An integrated model of the geomorphological and topographic landscape of the necropolis at Dra Abu el-Naga

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ABSTRACT

This paper describes the archaeological, topographical and geomorphological survey and modelling of the topography of Dra Abu el-Naga from prior to the building of the New Kingdom tombs until today. The ancient topography of Dra Abu el-Naga has been reconstructed, offering a more accurate and complete image of this part of the necropolis for the study of its organisation, and the distribution and placement of the tombs.

This work opens up new lines of investigation into the landscape of the necropolis and this approach could be productively applied to other ancient Egyptian tombs, necropolises and funerary landscapes in general.

KEYWORDS

archaeological survey – Differential-GPS – Dra Abu el-Naga – landscape modelling – Geographic Information Systems

نموذج متكامل للمشهد الجيومورفولوجى والطبوغرافى لجبانة ذراع أبو النجا

أنجيليس خيمينيز-هيغيراس – ديفيد غارسيا-غونزاليس – هانا بيثن – ليز جونز – تيريزا بارديا – أنطونيو مارتينيز – سيرجيو سانشيز-مورال

الملخص

تصف هذه الورقة المسح الأثرى والطبوغرافي والجيومورفولوجي ونمذجة تضاريس منطقة ذراع أبو النجا منذ الفترة ما قبل عصر تشييد مقابر الدولة الحديثة وحتى يومنا هذا. تم إعادة بناء التضاريس القديمة لذراع أبو النجا، وهو الأمر الذى يوفر صورة أكثر دقة واكتمالًا لهذا الجزء من جبانة الأقصر القديمة لدراسة تنظيمها وتوزيع ووضع المقابر بها.

يفتح هذا العمل خطوطًا جديدة للبحث فى التضاريس القديمة للجبانة ويمكن تطبيق هذا النهج بشكل فعال على المقابر المصرية القديمة الأخرى والجبانات والمواقع الجنائزية بشكل عام.

الكلمات الدالة

المسح الأثرى – GPS -تفاضلى – دراع أبو النجا – نمذجة المناظر الطبيعية – نظم المعلومات

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Dra Abu el-Naga, at the northern end of the Theban necropolis, has seen human activity since prehistoric times. By the Middle Kingdom it formed part of the necropolis for the local elite (Betrò – Del Vesco – Miniaci 2009: 14–33) and was the burial place for the local Theban rulers during the Second Intermediate Period (Polz *et al.* 2003: 317–388; Polz 2003: 12–15). Archaeological investigations have taken place at Dra Abu el-Naga since the 19th century and important archaeological research continues in this area (Jiménez-Higueras 2020: 10–14).

Like many other sites (Bitelli – Girelli –Tini – Vittuari 2006: 15–21; Capriotti Vittozzi – Angelini – Iacoviello 2018: 221–232; Chiesi – Davoli – Occhi – Raimondi 2012: 23–29; Fenwick 2004: 880–885; Fenwick 2005: 20–21; Giorgi and Buzi 2011: 175–180; Goosens, De Dapper and De Paepe 1997: 13–20; Hinojosa Baliño 2019: 44, 50; Jeffreys 2003: 1–18; Jeffreys 2020: 197–213; Jeffreys – Tavares 1994: 143–173; Jones – Pethen 2012: 45–54; Kemp – Garfi 1993; Lauffrey – Sauneron – Anus 1981: 491; Mathieson – Dittmer 2007: 79–93; Mills 1988: 6–7; Papi – Bigi – Camporeale – Carpentiero – D'Aco – Kenawi – Mariotti, – Passalacqua 2010: 239–250; Schiestal 2016: 172; Spencer 1974: 1–11; Strutt 2016: 75–77; Tavares 2011: 203–216; Tavares 2020: 252–265; Trampier 2014: 81; Weeks 1989: 286–287), there has been a long history of archaeological and cartographic survey in the Theban necropolis, but the many different cartographic resources produced since then are all insufficient, for one reason or another, for the requirements of the modern missions working at Dra Abu el-Naga or any further landscape-archaeological analysis.

"Landscape" is recognised as a highly complex concept, that includes space and topography as well as the embodied human experience of that space and topography and its incorporation into human life and relationships (Anschuetz *et al.* 2001; David – Thomas 2008; Ingold 1993; Knapp – Ashmore 1999; Pethen 2012; Pethen 2023; Thomas 2001: 165–168; Wilson – David 2002: 5–8). Nevertheless, before it is possible to consider landscape as an embodied or experienced space, it is necessary to determine the physical topography that forms its underlying foundation. Any future landscape-archaeological analysis of Dra Abu el-Naga would therefore require a reliably and consistently surveyed topographic and cartographic record of Dra Abu el-Naga and its archaeological structures. This research is intended to provide that consistently surveyed topographic and cartographic model of the extant and, as far as can be reconstructed, ancient topography and geomorphology, precisely locating each tomb and its elements (pylons, courtyard, entrance, superstructure) and situating the whole in a model of the entire Theban area.

In 2013, a formal application was presented to the then Egyptian Ministry of Supreme Antiquities (MSA) to request official permission to carry out a surveying campaign, consisting of a micro-topographical survey and a geomorphological-geological study at the southern end of Dra Abu el-Naga. This survey was approved and the fieldwork was carried out from 24th February to 4th April 2013 by a group of cartographers, archaeologists, surveyors, geologists and geomorphologists. The data were interpolated to create the digital elevation model (DEM) necessary for future research analyses. This DEM included a complete reconstruction of the area in the New Kingdom and a model of the changes to that topography, from prior to construction of the New Kingdom tombs to the present day. To contextualise this research, enable integration with other missions and undertake future research into the inter-visibility and movement around the necropolis, the survey data from Dra Abu el-Naga were subsequently integrated into a digital elevation model of the entire Theban area.

METHODS AND MATERIALS

This interdisciplinary project combined archaeological research and survey, archival cartographic research, micro-topographical, geomorphological and geological survey to construct a DEM of Dra Abu el-Naga (south) and model the evolving Dra Abu el-Naga topography from the original ground surface to the present day. Following initial archival research into existing cartographic resources, archaeological, micro-topographic, geomorphological, and topographic survey took place during fieldwork in 2013. Subsequently, the topographic survey data was used to create a digital elevation model (DEM) of the survey area in geographic information system (GIS) software.

CARTOGRAPHIC RESOURCES

Detailed cartographic records of Dra Abu el-Naga are lacking and each mission currently working there makes their own plans and maps, using different criteria and coordinate systems, usually without communication or data-sharing. Many areas of Dra Abu el-Naga are not currently being investigated and have not been cartographically recorded since the demolition of the village on the site. In the absence of good, recent cartographic data and a consistent grid system for the Theban necropolis, it is difficult for the different missions to pool knowledge, share data, or relate their results to those of other excavators, past and present. It is also impossible to undertake detailed landscape-archaeological investigations without detailed, reliable data on the underlying physical topography. High quality plans of the area as it is now, precise tomb coordinates, and detailed topographic data on a consistent coordinate system, are urgently needed for all the missions working in the area.[2]

A small number of existing historical maps, drawings, plans, satellite images and topographical data from missions working in this area supplemented the data from the fieldwork. These sources are described below, together with how they have been incorporated into this research.

The earliest maps of the Theban necropolis, including the Description de l'Égypte (French Commission des sciences et arts d'Égypte 1809–1822) and Wilkinson's map (1830)[3] provided little useful information. Baraize (1904)[4] did not even include Dra Abu el-Naga. The Survey of Egypt 1:1000 scale maps of the complete Theban necropolis (Survey of Egypt 1924–1926) were the earliest useful cartographic record of Dra Abu el-Naga (folios C6–D6).[5] These maps show the topography with 2 m contour lines, the buildings and infrastructure; the tombs, funerary

2 Ideally the results and records produced by this research project would be used by each of the missions working in the area, with the intention of creating a unified system and consistent data across all the missions.

3 This map was checked at the Bodleian Library in Oxford during a research visit at Oxford University. We are very grateful to the Library for allowing us to use the Special Collection section.

4 This set consisting of 61 maps with a 1:500 scale was checked at the Bodleian Library in Oxford during a research visit at Oxford University. We are very grateful to the Library for allowing us to use the Special Collection section. Other maps checked in Oxford which included the research area were: *Western Thebes*, scale 1:10000 and *Luxor and Thebes*, scale 1: 1000000.

5 This set of maps was first checked at the Egypt Exploration Society Archive in London, for which we are very grateful to the then EES director, Chris Naunton. A high-quality digital copy of this map was purchased from ‚The National Archives', to be used by this project, by the Sydney Jones

temples, and the excavation areas labelled by institution. They provided important topographic information in areas where archaeological and topographic survey was impractical and supplemented the survey data. Two further Survey of Egypt folios named *Qurna* (Survey of Egypt 1922) and *Luxor and Karnak* (Survey of Egypt 1922) were created in 1922 at a 1:10000 scale, and published as tourist editions. These were used to complete the areas (specifically the mountain, El Qurn, and the East bank of the river Nile where Luxor and Karnak temples are located) omitted from the 1:1000 scale Survey of Egypt maps.

