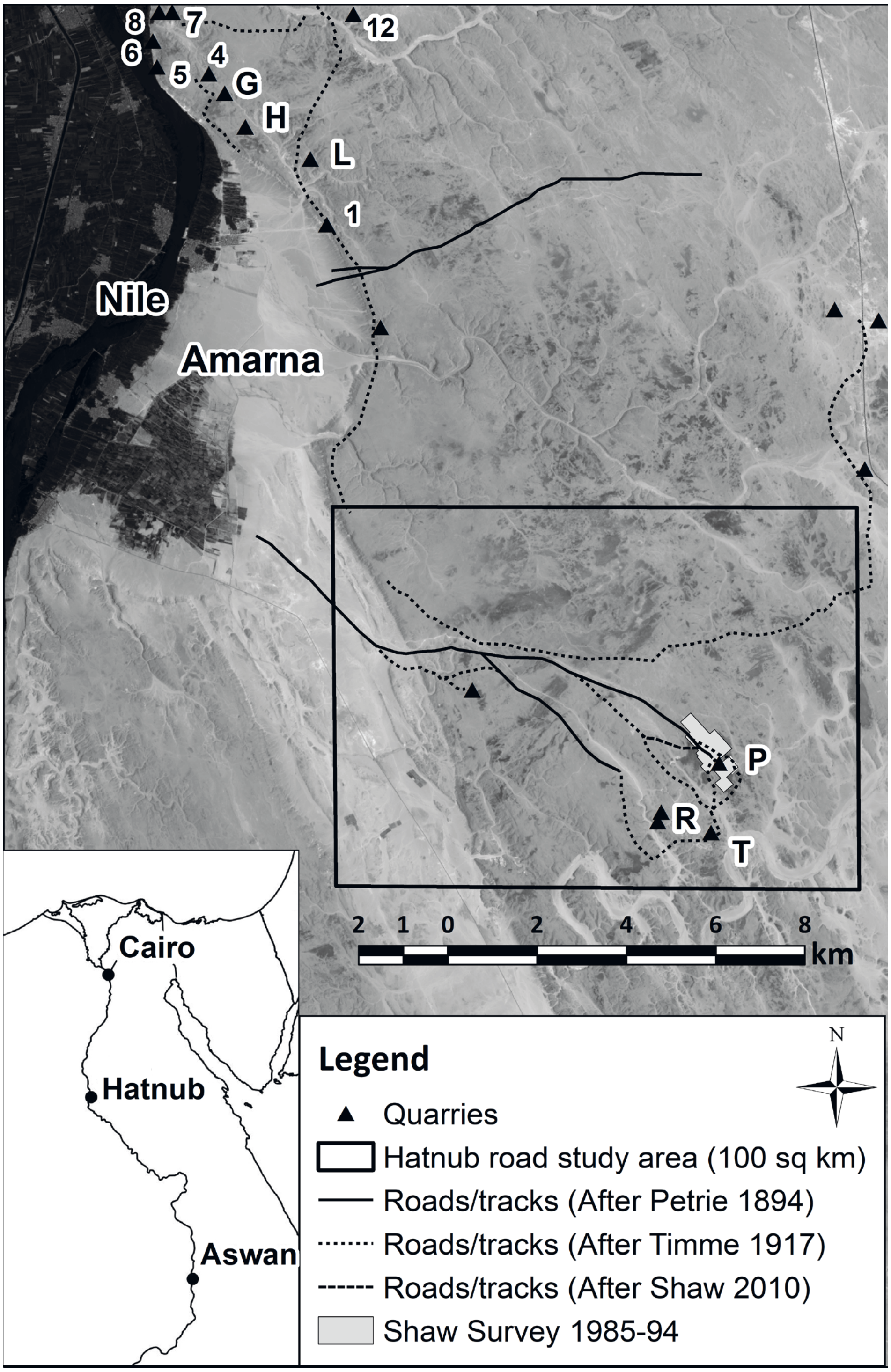


Figure 1. The location of the Hatnub travertine quarries, Quarry P, the 100 km^2 study area and the area surveyed by Shaw (2010) in 1985-94. Lettered quarries were recorded by Petrie (1894) and numbered quarries by Harrell (2001) (Underlying Landsat 8 data from the United States Geological Survey).

Methods and Materials

The Hatnub landscape comprises an open desert, with limited rainfall and almost no vegetation, but a large number of small, diffuse archaeological features. Modern activity is restricted to certain specific quarrying areas. This makes it an ideal landscape to test the use of detailed 'off-site' archaeological survey using high-resolution satellite imagery. Naturally in other countries or regions with different ecological and geomorphological attributes, alternative techniques would be required to record archaeological remains obscured by cloud, vegetation (whether natural or agricultural), or modern structures.

Materials

Google Earth was used initially to confirm the visibility of small archaeological features across the Hatnub landscape before any commercial satellite imagery was purchased or archaeological features recorded. A number of issues with Google Earth and other freely available satellite imagery make it unsuitable for this large-scale, detailed, archaeological survey. Some freely available satellite imagery (such as Landsat and similar data available from the United States Geological Survey) is of medium or low resolution (i.e. no greater than 10-15 m) and the small (typically 1-5 m) archaeological features at Hatnub would not be visible in it. While other higher resolution free satellite imagery (such as Google Earth, Bing Maps, and other similar providers) comes with restrictions on the processing or availability of specific images. Although these issues may not be prohibitive or can be overcome under certain circumstances, the most significant problem with free high-resolution satellite imagery is its often poor geolocation and the tendency for imagery to shift location over time (Parcak 2009: 363; Pedersén 2012: 388). This clearly makes even high-resolution, free satellite imagery unsuitable for the very precise and accurate large-scale survey of small archaeological features that is at the heart of this project.

This project used a 4-band, pan-sharpened 0.4 m resolution satellite image created from blue, green, red and near infra-red 1 multi-spectral bands pan-sharpened with the panchromatic band of the DigitalGlobe Worldview-3 satellite (DigitalGlobe 2017) image recorded on 9 June 2016. The four multi-spectral bands have a sensor resolution of 1.24-1.38 m (ground sample distance) and the panchromatic band has a 0.31-0.36 m sensor resolution (European Space Imaging 2014: 38). The pan-sharpening used an enhanced resampling kernel and the image was radiometrically-corrected, sensor-corrected (European Space Imaging: 24), and orthorectified using a 4 m resolution digital surface model (DSM) created from stereo-pair Worldview-3 imagery of the same area. It was not possible to georeference the Worldview-3 image with ground control points, as these were not available at the time. European Space Imaging (European Space Imaging 2014: 24) calculates that when orthorectified with SRTM data, which now has a resolution of c. 30 m (USGS n.d.), this type of Worldview-3 product has an accuracy of 6.6 m RMSE. Since the satellite image used in this project was orthorectified using a 4 m stereo-pair DSM, it should be better than 6.6 m RMSE, although currently it is not possible to calculate the precise error. The 100 km^2 Worldview-3 image purchased from European Space Imaging will not only provide consistent geolocation of the surveyed archaeological features but is also the most accurate source of geolocational data available to the project at present.

