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Geomorphology of Dra Abu el-Naga (Egypt): The basis of the funerary sacred landscape

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A B S T R A C T

A geological and geomorphological analysis has been performed in the necropolis of Dra Abu el-Naga in order to understand the role played by these two factors in the development of the sacred landscape. The investigation focuses upon two aspects of the development of the necropolis, the selection criteria for tomb location and the reconstruction of the ancient funerary landscape. Around 50 tombs were surveyed, analysing the characteristics of their host rock and classifying them according to a modified Rock Mass Rating Index, in order to understand how rock quality affected tomb construction. This analysis resulted in the definition of five rock-quality classes (I to V) from very good to very poor rock. The geological study also resulted in a proposed geological-geomorphological model for the evolution of this zone of the Theban necropolis that complements previous works by other authors. Due to the lack of precise dating evidence this chronology is a relative one and is based on the chronology given by other authors for similar deposits and events. Two catastrophic events, represented by mega-landslides, have been identified, the first one predates the deposition of early Pleistocene fluvial deposits, and the second one possibly occurred during the middle-late Pleistocene. Two weathering surfaces developed under wetter than present climatic conditions and have been tentatively correlated to the mid-late Pleistocene humid period and the African-Humid Period (early-mid Holocene).

1. Introduction

The Theban necropolis is located on the West Bank of the Nile, opposite the modern city of Luxor (Fig. 1), and close to the Theban Mountains. It extends approximately 4 km from the temple of Ramesses III at Medinet Habu to the necropolis of el-Tarif. The main areas in the Theban necropolis comprise: the Valley of the Kings (KV in Fig. 1) and the Valley of the Queens (QV in Fig. 1), the mortuary temples of the royalty or "temples of Millions of Years", and several necropolises including the tombs of the nobles, such as Dra Abu el-Naga (Fig. 1), which is the object of this paper.

Dra Abu el-Naga is a small hill approximately 1 km in length and 250 m in width. Its boundaries are the valley of Deir el-Bahari to the south, the *wadi* Biban el-Moluk that leads to the Valley of the Kings to the north, and el-Tarif along its north-eastern border. Topographically, Dra Abu el-Naga consists of two different parts, a flat area close to the cultivation land, and a hilly zone (Betrò et al., 2009).

In modern times, the necropolis has been divided into two main areas, Dra Abu el-Naga north and Dra Abu el-Naga south, which are clearly identified by the orography of the area, since they coincide with two small hills separated by a narrow *wadi* (*Shig el-Ateyat*) at the intersection of the road which leads to Deir el-Bahari. In the area of Dra Abu el-Naga South the main topographical element is the main hill called el-Mandara. This area of the necropolis is characterised by several groups of tombs, including clusters where

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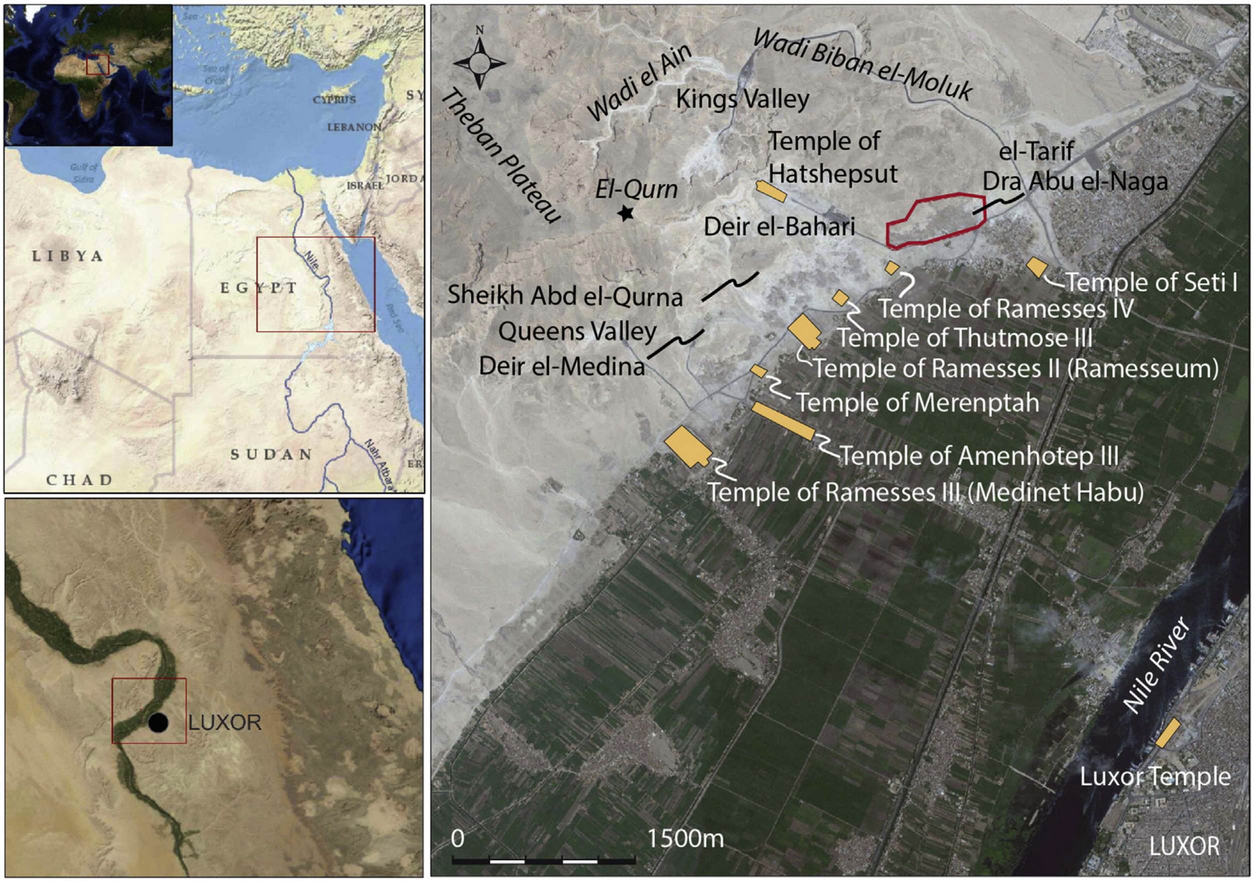

Fig. 1. Location of research area within the framework of the Theban necropolis. KV: Valley of the Kings; QV: Valley of the Queens.

the mud-brick remains of tomb superstructures are quite well preserved.

Concerning the diachronic development of the Dra Abu el-Naga tombs, the earliest features are the *saff* tombs –with a singular pillared façade-dating to the Middle Kingdom (ca. 2000–1700 BCE). There are also tombs dating from the Second Intermediate Period (15^{th}-17th dynasties, 1650–1550 BCE), among which special emphasis is placed on the tombs of the 17th Dynasty kings. The tomb of the king Nubkhepere Intef in the northern area of Dra Abu el-Naga is a good example of these 17th Dynasty tombs (Polz, 2003a, 2003b). Finally, there are 152 private tombs of high ranking nobles dating from the New Kingdom (18^{th}-20th Dynasties, 1550–1069 BCE).

In the Theban necropolis, several projects have been undertaken relating to the geology and geomorphology of the area, with excellent summaries provided by Aubry et al. (2009, 2016). Most of the reported work is devoted to the analyses of factors driving tomb deterioration, and is aimed at conservation and restoration. Salam (2002) and Aubry et al. (2009) focus on the lithology of the rock into which tombs have been carved ('host-rock') and its role in tomb placement. Conversely Wüst and Sluchter (2000), Wüst and McLane (2000) and Cobbold et al. (2008) analyze the role played by lithology in the damage to the tombs and the agents causing this. A different approach is taken in the works of McLane and Wüst (2000) and Weeks and Hetherington (2006) who focus on the threat to the Theban necropolis posed by natural hazards. However, and with the exception of the work by Karlshausen and Dupuis (2014), few attempts have been made to fully understand tomb placement with regard to the geological and geomorphologic framework. The geoarcheological analysis done by these authors in Sheikh Abd el-Qurna (west of Deir el-Bahari, Fig. 1) is aimed at understanding the reasons for the selection of a given place for tomb construction. They found that the characteristics of the host-rock (homogeneous limestone, lack of fractures, etc.) did not seem to be the main criterion in the selection of the site, and other criteria should be taken into consideration such as the presence of structural rock features (joints, fractures, etc.), proximity to or visibility of the funerary temples and other cult places, or just proximity to a relative.