Despite their detail and accuracy these maps present several problems. They were created in the 1920s and, consequently, showed the topography of the area at that time. This included the changes to the topography of the New Kingdom necropolis resulting from the numerous historic and more recent excavations in the area. Excavations continued after the maps were completed, so the topography shown in them has no exact correlation with modern areas and the tombs that have been discovered since the completion of the maps are not recorded upon them. The Survey of Egypt maps also include the houses and other structures of the modern village covering parts of the ancient topography. The village and its inhabitants were moved by the Egyptian government in 2006–2007, and the buildings demolished, although the resulting debris was not removed (Bednarski – Tully 2020: 508–522; Simpson 2003: 244–249; Tully – Hanna 2013: 362–397; Van der Spek 2016: 567–581).[6] This demolition led to the discovery and subsequent study of previously obscured funerary structures (Abou Zaid – El-Asfar – Ezz *et al.* 2015: 71–77), even as the accumulated debris altered the topography further. Nevertheless, the Survey of Egypt 1:1000 scale map was used for planning the fieldwork and to contribute to the DEM. The Survey of Egypt data was essential since the collection of topographic survey data across such a vast area as the Theban Necropolis, was very complicated.

Kampp provides a map of the tombs at Dra Abu el-Naga discovered up to 1996 with their location and a plan of their layout (Kampp 1996: plans VI–VII). However, this map can only be used as a reference for tomb locations and numbering as it is not topographically accurate, and the tombs are not drawn to scale. Kampp's plans were, therefore, used to locate the tombs and provide digital plans of the tomb interiors, as access to the interior of the tombs fell outside the scope of the fieldwork.

Numerous aerial photos and satellite images, obtained as free Google Earth imagery, offer valuable information on the archaeological sites over the last 50 years. The purchase of bespoke high resolution satellite imagery was beyond the budget of this research, but two sets of Quickbird satellite images were kindly offered to our survey project by the American Research Center in Egypt,[7] and the Spanish Mission TT11–TT12.[8] These are particularly valuable to the

Library in Liverpool thanks to a University fund. We are very grateful to the Sydney Jones Library and especially to Martin Wolf through whom this acquisition was made possible.

6 In 2015, after the completion of our fieldwork, the debris was removed and the area cleaned by the American Research Center in Egypt.

7 These Quickbird satellite images were purchased from Space Imaging Middle East and consist of panchromatic standard imagery of 50 cm resolution, dated 2nd November 2011, and a natural colour standard image of 50 cm of resolution, dated 6th August 2010 and 26th July 2010. Both images included an area of 25 km^2. The Dra Abu el-Naga south survey team are grateful to the then associate-director of ARCE at Luxor, John Shearman, and to his then assistant Andrew Bednarski.

8 Two Quickbird images from 2004 (kindly offered by the 'Spanish Mission TT11–TT12'). One of them is a general view that includes the area from the Ramesseum to Carter House; and the

project since they are of higher resolution and better quality than many of the other satellite images and they are also projected on a stable coordinate system, which is compatible with the rest of the data held in the GIS. The project also made use of high resolution black and white photographic imagery from the CORONA KH-4b satellite (September 1967 to May 1972), whose best resolution is 2 m and typical ground coverage is 12.1 km.[9] The satellite images were used to locate the tombs and document changes to the necropolis over the last 50 years. Five additional maps of the research area were obtained from CAMEL, consisting of a map series produced by the Survey of Egypt at varying scales from 1:5000 to 1:100000.

TOPOGRAPHICAL AND ARCHAEOLOGICAL DGPS SURVEY

The archaeological, topographic, geomorphological and geological survey was undertaken at the southern end of Dra Abu el-Naga from 24th February to 4th April 2013. The aims of the Dra Abu el-Naga survey included recording precise geographic coordinates for the tombs of Dra Abu el-Naga south, from el-Birabi up to el-Ateyat and generation of topographic survey data for a DEM of the area.

The survey used differential Geographic Positioning System (GPS) and Total Station survey equipment to locate tombs, features and topographical survey points with precise geographical coordinates. Fig. 1 shows how the survey contributed to and improved understanding of the archaeological remains across Dra Abu el-Naga south, and a DEM of the study area. The data were processed in Leica GeoOffice and exported and analysed in ArcGIS.

DIFFERENTIAL GLOBAL POSITIONING SYSTEM SURVEY

Data were recorded with a Differential Geographic Positioning System (DGPS), using Real-Time Kinematic (RTK) GPS kit. This equipment uses Global Navigation Satellite Systems (GNSS) receivers capable of processing L1 and L2 GPS bands and other satellite navigation systems.[10] The RTK method used two receivers: a reference receiver set up at a control (base) station with known coordinates, and a roving receiver (rover), which moved around collecting data. The reference receiver provided the rover with a set of corrections for navigation errors, based on a comparison between the known coordinates for the reference receiver and those based on the satellite data.[11] The reference receiver comprised a Leica GNSS 1200 receiver with an AX1202 GG antenna for collecting information from satellites. Each rover comprised an ATX1230 GG smart antenna and an RX1250 controller. The reference receiver and rover communicated using Satelline 3AS radios.

second is a detailed image of Dra Abu el-Naga. We are very grateful to José Galán for all his help and support.

9 These georeferenced images were kindly supplied by the Center for Ancient Middle Eastern Landscapes (CAMEL) of the Oriental Institute of Chicago. We are very grateful to Elise V. MacArthur from CAMEL for all her help and support.

10 Currently the main alternative GNSS system to the United States GPS system, is the Russian Aerospace Agency's Global Navigation Satellite System (GLONASS). The European Space Agency's Galileo system, and China's Compass systems are under development according to Uren and Price (2010: 254–255).

11 For a more detailed discussion of this method, see Uren and Price (2010: 256–282).

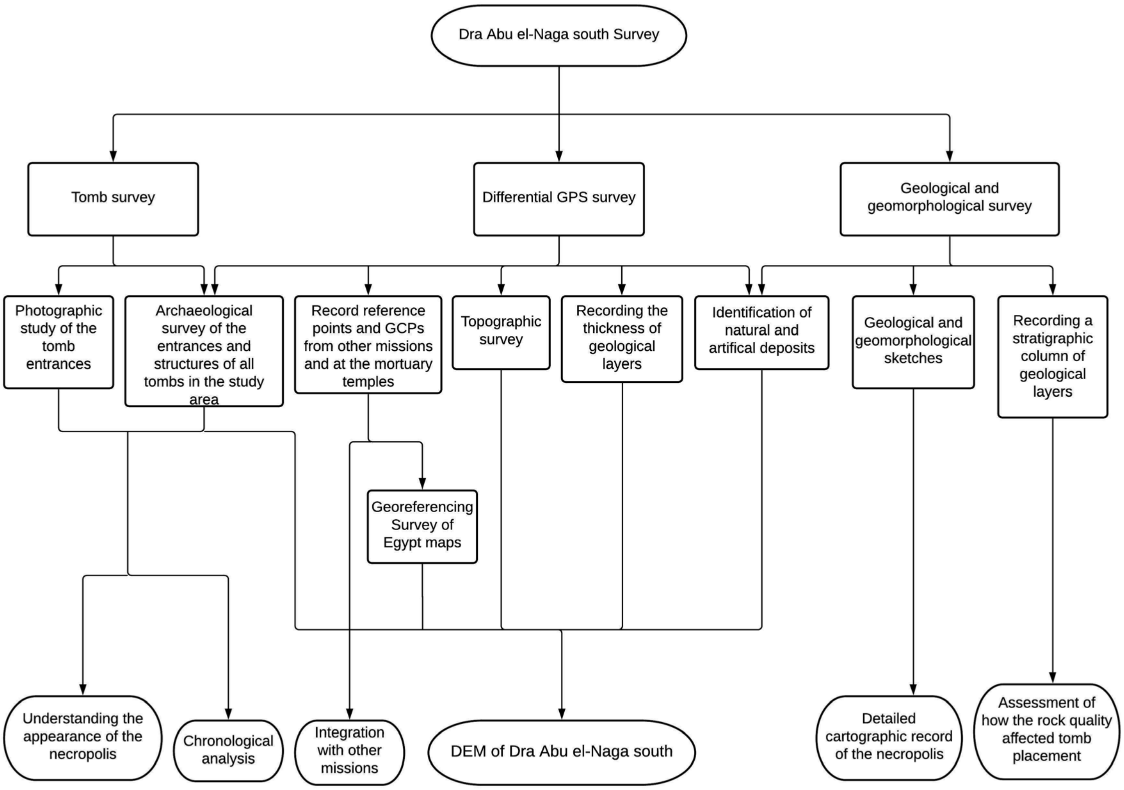

Fig. 1 Workflow of the Dra Abu el-Naga Survey

The RTK kit used the World Geodetic System 1984 (WGS84) geographic coordinate system and the GRS80 ellipsoid (Uren and Price 2010: 314; U.S. National Geospatial Intelligence Agency 2023). The WGS84 coordinates were projected in the Geographic Information System (GIS) software using the Universal Transverse Mercator zone 36 north (UTM36N) coordinate system, which converts geographic coordinates onto a flat plane using a Transverse Mercator projection (Morton n.d.; Conolly and Lake 2006: 20–21; NGA 2002; NGA 2014). The UTM projection is ideal for this project because it is conformal, results in minimal distortion of scale and distance, and has a metric coordinate system, allowing data to be easily analysed, compared and presented using GIS software.[12] Heights above mean sea level were obtained from the WGS84 ellipsoidal heights using the EGM2008 geoid (Uren – Price 2010: 311–312).

