Human intervention in the landscape through ancient mining: a regional study applying satellite imagery

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Introduction to Ancient Mining

The extraction of minerals and precious metals has been a focus of human action for millennia. Whether for building materials, making tools or for decoration or status, the human action of mining has left a significant imprint on ancient landscapes in many regions of the world. The industrial archaeology of mining can answer questions such as how ancient mineral extraction activities were carried out and how they were supported. We can also consider how mining regions were accessed and investigate the nature of human interaction with the landscape and the impact of settlement patterns.

Throughout the Pharaonic period in Egypt, gold mining and other mineral extraction activity was frequently associated with the expansion of territories under occupation. This was the case in the Middle Kingdom below the Second Cataract of the Nile (modern Sudan) and also in the New Kingdom Period (*c.* 1550-1100 BC) as far south as the Fourth Cataract. Evidence of mine workings and mineral processing activity remains in the archaeological record on the ground in these regions (Figure 1). It was only appreciated recently that the 18th Dynasty site of Sesebi between the Second and Third Cataracts of the Nile, might have owed its existence to mining in the interior (Spence *et al.* 2009).

The focus of the study was a region of Northern Sudan, covering an area of 2,400km^2 shown in Figure 2 and bounded by the four corner sets of coordinates, around Sesebi, at 19° 55' N/30° 15' E - 20° 25' N/30° 15' E - 20° 25' N/30° 40' E - 19° 55' N/30° 40' E. Using public-domain satellite images from Google Earth the region was documented in a database which characterised the visible archaeology applying a framework and descriptions which were adapted from the work of the Oxford based EAMENA project (Endangered Archaeology in the Middle East and North Africa).

The data set and exact locations of ancient sites have been captured in the detailed database submitted with the author's thesis. To protect the locations of sites, only those which have been subject to recent destruction, mostly by artisanal mining, are published here.

Sesebi

Until the past 20 years there had been limited archaeological survey work undertaken in this region of Sudan. Recently however, Osman and Edwards (2012) published the results of their extensive survey of the Mahas Region between

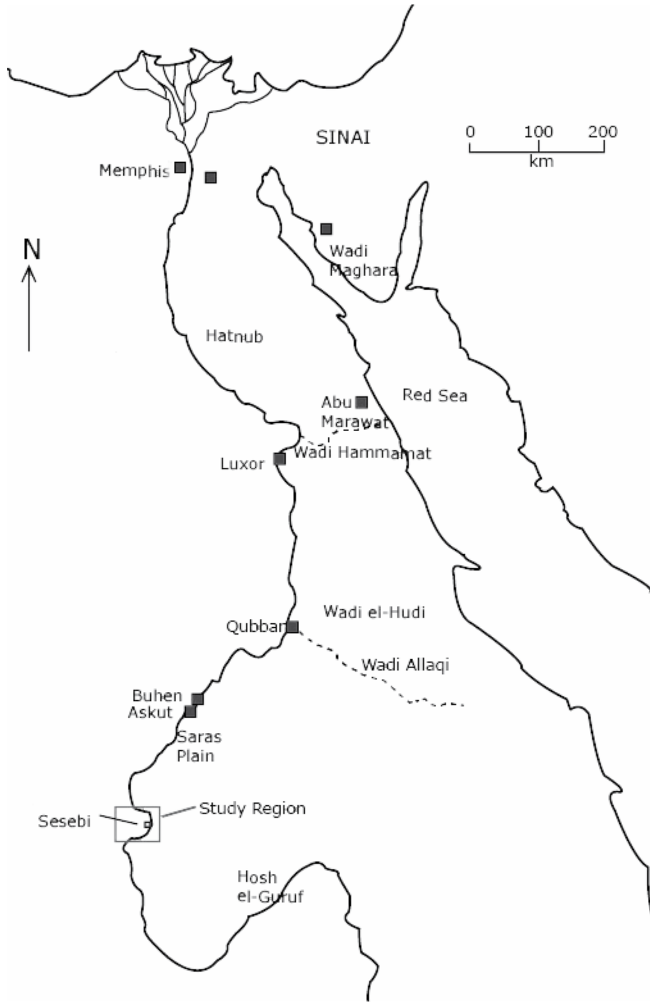

Figure 1 General Map of Egypt and Northern Sudan showing several mining and quarrying locations (after Shaw 1998, 254 fig. 15.1).

Delgo and Tombos in the vicinity of the Third Cataract of the Nile. This was built upon early survey work beginning in the 1980's which over a period of 20 years covered a region of more than 60km along the Nile Valley but was limited to some 1.5km on either side of the river. In addition, since 2009, the joint Cambridge and Austrian Archaeological Institute team of Spence and Rose has conducted several seasons of fieldwork at Sesebi.

In three field reports, the team of Spence and Rose has provided new insights into the role of Sesebi. Located on the west bank of the Nile opposite the modern settlement of Delgo, the site covers some 5.4ha bounded by walls 195m (east-west) by 266m (north-south). Besides the New Kingdom Temple constructed during the reign of Akhenaten, there is a northern temple which is also described as having architecture similar to that applied at Amarna. The site was believed to have been abandoned during the Ramesside period but the cemetery and ceramics suggest some occupancy during the 25th Dynasty (Napatan) period. The locus of subsequent activity in Medieval and Ottoman periods appears to have moved to the north of the walled town. Excavation of the crypt of the main temple revealed decoration dating to early

Figure 2: The Study Region 31/03/2006 Composite (source: Google; Digital Globe, Earth Point) (accessed 26/7/16).

in the reign of Amenhotep IV (Akhenaten) and a seal impression of Thutmose IV was found during H. W. Fairman's excavation in 1937. A structure outside of the north-east corner of the walls has provided indications of earlier occupancy in the 18th Dynasty; the ceramics and the presence of bread cones (moulds) has led the excavators to conclude that this structure was the site of an earlier temple with a bakery attached (Fairman 1938; Spence *et al.* 2009; 2011; Spence and Rose 2014). The population of the residential area of the town has been suggested by Osman and Edwards to total approximately 1000 (2012, 80).

The recent work also revealed further evidence to suggest that Sesebi may have played a part in gold mining in the region. The 2009 survey had identified a number of whole and broken grinding stones together with granite pounders, associated with quartz grinding in the New Kingdom. The site was understood to be at the southern edge of the gold mining zone in the New Kingdom which extended from the Eastern Desert to the Wadi Allaqi past the Second Cataract at Duweishet and deeper into Nubia.

Regional Geology

The geology of North-East Africa is central to understanding why the region became significant in gold production in Pharaonic times. The area is part of the Arabian-Nubian Shield (ANS) and lies within one of four major 'cratons' (stable parts of the earth's crust'), the East Sahara Craton. Major tectonic processes forced the ANS into the craton, in the process forming heavily folded bedrocks, leading to the creation of rocks such as greywacke and siltstones. There are known to have been as many as seven orogenic events in Africa at various (geological) times. During formation, shear zones were created in the rocks. Subsequent orogenic events throughout the north east of Africa led to the creation of granitoid magmas. These produced significant thermal energy, which generated gases and steam from water trapped in rocks. This super-heated fluid in turn dissolved minerals from the base rocks and combined with silicon dioxide, flowed through hydrothermal convection cells and channels. This interstitial water cooled in the open spaces of the shear zones allowing gold to deposit in economic concentrations in narrow veins in the host quartz material. This basic gold deposit formation process is similar where the bedrocks are basic (such as basalt) or acidic (such as rhyolite). In the Eastern Desert of Egypt, a region of major gold production in Pharaonic times, the ANS is largely covered by later sandstone and limestone deposits whereas in Nubia the contact is with more metamorphic rocks and gneiss (Kroner and Stern 2004; Klemm and Klemm 2013, 29-31; Klemm *et al.* 2002).

The field report from Sesebi describes the immediate geology of the Sesebi site. It describes the metamorphosis of basement rocks to create a very durable and hard 'greenschist' material with quartz and pegmatite veins in the bedrock and overlaying sandstones which have been altered by intrusions. These latter features are generally basaltic such as the plugs at Jebel Sese and Jebel Delgo (Spence *et al.* 2009)

Mining – Footprint in the Landscape

Gold mining – Methods and Chronology.

As described above, gold deposits in Egypt and Sudan are a result of super-heated fluids circulating through Pre-Cambrian rocks which remove and concentrate the metals, depositing them in quartz veins in fractures, so that gold veins are linked with igneous intrusions. Other minerals associated with gold deposits include iron and copper sulphides which provided key markers of mineralization for ancient prospectors (Killick 2013). In general, gold is usually found as the native metal whereas silver, lead and copper form weak bonds and, while occasionally found as native metals, will usually occur as sulphides or oxides. As Killick and Fenn point out (2012), the presence of smelted metal in the archaeological record is used to identify advances in how humans manage their material world.

The basic process involved in liberating gold from the quartz involves crushing the quartz ore to pea size pellets and, if dealing with fine particles, a secondary grinding followed by a 'washing' process. This may involve a sloped board with ridges (or animal fleece) to 'catch' the fine grains of gold (Klemm *et al.* 2001).

Gold concentrations vary throughout a deposit but it has been estimated that grades in New Kingdom mines must have been in the range of 30 grammes/tonne (g/t) with lower limits of 10g/t. This is based on some of the grade profiles seen from alluvial wash outs and tailings from ancient operations which have recorded grades in the order of 5g/t (Klemm and Klemm 2013, 2). Mining today is carried out on veins and deposits with grades closer to 1 g/t - 1.5 g/t. The original Egyptian workings were in high grade material so in certain areas the run-off material on the *wadi* sides and floors contain grades higher than most modern mining operations.

