Early Late Pleistocene environments in Northeast Africa and their relevance for Anatomically Modern Human dispersal

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Preface

Starting in 2011 as student research assistant during my bachelor studies in geography, this dissertation results after almost eight years of my association with the CRC 806 „Our Way to Europe“. After finishing my bachelor-thesis in subproject C1 under the supervision of Dr. Martin Kehl, I got the chance to work during my master study course in quaternary science & geoarchaeology as a student research assistant in sub-project A1. Subsequent to my master thesis in this project, I continued as PhD-student under the supervision of Prof. Dr. Olaf Bubenzer.

I´m deeply grateful to Olaf Bubenzer for all the support he gave me throughout the last years. He provided me not only the opportunity for this thesis, but also integrated me into the overall framework of starting an academic career at a university-level, including to work with students and teaching. Thereby, I got the chance to concern myself also with other topics and responsibilities. This was crucial, as the realisation of the initial ideas for this PhD-project project in Egypt were far from being easy during the first years, due to the political situation in Egypt and lacking opportunities to conduct fieldwork. During this time, I also learned that starting an academic career is not always straightforward, but retrospectively seen each negative issue might also be the chance for something positively new.

Prof. Dr. Georg Bareth is being thanked for his willingness to co-supervise this dissertation and Prof. Dr. Frank Schäbitz is thanked to approve the chair of the commission for this dissertation. Dr. Andreas Bolten is not only thanked for being the secretary at the disputation of this thesis, but also for providing the Worldview-2 Digital Elevation Model. He also helped in all issues regarding the acquisition of satellite images and digital elevation models in our project.

Special thanks goes to Dr. Karin Kindermann! The project would not have been able to continue the fieldwork in Egypt without her effort, especially during the last years of political and administrative unsteadiness. She managed to keep things running and I strongly benefited from her experiences and assistance.

All scientific investigations, not only of this thesis and our project, but also of the CRC 806 in general, would not being possible without the excellent non-scientific work of Dr. Werner Schuck as Head of the Speaker´s office. He is acknowledged for all administrative and financial

issues. The German Research Foundation is thanked for the long-term funding of the project. I would also like to thank the supreme council of antiquities in Egypt (SCA) and the Egyptian Mineral and Resources Authority (EMRA) for providing permits to work in the Eastern Desert of Egypt, especially due to the assistant and organisation of Dr. Ahmed Almoazamy during the last years. Ahmed Ebaid helped us a lot for logistical support in Quesir and corresponding with the administrative in Egypt.

This thesis would not have been possible without the help and intense discussion with my co-authors of published and planned publications. Dr. Nicole Klasen is particular thanked for the OSL-dating of samples from Sodmein playa and her valuable input to this thesis. Dr. Christian Willmes brought me into the world of computational science and initiated the idea for the Palaeo-Köppen-Geiger climate computation for the Last Interglacial. Prof. Dr. Philip Van Peer and Dr. Mohamed Youssef are thanked for the cooperation and already published papers. Particular thank is also to Rene Eichstädter and Dr. Andrea Schröder-Ritzau from the working group of environmental physics, leaded by Prof. Dr. Norbert Frank at Heidelberg University, for conducting Th/U-dating of speleothems from Saquia and Nakheil Cave. Dr. Mathias Ritter is thanked for his work during the first phase of the project, when he conducted initial work at Gebel Duwi. Especially the investigations at Saquia Cave would not being possible, as he discovered the speleothem and it might be still undiscovered until now.

Norman Klahre, Christian Schepers and Dorothee Lammerich-Long participated at different field trips in the Eastern Desert and helped with data acquisition, as well as Malte Hochum and Jonas Handke during their work in Cologne. I´m very thankful to Christina Brake for her effort in proofreading and English corrections of this thesis.

Thanks are also dedicated to my old colleagues and friends at the Institute of Geograph, University of Cologne, as well as the new colleagues at the research group "Geomorphology, Soil Geography - Geoarchaeology" at the Institute for Geography at Heidelberg University, as a good daily office routine is still the most fruitful working environment.

Lastly and most important, I dedicate this thesis to my wife Mareen, where no words can express my gratitude for her support, confidence, and love!

Abstract

The history of humanity and the occupation of humans of the entire earth is a major scientific topic in various research disciplines, but also a subject of broad interest for the society. Thereby, research on the migration of Anatomically Modern Humans (AMH) has arisen in various specialised sub-disciplines of natural sciences (e.g. physical geography, geology, palaeoclimatology, etc.), but also in social sciences (e.g. archaeology, anthropology, ethnology, etc.). The complexity of the subjects involved has both opportunities and challenges, but only the integration of natural and social sciences comprises the ability to answer questions about the natural and cultural context for the spread of our species. One of the important research questions that still exist is the dispersal of AMH in Northeast Africa into the southern Levant and Southwest Asia. On the one hand, this region provides the only full terrestrial migration route Out of Africa that exists since the first appearance of AMH. On the other hand, it is part of the Saharo-Arabian Desert belt, where human occupation was mostly limited due to hyper-arid climate conditions. Therefore, the identification of palaeoenvironmental changes throughout the Late Pleistocene are crucial, as they provide the possibility for humans to occupy and disperse in this region when climate conditions were more favourable.

One important aspect of this study is the discussion of all results not only from a geoscientific perspective, but also within the ambiguity of other research disciplines involved. It is identified, that perspectives about spatial and temporal scale strongly differ between archaeology and geoscience and need to be overcome. Only an integrative approach accomplish for a better understanding of past human-environment interactions with their relevance for AMH dispersal, as it is a prime example where scale issues are very relevant. A proposed schema for a more precise consideration for spatial scales is given, based on the classification of different relief types, which sizes are integrated into research topics in archaeology. Even though, the spatial scale of daily activities, mobility pattern and large scale dispersal of humans are far from being define, the schema helps within interdisciplinary research as common language and to bridge different perspective about what are large and small scales.

The main importance of scale related issues is also reflected by the investigated study areas. The integration of field-based research at Gebel Duwi in the Eastern Desert and the analyses of a GIS-based reconstruction of the environment in Egypt aim together to give new insights into possible windows of opportunities for AMH dispersal in Northeast Africa.

The synthesis of a PalaeoMap for Egypt during the Last Interglacial identifies several regional differences based on the analyses of climate data, ecozones, relief types, drainage systems, and surface geology with focus on raw material bearing formations. There exist no environmental limitations for human occupation over almost all regions in Egypt during the Last Interglacial in general. Regional ecozones are mapped with the semi-quantitative integration of modern analogues with annual precipitation and Köppen-Geiger climate during the Last Interglacial. They point to a high regional variability in Egypt. In addition, abiotic parameter like geology and topography fabricate a more sophisticated characterisation of possible difference landscapes in Egypt where humans were influenced. The Western Desert has a more limited access to flint and chert bearing strata as important raw material for hunter-gatherers in comparison to the Eastern Desert and the Sinai Peninsula. The data compilation highlights, that the understanding of environmental factors influencing human behaviour is better achieved with a cumulative approach of parameters, although it has more uncertainties in comparison to highlight one detailed investigated parameter. It avoids an one-way interpretation, where only one parameter, even though more detailed, is seen as the main trigger for human dispersal.

The investigations from the area at Gebel Duwi provide new results for palaeoenvironmental changes and wetter climate during the Last Interglacial and Holocene. The sediment stratigraphy of Sodmein Playa indicates enhanced climate conditions at around 9 and 7.5 ka, which correlates with human occupation at Sodmein Cave during wetter climate phases of the Holocene. The dating of speleothem deposits at Saquia Cave show the presence of more humid climate conditions during MIS 5 and provide an important new climate archive in the Eastern Desert, but also for the Saharo-Arabian-Desert in general. All phases can be linked to the so far known times of human occupation at the nearby Sodmein Cave during this time. The fact that speleothem growth phases occur over all substages of MIS 5, not only during times of high insolation and a congruent northward migration of the monsoon, but also during phases of low insolation, indicates the significance of a regional climate archive. It provides a more detailed insight into wetter climate phases, as they can be derived from large scale proxy records as for example marine records or climate modelling. Several possible sources of enhanced rainfall in the Eastern Desert are discussed, where the proximity to the Red Sea and orographic rainfall in the Red Sea Mountains lead to regional differences and might trigger a more humid corridor in the Eastern Desert in comparison to other regions in Egypt.

The observations noted by field investigations for the correlation between the importance of regions with wadis draining flint and chert bearing geological strata is mapped with the given data at larger scale. It exemplifies the up- and downscaling of parameters in scale. The importance of the Eastern Desert as possible migration corridor is derived from the integration of the results from the PalaeoMap, field results, and integration of the over regional context. Here, the understanding of this region is still insufficient, but the synthesis of all results highlights this region as one of the key area for human migration Out of Africa.

Zusammenfassung

Unsere eigene Menschheitsgeschichte und die frühe Besiedlung nahezu jeglicher Regionen der Erde ist weiterhin ein weit umfassendes Forschungsfeld, welches auch eine große Relevanz für die Gesellschaft hat. Forschungen zur frühen Migration des Anatomisch Modernen Menschen spiegeln sich sowohl in den Geistes- als auch Naturwissenschaften wieder. Hierbei stehen sich jedoch teils unterschiedliche Forschungsperspektiven und Methoden gegenüber. Dies ist in der hohen Komplexität des Themas begründet, jedoch kann nur eine grundlegende Zusammenarbeit von unterschiedlichen Fachdisziplinen einen umfassenden Erkenntnisgewinn erreichen. Eine der wichtigsten Forschungsfragen zur Ausbreitung des Menschen ist die Frage nach frühen Mensch-Umwelt-Beziehungen, beispielweise in Nordost Afrika und angrenzenden Regionen der südlichen Levante und Südwest Asiens. Auf der einen Seite spiegelt sich in Nordost Afrika die einzige terrestrische Ausbreitungsroute Out of Africa wider, welche über den gesamten Zeitraum des modernen Menschen existierte, jedoch liegt diese Region im heutigen hyper-ariden Landschaftsraum der Sahara. Möglichkeiten der Besiedlung durch den frühen Menschen sind hier aufgrund der vorherrschenden Umweltverhältnisse über lange Zeiträume limitiert. Daher ist es aus wissenschaftlicher Sicht umso wichtiger die möglichen feuchteren, klimatisch attraktiveren Zeitphasen während des Spätpleistozäns besser zu erkennen und zu verstehen.

Ein grundlegender Aspekt dieser Arbeit ist die Integration der gewonnenen Ergebnisse nicht nur in den geowissenschaftlichen Kontext, sondern auch in den übergeordneten interdisziplinaren Zusammenhang der Forschung. Es wird deutlich, dass verschiedene Perspektiven und unterschiedliches Verständnis über zeitliche und räumliche Skalen zwischen den beteiligten Disziplinen, beispielsweise Geowissenschaften und Archäologie, bestehen. Jedoch kann in der Zusammenarbeit an einer gemeinsamen Fragestellung zu frühen Mensch-Umwelt-Beziehungen nur eine gemeinsame Sprache ein gemeinsames Ziel verfolgt werden. Daher ist die Kategorisierung von räumlichen Skalenebenen basierend auf der Größe unterschiedlicher Relieftypen mit der Integration archäologischer Fragestellungen ein wichtiger Ansatz dieser Arbeit. Auch wenn keine definierten räumlichen Skalen für unterschiedliche Aktivitäten des frühen Menschen von seiner täglichen Bewegung über grundsätzliche Mobilität und Migration

existieren, ist dieses Schema ein wichtiger Ansatz. Hierdurch kann eine gemeinsame Sprache gefunden werden, da die Perspektiven bezüglich groß- und kleinmaßstäbiger Fragen zwischen den Disziplinen stark variieren.

Die grundsätzliche Bedeutung verschiedener Skalen spiegelt sich auch in den zwei unterschiedlichen Maßstäben der Untersuchungsregionen wieder. Zum einen sollen Geländearbeiten im Umfeld des Kalksteinrückens Gebel Duwi in der ägyptischen Ostwüste Fragen zur Landschaftsgeschichte im Umfeld der dortigen archäologischen Fundstellen nachgegangen werden. Zum anderen soll eine GIS-basierte Übersicht ganz Ägyptens zum Zeitpunkt des letzten Interglazials die übergeordneten Umweltverhältnisse rekonstruieren.

Die Synthese für Ägypten verdeutlicht das Auftreten unterschiedlicher Landschaftsräume basierend auf den Parametern Klima, Ökozonen, Relief, Flusssysteme und Verfügbarkeit von Rohmaterial. Mit einem semi-quantitativen Ansatz und dem Vergleich heutiger Ökozonen ist eine regionale Differenzierung vorgenommen worden und dies spiegelt Unterschiede zwischen den einzelnen Regionen Ägyptens wider. Grundsätzlich bestehen zum Zeitpunkt des letzten Interglazials keine limitierenden Umweltfaktoren hinsichtlich ausreichender Niederschläge. Daher kann die Rohmaterialverfügbarkeit abhängig von Flint-Vorkommen als weiterer wichtiger Parameter integriert werden, um mögliche attraktivere Regionen für den Menschen auszugrenzen. So befinden sich in der Ostwüste und auf der Sinai Halbinsel deutlich größere Vorkommen als in der Westwüste. Grundsätzlich verdeutlich die Verbindung der unterschiedlichen Parameter in einem kumulativen Ansatz, dass trotz der Unschärfe einzelner Faktoren ein umfassenderes Bild entsteht im Vergleich zu singulären Parametern. Diese können zwar detaillierter vorliegen, die Interpretation des einzelnen Parameters ist jedoch zu einseitig als Schlüsselfaktor für die menschliche Besiedlung.

Die Ergebnisse im Umfeld von Gebel Duwi verdeutlichen feuchtere Klimabedingungen während des letzten Interglazials und Holozäns. Die Sediment-Stratigraphie von Sodmein Playa zeigt ein feuchteres Klima in der Region vor etwa 9000 und 7500 Jahren an und korreliert mit der holozänen Besiedlung der Sodmein Höhle zu diesem Zeitpunkt. Datierungen an sekundären Karbonatablagerungen in Saquia und Nakheil verdeutlichen Tropfsteinwachstum während des letzten Interglazials, welches unter heutigen Klimabedingungen aufgrund des

Wassermangels nicht stattfindet. Diese Ergebnisse korrelieren auch mit der Besiedlung während des letzten Interglazials im direkten Umfeld der Sodmein Höhle. Die gute zeitliche Auflösung der Datierungen zeigt, dass feuchtere Klimabedingungen für Tropfsteinwachstum nicht nur mit Phasen starker Insolation korrelieren, sondern auch mit Phasen schwacher Insolation in Nordost Afrika. Somit haben regionale Besonderheiten, wie die Nähe zum Roten Meer oder die Topografie des Roten Meer Gebirges, abseits von übergeordneten Klimaverhältnisse in Nordost Afrika eine bedeutende Rolle.

Geländebefunde zeugen von der großen Attraktivität von Wadis, welche Flint-führende geologische Schichten entwässern und quartäre Sedimente aufweisen, als Rohmaterialquelle für den Menschen. Diese Ergebnisse können mittels GIS-Kartierungen in den überregionalen Kontext extrapoliert werden. Dies steht beispielhaft für die Möglichkeit skalenübergreifender Interpretationen der unterschiedlichen Maßstabsebenen.

Basierend auf der Zusammenführung aller Skalen und Ergebnisse sowie der Integration angrenzender Regionen, kann die ägyptische Ostwüste als möglicher Korridor für die Ausbreitung des Menschen bewertet werden. Auch wenn das Wissen über die Forschungsregion weiterhin durch einen Mangel an Daten begrenzt ist, repräsentiert sie trotzdem eine der wichtigsten Regionen für den frühen Menschen auf seinem Weg Out of Africa.

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1. Introduction

The history of humanity and the occupation of humans to the entire earth is a major scientific topic in various research disciplines, but also a subject of broad interest for the society. Our own species, *Homo sapiens*, is the only surviving species of the genus *Homo*, which originated in the late Middle Pleistocene and dispersed to all continents of our planet - except of Antarctica - by the end of the late Pleistocene (Groucutt et al. 2015). Thereby, research on the migration of Anatomically Modern Humans (AMH) has arisen in various specialised subdisciplines of natural sciences (e.g. physical geography, geology, palaeoclimatology, etc.), but also in social sciences (e.g. archaeology, anthropology, ethnology, etc.). The complexity of the subjects involved has both opportunities and challenges, but only the integration of natural and social sciences comprises the ability to answer questions about the natural and cultural context for the spread of our species.

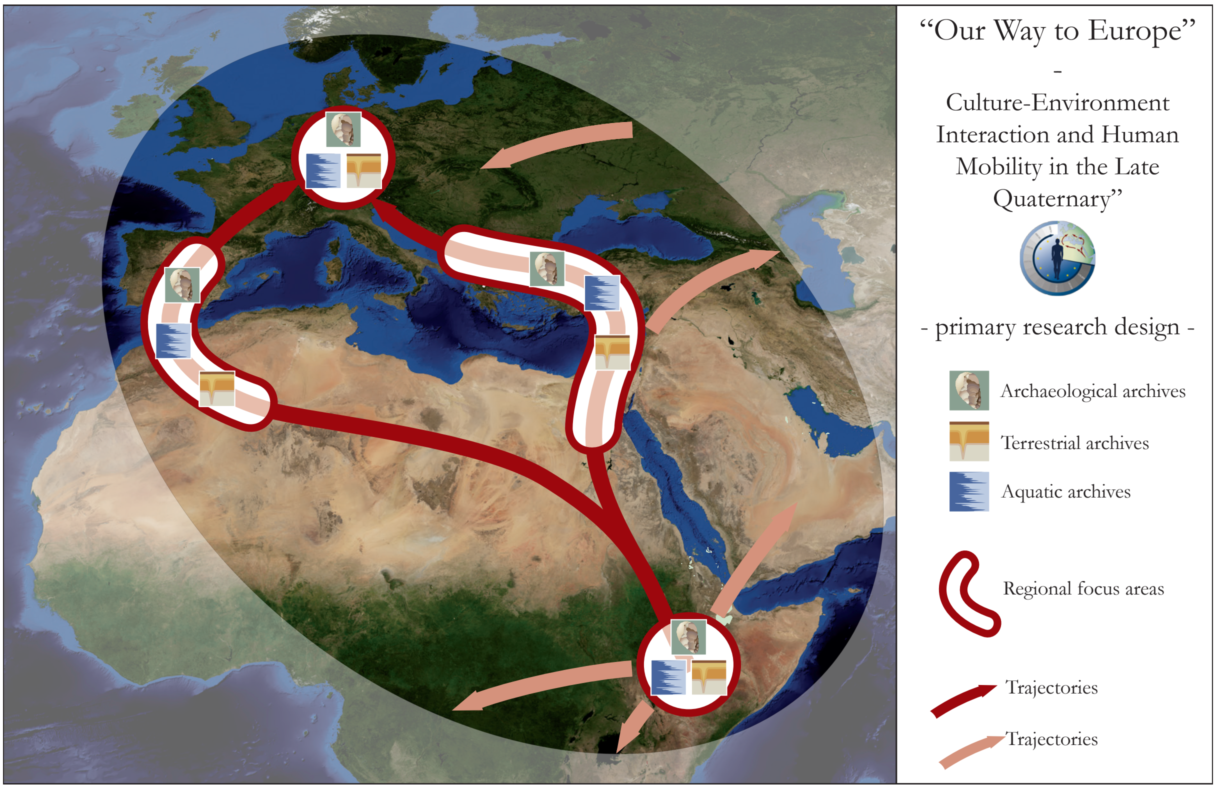


Figure 1: Primary research design of the CRC 806 „Our Way to Europe“ for the study of AMH dispersal from one of its "source region" in East Africa, either over an eastern or western trajectory into one of its "sink" in central Europe.

The long-term Collaborative Research Centre (CRC) 806 "Our Way to Europe - Culture-Environment Interaction and Human Mobility in the Late Quaternary" (funded by the German Research Foundation (DFG) since 2009) is a prime example of an interdisciplinary research project, which aims to integrate disciplines of natural and social sciences to investigate the spread of AMH from its "source" in Africa, to one of its "sinks" in central Europe (figure 1).

Thus, different regional projects and methodological cluster from archaeology and geosciences interact with each other and investigate various geo- and archaeological archives. Mainly two major dispersal routes of AMH Out of Africa into central Europe were emphasised at the beginning of the research project in 2009. A possible western trajectory connects Northwest Africa via the Strait of Gibraltar with the Iberian Peninsula and further on into central Europe and a possible eastern trajectory runs from Northeast Africa via the Sinai Peninsula towards the Levant and the Balkan into central Europe.

This thesis is embedded in the CRC sub-project A1: "Out of Africa – Late Pleistocene Rock Shelter Stratigraphies and Palaeoenvironments in Northeastern Africa" (PI Prof. Dr. Olaf Bubenzer, Dr. Karin Kindermann, Dr. Ralf Vogelsang). The areas of investigations in this project are located in Ethiopia and Egypt and this thesis is affiliated to the Egyptian part of the project. Here, the project has its regional focus in the Central Eastern Desert in Egypt at Gebel Duwi, where the important archaeological site of Sodmein Cave is located and the initial motivation for this sub-project is based on. Interdisciplinary research from archaeology and geosciences intend to provide a better understanding of palaeoenvironmental conditions, site-formation processes and human-environment interaction. Although Egypt is the only region which provides a full terrestrial route (so called northern route) Out of Africa, it is challenging because only little is known from complementary archaeological and environmental archives. Instead, palaeoenvironmental information are often derived from marine records or global climate models representing an over-regional climate reconstruction without direct context to archaeological sites. Direct field investigations of the CRC have the objective to fill this gap for the chosen study area in the Eastern Desert, but also in the overall context of Northeast Africa.

Geosciences and archaeology often challenge a common temporal and spatial perspective, not only due to the temporal and spatial resolution of the studied archives and results, but particular important with regard to their interpretations. It is worth to note that successful interdisciplinary field investigations and further upscaling of the results in space and time need to include a common language between involved subjects and vice versa. Given this ambiguity of the involved subjects in the CRC, it is important to note why interconnected subjects as geography, where this thesis is originated, matter so much as a link between natural and social sciences within this topic. GOUDIE (2016) sees the environmental history with its influence on humans in the past as one of the major interweaved themes between human and physical geography and thus, as a link between natural and social sciences. Although the study of prehistory in social sciences is mostly studied by archaeology rather than human geography, a geographical perspective is crucial as the subject can be defined as the "science of integration", where "space and time frame all aspects of the discipline of geography" (GOODCHILD 2013). Geography is the most appropriate subject to integrate various perspectives in space and time, and thus, needs to fulfil a confident leadership position in interdisciplinary research of human-environment-interaction, respectively "claim the high ground" (STODDART 1987). It is deeply rooted in the long history of geography that the subject is neither natural science nor social sciences (HETTNER 1905), but this ambiguity is often challenging as the integral branch of (geographical) knowledge has suffered due to the specialisation of all related sub-disciplines (STODDART 1987). This drifting is no phenomenon caused by recent developments in techniques and methods, as RICHTHOFEN (1883) already discussed almost 150 years ago the questions about the need of geography as particular science, which need to persist next to other specialised (sub-) disciplines. It is worth to mention, that interdisciplinarity is easier said than done, and none of the associated disciplines can be right in providing an ultimate unified theory of everything to answer the research question. The subsequent applied geographical perspective of this thesis is not independent, but strong advantages of its interdisciplinary bridge between social and natural sciences are supposed. Overall, this geographical point of view is attributed to Humboldt´s interdisciplinary perspective "Everything is interaction" (HUMBOLDT 1808).

1.1 Aims of thesis

A better understanding of the temporal, spatial and environmental context of AMH dispersal in Northeast Africa, as overall topic of subproject A1, serves as a background for the aims of this thesis. Thereby, two scales frame the focus where this study is conducted. Firstly, local investigations in the central Eastern Desert at Gebel Duwi and secondly, over-regional investigations for Egypt as distinct area in Northeast Africa. The research design is based on a fundamental interdisciplinary character, aiming to integrate various investigations from theory to practice, from field to (computer) lab based investigations, contemporaneous knowing that each aspect cannot be intent upon the most detailed profoundness, but draw its strength from the integrated character of investigations.

The workflow (figure 2) uses a traffic-light system for the three steps of research investigations. The first step (red) is the identification of main aims and research questions as a background and guideline for this thesis. These goals and hypotheses are breakdowns of proposed research questions of the CRC, with particular focus on subproject A1, and are adapted to the capacity for this thesis. Each goal with its according hypothesis is assigned to one of the 19 overall research questions of the CRC.

Goal I: Identification and definition of distinct spatial scales for Late Pleistocene human-environment interaction in Northeast Africa

Hypothesis I: The systematic application of relevant geomorphological relief units based on the spatial extent of landforms provide a sufficient quantitative and assignable background for the identification of distinct research areas in Egypt.

Goal I can be integrated into the overall research question of the CRC: "Is it possible to establish new methods for tracing the migration history?"

Goal II: Integration of field-based investigations and GIS-based investigations to provide a sufficient background for the landscape context at the archaeological site of Sodmein Cave and sites in the Central Eastern Desert in general.

Hypothesis II: The chance to encounter stratified geo- and archaeo-archives in the study area is very limited and sites of investigations can be attributed to distinct geomorphological landscape settings.

Goal II can be integrated into the overall research question of the CRC: “Where and when was *Homo sapiens* present in the CRC study area? “

Goal III: Establishment of a better identification of environmental and climate changes in the study area during the Late Pleistocene

Hypothesis III.I: Global climate models are insufficient to predict the detailed climate at the scale of the study area, but represents a first order approximation for the general climatic situation during the late Pleistocene, where second order interpretations can be based on.

Hypothesis III.II: The analysis and dating of growth periods of speleothem deposits in the Eastern Desert provide a regional climate archive, which allows a more in-depth study of climate changes in comparison to large scale climate records derived from marine records.

Goal III can be integrated into the overall research question of the CRC: “Which conclusions can be drawn from the temporal and spatial patterns of climate events for the position and intensity of dominant circulation systems as well as the leads and lags of their teleconnections?” and “Was the regional presence or absence of *Homo sapiens* connected with climatic and environmental changes?”

Goal IV: Infer possible attractive corridors for AMH migration Out of Africa

Hypothesis IV.I: Based on the derived palaeoenvironmental information in Egypt and the Eastern Desert during the late Pleistocene and the established GIS method to create a PalaeoMap of Egypt, the main aspects of a possible attractive landscape become visible.

Hypothesis IV.II: Possible migration corridors of AMH are not only related to “best-climate” scenarios, but important other factors such as the availability of raw-material have a high impact, which is often neglected.

Goal IV can be integrated into the overall research question of the CRC: “Which role did the palaeogeography (barriers and bridges) as well as the fauna and flora play for migration?”

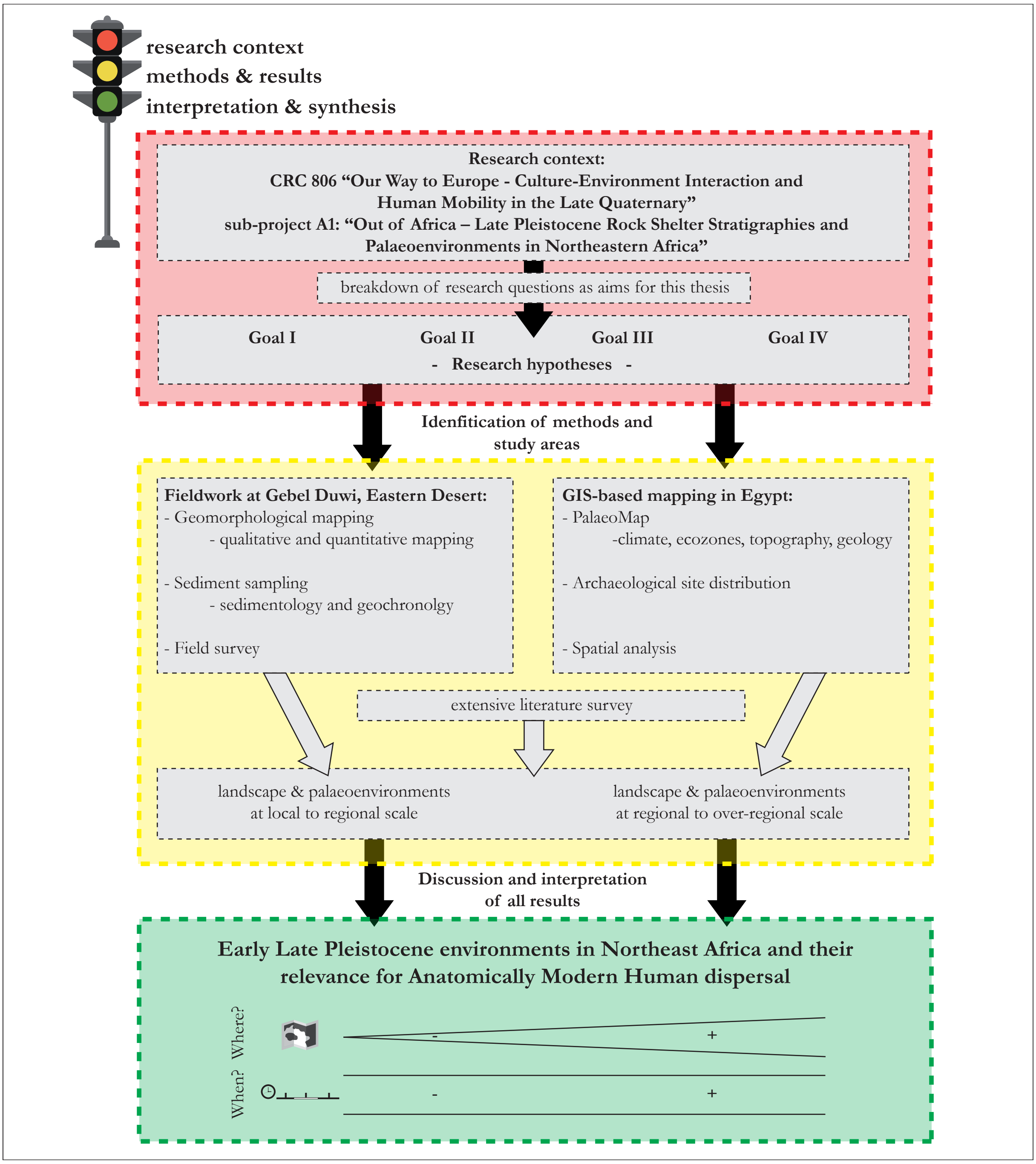


Figure 2: Workflow of this thesis using a traffic-light system for the tripartite steps of research (own design).

The second step (yellow) is data acquisition by the use of different methods and the presentation of the results according to the two scales of primary focus. Thereby, all single investigations have either its primary focus on temporal or spatial aspects and in doing so, the fundamental geographical approach is obvious. The final step (green) is the spatio-temporal synthesis of all results and their integration into the overall research context and proposed research goals.

1.2 Outline of thesis

This thesis starts with the research contextualisation and theoretical background for the given topic (chapter 2). The study area in the Central Eastern Desert of Egypt and sites of investigations, where fieldwork was conducted as part of this thesis, is subsequent presented in chapter 3. Chapter 4 provides the applied methods, from fieldwork, laboratory analysis, dating techniques and GIS investigations, following by the presentation of the results (chapter 5). These are subsequent discussed and interpretations are given for each results (chapter 6), before chapter 7 provides the discussion of all results as background for new implications for AMH dispersal. The synthesis of this thesis is finally given in chapter 8.

2. Research contextualisation and theoretical background

This chapter aims to give a general overview is provided about the first appearance of AMH and accordingly its current knowledge about its initial temporal and spatial dispersal Out of Africa, as main research background particular importance for sub-project A1. In addition, the theoretical discussion about the different research approaches and disciplines with particular importance of spatial scale related issues are presented.

2.1 The origin and first dispersal of AMH

The study of the history and evolution of the genus *Homo* and particular of *Homo sapiens* raises controversial debates during the last decades. The current knowledge point to the evolution of the genus *Homo* to 2.8 Ma, where its lineages diverted into different sub-species of the genus *Homo* (*cf.* summary in Potts 2018). Some of the early species of *Homo*, e.g. *Homo erectus*, already left the African continent which merged into the concept of Out of Africa 1, whereas for instance *Homo neanderthalensis* evolved outside of Africa from *Homo erectus* and lived in Eurasia between 200 - 40 ka before it was replaced by the spread of *Homo sapiens* (Richter et al. 2012). The second spread of the genus *Homo* from Africa, here *Homo sapiens,* is examined by means of the concept of Out of Africa 2. Based on genetic data, *Homo sapiens* and *Homo neanderthalensis* shared its last common ancestor around 700-400ka (Stringer 2016). Different models exist about the particular evolution of *Homo sapiens* (*cf.* summary in Henn et al. 2018): (1) African Multiregionalism, (2) Single Origin Range Expansion with Local Extinctions, (3) Single origin Range Expansion with Regional Persistence and (4) Archaic Hominin Admixture in Africa. Although the study of human genomes shows some mixing of DNA with archaic populations outside of Africa, the recent African origin hypothesis (*Homo sapiens* emerged and started its spread to the world from the African continent) is still supported by the integration of all evidences (Stringer 2014). Given the African origin of *Homo sapiens* as accepted, its actual regional evolution within the African continent is still a matter of debate. Scerri et al. (2018) return questions about the evolution in single or subdivided early populations of *Homo sapiens* on the African continent and emphasise, that the interlink of different groups with changing connectivity, e.g. forced by environmental changes, need further investigations. The oldest known dated fossil of *Homo sapiens* comes from Jebel Irhoud (Morocco) and is dated between 315 ± 34 and

286 ± 32 ka (Richter et al. 2017). The fossil remains show morphological characteristics comparable to recent or early AMH, but also more archaic features and thus, show an early stage of *Homo sapiens* (Hublin et al. 2017). Apart from this latest published results from Northeast Africa, most evidences for the first appearance of our species exist in the East African Rift System, where for a long time the oldest fossils were found, dated to 195 ± 5 ka (Omo Kibish 1) and 160-154 ka (Herto 1 and 2) (McDougall et al. 2008; Clark et al. 2003). East Africa provides also one of the most comprehensive records of palaeoenvironmental reconstructions, e.g. by analysis of long-lasting lacustrine archives of the East African (palaeo-) lakes currently done be the Hominin Sites and Palaeolakes Drilling Project (Cohen et al. 2016), but also with regard to archaeological findings. This is equally important for a better understanding of early human-environment interaction, as fossil based reconstructions of the evolution of our species is limited. Particularly the oldest fossils do not show clear comparable components and represent intermixtures between more modern and archaic morphological features and thus, other aspects need to be included. Outstanding information about the transition from *Homo erectus* to *Homo sapiens* are gained in the Olorgesailie basin (southern Kenya rift valley), where one of the most detailed records exist to study the transition from Acheulean, associated with *Homo erectus*, to Early Middle Stone Age (EMSA) associated with the emergence of *Homo sapiens*. Here, the determination of the late Acheulean is dated to 615 - 499 ka, before definite Middle Stone Age (MSA) elements occur between 320 - 305 ka (Deino et al. 2018). This transition is associated with a remarkable change in stool tool technologies from highly persistent mode during the Acheulean towards an increasing complexity and technological innovations during the onset of the MSA. Fundamental changes also occur in the environmental dynamics from more long lasting stable climate conditions before 500 ka to enhanced wet-dry variability and a turnover of 85% in the total faunal composition beginning at 300 ka (Potts et al. 2018). Apart from the discussion about the oldest fossils of AMH, this and other comprehensive records of the MSA in East Africa provide a comparable detailed record for the time of early *Homo sapiens*. It might not be the discrete source region for the origin of AMH, but it still acts as one of the most important regions to study the dispersal of AMH Out of Africa (Blinkhorn & Grove 2018). Thus, the temporal and spatial dispersal of AMH from East Africa provides the framework of

the CRC and particular the overall research questions for sub-project A1.

Based on an East African perspective for the spread of AMH Out of Africa, two major pathways are discussed. A possible northern route runs through Northeast Africa via the Sinai Peninsula into the Levant. Here, AMH fossils found in Israel at Quafzeh and Skuhl have been the oldest fossil evidences outside of Africa for a long time and were dated to 100 ±10 ka and 120 ±8 ka at Quafzeh (Schwarcz et al. 1988) and 135 - 100 ka at Skhul (Grün et al. 2005). Recently, new datings for AMH fossils found at Misliya Cave are even dated around 194 - 177 ka (Hershkovitz et al. 2018). Therefore, in addition to archaeological findings at long-lasting cave stratigraphy's, the presence of AMH in the Levant is well documented and serves as a connection between this region and Northeast Africa (*cf.* summary of archaeological sites in Enzel & Bar-Yosef 2017).

An alternative pathway Out of Africa is associated with a southern route, crossing the southern Red Sea via the Bab el-Mandeb at the southern end of the Red Sea from East Africa towards the Arabian Peninsula. This possibility is discussed with the integration of archaeological findings on the Arabian Peninsula dating back to MIS 5, e.g. at Jebel Faya (Armitage et al. 2011) or Dhofar (Rose et al. 2011) and possible sea-level low stands at Bab el-Mandeb, which enables humans to cross this barrier and to migrate into the Arabian Peninsula (Lambeck et al. 2011). Even with the recent findings in Northwest Africa at Jebel Irhoud, missing evidences of the fossil record and cultural similarities on the western trajectory between Northwest Africa and the southern Iberian Peninsula do not prove the initial hypothesis of the CRC of possible sea crossing over the Strait of Gibraltar for AMH Out of Africa (Tafelmaier et al. 2017). Therefore, apart from the discussion where *Homo sapiens* first occurred, investigations about the actual dispersal routes where AMH left the African continent persist between the two possibilities between East Africa and the southern Arabian Peninsula or Northeast Africa and the southern Levant respectively northern Arabian Peninsula.

By integrating palaeoenvironmental changes, archaeological and fossil based evidences, mainly two periods are emphasised for different dispersal models: an early dispersal during early MIS 5 with occupation of AMH outside of Africa, e.g. in the Levant, Arabian Peninsula, southeast Asia and Australia (*cf.* Westaway et al. 2017, Clarkson et al. 2017) and a later dispersal phase starting at around 60 ka during MIS 3 (*cf.* Mellars 2006). However, increasing evidence point to a more complex dispersal history and multiple variations of the Out-of-Africa model and multiple dispersal phases, where also possible re-migrations back into Africa are important to consider (*cf.* Groucutt et al. 2015, Van Peer 2016, Bae et al. 2017, Cabrerea et al. 2018). This background serves as a framework, where the sub-project A1 of the CRC 806 investigates potential pathways and periods for a better understanding of possible windows of opportunities for AMH dispersal in Northeast Africa.

2.2 Arid environments

Today, the northern, but also southern migration route crosses the largest continuous arid zone in the world, the Saharo-Arabian Desert (SAD). Therefore, desert regions have a high importance for the understanding of AMH migration. From a geoscientific point of view, desert regions consist of five main process domains (Parsons & Abrahams 2009): Hillslopes, rivers, piedmonts, lake basins and aeolian surfaces. Each of them has different significance in terms of providing archaeological features and serve as geo-bio archives. Former lake basins and hydrographic features are probably the most attended domain for geoarchaeology in arid environments (*cf.* Mandel 1999; Bubenzer & Riemer 2007), because human occupation in nowadays desert regions often took place in wetter climatic periods and humans were concentrated at streams, lakes or ponds to have a sufficient availability of freshwater. Mandel (1999) argues that it is therefore not surprising, that many sites found in desert regions are concentrated at the present or former sources of water and it seems straightforward to look for archaeological sites near streams, playas, springs and other potential sources of water. On the other hand, a general increase of available water occurred during wetter climatic periods within the landscape, not only directly related to hydrographic features and the straightforward look to these features is limiting a wider view of the environment. People can exist in drylands as they have sufficient food and water resources, and one does not always need to invoke wetter conditions to gain access to this. Allogeneous rivers (e.g. Nile) or groundwater feed lakes and oasis (recent examples for lakes in the Sahara exist today for instance at Ouniangam or Guelta d'Archei, Tschad) could serve as refuge, and it is possible that desert regions were suitable for periodic exploration or migration through even during drier conditions (McLaren & Reynolds 2009). Arid to semi-arid environments are mainly characterised by a strong seasonal change with a distinct dry and wet season throughout the year. Ephemeral runoff of rivers, shallow pools and gueltas exist, where water is available after occasional rainfalls or following the rain seasons. In cases where at least a seasonal/temporary lake can be postulated for a given location, from morphological (pool, depression) and sedimentological investigations, it is difficult to link such seasonality with the direct archaeological evidences, because seasonal mobility of hunter-gatherer societies are hard to discover. Partly, this is a problem of the temporal scale, as the absence of dated evidences in arid environments is still a considerable problem (Stewart & Jones 2016).