A certain system is evident in the distribution of the tombs in the Theban necropolis (Engelmann-von Carnap, 1999; Helck, 1962, 225), and in the particular case of Dra Abu el-Naga, the spatial interrelationship between tombs reveals that their location was not a matter of chance. Besides the rock quality or lithology, Jiménez-Higueras (2016) states that multiple criteria could have influenced the choice of a tomb's location such as chronology, typology and architectonical features of the tomb, and distance between tombs; kinship, titles of the owner and administrative connections between owners; visibility criteria including connections between the tombs and the temples, as well as between the tombs and the main areas of the Theban necropolis involved in religious festivals and processions.

However, this work deals with the characteristics of the physical environment, specifically the geological units and their quality as host-rock for tombs, and the morphology of the ancient landscape. Both elements constitute partial results of a wider project entitled "The Sacred Landscape of Dra Abu el-Naga", which is part of a PhD research project 'Development and Landscape of the Sacred Space at Dra Abu el-Naga: A case study within the Theban necropolis' (Jiménez-Higueras, 2016).

The principal aim of this project and thesis was to study the sacred landscape of the southern area (Dra Abu el-Naga south) and the first part of the northern area of Dra Abu el-Naga (Dra Abu el-Naga north), and its evolution from the 18th to the 20th Dynasties (1550–1069 BCE). The purpose was to understand the spatial development, how the organisation of the necropolis took place and its connection with the surrounding religious-cultic zones. However, due to the changing nature of the landscape, it was also necessary to become acquainted with the geology and geomorphology of the area,, in order to have a full understanding of the sacred landscape. The geomorphologic study of the area contributes to specifying whether some elevations are natural to the territory or if they are in fact accumulations of debris formed by the passage of time and human activity. This research contributed to an important study of the visual aspect of the necropolis during the New Kingdom as well as the dynamic changes that took place within it.

The geological study done within and around the tombs (i.e. tomb-by-tomb), and on the surface of the necropolis, provided us with relevant data for the identification of the surface of the ancient landscape (palaeo-landscape) and for the establishment of a geological-geomorphological evolutionary model of the area, broadly called "the northern basin" by Aubry et al. (2009, 2011; 2016) and Dupuis et al. (2011). The site's general characteristics potentially played an important role in the selection of locations for tombs and the study of the stratigraphic column is also essential since the quality of the rock could have been one of the criteria determining the tomb placement.

2. Study area

2.1. Geological framework

The Theban Mountains are formed by more than 400 m of Upper Paleocene to Lower Eocene sedimentary materials, involving three main stratigraphic formations, (Said, 1960, 1962): Tarawan Chalk Formation, Esna Shale Formation and Thebes Limestone Formation. Pliocene-Pleistocene conglomerates unconformably overlay these units (Said, 1990; Tawfik et al., 2011). The Upper Paleocene (Aubry et al., 2011) Tarawan Chalk Formation only crops out at a few locations on the West Bank as for instance at the foot of the hills of Sheikh Abd el-Qurna (Aubry et al., 2016), with thickness ranging from 15 to 20 m of chalk and nodular limestones. The contact with the overlying Esna Shale Formation is transitional and marked by an upward decrease in carbonate content (Aubry et al., 2016). This formation, with a total thickness of more than 60 m, has been subdivided into four formal members (Aubry et al., 2016). The Global Stratotype Section and Point for the Paleocene – Eocene Boundary is defined within this formation in the neighbouring locality of Dababiya (Aubry et al., 2007). In spite of the sharp stratigraphical contact, interbedded limestone layers at the top of this unit mark the transition to the overlying Thebes Formation.

The Thebes Formation is the most characteristic one in the Theban Mountains and was firstly defined by Said (1960) on the West Bank of the Nile River, opposite Luxor (ancient Thebes). This formation comprises a more than 340 m thick carbonate sequence, disconformably overlying the Esna Formation behind Deir el-Bahari. Subdivisions and definitions vary depending upon the authors (see Aubry et al., 2007 for discussion), but this discussion goes beyond the scope of this paper. Therefore, we will take the definition given by Curtis (1995) and Tawfik et al. (2011), followed in the previous geological studies of Djehuty's tomb, TT 11, (Cuezva et al., 2016).

These authors subdivide this formation into four members (Fig. 2), from bottom to top:

<u>Member I:</u> 80–100 m thick sequence of micritic-massive limestones with interbedded thin beds of marly limestones with sparse lenses of flint (silica or chert nodules). Although these materials have a low mechanical strength, they present better mechanical stability than any other from the geological sequence. At the top, this member consists of 15–17 m of thin-bedded silicified dolomitic limestone, very useful for correlation.
<u>Member II:</u> more than 100 m of massive calcareous mudstone and argillaceous limestone with centimetric chert bands alternating with beds of calcareous nodular limestone that usually show a pseudoconglomeratic appearance. Chert bands often appear parallel to bedding planes showing persistent lateral extension and sharp contacts with the surrounding sediments. Reddish levels of calcareous shale appear at the lower part of the member.
<u>Member III:</u> very similar to the previous one, this member is characterised by an almost 60 m thick sequence of yellowish nummulitic limestone and interbedded chert nodules and nummulitic limestone, both of which are rich in macrofossils (pelecypods, gastropods, echinoderms), and a 20 m thick nodular limestone with a pseudoconglomeratic appearance at the top of the member.
<u>Member IV:</u> a sequence of 50–70 m thick nummulitic limestone alternating with chalk to nodular and bioclastic limestone with abundant oysters and shell fragments. A ferruginous crust can be observed at the upper structural surface of the Theban hills covering the limestone (mainly bioclastic coquinite levels). The ferruginous levels are also useful for correlation.

2.2. Geomorphologic framework

The Theban Mountains have been subdivided into three different geomorphologic domains (Aubry et al., 2009; Dupuis et al., 2011) all of which have distinctive geomorphologic features (Fig. 3): a) The Theban Plateau, with the dominant tabular reliefs presided over by El Qurn; b) the Tilted Blocks that constitute the lower hills located at the foot of the Theban Plateau; and c) the so-called "Northern Basin", comprising the hills between *wadi* Biban el-Moluk, Deir el-Bahari and the Nile alluvial plain, where Dra Abu el-Naga is located.

The Theban Plateau constitutes the main regional geomorphologic feature in this part of Egypt, from Aswan to Qena and towards the Western desert. An almost horizontal disposition of the sedimentary layers of Esna and Thebes Formations characterises this plateau. However, this horizontality and apparent stability is far from the rule across the whole area. The view from El Qurn towards the Valley of the Kings reveals a subtle northwards dipping of these layers (Fig. 4), and anticline structures and faults have been described (Aubry et al., 2009), giving the elevation of the older Tarawan Formation at the same topographic altitude as the contact between Esna and Thebes Formations.

The Tilted Blocks, located at the foot of the vertical cliffs of the Theban Plateau, present the same stratigraphic series, but dipping towards the mountain, revealing their detachment from the plateau (Cobbold et al., 2008; Dupuis et al., 2011; Aubry et al., 2016). The Valley of the Queens, Deir el-Medina and the tombs of the nobles are some of the most prominent funerary sites and monuments located in this domain. Dupuis et al. (2011) describe them as the result of successive gravitational collapses (or slumps) triggered by listric faults during successive Pleistocene pluvial stages.