Determining a chronology of mining sites is challenging because there is rarely any epigraphical information. Usually the archeological evidence for dating of activity relies on elements such as ceramics and tools. In addition, many sites are palimpsest as workings have been expanded or deepened by subsequent operations. However, it is possible to establish a chronology based on layout and certain features. The leaders in this field are Rosemarie and Dietrich Klemm. In an extensive survey (2013) over 25 years, they visited over 250 major gold production sites in North-east Africa. Ian Shaw (1998; 2007; 2010) has studied quarrying but several elements of the related settlements (camps) are also common in gold mining. These include issues such as protection, whether by proximity to forts or by fortification of the camps themselves. Within the study area covered here there has been no opportunity to 'ground-truth' the analysis and suggested characterisation, but where evidence may still be in place the examples below constitute a useful typology. As will be discussed here and in another paper (in preparation) the majority of the sites visible in satellite images from 2003 up to 2013 have subsequently been subjected to major disturbance. Access to the sites has also been disrupted by the extraction of significant amounts of gold-bearing alluvial material from the *wadi* floors.

Certain regions such as Nubia south of the Wadi Allaqi became accessible during the New Kingdom and their exploitation can be firmly dated to this period because there was a significant 'retreat' from the region in the political decline after the 20th Dynasty.

New Kingdom sites in the Eastern Desert often show metal tool wear marks suggesting that veins were removed for processing away from the mine site. There was a limit to the depth that New Kingdom miners could follow a vein 'down dip'. Beyond 30-40m there were practical issues of ventilation. This is because most slots would not exceed the vein thickness and ensuring air movement in narrow veins below 30m would have been challenging (Klemm and Klemm 2013, 8-12). In addition, gold separation from sulphide minerals in the deeper, less oxidised, settings would have been more difficult. The earliest securely dated evidence for gold refining is in the 6th century BC in Greece (Ramage *et al.* 2000, 32), making it unlikely that deeper deposits, which would require some processing and separation, were mined.

The Identification of Mining in the landscape

As the current study was unable to confirm specific material culture on the ground, an assessment of the archaeology of the Gorgod Hills was made based on pattern of mineralization, types of exploitation, and infrastructure using satellite images.

There are key indicators of mining activity in antiquity which correspond to four types of mineral extraction.

1. Surface activity on 'colluvial' detritus on the sides of *wadis*. In this, material from vein outcrops on the shoulders, or higher slopes of *wadis,* erodes down the sides of the *wadi* and is deposited over time on the lower slopes. This material contains blocks of coarse fragments and because of the relatively dry environment it was accessible for selective extraction. The extraction of colluvial material became common in the New Kingdom. This type of mining leaves a characteristic 'pockmarked' profile on the *wadi* sides; an example (Figure 3) from the Eastern Desert provides a useful illustration.

Figure 3. New Kingdom Colluvial Workings at Liseiwi (south of Wadi Allaqi) (source: Klemm and Klemm 2013, 510 fig. 6.163).

2. Extraction of alluvial outwash gold on the *wadi* beds. An alluvial deposit is normally associated with fine material which has been transported and deposited by water. This type of deposit is harder to identify by satellite but may be closely associated with adjacent infrastructure/settlement. On *wadi* margins some leaching may be visible because in acid volcanics (rhyolites) a sponge type silica residue may be visible as a result.

3. Pitting, in which small concave excavations are 'dotted' over a landscape as near surface mineralization is extracted by shallow digging.

4. Trenching (slot cutting), in which the vein can be seen to have been extracted along the strike for a distance of up to 100m. The depth is hard to determine without being on the ground but some indication may be taken from the width of the opening. This type of mining approach includes incline openings on *wadi* sides. While these may sometime be hidden by overhanging rock in openings, they can often be identified by different surface patterns of oxidation or of spoil heaps in a satellite image.

Mine sites generally lie some distance from towns and temples. In Ancient Egypt it was common, from the Middle Kingdom, for campsites to be established adjacent to the mining operations. These were organised areas with work rooms where crushing and grinding took place, and where for the period of time that they were 'in the field' the workers slept, ate and prepared for the next shift either in the mines or in primary separation of gold. This is evident from the material remains of many such sites in the Eastern Desert and from the archaeological record in Nubia with the presence of water jars, ceramics, grinding bases and pounders. The settlements around gold mining sites have a 'distinctive appearance' (Shaw 2007, 143) and feature clusters of drystone huts. These huts were 3-4 roomed houses with walls some 300mm wide and around 1.5m high. The size varied between 3 x 3m to 4 x 3m and 5 x 4m. The location most frequently chosen was on the *wadi* margins, away from the risk of flooding but generally parallel to the slopes as shown in Figure 4 (Klemm *et al.* 2001, 250).

Figure 4. Typical New Kingdom settlement on wadi *edge (Eastern Desert) (source: Klemm and Klemm 2013, 250 fig. 5.191).*

Satellite Imagery in Archaeology.

There is a long tradition of mapping and imaging to identify key landmarks. One of the earliest known maps in the world is that depicted by the Turin Papyrus. This depicts the Wadi Hammamat as the main artery between Qift and Quseir and is dated to the 12th century BC, around the time of the expeditions of Ramesses IV (1151-1145 BC).

In the 1930's the use of aerial photography expanded for map-making, completing surveys and for the recording of ancient monuments. However, in the past 20 years, the application of satellite imagery has expanded in archaeology

(Montufo 1997; Altaweel 2005; Goossens *et al.* 2006; Parcak and Mumford 2012.)

Beginning in the 1990s the US Government began to release satellite images taken in the 1960s. These, taken together with some available aerial photography, led to their early use in archaeological settings (Montufo 1997). Initially these images required careful geo-referencing and specialist software to be able to exploit their 3-D capability.

Since the introduction of Google Earth and Google Earth Pro, free access to quality images has now become available to the general public. In addition, historical images are now accessible extending over a 13 year period (from 2003 to 2016).

In January 2015 the Endangered Archaeology in the Middle East and North Africa (EAMENA) program was established. This research group is based in the Universities of Oxford and Leicester and is backed by the cultural heritage and environmental fund, Arcadia. The program had a mandate to complete rapid surveys in areas where archaeology is at risk or endangered with the aim of disseminating information and helping those responsible for preserving archaeological heritage across the region. The program 'uses satellite imagery to rapidly record and make available information about archaeological sites and landscapes which are under threat' (http://eamena.arch.ox.ac.uk/). EAMENA is working across the Middle East and North Africa and has recorded more than 18,000 sites across 65,000km^2. Sudan is not included in their research area. An example of EAMENA's work is provided by the summary of findings from the Eastern Desert of Egypt recording damage to sites caused by modern mining at Centamin's mine at Sukari and by local artisanal workings to the north of Edfu, on the Nile, and to Marsa Alam on the Red Sea (east/south east of Luxor) (Bewley *et al.* 2016).

Satellite data for archaeology is becoming increasingly useful as a pre-cursor to field work. This is especially the case where access may be limited, whether as a result of funding constraints or concern for security.

Methodology

Data Capture

One challenge of using satellite images is the need for a common language and data capture to enable sharing of information. The EAMENA methodology provides a possible framework for the evaluation of sites.

This study has used the protocol established by EAMENA, which involves the description and characterisation of each site. This methodology offers a new approach, avoiding the challenges of geo-referencing and image manipulation that prevented easy adoption of remote imaging in the past.

To study the region a set of 30 grids was established in a layer in Google Earth Pro (Figure 5) which covers an area 55 x 44km. Each main grid was itself divided in 25 grids (a-y) based on 1' of latitude and longitude (Figure 6). At these general coordinates (e.g. Sesebi 20.06.34 N, 30.32.34 E) of the Earthpoint Grid (www.earthpoint.us) 1' of longitude represents 1,740m on the ground while 1' of latitude is equal to 1,840m. Each location of interest was given a grid/coordinate locator number and described using the terminology of the EAMENA database.

A dataset was generated around the four main description headings (tabs) of the EAMENA framework. These are summarised in Table 1 below. In each case and under every heading there is a 'drop down menu' to prompt an appropriate description. In several cases the certainty of the assessment is characterised, usually on a simple high to low scale.

Table 1. High level descriptors in the data base for feature identification (Source: EAMENA).

1**) Resource Summary and Location**	The feature is given a unique identifier and the morphology, shape, certainty and cultural period (with degree of certainty) are recorded. The spatial location is captured and its extent and topographical setting are noted.
2) **Main Descriptors**	The arrangement, shape and form are recorded as well as the number of the features present.
3) **Interpretation**	Based on the set of descriptors, an interpretation of the function of the resource is noted (with a degree of certainty).
4) **Threat and Change**	The extent, cause (with the degree of certainty), categorisation and effect of any visible disturbances, as well as future threats. Threats noted in terms of potential and category.

The first category in the data generates a Resource Summary. In this category each site was given a unique *Resource Identity* and its *Location* established. The morphology of the sites and general *shape* was recorded and the *size* and degree of *certainty* noted.

For this study, an identifier was established to define each feature in the survey region. This unique record was based on a combination of the grids and sub-grids and the last four digits of the full coordinates (northings and eastings). For example, infrastructure in the form of stone-walled huts was noted at 24p 18.08.66 30.19.06. This identifier places the site in Grid 24, Sub-Grid p which is at 20.18.08.66 N, 30.30.19.06 E. This means that sites are also 'securely' described on the grid map, and key coordinates are used to locate the site. (As a comparison, the Osman and Edwards Third Cataract Study (2012) uses place names in the region alongside a number assigned to each site with coordinates). At this level of the dataset a brief summary description of the feature was also recorded. In sub grids where there were no features of archaeological interest, a basic description of the physical geography was added in the summary.