CONTROL STATIONS

To establish control coordinates for the reference receiver, six control stations (fig. 2 and fig. 3) were located to ensure full coverage of the survey area: five across Dra Abu el-Naga south (see fig. 3), and one at the Theban Harbours and Waterscapes Project control point on top of the Marsam hotel (fig. 2).

12 Conformal map projections preserve the 90° angle between lines of latitude and longitude and therefore the angles between other features on the ground (Conolly – Lake 2006: 20).

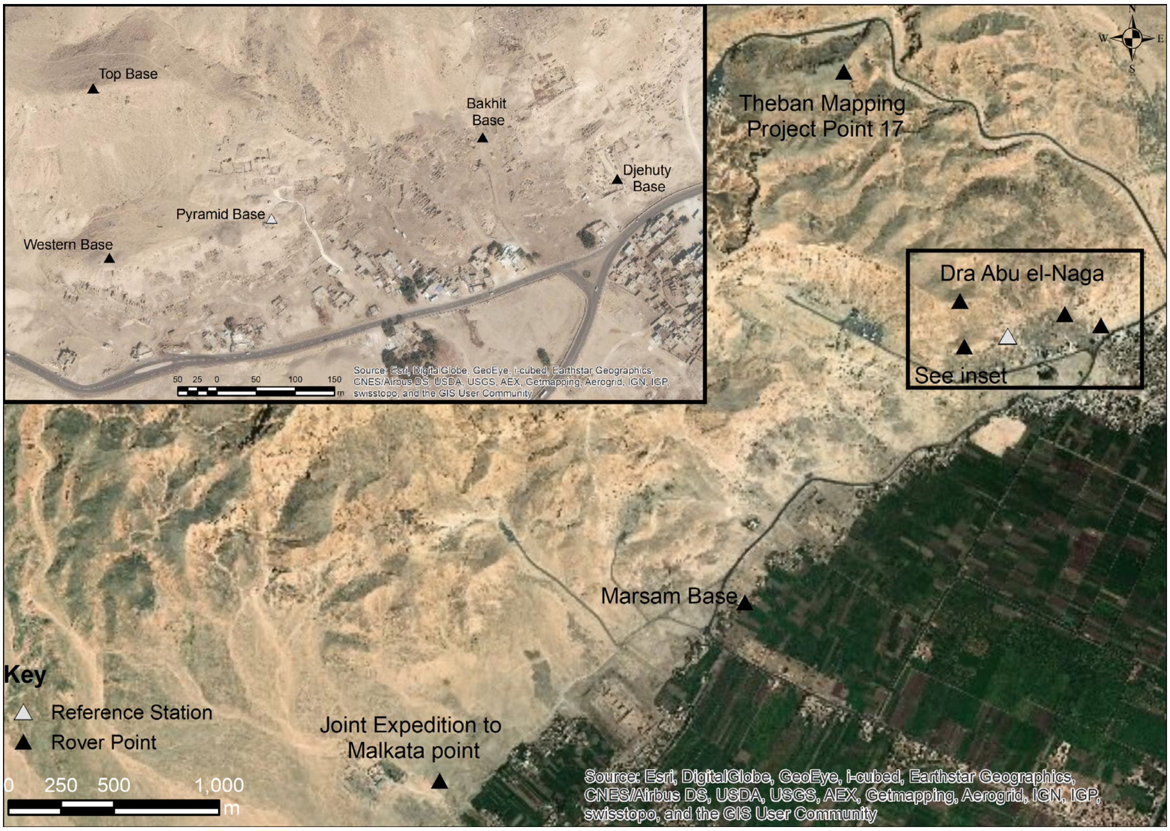

Fig. 2 Control stations of the Dra Abu el-Naga survey project and two other points occupied during the static survey

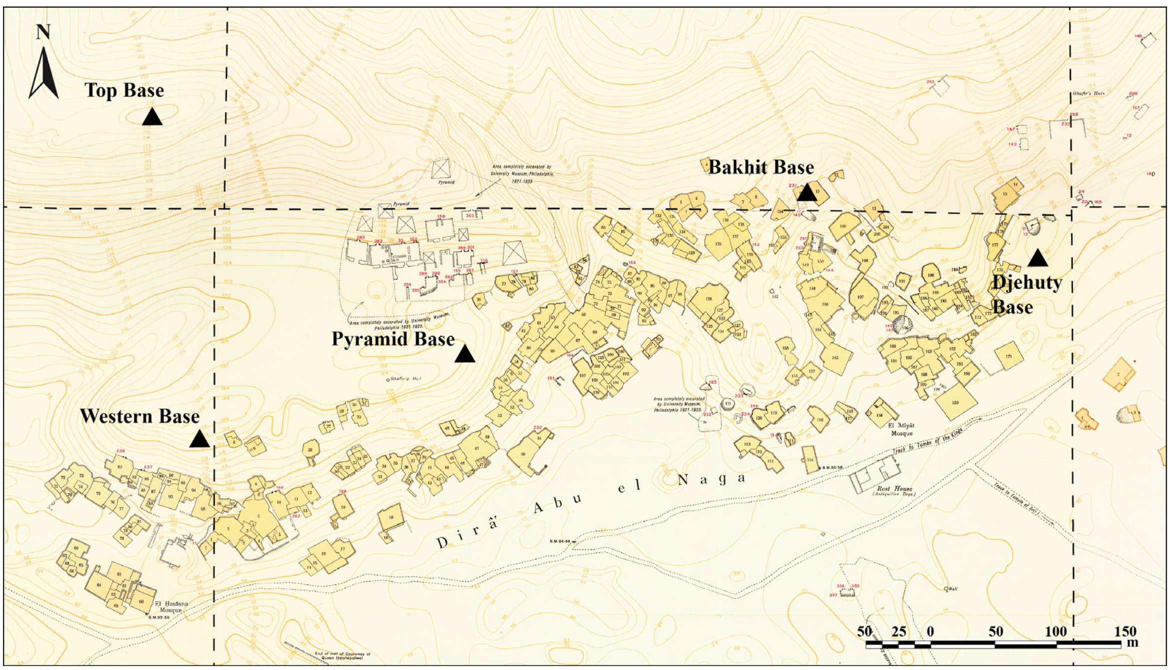

Fig. 3 Location of the control stations at Dra Abu el-Naga south, shown with reference to the Survey of Egypt 1:1000 scale map of the Theban Necropolis, 1921–1926

The first control station was named 'Djehuty Base' because it was in front of the tomb of Djehuty (TT11), on a control point used by the Spanish-Egyptian mission at TT11–TT12. When the Dra Abu el-Naga south survey was initiated, it was not possible to obtain precise geographic or projected coordinates for any suitable base station. There are only a limited number of datum points with known coordinates in the Theban necropolis and where datum points were present in a suitable location, coordinates were either unavailable, or were insufficiently defined for an RTK survey. The geographic coordinates of the Djehuty Base control point were initially fixed using the navigation solution on the morning of 2nd March 2013, to permit data to be reviewed during the survey. The final coordinates would ultimately be determined using Precise Point Positioning (PPP) during post-processing after the completion of the survey.[13] Until the completion of the PPP process, the precision of the coordinates for this control point was anticipated to be within 10 m of the horizontal and 20 m of the vertical (Royal Institute of Chartered Surveyors 2010). Whilst RTK methods can establish fairly high precision between the reference station and rover points, the accuracy of the latter will be dependent on the accuracy of the coordinates of the reference station, with errors in that point propagating through all subsequent measurements to the rovers (fig. 3).

RTK AND TOTAL STATION SURVEY

RTK was used wherever possible because it provided an appropriate balance of accuracy and speed for recording multiple archaeological and topographic features, but it could not record archaeological features that were too dangerous to access physically or where the equipment lacked satellite signal. These features were typically deeply located tombs or high façades and were recorded with a combination of RTK and total station. The coordinates of two secondary control points were established with RTK and used as setup and reference (backsight) objects for the total station survey (fig. 4). Data was captured using a pole mounted prism wherever possible, but inaccessible points were recorded by the total station in reflectorless mode. The survey used a Topcon GPT700si total station.

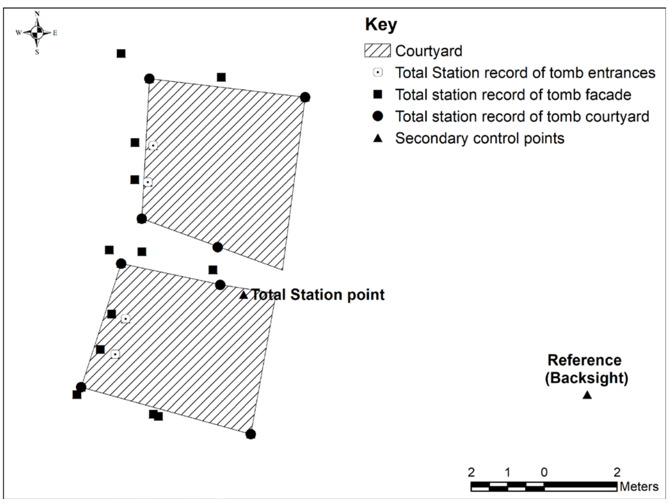

Fig. 4 Method of surveying inaccessible or dangerous tombs using a combination of DGPS and a total station

13 For a description of the PPP techniques, see the subsequent section on post-processing the positions of the control stations.