The greening of the Sahara during the Holocene climate optimum shows one example, where human-environment interactions in response to climatic changes in a hyper-arid environment can be reconstructed (*cf.* Kuper & Kröpelin 2006), and the Holocene is probably the only time period, where human occupation of arid lands can truly be dated (McLaren & Reynolds 2009). Based on a good chronology and detailed archaeological records with various function of a site, also more detailed information like seasonal movements of humans, and highly mobile subsistence strategies due to of seasonal changes in available water can be investigated, e.g. at the archaeological site of Djara in the Western Desert of Egypt (Kindermann et al. 2006). Together with geomorphological investigations, human settlement concentrated on palaeohydrological features and favourable drainage systems can be correlated in the Western Desert for the Holocene (Bubenzer & Riemer 2007). Normally, this cannot be achieved in such detail by studying human-environment interactions during the late Pleistocene in arid environments, although the human behaviour patterns like mobile subsistence strategies have already existed. This brings issues of scales in particular focus. They are subsequent discussed within the research context of geoarchaeology, as one very prominent buzzword today in interdisciplinary study of human-environment interaction, and archaeogeomorphology, which is so far comparable unknown but likewise important.

2.3 Scales in geoarchaeology and archaeogeomorphology

In fact, human behaviour and processes about palaeoenvironmental changes operate at different spatial and temporal scales (*cf.* Stein 1993; Goldberg & MacPhail, 2011; McLaren & Reynolds, 2009). However, geoscientists, geographers, archaeologists, and researchers from other associated disciplines have different definitions and understandings of scale, which can be summarised in the statement by Quattrochi & Goodchild (1997: 395): "Scale is a confusing concept often misunderstood, and meaning different things depending on the context and disciplinary perspective". (McLaren & Reynolds 2009). As an example, archaeologists in general will tend to study smaller scales in more detail in comparison to geographers. One also has to keep in mind that each scale in which observations are made does not necessarily correspond to the scale at which a process operates (Schlummer et al. 2014). A general problem is, that "examinations of landscapes traditionally focused only on the high-density "sites", rather than both sites and non-site areas" (Olszewski et al. 2010: 192). It is a challenge to correlate "site-areas", seen here as local, spatially limited direct evidence of human behaviour derived from archaeological findings, with "non-site-areas", seen here as regions, where the presence of humans in the past can be postulated, but where there is no direct evidence derived from archaeological findings. This is of particular interest in older time periods, e.g. for the late Pleistocene, because the quantity of meaningful sites where the study of human-environment interactions in direct context is possible falls substantial. As it was shown, this is even more challenging in (nowadays) arid environments, where a wide range of temporal possibilities (exploration - migration - long-term settlement) and spatial occurrence (high specialised refugee vs. expanded settlement) for human exist (McLaren & Reynolds 2009).

The affiliation to a specific research context is difficult as there are co-evolutionary research trends in the individual disciplines (Hill 2017), but the history and application highly affects the usage of various scales in the given research context. The answer to "What is geoarchaeology?" varies depending on, respectively, the disciplinary and the geographical background (Engel & Brückner, 2012, Hill 2017). Although a broad discussion about definitions and the research history in the field of geoarchaeology is not the intention of this paper, it affects the meaning and usage of the term scale in the context of geoarchaeology. One definition of geoarchaeology states that it is "the application of any earth science concept, technique, or knowledge base to the study of artefacts and the processes involved in the creation of the archaeological record" (Rapp & Hill 2006: 1). It can be observed, that the direct link to an archaeological record, respectively a site, in the application of geo- and earth sciences is crucial for the term geoarchaeology, per this definition.

Gladfelter (1977) was one of the first to highlight the importance of scale in geoarchaeology. He describes microscale as the context of artefacts found in a specific depositional environment (i.e., a site-specific location). The term mesoscale describes the local landscape setting, while the macroscale is the regional morphogenetic environment (Gladfelter 1977). Butzer (2008) claimed that in geoarchaeology spatial components need more systematic consideration. He defines the microscale environment as "on-site geoarchaeology", with focus on sediments, syn- and post-depositional processes, and micro-stratigraphy. The mesoscale environment "focuses on direct, empirical identification of the spatial patterns of geomorphic context for a proven site or for undetermined but promising locations" (Butzer 2008: 404). Macroscale is the "particular landscape in which a known site is located or unidentified sites may be located" (Butzer 2008: 403). The environment at this scale helps determine the "potential combinations of geomorphic and other processes operating in the region, and affecting sites in particular kinds of topographic settings" (Butzer 2008: 403). In total, all these parameters have a potential influence on the site itself. The matter of scale always refers to the site and the investigations under the framework of geoarchaeology tend to focus in these on-site archives.

With respect to the tripartite approach of spatial scales in geoarchaeology and the direct context to a given (or unidentified) site as common denominator, it becomes evident that it cannot satisfy all spatial scales where important hypothesis and aims of this thesis, but also for the CRC 806 in general, can be investigated. Questions about possible morphological bridges, barriers or corridors for AMH migration in Northeast Africa are often isolated form given sites. A geomorphological perspective can investigate these areas from a morphological point of view to analyse possible pathways along large (palaeo-) drainage systems or valleys, but geomorphological processes also affect the existing of possible raw-material or water sources.

Wandsnider introduced the term "archaeogeomorphology" in 1992 and Thornbush (2012) picked up this term again and tried to identify it as an application of geomorphology apart from geoarchaeology. According to THORNBUSH, archaeogeomorphology is "where excavation is lacking and there is no real collaboration with archaeologists, only consultation" (THORNBUSH 2012: 327). In fact, there should be no reduction in intensity of the collaboration from geoscientists and archaeologists in archaeogeomorphology. The difference between geoarchaeology and archaeogeomorphology is the study object, not the degree of knowledge exchange and collaboration between the involved disciplines. Therefore, archaeogeomorphology can be better defined as geomorphological studies of landscapes uncoupled from archaeological sites with regard to past human behaviour between sites. Thus, it is delimited to geoarchaeology, which is shown to be in general site-orientated with focus on the formation and transformation of archaeological sites as the main research target. CORDOVA (2018) also sets the term archaeogeomorphology apart from what he called the geomorphology-soil tradition as one background of geoarchaeology. This tradition in geoarchaeology focusses on the formation and transformation of archaeological sites, mainly with aspects from sedimentology, pedogenesis and stratigraphy. The updated definition indicates that the term does not refer to this point of view. With the strict definition about geomorphology as the science of the georelief of the earth crust and the study of landforms (BRUNOTTE 2002), the given definitions sets archaeogeomorphology as a sub-discipline of geomorphology, similar to other sub-disciplines of geomorphology, e.g. biogeomorphology or anthropogeomorphology. The given delimitation to geoarchaeology also shows that geoarchaeology cannot be seen as sub-disciplines of geomorphology, as for instance suggested by FUCHS & ZÖLLER (2006). This is in accordance with GERLACH (2003), who criticised that the semantic origin of the term geoarchaeology is archaeology is often neglected, so the direct focus should normally be seen in archaeology. Thus, archaeogeomorphology also emphasises the semantic origin of the term in geomorphology as distinction to geoarchaeology. Based on the geomorphological perspective, established spatial scales of landforms can serve as a quantitative and distinct definition distinguish between geoarchaeology and archaeogeomorphology (figure 3).

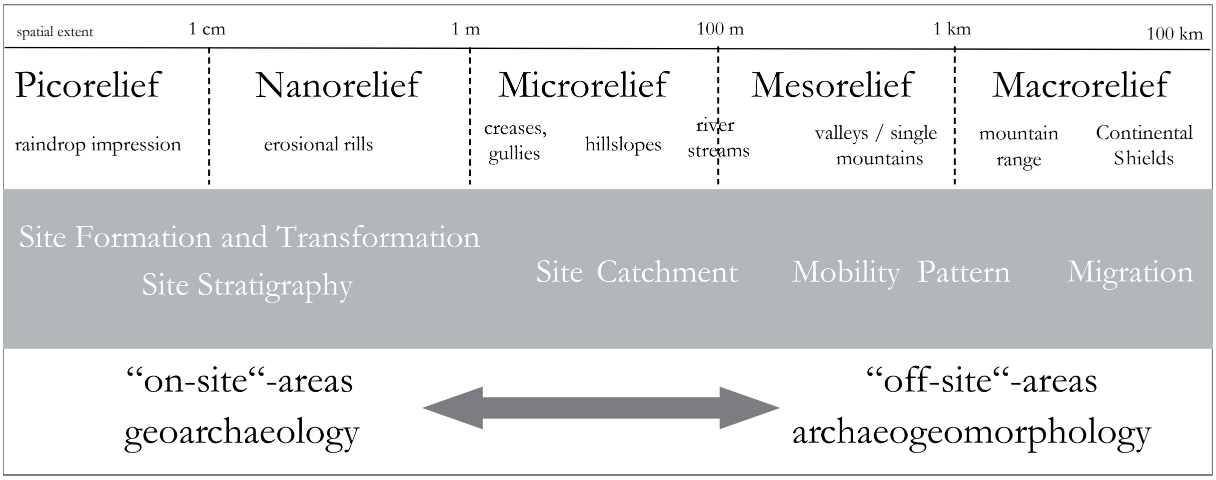


Figure 3: Relief based scales (after DIKAU 1988) in geoarchaeology and archaeogeomorphology for the relationship between geomorphological relief units and research questions between an on-site focused geoarchaeology and off-site focused archaeogeomorphology (own design).

Geomorphic processes operate on a wide spectrum of spatial scales, ranging from a few millimetres up to several hundreds of kilometres, resulting in a wide range of landforms. There are numerous scale-related relief classifications and theoretical investigations on the morphometry of landscapes as background in geomorphology. It is not the aim to provide a detailed discussion about the history for these classifications, as given for example in BUBENZER (2009) and MACMILLAN & SHARY (2009), but the transfer of such classifications is given. The spatial extent of a given landform is one approach (DIKAU 1988) for the classification of different relief units. DIKAU classified six relief types ranging from picorelief to megarelief, based on the extent of its basis, its area, and the depth-height ratio. This can range between 10^{-7} km to more than 10^{3} km. Examples of geomorphological landforms range from small-scale erosional rills, gullies, hillslopes, rivers or larger mountains, and valleys up to continental shields. Just as all (floating) thresholds, it is quite evident, that the defined boundaries of these relief types can also be crossed, as the natural relief and morphological objects represent a continuum. In addition to the geomorphological features, common archaeological research questions about site formation, site catchment, or the mobility and migration of humans can be placed according to its general spatial scale. It results in the question at which scale geoarchaeological and archaeogeomorphological work can be integrated.

Principle examples of such archaeogeomorphological studies at scales of the meso- to macrorelief are for example GIS-based modelling of least cost paths and distance modelling in between archaeological sites based on the analysis of digital elevation models. Here, the focus is clearly on the investigation of distinct landforms and the relief, without direct investigations on a specific site and its formation and transformation. Examples of this can be found in the results of cost distances and site catchments for prehistoric sites in Andalusia (Becker et al. 2017) or a least cost path model for hominin dispersal routes in Africa (Beyin et al. 2019). These are explicit examples for archaeogeomorphology in the sense of the given definition, although the authors do not claim its approach as archaeogeomorphology. It is mostly due to the buzzword of geoarchaeology, rather than archaeogeomorphological work, that the term is relatively disregarded in the scientific literature. Cordova (2018) claimed that the term first needs to be more popularised in the field of researcher from geoarchaeology. However, this can only be achieved, if researchers identify and recognise the differences between geoarchaeology and archaeogeomorphology and ask themselves, if their work is actually geoarchaeology or archaeogeomorphology (*cf.* Nicu 2016). To sum up the different perspectives of geoarchaeology and archaeogeomorphology based on the given characteristics of interdisciplinarity and spatial focus of its research object, geoarchaeology has a high interdisciplinarity, is mainly site orientated and thus, has its focus on smaller spatial scales in comparison to archaeogeomorphology. Archaeogeomorphology is equally interdisciplinary, but its focus is on investigations apart from sites and thus has a larger spatial scale (figure 4). In practice, these differences overlap and there is no strict boarder of research fields, but to get a common language among disciplines, these considerations are very important overcome the initial challenges.

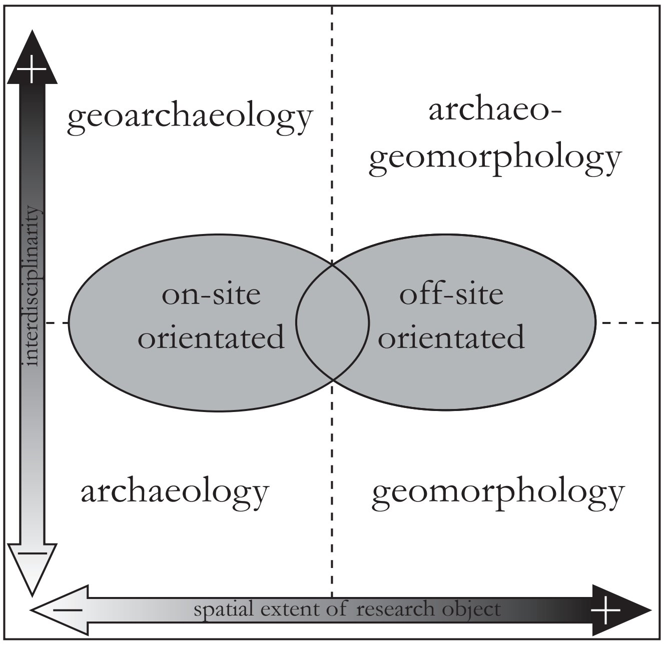


Figure 4: Spatial context between interdisciplinary approaches in archaeology, geomorphology, geoarchaeology and archaeogeomorphology with its relative spatial extent of the study object (own design).

3. Study area

The study area is not only limited to the area of field investigations at Gebel Duwi, but also needs to integrate the overall context of Egypt. Geographical, geomorphological, and geological Egypt can be separated into four regions (EMBABI 2018): the Western Desert, the Eastern Desert, the Sinai Peninsula, and the Nile Valley with its delta. All of them represent major environments and particularly characteristic landscape units (figure 5).

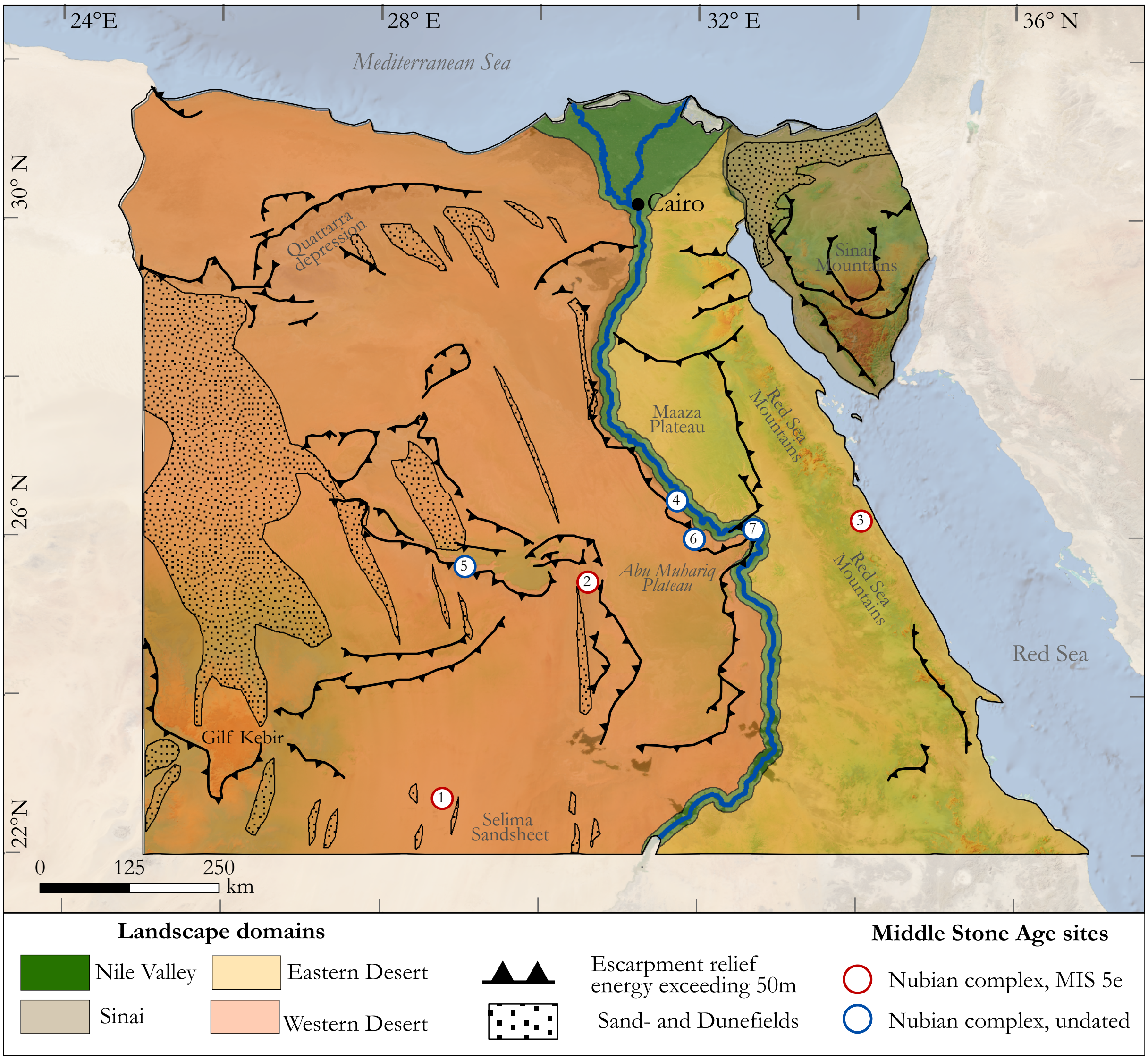


Figure 5: Landscapes of Egypt after EMBABI 2018 and archaeological sites after table 2. Data: Digital elevation model SRTMv3, USGS. Satellite image: MODIS-Blue Marble - Stöckli et al. 2005. Escarpments & dunefields: BOLTEN & BUBENZER 2007. Cartography: HENSELOWSKY

The Western Desert is characterised by large limestone plateaus (e.g. Abu Muhariq Plateau) and depressions (Quattara, Siwa, Kharga, Dakhla), bounded by distinct escarpments. Sand seas exist in its western and central part (Great Sand Sea and Farafra Sand Sea) and smaller dune fields occur occasional. The south-western part is the only part where heights exceed above 1000 m in the Gilf Kebir plateau. The Gebel Uweinat is an isolated granite inselberg with heights up to 1934 m, but has no impact to the overall characteristics of the Western Desert in Egypt due to its remote location at the triangle between the borders of Egypt, Libya, and Sudan. In the southern part, the Selima Sandsheet represents a flat sandy landscape and reaches from Egypt into Sudan.

The river Nile has created a huge canyon-like deep incision during its geologic past, which separates the Eastern and the Western Desert. Large escarpments on the western and eastern side of the valley, e.g. well developed in the Qena area in Middle Egypt, mark the valley as a distinct relief element in the overall morphometric setting of Egypt. The Nile Delta was mainly built up during the Holocene and represents one of the youngest major landscape of Egypt. Late Pleistocene deposits are found in the submerged parts of the delta in the Mediterranean Sea. Older Pleistocene terraces throughout the course of the Nile exist, but are often overprinted by human impact.

The Eastern Desert and the Sinai Peninsula are in most parts mountainous areas, where one-third of its surface persists of exposed Precambrian basement rocks. They form a complex topography with high mountains, strong tectonic displacement, and deep incised wadis, often related to tectonic fault lines. Due to the rifting and opening of the Red Sea since the Late Eocene, the rift shoulders were tectonically uplifted and form Egypt`s maximum heights, with Gebel El-Shayeb (2,187 m asl.) as highest point in the Red Sea Mountains and Mount St. Katherine (2,641 m asl.) in the south of the Sinai Peninsula as the highest absolute point of Egypt. The central Eastern Desert and the area around the limestone hogback of Gebel Duwi is subsequent characterised in more detail, as this regions represent the background for field investigations as part of this thesis.

3.1 Geology of the Central Eastern Desert and Gebel Duwi

The central Eastern Desert consists of a complex geological and tectonic setting, resulting in a high diversity of exposed bedrock, fabricated in a small structured landscape. The Red Sea Mountains exist as a mountain range parallel to the Red Sea from north to south. Adjoined areas towards the north of the Sinai Mountains and the western areas of the Red Sea Mountains are covered with Mesozoic and Cenozoic sedimentary rocks. Almost all different types of sedimentary rocks, which occur in Egypt, are also exposed in the Eastern Desert (figure 6). The most important process of landscape evolution for the current setting in the Eastern Desert is the opening of the Red Sea since the late Eocene and associated tectonic activity, with rifting and tectonic uplift of rift shoulders (Embabi 2018). A schematic cross-section between the eastern limestone plateau of the Western Desert, and the southern Sinai Peninsula crosses the Nile valley via the Eastern Desert, and the Gulf of Suez from southwest to northeast direction represents the main geological strata.

High rates of tectonic uplift in the western and eastern side of the Red Sea lead to the erosion of Phanerozoic sediment rocks and exhumation of the Precambrian basement. Major tectonic displacements with high angle deep-seated fault systems are concentrated in the Red sea basins, respectively the Gulf of Suez and the adjacent areas of the Nile Valley (Sultan et al. 2007). El-Gaby et al. (1990) classify the basement rocks in three different groups: (1) pre-pan African rocks with a high-grade of metamorphic rocks, (2) Pan-African rock assemblage with ophiolites and island arc associations, and (3) Phanerozoic alkaline igneous rocks. These groups are merged into the basement complex of the Eastern Desert, which are apart from the minor Phanerozoic volcanic rocks, of Precambrian age. Detailed studies and summaries of the basement complex, the tectonic evolution of the Neoproterozoic the Arabian-Nubian shield, exist extensively, but are only referred to at this point (*cf.* El Gaby et al. 1990), as the detailed differences of the Precambrian basement have no significant impact to the given research questions.

The general stratigraphy of exposed post-Precambrian rocks in the Central Eastern Desert is of Cretaceous to Quaternary age and is divided into three lithological divisions (Embabi 2018). The lower clastic division consists mainly of Jurassic to Upper Cretaceous sedimentary rocks with a thickness of more than 1000 m. The Nubian group represents thick sandstones of various environments with fluvial, deltaic, and lacustrine environments (Said 1990). In the central Eastern Desert, the Nubian sandstone is exposed with the Taref formation at the west, parallel to the Red Sea Mountains and the basement complex (Conoco 1987). The Middle Calcareous Division was deposited between the Upper Cretaceous (Quesir and Duwi formation)

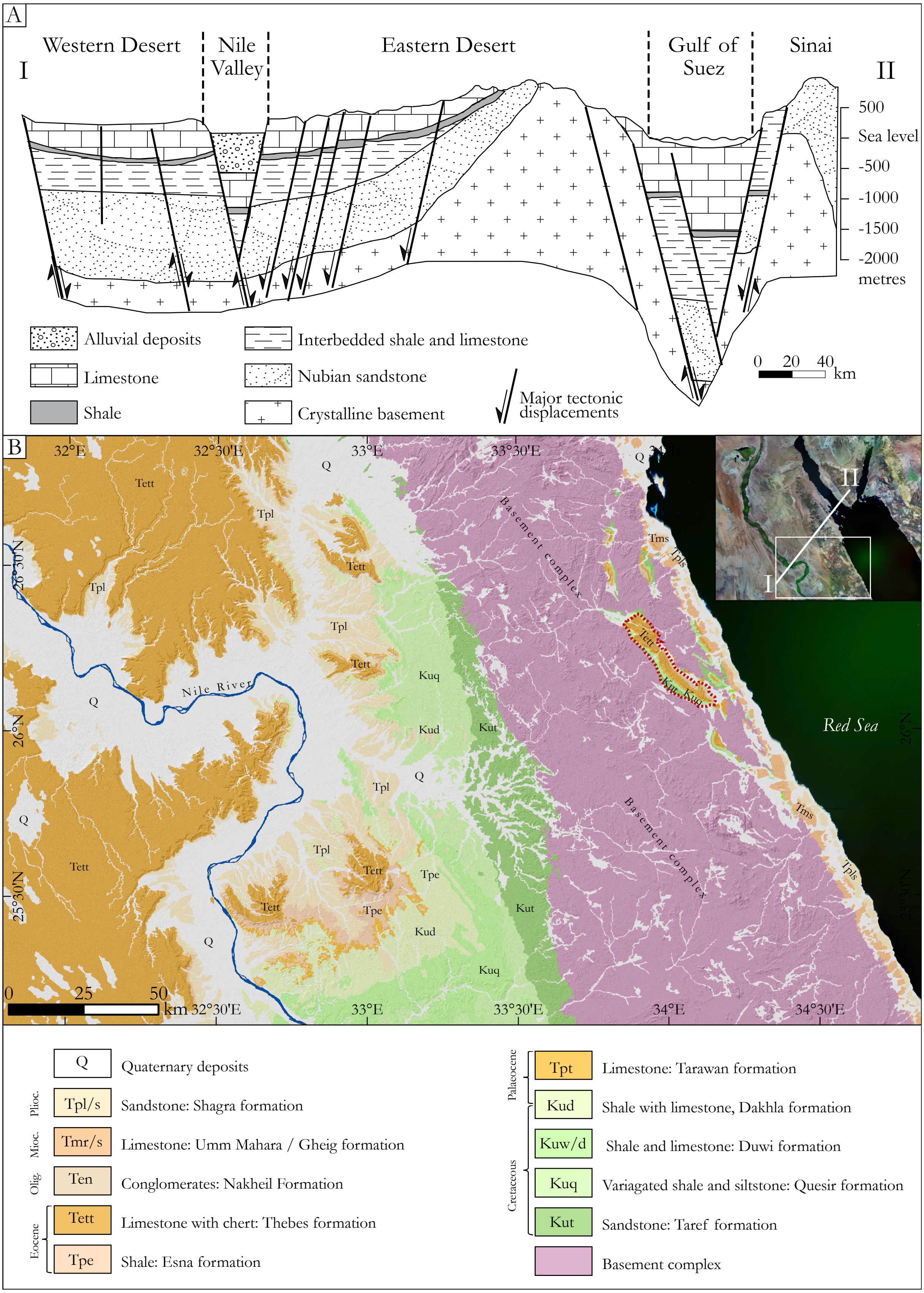


Figure 6: Geological cross-section and surface geology of the Central Eastern Desert. A) Schematic geologic cross-section between the Western Desert (I) and the southern Sinai Peninsula (II) modified after SULTAN et al. 2007; B) Surface geology of exposed bedrock, modified after Geological Maps of Egypt 1:500.00 CONOCO 1987, Gebel Duwi indicated with red dotted line. The index map is based on LANDSAT Geocover ETM+. Cartography: HENSELOWSKY

and the Eocene (Thebes formation). During this time, the transgression of the Tethys Sea lead to the formation of these thick marine limestones and shales. Due to the high uplift of the Red Sea Mountains, these sedimentary rocks are today eroded in the most elevated areas of the Central Eastern Desert, but are subsequent exposed up to the Nubian sandstone. The sandstone is expsed parallel towards the Nile Valley, where the uplift of the rift shoulders does not reach the heights of the Red Sea Mountains. The Gebel Duwi (figure 7) is a geological exception, where the Post-Precambrian sediment rocks are exposed within the basement complex of the Eastern Desert.

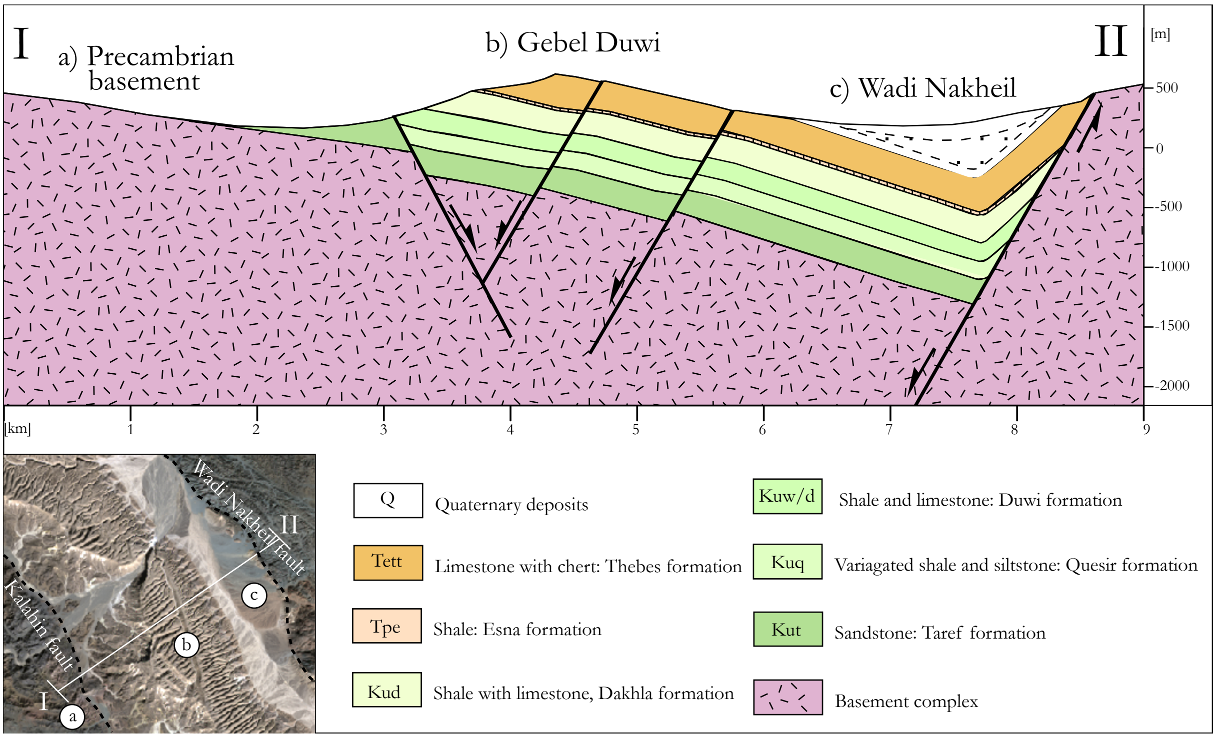


Figure 7: Schematic geological cross-section of Gebel Duwi modified from Khalil & McClay 2002 and geological map of Egypt 1:50000, sheet NG 36 NE Quesir (Conoco 1987). Index map is based on Sentinel-2 image, bands 432 (acquisition date 16.01.2019).

The Upper clastic division of Oligocene to Quaternary age is mainly exposed at the eastern side of the Red Sea Mountains at the coastal areas of the Red Sea and is of fluvial origin. These deposits consist of the erosional rock debris from lower and middle clastic division of sedimentary rocks. Along the Red Sea coast, they are intercalated with shelly-coralline sandy and silty deposits originating from a reef marine environment during sea level high stands of the Red Sea (Embabi 2018).

3.2 Current climate in the Central Eastern Desert

The Eastern Desert of Egypt is located in the sub-tropical hyper-arid belt of the Saharo-Arabian-Desert. The SAD is the largest connected desert region in the world and the spatial extent of this regions is exceptional (figure 8). The aridity-index after the United Nations Environment Programme (UNEP) (Cherlet et al. 2018) summarises precipitation and potential evapotranspiration in one factor (P/PET) and shows, that Egypt belongs to an hyper-arid environment, where only minor regions located at the Mediterranean coast show an arid environment.

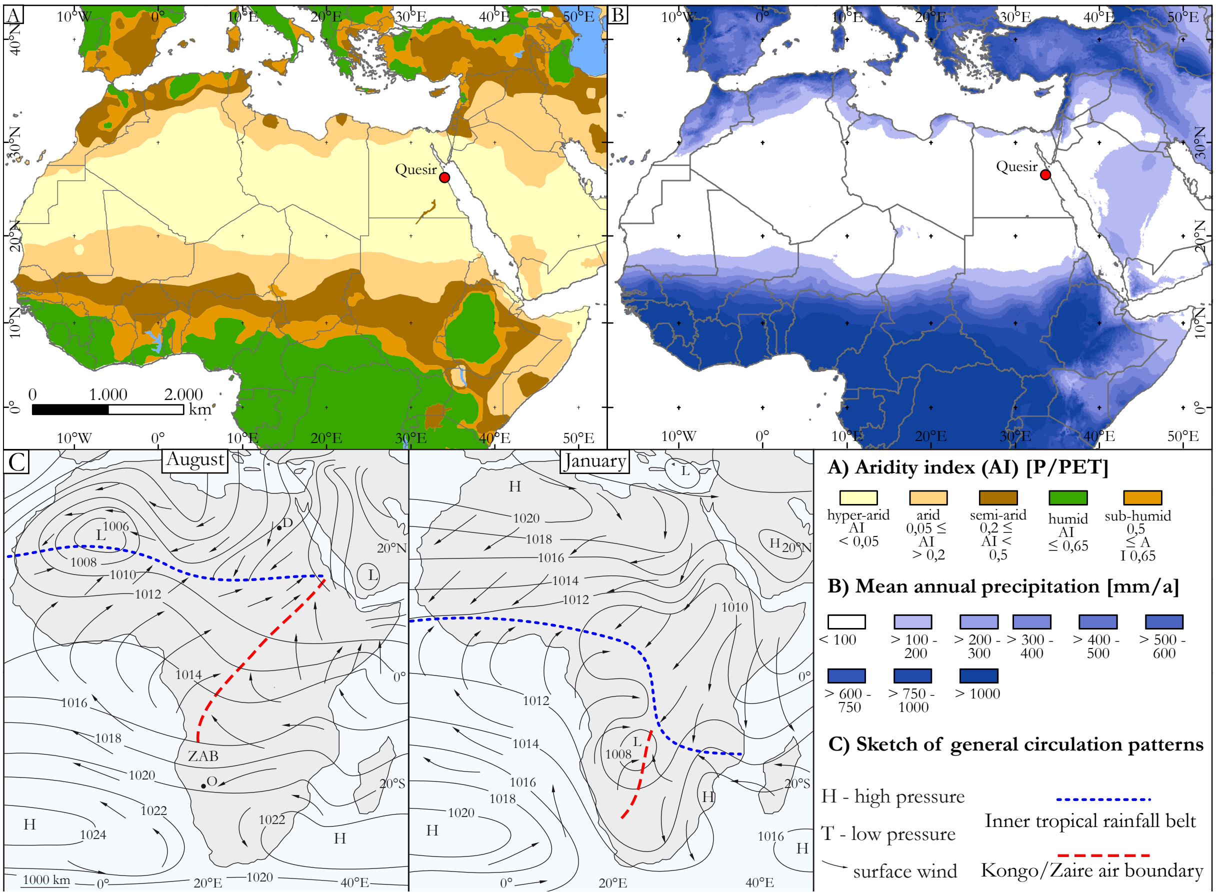


Figure 8: Aridity-Index and current climate in North Africa. A) Aridity-Index calculated on Precipitation/potential Evapotransprration based on United Nations Environment Program – Global Resource Information Database (UNEP-GRID, Charlet et al. 2018); B) Total annual precipitation (Fick & Hjimans 2017, www.worldcim.org). Cartography: Henselowsky; C) General circulation pattern of the atmosphere over Africa during (A) January and August, modified after Bubenzer & Ritter 2007

Annual total precipitation accounts for less than 20 mm on average, with erratic rainfall events, and very high evaporation rates. The seasonal shifts in rainfall over the North African continent are mainly driven by the yearly migration of the inner tropical rainfall belt. It follows the yearly peak in insolation, where a northward shift causes summer rainfall during the northern hemisphere summer months. Only some minor parts on the most south-eastern region of Egypt receives these summer rainfall in June, July, and August regularly (Embabi 2018). A southward shift to the southern hemisphere takes the coastal region of North Africa under the influence of the extratropical westerlies transporting rainfall in the northern hemisphere winter months. Winter rainfall is only recorded in the most northern parts of Egypt at the Mediterranean coast, where mean annual precipitation does not exceed 200 mm. The most favourable months for rainfall are December, January, and February.

The nowadays hyper-arid conditions in Egypt are caused by three main factors: Firstly, the geographical position in the subtropics as part of the overall circulation of the Atmosphere between the geographical latitude of 22-32 N°. Neither the northward migration of the summer rainfall, nor the southward migration of the winter rainfall zone, bring substantial rainfalls and Egypt is mostly under the influence of the subtropical high pressure zone. The descending trade winds of the Inner Tropical Convergence Zone causes the main aridity in this region (Bubenzer & Ritter 2007). The second factor is the strong continentality and far distance to the rain bringing moisture sources, and thirdly to the reinforcement of the aridity caused by the tropical easterly Jetstream (Besler 1981).

Apart from the long-term average of annual rainfall and a comparable climate in the overall context of Egypt, the Eastern Desert has some specific regional features, due to the close distance to the Red Sea and the Red Sea Mountains. Extraordinary rainfall events occur more frequently in the Eastern Desert than in the Western Desert of Egypt. These events can cause large flash-flood events in the Eastern Desert e.g. at Wadi Qena in 2012 (Badawi et al. 2014), but also at the Sinai Penisula a, e.g. at Wadi El-Arish in 2010 (Badawi 2013). Extraordinary rainfall events are attributed to distinct weather situations. Today, tropical moisture source can bring sporadic rainfalls to Northeast Africa, the southern Levant and the Arabian Peninsula. This can be associated with a tropical plum (Ziv 2001) or the activation of the Red Sea Troughs transporting moisture from East Africa to the Sinai Peninsula and the southern Levant (Ziv et al. 2005, De Vries et al. 2013). Nowadays examples for the interaction of tropical-extratropical pressure systems forcing extreme rainfall events in the Red Sea region in 2005 and 2013 are given in De Vries et al. 2016.

The characterisation of ecozones and associated types of vegetation is based on the mapping of worldwide ecozones (figure 9). They provide 867 distinct units, which are integrated into 14 overall biomes (Olson et al. 2001). The terrestrial ecozones in Northeast Africa and adjacent regions are very divers and are mapped in more detail in comparison to biomes. The environmental context, which classify ecozones, is more divers and regional impacts have an overprint to large-scale climate. This causes the more variable ecozones in comparison with the annual precipitation.