The second grouping included the general description of the site. In this category the form, shape and general arrangement of a feature was captured. Detailed *Form* included ditches, pits, modified rock surfaces as well as walls or structure. The *Shape* and *Arrangement* descriptors included whether the feature was circular or rectangular and in clusters, linear

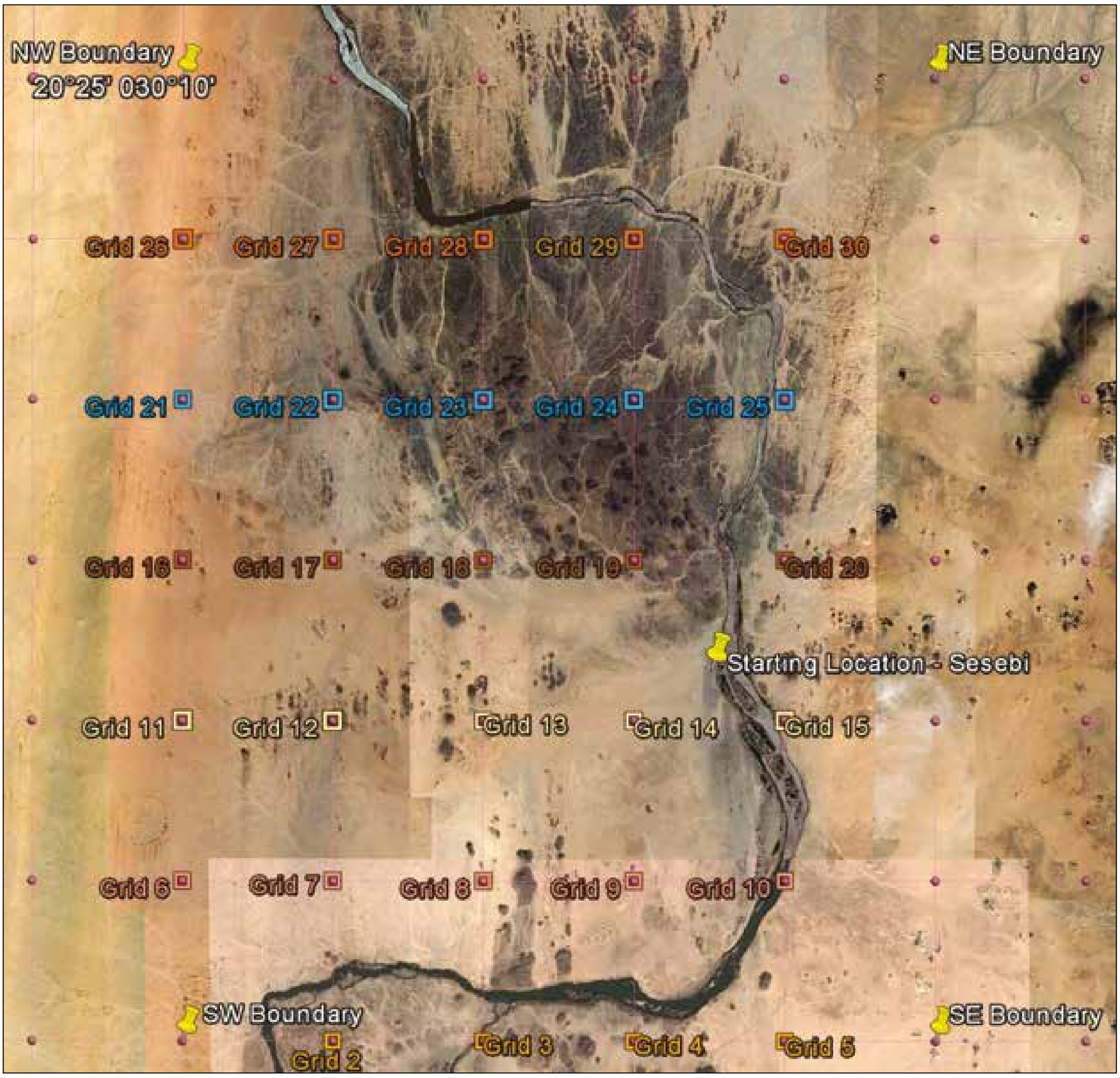

Figure 5. Study Area showing major grid locations (source: Google; Digital Globe, Earth Point) (accessed – 28/08/16).

26	27	28	29	30
21	22	23	24	25
16	17	18	19	20
11	12	13	14	15
6	7	8	9	10
1	2	3	4	5

u	v	w	x	y
p	q	r	s	t
k	l	m	n	o
f	g	h	i	j
a	b	c	d	e

Figure 6. Major grid (above) and sub grid (below) nomenclature and patterning.

or multiple. In this data the surface extent of a feature was recorded in the notes.

The third major heading included the various interpretation criteria for the site. The EAMENA criteria included a detailed set of descriptions for *Feature Interpretation* from altar to well and including settlement/habitation, mining/quarry and production processing (mining). The *Functional Interpretation* sub heading included aspects such as agricultural/pastoral, defensive fortification and industrial/productive.

The fourth category examines the *Threat and Disturbance* that the feature might be experiencing whether from construction, development or mining/quarrying.

Where possible, cross referencing with ground survey data was used. This also helped in the interpretation of features.

The earliest freely available data in Google Earth for this region was produced either in 2003 or, for some grids, 2005. Resolution to within 1m is now possible with Google Earth making small buildings (say 3 x 3m) stand out clearly in the landscape. The earliest data possible was used to provide a baseline and the database was populated with this data. Throughout the process the later images, mostly from 2016 but occasionally from 2013, were used to identify changed and unchanged landscapes. The degree of disturbance shown in the region also provided a useful confirmation of the initial identification of areas of mineralization and ancient mining activity.

Results and Discussion

Summary

Overall 199 individual sites were identified as showing evidence of mining having occurred in that location. In addition, 58 examples of support infrastructure were recorded. The mineralization and exploitation appears to have occurred in three 'bands' running north west-south east through Grids 18-22-27 and north north west-south south east through Grids 19-23/24 and north-south on the east side of Nile through Grids 25-29 (see Figure 5).

These sites bear the hallmarks of the four key indicators outlined above. An example of each is illustrated below in Figure 7.

Mining sites appear throughout the region and the majority are closely associated with one of the 58 examples of camp (housing) infrastructure in the study area. These are all collections of stone huts ranging in size from small groupings of 2-5 to large camps of up to 20 or 25 huts characteristic of Pharaonic work-camps. There are no examples of later styles of encampments which might be expected to show greater order and even fortification (Shaw 2007, 143-144).

The review in this paper is set out in two sections. The first examines in detail Grids 18 and 23 to illustrate the features of the main production centres and the relationship between the work camps and mine sites. These two grids were chosen because both show a diversity of work camps combined with evidence of mining. The second section considers the logistics associated with the campsites and what the data set reveals of the likely work practices. All the sites examined have been impacted by recent artisanal mining.

In the detailed sketches that follow (Figures 9, 10 and 14), mine types are indicated by different shapes. This includes indications of colluvial, slot mining or trenching, and pitting as well as evidence of alluvial mining in one grid. Also, the scale of infrastructure is indicated by the diameter of the place marker.

i. Image Grid 18s – Colluvial workings (image from 15/11/2003). Note the pockmarked sides of the *wadi* (accessed 22/5/17).

ii. Image Grid 20u – Alluvial workings (image from 28/11/2003) (Hard to detect – covered by outwash). Workings on *wadi* floor (accessed 30/7/16).

iii. Image Grid 17t – Pitting (image from 15/11/2003). Note the small shallow circular scars (accessed 30/7/16).

iv. Image Grid 23y – Trench and Slot workings (image from 15/11/2003). Note 'cuts' running east north east to west south west centre images (accessed 30/7/16).

Grid Analysis

A: Grid 18

Grid 18 lies 14.7km from Sesebi and 30.7km from Soleb. It features a major *wadi* which runs from the north west to the south east with an important tributary from high ground to

Figure 7. Mining markers from the study region. To be compared with Figure 3 from The Eastern Desert above (source: Google; Digital Globe, Earth Point).

the north east (Figure 8). A series of mine sites run parallel to the northwestern branch and the northeastern limb contains a series of mine and infrastructure clusters. These are shown in Figure 9. In total the grid contains 11 different settlement locations and 25 individual mine sites.

The illustration shows that this grid contains evidence of slot/trench mining and a cluster of campsites accessing multiple mine locations in the north-east quadrant. Figure 9 also illustrates a line of campsites on a major route to the north (see below).

in Figure 10. In Grid 18i, a major camp lies on the shoulder of a *wadi* system with a total of 40 plus buildings. These all appear to be stone wall hut-like buildings in clusters over a distance of 220m running north-south. The structures vary in size from 3 x 4m to a multi-roomed 8 x 5m. It is of note that there are no mine sites in the immediate (<500m) vicinity. There were 11 sites within 3km, four within 2km and one within 1km. The scale of the settlement suggests it may have been a processing centre as well as a residential centre. This is suggested by the clustering and separation visible in Figure

Figure 8. Grid 18 coordinates 20.10 N, 30.25 E. 2003 image (source: Google; Digital Globe, Earth Point) (accessed 22/05/17).

The region defined by Grid 18 contained four campsites of between 11-20 huts and one location with more than 20 huts. The ancient mining evidence shows more trench and slot work than pitting or colluvial excavation. This suggests that vein outcrops were common in the location, a conclusion supported by the modern workings, as this region has seen significant opening and deepening of slots.