Survey Method

During the remote-survey the archaeological features were located using visual inspection of pan-sharpened Worldview-3 0.4 m resolution satellite imagery in ArcGIS 10.4 software. Prior to visual inspection, a 100 m^2 survey grid was overlaid on the 100 km^2 Worldview-3 image using the ‘Create Fishnet’ tool in ArcGIS 10.4 in order to provide a systematic grid for visual inspection and provide the basis for future sampling. A ‘Surveyed’ field was added to the grid attribute table. Upon completion of the visual inspection of a grid-square the ‘Surveyed’ attribute of that grid square was changed from ‘Null’ to ‘Yes’, tracking the progress of the research.

Archaeological features located in the Worldview-3 imagery by visual inspection were digitised as vector polygons and points or lines. Each contiguous polygon feature (such as a wall) was digitised separately as a vector polygon with a unique number. These polygons were grouped into archaeologically meaningful structures (such as huts, shelters or cairns) and recorded as point data with unique numbers. Long linear features (such as roads and tracks) were recorded in a separate vector line layer with unique numbers. Point, line, and polygon features were cross-referenced by their unique numbers where structures or lines were composed of multiple individual polygon features.

The archaeological features represented by point and line data were classified following a modified version of the method used by the Quarryscapes Project (Bloxam and Heldal 2008: 20-21), recorded in the attribute table of each point and line layer. This en-

Element	Feature Type	Feature Subtype
Resource	**Rock**	
	Commodity	
	Occurence	
Production	**Quarry morphology**	
	Quarry face	
	Quarry	Quarry
	Tool marks	
	Tools	
	Spoil	Spoil heap
	Work areas	Work areas
	Objects and object blanks	
Logistics	**Road**	Road
		Causeway
		Ramp
	Slipway	
	Track	Track
	Path	Footpath
	Stockpile	
	Harbours	
	Vehicle Track	Vehicle Track
	Stone feature	Cairn
		Alam
		Dam
	Carved feature	Petroglyph
Social infrastructure	**Stone built feature**	Windbreak
		Shelter
		Hut
		Hut (x room)
		Four poster
		Shrine
		Cairn
		Quarry P settlement
		Wall
	Ceramics	
	Epigraphics	
	Wells	Well
	Faunal/floral remains	
	Domestic artifacts	
	Blank Area	Tent circle

Table 1. Elements, feature types, and feature subtypes, used in the remote-survey. Quarryscapes categories (Bloxam and Heldal 2008: 20-21) are shown in bold and additions for the Hatnub Road remote-survey in normal type. Empty cells in the ‚Feature Subtype' column indicate that the Quarryscapes feature type was not used to date, but could be brought into use during subsequent phases.

sured that subsequent analysis was compatible with the Quarryscapes landscape characterisation in case of any future comparison. During the remote-survey it became necessary to make some additions to the Quarryscapes characterisation and add an additional 'Feature subtype' field to allow the remote-surveyor to make more specific observations about the shape of the structures and ensure all the information available in the satellite imagery was included in the attribute data. The hierarchy of 'Element', 'Feature Type', and 'Feature Subtype' categories used in the classification is shown in Table 1.

The attribute tables of the archaeological structures in the point and line layers also included an 'Uncertain' field, where the remote-surveyor recorded if they were uncertain about whether a feature was anthropogenic or natural. This system of data and attribute management made it possible to record all the information that was available in the satellite imagery in a flexible way that recognised uncertainty in the identification and interpretation of the features. All anthropogenic features visible in the satellite image were recorded using this system, except for clearly modern vehicular tracks.

Assessing the Accuracy of the Remote-Survey

To determine if remote-survey could substantially supplement or partially replace field survey it is necessary to determine how accurately it records anthropogenic features by comparing the features recorded in the satellite imagery to those present on the ground, a process known as 'ground-check' or 'ground-truthing' (Bubenzer and Bolton 2013; De Laet et al. 2015). This is an important part of the process of determining the accuracy of remote- survey in general and of the ongoing evolution of definitive method-

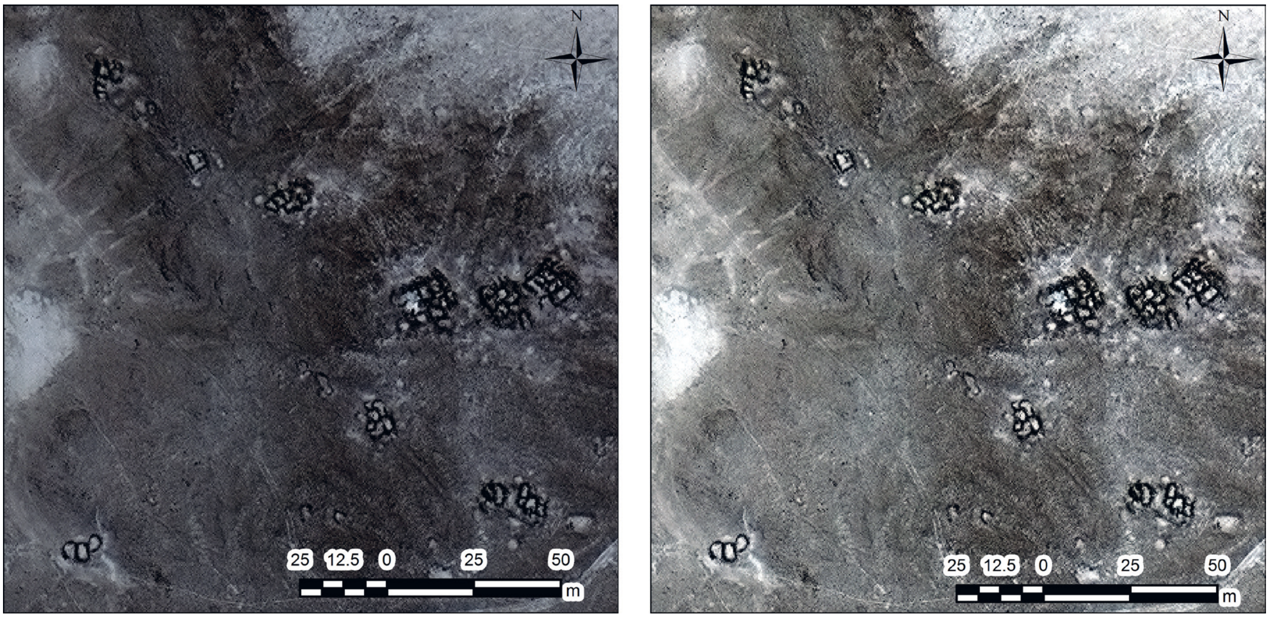


Figure 2. The effect of contrast stretching upon a darker area of the desert surface. Prior to contrast stretching (left) archaeological features are partly obscured. After contrast stretching (right) the archaeological features are clearly visible (Worldview-3 imagery © 2016 DigitalGlobe Inc supplied by European Space Imaging. Reproduced with permission).

ologies for archaeological remote-sensing (Parcak 2008: 67; Parcak 2009: 362).