Finally, the so-called "Northern Basin", where Dra Abu el-Naga is located, presents some distinctive geological and geomorphological

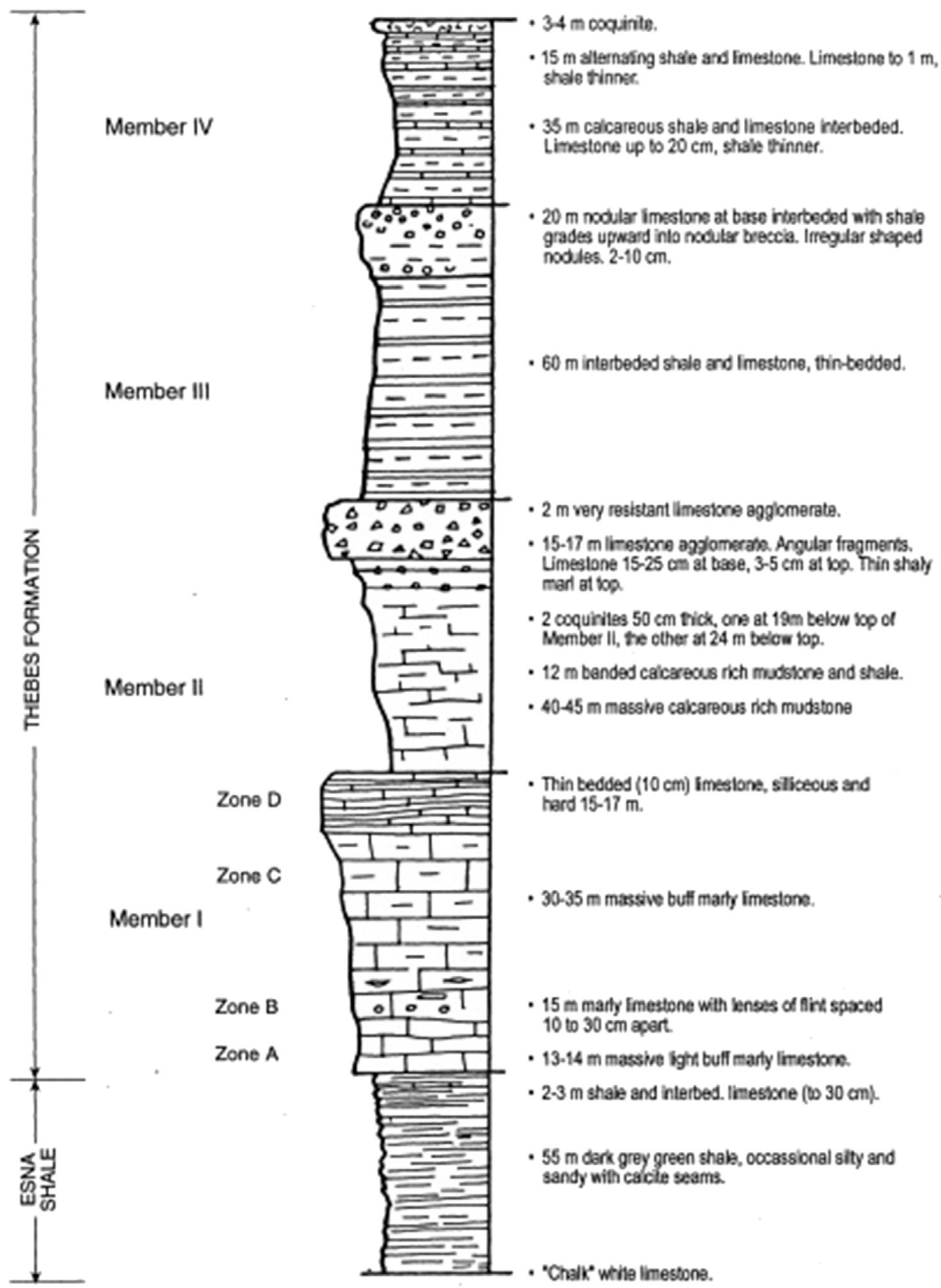

Fig. 2. Synthetic stratigraphic column of the Esna – Thebes Formations (after Curtis, 1995).

characteristics never fully described before. Said (1981) described fluvial deposits of the Armant Formation (Plio-Pleistocene) in this area, while for Aubry et al. (2009), it is apparently filled with interstratified conglomerates, clays and calcareous-dolomitic playa deposits. A similar interpretation is given by Dupuis et al. (2011) who propose its sedimentary filling with detrital deposits issued from the erosion of the Theban Plateau. However, field observations show anomalous disposition of the stratigraphic sequence, with high angle dipping layers of the Thebes Formation, suggesting former gravitational collapses. For this reason we have renamed this area as the "Northern Collapse" (Fig. 3).

2.3. Seismotectonic framework

Archaeological research carried during conservation works of the Colossi of Memnon and the Amenhotep III Temple (Karakhanyan and Avagyan, 2011), points to the existence of numerous archaeoseismological and geological effects of earthquakes across the Theban necropolis. The size and characteristics of the liquefaction structures found in the area indicate an INQUA-ESI 2007 (Guerrieri and Vittori, 2007) intensity IX, pointing to a 5.5–6.5 minimum magnitude for a near-field earthquake located not farther than 50 km away. An oblique-slip basement fault at the foot of the Theban Plateau is proposed as the source of this earthquake at around 1200 BCE. Active motion along this blind basement fault could also trigger the listric slumps described above (Karakhanyan and Avagyan, 2011).

3. Analysis of rock quality

The first goal of the geological and geomorphological studies was to analyze the quality of the sites chosen for the tombs,

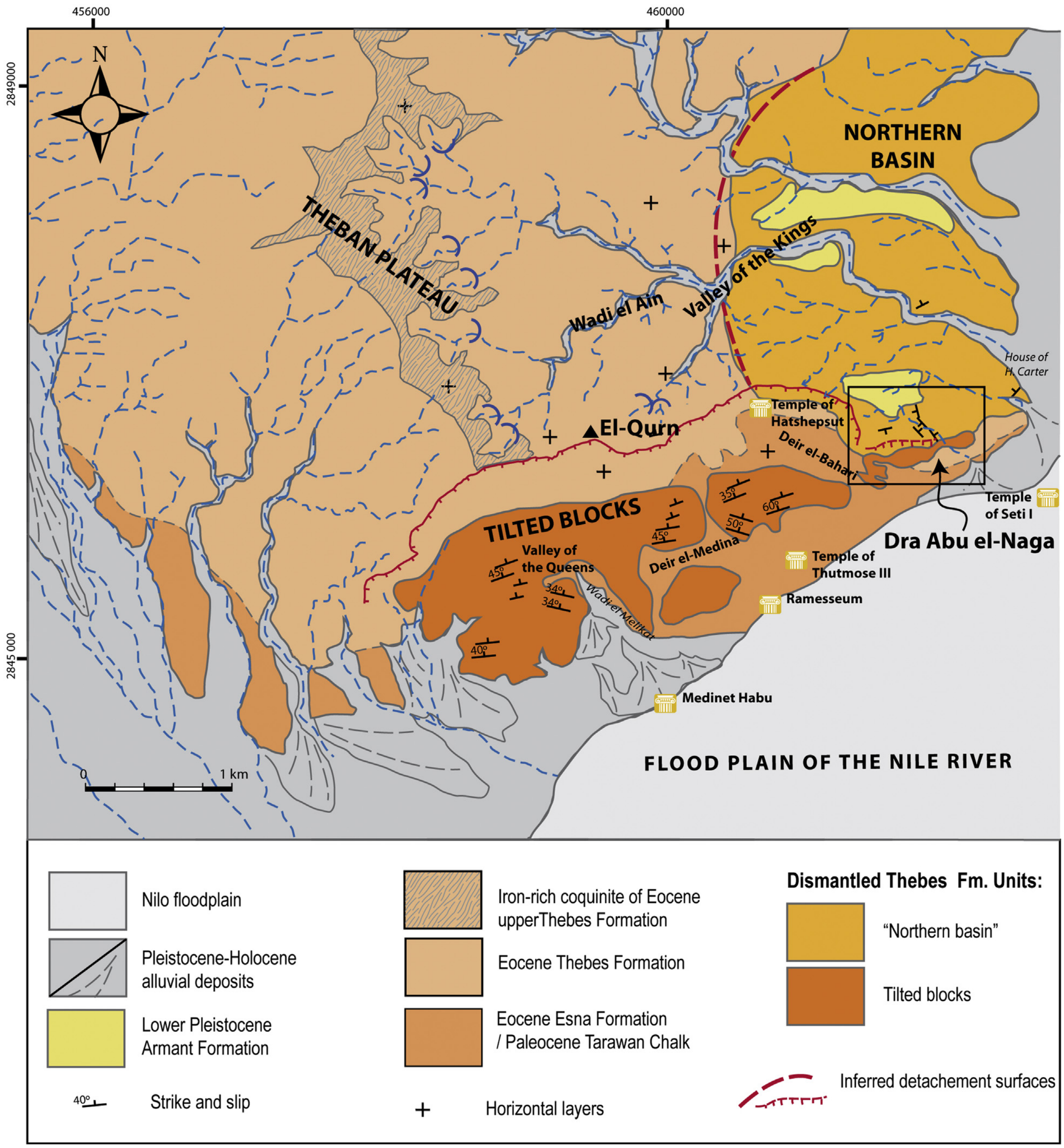

Fig. 3. Schematic geological map of the Theban Mountains (mod. after Aubry et al., 2009; Dupuis et al., 2011), showing the three different geomorphological domains described for the area, and the extension of the dismantled units later discussed in this paper (Northern Basin renamed as Northern Collapse).

including lithology, weathering, "in situ" properties" and site-quality. However, since this work deals mainly with the geology and geomorphology of the area, only the characteristics of the rock have been included here.