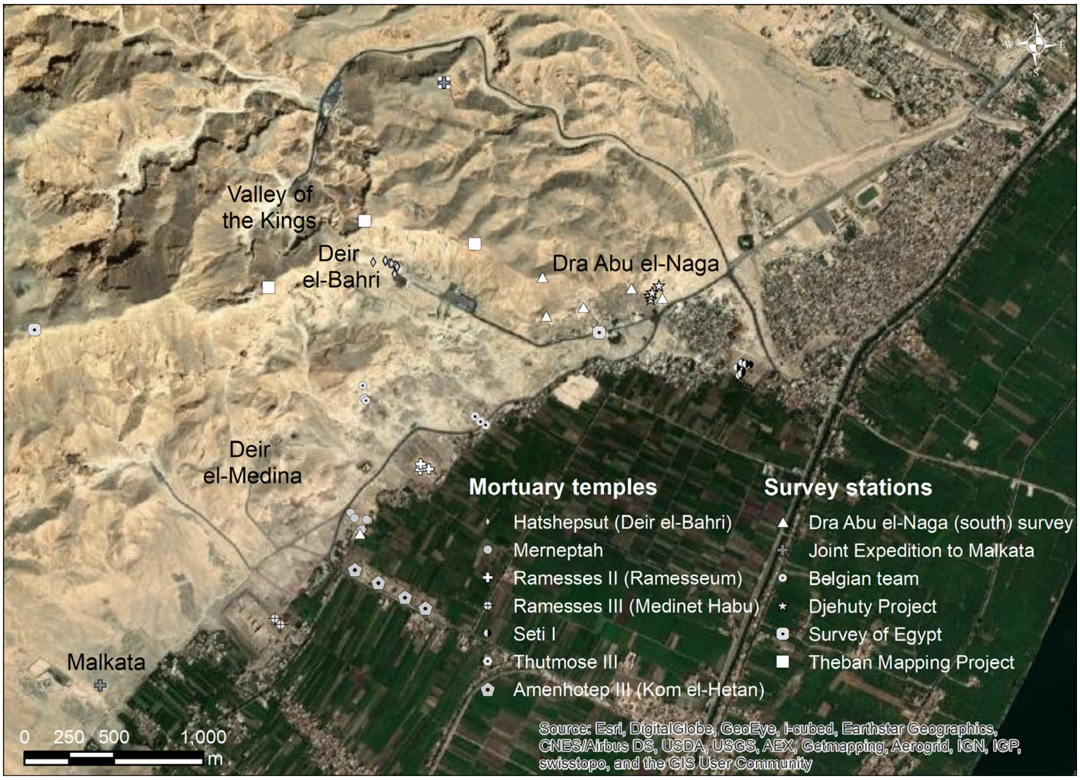

Fig. 5 Location of the Dra Abu el-Naga survey control stations, control points taken in the mortuary temples and those of other missions working in the Theban area

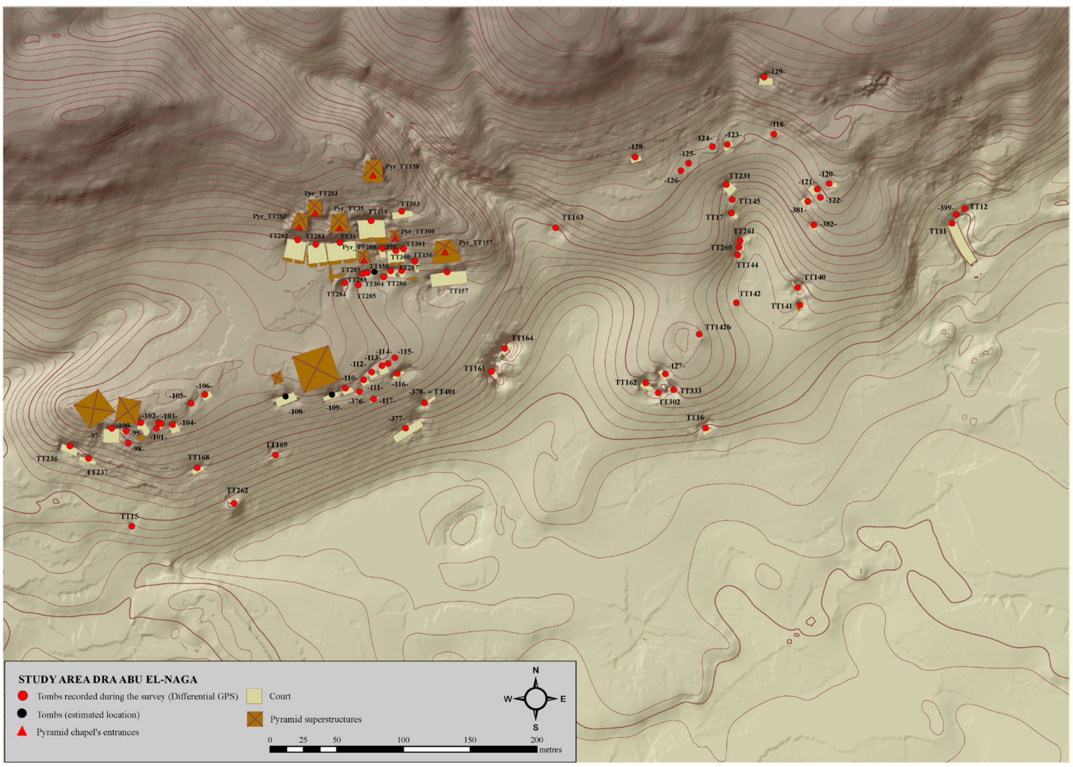

Fig. 6 DEM of the study area, Dra Abu el-Naga south, with the location of New Kingdom tombs

TOMB AND TEMPLE SURVEY

The survey recorded precise geographic coordinates for the tombs of Dra Abu el-Naga south from el-Birabi up to el-Ateyat.[14] The entrances, external structures, façades, and the entrances of mudbrick pyramid chapels were all recorded. Points were taken across the surviving mudbrick pyramids permitting a volumetric analysis of the pyramids to be undertaken in the GIS software. The DGPS point data was used to create ArcGIS polygons for the structures associated with each tomb, courts, mudbrick pyramid, pylons and walls. This is the first time such precise coordinates have been obtained for the 79 surveyed tombs, of which 59 had surviving external structures (see fig. 6).

To permit existing plans of the Mansions of Million of Years (also commonly known as 'Mortuary Temples') and Survey of Egypt maps to be georeferenced in GIS, the survey recorded existing control stations at Kom el-Hetan and the temple of Thutmose III with the permission and assistance of the current expeditions. Fixed features were recorded within the Mansions of Million of Years of Amenhotep III (Kom el-Hetan), Seti I, Ramesses II (Ramesseum), Hatshepsut (Deir el-Bahri), Thutmose III and Merneptah (fig. 5).

To improve data consistency and quality control across the Theban Necropolis, control points associated with other projects were also occupied by RTK to provide more accurate UTM36N coordinates and assist in future collaboration (fig. 5). In addition to the Mansions of Million of Years of Kom el-Hetan and Thutmose III, the Theban Harbours and Waterscapes Project, the Joint Expedition to Malkata (JEM), the Belgian Mission in the Theban Necropolis, the Spanish Mission TT11–TT12, Theban Mapping Project and Survey of Egypt points were also captured in the survey.

POST-PROCESSING WITH PPP

With no known control stations in the area and without access to data from Continuously Operating GNSS Receivers (COGRs), the raw observations from the RTK Survey required post-processing to achieve a satisfactory level of accuracy. Precise Point Positioning (PPP) techniques were used to fix the coordinates of the control stations and subsequently update the coordinates of all the surveyed points.

The data was processed through the Canadian Spatial Reference System (CSRS) Precise Point Positioning (PPP) tool (Natural Resources Canada 2021) and also through the Jet Propulsion Laboratory's Automatic Precise Positioning Service (APPS) as a consistency check (NASA Jet Propulsion Laboratory n.d.).

Table 1 shows the PPP results of the RTK control stations, observed at a 1 second epoch rate, as Cartesian coordinates in WGS84 with units in metres. For most of the control stations the uncertainty in the position (the standard deviation) is less than 14 mm in X, 11 mm in Y and 9 mm in Z. The Mean Radial Spherical Error (MRSE) gives an indication of the quality of the 3D point.[15] These results are satisfactory and fit-for-purpose for the Dra Abu el-Naga south survey project.

14 The survey focused on the southern area of Dra Abu el-Naga but the tombs TT11, TT12 and -399- were also included, permitting comparison of the southern and northern areas.