In this project the accuracy of the remote-survey was assessed by comparison with extant data from Shaw's (2010) previous fieldwork on the site. To undertake this comparison Shaw's (2010: fig 3.1, fig 3.8, fig 3.12, fig 3.14, fig 3.16, fig 3.19, fig 3.21, fig 3.22 and fig 3.28) published plans were georeferenced and incorporated into the GIS as a layer. The archaeological features recorded in these plans were identified as far as possible in the remote-survey data and the feature numbers they had been given by Shaw were added to the attributes of the relevant points and lines in the remote-survey data. This made it possible to directly compare the results of the remote-survey with the field survey data and make an initial assessment of the accuracy of the remote-survey prior to further 'ground-truthing' fieldwork.

In accordance with current practices for assessing the accuracy of remote-sensing research (Dore and McElroy 2011: 16–17; Parcak 2007: 75), it was important to provide a numerical measure of the accuracy of the remote-survey when compared to the Shaw (2010) survey data. The results section includes the percentage of archaeological features recorded by the remote-survey that were also present in the Shaw (2010) survey data, as well as the percentages of false negatives (i.e., real archaeological features which were not found during the remote-survey) and false positives (i.e., features recorded in the remote survey which are not in fact archaeological). It should be noted that the calculation of false positives and negatives depends upon the accuracy of Shaw's fieldwork. It is possible that a feature recorded in the remote-survey will be classified here as a false positive if it was not recorded by Shaw (2010), only for subsequent ground-truthing to find that it is a real archaeological feature. This potential issue will be discussed further in the results section.

Results

This research project demonstrated that the method of remote-survey presented here is effective for the identification of small (greater than c. 1 m diameter) archaeological features across an open desert landscape, such as the Hatnub quarrying area. General observations on the method are presented below, followed by a direct comparison between the results of the remote-survey and an earlier on-site archaeological survey of 890 m^2 of the same landscape, undertaken by Shaw (2010) between 1985 and 1994.

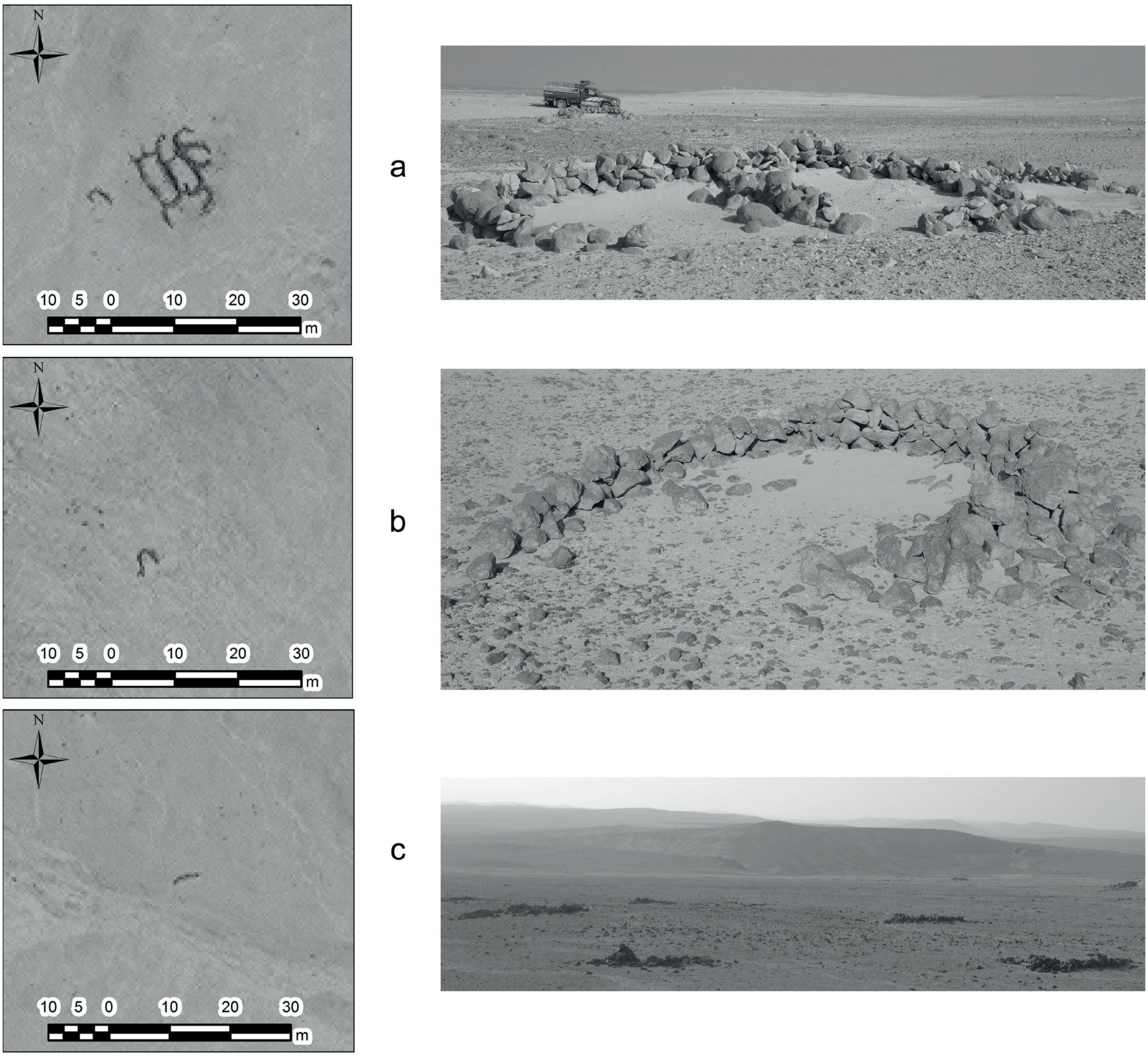


Figure 3. Types of habitations visible in the satellite imagery (left) and on the ground (right). (a) hut, (b) shelter, (c) windbreak (Worldview-3 imagery © 2016 DigitalGlobe Inc. supplied by European Space Imaging. Photos: Roland Enmarch. Reproduced with permission).