3.1. Methodology

Around 50 tombs were surveyed. The characteristics of rock from the entrances and façades was analyzed, together with rock from the interior where this was possible and tombs had not been closed by the Egyptian Ministry of State for Antiquities. The Rock Mass Rating Index (RMR), defined by Bieniawski (1989), has been adapted to the characteristics of our site and our research to include both the rock masses and the transported materials which were used as host-rock for tomb construction. This index was based on the following field data: lithology, degree of weathering, and in situ properties such as friability or structural data. The presence of water was dismissed given the hyper arid conditions of the study area.

Lithology. Although many of the tombs are carved into the Thebes Formation, some of them are location in other materials, so our first approach was to broadly identify the lithology: consolidated rock or transported detrital material, and if the lithology was consolidated rock we differentiated among the different members of Thebes Formation (see Fig. 2). The

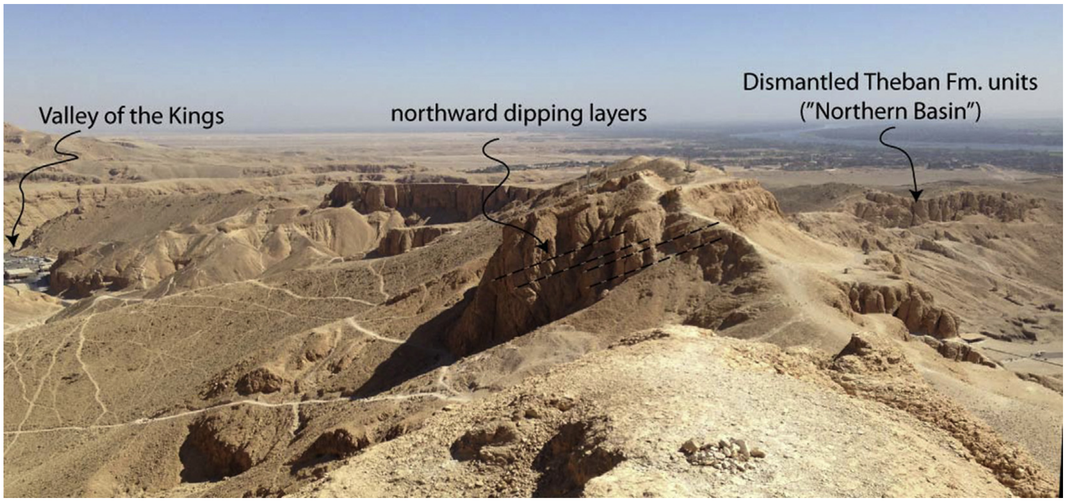

Fig. 4. Northwards dipping layers of the upper member of Thebes Formation. View from El Qurn towards E – NE, with the Nile floodplain in the background.

hardness or homogeneity of the host-rock is one of the main lithological characteristics that have been taken into account in determining the rock-quality of the tomb sites.

Weathering degree: Chemical weathering processes are particularly effective on the calcareous members of the Thebes Formation with different degrees of intensity, in the same way as they affect the quality of the host-rock. The higher the weathering the lower the quality is.

"In situ" properties: We include here those features or properties that alter the characteristics of the main rock.

Friability. The host-rock was in many cases broken and crushed by different processes, which highly altered its properties and hence its quality for tomb construction. We consider these characteristics within the description of "in situ" properties.

Structural data. In certain cases the tombs were carved into stratified rocks with a given strike and dip that conditioned their quality; in other cases the rock was crushed by the presence of joints and faults, in those particular cases strike and slips were also measured.

In accordance with the RMR Index defined by Bieniawski (1989), but including transported materials, we have classified the host-rock into 5 classes: Class I (Very good rock); Class II (Good rock); Class III (Fair rock); Class IV (Poor rock); Class V (Very poor rock). This quality expresses the general condition of the rocks that contribute to the durability of tomb architecture and decoration. Class I allows better decoration with long-lasting reliefs cut into the rock, while in Class V tombs decoration needs to be provided by painting onto applied stucco, with the durability of the decoration depending on the roughness and stability of the underlying host-rock.

Placement. Besides rock quality, the location of tombs on the hillside was initially considered in terms of two main features: orientation and topographic altitude. Both characteristics are related to the visibility of the main mortuary and cult temples in the area. However, a proper analysis of these other parameter affecting site-quality is not included in this work, but they have been taken into consideration elsewhere (Jiménez-Higueras, 2016).

3.2. Results

Rock quality is not only related to the hardness and superficial stability that the characteristics of the host-rock can give to the tomb, but also to the smoothness of the rock for carving and other ornamental purposes.

Although geological research was done in each of the tombs located within the study area, not everyone provided valuable information for this study. Many of them were badly preserved or located at the front of the necropolis, below the remains of the former village of Qurna. In Table 1 only those tombs considered good examples of a given Class have been included. The lithology of the tombs clustered into seven types, which were arranged into five classes (Table 1) from higher to lower quality. In some cases, different lithologies occur in different parts of the tomb or different walls of the courtyard (e.g. TT 300 or TT 158), so the tomb is included in the two corresponding classes where it represents good examples of both of them.

3.2.1. Massive limestone (lower member 1 of Thebes Formation); (Class I)

This lithology consists of thick white limestone strata (Class I) with nearly horizontal dip and scarce widely spaced fractures. Tombs with this lithology are mainly located at the lower or middle part of the hillside, but not exclusively. Good examples of this rock

Table 1
Classification of studied tombs by rock quality. Only the tombs considered to represent good examples of each class have been included.

Class	Rock Quality	Lithology	# Tombs
I	Very good	Massive limestone	TT 17; TT 156; TT 157; TT 158; TT 159; TT 161; TT 164
II	Good	Slate-like limestone	TT 143; TT 147; TT 260; TT 261; TT 288; TT 300; TT 301
III	Fair	Layered nodular limestone	TT 303
IV	Poor	Highly weathered limestone	TT 283; TT 300; TT 158 (eastern wall)
		Distal alluvial fan facies	TT 305; TT 306; TT 307
V	Very poor	Heterometric breccia	-121-; -122-; TT 16; TT 144; TT 231; TT 237
		Colluvial deposits	-125-; -126-; TT 163; TT 282

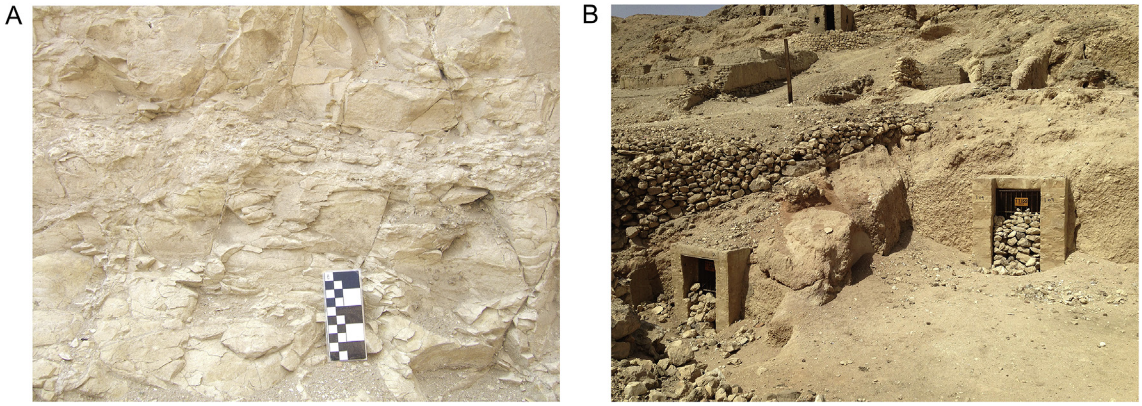

Fig. 5. Characteristics of limestone from Thebes' formation in: A) Djehuty's tomb and B) TT 159.

type are Djehuty's tomb, TT 11 (Fig. 5A), or the tomb of Raya, TT 159 (Fig. 5B), located in the mid hillside.

Another good example is Tjanefer's tomb, TT 158, located high on the hillside, where decorative funerary reliefs are still preserved in the façade (Fig. 6A). However, the lateral eastern wall of the courtyard of this tomb, presents a highly fractured and weathered Thebes Formation massive limestone, with an important crushed mylonitized zone crossing the frontal court in a N50ºE direction (Fig. 6B) that lowers the quality to Class IV there.