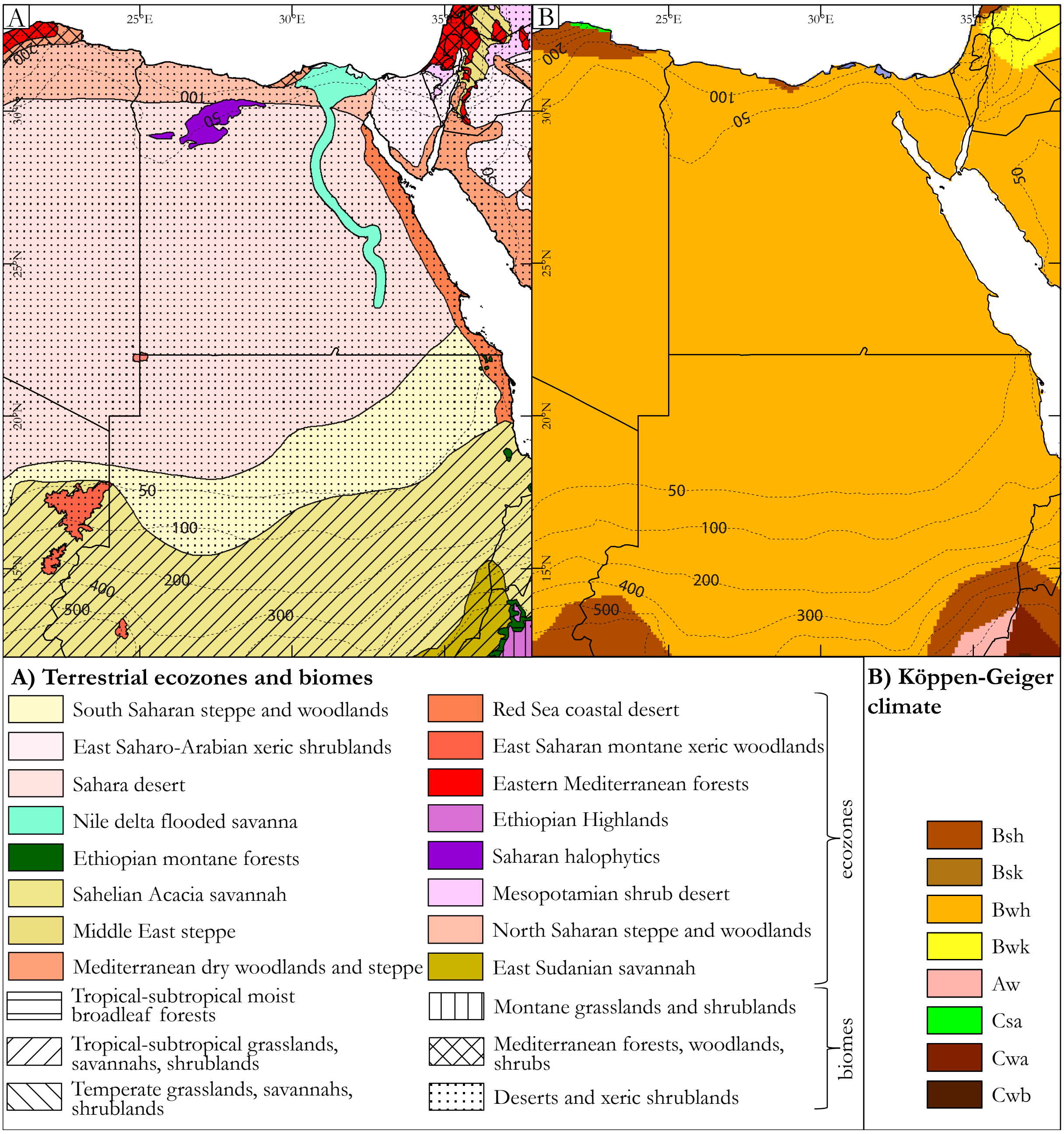


Figure 9: Current terrestrial ecozones (after Olson et al. 2001) and Köppen-Geiger climate in Northeast Africa (after Willmes et al. 2017b). Cartography: Henselowsky

The Red Sea coast, the Qattara valley or the southern coast of the Sinai Peninsula represent regional variabilities in ecozones apart from annual precipitation and within the biome of desert environments. The transition from today`s Bs to Bw Köppen-Geiger climate in North-Africa under influence of summer rainfall is bounded at an annual precipitation of around 250 mm. The terrestrial ecozone of this region is a Sahelian Acacia savannah, as part of the tropical-subtropical grassland, savannahs, and shrubland biome. . This ecozone is not equated to the Bs Köppen-Geiger climate, as it follows up regions with a limiting precipitation of around 200mm/a and thus it includes the Bs as well as Bw climate after Köppen-Geiger. The south Saharan steppe vegetation follows the Savannah ecozone up to an annual precipitation between 200 to 50 mm, where the Köppen-Geiger climate is only defined as Bw. This ecozones is part of the Deserts and Xeric shrublands biomes, but still exceed more precipitation and different types of vegetation to the Sahara desert ecozone. The Mediterranean coast is today classified as North Saharan steppe and woodlands. This classification is further used as modern analogues for the characterisation of ecozones during the LIG.

In general, the Eastern Desert of Egypt is sensitive to climate variability because of its geographic position within the general circulation patterns of the atmosphere. A northward shift of the monsoonal system, but also a southern shift of the extratropical winter rainfall zone can cause changes in the precipitation regime and the total amount of annual precipitation in Northeast Africa, the Arabian Peninsula, and the southern Levant (summarised in Bar-Matthews 2014). The palaeoenvironmental conditions in the Eastern Desert throughout the Late Pleistocene are discussed according to the results of this thesis.

3.3 Sites of field investigations

The focus of field investigations in the Central Eastern Desert is on the limestone hogback of Gebel Duwi, where Wadi Sodmein breaks through the limestone ridge from east to west and tectonic activity formed the Wadi Sodmein basin to the west of Gebel Duwi and Wadi Nakheil basin to its eastern side. Four sites are highlighted for distinct field investigations at Sodmein Cave, Sodmein Playa, Nakheil Cave, and Saquia Cave, whereas the overall geological and geomorphological landscape setting is mapped at the central part of Gebel Duwi (figure 10). Here, the presence of old wadi terraces is object of further in-depth investigations for a better understanding of recent and past geomorphological processes within the study area. These terraces are showing a black surface, caused by a strong desert varnish of the gravels, which form a desert pavement. Lithic artefacts occur on top of most terraces, ranging from the MSA to the Neolithic, and are predominantly found without any indications of dislocation insitu, which leads to the assumption that these terraces can represent parts of the former landscape surfaces during the Pleistocene (Kindermann et al. 2018).

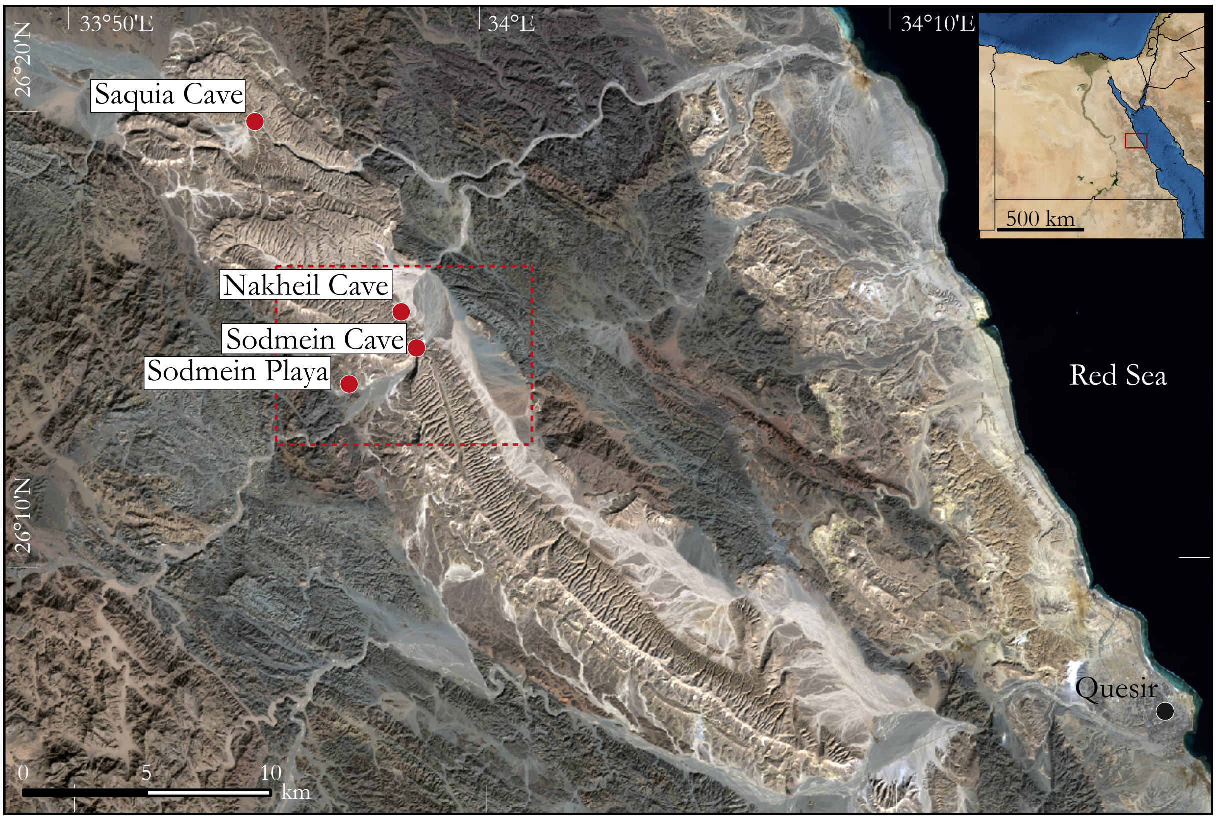


Figure 10: Overview of Gebel Duwi and sites of field investigations. The red frame indicates the area of detailed geological and geomorphological mapping. Data: LANDSAT 8 (U.S. Geological Survey products, Bands 2, 3, 4), Index-map MODIS- satellite image Stöckli et al. 2005. Cartography: Henselowsky

3.3.1 Sodmein Cave

Although Sodmein Cave represents no site of in-depth field investigations, where results could be gained as part of this thesis, the site is of highest importance, as it provides the fundament of the initial research object of sub-project A1 in the Eastern Desert. The cave (26°14’27”N, 33°58’12”E, figure 11) is situated at the breakthrough of Wadi Sodmein in the central part of Gebel Duwi and today located at around 20 m above the recent wadi floor.

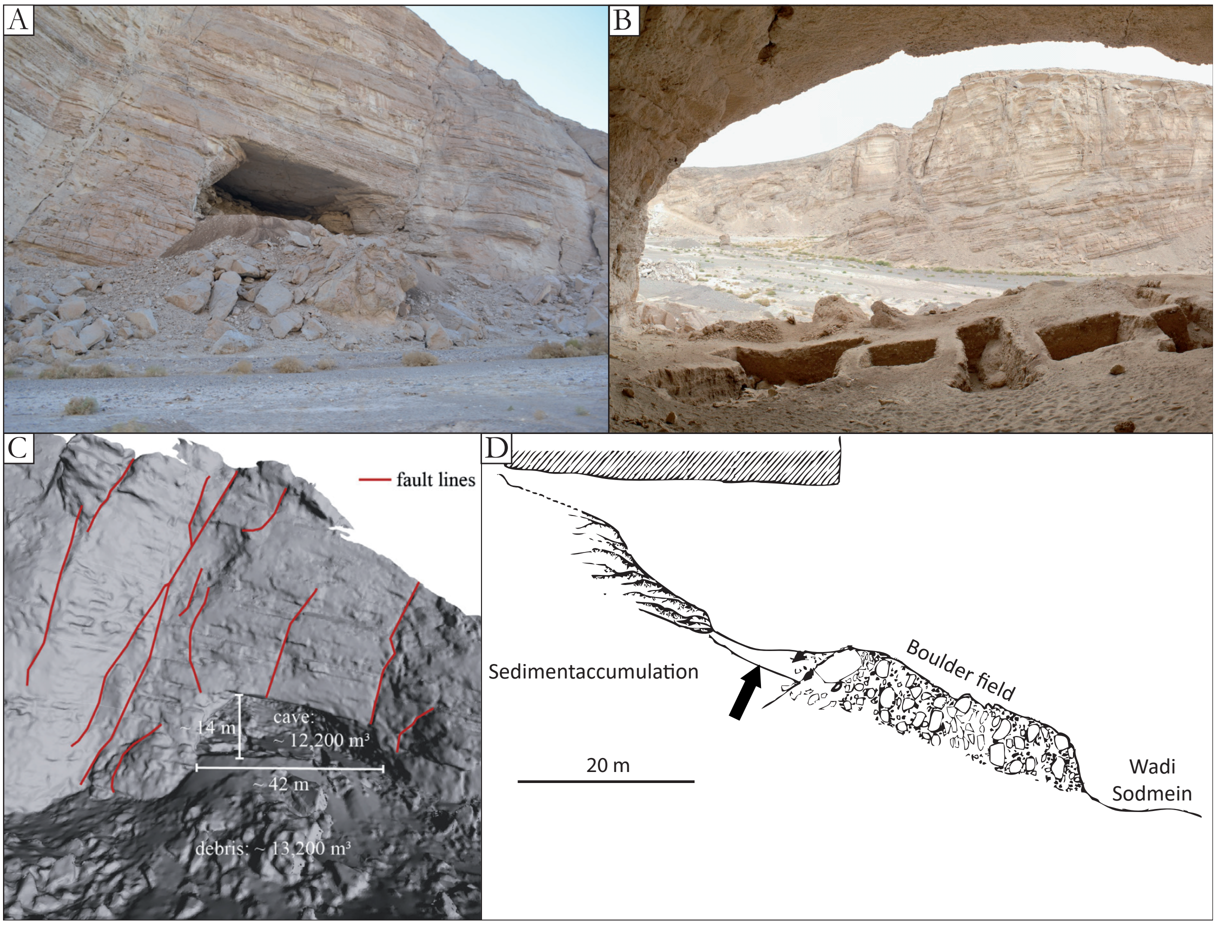


Figure 11: Impressions Sodmein Cave (26°14’27”N, 33°58’12”E) at Gebel Duwi, Central Eastern Desert. A) Picture from recent Wadi bed towards the entrance of the cave (pictureHENSELOWSKY 2014); B) View from inside of the cave towards Wadi Sodmein with excavation trenches of the BMEP and CRC 806 (picture HENSELOWSKY 2014); C) Laserscan of the cave and fault systems in the Thebes limestone (HOFFMEISTER et al. 2014); D) Cross-section of Sodmein Cave with sediment accumulation as backfill deposits behind the boulder fild of collapsed limestone (MOYERSONS et al. 2009).

About 40 years ago, Sodmein Cave was discovered during a regional survey of the American Research Centre (PRICKETT 1979). The site was initially labelled QSR-44 and was subsequently named Sodmein Cave by the Belgian Middle Egypt Prehistoric Project (BMEPP), which conducted field research during the years 1993, 1995, and 1999 (VAN PEER et al. 1996, MOEYERSONS et al. 1996, MOEYERSONS et al. 2002).

The cave is a remnant cavity, probably of karstic and tectonic origin, whose subsequent formation was caused by the physical breakdown of limestone bedrock (MOEYERSONS et al. 2002). The slightly sloping cave floor measures about 40 by 25 m, with a height of around 13 to 14 m in the section of the cave entrance. The cave floor is relatively flat and dips slightly towards the cave entrance, whereas in front of the cavern, a boulder field of limestone rocks extends. Volumetric determinations based on terrestrial laser scanning of the cave interior (around 12,200 m^3 volume) and rockfall in front of the cave (around 13,200 m^3 volume) show nearly similar debris volume (HOFFMEISTER et al. 2014). The archaeological remains are mainly situated near the cave entrance at the interface of the angular rockfall deposits and sediments that accumulated inside the cave, classified as backfill and strongly protected from erosion (MOEYERSONS et al. 2002). Whereas the Holocene occupation at Sodmein Cave is well studied (VERMEERSCH et al. 2015), investigations of Pleistocene occupation layers (VAN PEER et al. 1996) still enable the possibility for further investigations and is focussed of the re-investigations of the A1-Project of the CRC 806 in collaboration with the University of Leuven. Most of the newly conducted archaeological efforts were concentrated in the north-eastern part of the cave, where the Pleistocene occupation layers mainly concentrate and the human occupation debris of this time period is particular thick.

In general, the stratigraphy of Sodmein Cave was first described by MOEYERSONS et al. 1996 and were subsequent studied in more detail in MOEYERSONS et al. 2002. It is subdivided in 10 layers labelled from A (young) to J (old) and characterised by an alternation of whitish and dark deposits. The following description of the layers are based on MOEYERSONS et al. 1996, 2002. Layer A is the superficial sediment layer, whitish in colour and consists of calcareous sand and small angular limestone rock falls. The first organic rich layer, brownish to dark in colour, is classified as layer B. The amount of organic material rises up to 36% and contains faunal and floral elements of animal droppings, plant remains, seeds, small bones, and remnants of insects. Whitish layer C consists of dust and flakes of Thebes limestone with rock fall deposits from the roof top of the Cave. A stratigraphic hiatus between layer C and D is associated with a disconformity of the sediment deposits. Layers D (organic), E (whitish) and F (organic) represent the middle stratigraphic unit of the stratigraphy, before the middle disconformity exist between layer F to G. Layer G is in most excavated trenches by far the thickest organic rich layer and is separated by the thin whitish layer of H to the organic layer of I. The lower disconformity lead to the succession from organic layer I the layers of the J-complex (Moeyersons et al. 1996, 2002).

From an archaeological point of view and with the integration of dating results, the stratigraphy integrates the Neolithic in layer B and C, the Upper Palaeolithic in Layer D and Middle Palaeolithic artefacts in Layer E to J. Current datings point to human occupation of the cave in the Holocene at around 7.1-6.4 ka cal BC and 6.2-5.0 ka cal BC (Vermeersch et al. 2015). The deposits from the Upper Palaeolithic layer are dated to ±25,200 ka. A LIG occupation dated with thermoluminescence on burned flint from layer J to around 118 ±8 ka (Mercier et al. 1999) and <121 ±5 ka, 87 ±9 ka (Schmidt et al. 2015). The Middle Palaeolithic layer G, F and E are so far undated. In particular, layer G represents one of the thickest archaeological layers and the presumption for the age of these deposits from a stratigraphic point of view need to be stated somewhere around 90-25 ka. Technological the oldest settlement during the Middle Palaeolithic is associated with Early to late Nubian Complex technology. The Nubian Complex serves as the regional manifestation of the Middle Palaeolithic in Northeast Africa, but also on the Arabian Peninsula (Van Peer 2016). Thus, it represents the guidance of comparisons for the archaeological record in the region and an important cultural unit for any discussion within the study of human migration out of Africa.

3.3.2 Sodmein Playa

The site Sodmein Playa (initially named site 14/01) was found during a geoarchaeological survey of the CRC in 2014. The overall setting at Sodmein Playa and the introduction of the archaeological findings is given in Kindermann et al. 2018, whereas the results of sedimentological and geochronological analyses are presented in this thesis. Important to note is that the archaeological material is comparable to the findings of the LIG occupation layer at Sodmein Cave attributed to the Early Nubian Complex technology. In addition, it is the first MSA open-air site in the Eastern Desert in the context of a possible small lacustrine environment.

The site is located at the western part of Gebel Duwi between small outcrops of Nubian Sandstone and is only 3 km apart from Sodmein Cave (figure 12).

Figure 12: Overview of Sodmein Playa. A) Map of Sodmein Playa and excavated profiles 1-9, extended after Kindermann et al. 2018 (satellite image Quickbird bands 432); B) and C) Panorama overview picture the site and landscape context (pictures Henselowsky 2014).

A wadi terrace bar is elevated up to 2 m above the present wadi floor, presenting a marked cuesta-like profile as a consequence of posterior wadi incision. Behind this terrace remnant, which acts as a kind of barrier, a low and flat area is situated. The surface of this small basin consisted of sand and fine gravels. This so-called central depression of the Sodmein Playa covers an area of about 12,000 m² at an altitude of 243 m. The surface gently slopes up to the southwest, extending between low outcrops of Nubian Sandstone towards the southwestern extension. This area is covered with a desert pavement made out of fine gravels of sandstone. Here, the concentration of MSA were first encountered. Profile 5 at the central part of the depression consists of a thick sequence with fine sediments underneath the surface. About two metres of sediments below the present-day surface were analysed by digging and hand auger drilling but without reaching bedrock. Initial interpretations of the different sedimentological units according to the field results in 2014 were reported in Kindermann et al. 2018 (figure 13).

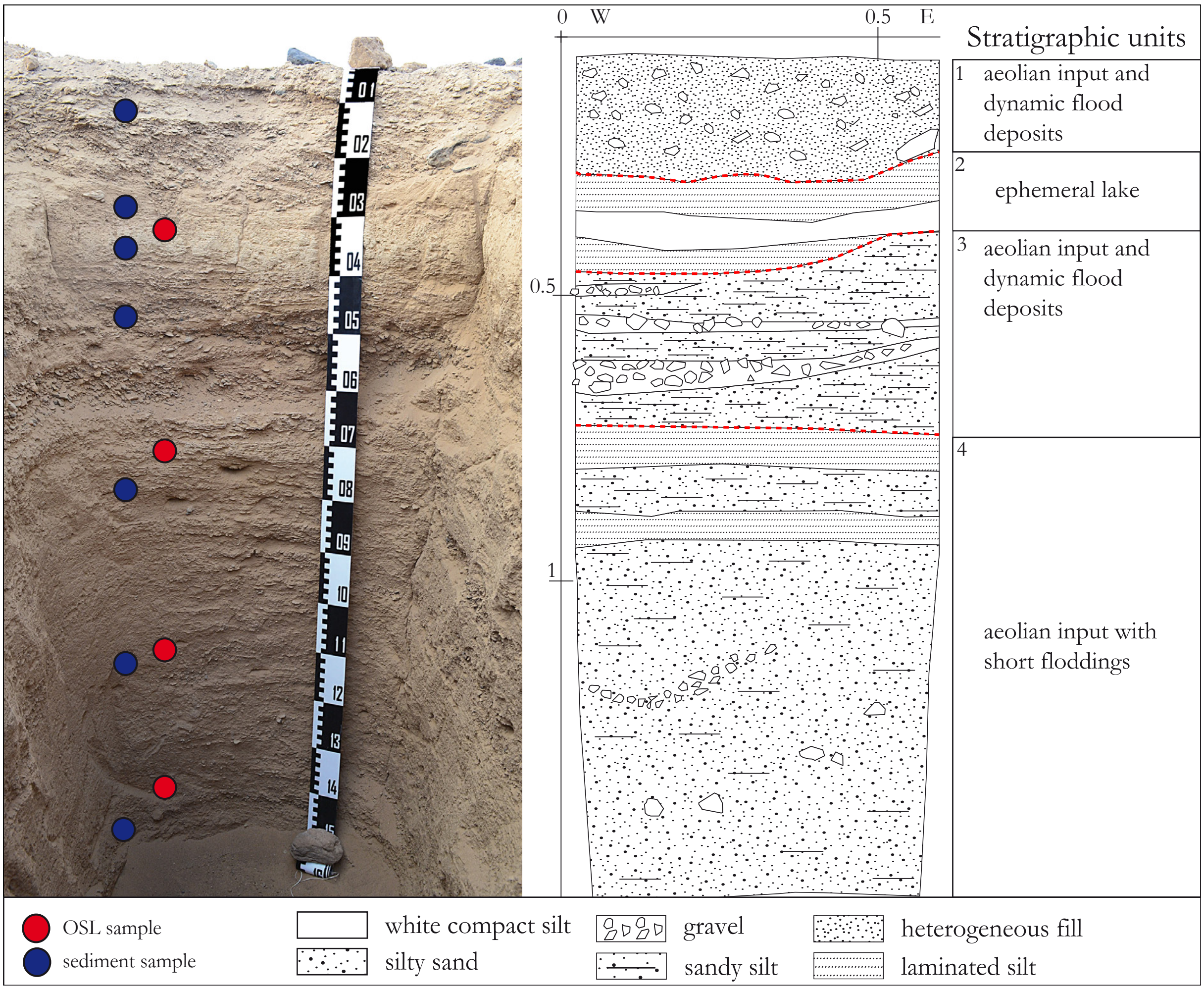


Figure 13: Sediment stratigraphy central Sodmein Playa, Profile 5 (picture Henselowsky 2017); Profile Sketch and initial interpretation of stratigraphic units after Kinderman et al. 2018.

The lowermost part of the sequence consists of a thick, predominantly sandy unit, which most probably is due to aeolian input into the depression. Within these sands, very fine laminations of silt, but also small gravels occur, indicating slight water events (stratigraphic unit 4). More laminated silts (sandy silts) with gravel layers follow this stratigraphic unit, indicating a fluvio-lacustrine sedimentation during wetter climate conditions (stratigraphic unit 3). The fluvio-lacustrine unit is capped with thick and homogeneous, carbonated, white silts with a very compact texture, which represents an ephemeral lake (stratigraphic unit 2). The uppermost layer (stratigraphic unit 1) is of heterogeneous material with mixed gravels, sand, and some silt accumulations. Small molluscs were found in several sections of the entire profile.

Sampling for sedimentology and dating of profile 5 was followed up during subsequent fieldwork and is analysed within this thesis. This gives the opportunity for further in-depth studies about the site formation, possible environmental changes, and the context of this site in the overall landscape at Gebel Duwi. Previous interpretation given in Kindermann et al. 2018 is discussed according to the new results. Comparable small basins occur between the outcrops of the Nubian sandstone towards the north-western side of Sodmein Playa, but could only be surveyed during fieldwork without further in-depth studies and sampling.

3.2.3 Saquia Cave

Saquia Cave (26°19'43"N, 33°54'18"E, figure 14) was discovered during a regional geoarchaeological survey of the CRC in 2011. It is located in the northern parts of Gebel Duwi and its direct distance to Sodmein Cave is 11km. It consists of a small cavity, which is incised a few metres into the Thebes limestone (Serai/Thebes formation) and is today blocked by massive sand accumulation. Above the cavity, a massive crack was washed out from percolating water during previous wet phases in the area. Vertical seepage of water during these wetter climate phases has led to the outwash of cracks in the limestone, were afterwards secondary carbonate were deposited within these cracks.

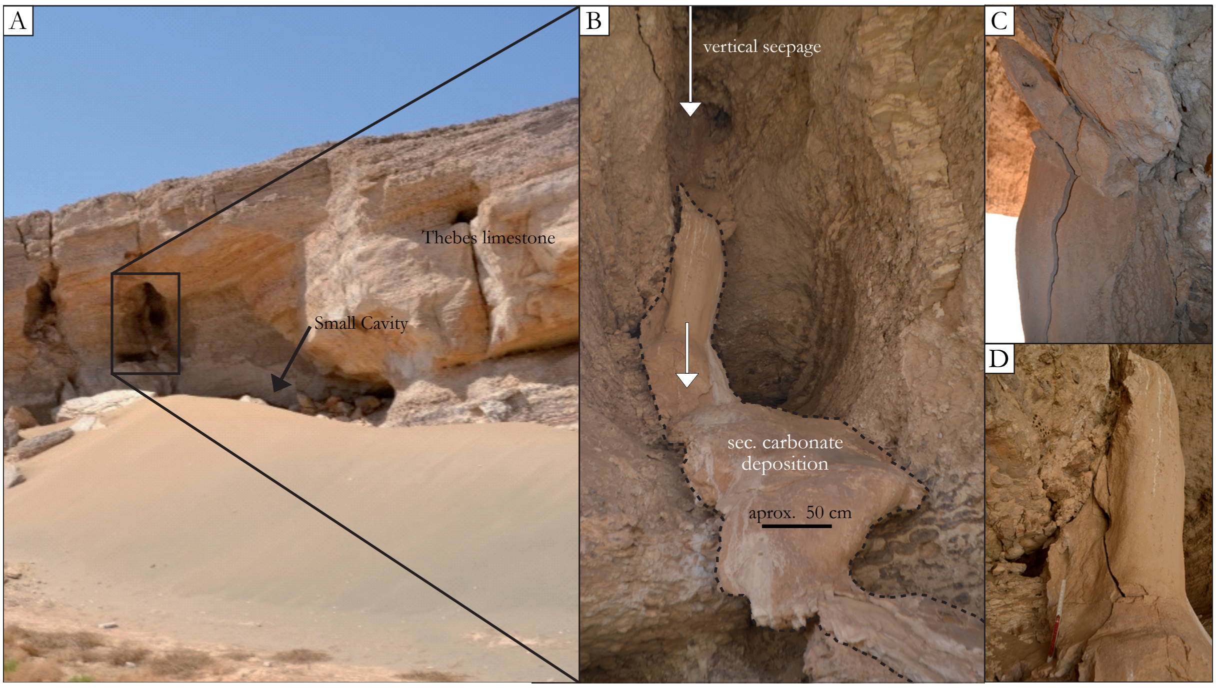


Figure 14: Speleothem deposits at Saquia Cave (pictures HENSELOWSKY 2014)

A massive flowstone was deposited at around 4-6 metres above the cavity. The morphometry of the flowstone is very complex and post-depositional strains lead to a crack at the backside of it. The flowstone has an approximately diameter of 27 cm at its central part and a height of around 2-3 metres, where the upper part is consisting of the actual flowstone, and the lower part is an overflow of secondary carbonates on the bedrock.

3.3.4 Nakheil Cave

Wadi Nakheil Cave was first visited in 2017 and sampling of speleothems was conducted in 2018. An initial short report about the cave is given in HENSELOWSKY et al. 2019. The cave is located around 1.5 km northeast of Sodmein Cave and its entrance is located at a small drainage stream draining from the top of Gebel Duwi towards the Nakheil basin. The cave has an approximately size of at least 120 m length with heights up to 12-15 m (figure 15).

The cave room follows the general inclination of the strata of Gebel Duwi and rises from the western part of the entrance towards the west. It is assumable that the cave is - comparable to Sodmein Cave - of karstic origin in the limestone, where dissolution was the main initial process, followed by outwash and fluvial erosion of the cave. Due to the long phase of aridity in Northeast Africa with only short wet periods in the Quaternary, it is assumable that these processes occurred during wetter periods of the late Tertiary. The Zeit Wet Phase was here

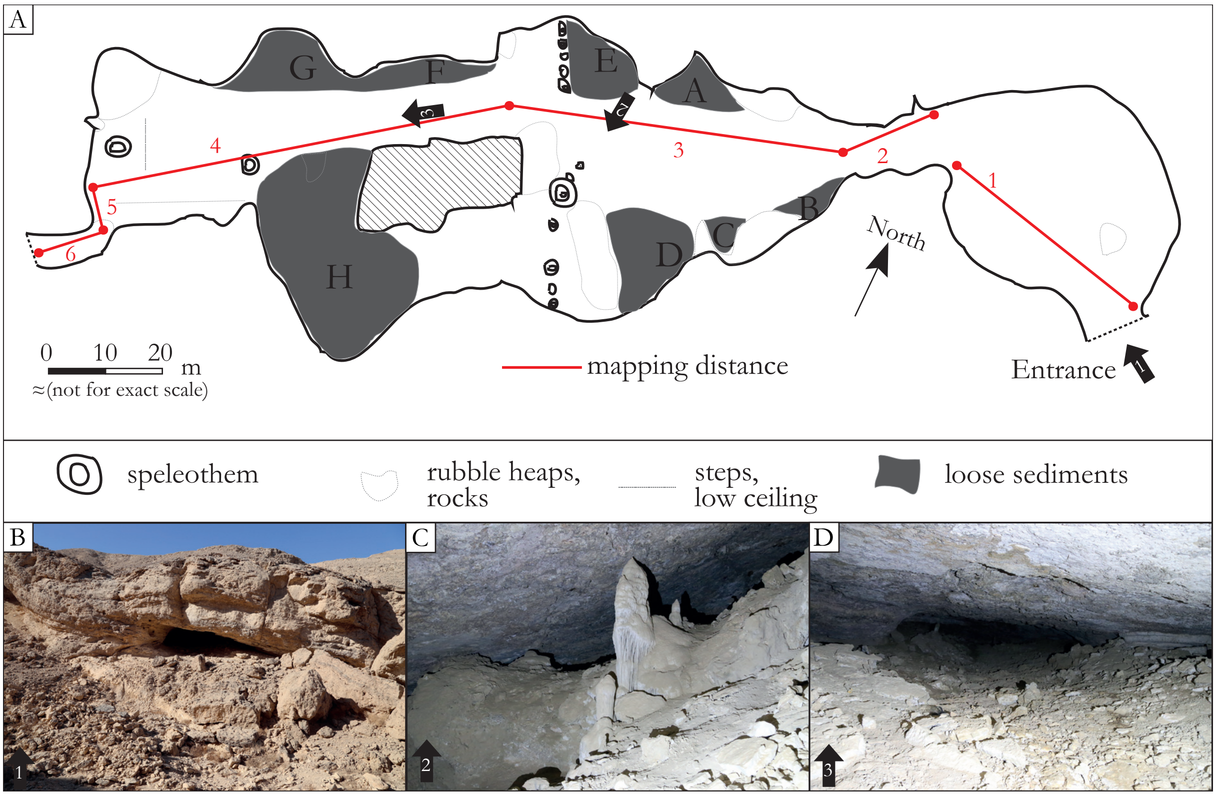


Figure 15: Overview of Nakheil Cave. A) Sketch of map after HENSELOWSKY et al. 2019. B) Cave entrance; C) Speleothem deposits in the central part of the cave. D) Coarse grained limestone deposits in fine grained matrix (picutres HENSELOWSKY 2017).

the last major wet phase in long-term geological times, which occurred during the Messinian with its maximum at about 5.8. Ma (GRIFFIN 2002). Karst landforms at the Red Sea area are also known from other examples, where intensive rainfalls similar to humid tropical climate produced a strong weathering and karstification of the sedimentary limestone rocks (EL-AREF et al. 1986). After or even during the main erosional phase of the cave, the current entrance was cleared and provided the opportunity that the infill of the cave could be eroded. The fluvial outwash can be seen in the large main stream of the cave, which is today filled with coarse sediments. Next to the main stream, smaller areas exist, where loose sediment was deposited and protected from erosion. These fine-grained sediments, very rich in silt, indicate a different taphonomy and therefore show a different sedimentary deposition, probably due to a different environment/climate. A significant accumulation of stalacmites can be observed in the central part of the cave. All stalacmites are following a fault line on the rooftop of the cave interior, where different solution and dissolution create varying stalacmites in size and shape. The maximum size reaches up to 2-3 m.

4. Methods

4.1 GIS-Methods

Substantial part of this thesis was done by the use of GIS-techniques and is separated into two major objectives: Firstly, detailed geomorphological mapping in the area of Gebel Duwi based on the analysis of digital elevation models and satellite images serve as background for the landscape setting and thus, provide the context for the archaeological findings in the area. In addition, it also supports the field investigations. They can be a substantial part in advance (e.g. mapping of promising landscape elements for field survey), during fieldwork to achieve ground-check (e.g. morphometric mapping by the use of differential GPS, mapping of out-crops) and after the field trip for interpretation and extension of all results.

Secondly, a GIS based database integrates various palaeoclimatological, hydrological, topographical, geological, and archaeological data at the over-regional scale of Egypt to develop a PalaeoMap of Egypt, which provides the environmental background for further modelling approaches of AMH behaviour and dispersal in Northeast Africa. There is a high potential to use such approaches to study human-environment interactions due to strong increase in (palaeo-) data availability, enhanced computation capacities, and the focus of interdisciplinary research approaches combining geosciences and archaeology with applications from remote sensing and geoinformatics. This merged into the concept of digital geoarchaeology, were the digital dimension of human-environment studies bridges natural sciences, humanities and (geo-) informatics (Siart et al. 2018). Especially the integration of different types of data sources (e.g. texts, non-GIS data such as CSV, spreadsheets, analogue maps, GIS-data) into a GIS-environment is important. This approach is done under the framework of the PalaeoMaps project of the CRC as guideline for open palaeoenvironmental GIS data (Willmes et al. 2017a).

4.1.1 Data sources for geological-geomorphological mapping at Gebel Duwi

Geomorphological field mapping at Gebel Duwi is subsequent supported by the analysis of a high-resolution digital elevation model (DEM) (Worldview-2, ground resolution 1m) and satellite image (Quickbird, ground resolution 0.61m). The acquisition of these data is done in close collaboration with sub-project Z2 “Data Management and Data Services (PI Prof. Dr. Georg Bareth & Prof. Dr. Olaf Bubenzer)”. Worldview-2 is a commercial satellite launched in October 2009 and operates at an orbit height of 770 km. It consists of eight multispectral bands ([nm] 450 - 510 (blue), 510-580 (green) 630 - 690 (red), 770-895 (NIR), 400 - 450 (blue-green), 585 - 625 (yellow), 705 - 745 (RedEdge-Band), 860 - 1040 (NIR2) and one panchromatic band 450 - 800 nm (Digitalglobe). Two images of the panchromatic band are used to calculate a DEM based on stereoscopic combination of both images using the DEM extraction module of the software ENVI, done by Dr. Andreas Bolten.

Quickbird was a commercial satellite launched in 2001 and operated until 2015 at an orbit height of 450 km. The spatial resolution of the satellite images consists of 0.61 m with five bands ([nm] 450-900 (Pan), 450-520 (Blue), 520-600 (Green), 630-690 (Red), 760-900 (Near IR)). A pan-sharpened RGB satellite image of the study area was created using Gram-Schmidt pan sharpening in ENVI.

Furthermore, free available remote sensing data are integrated to compare their benefits in regard to the geomorphological mapping at the proposed scale. Here, the DEM's are derived from ASTER, SRTM and TanDEM-X missions. Free available satellite images used in this study are derived from LANDSAT-8 mission (USGS) and Sentinel-2 mission (ESA).

The extent of the wadi terraces is mapped based on fieldwork including differential GPS measurements and the interpretation of the given satellite images based on their surface colour. A strong dark desert pavement differentiates the presumable old surfaces in contrast to recent active streams of the wadi characterised by bright colours.

Morphometric parameters of the terraces are derived from all different DEM's based on the clipped extent of each mapped terrace. The height of each terrace above the recent wadi ground was calculated on the difference between mean elevation for the terrace and mean elevation of the wadi ground with a buffer of 20 m.

4.1.2 Data sources PalaeoMap of Egypt

The environmental parameters for the PalaeoMap (climate, biomes, topography, lithology, and raw material outcrops) are one of the major factors for hunter-gatherer societies at large scale (Schlummer et al. 2014). The modern administrative borders of Egypt delimit the extent of the data processed for the PalaeoMap. Trans-border features at adjacent regions are discussed were necessary. With an extension of about 1100 km north to south and 1200 km east to west, Egypt represents on the one hand an area, where large scale assumptions based on continental scale environmental changes are valid in general, but on the other hand provides the opportunity to study regional distinct landscape patterns.

All used datasets (table 1) are freely available, except of the geological maps of Egypt. It is a major advantage to use such an open-source concept to transmit and to apply this approach easily to other regions and time periods, and hence to guarantee a consistent and replicable data set.

Table 1: Datasets for PalaeoMap of Egypt used in this study

Parameter	Dataset	Source	Link
Palaeoclimate	CCSM-3 Model	Otto-Bliesner et al. 2006, Hijmans et al. 2005	http://www.worldclim.org/
Köppen-Geiger Climate	This study	after Willmes et al. 2017b	http://crc806db.uni-koeln.de/start/
Drainage system	HydroSHED	Lehner et al. 2006	https://hydrosheds.cr.usgs.gov/
Elevation	SRTM-3	U.S. Geological Survey (USGS)	https://earthexplorer.usgs.gov/
Landforms	Global Relief classes Mountain typology	Meybeck et al. 2001	https://esdac.jrc.ec.europa.eu/
Bathymetry	GEBCO 2014	Weatherall et al. 2015	https://www.gebco.net/
Raw Material	Geological Maps of Egypt 1:500,000	Conoco 1987	Digital available on request Egyptian Mineral Resources Authority
Quaternary playa/ wadi deposits	Geological Maps of Egypt 1:500,000	Conoco 1987	Digital available on request Egyptian Mineral Resources Authority

The overall produced dataset is compared and discussed with proxy data and direct dated evidences of environmental changes in Egypt during MIS 5e derived from an extensive literature survey. Willmes et al. (2017a) classified four different types of data sources, which serve as background for the creation of a PalaeoMap.

All data represents spatial information, which need to be integrated into a GIS-environment. The used datasets of this study represent each of these four types (figure 16) and thus, a comprehensive framework for the PalaeoMap is achieved. As a fact that all mapped features represent the nowadays situation (except of the palaeoclimate model) and are highly depending on spatial scale, some pre-assumption to each applied methods are made.