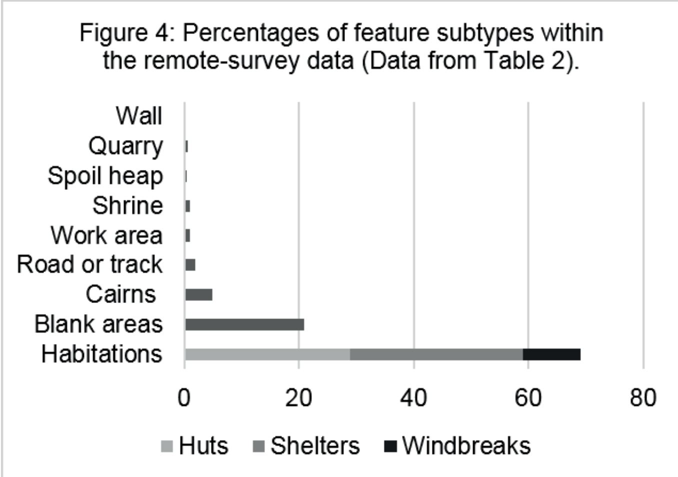
General Observations

The Hatnub desert surface is divided into two different types. In some areas weathering has eroded the natural limestone strata, leaving a dark stony surface that is known as 'hamada' in Arabic (Bubenzer and Bolton 2013: 71), interrupted by larger limestone outcrops. Other strata present a lighter surface colour and have a much softer, friable texture when exposed by weathering.

The initial review of the landscape using Google Earth imagery and subsequent analysis of the Worldview-3 image demonstrated that archaeological features appear clearly across both the dark and lighter parts of the desert surface because they inevitably present a discontinuity in it. Upstanding archaeological features are generally constructed from the dark weathered limestone pieces that cover the darker areas of the desert surface. They appear very clearly against the lighter-coloured areas and, despite being constructed of the same material, can be distinguished from the darker stony surface by the intensity of their colour and by drifts of lighter sand against the upstanding walls. Negative features (such

Feature subtype	Features	
	No	%
Huts	236	29
Shelters	244	30
Windbreaks	85	10
Blank areas	170	21
Cairns and alam	37	5
Road or track	20	2
Work area	9	1.1
Shrine	9	1.1
Spoil heap	3	0.4
Quarry	6	0.7
Wall	1	0.1
Total	820	100

Table 2. The 820 remotely-surveyed structures within Shaw's (2010) survey area, broken down by feature subtype.



	Structures	Roads, tracks, paths	Within destroyed 'Quarry P settlement south'	Total
Number recorded by Shaw	390	10	29	429
Number recorded by remote-survey	379	10	9	398
% of Shaw's features recorded by remote-survey	97	100	31	93

Table 3. Comparison of features recorded by Shaw (2010) and the remote-survey showing the percentage of Shaw's features that were accurately identified by the remote-survey.

as wells or pits) can be identified by the discontinuity they create in the desert surface and drifts of fine sand in the resulting depressions.

No additional enhancement was necessary beyond contrast stretching ('Lillesand, Kiefer, and Chipman, 2004: 492-499), which was also effective in the identification of Egyptian desert trails at Deir el Bersha (De Laet et al. 2015: 292). Figure 2 shows the effect of contrast stretching on the visibility of archaeological features in darker areas of the desert surface.

During his archaeological survey Shaw (2010: 40-48) noted that the habitations around Quarry P can be divided into three different types. The remote-survey revealed that these three types are also clearly visible in the satellite imagery (Figure 3):

a. 'Huts' include any feature with a full circuit of walls broken only by a small entrance, and any feature with more than one room. Where more than one room was present the number of rooms was recorded during the remote-survey.

b. 'Shelters' were less substantially built than 'huts' and were typically U-shaped. The central part of the U was usually lighter in colour than the surrounding desert, where stones had been cleared and sand had gathered. This assisted in distinguishing shelters from natural curving outcrops in the satellite imagery.

c. 'Windbreaks' were the most ephemeral of all, being little more than a single, slightly curving or sinuous low wall offering protection from the prevailing wind. Like the shelters the area inside the wall was usually lighter in colour than the surrounding desert.