15 In table 1 the given level of probability for the MRSE is 61%.

Station ID	Duration	East X	North Y	Up Z	standard deviation X	standard deviation Y	standard deviation Z	MRSE 61%
Pyramid Base	5h38'52"	4842404.9620	3099131.711	2752772.697	0.0137	0.0107	0.0082	0.01681577
Djehuty Base	6h23'56"	4842123.2140	3099475.7980	2752805.3350	0.0120	0.0094	0.0071	0.01922030
Western Base	6h24'55"	4842538.4970	3098971.4410	2752728.6830	0.0119	0.0089	0.0071	0.01646906
Top Base	7h40'43"	4842513.8650	3098929.8760	2752948.7110	0.0119	0.0089	0.0071	0.01646906
Marsam Base	6h15'54"	4843510.2750	3098359.2690	2751612.6500	0.0126	0.0093	0.0075	0.01736376
Bakhit Base	2h08'25"	4842210.8410	3099327.4150	2752861.0180	0.0285	0.0229	0.0172	0.04040421

Tab. 1 Coordinates of the control stations processed by PPP (all measurements in metres)

STATIC SURVEY

At the end of the project, the control stations were also acquired using rapid static surveying techniques, as a gross error check for the PPP and to incorporate, for comparison, control stations collected by Joel Paulson of the Joint Expedition to Malkata (fig. 5). At 'Pyramid Base' the reference receiver logged data at an epoch rate of 20.0 seconds for 9 hours. Whilst this was logging, the rovers recorded 10 minutes of data, at the same epoch rate, at each of the control stations at Dra Abu el-Naga south, Malkata and TMP17 above the road to the Valley of the Kings (see fig. 2). Both receivers are usually tripod-mounted, but, at Dra Abu el-Naga, there was only one tripod available, so the rover receivers were pole-mounted.[16] This introduced errors into the survey and reduced the occupation time because the rovers had to be held.

The static survey results were post-processed twice, with Pyramid Base as a fixed location. In the second processing the position of Pyramid Base was improved with PPP (hereafter referred to as PPP-SS), improving the standard deviations of the station coordinates from around the 3 m level to 0.02 m. Overall the data from the RTK survey after PPP were the most reliable because the occupations were much longer, the equipment was tripod-mounted and the positions were derived from high precision clock and ephemeris data. The PPP-SS results show good agreement with the PPP-RTK ones and produced positions only 0.02 m from the PPP-RTK ones. Static Survey without PPP of Pyramid Base were much less accurate, being 1.4 m from the PPP-RTK positions, stretching to up to 8 m away if a navigated (code only) solution is used. Table 2 gives the UTM36N coordinates of the control stations as exported from Leica GeoOffice after PPP-RTK.

UPDATED SURVEY DATA FOLLOWING POST-PROCESSING

Since the coordinates of the survey data were determined by reference to the control stations during the RTK survey, improved coordinates for the control stations derived by PPP were used to improve the accuracy of the survey points (table 3). To achieve this, the coordinates of the control stations used during the survey were manually changed in Leica GeoOffice 7 to the

16 For more details of Static Survey practice see RICS 2010, table D2.

Survey Method	Duration	Epoch Rate	East X	North Y	Up Z	standard deviation X	standard deviation Y	standard deviation Z	magnitude of error vector
PPP-RTK	6h23'56"	1s	4842123.2140	3099475.7980	2752805.3350	0.0120	0.0094	0.0071	–
PPP-SS	0h10'0"	20s	4842123.2062	3099475.7806	2752805.3248	0.0015	0.0010	0.0008	0.0216
SPP	6h23'56"	1s	4842123.9511	3099475.8523	2752805.2259	0.0117	0.0095	0.0075	0.7471
NoPPP-SS	0h10'0"	20s	4842124.1426	3099475.8358	2752806.4252	0.0015	0.0010	0.0008	1.4326
NAV-RTK	6h23'56"	1s	4842127.1740	3099475.5660	2752812.3400	3.5780	2.4674	1.7020	8.0502

Tab. 2 Comparison of coordinates for Djehuty Base by survey method (all measurements in metres)

Station	Easting	Northing	Orthometric Height
Djehuty Base	462245	2846520	88.6768
Pyramid Base	461803	2846470	121.1577
Top Base	461575	2846636	182.2058
Marsam Base	460554	2845205	81.2245
Western Base	461596	2846419	125.5383
Bakhit Base	462073	2846574	107.2648

Tab. 3 UTM36N coordinates for the control stations (all measurements in metres)

improved coordinates supplied following PPP-RTK. The coordinates of the survey points then updated automatically. The improved survey data were then exported from Leica GeoOffice as shapefiles with the new X, Y and Z coordinates on the UTM36N projection and imported in the GIS project for further analysis.

The revised points shifted 0.76–0.86 m to the south-east in the XY coordinates and the heights (Z coordinate) were reduced by 1.18–1.22 m. Points taken using the total station[17] and by DGPS auxiliary points needed further adjustment as they did not update automatically.

The XY coordinates of both the auxiliary-derived and the total station points were shifted through a spatial adjustment with the Spatial Analyst extension of ArcGIS using the total-station setup and reference points, and the tomb structure polygons, as control points. The root-mean-square error (RMSE) of the operations was 0.0036–0.006 m, which is acceptable considering the accuracy of the post-PPP survey data.

Changes in height (Z) data for the auxiliary-derived and total station points were calculated based on the change in height of the nearest survey points with updated post-PPP coordinates, recorded on the same day as the auxiliary-derived points.[18] For the eight auxiliary-derived

17 Described above in the section on RTK and Total Station survey.
18 It was observed that data recorded on the same day all exhibited a consistent shift in height to two decimal places (*i.e.* 0.01 m), but that data recorded on other days could be different. Therefore, it

points which did not have original height data the height was simply taken from the nearest logical point.[19]

As a gross check on the accuracy of the post-PPP survey data, they were overlaid upon the 2011 satellite image to determine how closely the survey data matched the location of the features as recorded by the satellite imagery. The difference in location between the survey data and the 2011 satellite image was so small it could not be accurately measured given the 0.5 m resolution of the satellite image.[20]

PPP-RTK SURVEY CONCLUSIONS

Obtaining precise and accurate coordinates for archaeological features and structures is an increasing necessity with the growing use of GIS and other digital research tools. Hand-held GPS and other methods that use a 'navigation solution' precise to only *ca.* 10 m are sufficient for locating larger structures and sites, but for smaller features and intra-site planning more precise methods are necessary. The results from Dra Abu el-Naga demonstrate that RTK surveys post-processed with PPP produce GPS data precise to *ca.* 0.10 m, sufficient for most archaeological purposes. This could be improved by total station observations between the control stations, and a network adjustment, if required. For survey projects working in areas without known reference points precise point positioning of RTK surveys produces (i) improved precision without the need for additional receivers, hence (ii) reduced equipment and staffing costs, and (iii) online PPP services are provided at no additional cost.

TOPOGRAPHICAL MODELLING

The topographical and archaeological survey of 2013 provided the data for a DEM of the survey area. This model formed the basis for a DEM of the area in the New Kingdom and a model of the changes to that topography, from prior to construction of the New Kingdom tombs to the present day. To contextualise this research, enable integration with other missions and undertake future research into inter-visibility and movement around the necropolis, the survey data from Dra Abu el-Naga were subsequently integrated into a digital elevation model of the entire Theban area.

DEM OF THE DRA ABU EL-NAGA (SOUTH) SURVEY AREA

The DEM of the Dra Abu el-Naga survey area was generated in the GIS using a Triangulated Irregular Network (TIN) to interpolate the height of the land between the topographic survey points and so create a three-dimensional model of the current topography. This DEM of the survey area (fig. 6) formed the basis for the reconstruction of the original ground surface and

was important that the points used to calculate the height difference for the auxiliary-derived points were recorded on the same day.

19 These points were TT157CT2 (*i.e.* TT157 court 2); TT157CT4, TT158CT5; TT158CT7; and TT300CT8, -131-L(left) and -131-R(right) marking the entrance to tomb -131-.

20 The resolution of the 2011 satellite imagery is detailed in the metadata provided to ARCE by Space Imaging Middle East.

its development through time. Dra Abu el-Naga has been repeatedly covered by rubble, during the construction of the tombs, during excavations within the necropolis, during the 20th century occupation by the modern village, and by the rubble from the demolition of the village in the winter of 2006–2007. These anthropogenic deposits mask the original ground surface prior to the construction of the New Kingdom tombs. To reconstruct the ancient landscape, it was necessary to become acquainted with the geology and geomorphology of the area and identify the changes to the topography since ancient times. The following sections describe how the changes to the topography were identified and accounted for in the reconstruction of the original ground surface and the final New Kingdom model.

RECONSTRUCTION OF THE ORIGINAL GROUND SURFACE AND ITS DEVELOPMENT THROUGH TIME

The geological and geomorphological studies (Bardají – Martínez-Graña – Sánchez Moral *et al.* 2017: 233–250) which took place during the fieldwork were undertaken in order to reconstruct the ancient palaeo-surface (or palaeorelief) in order to establish the visual appearance of the necropolis during the New Kingdom and identify subsequent dynamic deposits. The satellite images and historical maps provided a cartographic base upon which the erosive and sedimentary landforms, stable and unstable areas, were recorded as revealed by the geological and geomorphological study.