Of particular note is the combination of mine sites and two camps in sub grids 18i and 18j. These are detailed below

10. The closest mine site to 18i is in 18j which was adjacent to a collection of stone huts the largest of which is a multi-roomed structure 4 x 9m at the northern end of the camp. This appears to have been a focused production site because the mining area is within 500m on a north northeast to south southwest strike line. It featured a combination of trenches/slot cuts and pitting as methods. This location also illustrates the trackway network between sites that (in 2003 images) was still visible on the ground. Approximately 500m to the north

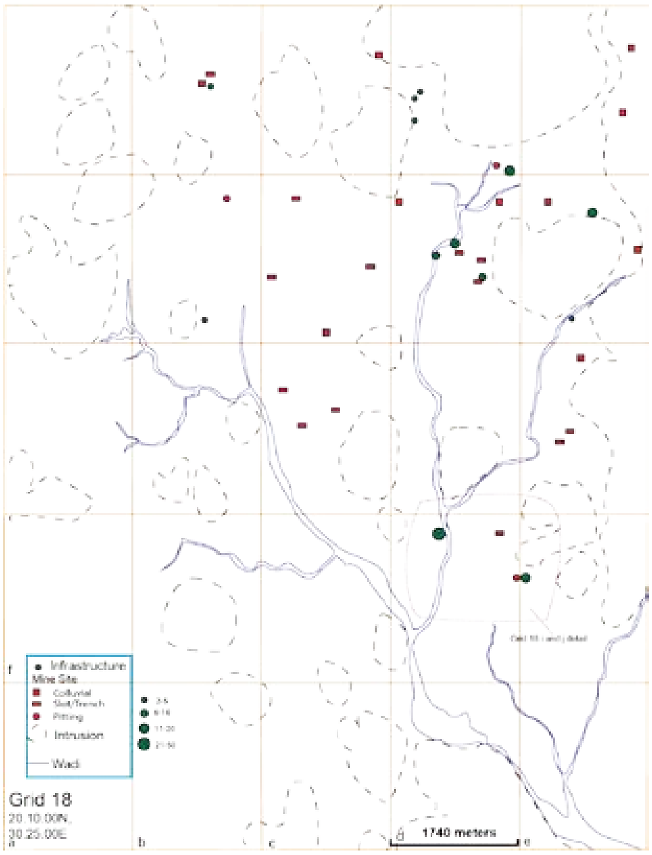

Figure 9. Grid 18 detail.
Note: 'Intrusion' = igneous rock plug.

west on the trackway was a mine site with an apparent slot cut in the side of a *wadi* on an east-west strike line.

B: Grid 23

Grid 23 begins 20.4km from Sesebi and 22.1km from Soleb. It contained six campsites and 19 mine locations (Figures 11 and 12). The majority of these were located in a north north east to south south west trending mineralised zone in the north-east quadrant of the grid (and into Grid 29). The land generally dips to the north and at its northern edge is less than 3km from the Nile.

For the most part the mine sites consist of colluvial workings with the exception of two pitting locations in 23t and a major slot/trench activity in 23y described below. There were also two camps of between 11-20 huts both of which were in close proximity to multiple workings, suggesting a base location for working a region.

The campsite on the divide between 23j and 23o is shown in Figure 13. This site extends over 350m and the approximately 20 stone huts are the typical 3 x 4m size with the occasional two-roomed joined structures. The separation between clusters suggests different functions by zone and most sit on the shoulder of the *wadi* edge. This location had 23 different mine sites within 3km, 15 within 2km and four within 1km.

One of the locations mentioned in the ground survey of Klemm and Klemm is that of Sokar in Grid 23y. They confirmed the presence of New Kingdom operations with later shaft sinking in the 20th century. The survey discovered hand pounding tools suggesting very early extraction in the Old Kingdom period by local Nubians (Klemm and Klemm 2013, 576-578). The study images show some of the old workings and pitting linked by a network of pathways (Figure 14).

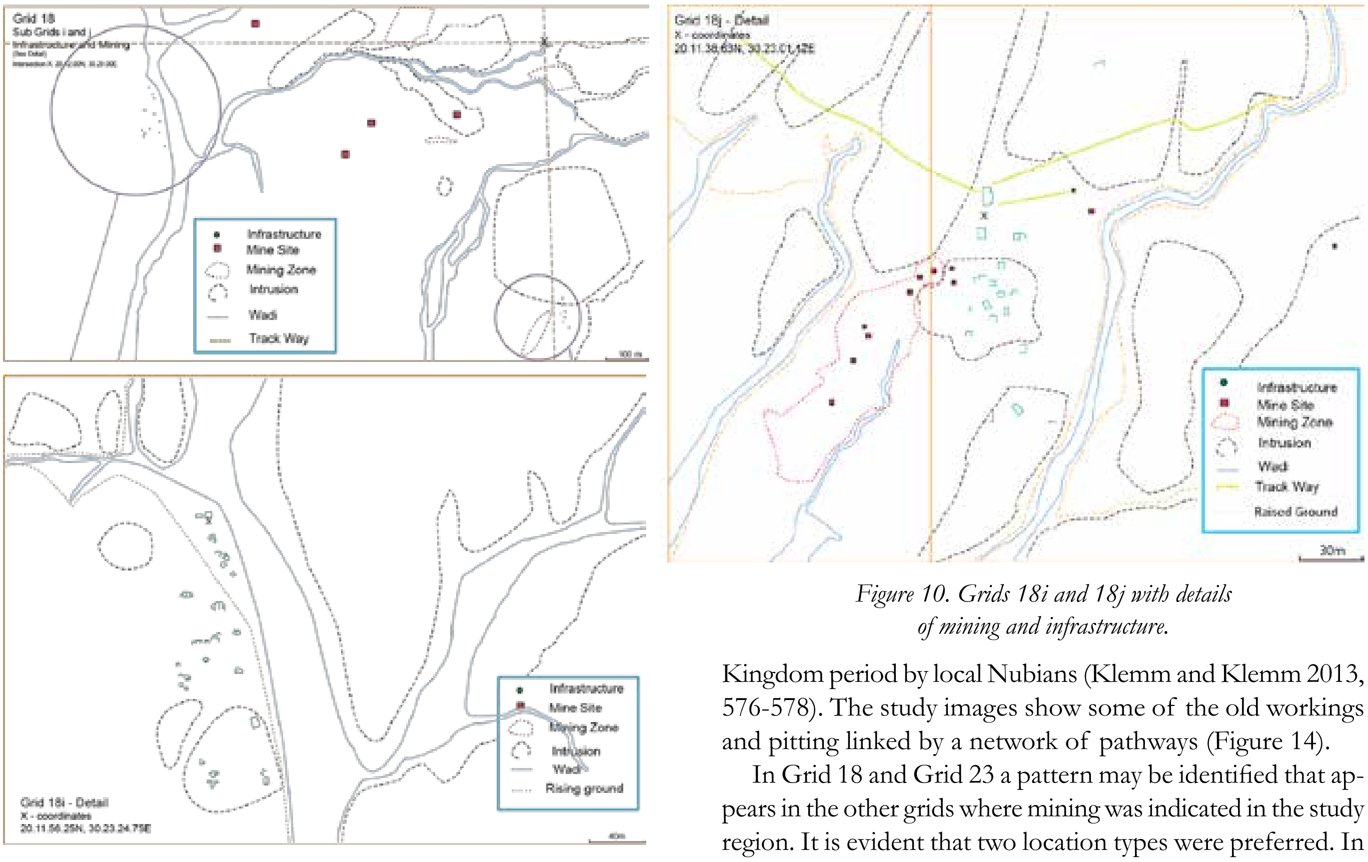

Figure 10. Grids 18i and 18j with details of mining and infrastructure.

In Grid 18 and Grid 23 a pattern may be identified that appears in the other grids where mining was indicated in the study region. It is evident that two location types were preferred. In