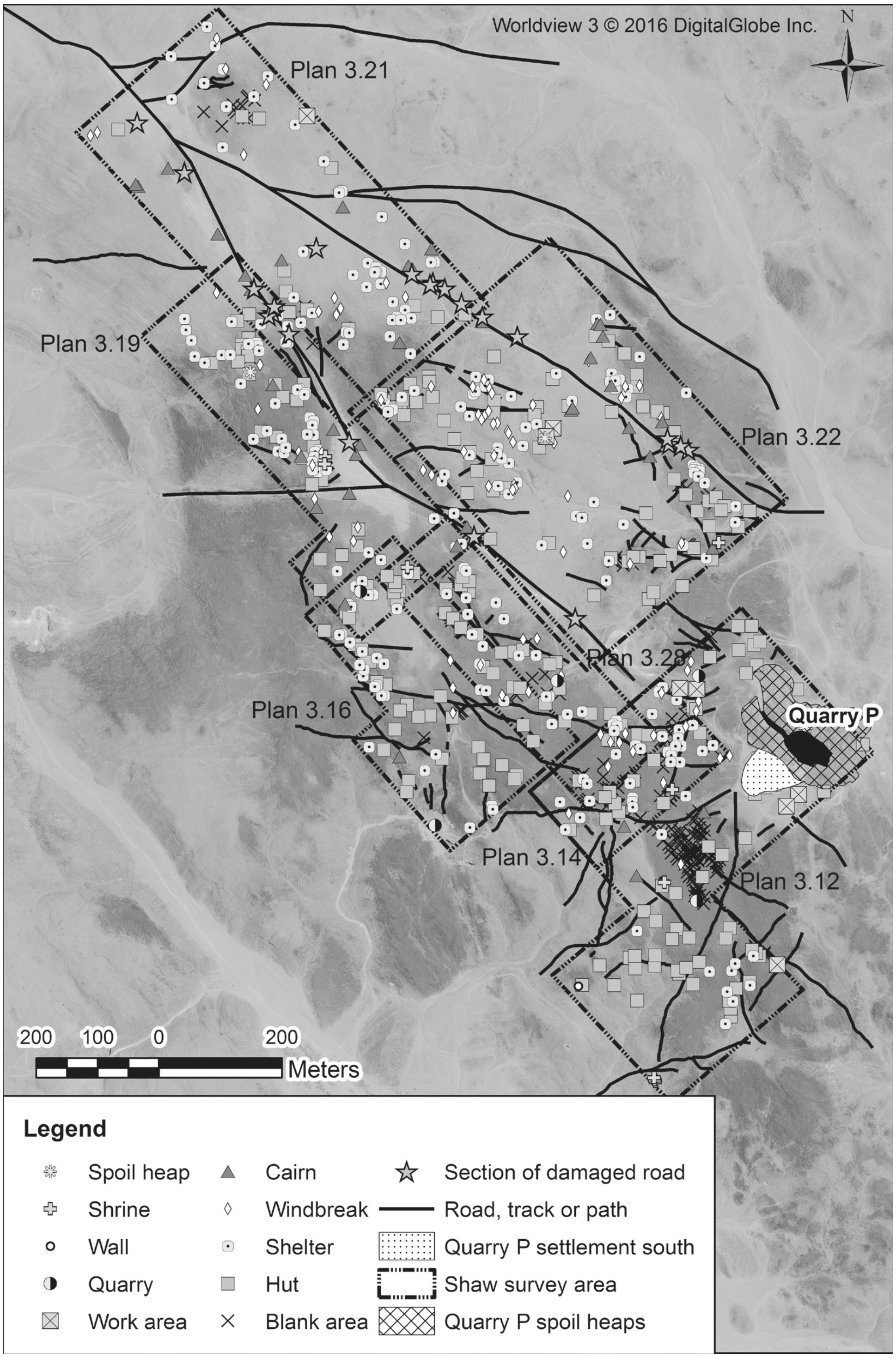


Figure 5. Distribution of archaeological features by feature subtype as recorded by the remote-survey, across the area originally surveyed by Shaw (2010) (Worldview-3 imagery © 2016 DigitalGlobe Inc. supplied by European Space Imaging. Reproduced with permission).

Comparison Between the Remote-Survey and Shaw's Survey Data

It took 20 days to prepare and remotely survey the 890 m^2 area originally surveyed by Shaw (2010) between 1985 and 1994. During these 20 days 820 structures and 125 roads, tracks, and paths were surveyed (Figure 4, Table 2, Figure 5).

To provide a numerical calculation of the accuracy of the remote-survey, the percentage of archaeological features found by the remote survey that were also present in the Shaw (2010) survey data was calculated, as well as the percentage of false negatives and false positives.

False Negatives in the Remote Survey | Table 3

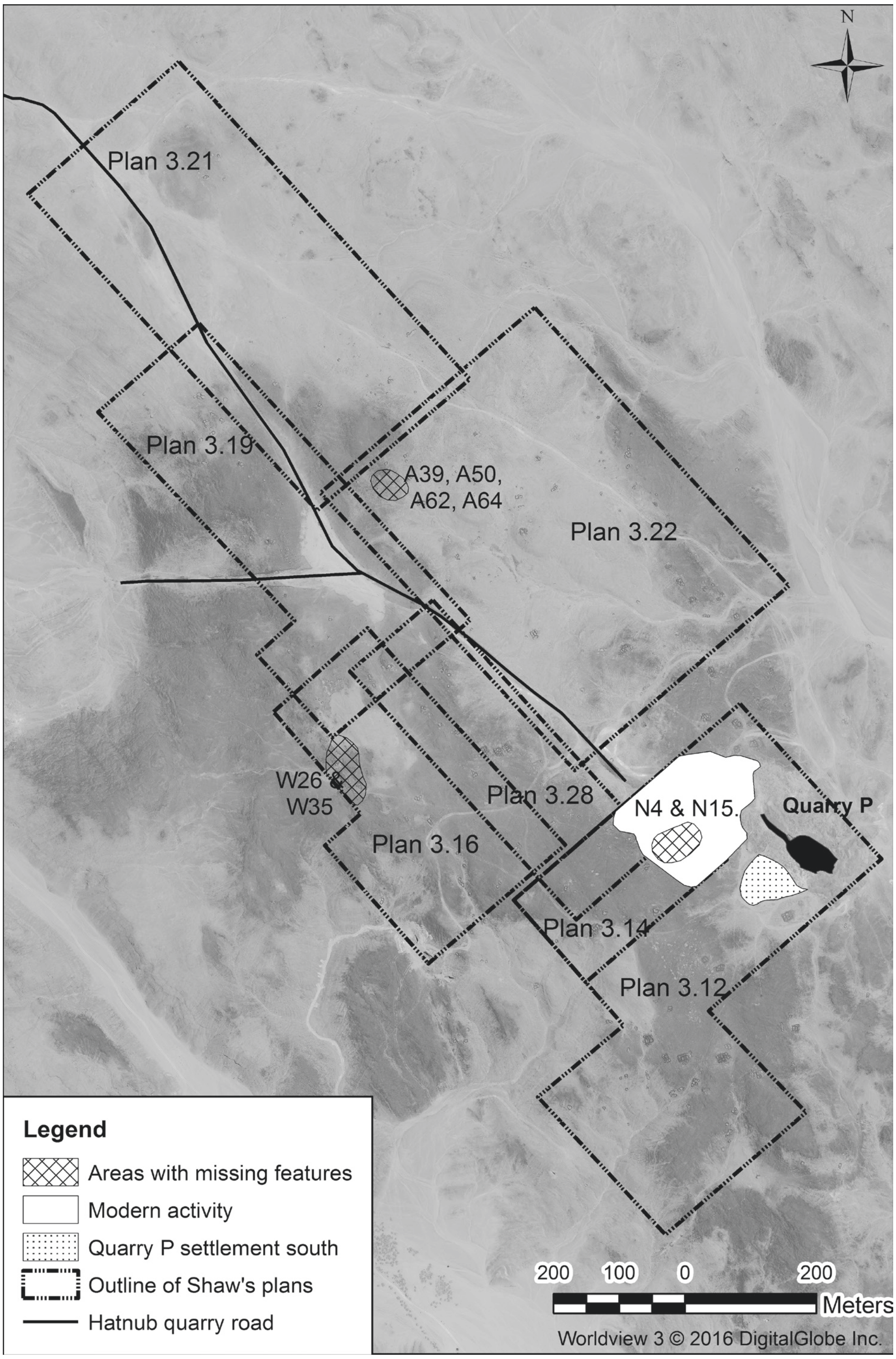


Figure 6. The area surveyed by Shaw (2010) showing where features recorded by him are missing from the remote-survey at the edges of his plans 3.22 and 3.16 and in the area of modern disturbance immediately west of Quarry P. (World-view-3 imagery © 2016 DigitalGlobe Inc. supplied by European Space Imaging. Reproduced with permission).

compares the numbers of structures recorded by Shaw (2010) with the remote survey data to determine the efficacy of the remote-survey in identifying archaeological structures already known from Shaw's survey. Overall the remote-survey was very effective, finding 93% of the features recorded by Shaw and producing a very low number (7%) of false negatives.