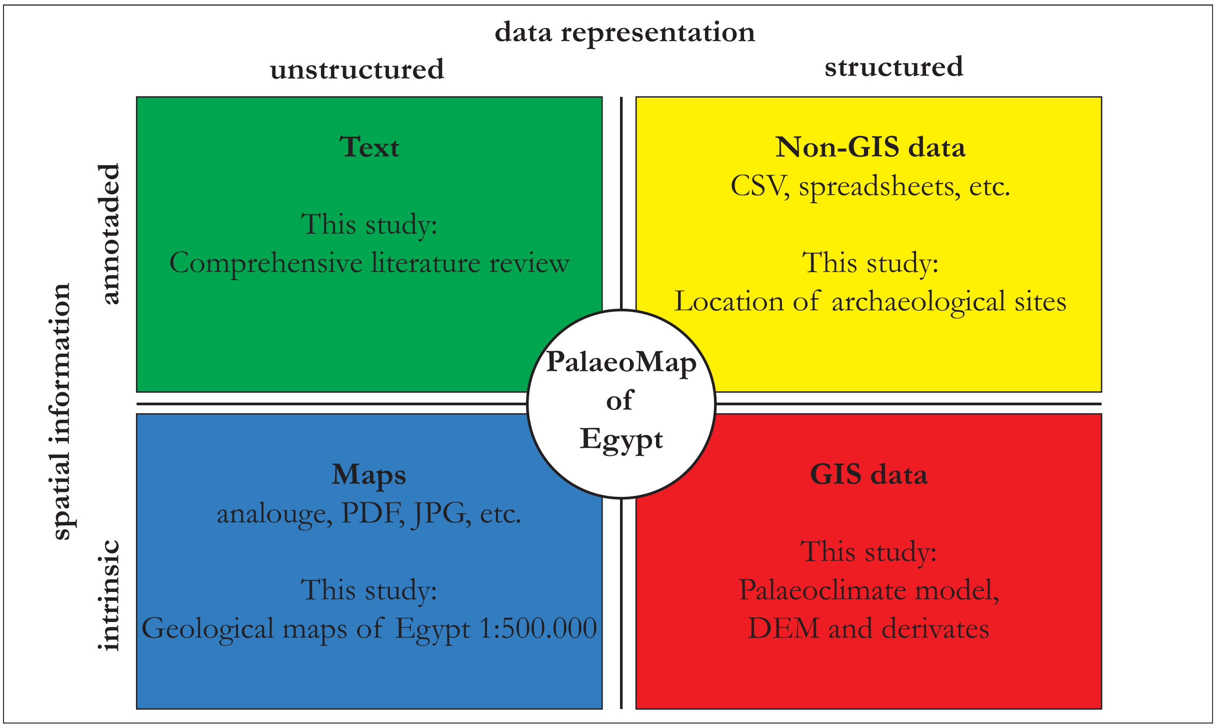


Figure 16: Different Types of input data are integrated into the PalaeoMap of Egypt, (adapted after WILLMES et al. 2017a)

Climate

Climate data for the LIG are based on the Community Climate Systems Model version 3.0 (CCSM3), which has a spatial resolution of 1.4° (± 150 km at the equator) and represents the time between 120-130ka (OTTO-BLIESNER et al. 2006). HIJMANS et al. (2005) developed a method for downscaling of large-scale climate models by integrating topographic data and data from recent weather stations. This was applied to the CCSM3 model in order to get a high-resolution climate model with a spatial resolution of 30 arc seconds (± 1 km at the equator). The generated downscaled version of the CCSM3-model for the LIG is available at the website www.worldclim.org, from which the bioclimatic variables as well as the temperature and precipitation data derived from. Although different palaeoclimate models for the LIG exist (e.g. CCSM3, COSMOS, KCM, NorESM, HadCM3) JENNINGS et al. (2015) convincingly demonstrate for the Arabian Peninsula that the main aspects of the climate systems are comparable.

Climate diagrams are calculated based on the monthly temperature (max/min) and precipitation values for four sites in Egypt at Bir Tarfawi, Sodmein Cave, Sannur Cave, and Marsa Mathra. The represented examples on the first three sites were chosen to compare the model-based climate reconstruction with proxy data from archaeological or geoscientific investigation, whereas no archaeological or geoscientific site exist at the Mediterranean coast for comparisons. Therefore, Marsa Mathra represents one site outside of the Nile Delta.

A Köppen-Geiger classification for the LIG is achieved by the usage of an open-source pyGRASS script (Willmes et al. 2017b), in which climate output parameters of climate models (e.g. precipitation and temperature) serve as a background to the compute palaeo Köppen-Geiger classifications. The effective climate after Köppen & Geiger is the most frequently used classification and is an important link between climate and biomes, as it is based on comparisons of the occurrence of different vegetation types in different climate regions (Kottek et al. 2006). In addition to the calculated Köppen-Geiger climate classification, an extensive literature survey adds information about possible biomes in Egypt during the LIG, which are compared with the climate classifications. All investigations and calculations based on the CCSM3-climate model and comparisons with proxy record aim to serve as a validation of the model and to characterise the climate during the LIG.

Three proxies are used for the semi-quantitative calculation of ecozones in Egypt during the LIG: total annual precipitation during the LIG, the palaeo Köppen-Geiger climate and the nowadays characteristics of terrestrial ecozones and biomes as modern analogues. This revels a top-down approach, as the large scale data are integrated into their regional context. In addition, a bottom-up approach integrates local evidences about the environmental regional ecozones based on the integration of palaeoproxy data, e.g. from archaeobotanical and archaeofaunal remains.

Topography & drainage system

Relief roughness in combination with elevation represent the background for the classification of the overall topography of Egypt, based on a global relief classification dataset after Meybeck et al. 2001. The relief types are calculated on the GTOPO30-DEM with a spatial resolution of 1 km/pixel. 15 classes represent the global distribution of all possible relief types based on this classification.

Sea level changes and adjacent palaeocoastline are calculated and based on the GEBCO2014 dataset, which is a compilation of worldwide existing bathymetric datasets with a spatial resolution of 30 arc sec (± 1 km at the equator), where the underlying data have an exceptional good quality for the Mediterranean and Red Sea (Weatherall et al. 2015). A palaeocoastline for the LIG is set at a maximum sea level of +6 m above the recent sea level (Grant et al. 2012).

The mapping of major drainage systems derives from the HydroSHED dataset (Lehner et al. 2006). This is the world largest consistent dataset combining drainage lines and river catchments based on a spatial resolution of 15 arc seconds (± 500 m at the equator). Thresholds for the derivation of river streams are set at a catchment area of 100 km², 500 km² and 1,000 km². Smaller river streams are excluded, as they represent distinct local landscape settings, which cannot be validated for the total area under investigation. The comparison of major drainage systems > 100 km² with satellite images serves as validation of the drainage system. Streams were connected in areas where nowadays small dunes or other geomorphological relief barriers are likely to represent post-LIG elements and a consistent drainage system exist. The Great Sand Sea and the Farafra Sand Sea are excluded in the derivation of the drainage system, as no secure information exist about their morphological setting during the LIG. The mapping of quaternary wadi deposits based on the geologic maps of Egypt with a scale of 1:500,000 (Conoco 1987). This serves as a relief independent mapping of the drainage system and combines the results of the analysis with DEM derived data.

Playa deposits are mapped based on geological maps (Qy = Chalcedony Cover, Qs=Sabkah deposits, Qp = Quaternary Playa) and manual corrected due to inconsistent syntax between different geological maps. All coastal Sabkahs are excluded, as they represent features of to the recent coastline.

Archaeological sites & raw material

Middle Palaeolithic sites in Egypt (table 2) are used to compare different landscapes, where the sites are located and to link the use of different raw-material to the regional surface geology. Main criteria for selection of archaeological site was either a direct chronometrical dating of each site to MIS 5 or the associated technological classification of the stone tool to the Nubian

Complex technology, which is the regional manifestation of the Middle Stone Age in Northeast Africa during MIS 5 (VAN PEER 2016). In total, 10 sites fulfil these criteria. Mainly flint was used for production of artefacts at these sites, except the sites at Bir Tarfawi / Bir Sahara, where quarzitic sandstones was used as raw material. Primary sources of flint (respectively chert) is mapped based on the geological maps of Egypt with a scale of 1:500,000 (CONOCO. 1987).

Spatial limitations for mapped raw materials are set to the occurrence of flint bearing strata

Table 2: Middle Palaeolithic sites in Egypt dating back to MIS 5e or showing comparable technologies in stone tool technology of the Nubian Complex

Site	Raw Material	Technology	Dates	Reference
Farafra/Hidden Valley	fine-grained flint	Nubian Complex	Typological determination	VAN PEER 2014
Kharga Oasis (Bulaq Wadi 3 Locus 1)	Flint	Levalloiso-Khargan	Tufa above lithic assemblage 114.4 ± 4.2 ka	CATON-THOMPSON 1952; SMITH et al. 2007
Kharga Oasis Mata'na Site G (KH/MT-02)	Flint	Upper Levalloisian	Tufa underlain lithic assemblage 127.9 ± 1.3 ka and overlain by tufa 103 ± 14 ka	CATON-THOMPSON, 1952; SMITH et al. 2007
Bir Tarfawi / Bir Sahara	Quartzitic sandstone		Artefacts associated with MIS 5a Green Lake phase	HILL 1993; WENDORF et al. 1993
Taramsa 1	fine-grained flint	Late Nubian Complex	OSL 79.2 ± 5.2 ka aolian sands filling a late Nubian Complex exploitation pit	VAN PEER et al. 2010
Sodmein Cave	fine-grained flint	Nubian Complex	TL <121 ± 15 ka (maximum age) and 87 ± 9 ka	MERCIER et al. 1999; MOEYERSONS et al. 2002; SCHMIDT et al. 2015
Sodmein Playa	fine-grained flint	Early Nubian Complex	Typological determination	KINDERMANN et al. 2018
Makhadma 6	fine-grained flint	Nubian Complex	Typological determination, most probably contemp. Late Middle Pal Alluviation 70 and 40 ka	VAN PEER 2000
Nazlet Khater 1		Nubian Complex	Typological determination	VERMEERSCH et al. 2000
Abydos	fine-grained flint	Nubian Complex	Typological determination	OLSZEWSKI et al. 2005, 2010; CHIOTTI et al. 2007, 2009

on these geologic maps, whereas the distinct geological formations represent the stratigraphic limit of flint occurrences up to different subdivisions of geological stratigraphic stages (Conoco 1987). Due to the inconsistent geological mapping of Egypt for different regions, this dataset has the highest spatial resolution and differentiation of geological strata where a countrywide overview about main raw-material sources is available. Local flint varieties and different qualities for producing artefacts cannot be included at this scale, as well as the detailed differences between various types of Quartzite and quarzitic sandstone. They cannot be based separately on the available geological maps and are excluded in this mapping.

4.2 Laboratory methods

Subsequent to the fieldwork, laboratory investigations of sediment samples, e.g. grain-size analysis and geochemical analysis provide information about the sedimentological characteristics and can be linked to different environmental and depositional processes of the sediments. Dating of sediment samples by the use of Optical Stimulated Luminescence (OSL) and Th/U-dating techniques serve as a framework for the geochronological context of sediment deposition. Due to the minimal possibility of field work and subsequent export of samples, laboratory investigations on sediments from different archives are very limited. However, initial results help for a better understanding about the site formation processes, e.g. at Sodmein Playa, and can serve as a background for future investigations. Samples from the stratigraphic profile at the central depression from Sodmein Playa were analysed. All sedimentological analyses were done on dried and sieved (<2 mm) sediments at the laboratory for Physical Geography at the University of Cologne.

4.2.1 Grain-size analysis

The analysis of the grain-size distribution of a sediment provides possible information about the origin and transport of a sediment before deposition. It can also give insights into post-depositional processes and weathering processes.

Grain-sizes analyses were done by laser diffraction using a Beckmann Coulter LS 13320. It can analyse the particle size between 2000 - 0.04 μm and provides 126 distinct classes for the grain size distribution. The analyser calculates the grain size distribution of a given sample based on the different diffraction of a standardised laser light with a wavelength of 750 nm, when the particles flow through the sample cell and path the laser beam. The different diffraction of the laser on different particles are detected and the size of the particle is calculated on the Frauenhofer diffraction theory (Blott et al. 2004). Laser diffraction analyses are today a widespread application in sedimentology, as it offers the advantage of relative fast analyses where large sample sets can be analysed in comparable short time and the results offer very precise and detailed grain-size distributions. However, the method is very sensitive to the effect of particle shape and instrument sensitivity and the results cannot be directly compared to other methods of grain size analyses, e.g. sieving or optical measurements (Blott & Pye 2006). In addition, sample pre-treatment can have a significant impact on the grain size distribution. Standardised pre-treatment of the sample includes the dissolvent of carbonates and organic material. All samples were treated with hydrogen peroxide (H_2O_2 15%) to remove the organic matter. Before measurement, the samples were treated with sodium pyrophosphate ($Na_4O_7P_2$, 46 g/l) to avoid any coagulation before the samples were set to the laser diffraction. A duplicated sample set was measured without and with carbonate solutions. Carbonate solution of the samples were done with HCL treatment. The raw-data of the laser diffraction were investigated by the excel-spreadsheet GRADISTAT for grain size distribution statistics (Blott & Pye 2001).

Schulte et al. (2016) show the effect of misleading grain size distributions using laser diffraction due to the effect of pre-treatment with hydrogen peroxide and hydrochloride acid. Different pre-treatments lead to variations of the measured grain size distribution depending of the content of organic matter, weathering degree, presence of stable aggregates and organo-mineral complexes of loess-palaeosol samples (Schulte et al. 2016). As the sediments from Sodmein Playa show no indications of post-depositional weathering, significant amount of organic matter or organo-mineral complexes, the overall impact of the different treatments are of minor significance. Internal comparisons of the samples are possible as all samples have the same pre-treatment and relative changes in the grain size distribution throughout the sequence can be derived. Comparisons with the results from other studies and different methods need to be done carefully.

4.2.2 Geochemistry

In addition to granulometric analyses, the geochemical composition is another source of information for the characterisation of a given sediment and can e.g. provide insights into different source regions of a sediment, but also to possible weathering processes of the sediment after deposition. The samples from Sodmein Playa were analysed for their element composition and their salinity.

All samples for geochemical analysis were pre-processed using a mixer mill (Retsch MM 400) to provide a well-mixed and homogenised sediment composition for geochemical analyses. Elemental analyses were done by using a portable X-Ray Fluorescence (pXRF) scanner (Niton XL3t). This technique is a non-destructive analysis, where the element composition of a sample is calculated and based on the measurement of the secondary X-ray emitted from the sample after an artificial emission by a primary X-ray source. Each element has a specific X-ray fluorescence during the exposure to external X-rays and thus, due to this specific "fingerprint" of each element, the element composition of a given sample is achieved (Markowicz 2008). However, the characterisation of the element composition for a given sample is limited to elements, which are heavier than Sodium, respectively have a chemical ordinal number ≥12. Magnesium is the lightest element which can be detected by pXRF, but the detection limit of comparable light elements is highly depending on the sediment matrix and composition.

All pXRF analyses were done on pressed sediment samples, using a hand press to produce 2-3 mm thick sediment pellets. This allows a homogenised sample with a smooth surface, where stable measurements conditions are given. Any physical matrix effect of the sample, uniformity, homogeneity, moisture content, particle size and surface conditions, which have an influence on the measurement (Markowicz 2008), are set to a minimum. Each sample was measured three times using the mining mode with a sample processing time of 160 seconds. Afterwards, an average of each measurement was calculated.

Carbon and Nitrogen are other elements with high importance in the geochemical characteristic of sediments. As these elements are lighter than magnesium and beyond detection limit of pXRF analyses, these measurements were done by using another element analyser (Vario El Cube). This analyser measures the amount of carbon and nitrogen based on the chromatographic fingerprint of a sample after burning and thus, can also detect very light elements. The carbon fraction is divided into total carbon (TC) and total organic carbon (TOC). The amount of TOC of a given sample is determined after a pre-treatment of the sample with HCL, to dissolve the anorganic carbon before measurement. Each sample was measured twice, and an average of both measurements was calculated.

4.2.3 Uranium-series dating of speleothems

Carbonate precipitates refer to secondary deposits of calcite and aragonite (with minor other minerals) and include the general terms of speleothem, sinter, travertine and tufa. Speleothems and sinter deposits are mainly used to describe secondary carbonate deposits within a cave, whereas travertine and tufa deposits are associated with springs. The term speleothem can be subdivided into stalactites, stalagmites, helictises and flowstones (Ford & Williams 2007), although other authors uses the term sinter instead of speleothem as umbrella for secondary carbonate precipitates of groundwater or dripping water in caves (Holzkämper 2004). In the following, the term speleothem is used, as the investigated sites represent cave/rock-shelter locations and to overcome ambiguity with sinter, which are commonly used in geomorphology to describe secondary carbonate deposits in open-air situations associated with fluvial activity (sinter-terraces). The formation of secondary carbonate deposits depends mainly on water and vegetation availability. Water leads to the solution of primary carbonates in a limestone (host-rock), when the water dissolves carbon dioxide in a superficial soil above the limestone, forms carbonic acid and percolates through the host rock. When the vertical seepage follows cracks or reaches a cave, partial pressure of carbon dioxide changes and secondary carbonates are deposited. Next to the advantages of the distinct formation processes of speleothem deposits, the use of Uranium-series (U-series) dating techniques is a powerful tool to date the time of speleothem growth (figure 17).

Uranium-series dating is apart from radiocarbon and luminescence dating technique one of the most applied radiometric dating technique in Quaternary research (Walker 2005). ^{238}Uranium decays due to alpha and beta particle emission to ^{208}Pb with intermediates of ^{234}U and ^{230}Th. Whereas ^{238}U is soluble in water, ^{230}Th is insoluble in water and thus, the initial deposition of secondary carbonates from drip water is absent from ^{230}Th. This is known as the daughter deficient method (Walker 2005), where the initial deposition has a deficit of ^{230}Th, which starts to grow from zero towards and equilibrium at a defined rate after deposition. The ratio of ^{230}Th/^{234}U in a speleothem sample can be used to date the time of speleothem deposition (figure 17). With the half-life from ^{230}Th of around 75.2 ka, the time range of possible ^{230}Th/^{234}U dating's is up to 500 - 700 ka. A very high analytical precision for the measurement of the different isotope ratios of Uranium and Thorium is today achieved by using mass spectrometry. In contrast to the previous measurement of the isotope composition using the alpha particle counting, the measurement of individual isotopes allows a much higher precision of the ^{230}Th /^{234}U ratio, where a 2σ error of calculated samples is usually better than 1% of the age (Latham 2017). For a detailed review about this dating technique see Walker 2005, Latham 2017.

The dating of speleothems from Saquia and Nakheil Cave (stalagmites & flowstone) was done at the Institute for Environmental Physics at Heidelberg University in the working group "Climate, Environmental Archives, and Isotopes" (group leader Prof. Dr. Norbert Frank), carried out by René Eichstädter and Dr. Andrea Schröder-Ritzrau. Mass spectrometric measurements were done by using thermal ionisation mass spectrometry (TIMS) and multi-collector inductively coupled-plasma mass spectrometry (MC-ICPMS). Whereas TIMS (Finnigan MAT 262 RPQ) was applied to a first set of samples in 2012, the new establishment of a MC-ICPMS device (Thermo Scientific Neptune Plus) in the laboratory of the working group leads to a

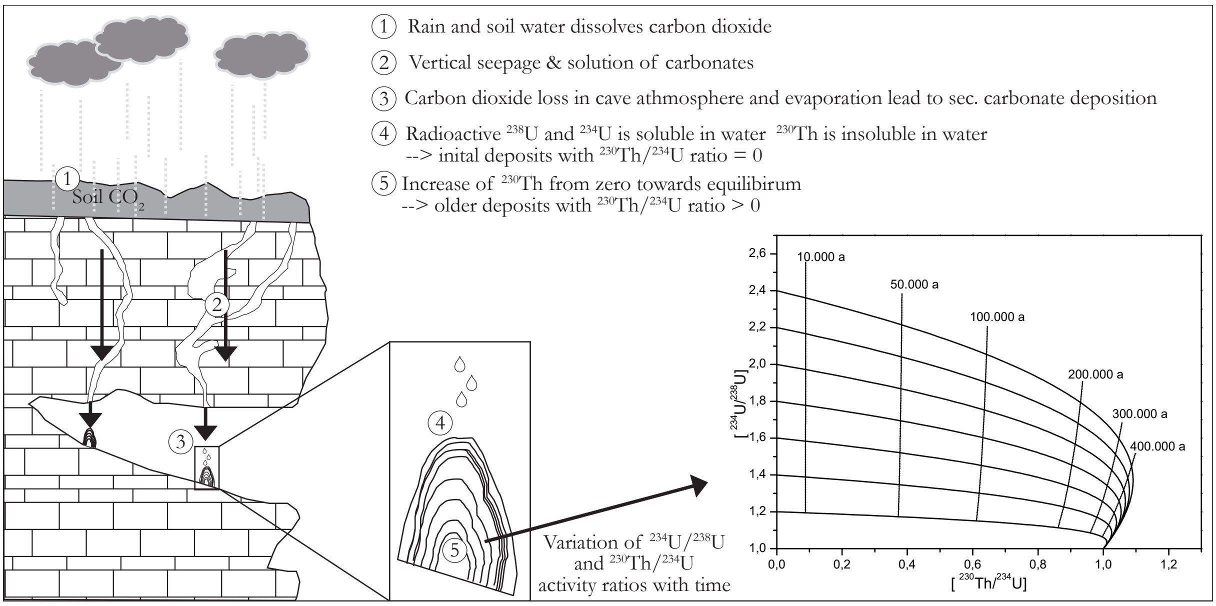


Figure 17: Schematic overview of speleothem deposits and subsequent dating of growth phases using Th/U-series dating. Th-U ratios after Holzkämper 2004.

better precision of the measurements for following samples. Sample preparation and measurements were done after the method described in Douville et al. 2010 and Wefing et al. 2017.

Sampling of speleothems were done with a wet core diamond driller (Weka DK12), using a 20mm tube for the collection of cores. Due to the very complex structure of the flowstone at Saquia Cave, initial test drillings (2012) were done at the central part of the flowstone with a horizontal crossing of the expected stratigraphy (Saquia_1) and at the bottom of the flowstone (Saquia_bottom). A second set of samples with two more cores (Saquia_2, Saquia_3) were done at a subsequent second field trip (2014), after initial dating's of core 1 gave the most promising results. At Nakheil Cave, four stalacmites were cored vertical from its central part of the top, presumable the youngest deposits, towards the bottom. All cores were separated in two halves, one section for Th/U-dating and the other half was archived for possible further analyses.

4.2.4 Optically stimulated luminescence dating

The use of luminescence dating techniques is a fundamental tool in quaternary science. The technique allows dating of sediments, where organic material is lacking and the application of radiocarbon dating is not possible and thus, is an important dating approach in arid environments. Whereas radiocarbon dating, based on the radioactive decay of ^{14}C with a half-life of around 5,700 years, is limited to an upper age limit between 40 - 50 ka (conventional decay or beta counting) to an maximum of 75 ka (isotopic enrichment and very large sample sizes) (Taylor 2017), luminescence dating can be also applied to older time periods. The upper limit of luminescence dating is depending on the mineral characteristics of the samples and the environmental radiation of the sampling location. Age estimates up to a few hundred thousand years can be achieved with recent technological developments and depending on the environmental radiation (Jacobs 2017). Due to the lacking of organic material at Sodmein Playa, luminescence dating is of particular importance for the chronology of the studied archives at the Gebel Duwi area. Whereas the dating results from Sodmein Cave are still in progress and no part of this thesis, the age of the sediments from Sodmein Playa can provide information's about the site formation processes.

An overview about the physical background of optically stimulated luminescence dating and the wide range of applications are given in PREUSSER et al. 2008. Radioactive decay of Uranium, Thorium and Potassium, which occur in nature, generate a weak radiation field (ionising radiation) in the sediment. Quartz and potassium feldspar minerals store the energy, respectively the dose (1 Gy = 1 J kg-1), which is emitted from the ionising radiation in form of electrons in defects in their crystal lattice. The minerals act as a dosimeter and the longer they are exposed to the ionising radiation, the higher the amount of trapped electrons. In case all defects in the crystal lattice are trapped with electrons, the minerals are saturated. Once the minerals are stimulated with light (i.e. during sediment transport) the electrons recombine and release their energy as a photon emission. This photon emission is the luminescence signal and it can be recorded using sensitive measurement devices. The luminescence signal is a function of dose and the accumulated dose can be determined in the laboratory. Minerals from various sources differ from each other and have different luminescence signals. It is not possible to deduce the accumulated dose from the intensity of the luminescence signal. Therefore, in the lab the luminescence signal is normalised with calibrated radiation sources to the individual luminescence sensitivity of the sample. The basic principle of dose determination is the comparison of the natural luminescence signal with artificial irradiation in the laboratory. The result of dose determination is the equivalent dose, i.e. the dose which represents a luminescence emission that is equivalent to the natural luminescence signal. The most common measurement protocol for equivalent dose determination is the single-aliquot regenerative-dose protocol (MURRAY & WINTLE 2000, 2003). This protocol was used to date the quartz samples from Sodmein Playa.

The OSL-dating at Sodmein Playa was done by a collaboration with the CRC sub-project F2 "Application of Luminescence Dating Techniques in Geoarchaeological Studies (PI: Prof. Dr. Helmut Brückner & Dr. Dominik Brill)" at the Cologne Luminescence Laboratory (CLL). All laboratory measurements and the calculation of the age estimates of the sediments were done by Dr. Nicole Klasen.

The sampling from Sodmein Playa took place in 2016, where the excavated archaeological trenches from 2014 were re-investigated. After cleaning the sediment profiles, four OSL-samples were taken from profile P5, from the central part of the depression (compare figure

13). All samples were collected in opaque plastic tubes to prevent any contact to daylight. The surrounding material of each sample was taken into plastic bags to measure the radionuclide concentrations of each sample with high-resolution gamma-ray spectrometry.

Sample preparation (remove of carbonates, organics, clay, and density separation for quartz) was following standard procedures described in Klasen et al. 2018. The grain size fraction of 150 -200 µm was used dating. The single-aliquot regenerative-dose protocol (Murray & Wintle 2000, 2003) was used to date the quartz samples from Sodmein Playa (appendix 1).

5. Results

The results follow the proposed scales for geoarchaeological research of this thesis. Firstly, the results from geomorphological investigations at the central part of Gebel Duwi are presented and serve as the natural background and landscape setting, where the archaeological findings of the area can be integrated. Secondly, and as main focus for the overall topic, the results for the reconstruction of early Late Pleistocene environments based on the compilation of the produced GIS-datasets and dating of speleothems are presented.

5.1 Geological-geomorphological map of the Central Gebel Duwi

The geomorphological-geologic map of the central Gebel Duwi (figure 18) presents the landscape setting, where the archaeological sites of Sodmein Cave and Sodmein Playa are located. The cave is situated at the breakthrough of Wadi Sodmein. Sodmein playa is located at the eastern part of Gebel Duwi between small outcrops of Nubian sandstone. Nakheil Cave is located at a small wadi stream draining the top of Gebel Duwi and entering the Nakheil basin two kilometres north of the breakthrough of Wadi Sodmein. The site of Saquia Cave is located 10km north of Sodmein Cave at the northern edge of Gebel Duwi. The two tectonic faults (Kalahin & Wadi Nakheil fault) divides the area into two major types of landscape. It represents the sharp contact between Precambrian basement and Cenozoic sedimentary rocks. The north-eastern and south-western area is composed of the undifferentiated Precambrian basement rock, where wadis show a strong incision into the bedrock often along tectonic fault lines and shear zones, e.g. at the Hamraween shear zone. Here, only minor quaternary deposits are deposited in the active drainage channel. The hillslopes in the Precambrian basement rocks are irregular shaped and have a rough topography with exposed bedrock and almost no accumulation of sediments.

The central part of the map is build up by the hogback of Gebel Duwi composed of Cenozoic sedimentary rocks and can be divided in more detail. At its western side, Cretaceous sandstone of the Nubian group is followed by the stratigraphic succession of Tertiary limestones from west to east. These rocks predominantly erode at the western side of Gebel Duwi, where they form a steep escarpment with scarp talus cover.

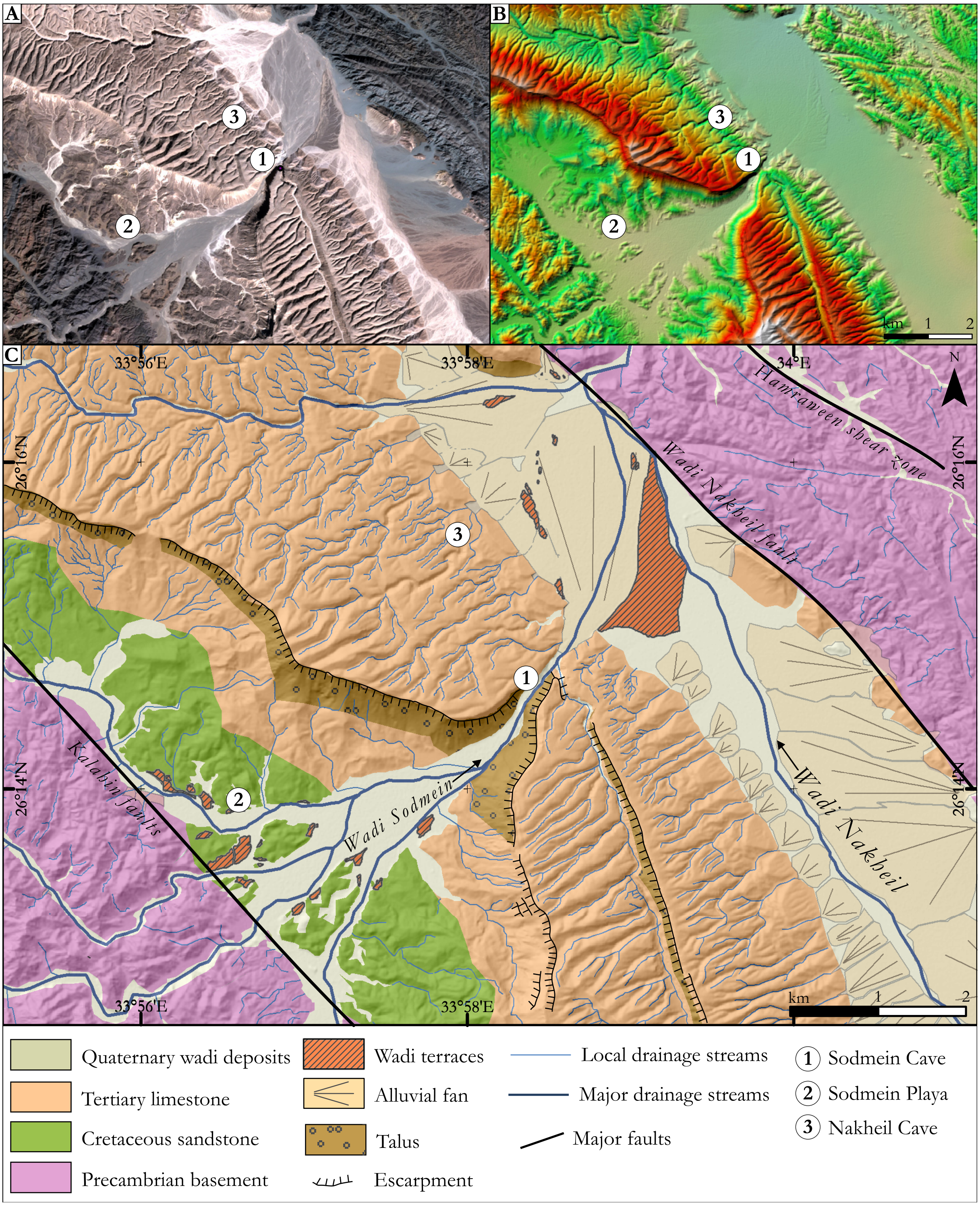


Figure 18: Geomorphological-geological map of the central Gebel Duwi. A) Satellite image (Sentinel-2 L1C, bands 432 - natural color); B) Shaded relief based on WorldDEM (12m pixel resolution); and C) Geologic-geomorphological mapping extracted from Geological Maps of Egypt 1:500,000 (Conoco 1987), satellite images and digital elevation models. Cartography and analysis Henselowsky

The hogback itself is dipping towards its eastern side and current drainage streams on top of the hogback entering Wadi Nakheil basins, where they form small alluvial fans. The two basins, Wadi Nakheil basin on the eastern side and Wadi Sodmein basin on the western side, are the result of extensional faults (Khalil & McClay 2002) and are filled with quaternary wadi deposits. These deposits consist mainly of coarse wadi gravels and the recent wadi floor is covered with gravels ranging up to a few decimetres. It shows, that wadi discharge after exceptional rainfalls is very strong and can produce flash-floods with a high transport capacity. The breakthrough of Wadi Sodmein through Gebel Duwi consists of a large canyon like corridor, where the discharge out of the western basin is concentrated. Besides the alluvial fans at Nakheil basin, elevated wadi terraces represent an important geomorphological feature at Gebel Duwi. These terraces occur as small remnants on the western and eastern side of Gebel Duwi. All terraces at the western side of Gebel Duwi are study object of more in-depth studies based on the high-resolution digital elevation model and satellite image.

Smaller depressions are found in context of the Nubian sandstone in the western part of Gebel Duwi. In case of an elevated wadi terraces towards the main wadi, these depressions are semi-closed and protected from erosion of large wadi discharges. Here, fine grained deposits are so far the only sediment archive in the study area. The investigations at the site of Sodmein Playa focus on these sediments and provide a more detailed insight into the specific morphometric context of the depressions and in dependency to the wadi terraces.

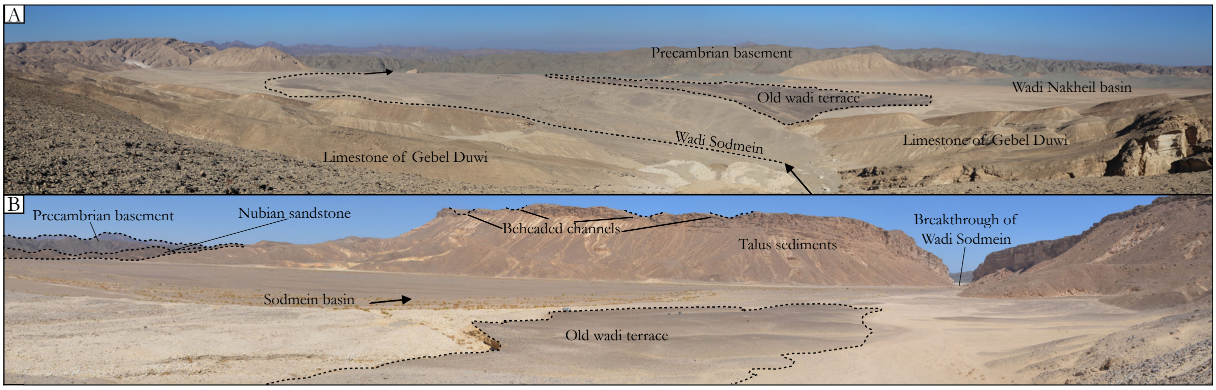


Figure 19: Landscape impressions of Gebel Duwi. A): View from Gebel Duwi towards Nakheil basin looking east (picture Schepers 2017); B) View into Sodmein basins towards the east. Sodmein Cave is located within the breakthrough of Wadi Sodmein (picture by Henselowsky 2014)

Overall, the geomorphological-geological map from the central part of Gebel Duwi summarise the general landscape setting (figure 19) with the presence of highly variable landforms, surface geology and sediment deposits. It indicates the rare existence of palaeoenvironmental archives and the mainly erosional character of the landscape, besides the stratigraphy of Sodmein Cave. It also shows, that the limestone hogback of Gebel Duwi is bounded within the Precambrian basement rocks and represents a very special landscape configuration, where geomorphological processes are mainly influenced by local parameters and geomorphological study objects represent the scale of the micro-to mesorelief.

5.1.1 Wadi terraces

The identified wadi terraces are the only landform, which represent presumable old surfaces dating back to the late Pleistocene, based on their desert pavement and archaeological findings. All terraces show a distinct difference between its surface colour and the surrounding wadi floor. Whereas the recent wadi sediments are characterised with brighter colours, the terraces show darker surface colours (compare also field images figure 12 and 19). Due to the very high resolution of the Quickbird satellite image with 0.61 m pixel resolution, the identified terraces in the field could be mapped on the satellite image and where subsequent completed. In total, fieldwork and satellite imagery mapping provided 20 different wadi terraces at the western side of Gebel Duwi located in the Sodmein basin (figure 20).

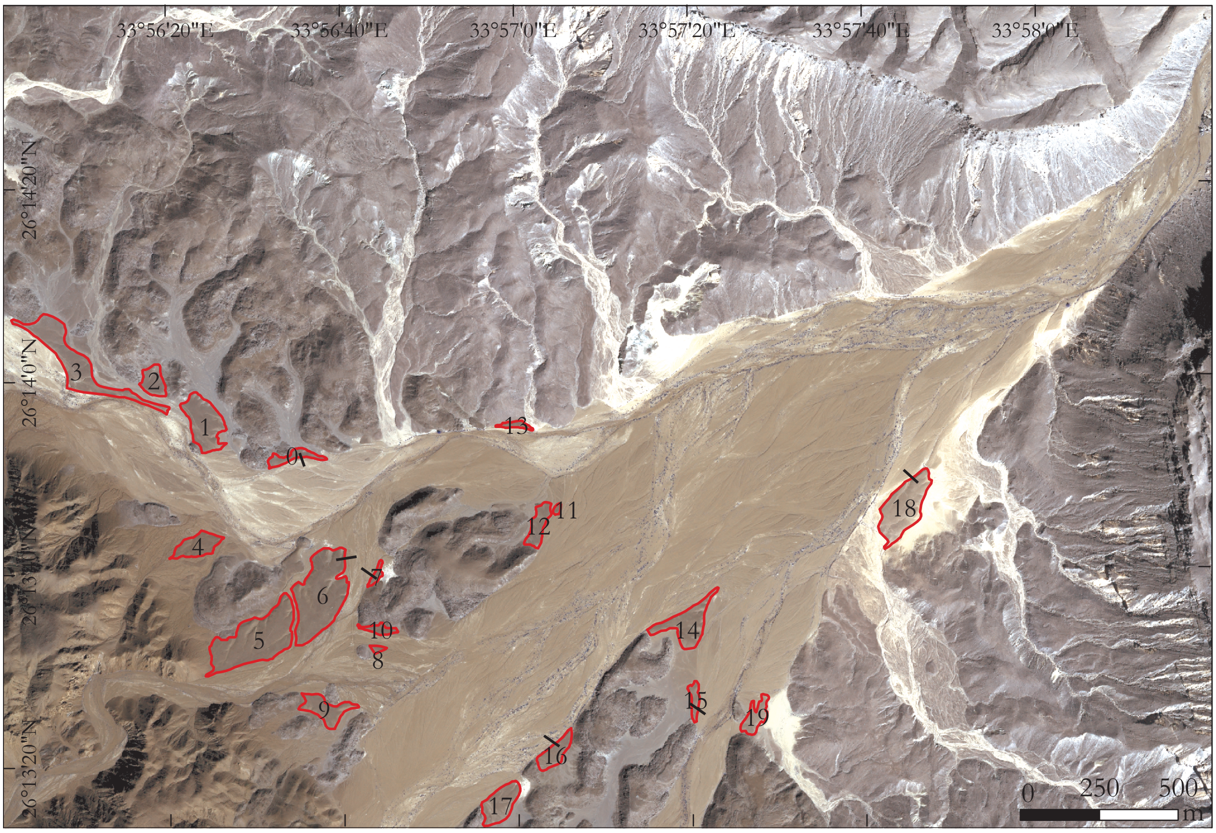


Figure 20: Identified wadi terraces at Sodmein Basin based on field mapping and analyses of satellite image (Quickbird, bands 432). Cartography: Henselowsky

Detailed mapping of terraces located at the eastern side of Gebel Duwi at Nakheil basin was not possible due to the limiting extent of the high-resolute satellite image. Field survey showed that all terrace surfaces consist not only of a strong desert pavement, but also a strong desert varnish of the exposed rocks, which alters the initial surface colour of the rocks. The surface colour of each terrace varies with strong dark colours at the western part of the basin (e.g. terraces 5, 6, and 9) and brighter colours in the eastern part (e.g. terrace 14 and 18).

The morphometric results for the wadi terraces can be separated into the 3D-characterisation (spatial extent and elevation) based on the given DEM`s and the 2D-cross-sections of field measurements using differential GPS.