Fig. 7 Fragment of reddish soil used to reconstruct the palaeosurface. During the New Kingdom the entire area probably looked similar to this

Fig. 8 Present day remains of the reddish light brown soil marking the former ground surface (at the feet of the researcher on the left)

The only method of identifying the former landsurface was to find an unequivocal continuous geomorphological feature that gave clear indications of a former weathered land surface. Two weathering formations have been found on the surface in this area: a *reddish soil* and an iron crust on scree deposits (Bardají – Martínez-Graña – Sánchez Moral *et al.* 2017: 233–250). These were identified as reliable features marking the previous ground surface, prior to the construction of the tombs and, therefore, were taken as a guide for reconstructing the topography of Dra Abu el-Naga during the New Kingdom (figs. 7–8). The GPS points of these features across Dra Abu el-Naga (hereafter 'geology points') were incorporated into the DEM to produce a 3D model of the topography prior to tomb construction (fig. 9, model A). Data from the rest of the archaeological survey was added to generate models of the New Kingdom topography after the construction of the tombs at the end of the New Kingdom (fig. 9, model B), the Theban necropolis of 1921 as surveyed by the Survey of Egypt (fig. 9, model C)[21] and the terrain in 2013 as surveyed during the fieldwork (fig. 9, model D). In addition to the palaeo-relief, models B and D required base and control points, total station points, geology points, topographic points, tomb entrances, façades and structures, pyramid volumes and pyramid chapel entrances. Additionally, model D included the points along the modern road, gaffirs' huts, modern houses (alabaster factories), and points associated with other missions working in the research area. The result was a sequence of DEM of the topography of Dra Abu el-Naga, from before the New Kingdom tombs were constructed, until 2013 (fig. 9).

21 Maṣlaḥat al-Misāḥah, Egypt, (1924), *The Theban Necropolis*, published by the 'Survey of Egypt' in collaboration with the Antiquities Department. 1:1000 scale map.

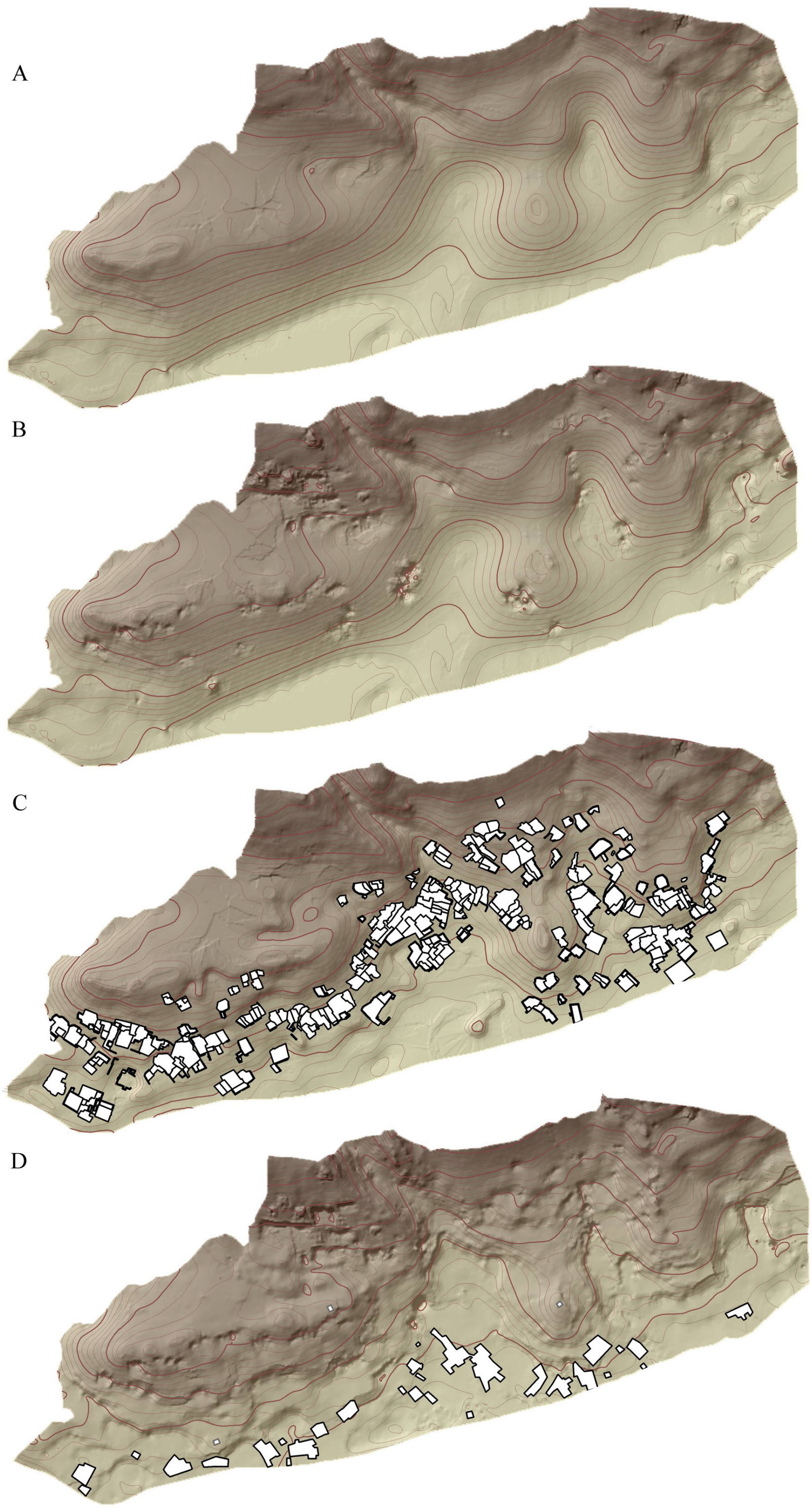

Fig. 9 Sequence of the study area surface models. A: Palaeorelief prior to the construction of the tombs; B: New Kingdom palaeorelief (after the construction of the tombs); C: DEM of the study area based on the Theban necropolis map surveyed in 1921; D: DEM of the current terrain, including tombs and anthropic mounds

The geomorphological study (Bardají – Martínez-Graña – Sánchez Moral *et al.* 2017) demonstrated that New Kingdom tombs were cut into the palaeosurface (*the reddish soil)* itself. The oldest tombs carved into this *reddish soil* date to the Middle Kingdom, but precise dating of the palaeosurface is currently impossible due to the difficulty of properly sampling and analysing the weathering formations (Bardají – Martínez-Graña – Sánchez Moral *et al.* 2017: 242–247). Thus, while there is local evidence that the palaeosurface is earlier than the Middle Kingdom in some places, the construction of the New Kingdom tombs represents a *terminus ante quem* for the palaeosurface in general.

THE FINAL MODEL OF NEW KINGDOM DRA ABU EL-NAGA AND SUBSEQUENT TOPOGRAPHICAL CHANGES

DEM are mathematical surfaces generated by GIS algorithms using data extracted from a physical topographic surface. They are imperfect recreations, of the actual physical topography, experienced and understood as a 'landscape' by the humans within it (Brück 2005: 52–54; Chadwick 2004: 1–31; Chapman – Geary 2000: 316–319; Cummings 2008: 285–290; Cummings – Whittle 2004: 21–22; Gidlow 2000: 23–30; Thomas 2004: 171, 198–201; Tilley 2004: 185–203). Various methods have been proposed to improve the accuracy of DEM as renderings of ancient landscapes and remove errors (Conolly – Lake 2006: 228; Hageman – Bennett 2000: 113–127; Maschner 1996: 1–24; Wheatley – Gillings 2002: 107–126; Wheatley – Gillings 2000: 1–27).

In this case, the model of New Kingdom Dra Abu el-Naga has necessarily been modified to ensure that subsequent analyses are as applicable to ancient Dra Abu el-Naga as is possible, given the evidence available. However, the model has only been altered where there was evidence that the DEM was unreliable, due to a limited number of reference points, or where it was clear from records made on the site that the DEM did not reflect the original ground surface (see the 'Sketch showing the procedures carried out to generate the final model', fig. 10). The procedures carried out to generate the final model are described in the following paragraphs (fig. 10).

Dra Abu el-Naga suffered an important orographical transformation during the last few hundred years. The village construction, use and demolition created an artificial hilly topography thanks to the accumulated debris (these anthropogenic debris are marked in the sketch in fig. 10 by the brown circle and ellipses at the bottom). Likewise, the excavations in the cluster of Ramesside tombs in Dra Abu el-Naga south, carried out by the University Museum of Philadelphia 1921–1923, left debris in the area in front of this group of tombs (marked in the sketch by the brown circle in fig. 10). These mounds currently obstruct the visibility from the Ramesside tombs, but they did not exist in the New Kingdom and, therefore, have been eliminated in the final model.

The reliability of the geological-geomorphological surface (fig. 11) used in the final New Kingdom model also varies. It is most reliable closest to the survey points marking the *reddish soil* (represented with triangles in the sketch in fig. 10). Moving away from these points the accuracy of the geological-geomorphological model decreases because the higher the number of surveyed points the more accurate the interpolated surface. The final New Kingdom model only follows the geological-geomorphological model where the number of points is highest.