The poorest result in terms of false negatives (features recorded by Shaw (2010) that were not located during the remote-survey) came from the dense concentration of settlement adjacent to the south side of Quarry P ('Quarry P settlement south' in Table 3 and Figure 6), where extensive modern activity around Quarry P has left this area almost entirely unintelligible since Shaw (2010) completed his research in 1994. If the 'Quarry P settlement south' is excluded from the data, the remote-survey produced false neg-

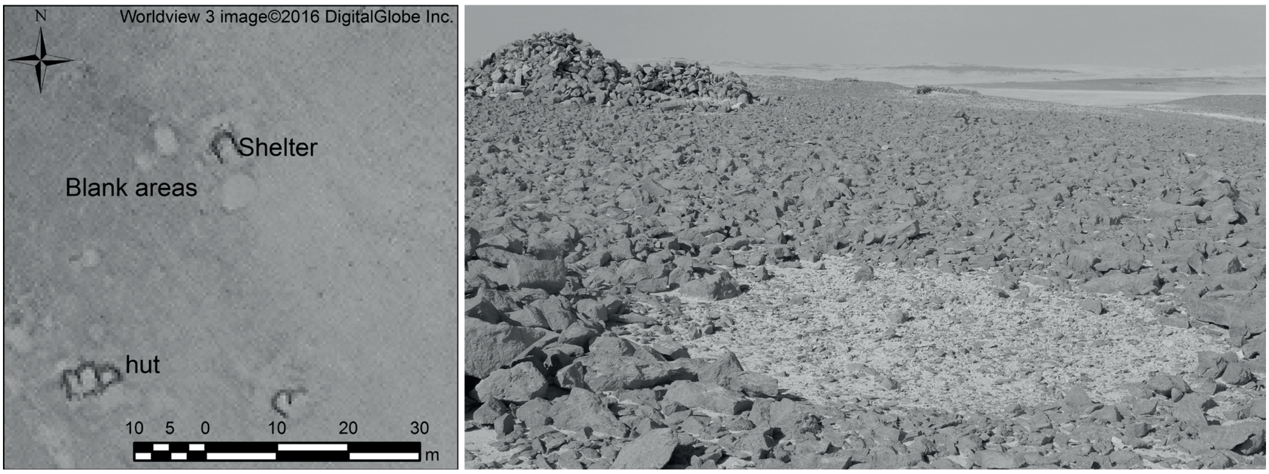


Figure 7. Blank areas' (left) as they appear in the Worldview-3 imagery and (right) on the ground (Worldview-3 imagery © 2016 DigitalGlobe Inc. supplied by European Space Imaging. Photo: Roland Enmarch. Reproduced with permission).

atives at a rate of only 3% across the rest of the area. A high proportion of the false negatives produced by the remote-survey are therefore the result of modern activity obscuring or destroying previously recorded archaeological remains.

Modern activity is probably also responsible for the absence of some other features (N4 and N15) from the remote-survey data. These features were recorded by Shaw (2010: fig 3.14) on the approach route immediately west of Quarry P, where the remote-survey found evidence of considerable modern activity.

Elsewhere the features in Shaw's survey which could not be located in the remote-survey tended to cluster in two areas at the edges of Shaw's field survey plans (Figure 6). Along the southwestern edge of the survey area it was difficult to relate Shaw's (2010: fig 3.16) plan to the satellite image and several features recorded by him (W26 and W35) could not be identified in the remote-survey data. Similarly in the centre west of the survey area on the edge of two plans (Shaw 2010: fig 3.21 and fig 3.22) several structures (A39, A50, A62 and A64) could not be identified in the remote-survey. As there is no evidence of modern destruction in these areas, it is difficult to determine why features recorded by Shaw do not appear in the satellite imagery. One possibility is that the records of the field survey are slightly less accurate at the edges of the plans. Alternatively genuine features might have been obscured in the satellite imagery. Only further fieldwork can determine if the features recorded by Shaw still exist and why they could not be found by the remote-survey. Despite these difficulties comparison of the remote-survey and Shaw field survey data reveals that the remote-survey produces a low number of false negatives and is almost as efficient as field survey at locating surviving archaeological features.

False Positives in the Remote Survey | The remote-survey recorded an additional 441 structures and 115 roads, tracks or paths that had not been identified by Shaw's (2010) fieldwork. The large number of additional roads and tracks recorded in the remote-survey is not a surprise since Shaw's plans only show the main quarry road, its spur to the southwest and very short paths approaching some of the shrines. There is no evidence that any other tracks, trails, or paths were recorded during Shaw's survey work. Confirmation of the archaeological nature of the additional 115 roads, tracks, and paths found by the remote-survey will therefore have to await further 'on site' ground-truthing.

Of the 441 additional archaeological structures recorded by the remote-survey but not by Shaw (2010), 21 are interpreted as modern features based on their highly rectilinear shape or superimposition upon areas of modern quarrying and disturbance. Most of these features have been constructed since Shaw's fieldwork was completed and would not have been recorded as ancient features by him even if they were in existence. Excluding the 21 modern features leaves 420 unexplained potentially ancient structures that were identified in the remote-survey but are not in Shaw's (2010) plans. These 420 features include 170 'Blank areas' (see Table 2). These areas were not