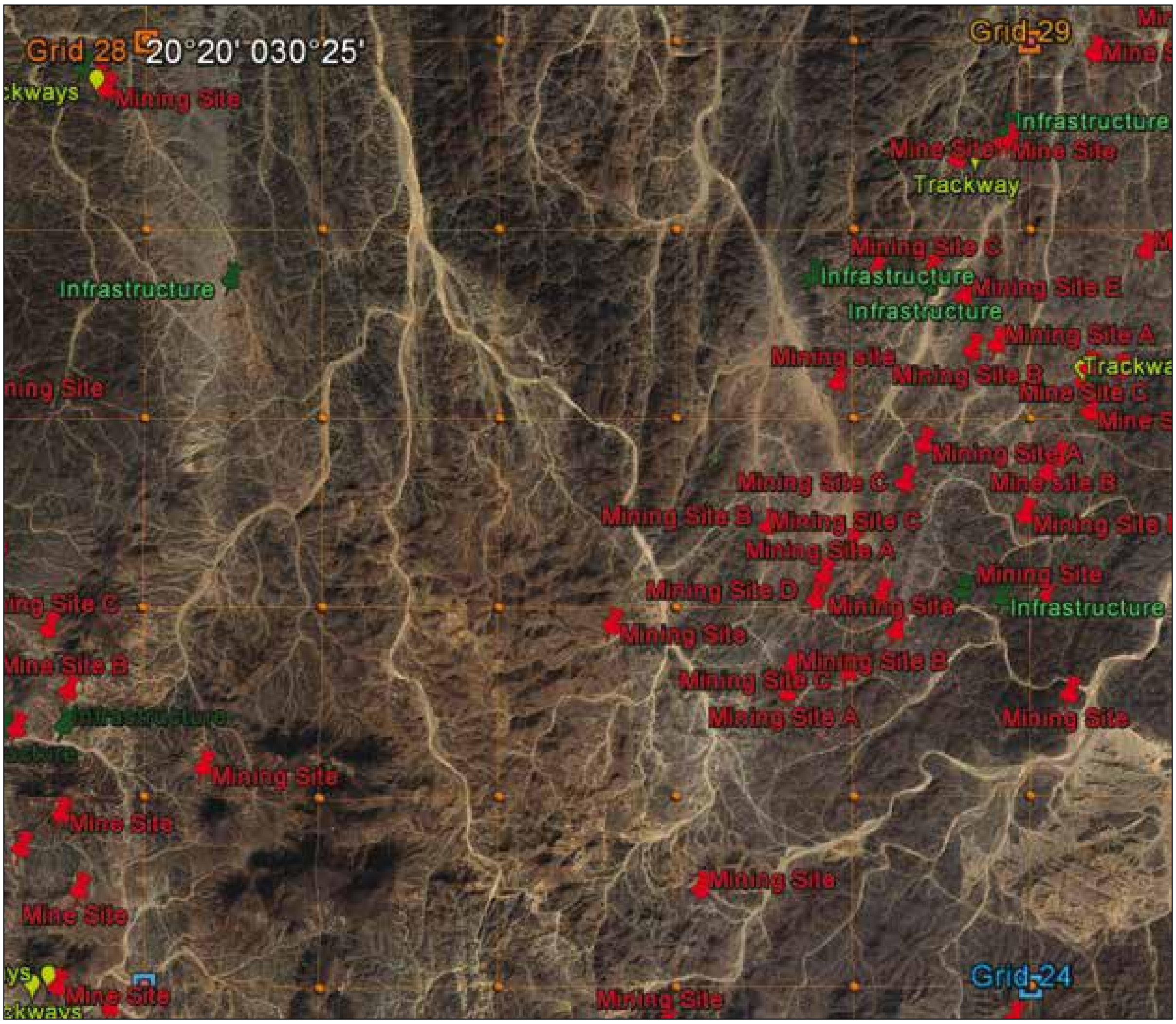

Figure 11. Grid 23 20.15 N, 30.25 E. 2003 image (source: Google; Digital Globe, Earth Point) (accessed 22/5/17).

Figure 12. Grid 23 features.

Figure 13. Campsite along wadi *margins on divide between 23j and 23o. Image dated 27/07/2005 (source: Google; Digital Globe, Earth Point) (accessed 30/7/16).*

most cases, campsites were situated close to supply routes, on the shoulders of *wadis* raised above the *wadi* floor. The other sites are generally found on spurs and ridge lines where they are connected with mine sites by footpaths along the contours.

Logistics

Zone of influence

To consider the possible zone of influence of each campsite, all 58 locations were examined to record the number of mine sites within 3km, 2km, 1km and 500m (Figures 15 and 16). These distances were chosen because of the practicalities of 'lost production' through travel time beyond 3km. The average walking speed of a 1.6m tall individual is 5km/hr. It may be expected that even over desert pathways the workforce could have maintained this pace. That would suggest that a

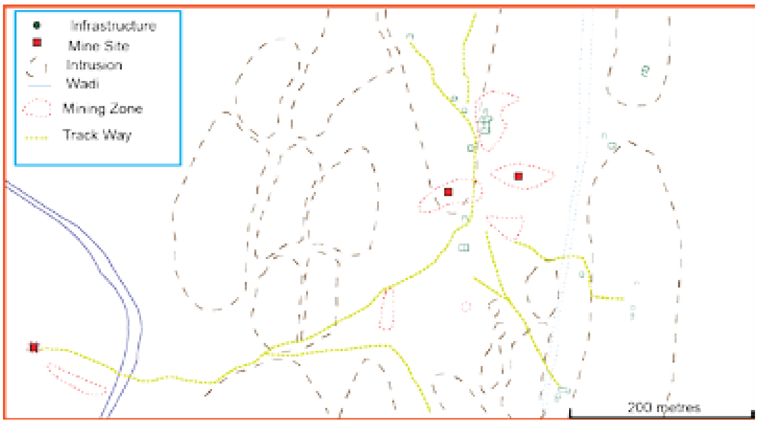

Figure 14. Sokar mine location grid 23y.

mine 3km away from a camp could be reached in 36 minutes and one 2km away in 24 minutes. Table 3 shows the summary results of how many mine sites are within these zones for each camp. Although the terrain in the region is uneven, the purpose of this analysis was to provide some indication of the possible extent of support for individual mine sites from a given camp site location. Some of the earlier (2003-2005) satellite images show pathways radiating from campsites along *wadi* shoulders and into *wadi* floors.

This data illustrates several key points. There are many examples where mine sites sit precisely on the 'border' at 3km and 2km. This suggests that thought was given to diverse resource exploitation before the camp was established. The percentage 'drop-off' from 3km to 2km is remarkably consistent throughout the study area.

Throughout the data set in the region there are examples where mine sites could have been worked from different camps. The 'overlap' is illustrated in several of the images above. There are a number of possible explanations, one being that the campsites moved within a sub region over time to keep travel times lower, or that different 'campaigns' selected different ground for other functional reasons such as improved environment or access.

Table 2 presents the data for all the camp locations (in grids where camps have been identified only). The average

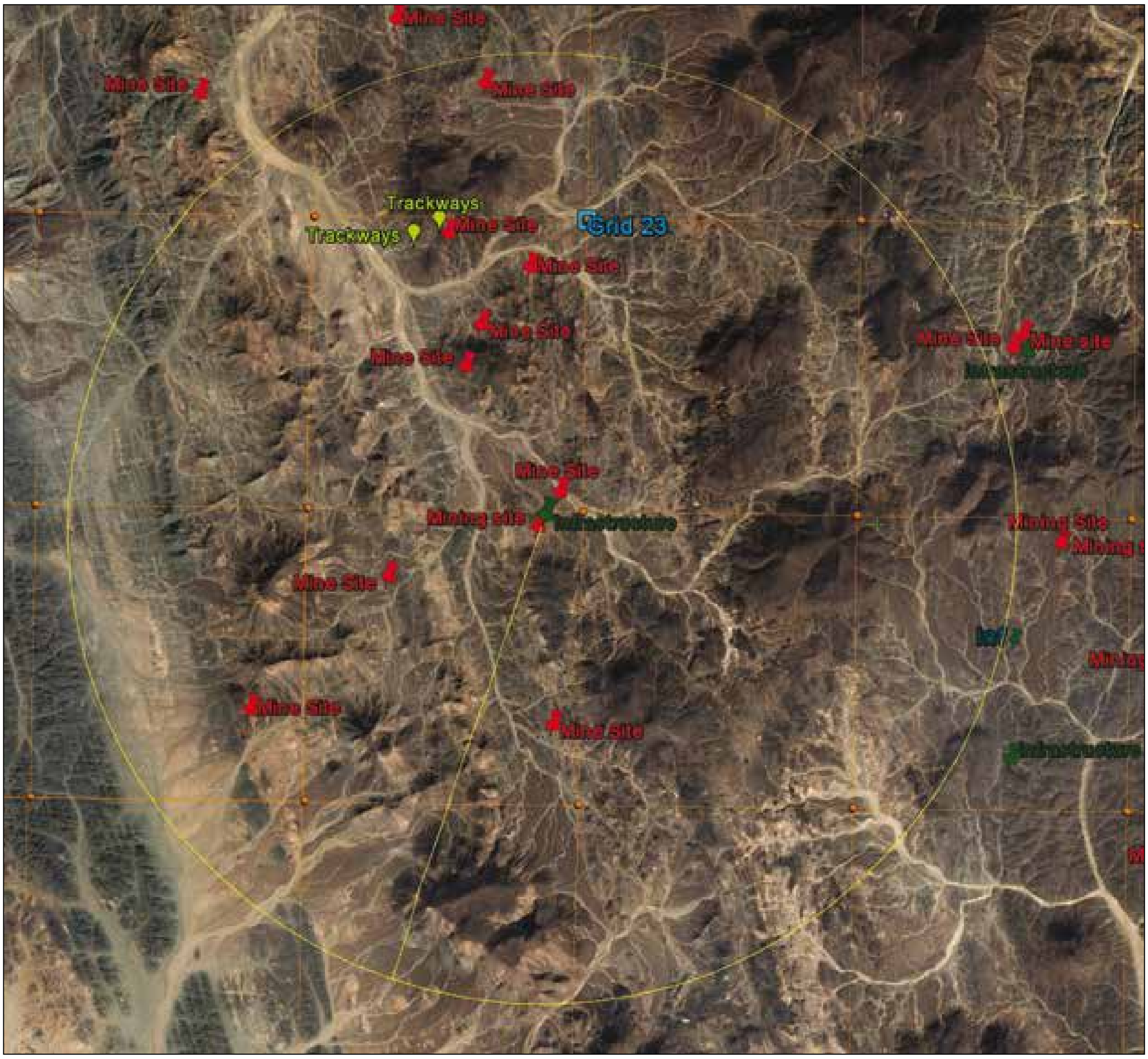

Figure 15. Illustration of 3km zone of influence in Grid 17t (source: Google; Digital Globe, Earth Point) (accessed 27/7/16).

number of mine sites within 3km of a campsite in the study area is 11 and the average number within a 2km range is six. The maximum number of mine sites within 3km of a