The geological-geomorphological model (fig. 11) made it possible to identify areas where recent human activities were very intense, due to house construction or excavations. In fig. 10, the pink polygon shows areas where deposits generated by post-New Kingdom human activ-

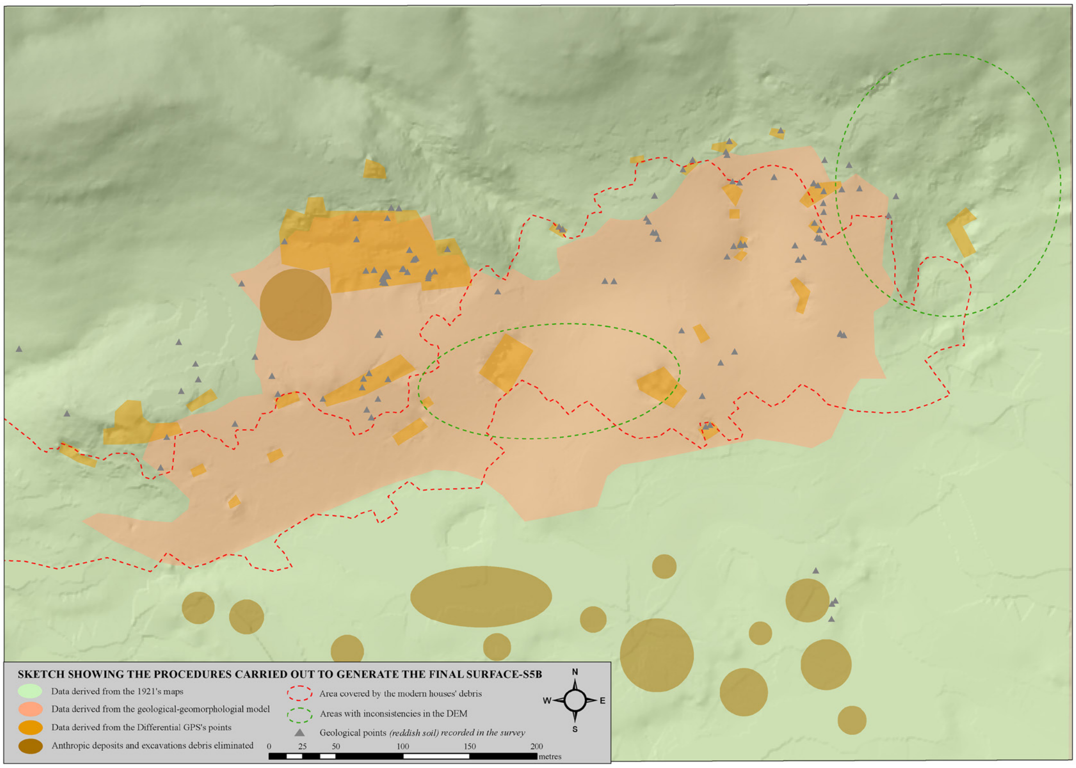

Fig. 10 Sketch showing the procedures carried out to generate the final model

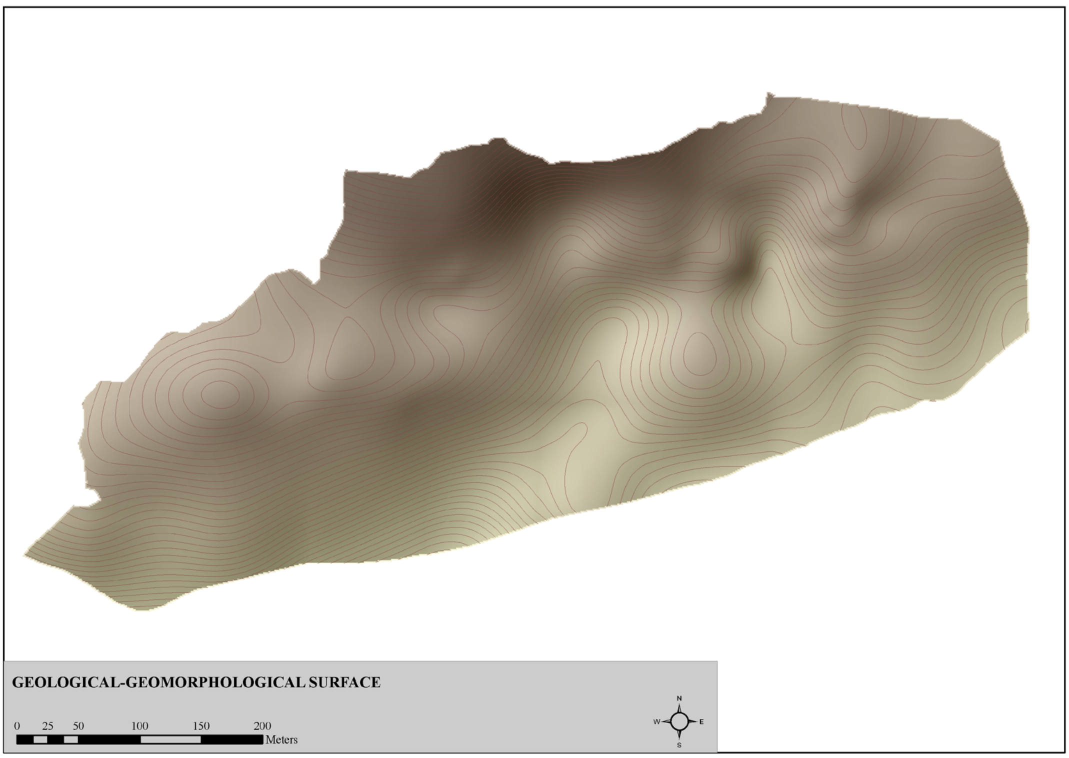

Fig. 11 Geological-geomorphological surface model

ity were identified and removed based on the geological-geomorphological. This was mainly between the cluster of Ramesside tombs at Dra Abu el-Naga and the modern road. During the New Kingdom this area had a soft undulation just interrupted by the tombs' courtyards, as is shown in the Model B in fig. 9. Today, the relief is rough because of the terracing necessary for the modern houses. The area covered by the modern house debris is delimited in the sketch (see fig. 10) by the red discontinuous line.

Inconsistencies were found in model B at the margins of the research area and in the central area, where two *wadis* cross Dra Abu el-Naga from north to south. These areas are marked with a discontinuous green line in the sketch in fig. 10. In the highest areas where no houses had been built throughout the history of the necropolis, the topography remained unaltered due to low rates of erosion. As the *reddish soil* could only be identified in areas subject to the erosive effects of intense human activity (Bardají – Martínez-Graña – Sánchez Moral *et al.* 2017), it was not visible where the topography remained largely unaltered. Therefore, levels extracted from the maps created during the 1920s were used to model the ancient ground surface in these areas (represented in pale green in the sketch in fig. 10), as this allowed a more reliable model to be generated than one interpolated from the limited number of geological points in or around those areas.

In the area of the *wadi Khawi el-Baradsah*, in the centre of Dra Abu el-Naga south, the relative absence of human activity limited the visibility of the *reddish soil,* resulting in very few geological points being recorded in this area. As a result, the wadi was represented by improbably smooth relief in the geological-geomorphological model (see fig. 11) due to the limited number of points available for interpolation. Although we do not know the precise nature of the *wadi* during the New Kingdom, it must have been steeper than the version created by the interpolation. Levels extracted from the maps created during the 1920s (areas represented in pale green in the sketch in fig. 10) were thus used to model the *wadi*. They do not differ greatly from the current levels but are likely to be more accurate than the version in the geological-geomorphological model (see fig. 11).

In the southernmost part of Dra Abu el-Naga (north) and around the tomb of Djehuty (TT11), the absence of geological data and the impossibility of identifying the *reddish soil*, prevented the generation of a reliable final model. The inconsistencies in this area are exemplified by the case of the tomb of Djehuty (TT11) where there is a difference of 17 m between the level of the entrance to the tomb and the top area of its façade in the model. In reality, the distance should be approximately 3–5 m since the preserved façade of the tomb is 3 m and there are archaeological remains to prove that it was increased to at least 5.20 m by a masonry wall (Galán 2007: 95). Because of that error, it was decided to use levels from the maps created during the 1920s (areas represented in pale green in the sketch in fig. 10) to model the New Kingdom topography around the tomb of Djehuty in the final model.

When tomb construction commenced and the necropolis developed, the topography of the study area changed. The tombs were carved out of the rock and the palaeorelief was cut away. Likewise, the superstructures and mudbrick pyramid-chapels were built, producing architectural additions to the landscape. The Differential GPS' survey of the tombs' superstructures (areas represented in orange in the sketch in fig. 10) have been incorporated into the final model to produce the most accurate representation of the necropolis during the New Kingdom.

The tombs in the research area include a type with a courtyard hewn in the rock giving access to the entrance to the funerary monument, which leads into the mountain. This courtyard produced an opening with a constrained view of the landscape for anyone present within it. The precise choice of location, together with the size and dimensions of the courtyard produced a 'window' on a specific area of landscape, which may have had a specific significance for the tomb owner. In these cases, there should not be any topographical points in front of any tomb entrance that are higher than the entrance in the final New Kingdom surface. The only exceptions are the tombs that are known to have courtyards cut down into the ground. This is the case, for example, for TT161 and TT164, whose courtyards were completely hewn below the surface and were accessed through a ramp.

Where the final model included points in front of tomb entrances and within courtyards at a higher level than the tomb entrance, the documentation from the fieldwork and photographs of each tomb were analysed separately to determine if the model accurately reflected the real topography or not. Where the fieldwork and photographic record indicated there were inaccuracies, these points were eliminated to better reflect the real topography. This was only done in the areas where the final surface was otherwise very reliable, such around tombs -128-, TT17, TT286, TT288, TT289.