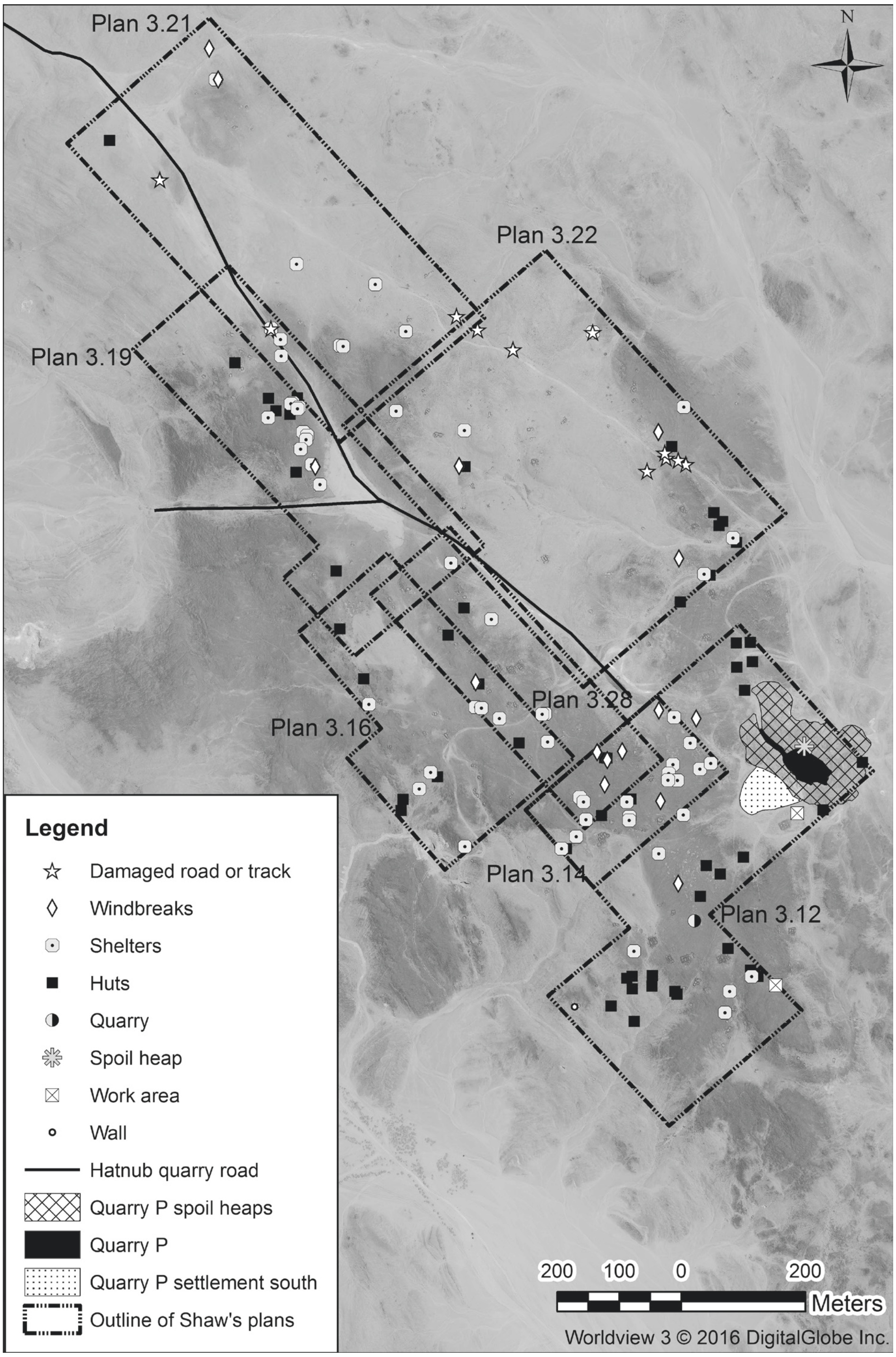


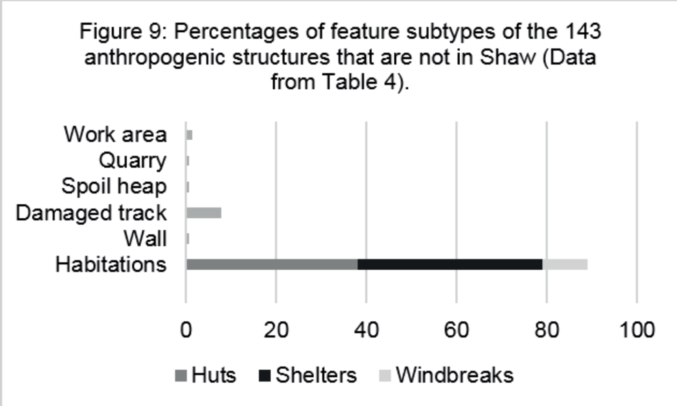
Figure 8. The 143 features classified as 'certainly' anthropogenic, but not in Shaw's survey data. Those around the edges and overlaps of Shaw's (2010) plans 3.16, 3.21, and 3.22 were probably missed by Shaw because of their peripheral location (Worldview-3 image © 2016 DigitalGlobe Inc. supplied by European Space Imaging. Reproduced with permission).

marked out by any specific walling, but appear as circular or sub-circular discontinuities in the stony surface of the desert (Figure 7). The most likely explanation for them is that they are small quarry pits filled with sand or 'tent circles' where the stones have been cleared from the surface to form a more comfortable space for a temporary shelter. Shaw (2010: 35) noted their existence but did not record them individually. The Blank areas were therefore excluded from the comparison with the Shaw survey data. This left 250 features in the remote-survey, which are of the types that Shaw recorded but are not present in his survey data. This is a high number of potentially false positives, representing 30% of the total structures recorded in the remote-survey.

The database shows that the remote-surveyor was reasonably certain that 143 of those 250 potential false positives were genuinely anthropogenic (Fig-

Feature subtype	Features	
	No	%
Huts	54	38
Shelters	58	41
Windbreaks	15	10
Wall	1	0.7
Damaged track	1	0.7
Spoil heap	11	1
Quarry	1	0.7
Work area	2	1.4
Total	143	100

Table 4. Breakdown of the feature subtypes of the 143 anthropogenic features that are not in Shaw's (2010) survey, but the remote-surveyor was certain were anthropogenic.



ure 8, Table 4 and Figure 9). As expected, the majority (127 or 89%) of these 143 structures were interpreted as habitations. This is consistent with both the remote-survey overall, where the majority (69%) of the structures were habitations of some sort, and with Shaw's (2010) survey data. Given the large size of some of the huts and the distinctive appearance of the other habitations recorded during the remote-survey (Figure 3), it is extremely unlikely that these 127 habitations are false positives. There is a faint possibility that some may have been constructed recently, but modern structures are generally identifiable by their square shape, thin walls (typically made with one layer of limestone bricks), and presence near modern quarries. Although final confirmation must await 'ground-truthing' fieldwork, it is likely that most, if not all of the 127 habitations are genuine archaeological features that were missed by Shaw.

Given the certainty with which the 143 anthropogenic structures were recorded by the remote-surveyor as genuine archaeological features, and the probability that many of them will be confirmed in 'ground-truthing' fieldwork, their absence from Shaw's (2010) data requires some explanation. Eleven of the 143 were located along the Hatnub quarry road and a secondary track to the north-east, and are probably either sections of these routes or nearby ancient structures broken up by modern traffic (Figure 8). Thus they may not have been visible as independent features when Shaw undertook his survey.

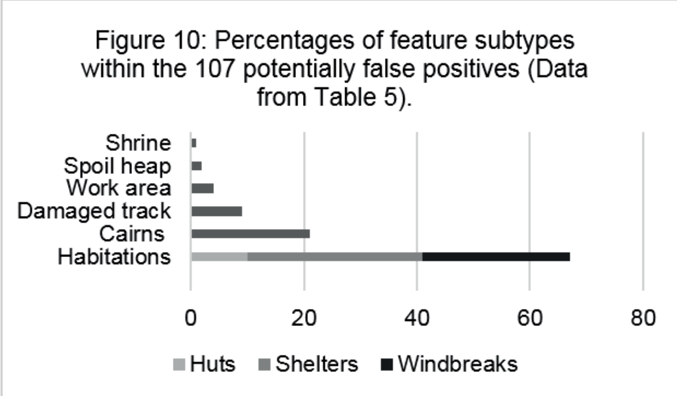
Figure 8 also shows that a number of the 143 features (including all the quarries and work areas as well as many habitations) cluster at the edges of Shaw's total survey area and along the edges of individual plans, particularly Shaw's (2010) plan 3.16, plan 3.21, and plan 3.22, and along the southern edge of plan 3.19. This suggests that the survey did not extend quite as far as these plans indicate and that archaeological features were missed at the intersection of survey plans, perhaps where one field season ended and another began. The distribution of habitations across Shaw's (2010) plans 3.12, 3.14, and in the centre of 3.19, is more difficult to explain, but these features may have been missed due to the practical difficulties of maintaining a consistent manual field survey over varied terrain. The identification of archaeological features in the remote-survey that were missed by field survey is consistent with the results of other remote-sensing surveys which undertook ground-truthing exercises (Dore and McElroy 2011: 16–17; Parcak 2007: 75). Further 'on-site' investigation of these features will confirm their anthropogenic nature and perhaps reveal why they were not included in Shaw's survey.