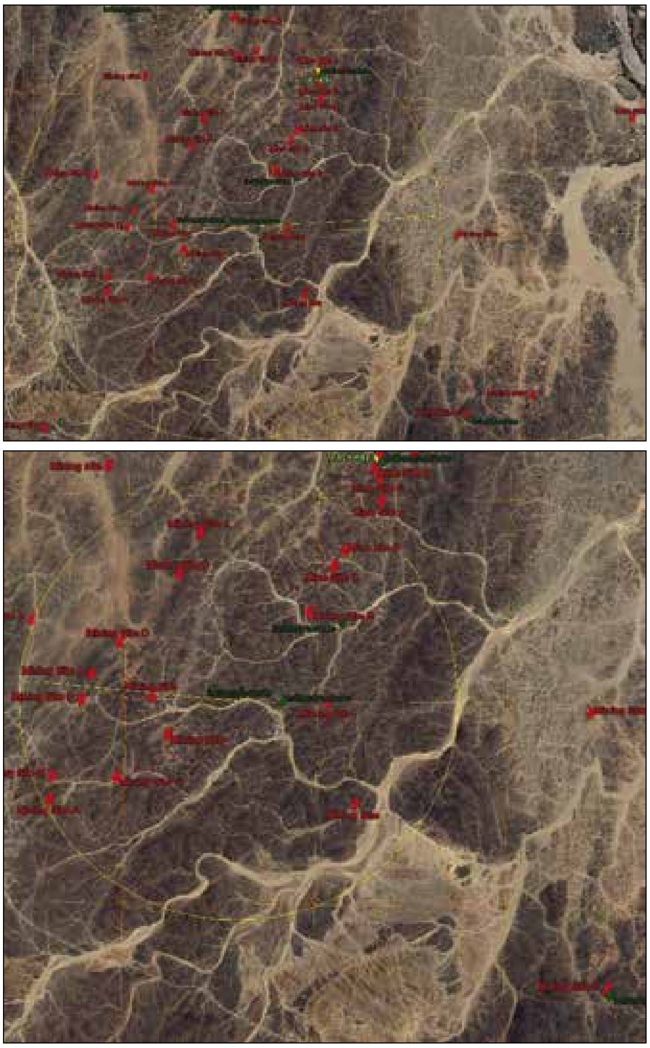

Figure 16. Grid 23o – example of 3km, 2km, 1km zones (source: Google; Digital Globe, Earth Point) (accessed 27/7/16).

campsite is as high as 26 and within a 2km radius is up to 15. The average 'drop-off' between 3km and 2km and between 2km and 1km averages 41% (standard deviation of 19%) and 57% (standard deviation of 25%).

This table points to a clear decision-making process and analysis of a region prior to establishing a camp. It appears as though sites were targeted to keep a balance between travel times and access to sites in a 2km-3km radius.

Pathways and Provisioning

Another consideration for the overall logistics is how the campsites were supplied with workers and provisions. Table 3 shows the distances from the two major New Kingdom settlements at Soleb and Sesebi to the south-western corner of the major grids in the study area. The time taken assumes a 5km/hr walking pace and so is only indicative The distances are taken from satellite measurements and are 'as the crow

Table 2. Zone of influence for 53 (of 58) identified campsites.

			Mining Locations within			
Grid	**Camp Size**	**Resource ID**	**3km**	**2km**	**1km**	**500m**
8	11-20	8i 01.25.22 28.21.65	0	1	1	1
12	2-5	12v 09.48.72 21.01.13	4	2	1	1
13	2-5	13v 09.48.79 26.39.59	2	2	2	2
14	2-5	14k 07.49.70 30.38.69	2	1	1	1
	21-50	14w 09.58.59 32.50.46	3	1	1	1
17	21-50	17t 13.56.65 24.51.02	10	8	2	2
18	21-50	18i 11.54.11 28.25.03	11	4	1	0
	11-20	18j 11.36.86 29.02.70	6	4	2	1
	6-10	18s 13.23.79 28.42.24	20	9	4	3
	6-10	18s 13.31.31 28.20.93	21	10	5	1
	11-20	18s 13.36.05 28.30.08	21	9	6	3
	2-5	18t 13.09.44 29.23.40	17	11	1	1
	11-20	18t 13.47.68 29.34.27	16	11	3	0
	2-5	18v 14.31.50 26.36.23	7	3	1	1
	2-5	18x 14.18.13 28.10.63	16	10	2	0
	2-5	18x 14.26.04 28.10.74	18	9	1	0
	2-5	18x 14.28.99 28.12.51	17	9	1	0
	11-20	18x 14.01.22 28.55.56	19	10	3	2
19	11-20	19h 11.12.16 32.39.23	8	4	2	1
	2-5	19h 11.25.11 32.18.14	9	7	2	2
	11-20	19i 11.58.62 33.13.90	8	6	1	1
	6-10	19i 11.53.86 33.46.56	8	2	1	1
	2-5	19q 13.42.26 31.10.85	11	4	2	2
22	2-5	22d 15.48.22 23.11.80	18	10	3	1
	6-10	22i 16.08.25 23.37.13	18	12	2	1
	2-5	22j 16.16.43 24.10.67	17	11	4	1
	2-5	22m 17.38.72 22.02.10	14	8	1	1
	6-10	22m 17.55.96 22.37.62	14	10	5	2
	2-5	22y 19.46.38 21.36.80	4	3	2	2
23	2-5	23j 16.57.65 29.48.73	26	13	4	1
	11-20	23o 17.00.66 29.35.43	23	15	4	0
	6-10	23p 18.38.84 25.27.34	3	0	0	0
	6-10	23s 18.40.03 28.44.45	18	8	1	0
	2-5	23t 18.36.77 29.24.23	23	14	5	2
	11-20	23y 19.94 54.32	19	8	2	1
24	2-5	24b 15.11.67 31.35.22	6	5	3	2
	2-5	24b 15.32.21 31.32.48	7	4	4	1
	2-5	24k 17.20.72 30.07.23	26	15	4	1
	11-20	24p 18.08.66 30.19.06	23	14	7	5
	2-5	24v 19.20.53 31.55.96	8	3	1	1
25	6-10	25f 16.33.64 35.05.92	12	5	3	2
	2-5	25g 16.36.35 36.43.87	8	3	1	1
	2-5	25h 16.56.02 37.55.75	4	4	1	1
	2-5	25i 16.58.32 38.09.33	4	3	2	1
	2-5	25k 17.17.25 35.57.12	8	5	3	2
	51-100	25m 17.41.65 37.12.41	6	2	0	0

Grid	Camp Size	Resource ID	Mining Locations within			
			3km	2km	1km	500m
25	11-20	25n 17.09.81 38.48.85	3	3	2	1
	21-50	25n 17.21.65 38.08.57	4	3	2	0
	2-5	25v 19.54.57 36.15.90	3	1	1	1
27	6-10	27h 21.19.97 22.23.90	4	2	1	1
28		28b 20.54.35 26.43.25	5	5	0	0
29	6-10	29i 21.11.81 33.07.16	12	8	3	2
	2-5	29i 21.34.43 33.14.29	14	9	3	1
	6-10	29j 21.11.88 34.06.50	14	8	2	1
	11-20	29j 21.43.46 34.18.15	16	10	3	1
	6-10	29j 21.53.07 34.44.48	13	8	4	1
	6-10	29m 22.49.08 32.55.53	11	4	1	0
	6-10	29n 22.57.29 33.55.37	15	9	3	1
	2-5	29t 23.32.16 34.26.13	12	4	1	1
	2-5	29v 24.28.70 31.04.39	2	2	1	1
30	6-10	30j 21.53.76 39.17.79	0	0	0	1

flies' rather than accurate 'on the ground' metrics.

Examining the terrain between Sesebi and most locations, there is a clear route which would have been followed to the north west up a major *wadi* which branches to the north east and north west at 11.5km from Sesebi. The majority of sites appear to have easy access from the south (Sesebi) although there is a clear *wadi* access route to Grid 22 sites from Soleb.

The satellite image (Figure 17) shows the *wadi* running from the middle of the southern edge of the figure feeding from the south and east up to the mining regions. The features are highlighted in Figure 18.

Table 3. Distances from major supply centres.

Grid	Mining Sites	Camps	From Soleb (km)	Hrs	From Sesebi (km)	Hrs
18	25	11	30.7	6.1	14.7	2.9
19	17	5	34.1	6.8	7.8	1.6
22	22	7	20.3	4.1	29.9	6
23	19	6	22.1	4.4	20.4	4.1
24	24	3	26.5	5.3	16.2	3.2
25*	15	8	33.1	n/a	1.6	n/a
29	25	7	20.6	4.1	25.1	5

* East bank of Nile

There are trackways (T) visible running over the watershed together with infrastructure (I) at several stages along one of the routes to the north east accessing the main mining sites.

As described above, the evidence suggests that several mine sites would have been serviced by a campsite location. Figures 10 and 14 both show the network of paths that were visible in satellite images from the early 2000's around two of the mining areas. Another example is provided by Figure 19 which shows the pathways between sites in Grid 24p.

As has been described, the campsites range in size from 2-5 huts to around 25-30 in the larger camps. Only one is recorded with more than 50 huts at Grid 25m in the area of Abu Sari.

As noted by Bloxam (2010) with reference to the make-up of labour forces for mining and quarrying, the material culture and textual sources appear to be contradictory. Evaluations of quarrying activities in other parts of Ancient Egypt such as in the Faiyum (Bloxam and Storemyr 2002) suggest work parties in the hundreds. In the Eastern Desert and Sinai (Shaw 1994) there are some larger sites such as Hatnub where extraction occurred over a 1000 years but many where much smaller work parties were used, numbering in the hundreds rather than in the thousands as the inscriptions of the Wadi Hammamat would suggest.

The camp sites identified in the study region appear as clusters of huts which would support work groups in the region of 50-100 workers. The layouts that can be identified also show some separation of activity. As seen in Figure 19 (and in other locations of the study) there are buildings of different sizes and configuration which may point to some specialization of task whether production-related, domestic or administrative in nature.