3.2.2. *Slate-like limestone (lower member I of Thebes Formation); (Class II)*

In some cases, the previously described massive limestone of the lower member of Thebes Formation showed a thinner bedding with a certain slate-like gross deformation, or even crushed features, which slightly lowered its stability and consistency as host-rock. A good example is tomb TT 300, with crushed limestone (Class II) on the façade (Fig. 7) and intense weathering (Class IV) in the eastern wall of the frontal court.

3.2.3. *Thin layered nodular limestone with interbedded chert nodules (upper part of member I of Thebes Formation); (Class III)*

Some of the topographically highest tombs in the necropolis are cut into this kind of rock, which has a characteristic arrangement of thin layers of nodular limestone with interbedded chert nodules. These thin layers do not present a horizontal disposition but instead they exhibit different strike directions and dip angles, reaching almost vertical dips in some locations. A good example is TT 303 with highly heterogeneous rock. The inner chamber is carved into nodular limestone with chert nodules, probably from the upper part of Member I of Thebes Formation, presenting a strike and dip of N116° - 70ºSW, while the jambs of the door entrance present southward dipping (N106° - 34ºSW) of massive calcareous mudstone and underlying reddish levels of calcareous shale, probably from the lower part of Member II, (Fig. 8).

3.2.4. *Highly weathered limestone (member I of Thebes Formation), (Class IV)*

A number of tombs located in the upper hillside at Dra Abu el-Naga are carved into extremely weathered and karstified limestone from the Thebes Formation. In some cases this weathering leads to significant instability in the rock, which can be easily removed and eroded. A good example of this is observed in the lateral walls of the court of TT 300, with fractured and highly weathered limestone, (Fig. 9).

3.2.5. *Distal alluvial fan deposits, (Class IV)*

Just two tombs were located in these kinds of deposits (TT305, TT 306 and TT 307). They consist of the distal facies of alluvial fans, mainly uncemented but compacted silts with some sparse gravel (Fig. 10).

3.2.6. *Heterometric breccia, (Class V)*

Uncemented heterometric and heterolithic breccia with angular to subangular clasts, with highly varying sizes (from several cm up to 1 m), appears discontinuously across the entire necropolis. These deposits are similar to the Valley of Colour Formation defined by Dupuis et al. (2011), and forms the small hill where the gaffirs' hut (at Shig el-Gharabat) in the research area is located (Fig. 11A). In some places these deposits appear associated with striated fault plains the strike of which is coherent with joint data in Deir el-Bahari (Pawlikowski and Wasilewski, 2004) (Fig. 11B; eastern wall

Fig. 6. Rock characteristics of Tjanefer's tomb, TT 158. Limestone of Thebes Fm. in the façade where reliefs are preserved, (Class I); weathered and crushed (fault breccias) limestone outcropping in the eastern wall (right) of the court (Class IV).

Fig. 7. Façade of tomb TT 300, classified as rock quality Class II.

on the court of TT 303), or deformed underlying Esna marls (Fig. 12).

3.2.7. Colluvial deposits, (Class V)

In our opinion, these kinds of materials provide the worst quality for host-rock for tombs. They consist of heterometric, angular pebbles, embedded in a reddish silty-clayey matrix that is poorly consolidated and produces unsteady and extremely rough surfaces. They mainly appear in the middle-upper part of the eastern side of study area (-125-, -126-) and also in the westernmost tomb (TT 282), (Fig. 13).

Fig. 8. Southwards dipping calcareous mudstone in TT 303 (probably corresponding to the lower Member II of Thebes Formation).

4. Reconstruction of the original surface

4.1. Methodology

To achieve the second goal of the geomorphological study, the satellite images (Quickbird images) and historical maps (Kampp, 1996; Survey of Egypt, 1924) employed in our survey were used as a cartographic base for the reconstruction of the original ancient land-surface. The main purpose was to reconstruct the landscape that Egyptians found when they first chose this area for their tombs. This is important in order to re-establish the visual appearance of the necropolis during the New Kingdom and identify the dynamic changes that this area was subjected to later. The main problem in creating this map was the huge amount of anthropic deposits that had been thrown over the surface, masking the natural landscape. Dra Abu el-Naga has been repeatedly covered by rubble, during the original excavation of the tombs, more recently during excavations within the necropolis, and finally during the 20th century when the area was occupied by the modern village until its demolition in the winter of 2006–07, leaving behind considerable rubble. In 2015, after the completion of our fieldwork, the debris of demolition started to be removed and the area cleaned thanks to the work of the American Research Center in Egypt.

In order to identify the surface of the former landscape, it was crucial to identify a specific and unequivocal geomorphological feature with geospatial continuation across the study area. The only method of identifying the surface of the former landscape was to find a superficial feature that gave clear indications of having developed on a former land surface, as the result of weathering, but whose development was not possible under the current and long-lasting hyper arid conditions. Two main weathering formations have been found on the surface in this area: a reddish soil and an iron crust on scree deposits.

Fig. 9. Highly weathered limestone in the eastern wall of the courtyard of TT 300 (Class IV).

Fig. 10. Tombs TT 305 and TT 306 carved into the distal facies of alluvial fans, with a mid-low preservation potential.

Fig. 11. A) Heterometric breccia at Shig el-Gharabat; B) Heterometric breccia associated with a striated fault plane in the eastern wall of TT 303's courtyard (δN85° β45ºSE).

Fig. 12. Heterometric breccia and crushed Thebes limestone overlying the deformed marls of Esna Fm. at the western end of Dra Abu el-Naga.

The difficulty of properly sampling and analysing the weathering formations, was overcame with the use of the classic field determinations of soils (Schoeneberger et al., 2011), which gave valuable information about former environmental conditions. Colour in soils (Munsell® Soil Color Chart, 1998) relates to the presence of a series chromogenic elements such as iron oxides, the formation of which is closely related to climate. Different oxides give different colours depending on hydration and/or degree of oxidation; reddish colours are linked to the presence of hematite (dehydrated iron oxide) while brownish colours are related to the presence of hydrated iron oxides.

The morphological analyses included the identification of special features found in pebbles such as dissolution marks or different thicknesses of iron coats. These features gave additional information about the formation of these coatings (in situ or transported) or about the degree of humidity needed to create the dissolution marks.

4.2. Results

As pointed out before, the reconstruction of the original surface in Dra Abu el-Naga was a hard task due to the accumulation of debris former by the passage of time and human activity in the area (Fig. 14).

Two weathering formations, a reddish soil and an iron crust on scree deposits, have been identified as reliable features that mark the ancient surface, prior to the construction of the tombs and, therefore, they have been taken as a guide for reconstructing the landscape of Dra Abu el-Naga. Their particular morphological and pedological features revealed that they could not have been formed under the present hyper-arid conditions.

4.2.1. The reddish soil

A reddish-light brown soil develops in an almost continuous way across the entire necropolis (Fig. 15). Field analysis revealed a not very well developed soil profile, (Bw and/or C horizons), where contrasting colours (Munsell® notation, Munsell Soil Color Chart, 1998; Schoeneberger et al., 2011) are interpreted as differences in weathering patterns (Fig. 15).

Reddening depicted in Bw horizon (2.5 YR 6/4 to 7/4) reflects former alternating moisture conditions in a seasonal climate (Wagner et al., 2012, 2014), and may be related to the preferential presence of hematite (Fe_2O_3) against goethite (FeOOH). This high iron content can only be related to a temporary increase in moisture in a generally dry environment that promoted its mobilization from upper ferruginous crusts during wetter periods.

In addition, the reddening affects the clays present in the soil, which are in turn linked to the weathering of the substratum during wetter periods. In this sense, weathering of the dolomitic substratum [$CaMg(CO_3)_2$] during humid periods, should have been the source of these clay minerals, possibly sepiolite [$Mg_4(Si_6O_{15})(OH)_2 \cdot 6H_2O$] and palygorskite [$(Mg, Al)_5(Si, Al) 8O_{20}(OH)_2 \cdot 8H2O$] by the release of Mg.

During dryer periods the absence of water would neither lead to the formation of clay minerals nor to the reddening of the soil produced by the release of hematite. In these cases only a C-horizon with a whitish colour (5 YR 8/4) could develop (Fig. 15).

4.2.2. Iron coatings on scree deposits

A view of the study area from El Qurn revealed the existence of a lower erosional surface, 200–250 m below the Theban Plateau (from the Kings Valley to Dra Abu el-Naga, Fig. 16), more than 80% of which was armoured by a layer of dark clasts. At first glance, the logical provenance of these clasts was the upper iron crust of the Theban Plateau. However, a close up investigation revealed that they were in fact the scree deposits of a former surface, covered by younger moderate to heavy ferruginous coatings and also affected by other weathering features related to dissolution (Fig. 17).