All single terraces have an extent varying from 632 to 35,330 m². The comparable small size of the terraces is the first limitation for the use of different DEM`s with varying pixel sizes. The terrace in front of Sodmein Playa (figure 21, terrace ID 0), which has an extent of 4,232 km², indicates the limitations for the Aster- and SRTM-DEM with a spatial resolution of 30m,

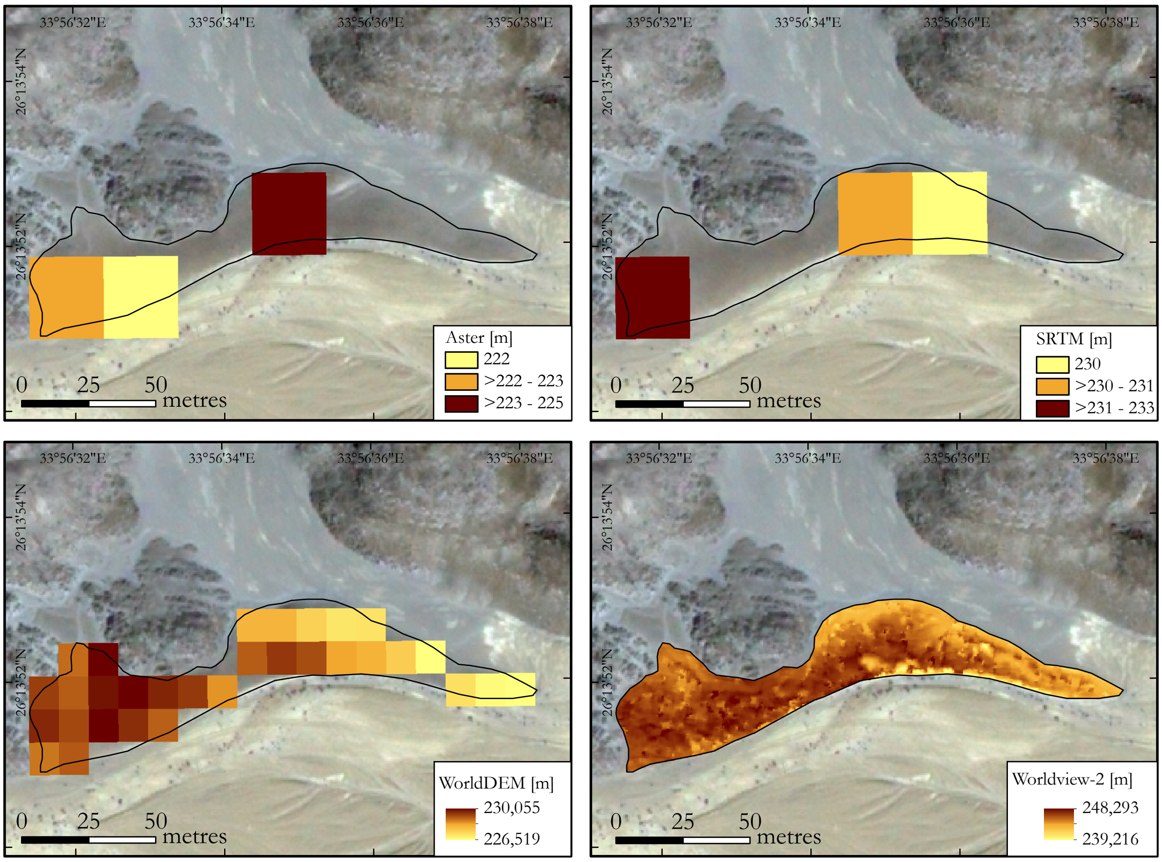


Figure 21: Wadi terrace in front of Sodmein Playa and comparison of different elevation models (SRTM, Aster, WorldDEM, Worldview-2).

where only three values represent the elevation of the terrace,(figure 21). Thus, the size of the terraces is too small for the spatial resolution of 30 m. The WorldDEM (12 m) and World-view-2 (1 m) represent the general shape of the terrace with its highest areas at the western side and lower areas on the eastern side. However, the WorldDEM has only limited data points, but a smaller standard deviation for the height of the terrace in contrast to the Worldview-2 data.

The mean elevation of all terraces based on the WorldDEM and Worldview-2 data (figure 22) show a general decrease in elevation from the terraces in the western part of the basin (e.g. terrace 3, 4, 5, 9) towards the eastern part (e.g. terrace 13, 11, 14, 19). The most eastern terrace (18) has the lowest elevation. The calculation of the differences between the elevation of the terrace and the elevation of the recent wadi floor might give indications for the presence of different generation of terraces. The mean height of the recent wadi floor next to each terrace follows the inclination from west to east and both data sources show a very high correlation coefficient (Worldview-2: 0.9871, WorldDEM: 0.944). The comparison between the mean elevation of the terrace and the wadi floor shows, that all data derived from Worldview-2 overlap within their range between maximum and minimum elevation.

The data from WorldDEM separates the elevation of the terrace and the wadi within the

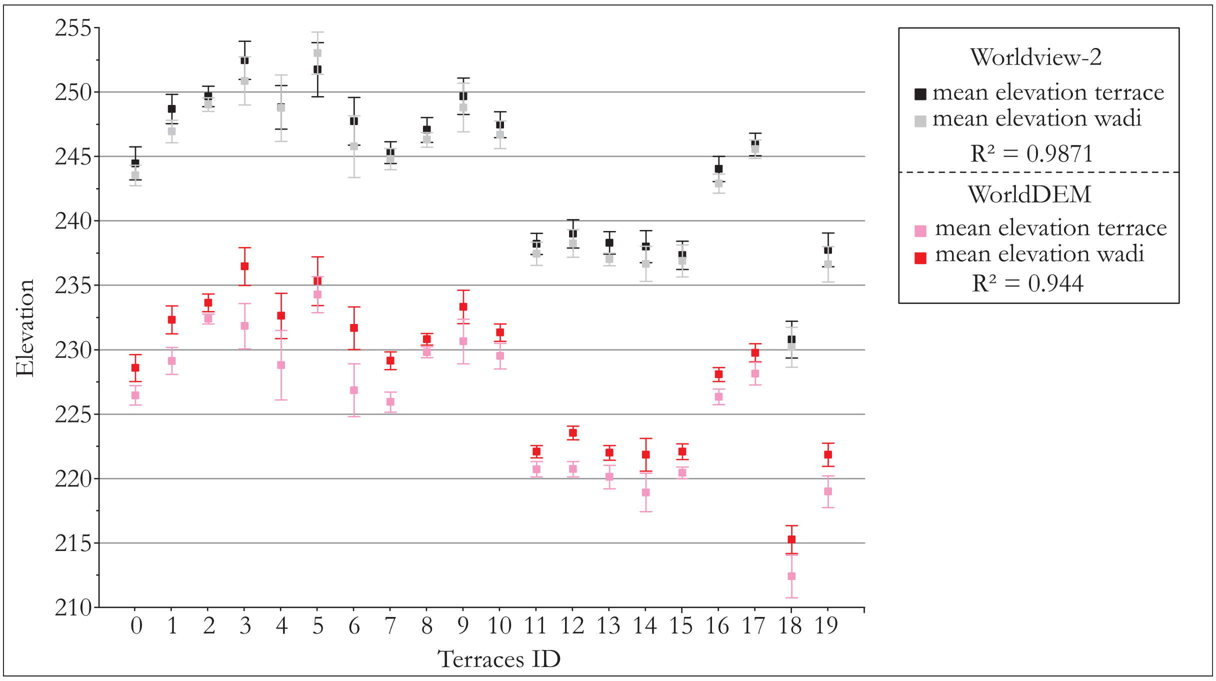


Figure 22: Mean elevation of wadi terraces based on Worldview-2 and WorldDEM digital elevation data.

range of their maximum and minimum values, except for the terrace 5 and 9, where the maximum value of the wadi floor is higher than the minimum value of the terrace.

The 2D field measurements of several cross-sections between the terraces and the wadi floor represent a spatially more limited morphometric characterisation, but in contrast can produce a more sophisticated insight into the actual height of the terraces. The measurements were done based on field investigations, where a visual identification of the morphometry allows a distinct definition of the differences between the terrace and the wadi floor. Here, the results for seven different terraces vary between 1.1 to 2.23 m (table 3). It indicates that the actual height of the terraces are within the range of the standard deviation for all measurements based on the DEM`s.

The presence of swimming blocks at Sodmein Gorge leads to the assumption, that most recent processes of the wadi here represent rather sediment accumulation instead of erosion. These large swimming blocks occur in the current wadi deposits at the break through of Wadi Sodmein and can be seen as an indicator for recent wadi processes. These blocks derive from surrounding rockfall at Gebel Duwi and are embedded into the recent wadi gravels with accumulation of wadi sediments (Figure 23).

Table 3: Results for DGPS-measurements Wadi Sodmein terraces

ID	wadi [m]	terrace [m]	difference [m]
terrace 0	245.84	243.61	2.23
terrace 6	245.29	244.19	1.1
terrace 7	246.38	245.33	1.05
terrace 12	239.42	237.44	1.98
terrace 14	238.32	236.6	1.72
terrace 16	244.28	242.27	2.01
terrace 18	230.81	228.88	1.93

As the blocks are located directly at the canyon, concentrated discharge and confluence

Figure 23: Swimming blocks at Wadi Sodmein as examples of partly embedded limestone blocks into wadi deposits in Wadi Sodmein (pictures Henselowsky 2016).

of water here is even higher as within the basins at the western and eastern side. Thus, a recent erosional character of Wadi Sodmein, e.g. under the current climate following high flash floods, would be highest at this location.

5.1.2 Sedimentology and geochronology of Sodmein Playa

The results of the grain-size distribution for the samples from the central depression of Sodmein playa verify the field observations about a varying deposition of gravels, sand, and silts throughout the stratigraphy (figure 24).

Differences between the grain-size distribution with and without HCL are very low for all samples excluding S2, which indicates a shift between its peaks without the removal of carbonates in the medium sand fraction towards fine sand after carbonate solution. The lowermost part of the sequence consists of a thick, predominantly fine sandy unit (S8). Within these sands, very fine laminations of silt, but also small gravels occur. Medium and coarse sand is enhanced in the following part of the profile, where also few gravels >2 mm occur (S7). The grain size distribution from S7 to S5 show a small trend towards more silt deposits and a more widespread grain-size distribution. The silt fraction is enhanced between S7 (9.5%) to S5 (23.4%). This is in accordance with field observations and an increase in lamination of silt particles between 70-90cm. The trend towards more silty sediments is interrupted with one layer of coarse grained material, predominantly fine and medium sand including coarse sand and gravels >2 mm (S4). This unit is capped with thick and homogeneous carbonated white silts with a very compact texture. Here, the maximum amount of silt within the stratigraphy is present with 52.4% (S3), followed by a small decrease towards 33.6% (S2). The uppermost layer is of heterogeneous material with mixed gravels, sand, and only limited amount of silt (20.5%).

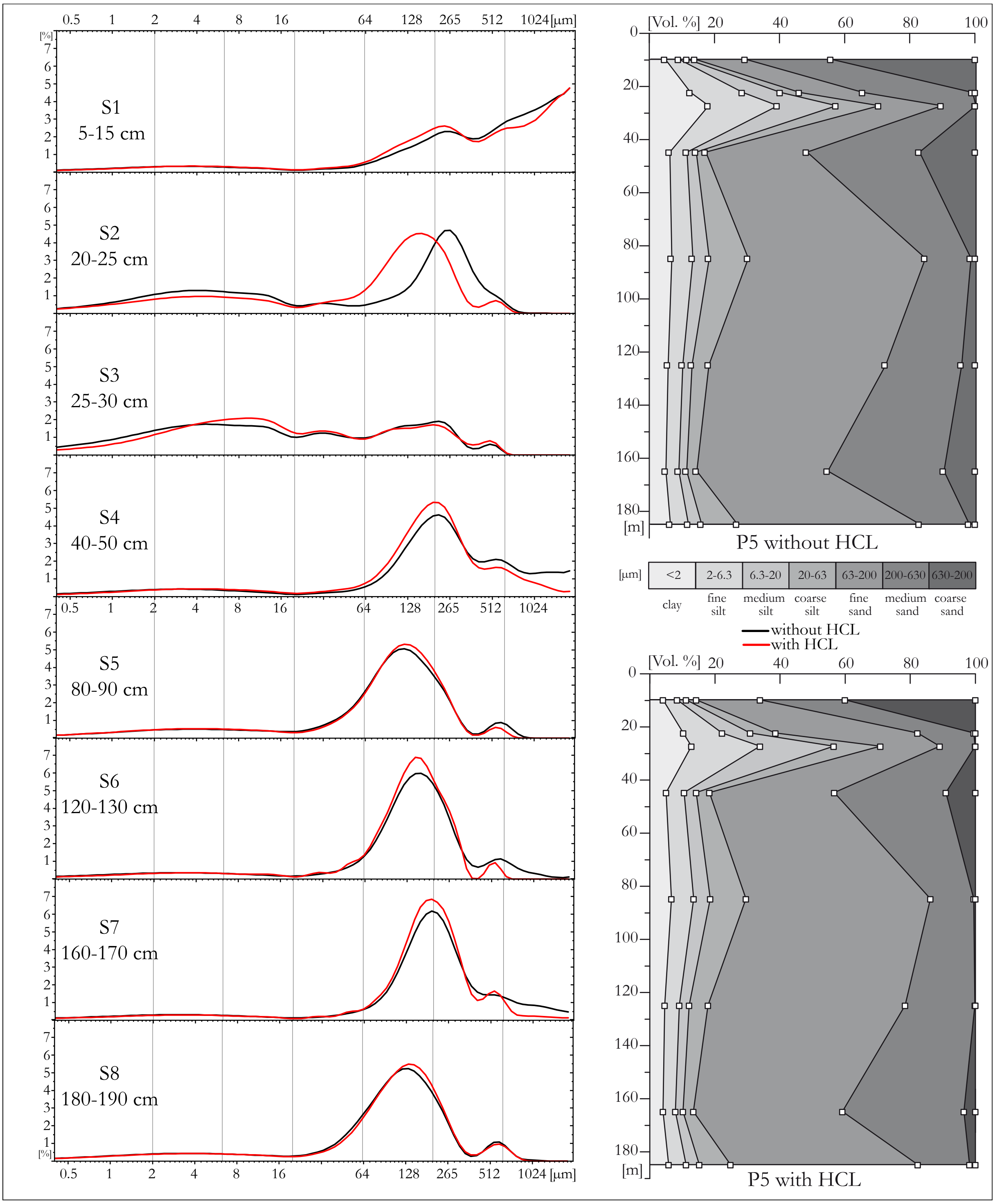


Figure 24: Grain-size distribution of sediment stratigraphy at Sodmein Playa without carbonate solution (black) and with carbonate solution (red).

The results of the pXRF analysis do not show large variations and point to a homogeneous geochemical composition of the sediments. No significant changes are observed throughout the stratigraphy. Changes in the amount of total organic carbon content is also very limited and varies only between 0.12 to 0.15%.

The chronology for the deposits based on the OSL-dating's (table 4) starts with an age of 10.3 ±0.5 ka (PL4) at the base of the sediment profile. A relative rapid sediment accumulation is observed in the lower part of the sequence, as the ages between 140 to 80cm (PL4 10.3 ±0.5 ka; PL3 9.88 ±0.2 ka; and PL2 9.19 ±0.4 ka) are very close to each other and partly overlap within their errors. The youngest age is obtained for the fine-grained deposits, dated to 7.61 ±0.2ka (0.35cm, PL1).

Table 4: Results of OSL-dating at Sodmein Playa, profile 5. Detailed measurements of water content, radionuclide concentration, dose rate and palaeodose are given in appendix 1

Sample ID	Sample name	Sampling depth [m.b.s.]	Age [ka]
C-L4479	1401 P1-1	0.35	7.61 ±0.20
C-L4480	1401 P1-2	0.8	9.19 ±0.42
C-L4481	1401 P1-3	1.2	9.88 ±0.23
C-L4482	1401 P1-4	1.45	10.3 ±0.49

The result of initial test excavations at the next small basins northeast of Sodmein Playa show a sediment filling >70 cm, where a stratigraphic composition of alternating coarse sandstone gravels with sand and silt deposits were observed (figure 25).

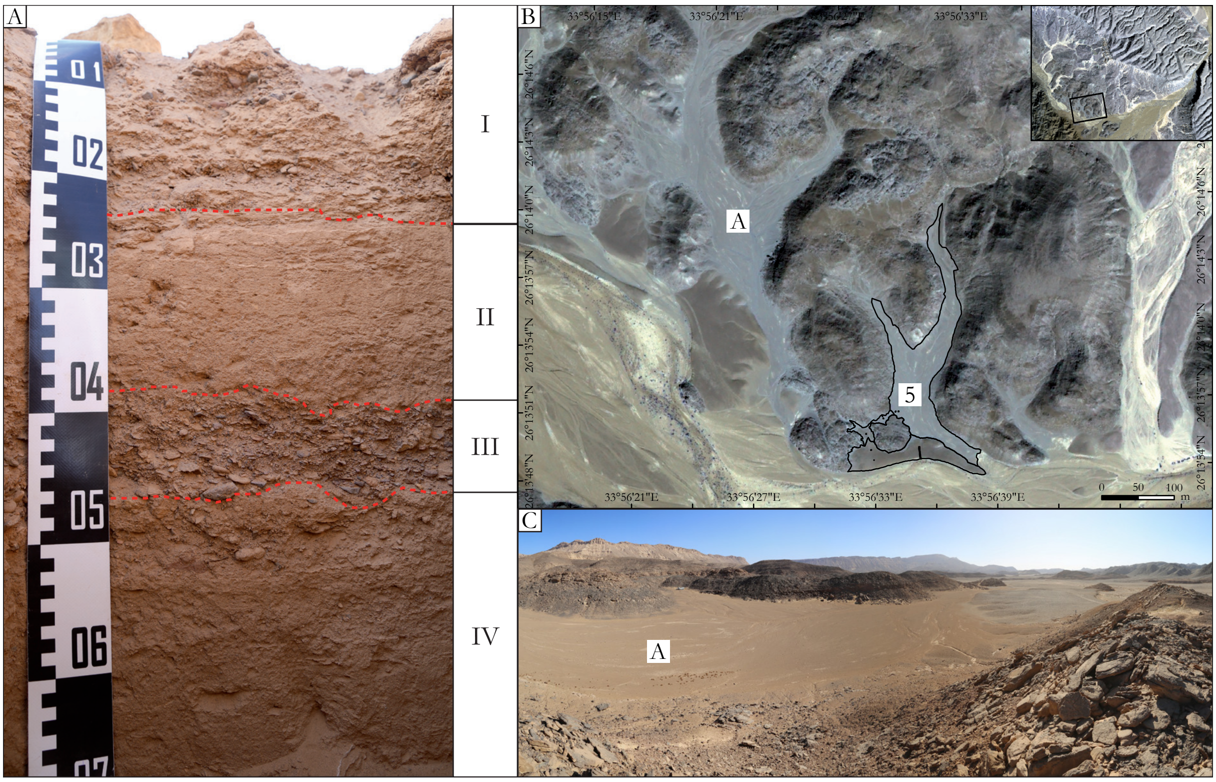


Figure 25: Sediment stratigraphy Playa 2. A) Sediment profile A with four stratigraphic units (picture Henselowsky 2016), B) Location of Playa 2 and profile A in comparison to profile 5 from Sodmein Playa, satellite image based on Quickbird, bands 432; C) Panorama view of Playa 2 (picture Klahre 2016).

Here, the uppermost 20 cm consists of sandy-silty sediments in a coarse matrix of sandstone gravels. The second layer (20-40 cm) is characterised with sand deposits and a weak fining upwards deposition with silt laminations occurring at around 22-25 cm. A second coarse layer with sandstone gravels occur between 40-51 cm, whereas the following layers are mainly dominated by sand with minor silt laminations. Unfortunately, due to missing sedimentological and chronological investigations at this site, comparison with the profile from Sodmein Playa are not possible, although the stratigraphy shows similarities.

The results from Sodmein Playa will be discussed within the landscape context at Gebel Duwi with integration of the results derived from the wadi terraces and palaeoenvironmental changes based on the chronology of the sediment deposits at Sodmein Playa.

5.2 Speleothem growth periods at Saquia Cave and Nakheil Cave

The results of the Th/U-dating (table 5) for the flowstone at Saquia Cave show 21 ages ranging between 185.7 ± 4.3 ka to 83.2 ±2.1 ka, whereas one age for stalagmite growth in Nakheil Cave could be maintained at 153.5 ±0.44 ka. This age comes from the top of the stalagmite and represent the youngest times of stalacmite formation and thus, no stalagmite formation occurs after MIS 6. Further age determination for the samples from Nakheil Cave were not done, as they do not present the time period of interest (≤ MIS 5) and the samples are archived for possible future investigations. 18 out of 21 ages from Saquia Cave are attributed to MIS 5, whereas the remaining three ages belong to MIS 6. All different sub-stages of MIS 5 (e, d, c, b, a) show the presence of speleothem deposits.

Table 5: Results of Th/U-dating of the flowstone at Saquia Cave and stalacmite from Nakheil Cave. Lab-No. = Institute für Umweltphysik (IUP). Detailed measurements and absolute concentrations of Th and U are given in appendix 2

	Location	Lab-No.	Age corr. [ka]	error [± ka]	MIS stage
1	Saquia	IUP-5786	83.2	2.1	5a/b
2	Saquia	IUP-5787	103.8	3.6	5c/d
3	Saquia	IUP-5788	84.4	2.2	5a/b
4	Saquia	IUP-5911	85.4	1.8	5a/b
5	Saquia	IUP-5912	96.7	2.7	5c/d
6	Saquia	IUP-5913	119.7	2.4	5e
7	Saquia	IUP-5945	114.5	2.2	5d/e
8	Saquia	IUP-5946	105.2	2.2	5d/e
9	Saquia	IUP-6004	99.1	2.3	5c
10	Saquia	IUP-6435	127.2	3.5	5e/6
11	Saquia	IUP-6436	127.1	2.8	5e
12	Saquia	IUP-6437	124.5	1.8	5e
13	Saquia	IUP-6438	185.7	4.3	6
14	Saquia	IUP-6439	174	4.6	6
15	Saquia	IUP-6440	155.6	3.9	6
16	Nakheil	IUP-9173	153.51	0.57	6
17	Saquia	IUP-9177	120.57	0.75	5e
18	Saquia	IUP-9178	105.87	0.72	5c/d
19	Saquia	IUP-9179	90.23	0.45	5b
20	Saquia	IUP-9180	110.03	0.48	5d
21	Saquia	IUP-9181	110.72	0.38	5d
22	Saquia	IUP-9182	85.48	0.4	5a/b

The age-depth plot for three cores from Saquia Cave reveal the complex internal structure of the flowstone (figure 26). The general stratigraphy follows a decrease in age from the right side towards its inner part up to 17cm. Saquia_1 has an abrupt increase between 17.5 to 18 cm, showing an age inversion from 85.48 ±0.4 ka to 185.8 ±4.3 ka. From 18.3 cm onwards the deposits are younger towards the outer side of the flowstone. Cores 2 and 3, situated 4 and 10 cm above core 1, are comparable with the oldest ages at its inner side and younger ages towards the central part. As these cores are only cored up to the central part, the observed age inversion is not recorded in these cores. Saquia_1 has one outlier at 5.8 cm with an age of 114.5 ±2.2 ka. All other ages from the outer side (right) towards the central part of the flowstone are stratigraphically in order within their 2σ error, e.g. Sauqia_1 at 7.5cm with 96.7 ±2.7 ka and at 4.5 cm with 99.1 ±2.3 ka. Samples measured with TIMS have higher 2σ errors in comparison with samples measured with MC-IPMS, based on the higher accuracy of Th und U measurements.

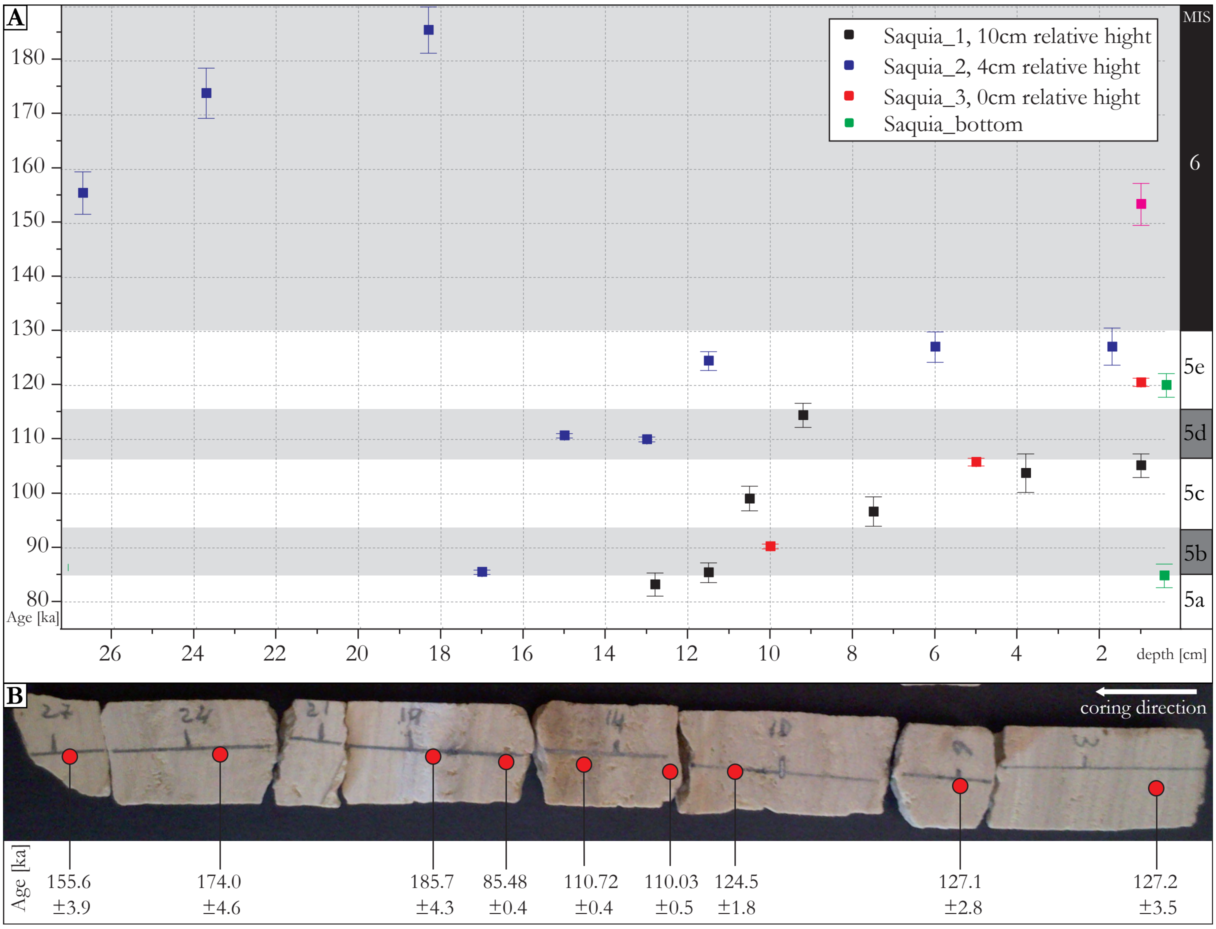


Figure 26: Age-depth plot for Th/-U dating results from Saquia Cave (A) and image and stratigraphy of sample Saquia_1.

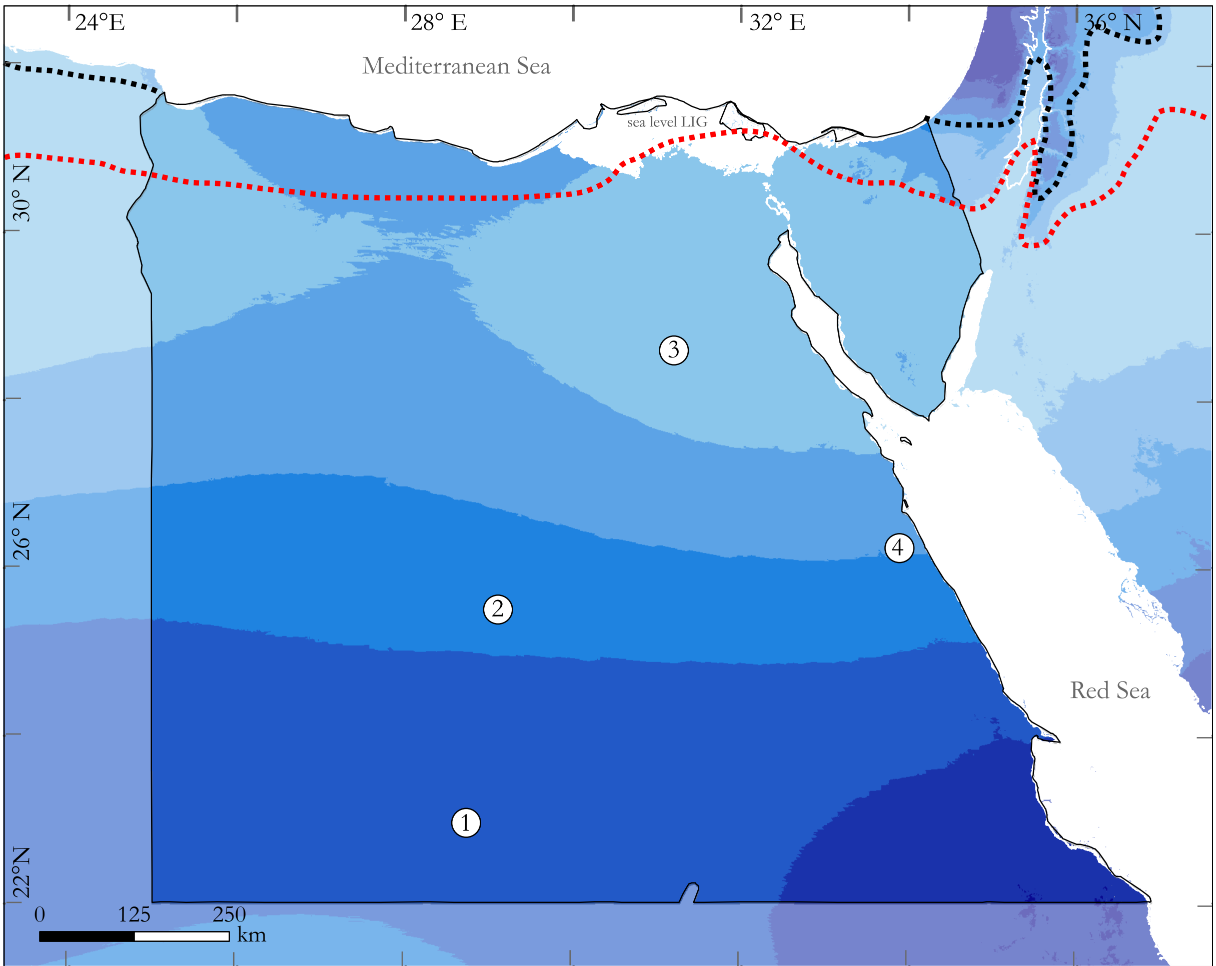
Due to the complex internal stratigraphy, no detailed age-model is calculated so far. Thus, the interpretation of dated speleothem deposits at Saquia Cave and Nakheil Cave reveal only insights into the onset and offset of secondary carbonate deposition due to enhanced precipitation and associated vegetation growth for soil CO_2 production.

5.3 GIS-based palaeoenvironments in Egypt during the Last Interglacial

Each of the derived results are presented individual, before the results are summed up to synthesise the palaeoenvironmental conditions and parameters for hunter-gatherer societies at large scale. All maps show a presumed palaeocoastline of Egypt during the LIG, which has changed due to global sea level changes and tectonic impulses, especially in the Red Sea area. Maximal sea level rise during the LIG in the Red Sea and Mediterranean Sea is assumed to be +6m above recent sea level (Grant et al. 2012). The largest changes occur in the Nile delta. Based on nowadays topography, a significant part of the delta is flooded during a sea level rise of +6m.

5.3.1 Genetic and effective climate classification

The results of the CCSM3-climate model provide insights into the precipitation distribution in Egypt during the LIG (figure 27). Rainfalls of more than 500 mm/a occurred in the south-eastern part of Egypt and decreased towards the north, with a precipitation of less than 200mm/a at around 30°N. In between, rainfalls of 500-200 mm/a are calculated. The Mediterranean Coast and inland areas up to 200 km received rainfalls between 200 - 300 mm/a. The monthly distribution of annual rainfall allows a calculation of summer and winter rainfall, where summer rainfall is classified as >66% of annual rainfall between April and September and winter rainfall as >66% of annual rainfall between October and March. The result shows, that Egypt is almost entirely influenced by summer rainfall up to 30°N, whereas the northern Mediterranean areas are located in between the northern limit of summer rainfall and southern limit of winter rainfall and received year-round rainfall. Distinct winter rainfall is only mapped at the adjacent boarders of Egypt at the Libyan coast and into the Levant. Next to climate simulations, only a few proxy-based estimates exist about the total annual precipitation amount for Egypt during the LIG, where the results of the climate model can be compared with (figure 27, B). Faunal deposits associated with the large interglacial palaeolakes at Bir Tarfawi and at Bir Sahara indicated precipitation of at least 500 mm/a (Kowalski et al. 1989), in comparison with an amount of 437 mm/a based on the CCSM3 model. A hydrogeological model for the Dakhla Oasis palaeolake assumed rainfalls between 410-670 mm to fill the basin during enhanced precipitation, e.g. during the LIG (Kieniewicz& Smith 2009), where the CCSM3 model points to around 370 mm/a. The differences between proxy and model based precipitation for this region in the Western Desert are in general agreement. A speleothem dated to MIS 5e in the Eastern Desert at Sannur Cave needed a minimum amount of precipitation for dissolution and solution of carbonates and associated speleothem growth (El-Shanawyet al. 2018). The CCSM3-model show a mean annual precipitation of around 150 mm for the LIG, which is too low for speleothem growth. Modern data from the southern Negev Desert indicate speleothem growth only over 300 mm/a in today's arid regions of the SAD (Vaks et al. 2010).



Last Interglacial precipitation [mm/a]

< 200 | > 300 - 400 | > 500 - 600
> 200 - 300 | > 400 - 500 | > 600

southern limit of winter rainfall > 66% of annual rainfall between October - March

northern limit of summer rainfall > 66% of annual rainfall between April - September

[mm/a]	CCSM3-model	proxy data
1) Bir Tarfawi	437	> 500
2) Dakhla	370	410 - 670
3) Sannur Cave	150	> 300
4) Sodmein Cave	280	600

Figure 27: Last Interglacial precipitation in Egypt, palaeoclimate model: after Otto-Bliesner et al. 2008, Hijmans et al. 2005, www.worldclim.org; B) Comparison of annual rainfall during the LIG based on the CCSM3-model and proxy data: (1) Kowalski et al. 1989; (1) Wendorf et al. 1993; (2) Kieniwicz & Smith 2009; (3) El-Shanawy et al. 2018; (4) Moeyersons et al. 2002. Analysis and cartography Henselowsky.

This leads to an underestimation of model based precipitation of 50%. Similar discrepancies can be derived from the Central Eastern Desert. Sedimentological, botanical, and faunal analyses of the J-complex deposits at Sodmein Cave, dated to MIS 5e (Mercier et al. 1999, Schmidt et al. 2015) indicate wet-conditions with precipitations estimates of 600 mm/a (Moeyersons et al. 2002). In this case, the model derived precipitation show 280 mm/a, which lead to differences of around 50%. Therefore, discrepancies in the Eastern Desert are higher than in the Western Desert, which is not displayed in the data of the CCSM3 climate model.

The annual rainfall distribution is studied in more detail with the climate diagrams of four different sites. From south to north these sites are Bir Tarfawi, Sodmein Cave, Sannur Cave , and Marsa Matruh (figure 28).

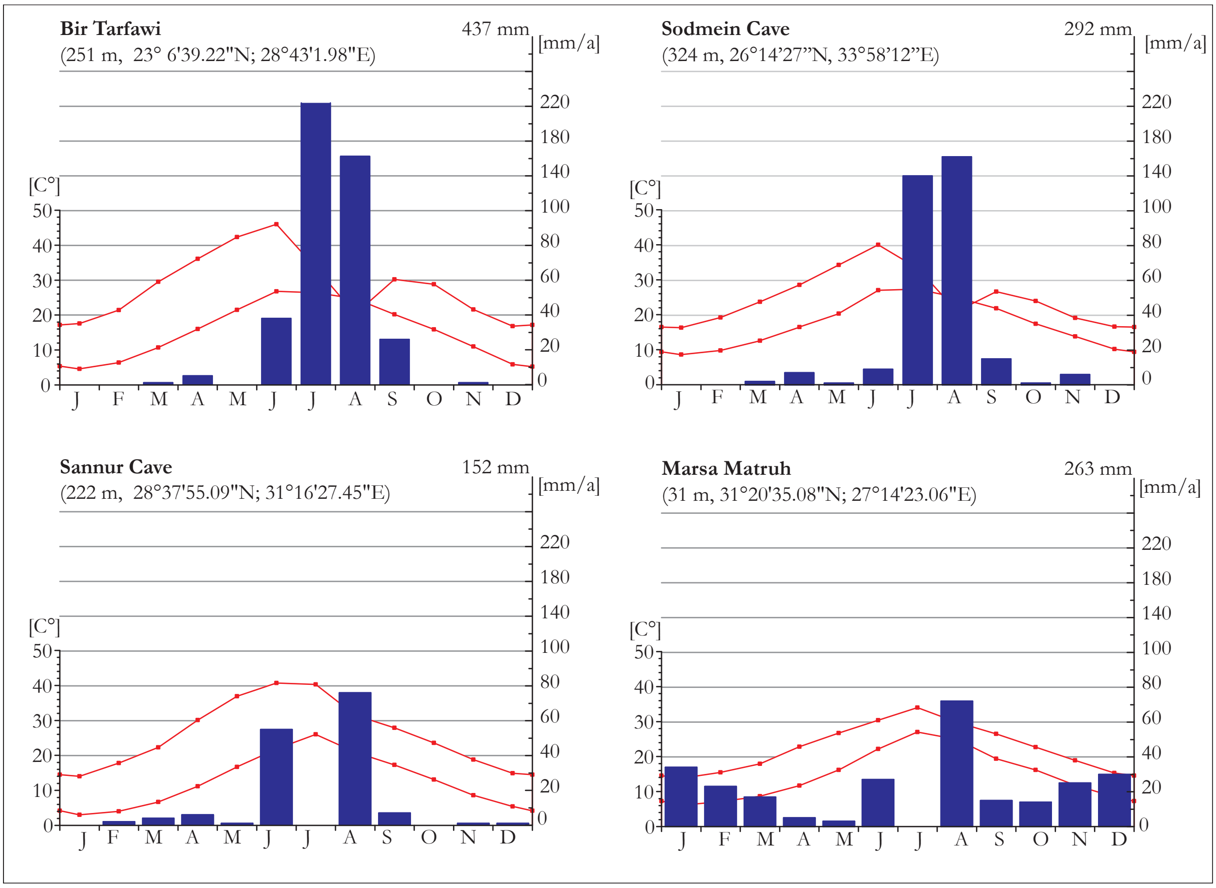


Figure 28: Climate diagrams of Bir Tarfawi, Sodmein Cave, Sannur Cave, and Masar Matruh during the LIG based on the CCSM3-climate model. Monthly input data are given in appendix 3,

Bir Tarfawi has a total annual precipitation of 437 mm, with highest monthly rainfalls between June and September. Only limited rainfall occurs apart from these months. Thus, the precipitation regime has a high summer seasonality with its maximum after the maximum of temperature in June. The maximum and minimum temperature range between 4.6-17.6°C in January and 26.8-46°C in June with a constant increase between January and June and constant decrease between July and December, where only the maximum temperature in August is out of order. The results for Sodmein Cave show a comparable course of the year in temperature and precipitation, but total annual precipitation is limited to 292 mm. Here, the maximum temperature in August is also out of phase and temperatures in general are lower in comparison to Bir Tarfawi in (maximum-minimum temperature 8.6-16.3°C in January and 27-40°C in June). Least annual precipitation occurred at Sannur Cave with a total amount of 152 mm/a. Highest monthly precipitation was in June and August, whereas the results of the CCSM3-model show negative precipitation (-1 mm) in July, which cannot be explained. Apart from the fact that precipitation values cannot be negative, a strong decrease between two months of higher rainfalls indicates an error within the model for this location. Minimum and maximum temperature follow a constant increase and decrease in the course of the year and no values are out of phase. The northernmost site of Marsa Matruh had an annual precipitation of 263 mm with rainfall over all months, except for July. Seasonal increase and decrease are observed from September to May with a rapid increase in June and August. The model indicates a negative precipitation of -2 mm for July. Apart from these outliers, rainfall distribution shows a typical winter rainfall dominated regime.

The application of the effective climate classification scheme after Köppen-Geiger, in addition to the data from literature about possible biomes in Egypt during the LIG (figure 29), provides the background for the environmental reconstruction apart from the absolute climate data. The Köppen-Geiger classification shows two main classes for Egypt during the LIG. The southern parts represent arid steppe climate (Bs), whereas the northern parts are classified as an arid desert climate (Bw). Both classes are subdivided in hot and cold desert/steppe (h/k), related to the mean annual temperature. The differences between hot and cold areas are mostly due to topographic effects, with lower annual temperatures e.g. in the elevated Gilf Kebir plateau and in the Sinai mountains, in comparison to the surrounding regions. In comparison with nowadays (pre-industrial) Köppen-Geiger classification (Willmes et al. 2017b), the Bsh climate migrated northwards for up to 2000 km during the LIG.