Understanding of the conditions of work for specialist workers in the New Kingdom is largely drawn from the evidence at Deir el-Medina. According to Davies (1999, xix) at Deir el-Medina, the workers followed 'ten days on one day off' cycle. The work was being performed in the Valley of the Kings, a two hour hike from the 'Workers' Village', and they were supplied with food from the village as demonstrated by requests for food recorded on *ostraca*. The workers were employees of the state conscripted to work at the site. They were paid in grain, and on their day off were able to generate additional income by producing items for sale at market (Lesko 1994, 22, 33-34; McDowell 1992). It is useful to compare the situation in Sesebi and the Gorgod Hills with Deir el-Medina.

The evidence from the study does not point to the use of fortifications at the campsites. The workings must have been deemed to be relatively safe in their location between Soleb and Sesebi. It is, of course, possible that the workers were regarded as not worthy of protection but a number of the scribes or administrators would have had knowledge of value, and the resources themselves were of importance. The lack of structural protection in the camps suggests that the sites were regarded as secure locations. Workers at Deir el-Medina came from the geographical breadth of the New Kingdom, from Nubia to Western Asia (McDowell 1994). It is possible to consider that Nubian prisoners of war may have been put to work in the mines at Sesebi but equally likely that the mine workers were as diverse a group as at Deir el-Medina.

Further work on the major settlements at Soleb and Sesebi is required to identify the evidence for the support functions of the operations. Key to maintaining the work cycle was the securing of supplies of food and water to support a work party. At Deir el-Medina the supply of water to the workers village was a full time role for a number of water carriers whose delivery schedule is described in sev-

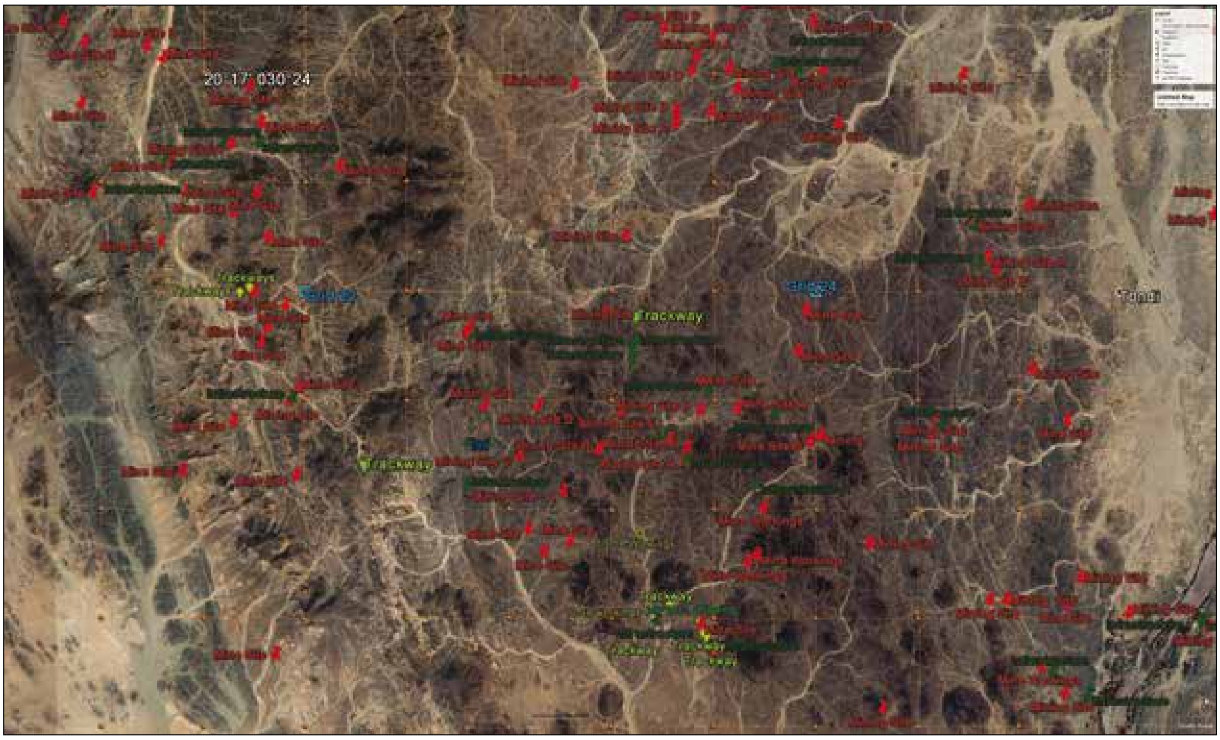

Figure 17. Satellite image of main wadi *routes from Sesebi to mine sites (source: Google; Digital Globe, Earth Point) (accessed 31/7/16).*

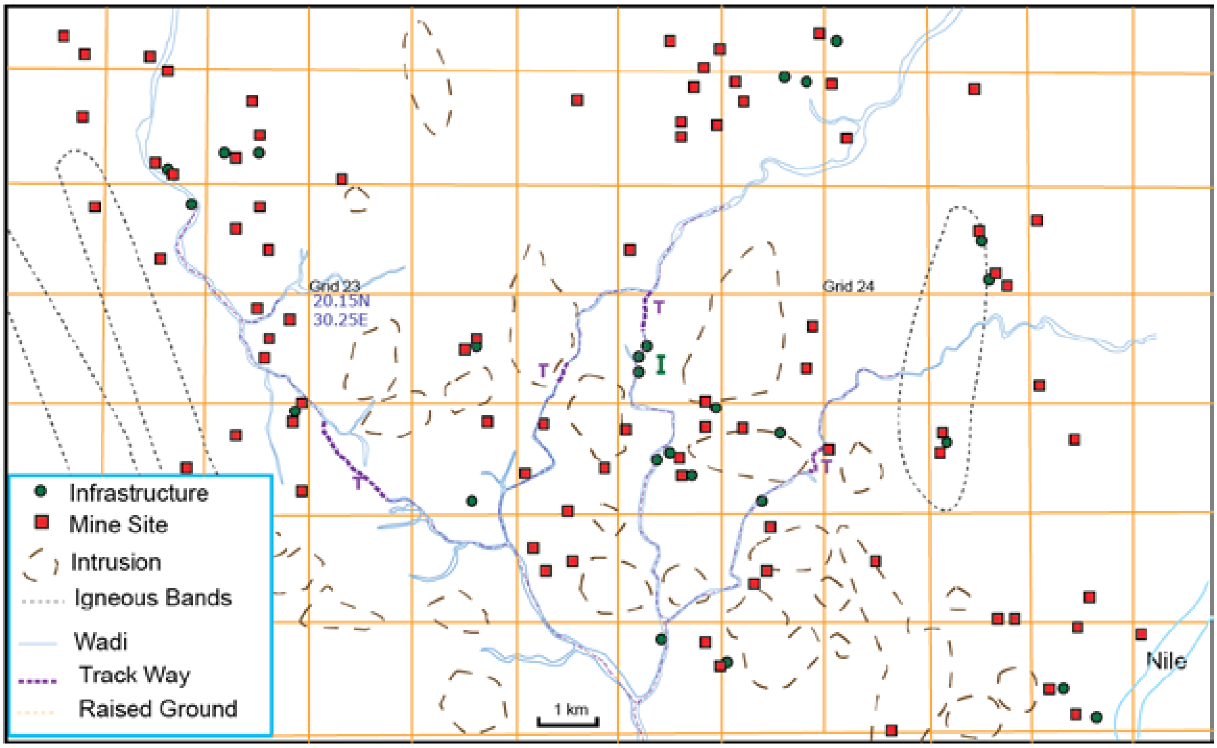

Figure 18. Main features showing wadi *routes and trackways from south to north (from Figure 17 above). Note Grid 23 coordinates provided as a frame of reference and the Nile runs through the bottom right-hand corner (which is Grid 19j).*

eral of the texts from the village (McDowell 1994, 61-63). The Ancient Egyptians were expert at moving water across significant distances. The remains of amphorae and ceramic storage jars are common at Egyptian sites and water was a key component, over millennia, in managing the challenges of travelling and working in the desert. The images from the study show sizeable camps which may have included room for storage. It is possible that some of the smaller dry-stone infrastructure elements may represent wells such as the shallow ground-water wells identified in small Middle Kingdom

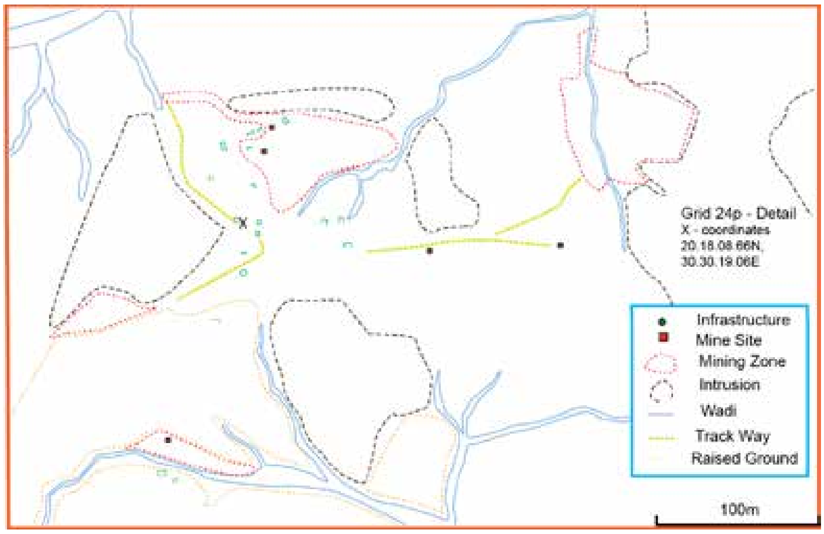

Figure 19. Grid 24p detail – campsite and associated mine workings.

camps adjacent to the quarry road to Gebel el-Asr north west of the Second Cataract (Shaw *et al.* 2010, 304).