Two weathering features were identified on clasts of Eocene silicified biomicrite from the Thebes Formation (Fig. 18): Dissolution marks and thick ferruginous coating.

A variety of microkarstic solution features are observed, such as discontinuous rillenkarren or rounded and/or flat-floored 'solution' pits. This microscale weathering seems to be closely linked to biological activity; those that retain available moisture dominate the weathering forms created (Smith et al., 2000). A selective

A

B

Fig. 13. A) Tomb -125- carved into reddish colluvial deposits; B) TT 282 front carved into colluvial deposits.

dissolution on the surface of the clasts produced a white silica-rich band (Fig. 18) better developed on the upper side (1–5 mm thick) than in the base of the clasts (<0.5 mm thick).

A thick ferruginous coating also develops at the interface between air, organisms, and mineral matter, being darker in the upper part of pavement clast and lighter in the bottom part of the clasts. It occurs as a continuous dark coating on outcrops and exposed scree (Fig. 17) and as discontinuous patches of variable thickness and texture. Colour ranges from dark brown (5 YR 3/1) to orange (2.5 YR 4/6) as a consequence of variable concentrations of different manganese (black) and iron oxides (red/orange).

5. Geological – geomorphological model

5.1. Methodology: field data

The particular geological features found during the research into the tombs provided useful structural and lithological information for the geological – geomorphological model. The geological field survey was extended around the necropolis, along the *wadi* Khawi el-Baradsah that crosses the study area, and towards the small hills south of Deir el-Bahari (Fig. 19). During this survey different strike and dip angles were measured in the stratigraphic outcropping sequence as well as in fault plains.

5.2. Results

This research found an almost vertical succession of thin-bedded silicified limestone outcrops along the *wadi* Khawi el-Baradsah (Figs. 19 and 20), as well as on top of the hill of Dra Abu el-Naga. The strong physical weathering affecting these rocks makes them extremely friable and transportable. Lithological and stratigraphic characteristics of this sequence suggest that it may be correlated with the upper part of Member I of Thebes Fm. (see Fig. 2).

At the head of the *wadi* Khawi el-Baradsah, an angular unconformity separates this Eocene vertical stratigraphic sequence from overlying horizontal layers of fluvial gravel deposits (Figs. 20 and

Fig. 14. View of the research area in Dra Abu el-Naga (*wadi Shig el-Ateyat*) before the cleaning work in 2015.

Fig. 15. Reddish soil (Bw) on western wall of TT 159 courtyard (Münsell colour 2.5YR6/4) and over TT 286 (Münsell 2.5 YR 7/4); and weathered limestone (C: Münsell colour 5 YR 8/4) above TT 159.

21) that can be followed along the road to the Valley of the Kings. The similarity of these gravels with the fluvial deposits defined as the Pleistocene Armant Formation (Said, 1981; Aubry et al., 2007; Zaki, 2007; Dupuis et al., 2011), points to an early Pleistocene age for this unit.

This fluvial unit is at present completely incorporated into the relief and affected on its surface by the ferruginous coating process described in section 4.2.2, which fossilises the post-Armant Formation palaeorelief, (Fig. 16).

A former torrential filling (Fig. 22) at *wadi* Khawi el-Baradsah, consisting of heterometric, poorly rounded pebbles and boulders embedded in a reddish clayey-silty matrix, is affected by an almost 2 m deep headwater erosion along this wadi. This deposit points to more humid conditions and aggradation processes, possibly associated with the same climatic humid phase that led to the development of the aforementioned reddish soil.

To the west of the study area, the upper Paleocene – lower Eocene Esna Shale Formation outcrops at the base of the scattered reliefs of the lower cliffs of Deir el-Bahari, usually overlaid by a chaotic heterometric breccia (see description in section 3.2.6),

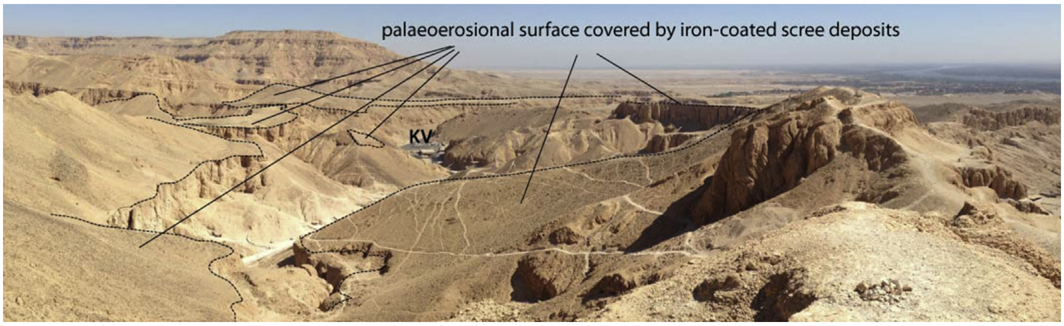

Fig. 16. Panoramic view from El Qurn (KV: Kings Valley), with the palaeorelief marked by the presence of iron-coated scree deposits highlighted by a dashed line.

Fig. 17. Close up of the scree deposits and mechanically weathered limestone covered by the ferruginous coating.

(Fig. 19). The mechanical contact between these units is interpreted as the lower horizontal part of the listric faults. The upper higher angle part of similar listric faults has been identified separating the Esna Fm. shales from the heterometric chaotic breccia (see Fig. 11).

6. Discussion

6.1. Rock quality

We propose here a classification of rock quality based on the Rock Mass Rating Index (RMR) defined by Bieniawski (1989) for civil engineering, which constitutes a Geomechanics Classification of rock masses. The classification procedure proposed by this author was based in six geomechanic parameters (uniaxial compressive strength; rock quality designation; spacing condition and orientation of discontinuities; and groundwater conditions) not all of them easy to get or relevant for our geo-archaeological purposes.

The main aim of our classification was to analyze the suitability of the geological substratum as host-rock for tombs. The rock quality classification was adapted to our site's characteristics and our research purpose, since both rock masses and transported materials were used as host-rock for tombs. Three main criteria have been used: lithology; degree of weathering; and "in situ" properties such as friability or number of joint families and their orientation, distance between discontinuities and their characteristics.

Karlshausen and Dupuis (2014) have recently published a similar approach in the near Sheikh Abd el-Qurna, based on the lithological diversity and the heterogeneities linked to fracturing. However these authors do not present a proper rating in classes, but a broad description of rock quality.

The rock quality index cannot be taken alone when analyzing the criteria used in the placement of tombs. In the Dra Abu el-Naga necropolis tomb placement may be a sum of several other criteria such as chronology, kinship and administrative positions, family relationships, titles or social status of the owners and visibility from the tombs to the mortuary and cult temples, as described elsewhere (Jiménez-Higueras, 2016).

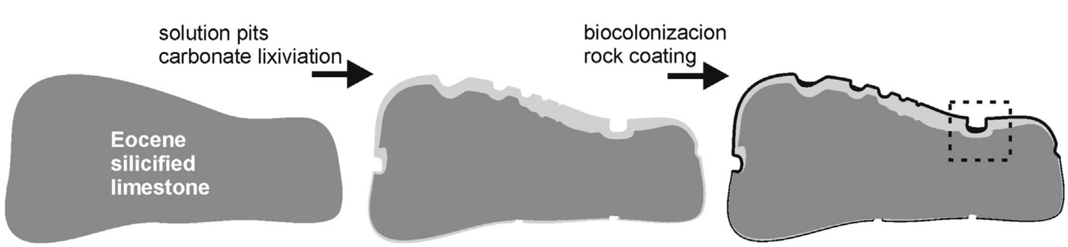

Fig. 18. Weathering features observed in an iron-coated pebble of the scree deposits.