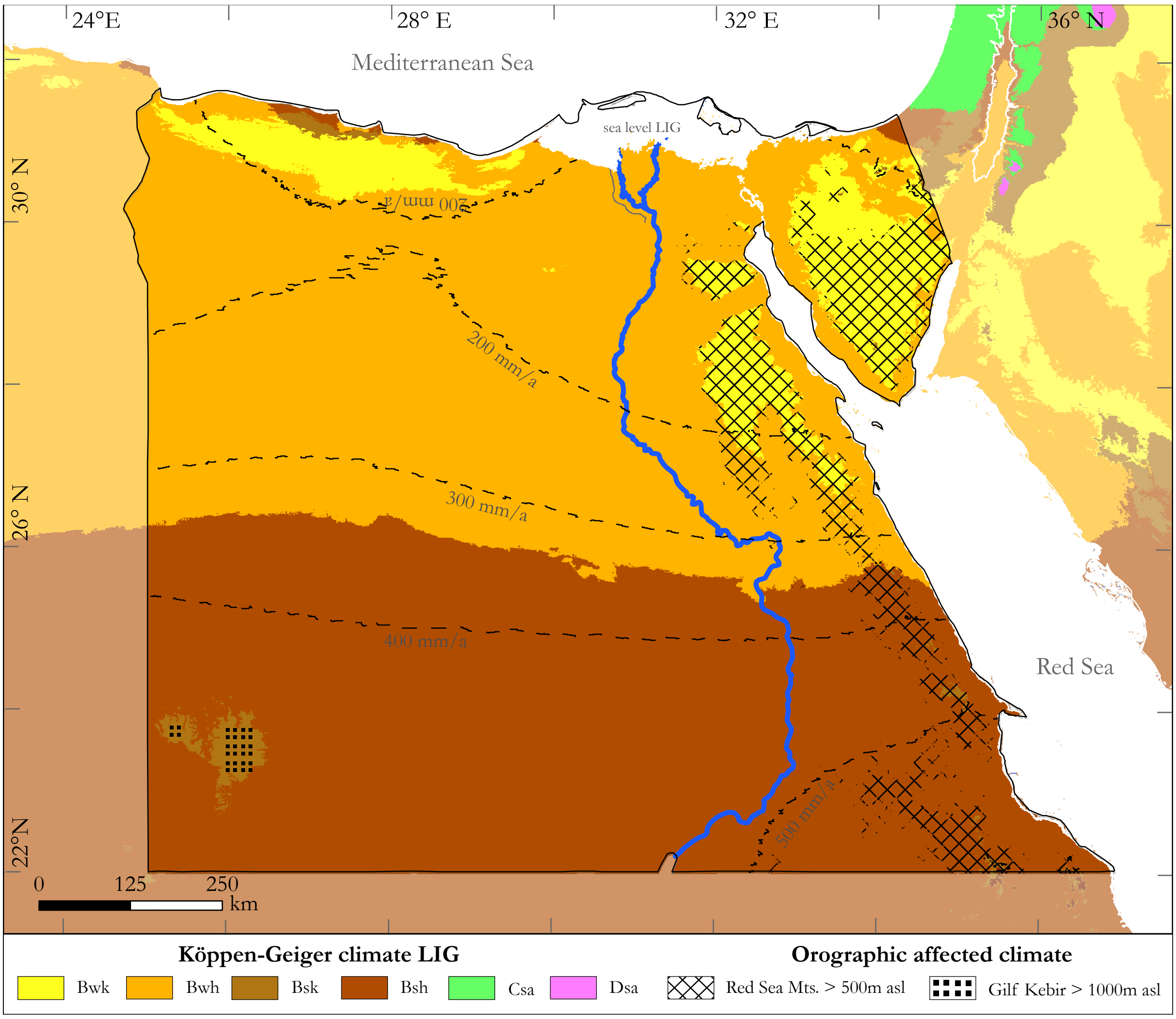


Figure 29: Köppen-Geiger climate in Egypt during the LIG computed after skript by WILLMES et al. 2017 a/b based on the CCSM3-climate model and topographic regions with strong orographic affected mountanoius areas. Analysis and cartography HENSELOWSKY

By comparing the results for annual precipitation and the calculated KÖPPEN-GEIGER climate classes, the current ecozones (compare figure 9) were transferred to the LIG (figure 30). In this case, the southern regions of Egypt under the influence of summer rainfall represent an Acacia savannah ecozone from the south up to around 25°N at the 250 mm/a isohyet. Towards the north, where precipitation further decreases, a steppe vegetation is proposed during the LIG, as annual precipitation do not fall under 50 mm/a. The extent of the today north Saharan steppe and woodland ecozone at the Mediterranean coast is also enhanced and has a larger extent towards the south, but also an increase in annual precipitation and represents Mediterranean woodland during the LIG. The areas of the Red Sea Mountains and the Sinai with regions above 500 m received more rainfall, and due to their topography, a mountainous savannah ecozone is proposed. The situation here is more influenced by further variable ecological conditions due to the heterogeneous landscapes driven by topography and geology, in comparison to the Western Desert. The Nile valley still preserved its special character as an allochthonous river and is associated with a large riparian gallery forest and marshes, not only influenced by the climate in Egypt, but also due to its large catchment.

It can be concluded, based on the combination of the palaeo Köppen-Geiger climate, the CCSM3-climate model, and the comparison with today's situation, ecozones in Egypt during the LIG are dominated by a savannah vegetation in different specifications, either dominated by woodland or grassland. A grassland savannah vegetation mixed with Mediterranean woodland vegetation occurs at the northern and coastal regions in Egypt.

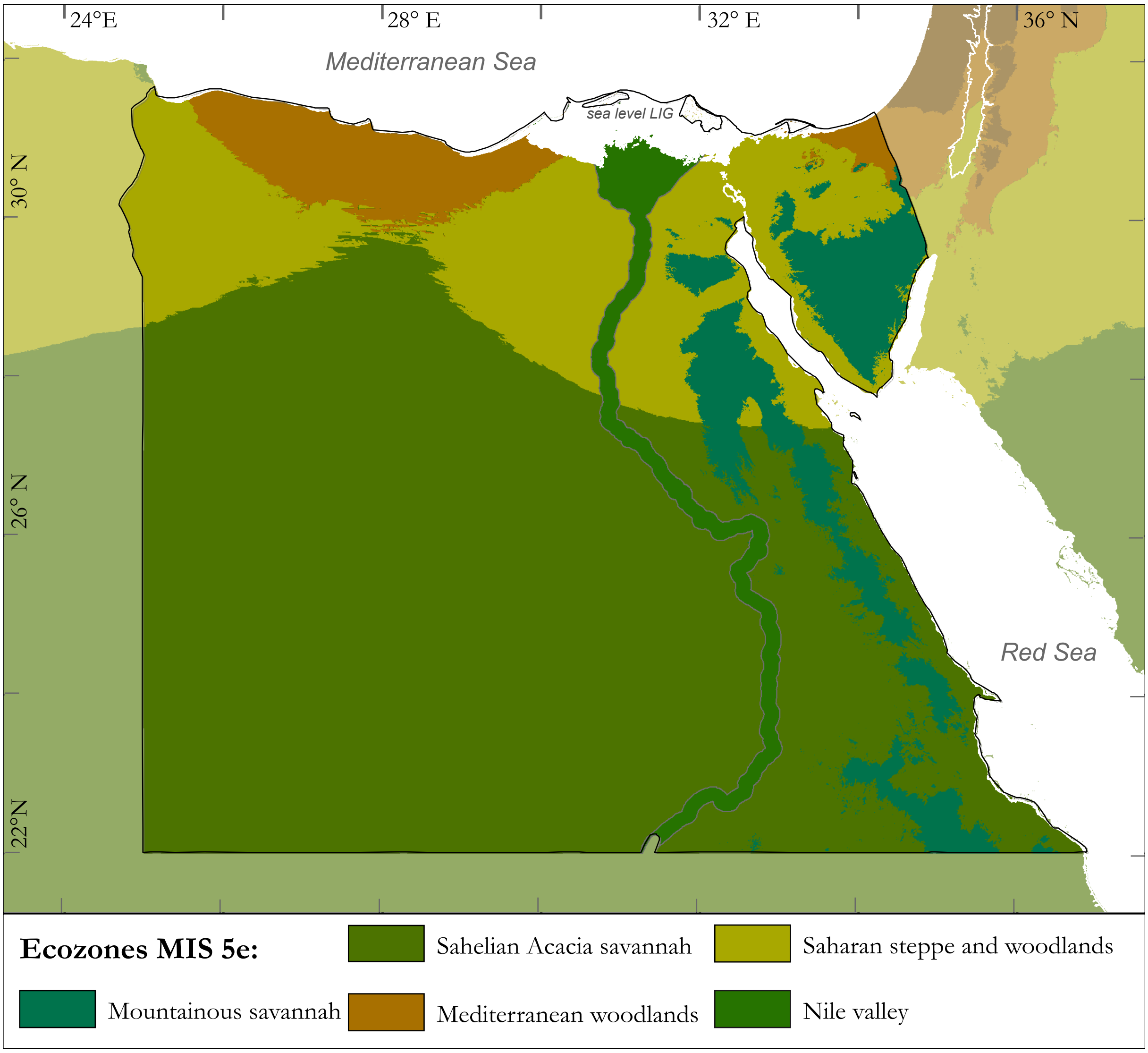
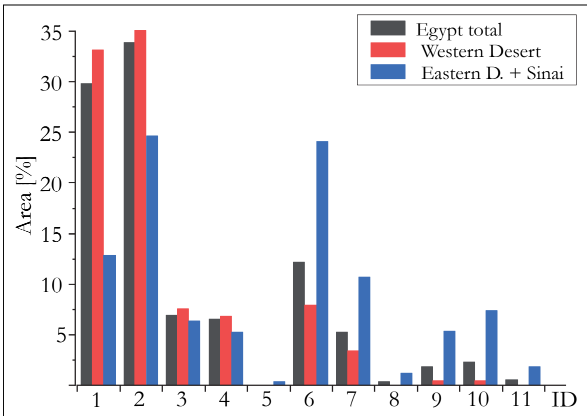


Figure 30: Ecozones in Egypt during the LIG based on the semi-quantitative calculation and analyses of annual precipitation, Köppen-Geiger climate and modern analogues. Analysis and cartography Henselowsky.

In summary, LIG climate regime of Egypt represents major shifts in its total annual precipitation compared to the hyper-arid conditions today, which also caused tremendous changes in the environment, visible in the effective climate classification. Summer rainfall migrated more than 1500km further northwards during the LIG in contrast to these days. A second region with increased precipitation between today and the LIG is the Mediterranean coast, which represents an absolute increase of rainfall, but also a spatial increase of this zone towards the south of approximately 200km.

5.3.2 Topography

All landforms represent the scale of the macrorelief, where single relief features have a spatial extent >1km. At the scale of the macrorelief, out of fifteen global relief types (classification after MEYBECK et al. 2001), eleven different types exist in Egypt, which are dominated by five relief types account each for at least 5% of Egypt (figure 31).



ID	Class	Class definition: Altitude [m asl]	Class definition: Roughness [‰]	Land area [%]: Egypt total	Land area [%]: Western Desert	Land area [%]: Eastern D. + Sinai
1	Plains	0-200	< 5	29.9	33.2	12.8
2	Mid-altitude plains	200-500	< 5	33.9	39.8	24.7
3	High-altitude plains	500-2000	< 5	6.9	7.6	6.4
4	Lowlands	0-200	5-20	6.5	6.8	5.2
5	Rugged Lowlands	0-200	20-80	0.3	0.2	0.4
6	Platforms	200-500	5-20	12.2	8.0	24.1
7	Low Plateaus	500-1000	5-20	5.3	3.5	10.7
8	Mid-altitude plateaus	1000-2000	5-20	0.4	0.1	1.2
9	Hills	200-500	20-160	1.8	0.5	5.3
10	Low mountains	500-1000	20-160	2.4	0.5	7.4
11	Mid-altitude mountains	1000-2000	20-160	0.5	0.0	1.8

Figure 31: Statistics for the distribution of different relief types in Egypt and their occurrences in the Western Desert, Eastern Desert, and Sinai Peninsula.

General differences of Egypt`s landscapes between the Western Desert, the Nile Valley, the Eastern Desert, and the Sinai exist also in the differences of their landforms. The Nile Valley as a large-scale canyon divides the Western Desert and Eastern Desert, and marks the border of the two regions. None very high plateaus and mountains (above 4000 m) and high plateaus and mountains (above 2000 m) exist in Egypt, even though some minor areas above 2000 m exist at the highest peaks of the Sinai Peninsula and Eastern Desert, but these classes do not exceed a minimum area of 0.1% of the total land area to be incorporate in the overall relief classes for Egypt (figure 31).

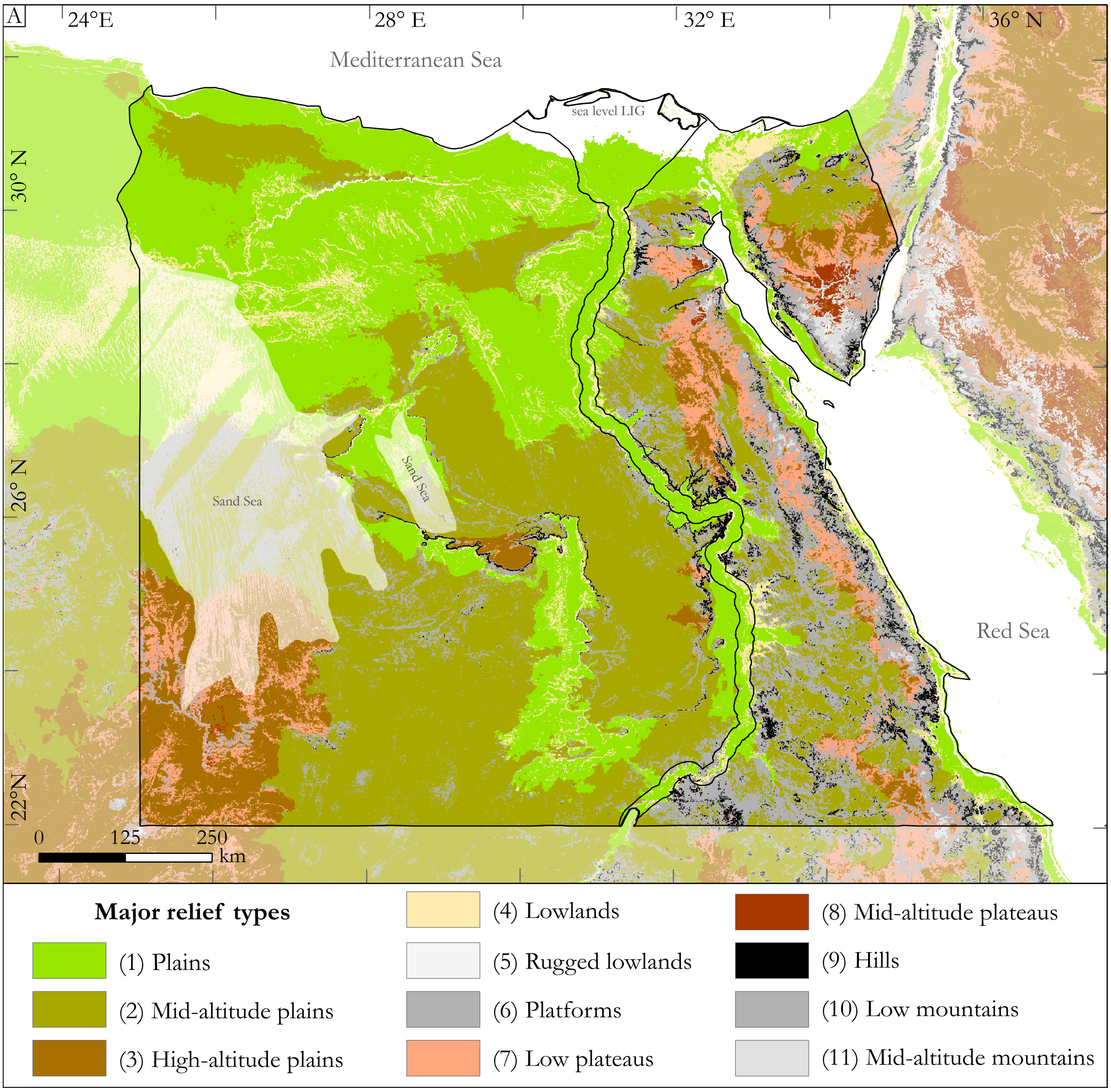


Figure 32: Major relief types in Egypt according to the classification schema of Meybeck et al. 2001, where relief roughness and elevation attributes to distinct relief types. Analysis and cartography Henselowsky

Around two-thirds of Egypt are characterised as plains at different altitude, mostly between 0 - 500 m (63.8%). Further relief types occur with an intermediate roughness (5-20‰) at lower areas (lowlands 0-200 m) or intermediate altitude defined as platforms (200 - 500 m) and plateaus (>500 m). Whereas the Western Desert is dominated by smooth roughness values and 80% of the area has a roughness less than 5‰, the areas of low and intermediate roughness in the Eastern Desert and Sinai is more balanced (44% with a low roughness of <5‰ and 41% with an intermediate roughness of 5 - 20‰). Intermediate roughness at an altitude between 200 - 500m (class 6) is higher in the Eastern Desert and the Sinai in comparison to the Western Desert and Egypt in total. Based on the given classification, the Eastern Desert is more heterogeneous with a higher variability in landforms at the scale of the macrorelief in contrast to the Western Desert. However, an area with very high roughness and topographic barriers do not exist in the Eastern Desert and Sinai Peninsula, with some exceptions of very singular high peaks.

5.3.3 Drainage Systems and Hydrology

The computed river streams revel insights into possible active catchments during MIS 5e induced by enhanced precipitation. The drainage streams are classified based on their catchment size to >500 km², >1,000 km², >5,000 km² and >10,000 km² (figure 33).

Large palaeo river systems occur in the Western Desert in the area of the Selima Sandsheet represented by the Tushka Watershed system. Their catchments start in the north of Sudan and draining towards the large palaeolakes at Bir Sahara/Bir Tarfawi, Bir Kiseiba, Nabta Playa, and Tushka lakes. Largest catchments in the Eastern Desert are Wadi el-Arish, Wadi el-Kharit, and Wadi Qena, whereas Wadi al-Arish is the most prominent one at the Sinai Peninsula. Internal draining in endogenic basins is absent and the catchments can be divided into the Nile-Mediterranean system draining towards the west, and smaller catchments draining towards the Red Sea. In contrast to the Western Desert and due to the rough topography, large playa basins are absent, but distinct river stream lines filled with quaternary wadi deposits appear frequently. Most wadis are deep incised into the uplifted Precambrian basement rocks and their low permeability leads to strong surface discharge.

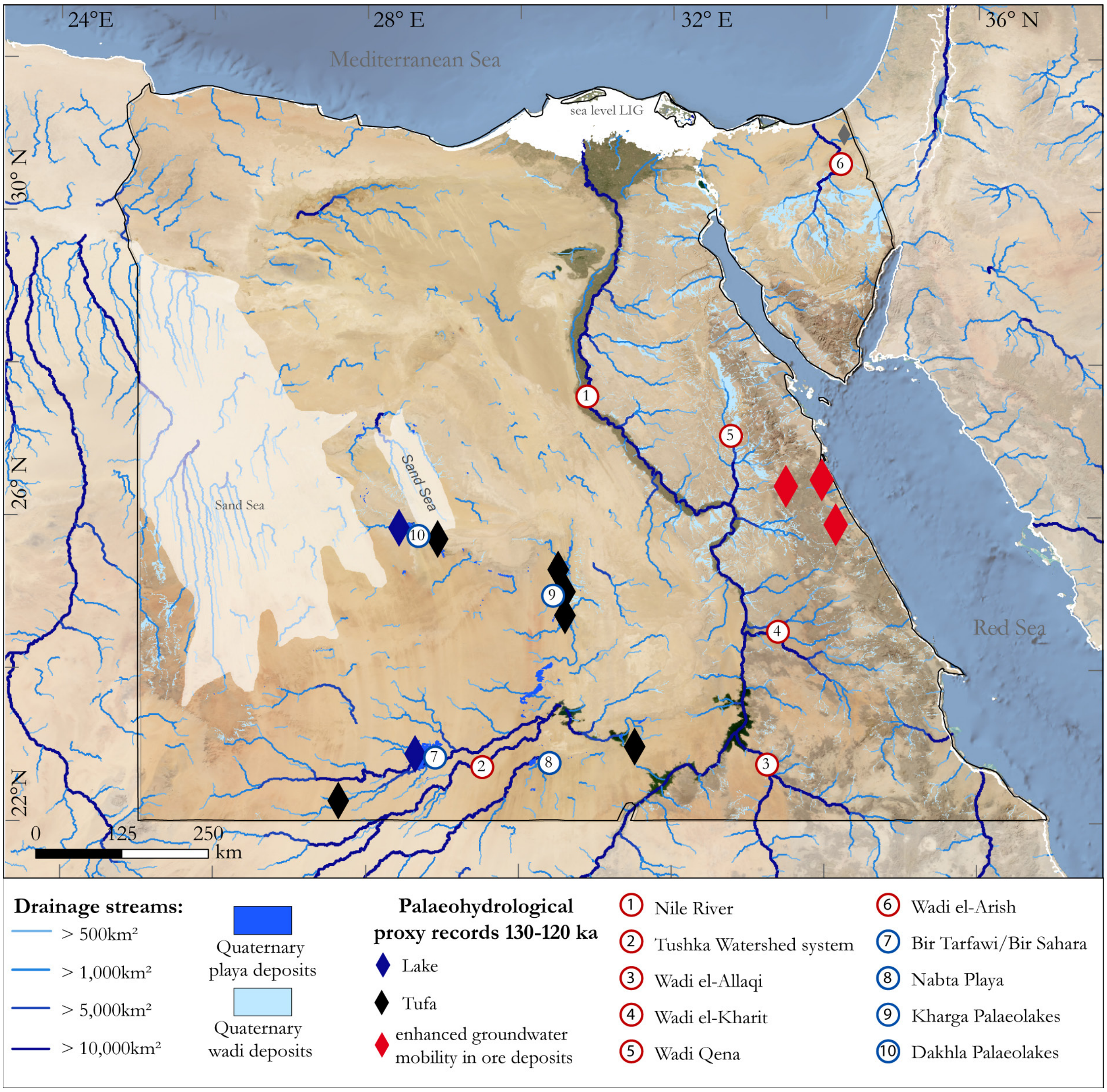


Figure 33: Drainage systems in Egypt and palaeohydrological proxy records between 120-130 ka. Drainage systems in Egypt based on the HydroSHED dataset (Lehner et al. 2006) and quaternary playa and wadi deposits based on geological maps of Egypt 1:500,000 (Conoco 1987) with largest drainage streams (red 1-6) and major palaeolakes (blue 7-10). Location of sites with palaeohydrological proxy records dated between 120-130 ka are discussed in chapter 6. Analysis and cartography Henselowsky

Quaternary wadi deposits (at today's surface) are almost absence in the Western Desert, whereas in the Eastern Desert and at the Sinai Peninsula, these deposits are widespread distributed. They occur widely at Wadi Qena and at Wadi el-Arish. Remnants of Quaternary playa deposits are mapped in the Western Desert, e.g. at Bir Tarfawi/Bir Sahara, Nabta Playa, Dakhla and Kharga Oasis.

5.3.4 Raw-Material

Flint and chert in primary geological context occur in different geological formations from the upper Cretaceous to the middle Eocene (table 6).

Table 6: Geological formations with flint and chert according to the geological Maps of Egypt 1:500,000 (Conoco 1987)

Formation	Age	ID	Remarks	Mapsheet
Wata Formation	upper Cretaceous	Kuyd	minor chert intercalations	(NH 36 NW) Cairo; (NH 36 NE) North Sinai
Sudr Formation	upper Cretaceous	Kus	locally flint concretions	(NH 36 SW) Beni Suef; (NH 36 NE) North Sinai
Matulla Formation	upper Cretaceous	Kua	minor chert intercalations	(NH 36 SW), Beni Suef
Thebes Group Drunka Formation	lower Eocene	Tetd	local flint bands	(NG 36 NW) Asuit; (NG 35 NE) Farafra; (NG 36 SW) Luxor
Thebes Group Serai (Thebes) Formation	lower Eocene	Tett	rich in chert bands	(NG 36 NW) Asuit; (NH 36 SW) Beni Suef; (NG 36 SE) Gebel Hamata; (NG 36 SW) Luxor; (NG
Thebes Group Dungul Formation	lower Eocene	Tetl	local flint bands	(NF 36 NW) El Saad El Ali
Thebes Group Egma Formation	lower Eocene	Tete	chert bands	(NH 36 SW) Beni Suef; (NH 36 NW) Cairo; (NH 36 NE) North Sinai; (NH 36 SE) South Sinai
Mokattam Group	middle Eocene	Tem	local chert	(NH 36 SW) Beni Suef
Umm Raqaba Formation	Pliocene	Tplu	chert pebbles (sec. deposit)	(NH 36 SW) Beni Suef

They are related to marine limestone deposits during the transgression of the Thethys Sea and represent the Middle Calcareous Division of Mesozoic sedimentary rocks of Egypt (Embabi 2018). In total, around 9% of the land surface in Egypt (figure 34) is covered with flint and chert bearing geological strata, with differences between the Western Desert, the Eastern Desert, and the Sinai Peninsula.

The percentage has its maximum at the Sinai Peninsula with around 31% of the land surface and lowest in the Western Desert with around 5%. The Eastern Desert is covered with around 15% of flint and chert bearing geological strata. The regional distribution of these formations is at the central Sinai Peninsula, the northern part of the Eastern Desert between 26°-31°N and western part of the Western Desert north of the Tushka lakes and west of the middle

Nile valley. Isolated areas occur north of the Great Sand Sea at the eastern areas of Siwa Oasis. Most of the formations contain flint in local bands and concretions with high regional variabilities. The Thebes formation has the quantitative highest amount of flint with good knapping quality. Large areas covered by this formation exist in the Eastern Desert at the Maaza Plateau and at isolated areas within the Precambrian basement, e.g. at Gebel Duwi.

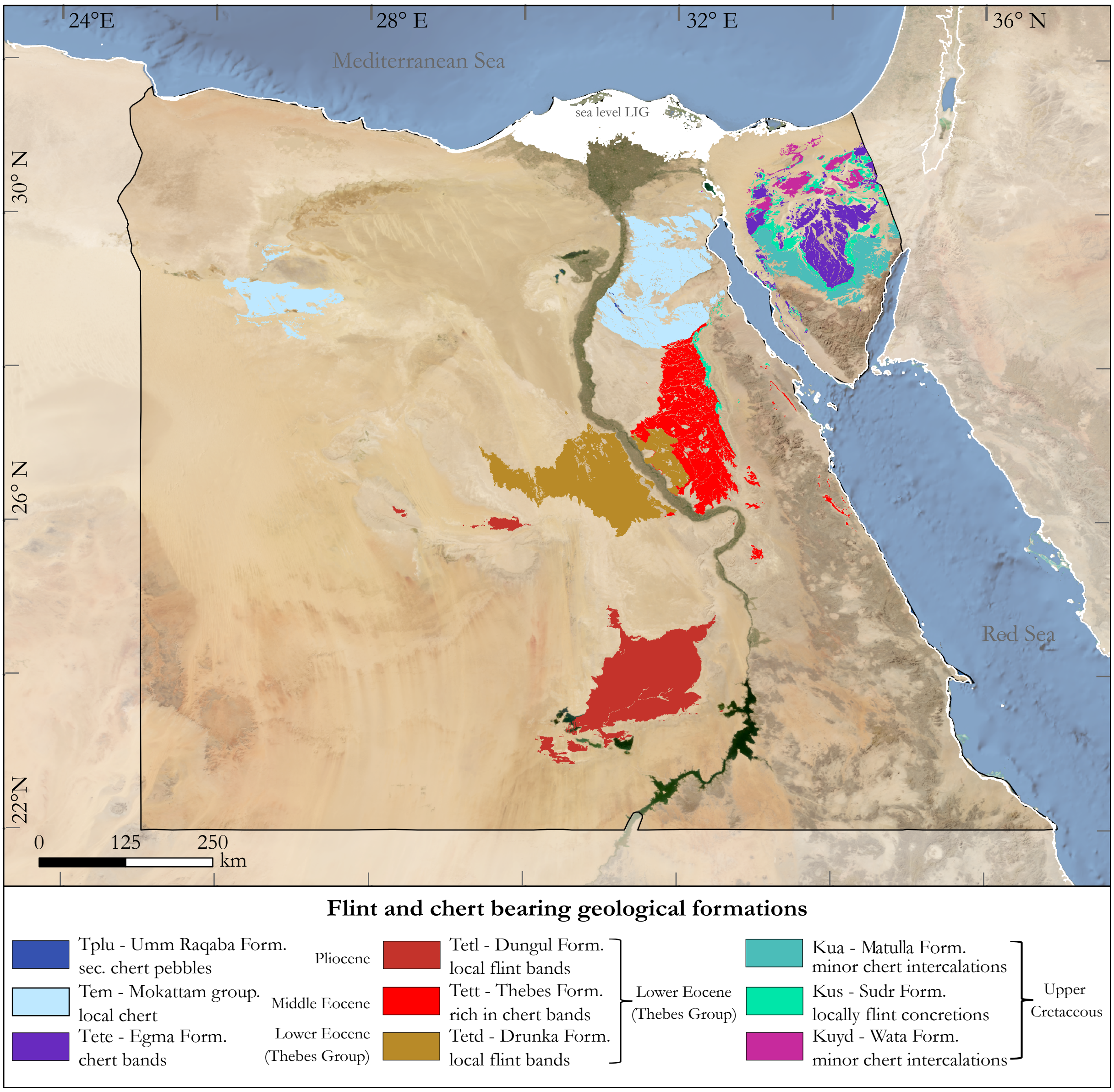


Figure 34: Flint and chert bearing geological strata based on the geological maps of Egypt 1:500,000 (Conoco 1987).

The chance to encounter secondary flint deposits in wadi terraces is achieved by the combination of the primary geological sources and drainage systems with quaternary wadi deposits (figure 35).

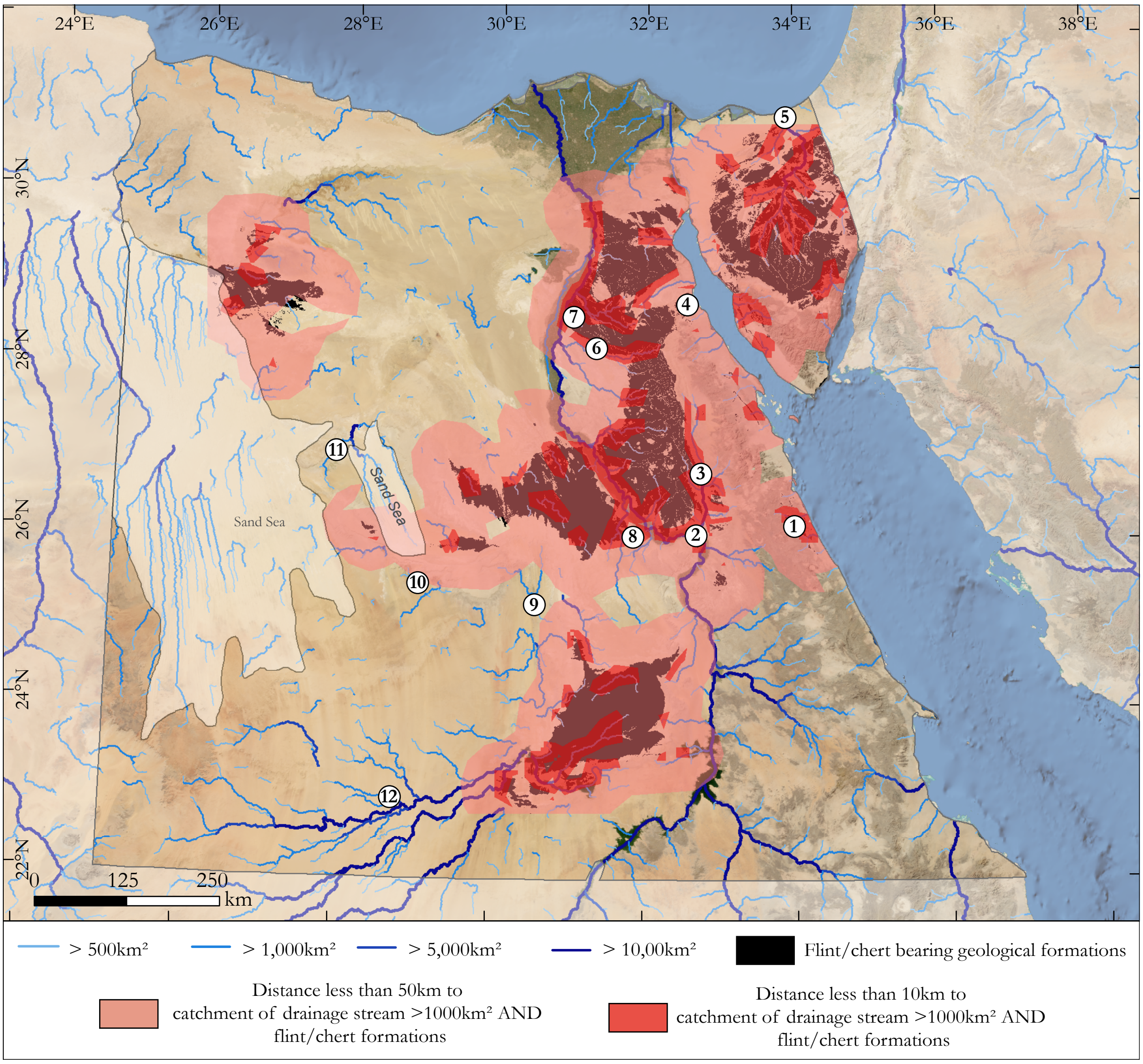


Figure 35: Calculated distances for raw-material access and large drainage streams in Egypt based on a threshold of 10 and 50 km to flint and chert bearing geological strata and drainage streams with a minimum catchment of 1,000 km². Archaeological sites: 1: Sodmein Cave, 2: Taramsa, 3: Wadi Umm Gilu, 4: Wadi Deir, 5: Wadi el-Arish, 6. Wadi el-Tarfa, 7: Wadi el-Sheik; 8: Abydos; 9: Kharga Oasis 10: Dakhla Oasis, 11: Farafra Oasis, 12: Bir Tarfawi (for references see table 2, sites 3 and 4 of this study). Analysis and cartography Henselowsky

The Nile is the only river, where long-distance transport of sediments and accompanied external raw-material sources plays a role. The produced GIS-dataset about areas with flint and chert bearing geological strata can be used for such spatial analysis and the distribution of primary flint and chert sources with drainage systems. This is for instance the distance to a drainage stream with a given catchment area or the distance to regions with abundance flint deposits. Thresholds (=distances) can be set to different values, as for example the distances to areas with flint bearing geological formations. In addition, distances to a drainage stream with a minimum catchment area as additional parameter can be calculated. Here, a threshold for catchments larger than 1,000 km² was used. Regions with a minimum distance of 10km and 50km to both parameters are presented. These spatial analyses are an important tool to classify distinct areas, which might be of importance for past human societies and have a high attractiveness for hunter-gatherer during the Late Pleistocene, here with focus on combined water and raw material availability in an area. The given examples with distances of 10 and 50km can be modified to any distances, which might be of interest for archaeological questions, e.g. the radius of daily activities or distinct walking distances.

All MISA sites in the Eastern Desert of Egypt occur in a maximum distance of 10km to the next geological formation containing flint or chert and a drainage streams with a minimum catchment of 1000 km². Sites in the Western Desert at Farafra, Dakhla, and Kharga Oasis, do not occur in such proximity of primary flint and chert sources and large drainage streams. However, it is important to note, that these sites are located in the vicinity of the Tarawan formation, which includes local chert sources, but are not charted on the geological maps with a scale of 1:500,000, thus they also cannot be integrated in the spatial analysis. The usage of other raw-material sources as quartz, quartzite, and quarzitic sandstone may have been important in areas with absence of flint. Artefacts found at Bir Tarfawi and Bir Sahara are made of quarzitic sandstone and it is also visible, that these sites are located beyond regional flint and chert occurrence

Based on the given observations about the interplay of secondary geological sources of flint and chert at wadi terraces and the occurrence of archaeological sites at these locations, the survey at Wadi Qena aimed to test the hypothesis and to gain more evidences about this correlation. It also tests the potential of the mapping approach of flint and chert bearing strata as part of the PalaeoMap for a possible prediction of archaeological sites. One site was found at Wadi Umm Guli, a small tributary of Wadi Qena (figure 36).

Its catchment is located in Thebes limestone, which contains high abundances of high-quality flint. Elevated terraces at the outflow of Wadi Umm Gilu preserve high amounts of artefacts, which can be attributed Middle Palaeolithic. The surface of these terraces consists of a dark coloured desert pavement, where surface artefact collections are found. Another example

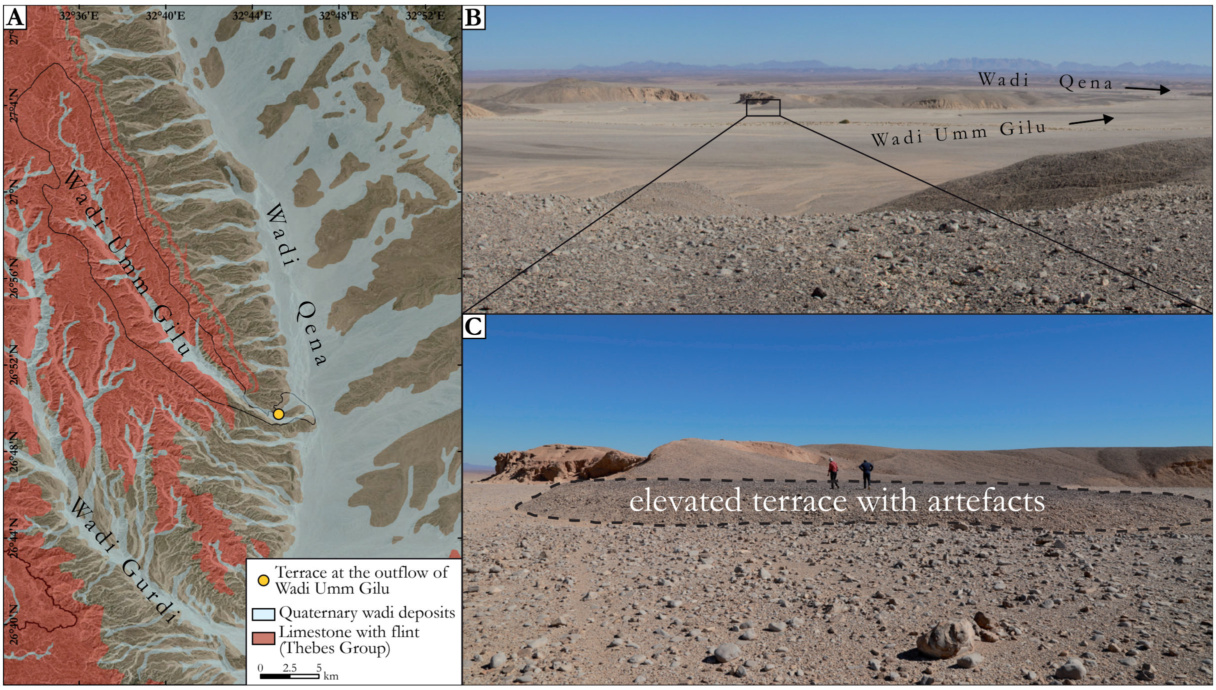


Figure 36: Landscape context at Wadi Umm Gilu. A): Geological mapping of flint and chert bearing strata and quaternary wadi deposits (Conoco 1987). B) Panorama view accross the outflow of Wadi Umm Gilu towards Wadi Qena. C) elevated terraces, where Middle Palaeolithic artefacts were found (pictures Henselowsky 2016)

is a small tributary of Wadi el-Tarfa draining limestone of the Mokattam group in the northern Eastern Desert. Presumable old terrace surfaces with a dark coloured desert pavement and Middle Palaeolithic artefacts occur several metres above the recent drainage streams. Here, the presence Middle Palaeolithic artefacts stands exemplified for the raw material use of this area.