There are 107 structures in the remote-survey data where the surveyor was uncertain as to whether they were truly archaeological features or not (Table 5, Figure 10). Of all the structures recorded during the remote-survey, these 107 are the most likely to be false positives, as they are not recorded by Shaw (2010) and the remote-surveyor was uncertain if they were genuinely anthropogenic.

This group is dominated by possible habitations, which is consistent with the number of habitations in the remote-survey data and Shaw's (2010) field survey records. Normally habitations are easy to distinguish from the desert surface, but badly dam-

Feature subtype	Features	
	No	%
Huts	10	9
Shelters	31	29
Windbreaks	26	24
Cairns	23	21
Damaged track	10	9
Work area	4	4
Spoil heap	2	2
Shrine	1	1
Total	107	100

Table 5. The 107 potentially false positives, by feature subtype. This table includes only those features that are not in Shaw's (2010) survey and where the remote-surveyor was uncertain as to whether they were truly anthropogenic or not.



aged or demolished habitations lose their distinctive appearance making them difficult to identify in the remote-survey. In almost all cases these features were classified as 'uncertain' because of the activity of modern traffic or quarrying that obscured their form or interrupted their distribution across the desert.

The only exceptions to this were the cairns and spoil heaps, which were often categorised as 'uncertain' because they appear as dark stony agglomerations on the desert surface, and look very similar to small natural outcrops, making them difficult to identify with certainty in the satellite imagery. Of all the features cairns and spoil heaps were the most likely to be categorised as 'uncertain', across the remote-survey area whether or not they were located in the area surveyed by Shaw (2010). Overall 70% of all cairns and 68% of all spoil heaps have been categorised as 'uncertain' to date. The difficulty of identifying these features emphasises the importance of the 'Uncertain' field in the remote-survey data. This field enabled questionable features to be recorded while ensuring the surveyor could express their doubts and flag the features for further fieldwork.

Given that Shaw (2010) did not record every single archaeological feature within his survey area, it is probable that some of the 107 uncertain features are genuinely ancient structures, but if they all proved to be false positives they represent 13% of the structures recorded within Shaw's survey area during the remote-survey. Some of these features will be targeted for 'ground-truthing' during the next phase of the project, together with other randomly sampled features elsewhere within the study area. Although some of these 107 features may prove to be genuine, prior to ground-truthing this figure of 107 or 13% is the best estimate for false positives within the remote-survey data.

Overall, and if corroborated in the field, the results presented above represent a substantial improvement over those recorded by Dore and McElroy (2011: 16) where analysis of satellite imagery only found 92 of 157 trail segments, giving a rate of 59% for false negatives. The Hatnub remote-survey results (with false negatives at 7% and false positives estimated at 13%) are more comparable to Parcak's (2007: 72-74) identification of Egyptian tells (settlement mounds) from multi-spectral imagery, which exhibited a rate of 2% false negatives and no false positives in Middle Egypt, and 2% false negatives and 10% false positives in the Egyptian Delta. De Laet et al. (2015) and Bubenzer and Bolton (2013) do not provide statistics on the numbers of false positives or false negatives in their research, although the trails they recorded were checked during fieldwork.

Conclusion

Overall, this research found that remote-survey of desert landscapes is a viable means of accurately and rapidly recording small diffuse features across a large landscape. Archaeological features of 1 m in diameter or larger were consistently visible in the satellite imagery despite variations in the natural surface of the desert and the type of archaeological feature. The imagery was sufficiently clear to enable the remote-surveyor to locate the different types of windbreaks, shelters, and huts. Although the speed of any survey is naturally dependent upon the number of archaeological features present, the remote-survey was clearly substantially quicker than the original fieldwork and also required little cost beyond the price of the imagery (£2000) and the software. The geolocational accuracy of the Worldview-3 image used in the remote-survey ensured that the resulting plan of archaeological features is as precisely and accurately located as is currently possible, which is critical for subsequent ground-truthing.

Comparison between Shaw's (2010) field survey data and the remote-survey demonstrates, even before ground-truthing fieldwork, that the latter is reasonably accurate and has a level of accuracy that compares well with that found during other projects. The remote-survey data has a low rate (7%) of false negatives, indicating that it is almost as efficient as field survey at identifying known archaeological features. Detailed examination of the survey data revealed that the false negatives were mostly the result of recent damage to archaeological features previously recorded by Shaw, which rendered them incomprehensible during the remote-survey. When the severely damaged Quarry P settlement south was excluded from the analysis, the rate of false negatives decreased to 3%.

Although the data initially indicated an alarmingly high number (441 or 54%) of potential false positives in the remote-survey, careful examination of the methodology employed by Shaw and the remote-survey revealed that some of this was due to different methodological approaches, particularly in recording the 'Blank areas'. After these differences had been eliminated, 250 remote-survey features remained unidentified in Shaw's survey data, indicating that up to 30% of the remotely surveyed features could be false positives. Given that the remote-surveyor was certain that 143 of these features were anthropogenic, it is likely that the true rate of false positives is much closer to the 13% (107) of structures where the surveyor could not be certain of their human origin.

Final confirmation of the accuracy of the remote-survey across the whole 100 km2 survey area awaits further 'ground-truthing' fieldwork in the near future, but this paper has demonstrated that high resolution satellite remote-sensing is a suitable method for generating an initial plan of small, diffuse archaeological features dispersed across a large area of varied desert terrain and can supplement or partially replace on-site archaeological field survey in desert landscapes.

Undertaking remote-survey prior to fieldwork at Hatnub will reduce the amount of time and resources required to record the archaeological landscape and ensure that fieldwork is targeted at uncertain or interesting structures. The creation of the remote-survey plan will also facilitate future fieldwork on a practical level. Using mobile-GIS technology the satellite imagery and remote-survey plan will be combined with GPS-enabled tablet-based recording devices to provide the maximum information during field survey and enable modifications to the data to be made directly. This will facilitate rapid data collection and eliminate the need to obtain and transport large survey equipment to the site, with a concomitant saving in time and resources.

Acknowledgements

The author is grateful to the Egypt Exploration Society for the funds to purchase the Worldview-3 satellite imagery, which were provided as part of a wider grant to the Hatnub Project. The author is also grateful to Roland Enmarch for permission to use his photographs in this paper and to Yannis Gourdon and the Institut Français d'Archéologie Orientale, our collaborators on the Hatnub Project. The author is also grateful to the organisers (Nazarij Buławka and Julia Chyla) of the CAA 2017 session on Mobile GIS and Field Survey, and to the reviewers of this paper for their comments and suggestions.

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