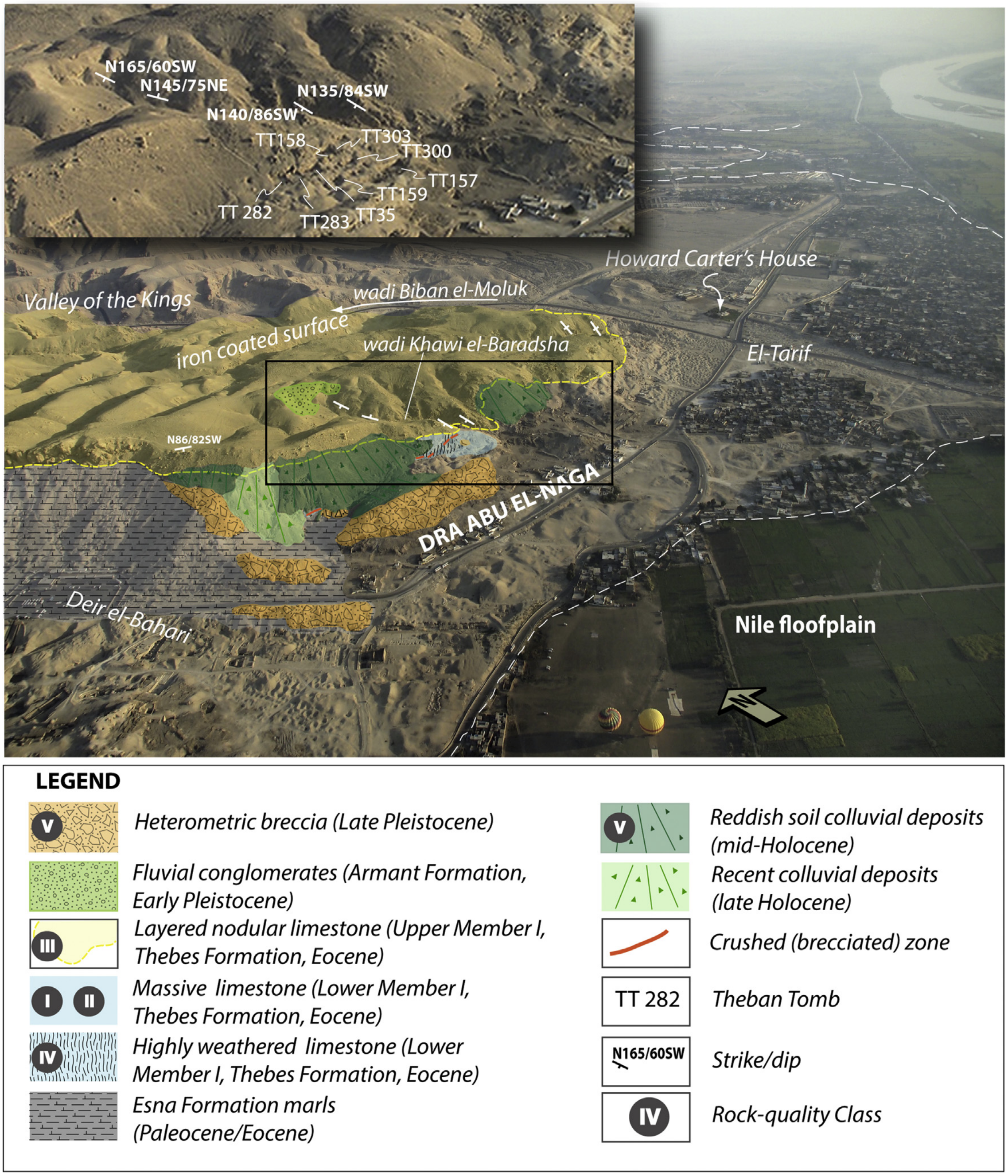

Fig. 19. Geological sketch based on field observations across the study area. Most of strike/dip measurements were taken along the wadi Khawi el-Baradsah. Location of tombs is approximated because of the scale of the image.

6.2. Reconstruction of the original surface: palaeoclimatic implications

The reconstruction of the ancient surface of the Dra Abu el-Naga necropolis was done thanks to the existence of two weathering surfaces, both of them associated with wetter climatic conditions (Table 2). An iron coating on scree deposits and a reddish soil have been identified as the landscape features that the Egyptians from the Middle Kingdom and New Kingdom found when they first came to Dra Abu el-Naga to build their tombs.

The oldest tombs found in the necropolis date from the Middle Kingdom (ca. 2000–1700 BCE; ca. 4000-3700 BP), so the humid phases that caused the weathering surfaces described above must be related to previous Pleistocene and Holocene wet periods.

Pleistocene climate in Egypt is characterised by the onset of hyperarid conditions punctuated by wetter episodes of increased rainfall and soil development. These pluvial episodes in Egypt were first defined by Said (1981, 1990) and later reinterpreted by Zaki (2007). The ages proposed for these classical pluvial events were: Idfuan and Armantian pluvial (early – middle Pleistocene); Abassian (I, II) (middle – late Pleistocene); and Saharan pluvial (late Pleistocene). Analyses of sedimentary fills in lakes from the Northern Sahara (Libya) and Saudi Arabia (Geyh and Thiedig, 2008; Rosenberg et al., 2013) allow the correlation of these humid episodes with interglacial periods during Middle and Late Pleistocene.

The fluvial deposits of the Armant Formation (early – middle

Fig. 20. Highly dipping layers corresponding to the upper part of Member I (Thebes Fm.) in the *wadi* Khawi el-Baradsah.

Pleistocene) have a younger smoothed topography on top, where a widely developed ferruginisation process points to a wetter than present episode that should have taken place during the middle Pleistocene (Table 2). Characteristics of the iron coating point to high humidity, conditions that can be tentatively associated with the wetter humid period identified by Geyh and Thiedig (2008) during MIS11 (>420ka).

A younger reddish soil covers the surface of the hill of Dra Abu el-Naga, including blocks fallen from the former ferruginizated surface. This reddish surface constitutes the real ancient landscape found by the Egyptians from the Middle Kingdom. Despite the lack of any precise dating, we propose that this younger than late Pleistocene wetter episode was associated with the "African Humid Period", (Table 2), described for Northern and Eastern Africa during the early – middle Holocene (Lario et al., 1997; deMenocal et al., 2000; Pachur and Hoelzman, 2000; Hoelzman et al., 2001; Tierney et al., 2011 among others). During this humid period the desert area was reduced in size, with an important spread of vegetation ("Green Sahara") as shrubs and trees covered large parts of the desert (Ehrmann et al., 2013), resulting in the development of soils. The age of the oldest tombs found in the necropolis (Middle Kingdom, 4000 - 3700 yrBP) and carved into this reddish soil surface, supports this chronology.

Another important climatic change occurred at 4200 yrBP (or end of the Old Kingdom) when the climate shifted towards more arid conditions (Stanley et al., 2003; Welc and Marks, 2014). This aridity could have been the cause of episodic catastrophic rainfalls that prompted the retreat of the cliff behind Deir el-Bahari, prior to the construction of the Hatshepsut Temple (ca. 3500 yrBP) and the earlier Middle Kingdom tombs behind it, and eroded the reddish soil surface.

6.3. Geological – geomorphologic evolution

As a result of the geological survey carried out in Dra Abu el-Naga, we propose a new geological - geomorphologic evolutionary model (Table 2). The study area has been previously called "Northern Basin" by Aubry et al. (2009), who describe it as an area

Fig. 21. Fluvial deposits of probable early Pleistocene age (Armant Formation; Said, 1981) unconformably overlying the vertical strata of the Thebes Formation at the head of *wadi* Khawi el-Baradsah.

Fig. 22. Valley fill at *wadi* Khawi el-Baradsah, affected by an almost 2 m deep headwater erosion.

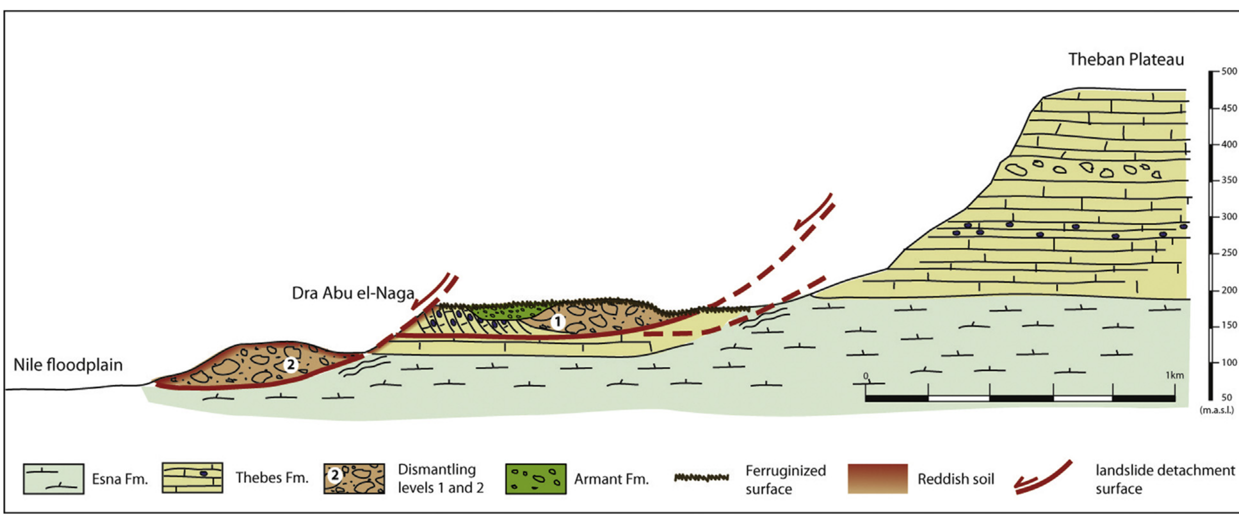

Fig. 23. Proposed geological-geomorphological model for Dra Abu el-Naga with two slumping events. 1 and 2: dismantling levels.