6. Discussion of the results

6.1 Landscape context at Gebel Duwi: Inside-Outside – Integrating cave and open-air archives

Investigations at cave and rock shelter archives in the study of past human-environment interaction are very common in geoarchaeology, but often lack an overall impression about the total environment where past humans lived. This needs to be investigated at open-air sites and in off-site regions at larger spatial scale. Kindermann et al. (2018) identified several important aspects with regard to this topic under the framework of "Inside – Outside: Integrating Cave and open-air archives". Caves and rock shelters have a distinct function for past human societies, e.g. for camps, but most of the daily activities e.g. hunting, gathering, access to water, and raw material procurement took place outside of such locations. A straight-forward look at caves and rock shelters without integration of open-air sites can overlook important information. This research bias is well known and increasing investigations with focus on the integration of various archives aim to close this gap (Kindermann et al. 2018). The identification of the landscape context is crucial, as the availability and preservation of possible open-air sites is strongly affected by the dynamic of the landscape and post-depositional processes affecting the occurrence of archaeological findings. This is subsequent discussed with regard to the results from Gebel Duwi.

The geomorphological-geological map indicates the rare existence of palaeoenvironmental archives in the study area. With exception of the wadi terraces and the small depressions filled with sediments located within the outcrops of Nubian sandstone in the western Sodmein basins, erosional processes dominate the landscape. This is related to the long-term aridity of the area and the very rough topography. The general framework and landscape evolution at Gebel Duwi pre-dates the time of interest for the interaction of humans within their environment during the early Late Pleistocene. However, it strongly affects the landscape evolution in the area and provides the context where the subsequent younger landscape features need to be integrated. Therefore, it is important to integrate the long-term geological and geomorphological processes at larger scale, which formed the current, but also Late Pleistocene landscape context at Gebel Duwi. This is summarised with the palaeohydrology at Gebel Duwi and its vicinities.

6.1.1 Palaeohydrology and wadi terraces

The detailed analysis of the palaeohydrology and associated impacts to groundwater in the area of Gebel Duwi are given in Yousif et al. (2018). Here, a short summary discusses the main points of this article with regard to the drainage system evolution in the Eastern Desert. It is in general the result of long-term evolution since the opening of the Red Sea accompanied with the uplift of the Red Sea Mountains. The Eocene Thebes limestone formation is the youngest geological unit, which pre-dates the opening of the Red Sea and was present all over the Eastern Desert. The uplift of this formation associated with the rifting, marks the initial erosion of the Cenozoic sedimentary rocks and the subsequent exhumation of the Precambrian basement rocks. The Nakheil formation (Oligocene) consists of a coarse breccia with reworked limestone and chert from the Thebes formation, but no components of the underlying Nubian sandstone and Precambrian basement. Therefore, it indicates that un-roofing of the Precambrian basement and the associated incision of the drainage system into these rocks must post-date the Oligocene (*cf.* Issawi et al. 2009). The first evidences for a proceeding incision of the drainage system into the Nubian sandstone and the Precambrian basement rocks are present in the Ranga formation dating back to the Miocene. Here, fan and delta deposits at the Red Sea coast are composed of Precambrian basement, Nubian sandstone but also chert and limestones (Khalil & McClay 2009). It indicates the strong uplift of the Red Sea Mountains and subsequent erosion with the initial incision of the drainage streams into the basement rocks. Therefore, the deep incision of all wadis within the Precambrian basement rocks in the Eastern Desert is the result of the long term drainage evolution since the Miocene. The occurrence of karstic features in the Miocene rocks of the Red Sea coast provide strong evidence that there must have been much wetter conditions following their deposition. The youngest major wetter climatic period in long-term geological time scales was the Zeit Wet Period during the Messinian (Griffin 2002). All of these evidences point to the existence of a highly developed drainage system in the Eastern Desert before the Quaternary, where also the general dry climate conditions do not allow such a strong incision of wadis into the basement, but preserved the general morphometry of drainage streams. This is very important, as short wetter climate periods in the Pleistocene encountered the highly developed drainage system and water discharge and confluence has been concentrated in specific regions. Here, Gebel Duwi presents an extraordinary situation with the presence of the two tectonic basins at its western and eastern side. Large filling with quaternary wadi deposits indicate the strong fluvial activity, and particular important the reduced water discharge due to the comparable flat topography in contrast to the deep incised drainage streams towards the west and east. Therefore, water availability for human occupation at Gebel Duwi area during the Late Pleistocene was also enhanced.

The general presence of the presumable old wadi terraces indicates previous incision of Wadi Sodmein into older deposits due to palaeoenvironmental changes. Compared to the overall landscape setting at Gebel Duwi, these isolated terraces represent an extraordinary landform, as the adjacent areas are either influenced by wadi activity or hillslope processes. The age of the wadi terraces is unknown so far, but evidences exist that these terraces represent comparable old landforms due to the formation of strong desert pavements and desert varnish with surface findings of archaeological artefacts related to the Middle Stone Age. The formation of the terraces could be triggered by possible changes in fluvial activity with varying sediment budget under different climate and/or tectonic movements. Due to the short distance to the Red Sea, Pleistocene sea level changes might also have affected depositional or erosional character of fluvial activity under varying base level. As the tectonic activity of Sodmein and Nakheil Basins is mainly characterised with subsidence (Khalil & McClay 2002), a tectonic impulse for terrace building is unlikely, although the long-term impact of tectonic activity in the overall drainage system in the Eastern Desert is high.

The results for the wadi terraces aim to derive at least a relative chronology of possible different terraces indicating varying fluvial activity and thus, could be possible link to palaeoenvironmental changes in the area. However, the results do not imply a distinct classification of the terraces and thus their significance as palaeoenvironmental archive is low. This is due to several factors: First, the applied methods using the analysis of the high-resolution digital elevation models is insufficient to classify the morphometry of the terraces. The spatial analysis of the terraces in three dimensions is not possible, due to the high spatial variabilities of the terrace itself, but also because of the inaccuracies of the DEM`s. Only the field based DGPS measurements allow an accurate measurement for the height of terraces in two dimensions, but cannot accomplish an area wide conclusion. The comparable small scale for the heights of the terraces ranging between 1-2 m accounts for the second limiting reason. Although the Sodmein basin with the recent wadi floor and terraces represent a very flat topography at the scale of the mesorelief in contrast to the adjacent areas of the Gebel Duwi and Precambrian basement, its internal topography is very rough at the scale of the microrelief. The high correlation between the elevation of the terraces and the elevation of the wadi floor reveals, that the surfaces of the terraces follow in general the surface inclination of the recent wadi from west to east and might represent the absence of different terrace levels. However, the morphometric results are too heterogeneous, that no morphometric parameter allows a distinct quantification of terrace levels. A good identification of the terraces is better achieved with the optical analyses based on the satellite image, as the parameter of the terrace (dark colour and desert pavement) allows a good delamination to the recent wadi (figure 37).

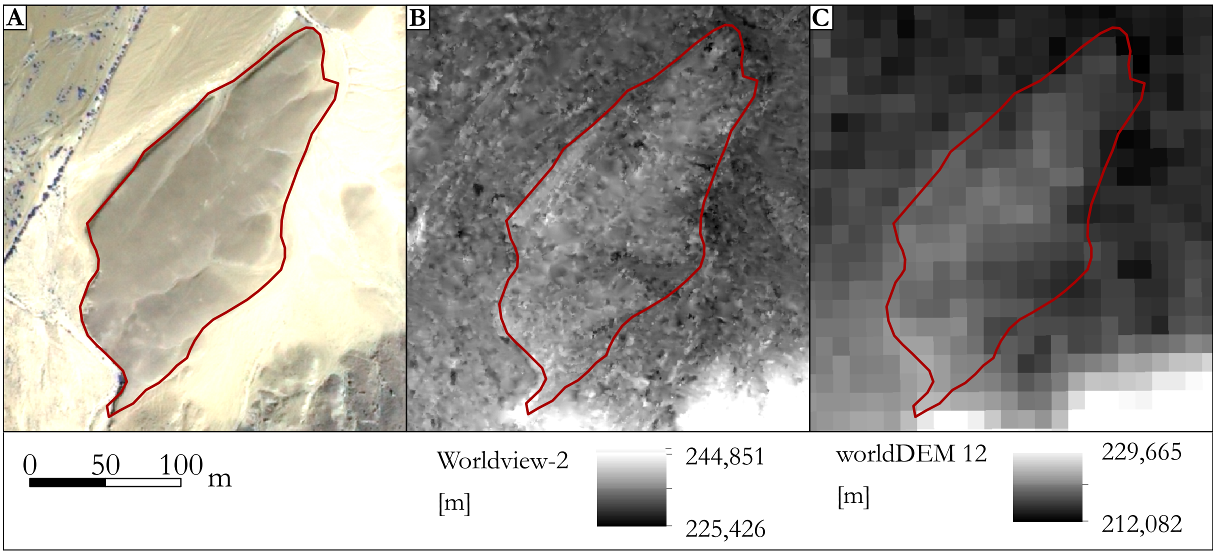


Figure 37: Comparison of data sources for GIS-based terrace mapping based on A) Quickbird, bands 432 (0.61 m, B) Wordlview-2 DEM (1 m) and C) WorldDEM (12 m)

The difficulties in the morphometric identification of the terraces is also strongly caused by the specific characteristics of fluvial activity in desert environments. It is summarised in the statement about dryland rivers, where “it is also apparent that few, if any, morphological features are unique to dryland rivers. The variety of dryland river forms and the absence of a set of defining dryland river characteristics makes it difficult to generalise about dryland rivers” (Powell 2009: 333). The discontinuous fluvial activity, highly variable sediment transport with strong peaks, e.g. during flash floods, can results in high erosion, but likewise in high deposition of sediments and congruent small scale variation in either accumulation or erosion.

Badawy (2008) summarised the different terrace levels at the lower course of the Red Sea drainage system into six classes of heights, where the lowermost terraces heights > 1.5 m are interpreted as the result of the present-day climate and resulted after the lowering of the erosional base following a sea level high stand above present day level during the Mid-Holocene. Only terraces heights above two meters up to 20 m are considered to reflect palaeoenvironmental changes throughout the Pleistocene. If the identified terraces at Sodmein basins with heights between 1-2 m above the recent wadi floor represent the nowadays incision of the wadi in its former deposits after the Mid-Holocene, the actual terrace surface would be comparable young. However, there are several arguments, why there exist no possible comparisons of distinct wadi heights in the study area at a regional scale, even the investigated terraces are less than 30 km apart from each other. The investigated terraces by Badawy are located at the distinct lower course of the wadis, e.g. at Wadi el-Ambagi, and do not represent a special context of the found terraces at the Sodmein basin, which are overprinted by local effects of an intercalated tectonic basin. Therefore, the general morphometric framework of the wadi terraces differ.

There are also several indications, why the investigated terraces at Sodmein represent parts of a former Pleistocene surface and were not formed during the Mid-Holocene. This hypothesis is supported by the archaeological findings on top of the terraces. The occurrence of mostly in-situ located Early Nubian Complex artefacts on top the terrace at Sodmein Playa indicates, that any impact of fluvial activity during and after the LIG is absent (Kindermann et al. 2018). It preserves the long-term stability of these surfaces and a stable landscape feature. The presence of further artefacts on additional terraces apart from Sodmein Playa could enhance the relative stratigraphy of the terraces, when technological differences between the stone tools at each terraces could give a relative cultural and chronological stratigraphy. The systematic record of all terraces is still outstanding, but some indications about differences between terraces predominantly covered with Middle Palaeolithic artefacts and terraces with more Neolithic artefacts occur. Nevertheless, these indicators can only provide a minimum age for the stability of the terraces, as chronological younger artefacts can also occur on older surfaces. Investigations on desert pavement development and occurrence of Upper to Middle Palaeolithic artefacts at the eastern Libyan plateau (Western Desert) show, that the surface findings indicates a surface stability over the last 100 ka (Adelsberger & Smith 2009).

Further proxy for the relative age indicators of wadi terraces in arid environments are the use of different desert pavement morphology (e.g. Al-Farraj & Harvey 2000). Whereas the terraces in the western part are mainly dominated by sediment deposits coming out of the Precambrian basement, the intermixing with sedimentary rocks from the Nubian sandstone and especially with limestone of Gebel Duwi is limited to the more eastern terraces. These terraces have a connection to small tributaries draining the sedimentary rocks. The differences between the surface colour and composition of the desert pavement are depending mainly on the initial composition of deposited rocks and their initial colour. Terraces located at the out-cropping sedimentary rocks of Nubian sandstone and limestone have a stronger influenced of original more bright colour in contrast to the mostly dark coloured rocks of the Precambrian basement. Thus, a straight identification of different generations of terraces based on the surface colour mapped with the high-resolution satellite image is also not possible. However, the presence of the strong desert pavement and desert varnish also indicates in general, that the surface of the terraces need to be isolated from wadi activity for long times and the surface represents a possible Pleistocene age.

Additional field work and sampling of the pavement and desert varnish would be necessary to get further insights. Initial OSL-samples for the fine-grained subsurface of the desert pavement are in progress and will help for a better understanding of the pavement development and questions about an accretionary or deflation pavement. Although desert pavements are a very common feature in arid environments, their evolution is still questionable, as the process is not monocausal and strongly affected by environmental input parameter (*cf.* Dietze et al. 2016, Fuchs & Lomax 2018). As the environmental parameters vary through time, the current characteristics of the pavement are the integral of environmental changes, which highlights the challenges for desert pavements as environmental archives.

In summary, the mapped wadi terraces present one of the youngest (Pleistocene?) palaeohydrological landform in the study area, in comparison to the overall drainage system evolution since the Miocene. The long-term evolution of the drainage systems developed a comparable dense and steep drainage network during wetter climate phases of the Tertiary, where wetter climate during the Pleistocene did not shape the overall drainage system at larger scale, but distinct morphological features as the wadi terraces at smaller scale. Their importance as a palaeoenvironmental archive is high, but equally challenging. The given particularities do not allow a quantitative calculation of the terraces based on remote sensing techniques due to the limiting accuracy of the DEM`s. Only field based investigations provided initial implications, but the limiting possibility for further in-depth studies still lacks a comprehensive analysis.

6.1.2 The stratigraphy of Sodmein Playa

The following environmental implications can be derived from Sodmein Playa. The chronological background of the sediment stratigraphy starts at the beginning of the Holocene. No Late Pleistocene sediments are found at Sodmein Playa and implications for the reconstruction of the environment at Gebel Duwi for Palaeolithic occupation is not possible. However, the results can contribute to the Holocene climate history, where Sodmein Cave was also occupied and still provides the possibility to link the geoscientific results into an archaeological context. So far, there is only little evidence that the Eastern Desert encountered wetter climatic conditions after MIS 5 and before the Holocene. Hamdan et al. (2015) report ^{14}C ages of carbonate and organic residues of tufas in the Eastern Desert, showing wet intervals during the late Pleistocene at 62-56 cal. yr. BP and 31-22. Cal. yr. BP. However, the data should be handled with caution. Only one age indicates the oldest wet interval at the limit of ^{14}C-dating and an assumed calibration. There are also difficulties in matching the different carbonate ages and organic residue ages of the tufas and potential reservoir effects (Hamdan et al. 2015).

The sedimentological results for the stratigraphy of Sodmein playa can be integrated into the initial classification (figure 38) and confirm the initial interpretations given in Kindermann et al. 2018. The stratigraphy shows that more humid conditions indicated by the gradual increase of silt deposits occur between 10-9 ka with the first occurrence of laminated silts between 70-90 cm, dated to 9.18 ±0.4 ka at the beginning of the Holocene wet period. This is in phase with the re-occupation of Sodmein Cave at the beginning of the Holocene wet period starting at 9 ka (Vermeersch et al. 2015).

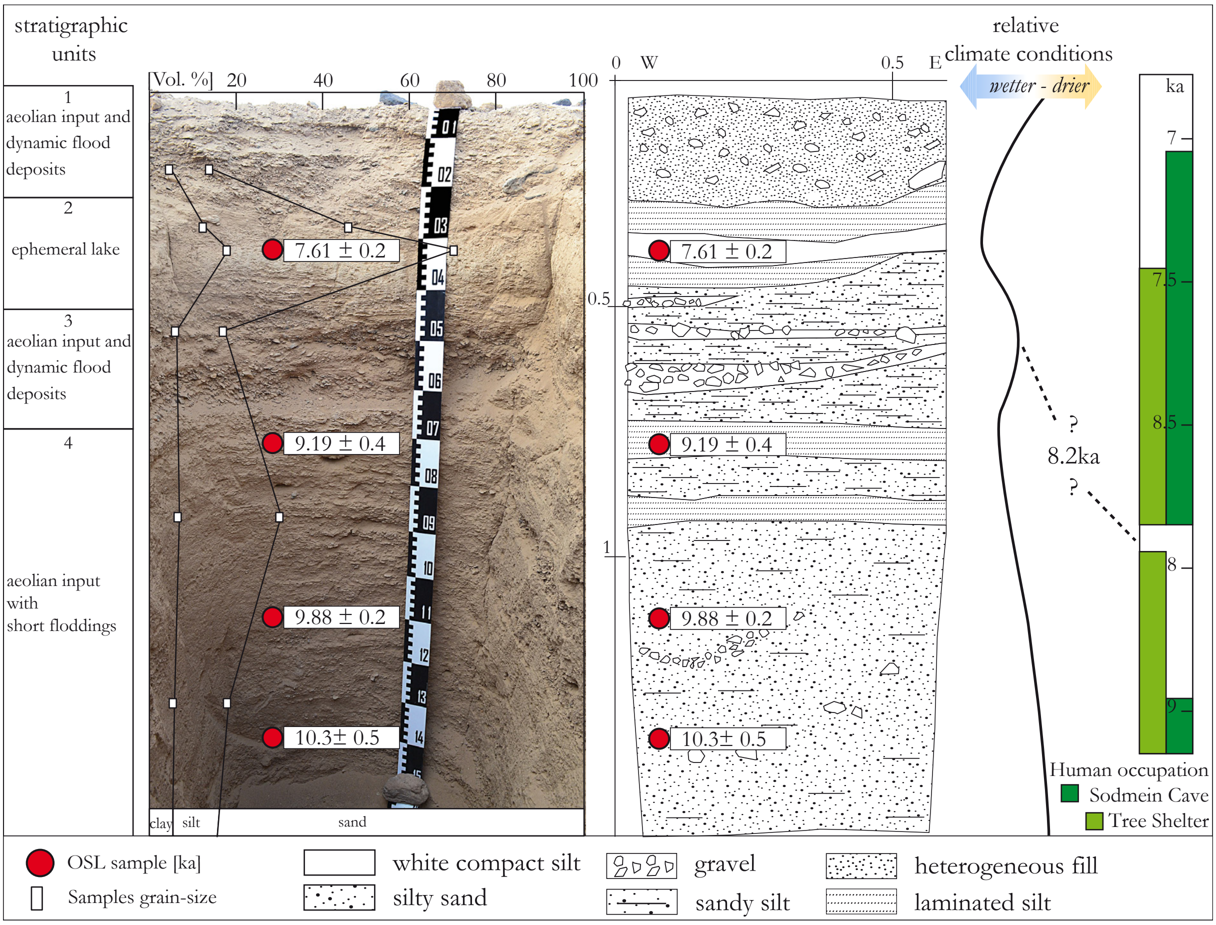


Figure 38: Chronology and environmental implications from Sodmein Playa. Sediment stratigraphy central Sodmein Playa, Profile 5 (picture Henselowsky 2017); Profile Sketch after Kinderman et al. 2018; Phases of human occupation at Sodmein Cave and Tree Shelter after Vermeersch et al. 2015.

After the first occurrence of laminated silts indicating possible times of standing water at the depression, more dynamic flood deposits exist in stratigraphic unit 3. Coarse-grained sandstone fragments from the surrounding hillslopes are washed into the depression, presumable during a very dynamic climate with short but intense rainfalls to deposit the coarse sediment. This can be associated with a drier climate in comparison to the sediment deposits below this unit. The chronology indicates that these deposits fall into the time, when the 8.2 ka phase/event took place. This is associated with a drier climate in Northeast Africa in comparison with wetter climate before and after this phase of aridity. No human occupation took place at Sodmein Cave during this time, as climate conditions were to dry and inhospitable for humans (Vermeersch et al. 2015). Afterwards, the strong increase in laminated silts and the white compacts silts in unit 2 possibly indicates a phase, where the depression received more precipitation and the existence of a small ephemeral lake/playa is given. This is dated to around 7.5ka and falls in the time of the Holocene wet period and is in phase with an abundant occupation at Sodmein Cave. More humid climatic conditions are also reported from the nearby Tree shelter by the determination of charcoal, which dates between 7.7 - 7.5 to 5.7 - 5.6 cal. yr. BP (Marinova et al. 2008). Together with dung deposits from domestic animals of the same time, Sodmein Cave and Tree shelter indicates that Gebel Duwi was visited by herders during these environmental conditions (Linseele et al. 2010). In addition, Moeyersons et al. (1999) have shown sedimentological and botanical studies from fan deposits at Gebel Duwi, indicating a wetter precipitation regime between 8 and 5k. Hamdan et al. (2015) found tufa growth in the Eastern Desert for the Holocene, in the timespan between 9 - 10 ka to 7.2 - 7.0ka. All archives show the beginning of the present day hyper aridity starting after 7 ka, where recent climatic conditions were established. The uppermost stratigraphic unit also indicates the overall arid climate conditions after 7 ka. Here, the coarse grained gravels, comparable to stratigraphic unit 3, indicating short term runoffs of water with high energy eroding the hillslopes from the surrounding Nubian sandstone, but no further accumulation of fine silts.

The stratigraphy from Sodmein Playa is a further argument for the existence of the terrace bar before the Holocene and thus, the height of the terrace is no parameter for comparisons with other heights of wadi terraces in the area (*cf.* Badawy 2008). If the terrace represents a Mid-Holocene surface, wadi deposits also filled the central depression at Sodmein Playa, as the depression is lower than the terrace bar in front. However, no wadi deposits are found in the stratigraphy of the depression to at least a depth of 2 m. As the dating for the stratigraphy reveals, it was deposited after 10 ka without any wadi deposits from the main stream, the terrace surface must pre-date the Holocene.

An important indicator for the presence of the wadi terrace before the filling of the depression exist at the exit of Sodmein Playa towards the main wadi. Here, terrace sediments are found at the foothill of the Nubian sandstone. They have a comparable composition like the terrace and can be distinguished from older wadi deposits in comparison to the recent wadi gravels. They also have no direct connection to the recent wadi and represent an isolated part. Some test diggings in between the isolated terrace material and the terrace reveal fine grained sediments, comparable to the central stratigraphy up to at least 40 cm near the terrace and up to at least 80 cm in the central part. Based on this observation, the following schema for the interplay between the wadi activity and formation of the depression at Sodmein Playa is proposed (figure 39).

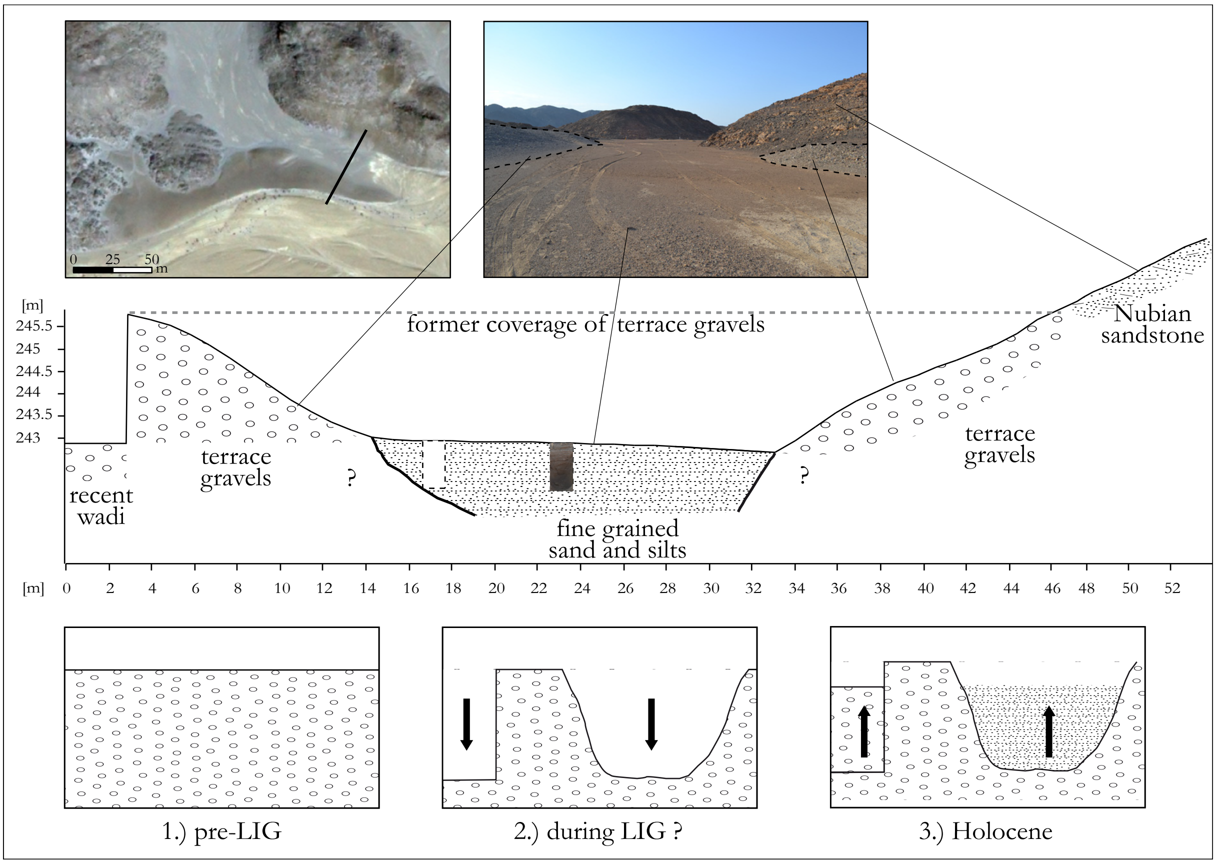


Figure 39: Site formation processes at Sodmein Playa as interplay between fluvial activity (erosion and accumulation) and sediment filling at the central depression. Cross-profile according to DGPS-measurements. Satellite image Quickbird bands 432, picture Henselowsky 2017

In a first step, the wadi accumulated fluvial deposits, which are today located at the height of the terrace, also occurred on the foothills of the Nubian sandstone. As the stone artefacts at Sodmein Playa are associated with the Early Nubian Complex and are comparable with findings from the oldest layer at Sodmein Cave dated to the LIG (Kindermann et al. 2018), this first accumulation of wadi material pre-dates the LIG. In contrast, the Holocene sediment fill at the depression indicates, that the erosional level of the playa and thus also of the wadi, must occurred at least 2 m below the current surface. Thus, a strong phase of erosion must have occurred somewhere in between the terrace accumulation and the filling of the basin. As the base of the stratigraphy is not reached so far, the actual depth is unknown. A working hypothesis would be a strong erosion of the basin and the wadi during the LIG, where a much wetter climate induced a strong activation of the drainage stream and possible leads to a strong erosion. This would also explain the so far not reached LIG sediments within the depression, as they also have been eroded. The basin would have been filled up with the fine grained silts and sands during the Holocene, where also the wadi creates rather accumulation instead of erosion up to today, based on the observation of the swimming blocks. The existence of the terrace bar in front of the basins causes the protection from erosion by the main wadi. Based on this assumption, the height of the terraces was higher before the Holocene.

Besides the local scale of evidences represented by Sodmein Playa, its main environmental implications are also comparable with sites form the Western Desert, where the Holocene occupation is much more documented in comparison to the Eastern Desert. Overall, four climate controlled phases of human occupation are documented, based on cumulative curves from radiocarbon dates from archaeological sites (after Kuper & Kröpelin 2006): (I) Reoccupation phase between 8500 to 7000 B.C.E, (II), Formation Phase (7000 to 5300 B.C.E.), which terminates very abrupt in regions without permanent water, (III) Regionalization phase (5300 to 3500 B.C.E.) characterised with highland refuges and temporary lakes, and (IV) Marginalization phase (3500 to 1500 B.C.E.), where human occupation of the Western Desert is limited to the most southern regions of Egypt and the northern Sudan. These periods, calculated in B.C.E. (before Common Era), are equivalent to before Christ (BC) or before present (BP) + 1950 years. Yet, the results of Sodmein Playa with the first impulse of wetter climate at Sodmein Playa (around 9 ka) correlates with the Reoccupation Phase, whereas the second phase at around 7.6 ka correlates with the Formation Phase in the Western Desert. Comparable Playa deposits at Djara (Western Desert) at similar geographical latitude show a fast sedimentation of alternated lacustrine and aeolian layers with a mean age of around 7.8 ka (Bubenzer & Hilgers 2003) and thus, represent the same time as the uppermost white compact silts at Sodmein Playa. Fluvio-lacustrine sediments from Abu Tartur (Bubenzer et al. 2007) are indicating a rapid sedimentation of silty playa sediments with sandy layers at around 9.4 ka. Here, the most homogeneous playa deposits are also associated with the second wetter climate impulse during the Holocene wet phase at around 6.23 ±0.43 ka. In between the two phases of playa deposits, wadi sediments were deposited between 9.20 ±0.46 to 7.16 ±0.28 ka (Bubenzer et al. 2007).

6.2 Environmental changes during the early Late Pleistocene in Northeast Africa

The reconstruction of wetter climate phases and associated environmental changes is the fundamental background for the time of possible AMH dispersal in and throughout the SAD during the early Late Pleistocene, as the nowadays hyper-arid climate conditions is the limiting factor for any hunter-gatherer occupation in the region. Thereby, the investigated climate archive from Saquia Cave adds important new information for the study area, but also for the overall context in Northeast Africa.

The presence and absence of speleothem deposits represent an on-off situation in arid environments, where deposition occurs during phases of enhanced water availability and vegetation growth ("on"), where it is absent under an arid climate ("off"), when no carbonates solutes within the host-rock. Investigations on speleothem growth phases are an important terrestrial archive and a powerful tool in the reconstruction of wetter climate phases in the SAD and adjacent regions (*cf.* Vaks et al. 2010, El-Shenawy et al. 2018). The 21 ages from the flowstone at Saquia Cave represent new time periods, where secondary carbonate deposition was active, caused by changing climate conditions and enhanced precipitation with associated vegetation growth. These changes occur during MIS 6 and mainly during MIS 5. However, the absence of evidences for speleothem growth after MIS 5 is no evidence of absence of a wetter climate in the Eastern Desert during MIS 4 and 3. Changes in the main growth axes of the speleothem or local changes in the catchment above Saquia Cave can led to the absence of deposits. It is also possible, that wetter climate during MIS 4 was not as pronounced as in MIS 5 and the specific threshold (minimum precipitation and vegetation needed for carbonate solution) for the deposition of secondary carbonates is not reached. So far, one published age of speleothem deposition in the SAD during MIS 4 is known from Sannur Cave (Egypt), dated back to 68 ±4ka (Osmond & Dabous 2004).

Speleothem growth in the southern Negev Desert (Israel) during the LIG at the northern edge of the SAD have been interpreted to reveal insights into possible climatic windows for an early migration of AMH Out of Africa (Vaks et al. 2007). Sites in the central Levant, e.g. at Pequin Cave, Soreq Cave, or the Jerusalem Caves, show continuous speleothem growth during the last 240ka and indicate, that annual precipitation did not fall under the estimated threshold of 250-300 mm/a (Bar Matthews et al. 2017). Thus, only the sites in the southern Levant, where today's annual precipitation is below this threshold, are used for the discussion of comparable on-off situation of speleothem growth in the SAD (figure 40).

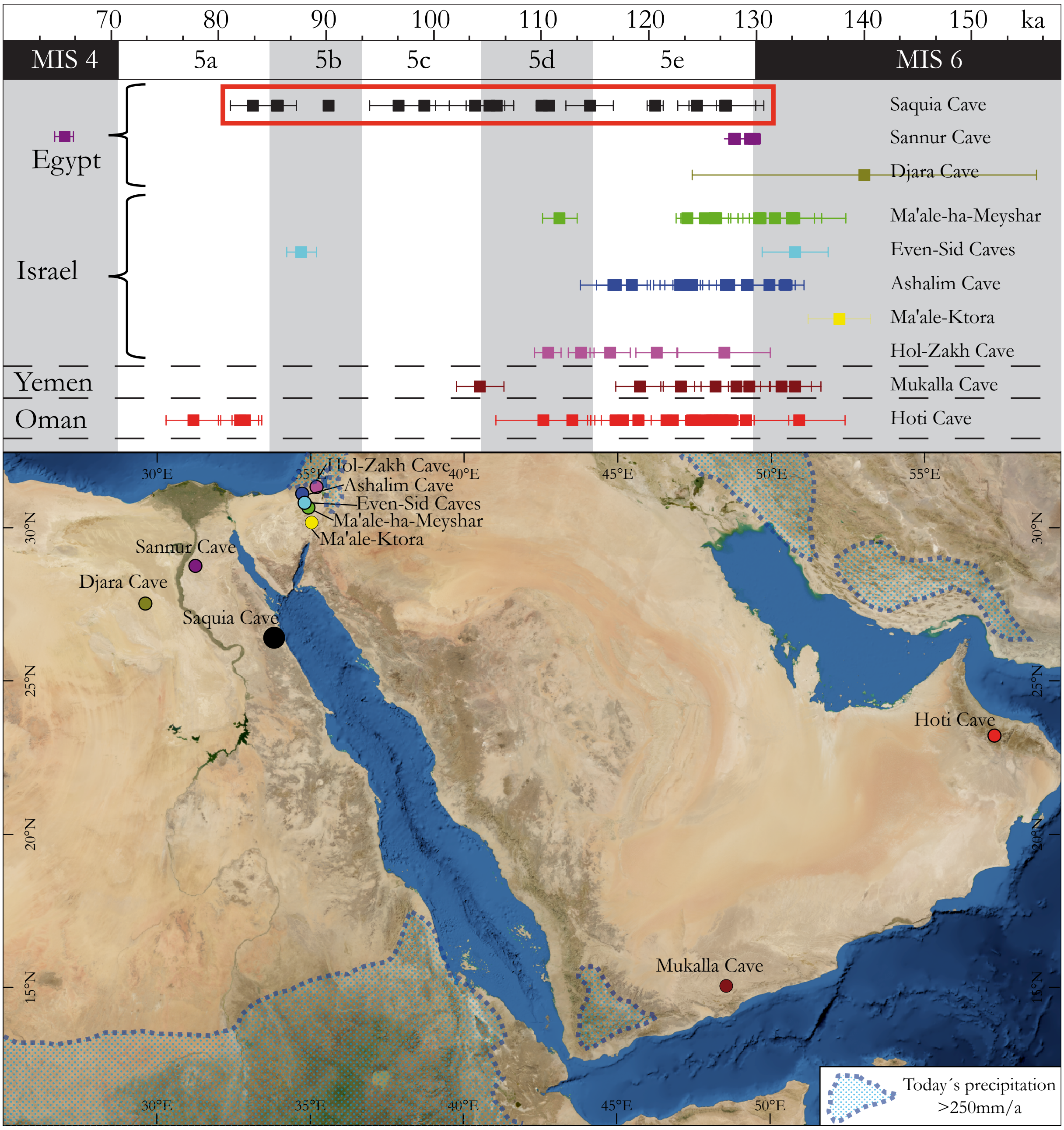


Figure 40: Late Pleistocene speleothem records in the SAD. Saquia Cave (this study); Sannur Cave (Osmond & Dabous 2004; El-Shanaway et al. 2018); Ma'ale-ha-Cave, Even-Sid Caves, Ashalim Cave, Ma'ale-Ktora, Hol-Zakh Cave (Burns et al. 1998, Burns et al. 2011; Vaks et al. 2010); Mukalla Cave, Hoti Cave (Fleitmann et al. 2003, 2011). Satellite base map MODIS- satellite image Stöckli et al. 2005. Today`s precipitation >250mm/a after Fick & Hijmans 2017, which represents the current limit of speleothem deposits.

At the southern limit of the SAD, two cave sites on the Arabian Peninsula at Hoti Cave (Oman) and Mukalla Cave (Yemen) are used to derive wetter climate during the Late Pleistocene in this region (Fleitmann et al. 2011). Growth periods in the southern Negev Desert cluster in MIS 5e with little occurrences during MIS 5d. So far, only one age is published indicating speleothem growth during MIS 5b from Even-Sid Caves (Vaks et al. 2010). The records from Mukalla and Hoti Cave show similar patterns with main deposition during MIS 5e/d and additional deposits during MIS 5a (Fleitmann et al. 2011). Thus, the main evidences of these climate proxy data link wetter climate phases during the LIG to MIS 5e (compare Vaks et al. 2007, 2010; Fleitmann et al. 2003, 2007, 2011; Bar-Matthews 2017). Sub-stages apart from MIS 5e are interpreted to be too dry for speleothem deposition, although the absence of evidences are here also no criterion for exclusion of wetter climate. Therefore, it is even more important for a better understanding of MIS 5 in total, that speleothem deposits at Saquia Cave cover all sub-stages from MIS 5e to 5a and extend the speleothem record in the SAD not only in time, but also in its spatial context due to location at 26°N in one of the core areas of the SAD. This is subsequent discussed with the overall situation of climate variabilities during the LIG in Northeast Africa and the results of the genetic and effective climate classification.

6.2.1 Forcing mechanism of enhanced precipitation during the LIG

The impact of two major atmospheric circulation systems are derived from the given climate data during the LIG and the calculation of the amount of summer and winter rainfall. Firstly, summer rainfall can be associated with the African monsoon and represents part of the tropical circulation system. Secondly, winter rainfall associated with extratropical mid-latitude circulations and Mediterranean cyclones occur during wintertime. However, the climate data of the CCSM3-model has some internal discrepancies. It is unexpected, that the maximum of precipitation at Marsa Matruh occurs in August, as the general seasonality shows a winter rainfall dominated climate. The exemplified high rainfalls modelled for August are one reason, why the Mediterranean coast is not calculated as winter rainfall zone with >66% of precipitation in winter months. This is not in agreement with the overall monthly rainfall distribution. In addition, the negative values for Sannur Cave and Marsa Matruh in July represent non-valid values. Two points are important for the interpretation of total precipitation in Egypt during the LIG based on the CCSM3-climate model.

Firstly, the initial spatial resolution of the CCSM3 model is about 1.4° (around 150 km at the equator) and it represents a global model rather than a regional model representing all regional characteristics of the climate. With the application of the downscaling method for the interpolation of high-resolution climate models, a better regional investigation of the global model can be applied, but also some challenges occur. Hijmans et al. (2005) stated, that especially in regions with a low density of modern weather stations and in mountainous regions, the downscaling algorithm captures not all regional varieties. Both is relevant for Egypt and it is obvious, that this has an influence on the downscaling of the global climate model to regional level. Although topography is part of the downscaling algorithm for the global climate model, the regional impact of mountainous areas with orographic rainfall cannot be modelled in detail (Hijmans et al. 2005). Following up the importance of the north-eastern parts of Egypt and the Red Sea corridor as transition zone of tropical-extratropical precipitation regimes, the impact of topography in this area on rainfall distribution must be stressed out. Even nowadays, the Red Sea Mountains and the Sinai mountains have an orographic effect on rainfall patterns. This is an important aspect, which explains the higher discrepancies between model-based precipitation estimates and proxy based precipitation estimates in the Eastern Desert in contrast to the Western Desert.

Secondly, Egypt's particular geographical position between the tropical and extratropical circulation patterns is of importance. Whereas nowadays, both climate circulations are bounded by the subtropical high-pressure zones, the two circulation patterns were more connected to each other during the LIG and it is highly presumable, that irregular rainfalls forced by tropical-extratropical exchanges existed more frequently due to the closer connection of these two circulation patterns. Extraordinary rainfalls in the transition zone of the two circulation systems are a common feature and occur, when both systems interact with another (De Vries et al. 2018). The integration of extraordinary rainfall patterns, e.g. tropical plums or activation of the Red Sea Troughs, on a decadal resolution into palaeo-climate models is challenging, and quantitative estimations cannot be made for the LIG (Kutzbach et al. 2014).