The cases of the tombs -378-, TT141, TT161, TT162, TT284 and TT302 should be highlighted. Examination of the documentation and photographs from the fieldwork demonstrated that the levels generated in the final model were higher than the levels of the actual terrain, so the tombs were erroneously located below ground level in the model but not in reality.[22] The case of TT161 is remarkable. Although this tomb was located completely below ground level in reality, the final model suggested that the ancient ground surface was 10 m higher than its current position, meaning the ancient Egyptians would have had to cut the surrounding surface 10 m before building the tomb, which is highly improbable. It is therefore likely that the ancient ground level in the final model requires some refinement in the area of TT161 as there may have been an undulation in the ancient ground surface, which was not visible to the survey team during fieldwork. Refinement may also be required around -378-, TT141, TT162, TT284 and TT302 where the difference between actual ground level and the final model was not so substantial (the inconsistencies are recorded within the green discontinuous line in the sketch in fig. 10).

These procedures ensured that the final model of the New Kingdom topography (fig. 9) was as accurate as possible without obvious errors resulting from the interpolation of the DEM and modern alterations to the landscape.

MODELLING THE WIDER THEBAN LANDSCAPE

Once the final New Kingdom model of Dra Abu el-Naga south had been completed, it was incorporated into a digital model of the Theban area, together with data on all the New Kingdom structures and funerary monuments. This digital elevation model of the entire Theban area represents a first attempt at contextualising the entire Theban landscape and facilitating

22 It is unfortunate that the model proved locally inaccurate in the immediate vicinity of these tombs, but some inaccuracies are inevitable since the DEM is ultimately only a model of the landscape created by interpolation from the available data points. Further fieldwork to improve the number of points in the area of these tombs would reduce these inaccuracies, but it was not possible to undertake this within the timeframe of this project.

integration with other missions. It could also contribute to future landscape-archaeological research, such as a study of the visibility of the Dra Abu el-Naga tombs (Jiménez-Higueras 2020).

The digital elevation model of the entire Theban necropolis used a different methodology to the high-resolution micro-topography that produced the final New Kingdom model of Dra Abu el-Naga south. Ideally, it would have been desirable to survey the entire Theban necropolis at the same resolution as the Dra Abu el-Naga south research area but due to its size this was not possible. Therefore, the rest of the Theban necropolis (approximately 5x5km) was modelled based on the georeferenced *Survey of Egypt* map. This model was not a primary goal of the project and was undertaken using the available resources as a first step towards a more accurate model of the Theban necropolis. It will inevitably incorporate intrinsic errors derived from the different methodologies used in the creation of the maps, and errors and anachronisms in the *Survey of Egypt* mapping. In particular, the Nile and its branches are represented in their 20th-century position, and the plans of various temples (specifically the Mansion of Million of Years of Amenhotep III and the temple of Karnak) are somewhat speculative in the *Survey of Egypt* map.[23] Research (Toonen *et al.* 2017; Toonen *et al.* 2019) undertaken since the completion of the project in 2013 could also be used to improve the model and correct the anachronisms derived from the *Survey of Egypt* map. However, we are convinced that this model is worthwhile and necessary as a first attempt at modelling the Theban area that can be refined and improved as methods and technologies develop and missions share data and research.

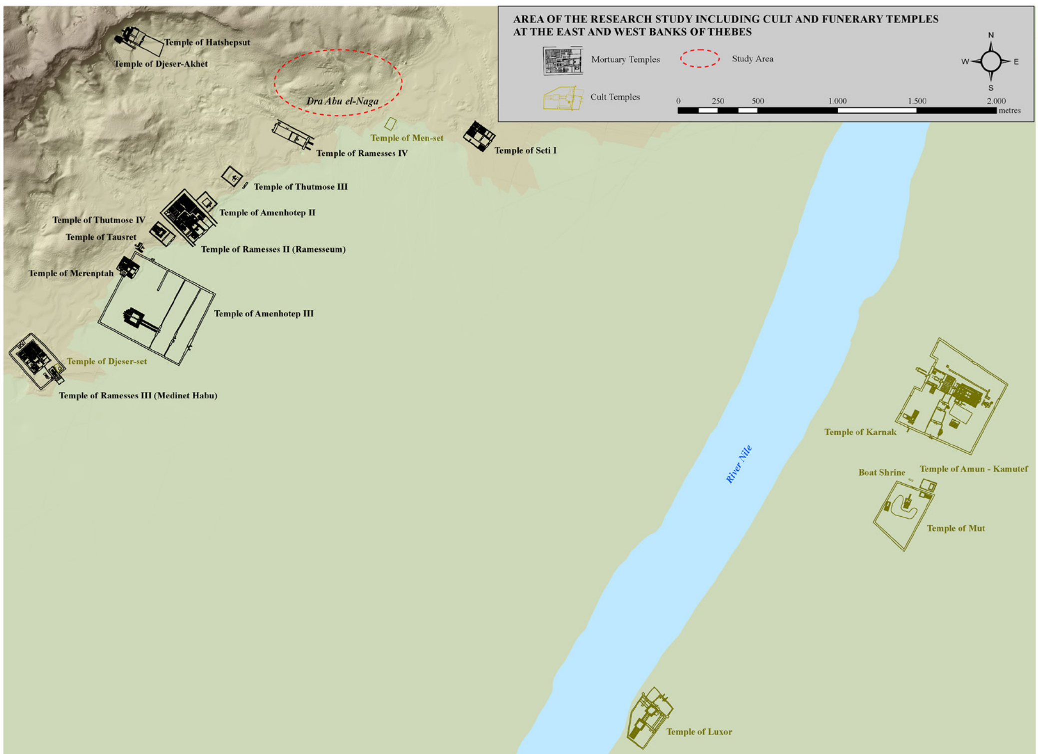

Fig. 12 Area of the research study including cult and funerary temples at the East and West Bank of Thebes

23 The authors are grateful to their reviewer for pointing out these specific issues with the *Survey of Egypt* map.

Before the model of the Theban area could be generated, the *Survey of Egypt* maps first required georeferencing. Ground control points for the georeferencing were recorded at several locations within the Theban necropolis, where precise features on the ground could be easily identified in the *Survey of Egypt* maps, including Mansions of Million of Years, some of the tombs, and old reference points. Once the *Survey of Egypt*'s map was georeferenced, data within it was digitised for the entire Theban necropolis; including the contour lines, placement of the Mansions of Million of Years and cult temples, the course of the river, and the modern paths and roads. The final New Kingdom model showing the micro-topography of Dra Abu el-Naga south was trimmed and inserted into the model of the Theban necropolis.

To accurately model the New Kingdom landscape, it was necessary to incorporate the Mansions of Million of Years and cult temples into the landscape model. All the bibliographical references and plans associated with each temple were checked and some of the mission directors currently working on the temples provided plans and data to be included in the model of the Theban necropolis (fig. 12).

CONCLUSION

The 2013 fieldwork and subsequent processing produced a first model of Dra Abu el-Naga from prior to the construction of the New Kingdom landscape up to the present day. Although some areas of the model of New Kingdom Dra Abu el-Naga are more reliable than others, it provides a new and useful resource for the investigation of Dra Abu el-Naga and the Theban necropolis. It also enabled the survey team to provide several other expeditions with coordinates for their survey points and initiated discussions about the accuracy and consistency of the coordinates obtained by each project.

The interdisciplinary nature of the research was crucial. The geological-geomorphological study provided crucial evidence of the *reddish soil* for the reconstruction of the palaeorelief. It also provided further evidence on the formation of the hills of Dra Abu el-Naga and the Theban necropolis, the development of the study area throughout history, and how it has been mainly anthropogenic activities that have altered the landscape from the New Kingdom to the present day. The robust PPP strategy improved the accuracy and precision of the DGPS survey and ensures consistency between any projects which make use of Dra Abu el-Naga Survey data, without the need for a regional control network. Only stations or hard features that can be accessed and used for error checks are required. For an appropriate level of consistency between projects, all that would be required is for projects to agree on a shared coordinate transformation (*i.e.* with identical transformation parameters) so that all survey data could be projected into the same coordinate system. This is particularly useful for the Theban necropolis because of the difficulty of obtaining precise geographic or projected coordinates for control points and problems with accessibility, which result in most expeditions in the region using local site grids to record their results.

There were several limitations to the research. Dra Abu el-Naga has not been completely excavated. Many excavations continue and some areas await investigation. Once the fieldwork project was completed, the total number of tombs had increased beyond those shown on Kampp's map and emendations to the orientation of the tombs were made to the tomb plans in the GIS data. The overall context of Dra Abu el-Naga within the extensive area of the Theban necropolis places limitations upon this research, since it is but one part of a much larger area which cannot be surveyed in detail to such a high resolution by any single research project. Nevertheless, the ancient landscape of Dra Abu el-Naga has been reconstructed to a satisfactory level, offering a more accurate and complete image of this part of the necropolis for the study of its organisation, and the distribution and placement of the tombs.

The work undertaken at Dra Abu el-Naga opens up new lines of investigation into the landscape of the necropolis and this approach could be productively applied to other ancient Egyptian tombs, necropolises and funerary landscapes in general. Ideally the detailed survey of Dra Abu el-Naga south would be extended across the Theban necropolis, providing a consistent micro-topographical model of the entire landscape.

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