of "relatively low hills, apparently filled with interstratified conglomerates, clay beds and calcareous dolomitic playa lake deposits". These authors base this geological interpretation on the data given by Said (1981), who ascribed all the sedimentary units along this area (Fig. 12 of Said, 1981) to the Armant Formation, a torrential conglomeratic unit unconformably overlying the marine Pliocene sediments. Said (1981) indicates that "some of the finest exposures (of the Armant Formation) are found at the footslopes of the towering cliffs of the Plateau in the Thebaid hills" describing the section at *wadi* Bairiya as the most complete one, but no other sections of this Formation are described in the area. Dupuis et al. (2011) also assume that this "Northern Basin" is filled up with "detrital deposits issued from the erosion of the Theban Plateau collected together with playa deposits". Field survey did not support this "Northern Basin" concept, and for this reason we have renamed it as the "Northern Collapse" (Table 2).

The detailed geological analyses revealed the existence of steeply dipping layers from the upper part of Member I of Thebes Formation (see Fig. 2), overlying horizontal massive limestone of the lower part of the same Member. Similar quasi-vertical layers have been found upstream of the wadi crossing the necropolis and at the easternmost reaches of it (Fig. 19), overlaid by the undisturbed fluvial conglomerates that correlate to the Armant Formation. These findings led us to propose a mega-landslide event as the cause of this particular stratigraphic disposition (Fig. 23), which might have occurred at least during the Late Pliocene, prior to the deposition of the lower Pleistocene Armant Formation, and possibly also previous to the emplacement of the tilted blocks detached from the Theban Plateau, and described by several authors between the Valley of the Queens and Deir el-Bahari, (McLane et al., 2003; Cobbold et al., 2008; Aubry et al., 2009; Dupuis et al., 2011).

A second, minor slumping event occurred at Dra Abu el-Naga

Table 2
Succession of events in the Dra Abu el-Naga necropolis. Light grey rows indicate the two humid phases responsible for the weathering formations used in the reconstruction of the Ancient Landscape.

Time scale	Event	Comment, References
20th Century	Occupation of the necropolis by the village of Qurna	Its demolition in the first decade of 21st century left important amounts of rubble
3500-3000 yr BP	New Kingdom necropolis	Devastating earthquake has been reported to occur at 1200 BCE (Karakhanyan and Avagyan, 2011)
4000-3700 yr BP	Middle Kingdom necropolis	Building of predecessor of Hatshepsut Temple (ca.3500yrBP)
End of Mid Holocene (4200yrBP). Old Kingdom draught	Catastrophic rainfalls promoted erosional retreat of cliff at Deir el-Bahari. Red soil eroded at the top of the cliff behind the temples of Hatshepsut and Mentuhotep. Headwater erosion at wadi Khawi el-Baradsah.	Climate became more arid (Stanley et al., 2003; Welc and Marks, 2014).
Early – middle Holocene (AHP)	Reddish soil	Wetter than present climate, possibly associated with the African Humid Period
Late Pleistocene (MIS 4 – MIS 2??)	Strong physical weathering leading to strong colluvial development	Strongest aridity reported at: ca.32ka, (Reade et al., 2016), ca. 95-84ka (Ehrmann et al., 2013)
Late Pleistocene (MIS 5?)	Gravitational collapse II at Dra Abu el-Naga	Possibly coeval with the younger episode of tilted blocks described by Dupuis et al. (2011)
Middle – Late Pleistocene (MIS 9 – MIS 7??)	Tilted blocks	Different episodes of gravitational collapses separated by periods of stability. Related to Pleistocene pluvial stages (Dupuis et al., 2011)
Middle Pleistocene (MIS 11?)	Iron crust on pebbles, high degree of humidity	Wetter than present and than younger humid episodes
Early – middle Pleistocene	Fluvial activity over Dra Abu el-Naga (Armant Formation)	Relatively higher than present base level
Late Pliocene?	Northern Collapse: Mega gravitational collapse I at Dra Abu el-Naga.	Relatively high base level. Possibly earthquake induced.

much later Fig. 23, probably coetaneous to the younger slumping episode described by Dupuis et al. (2011) during the late Pleistocene.

Two different causes can be adduced as the triggering factors for the slumping events described in the area: seismic events or increased rainfall during Pleistocene pluvials (Dupuis et al., 2011) or interglacial periods.

Said (1981) includes an old seismic map of Egypt, where only two areas are highlighted as occasionally affected by very strong earthquakes, one of them being Luxor and surroundings. More recently Karakhanyan and Avagyan (2011) on the basis of archaeoseismological and palaeoseismological effects proposed the existence of an oblique-slip basement fault just beneath the study area, at the foot of the Theban Plateau, as the source of a 5.5–6.5 magnitude earthquake that occurred at around 1200 BCE. These authors give a maximum INQUA ESI-2007 (Guerrieri and Vittori, 2007) intensity of IX to this earthquake, which implies the mobilization of up to 10^5–10^6 m^3 of material.

The reported existence of a blind basement fault with historical activity, together with the presence of faults and brecciated zones, point to a seismic source as a probable triggering factor, helped by more humid climatic conditions during interglacial periods. The giant dimensions of the pre-quaternary landslide, with more than 10^6 m^3 of mobilized material, point to XI-XII ESI-07 intensity suggesting an estimated magnitude of at least 7–7.5 for a near field earthquake.

The first catastrophic event that led to the oldest gravitational collapse in the Dra Abu el-Naga area, (Table 2), occurred before the deposition of the fluvial deposits that we correlate with the Armant Formation as described by Said (1981) and after the Eocene, since it involves rocks from this epoch. A plausible timing for this first catastrophic event is the Messinian Stage, when an important down cutting of the Nile River took place (Zaki, 2007) promoting severe instability around the Eonile canyon, and possibly accompanied by earthquake activity. However, during the Messinian the base level was much lower than now, and therefore the base of the collapse should have been much lower than they are. An alternative timing for this collapse would be the end of the Messinian, with a recovering base level or during the Pliocene, with the sea level higher than now.

The second catastrophic event is much younger and smaller, possibly being coeval with the second gravitational collapse event described by Dupuis et al. (2011) as occurring during the Abassian I or II pluvials (middle – late Pleistocene), or most probably, during interglacial MIS5.

7. Conclusions

The ancient landscape of Dra Abu el-Naga has been almost entirely reconstructed thanks to the presence of two weathering surface formations that resulted from former wetter conditions.

The identification of these weathering features along the slopes of the necropolis allowed us to interpret in the context of the known palaeoclimate. A first humid phase probably occurred during the middle – late Pleistocene (MIS 11?), after the deposition of lower Pleistocene fluvial deposits (Armant Formation), triggering the mobilization of iron oxides and promoting the development of an iron coating on the scree deposits.

A second, more recent, humid phase resulted in the development of a reddish soil that covered the slopes forming the ancient landscape of Dra Abu el-Naga. Relative chronological data correlates this soil with the early-middle Holocene African Humid Period, described for Northern and Eastern Africa.

The geological research undertaken as part of the archaeological study of the necropolis of Dra Abu el-Naga provided some relevant geological data beyond the initial aims of this work.

The characterization of the host-rock of the tombs allowed their classification into five different Classes, based on the stability and smoothness of their rock and its suitability for decorative purposes.

Finally, the distribution and disposition of the different members of the Thebes Formation across Dra Abu el-Naga, led us to propose at least two catastrophic events with important gravitational collapses. The first one probably occurred during the late Pliocene, and the second one was possibly related to the humid period of the Last Interglacial (MIS 5).

Conflict of interest

The authors declare they have no potential conflicts of interest.

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