Conclusions

The study has revealed new information on settlement patterns and the decisions made in exploiting resources in the late 18th Dynasty. In addition there are conclusions to be drawn on the use of the EAMENA methodology. One aspect of the study to be discussed in a subsequent paper is the significant loss of the archaeological record and heritage over the past three years, as captured by the more recent satellite images (McLean in prep.).

Settlement Patterns

The region of the Gorgod Hills of northern Sudan between the settlements of Soleb and Sesebi was a significant source of gold production in the 18th Dynasty. It is possible to identify several different types of mining activity which were carried out in the region supported by an extensive network of infrastructure.

Having studied the major grids, several patterns emerge. It is evident that mineralisation zones were relatively small and that miners exploited this resource through surface or near-surface workings. The characteristic campsites vary in size and there is an apparent relationship evident in the sketches above. Larger camps were associated with mine sites which involved slot or trench mining on veins, while smaller teams, from sites with 2-5 huts, were working on colluvial type surface extraction.

Analysis of the zone of influence of sites makes it clear that the infrastructure supported multiple sites. Around the miners' campsites there was a zone of approximately 2-3km within which sites were worked. This also implies that a degree of geological prospecting and planning went into the choice of campsite location in advance. The size of the campsites suggest that a relatively small number of workers did the mining of these sites in sequence rather than simultaneously, and possibly stretched over many months. This added to the need for campsites which could function with some areas of specialisation such as mineral processing (crushing and grinding), as well as cooking and support activities for the workforce. In general, the larger sites consisted of 15-20 or so huts, perhaps suggesting a possible workforce numbering in the range of 20-50.

The 2003 images revealed the imprint of ancient trackways and the direct links from the sites to Soleb and Sesebi including way-stations along the major routes. Further ground-truthing may also reveal whether well-structures are included in any of the campsite remains.

EAMENA Process

A framework such as that developed by EAMENA is essential for satellite image analysis. The database has captured details on the positioning, description, interpretation and risk of each archaeological feature.

However, the application of the EAMENA approach has highlighted a number of drawbacks in applying the method. It was to be expected that the descriptors would require expansion to capture certain mining terms. During data gathering it became clear that 'notes' were also required to describe aspects – particularly in the 'change' being recorded. A subsequent study would benefit from reviewing the notes, with consideration given to expanding the descriptors to encompass the more frequently used terms.

Within a study of this type there is considerable repetition in the recording. For it to be comprehensive this is not surprising, but there was a challenge in finding the balance between capturing purely archaeological features and describing the natural features – especially when several grids were largely desert.

The survey approach worked best when informed by field experience and benchmarks, such as in identifying known mining sites or change as a result of mining activity. It also worked well when combined with available field survey work to cross-reference against sites. One challenge is the volume of data generated even in a single regional study, so improved design of the data base allowing greater ability to interrogate the data is essential for future work. Certainly, the methodology, while not a full substitute for ground truthing, has captured an extensive network of ancient mining operations in the region of the Gorgod Hills and, given the impact of recent artisanal mining, these ancient sites might otherwise have remained unrecorded.

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Bibliography

Altaweel, M. 2005. 'The Use of ASTER Satellite Imagery in Archaeological contexts', *Archaeological Prospection* 12, 151-166.

Bewley, R., A. I. Wilson, D. Kennedy, D. Mattingly, R. Banks, M. Bishop, J. Bradbury, E. Cunliffe, M. Fradley, R. Jennings, R. Mason, L. Rayne, M. Sterry, N. Sheldrick, and A. Zerbini 2016. 'Endangered Archaeology in the Middle East and North Africa: Introducing the EAMENA Project', in S. Campana, R. Scopigno, G. Carpentiero, and M. Cirillo (eds), *CAA2015. Keep the Revolution Going: Proceedings of the 43rd Annual Conference on Computer Applications and Quantitative Methods in Archaeology*. Oxford, 919-932.

Bloxam, E. G. and P. Storemyr 2002. 'Old Kingdom Basalt Quarrying Activities at Widan el-Faras, Northern Faiyum Desert', *Journal of Egyptian Archaeology* 88, 23-36.

Bloxam, E. G. 2010. 'Quarrying and Mining (Stone)', in W. Wendrich, *UCLA Encyclopedia of Egyptology*. Los Angeles.

Davies, B. G. 1999. *Who's Who at Deir el Medina: A prosopographic study of the Royal Workmen's Community*. Nederlands Instituut voor het Nabije Oosten. Leiden.

Fairman, H. W. 1938. 'Preliminary Report on the Excavations at Sesebi (Sudla) and Amarah West, Anglo-Egyptian Sudan, 1937-8', *Journal of Egyptian Archaeology* 24, No. 2, 151-156.

Goosens, R, A. de Wulf, J. Bourgeois, W. Gheyle and T. Willems 2006. 'Satellite imagery and archaeology: the example of CORONA in the Altai Mountains', *Journal of Archaeological Science* 33, 745-755.

Killick, D. 2013. 'Gold and Gold Mining in Ancient Egypt and Nubia', *Azania: Archaeological Research in Africa* 48, No. 4, 539-541.

Killick, D. and T. Fenn 2012. 'Archaeometallurgy: The Study of Preindustrial Mining and Metallurgy', *Annual Review of Anthropology* 41, 559-575.

Klemm, D., R. Klemm and A. Murr 2001. 'Gold of the Pharaohs – 6000 years of gold mining in Egypt and Nubia', *Journal of African Earth Sciences* 33, 643-659.

Klemm, D, R Klemm, and A. Murr 2002. 'Ancient Gold Mining in the Eastern Desert of Egypt and the Nubian Desert of Sudan', in R. Friedman (ed.), *Egypt and Nubia, Gifts of the Desert*. London.

Klemm, R. and D. Klemm 2013. *Gold and Gold Mining in Ancient Egypt and Nubia: Geoarchaeology of the Ancient Gold Mining Sites in the Egyptian and Sudanese Eastern Deserts*. Heidelberg.

Kroner, A. and R. J. Sterne 2004. 'Pan African Orogeny', in R. C. Selley, L. R. M. Cocks and I. R. Plimer (eds), *Encyclopedia of Geology* Vol. 1. Amsterdam.

Lesko, B. S. 1994, 'Rank Roles and Rights', in L. H. Lesko (ed.), *Pharaoh's Workers: The Villagers of Deir el-Medina*. Cornell.

McDowell, A. 1992. 'Agricultural Activity by the Workmen of Deir el-Medina', *Journal of Egyptian Archaeology* 78, 195-206.

McDowell, A. 1994. 'Contact with the outside world', in L. H. Lesko (ed.), *Pharaoh's Workers: The Villagers of Deir el-Medina*. Cornell.

McLean, I. (in preparation). 'Loss of Heritage in the 18th Dynasty Mining Region of the Gorgod Hills between Soleb and Sesebi'.

Montufo, A. M. 1997. 'The Use of Satellite Imagery and Digital Image Processing in Landscape Archaeology. A Case study from the Island of Mallorca, Spain', *Geoarchaeology* 12, No. 1, 71-85.

Osman, A. and D. N. Edwards 2012. *Archaeology of a Nubian Frontier: Survey on the Nile Third Cataract, Sudan*. Leicester.

Parcak, S. and G. Mumford 2012. 'Satellite Imagery Detection of a Possible Hippodrome and Other Features at the Ptolemaic-Roman Port Town of Taposiris Magna', *Journal of Ancient Egyptian Interconnections* 4, No. 4, 30-34.

Ramage, R, P. Craddock and M. R. Cowell 2000. *King Croesus' Gold: Excavations at Sardis and the History of Gold Refining. Vol. 11*. London.

Shaw, I. 1994. 'Pharaonic quarrying and mining: settlement and procurement in Egypt's marginal regions', *Antiquity* 68, 108-119.

Shaw, I. 1998. 'Exploiting the desert frontier, The Logistics and politics of ancient Egyptian mining expeditions', in B. A. Knapp., V. Pigott and E. W. Herbert (eds), *Social Approaches to an Industrial Past: The Archaeology and Anthropology of Mining*. London.

Shaw, I. 2007. 'Late Roman Amethyst and Gold Mining at Wadi el-Hudi', in T. Schneider and K. Szpakowska (eds), *Egyptian Stories. A British Egyptological Tribute to Alan B. Lloyd on the Occasion of His Retirement*. Alter orient und Altes Testament 347. Münster, 319-328.

Shaw, I. 2010. *Hatnub: Quarrying Travertine in Ancient Egypt*. Egypt Exploration Society Excavation Memoir 88. London.

Shaw, I., E. Bloxam, T. Heldal and P. Storemyr 2010. 'Quarry and landscape at Gebel el-Asr in the Old and Middle Kingdoms', in F. Raffaele, M. Nuzzolo and I. Incordino (eds), *Recent Discoveries and Latest Researches in Egyptology: Proceedings of the First Neopolitan Congress of Egyptology, Naples June 18th-20th 2008*. Wiesbaden, 293-312.

Spence, K., P. Rose, J. Bunbury, A. Chapman, P. Collet, G. Smith and N. Soderberg 2009. 'Fieldwork at Sesebi', *Sudan & Nubia* 13, 38-47.

Spence, K. and P. Rose 2014. 'Fieldwork at Sesebi 2010', in J. R. Anderson and D. A. Welsby (eds), *The Fourth Cataract and Beyond. Proceedings of the 12th International Conference for Nubian Studies*. Leuven – Paris – Walpole, MA, 409-415.

Spence, K., P. Rose, R. Bradshaw, P. Collet, A Hassan, J. MacGinnis, A. Masson and P. van Pelt 2011. 'Sesebi 2011', *Sudan & Nubia* 15, 34-38.