The increase in Mediterranean storm activity during autumn/winter is in phase with enhanced summer precipitation caused by the northward shift of the monsoon and show the importance of low- and mid-latitude hydrological changes, e.g. during the LIG (Toucanne et al. 2015). An increase in wadis draining into the Eastern Mediterranean sea can also not exclusively be explained by the strengthening of the African monsoon but rather support in fact a southward shift of the Mediterranean winter rainfalls (Zhao et al. 2012). It is therefore argued, that the southern-tropical climate system superimposed the regional climate patterns in areas of winter rainfall and need a strong consideration, when interpreting precipitation regime during the LIG (Torfstein & Enzel 2017). A temporal southward migration of low-latitude rainstorms in the Red Sea region and the southern Levant is also suggested from speleothems and travertine records in the southern Levant (Waldmann et al. 2010) or the Dead Sea region (Torfstein et al. 2015). Flooding peaks during MIS 5e recorded at Red Sea core KL23 (Northern Red Sea) show the local input of discharge from wadis of the Eastern Desert draining in to the Red Sea during enhanced precipitation (Palchan et al. 2018). The authors conclude, that this is forced by active Red Sea troughs or tropical plumes, as they emphasise that the sites under investigation (KL23 at 24°44´N) did not receive direct monsoonal precipitation (Palchan et al. 2018). However, all regional records for Egypt show, that the African monsoon reached as far as 30°N and wadis received at least 300-400 mm/a. Thus, enhance flooding can be related to either summer monsoon, Red Sea troughs, tropical plumes, or even Mediterranean storms bringing precipitation to the Northern Red Sea. Kutzbach et al. (2014) simulate increased Mediterranean storm-track activity at precession timescales during times of maximum orbitally forced seasonality of insolation, exemplified with the precession high at around 125 ka. A southward shift of the Hadley cell is forcing the southward migration of the westerlies with enhanced winter rainfall zone. One maximum of orbitally-forced insolation seasonality exist during the LIG at around 125 ka and can be used as a trigger for increased winter rainfalls due to strong westerlies in Northeast Africa and the Middle East. The known wetter climate periods at precession time scales in this area need therefore a strong consideration of seasonal ambiguity in precipitation (Kutzbach et al. 2014). In addition, enhanced convective precipitation caused by stronger air-sea temperature differences are hypothesised for enhance precipitation in the Mediterranean during times, when total seasonal changes of insolation forced by precession changes are particular high (Bosmans et al. 2015).

Comparable to the situation of a precession high at around 125 ka, the beginning of the Holocene wet phase is also characterised with a high precession (figure 41). However, the amplitude during the Holocene is lower in comparison to the situation at around 125ka and the precession highs at around 105 ka and 83 ka are higher than during the Holocene. It is therefore very assumable, that the impact of the close synoptic interaction of tropical and extra-tropical systems and the resulting increase in precipitation is not only limited to MIS 5, but also during MIS 5c and 5a and the transition from MIS 4 to 3.

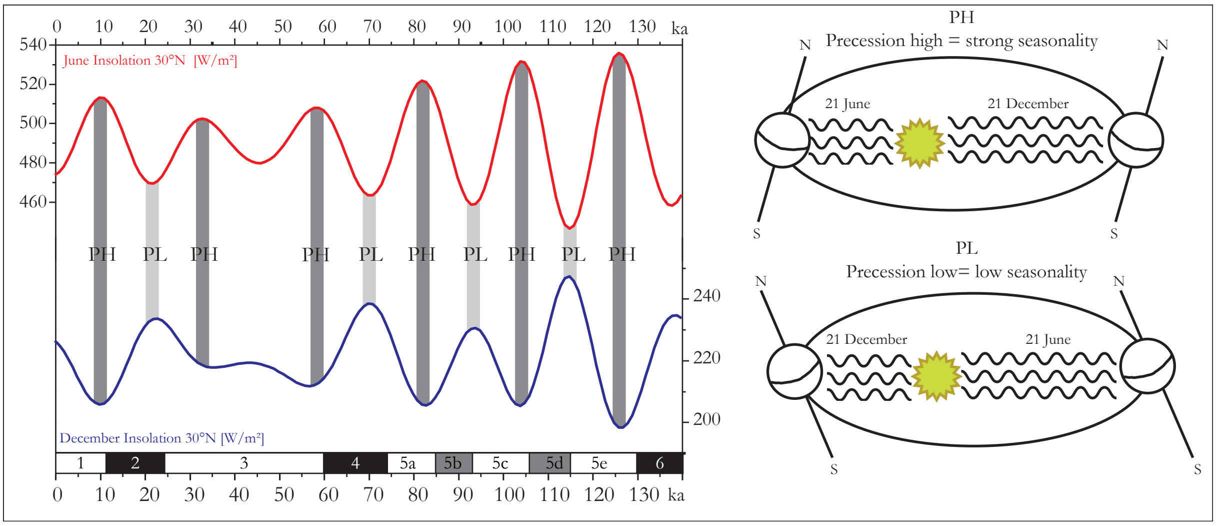


Figure 41: Insolation variabilities with precession high and lows during the Late Pleistocene and Holocene at 30°N (after Berger & Loutre 1991).

The explicit portion of each source region for precipitation during the LIG is still mostly unknown and seasonal variabilities throughout the year cannot be studied. This is due to the lack of high-resolution terrestrial archives in Northeast Africa to study the distinct forcing mechanism of tropical-extratropical atmospheric interactions during the LIG, e.g. based in the study of oxygen isotope compositions. Comparisons with the Mid-Holocene wet phase of the Sahara, where data availability is much higher in contrast to the LIG, more detailed analyses of possible atmospheric patterns in the Sahara exist. Although some differences exist in the wet phases of the LIG and Mid-Holocene, the basic mechanism of enhanced precipitation is comparable.

Results for the Mid-Holocene wet period show, that fall season tropical plumes have an impact of up to 30% of total rainfall, contributing a significant part of the total annual precipitation in the Sahara during this time (Skinner & Poulsen 2015). Holocene archaeo-botanical remains at Djara, Western Desert, indicate the possibility of a mixture from tropical and extratropical rainfall patterns in one specific region in Egypt and had an impact of vegetation distribution. The Jericho Rose (*Anastatica hierochuntica*) as indicator for Mediterranean vegetation type, associated with winter rainfall, is likewise found as Capparaceae-species (*Capparis decidua and Maerua crassifolia*), representing a summer rainfall moisture sources at Djara during the Holocene (Kindermann et al. 2006). As this situation is, apart from other influences, strongly driven by astronomic forcing resulting in the precession high, a strong interaction of winter and summer rainfall is also supposed for MIS 5e, c and a. Although, there exist no climate modelling data for these periods, apart from the study of Kutzbach et al. (2014).

In total, five different precipitation sources sum up the possibility for increasing annual rainfall during the LIG in Egypt (figure 42): The African monsoon during summer months, tropical plums mostly in autumn and winter, the activation of the Red Sea Through in spring and autumn, the Mediterranean storm track and cyclones (westerlies), and strong convectional rainfall during winter months.

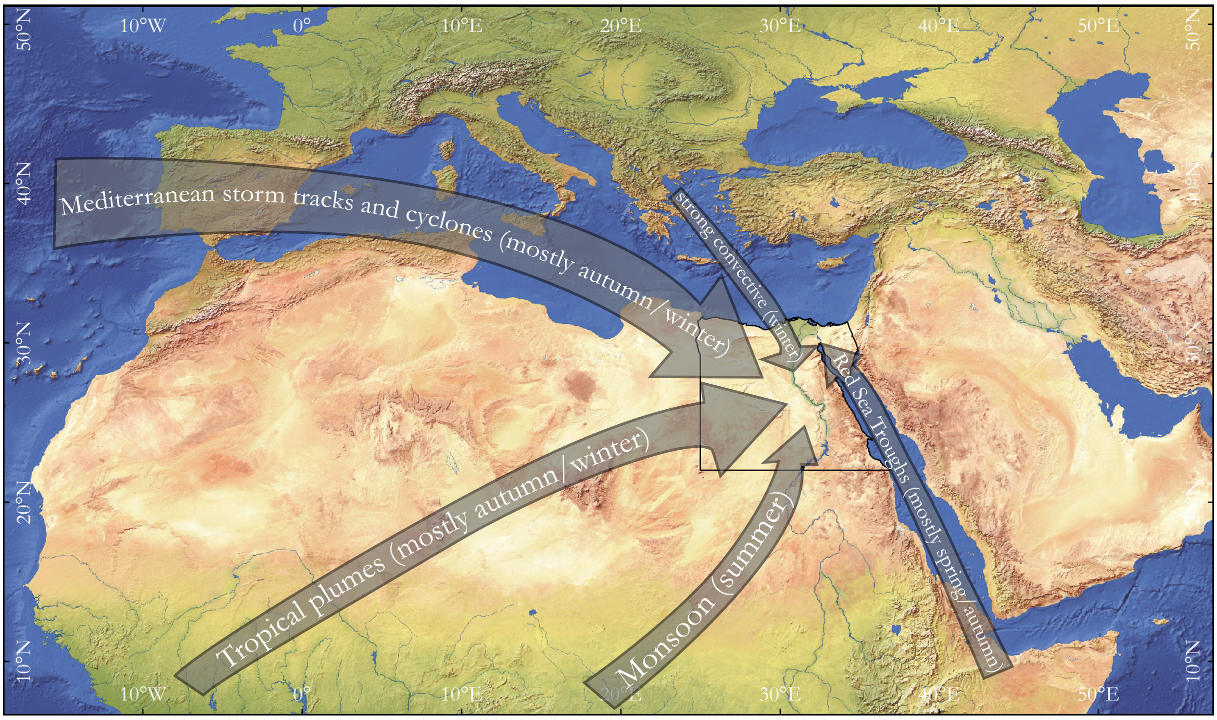


Figure 42: Possible sources of precipitation in Egypt during the LIG. Background image NaturalEarth.

6.2.2 Effective climate and associated ecozones in Egypt during the LIG

The effective climate classification after Köppen and Geiger helps to link climate to biomes and vegetation next to the total amount of precipitation and the general synoptic atmospheric situation during the LIG. This is often even more important under a geoarchaeological perspective and investigations about past human behaviour in (semi-)arid environments than the genetic climate, although both processes need to be considered equivalent.

The attributed ecozones with Sahelian Acacia savannah, Saharan steppe and woodlands, Mediterranean woodlands, and topographic influenced mountainous savannah show for the first time regional characterisation of ecozones in Egypt during the LIG apart from single proxy studies at smaller scale. The semi-quantitatively is the only approach to derive regional variabilities in ecozones. Environmental changes with expansion of Acacia savannah, grassland and scrubland during the LIG in Egypt are in accordance with large-scale vegetation shifts for Northern Africa on a continental scale with the increase of savannah types during the LIG and a woody cover of 10 - 40% in most areas of North Africa (Larrasoana et al. 2013). However, quantitative global models for the reconstruction of biomes are insufficient to give details at regional scale and the scale of ecozones cannot be modelled. Hoogakker et al. (2016), for example, modelled terrestrial biosphere changes over the last 120 ka, but Northeast Africa remains a desert biome over all time steps, which is in disagreement with proxy records and the provided results. It represents a scale issue, when integrating the results for Egypt into the global context and vice versa. It exemplifies the difficulties for the given scale, where large scale global modelling, e.g. the CCSM3 climate model, cannot be equated to regional climate variabilities and need to be downscaled to regional implications. This downscaling often lacks quantitative data and the qualitative integration of proxy data or comparisons with modern analogues is so far the only approach to gain insights at the regional scale. On the other hand, local information derived from archaeological and geoscientific archives need to be up-scaled to their regional implications.

Boivin et al. (2013) included topographic correlations in their distribution of vegetation zones and include qualitative regional extensive knowledge to create different vegetation zones for western Eurasia during MIS 5. In their study, the Eastern Desert represents a sub-desert and Sahel vegetation in contrast to the Western Desert with desert vegetation and minimal edible plant and animal resources. Where one can agree with about the general existence of an east-west gradient, the results of the Köppen-Geiger classification do not show longitudinal changes, as the underlying climate model for the computation of the Köppen-Geiger climate is insufficient to indicate precipitation changes between the Western Desert and the Eastern Desert. However, the results show, that the Western Desert is not characterised as desert vegetation with an absence of natural resources for humans. It indicates, that the environment proposed by Boivin et al. 2013 do not represent the actual situation. Most important archaeofaunal and archaeobotanical remains dating back to the LIG are found in the Western Desert at Bir Tarfawi and in the Eastern Desert at Sodmein Cave. The lowermost layer J of the archaeological excavation at Sodmein Cave shows faunal and flora associations with indications of permanent water bodies in the area, dating back to MIS 5e (Mercier et al. 1999, Moeyersons et al. 2002). Recently, Schmidt et al. (2015) confirmed these layers to be dating back to MIS 5, and strongly correlating with the shown general wetter periods in Northeast Africa during the LIG. Botanical remains of (e.g. *Acacia tortilis, Ficus, Sp., Clematis Sp., Balanites cfr. Aegyptiaca, Paliurus cfr. Gramineae*) and the occurrence of intact leaf remnants presenting foliage, show a fundamental change in the vegetation of the area in comparison to today. Faunal remains of a large bovid, kudu, and an elephantid represent a savannah associated fauna in this area. In addition, remains of crocodile and catfish, as well as gastropods (*Melaniodes tuberculate*) attest the existence of water pools, small (temporal) lakes and swamps in the surrounding of the cave (Moeyersons et al. 2002). The three Grey Lake phases of Bir Tarfawi and Bir Sahara in the Western Desert also contained fossil bone material of animals indicating more humid conditions (Kowalski et al. 1989). Besides, various rodents, different gazelles, bovidaes, also some reptiles such as lizards, snakes, crocodiles, land- and water turtles could be found, as well as some frogs, birds, and fish (Kowalski et al. 1989, Gautier 1993). Overall, it indicates the tremendous environmental change between today's situation and environments during the LIG.

In addition, palaeolakes at Kharga and Dakhla Oasis were not only fed by surface runoff, but also by increased groundwater discharge and associated springs during the LIG (Smith et al. 2004, 2007, Kleindienst et al. 2008, Kieniwicz & Smith 2009). This led to the possibility that these lakes could also exist in times of drier climate conditions and therefore served as a regional refugee. The riparian regions of drainage streams and lakes are an important local ecological niche. Here, surface water and groundwater are more available, and gallery forests and riparian lake vegetation are a prominent feature in savannah landscapes. Whereas savannah tree species occur dominantly in mosaics, with different density depending on total precipitation, intermitted gallery forests represents a dense tree cover with different tree species. Nowadays example show a gallery forest – savannah gradient along river streams with a threshold of 120 m beyond the edges of the river stream (Azihou et al. 2013). Thus, this type of environment cannot be mapped at the scale of Egypt, but need to be considered as an important ecological niche and corridor for flora and fauna. The archaeobotanical and archaeofaunal remains from Bir Tarfawi document species, which point to large gallery forests at the Tushka watershed system during the LIG (Wendorf et al. 1993).

The direct bounding of the tropical and extra-tropical atmospheric system at the transition among summer rainfall induced savannah ecozone and winter rainfall induced North Saharan steppe ecozone is in addition a remarkable effect, which dissolves an arid barrier in Egypt. This is not comparable with the recent position of the Savannah zone and the Mediterranean coast, which are only dominated by one moisture source and separated by the hyper-arid conditions of the sub-tropical high pressure zone. The two systems interact during the Mid-Holocene wet periods in the Sahara, but total annual precipitation and the position of the tropical and extra-tropical systems was even more pronounced during the interstadials of MIS 5e, c and a (compare chapter 6.2.1).

In summary, the reconstruction of different ecozones in Egypt during the LIG consists of a mosaic of large scale computation of effective climate classification and local findings of proxy data, which needs to be integrated for the scale of Egypt. Regional variability in ecozones exist between the Western Desert, the Eastern Desert and the Mediterranean coastal regions. No hyper-arid climate exist in Egypt during the LIG and ecozones do not show a desert environment, but a combination of steppe and savannah ecozone.

6.3 Morphometric and hydrological features in Egypt

The nowadays topography of the meso- and macrorelief in Egypt represents the relief during the LIG at the given over-regional observation scale. No fundamental vertical relief changes occur in the scale of decametres and the most dynamic landscapes with a changing topography are active dune fields/sand seas, which are excluded in the interpretation, but also do not represent the scale of the macrorelief. Tectonic displacement during the last 130ka has no significant impact on this scale. The impact of the global sea level high stand during MIS 5e does not change the overall landmass of Egypt in general and is negligible at the scale of Egypt, as only minor areas of a few kilometres exist at the coastal areas of the Mediterranean and Red Sea affected by a maximum sea level rise of +6 m. Spatial variations and local to regional changes affected by tectonic and hydro-isostatic effects overwhelm thereby the effective occurrence of the palaeocoastline in the Red Sea area and there exists no evidence that sea level high stand occurs spatial and temporal equal in the Red Sea (Lambeck et al. 2011). In fact, this shows that an assumed palaeocoastline at +6 m represents a maximum of submerged landmass during the LIG and regional variations cannot be drawn at this scale. Due to thick sediment deposited during the Holocene, the Pleistocene basis of the Nile delta is submerged up to 13 m below present surface (Pennington et al. 2017) and the coastal line for the Nile Delta during the LIG is unknown.

The characterisation of the meso- and macrorelief of Egypt is achieved by the classification of distinct relief types. The relief and landforms serve as boundary conditions for specific processes in the environment, e.g. for hydrology and ecology, but also for human behaviour. Bailey & King 2011 show distinct advantages of complex topography for human behaviour and use terrain roughness as an index for the heterogeneity of a landscape. Active tectonics and a high variability of landscapes can create different ecological niches or physical barriers and corridors, and have positive and negative factors on human behaviour, settlement, and dispersal (Bailey & King 2011). These factors are discussed as one of the main drivers in evolution of the species *homo*, e.g. “complex-topography-theory” (Winder et al. 2015) and early human fossils over longer geological time scales. Bailey & King (2011) see areas with a rough topography as an advantage for unspecialised hominin population, as there exist a high variability in ecological niches over short distances and sustained surface water supply related to topography in comparison to flatter landscapes, where water table changes due to climate changes are more effective. It also increases the possibility of geological outcrops for raw-material procurement, as complex topography and mountainous areas have in general a more multifaceted geology in comparison to flat plains. This is not only important for the evolution of the genus *Homo*, but also for late Pleistocene hunter-gatherer and serve as an important parameter for the study of human-environment interactions.

The heterogonous relief types in the Eastern Desert create varies facilities to encounter special geologic-topographic areas. Based on the idea that monotone and less topographic pronounced landscapes are more vulnerable to climate fluctuations in comparison to complex topography and rough landscapes, the Eastern Desert of Egypt at the scale of the macrorelief has in general a more attractive topography for humans in comparison to the Western Desert. Due to the enhanced precipitation of orographic rainfall, strong influence of Red Sea Trough in addition to the monsoonal and Mediterranean rainfall, all rivers in the Eastern Desert might have been very active during the LIG.

The morphometric mapping of palaeo-drainage system is so far the only approach for the identification of palaeo-river systems at large scale. Additional information based on the geological maps and the mapping of quaternary wadi and playa deposits serve as independent source for the reconstruction of the palaeohydrology at large scale.

The most important drainage system in the Western Desert, which was active during the LIG, is the Tushka watershed located at the Selima Sandsheet. It has been studied in detail by the use of SRTM-datasets and comparison of different palaeolake level indicating former surface hydrology. The use of radar images to detect submerged topography and valley with infilled quaternary sands have also shown large palaeoriver structures (Ghoneim & El-Baz 2007), and ground check geophysical prospection detect palaeostreams which represent a high fluvial activity of the nowadays relative flat topography of the Selima Sandsheet (Robinson et al. 2017). This region received strong summer rainfalls during the LIG and surface water availability in river streams during and after the monsoon season is abundance with large lakes and wetlands (Hill & Schild 2017). In addition, it is discussed how changes of the Nile discharge and overflow at wadi Tushka could have served as additional water source and lead to a connection of the Nile with the Tushka Watershed System (Maxwell et al. 2010). Findings of the Nile perch at Bir Tarfawi dating back to the LIG suggest at least a semi-continuous connection of the Nile with the palaeolakes (Van Neer 1993). Hill & Schild 2017 characterise the deposits at Bir Sahara as wetlands, ponds, small lakes, etc. during MIS5. Except of direct dating of lake, playa, and tufa deposits associated with springs, so far no published ages from large fluvial deposits exist for the Late Pleistocene. However, the integration of dated lake and wetland deposits associated at these river streams gives insights about the activity of these fluvial systems. The comparable large threshold for the identification of a drainage stream with a minimum catchment of 500 km² accounts for this uncertainty. It represent rather major rivers as possible corridors instead of exclusive areas for access to water during the LIG. Local to regional water sources cannot be reconstructed in detail at the given observation scale of Egypt in total. Therefore, the actual amount of active rivers during the LIG and their importance for humans is even higher, as past human behaviour, mobility, and migration in relation to different water sources in arid environments is not only limited to larger river systems. It is rather the general activation of drainage systems, no matter at which scale, which allows human groups to occupy distinct regions and environments (Mandel & Simmons 2001: 102): „All geomorphic settings in which water could be obtained were occupied by Middle Palaeolithic groups. These include wadi courses, internally drained basins, playas, and spring-fed pools". The mapped playa deposits based on the geological maps represent also a minimum size of possible palaeolakes during the LIG. Most former playas are nowadays cultivated and in areas, where remnants exist. They are complex to detect by remote sensing techniques, as their reflectance is comparable to the surrounding (Embabi 2018).

Drainage systems in the Eastern Desert are not associated with large lake deposits, as they are smaller and have distinct flow directions either into the Red Sea or the Nile valley. The absence of former large lakes is also contributed to the absence of endorheic basins, where the large lakes in the Western Desert were located. Episodic lakes or ponds in interdune corridors of the southern Great Sand Sea existed during the Mid-Holocene wet phase of the Sahara (Bubenzer & Bolten 2008) and it is highly assumable, that during the wetter climate of the

LIG in comparison to the Mid-Holocene, such lakes exist in today's area of the Great Sand Sea and adjacent regions. Palaeolake deposits found elsewhere in the Sahara at Fazzan Basin, Libya (Armitage et al. 2007, Breeze et al. 2018) or in the central Nefud Desert of Saudi Arabia (Petraglia et al. 2011, Breeze et al. 2015) indicate the general importance of today´s dune regions for such lakes. These palaeolakes are often mapped with remote sensing techniques, as differences in the surface reflectance of palaeolakes and surrounding landscape is given (Breeze et al. 2015). A number of surfaces reflecting previous possible lacustrine interdune environments are found in the northern part of the Great Sand Sea south of Siwa Oases, but up to now no equivalent deposits have been found and dated in the Great Sand Sea of Egypt. The so far oldest published age for palaeolake deposits in the Great Sand Sea date back to MIS 3 (Pachur et al. 1987 in Besler 2008). The majority of interdune lakes at the Arabian Peninsula are found in transverse dunes and complex dune morphology (Breeze et al. 2015) and also modern interdune lakes are also more commonly found in between complex dune systems, e.g. in the Badain Jaran Desert (Wang et al. 2016). In contrast, most of the Great Sand Sea persists of large longitudinal dunes with large interdune corridors, and transvers dunes with distinct morphological closed depression might be more suitable for larger lake formation and associated sediment deposit. These sediments deposits could also have a longer persistent through time with less erosion, where large interdune corridors are absent. Therefore, absence and presence of interdune lakes is not related to precipitation regime but might be also influenced by different dune types.

Even with considering the Great Sand Sea as dune free area, where river systems could follow the underline topography (Bubenzer & Bolten 2008), no large scale river systems exist in Egypt at the scale of the Sahabi and Kufra River System in Libya (Ghoneim et al. 2012, Coulthardt et al. 2013), or mega watercourses in the central Sahara, which are often seen as corridors for human migration throughout the Sahara (Drake et al. 2011). Comparable large river systems (>10,000 km² catchment) in the Egyptian part of the Eastern Sahara are therefore limited to the Tushka Watershed system.

The mapped sites based on the extensive literature with directly dated proxy records of palaeo-hydrological features associated to MIS 5e are an independent source of information for palaeo-hydrological changes. The large palaeolakes at Bir Tarfawi/Bir Sahara are dated to different phases of the LIG, where the most pronounced lake phase was during MIS 5e (Wendorf et al. 1993, Nicoll 2018). Several proxies in the oases of Egypt show, that with the intermixture of higher rainfalls and rising groundwater tables with activation of spring mounds, palaeolakes existed at several times during the Pleistocene (Blackwell et al. 2017). They are geological related to the large Kharga-Dakhla depressions in the central Western Desert. For the time period of the LIG, direct dated evidences exist at Dakhla (Kleindienst et al. 2008), Kharga Oasis (Smith et al. 2004, Smith et al. 2007, Kleindienst et al. 2008, Blackwell et al. 2017), and Kurkur Oasis (Crombie et al. 1997). Even though, direct influx of large river systems and surface water discharge is limited, rising groundwater table and outflow is an important source (Kieniewicz & Smith 2009). All playa deposits mapped on the geological maps represent the minimum size of the playa, as a strong erosion of these deposits occurred after the LIG and the deposits represent only small remnants of former large lakes/playas. Hundreds of small playa remnants are found in the depressions at Kharga and Dakhla, indicating several stages and phases of playa and lake genesis in this area, but are insufficient chronological dated. Enhanced groundwater mobility and re-activation of water mobility associated with wetter climate during the LIG was Th/U-dated in ore deposits to MIS 5e (Osmond et al. 1999; Dabous 2003). In addition, the findings at Sodmein Cave represent an environment, where active rivers must have occurred during the LIG (Moeyersons et al. 2002).

6.4 Archaeological sites in context of their raw material sources

Although the used geological maps represent the most consistent dataset, where an area wide comparison over Egypt is based on the lowest common denominator, spatial resolution of geological maps, and mapped details of geological formations, it is not exclusive. Hawkins & Kleindienst (2002) have shown, that the Tarawan chert is widely used in Dakhla Oasis during the MSA. However, no flint and chert deposits are mapped within the Tarawan formation at the given geological maps. This shows that regional to local case studies, here at Dakhla oases, are not represented at the over-regional scale of this dataset.

The Abydos Survey for Palaeolithic sites project is one of the rare studies, which systematically surveyed raw-material utilisation in the Middle Palaeolithic. Olszewski et al. (2010) investigate the artefact density and distribution at the eastern part of the Libyan limestone plateau and recorded technologies of the Nubian Complex and a circulating settlement system of AMH in the given study area. Raw material sources are described to occur as distinct flint nodules, where a lot of cobbles were knapped locally, not all of Middle Palaeolithic technology, but site density of artefacts which belong to the Nubian Complex is exceptional high (Olszewski et al. 2010). A comparison with the extent of the survey (Olszewski et al. 2010, figure 3) to the mapped geological formations containing flint show, that they overlay with limestone of the Thebes group, including the Drunka formation which contains local flint bands and the Thebes formation, which includes rich flint bands.

There is no senso stricto correlation of primary geological sources of flint and chert and usage by humans. The use of reworked flint in secondary geologic context, such as wadi terraces, seems to have an importance during the MSA (Vermeersch et al. 1990). Artefacts are often found in direct context to wadi terraces containing flint pebbles, e.g. in the Eastern Desert (Dittmann 1990, Kindermann et al. 2018), in the Nile Valley (Van Peer et al. 2010), as well as in the Western Desert (Hawkins & Kleindienst 2002). Additional Middle Palaeolithic sites for the study of the correlation of river streams draining flint and chert bearing geological strata are rare and often rely only on surface collections of artefacts. One example is found at Wadi Deir, in the northern Eastern Desert (Dittmann 1990). This wadi drains into flint bearing strata of the Mokattam group and Sudr formation. Middle Palaeolithic artefacts made of flint found at Wadi el-Sheik (Köhler et al. 2017), northern Eastern Desert, can be correlated with the occurrence of the Mokattam group, which is drained by Wadi el-Sheik. Palaeolithic research at the Sinai Peninsula is only limited available. Only few sites are reported, often without stratigraphic context and dating. Gilead (1984) reports on few Middle Palaeolithic sites on the northern Sinai Peninsula close to the recent coastline. Artefacts made with Levallois technology (Site A306) were made on small wadi pebbles consisting of flint (Gilead 1984). The site is located nearby the large Wadi Arish, which catchment drains large areas of the Sinai Peninsula, including major areas with flint bearing geological formations.

In contrast to the Western Desert, large amounts of quaternary wadi deposits are found in the Eastern Desert and the Sinai Peninsula, particular in the catchment of Wadi Qena and Wadi el-Arish. This allows a higher potential for the use of such deposits for raw-material procurement and serve as secondary geological source of flint and chert, when wadis draining flint and chert bearing geological strata. This is also reflected in the spatial analysis of distances to larger drainage streams and areas with possible raw-material sources, which occur mainly in the northern Eastern Desert and the Sinai Peninsula and only minor regions in the eastern Western Desert. These results highlight the integration of abiotic parameters (here geology) for the reconstruction of attractive landscapes. Therefore, a strait forward perspective for the presence of large river streams as possible migration corridors in North Africa (e.g. Osborne et al. 2008, Drake et al. 2011, Coulthard et al. 2013) represent only one environmental parameters, which is insufficient to display attractive landscapes for human dispersal and has a very limited meaningfulness when integrating socio-environmental interactions.

In summary, the mapping of flint and chert bearing strata based on the geological maps with a scale of 1:500,000 provides a first order overview, where possible raw-material sources exist in Egypt. This is not exclusive, as smaller regional outcrops beyond the scale of the given maps could also be used for raw-material procurement and each mapped formations varies in the total amount and qualities of flint and chert sources. Regional variabilities exist for the chance to encounter these geological formations over Egypt, and the Eastern Desert has larger areas covered with these formations in comparison to the Western Desert. The Sinai Peninsula also has large areas covered by limestone including flint and chert. The observation for the use of flint and chert from secondary geological context, e.g. in alluvial deposits, is linked with the combination of large drainage streams. The gained results from the survey at Wadi Qena added information about the positive attractiveness of the calculated areas in dependency of raw material and drainage streams. Based on this mapping, an important abiotic environmental parameter is achieved, which is often neglected in PalaeoGIS investigations and helps for a better identification of attractive areas for hunter-gatherers in Egypt.

7. New implications for AMH dispersal

In order to generate a better understanding for the main aims of this thesis about early Late Pleistocene environments in Northeast Africa, this chapter provides the discussion about possible new implications for AMH dispersal.

The presented data and discussion about climatic changes, associated ecological changes, topographic and geological mapping of Egypt serve as background for the synthesis of the PalaeoMap (figure 43).

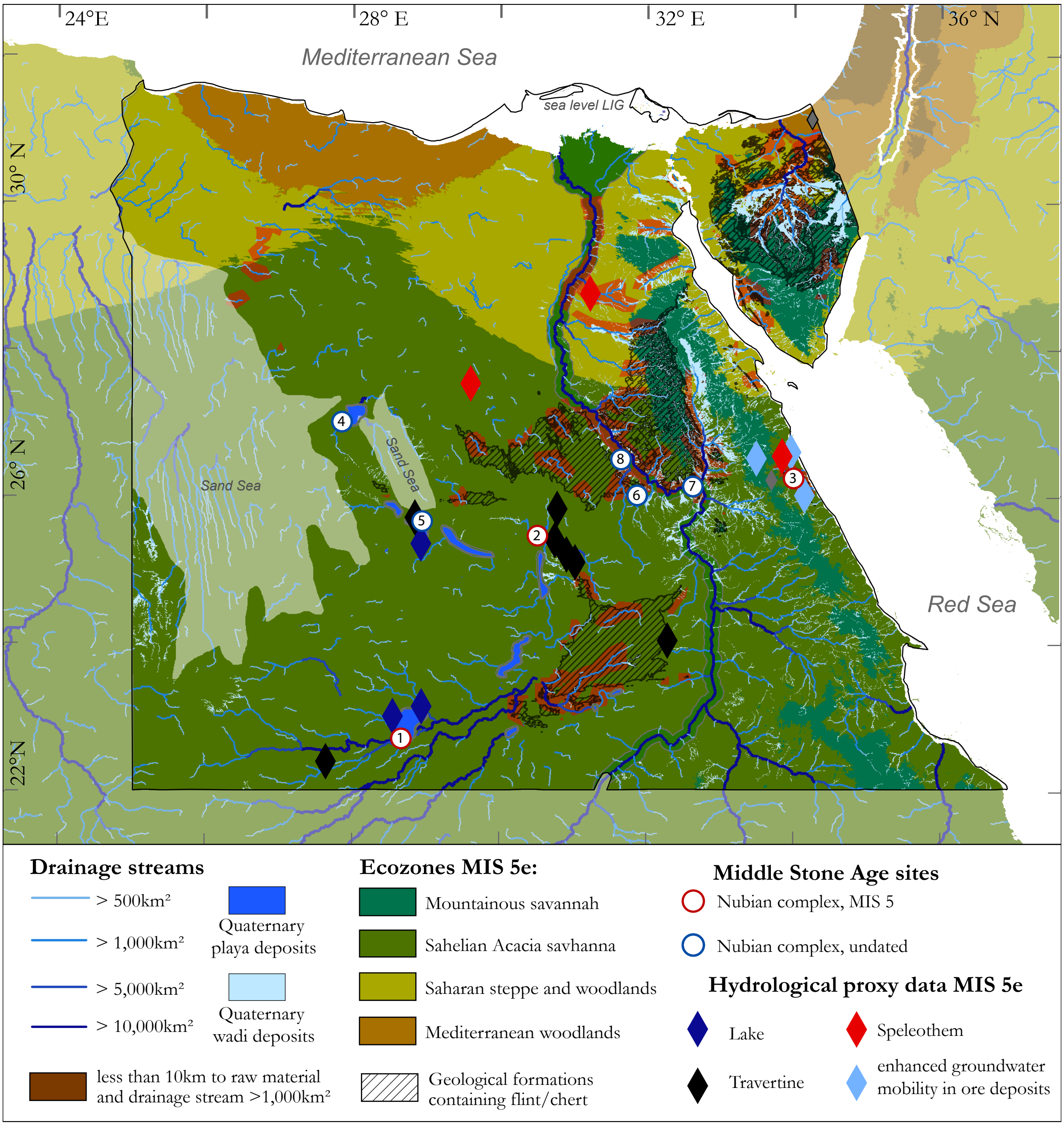


Figure 43: Synthesis of the PalaeoMap of Egypt during the LIG based on the presented GIS-dataset and discussed proxy data. Archaeological sites after table 2. Analysis and Cartography Henselowsky

The parameters of the map can be attributed to chronological independent layer, e.g. the location of raw-material areas and topography at the scale of the meso- and macrorelief, but also time-dependent layers, e.g. climate, ecozones, and sea level, which is represented for the distinct situation during MIS 5e. It summarises all discussed parameters and indicates the regional variabilities throughout Egypt, which serves as background for a more sophisticated characterisation for human behaviour and human-environment interactions. As already discussed, there is no monocausal interrelation between environmental parameters as push or pull factors for human presence and absence. The map indicates the variety of opportunities in different landscapes of Egypt during MIS 5e and break-up the Nile corridor hypothesis as most important pathway on the northern migration route. This corresponds to the presence of archaeological sites dating back to the LIG in different types of landscapes in Egypt. In the Western Desert, they are mostly related to the presence of the large palaeolakes e.g. at Bir Tarfawi, Kharga and Dakhla Oasis. The sites in the Nile Valley and adjacent regions e.g. at Abydos correlated well with the presence of large geological formations with the chance to encounter appropriate raw-material. Sodmein Cave in the Eastern Desert is the so far only long-term living site during the Late Pleistocene.

Nevertheless, there exist also regions, where the summary of all environmental parameters indicate a low attractiveness for humans due to the absence of larger drainage streams or raw material access. These regions occur in the north-western part of Egypt, where also precipitation and ecozones are not as favourable as in other regions. The large extent of the present-day Great Sand Sea is still an area, where no implicit predictions for the landscape during the LIG can be made. The Great Sand Sea passed through very dynamic processes, which overprinted the early Late Pleistocene landscape. The reconstruction of the landscape development based on morphometric quantification of the existing megadunes given by Bubenzer & Bolten (2008) demonstrate the high impact of post-LIG landscape changes, which leads to the nowadays absence of evidences for the LIG in this region. This is in contrast to other landscapes in Egypt, where the presence of early Late Pleistocene landforms and stable surfaces are present up to day, e.g. the archaeological surfaces sites in the Eastern Desert or at Abydos.

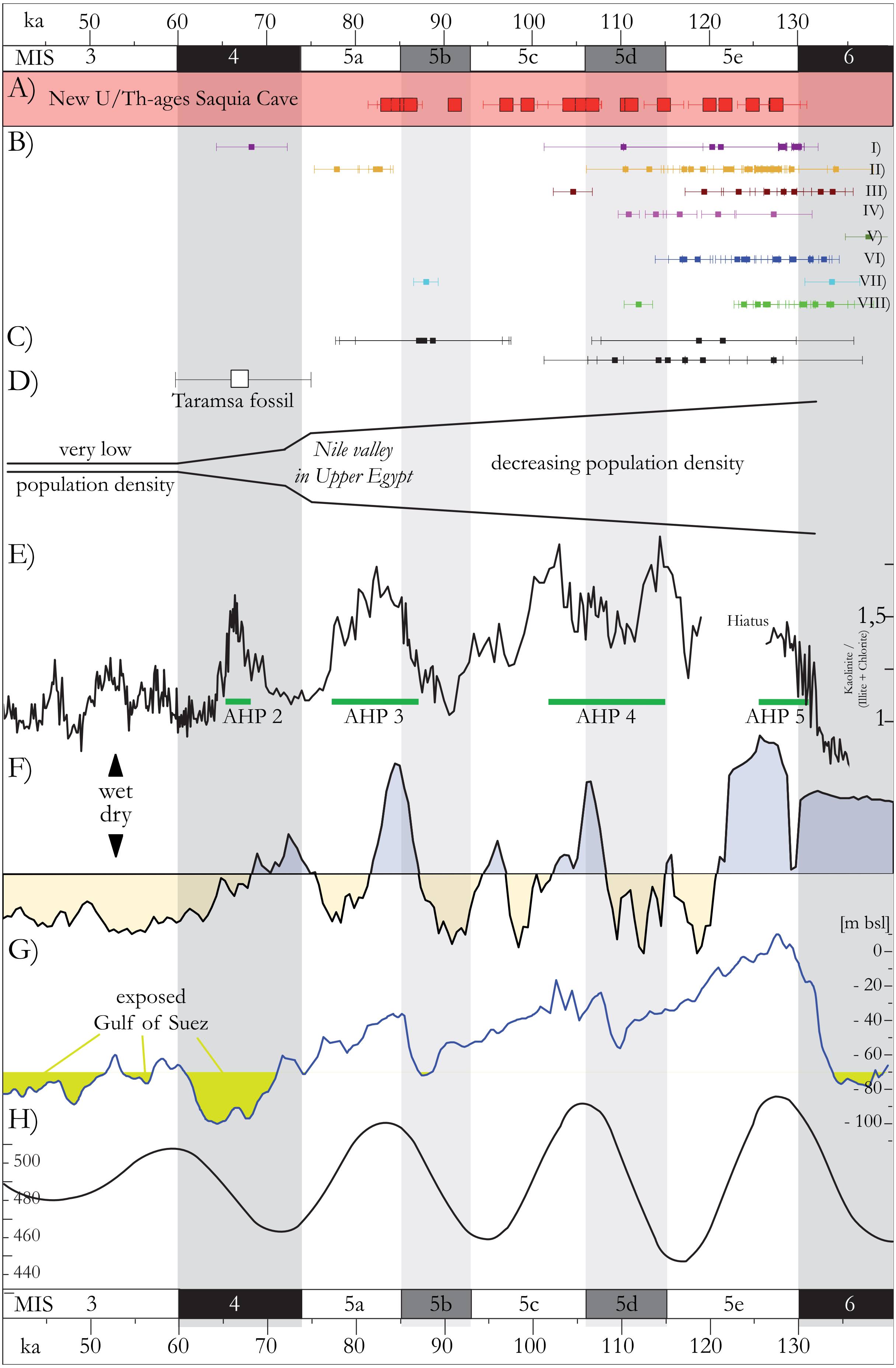
Therefore, the nowadays implications for reconstructing human-environment interaction at the scale of the PalaeoMap has two biases. First, it is evident that human occupation took not place equally distributed over Egypt, as the environmental needs for human e.g. access to water, fauna, flora, and raw material, have large regional variabilities. On the other hand, the persistence of the LIG landscape is also not equal over Egypt and thus, it cannot be reconstructed likewise. However, the compilation of the current state of knowledge and the integration of multiple parameters in the PalaeoMap for Egypt initiates possible new perspectives about the importance of multi-regional objectives for the migration of AMH throughout Egypt.

7.1 Climatic windows of opportunities

The compilation of the most important climate proxies in Northeast Africa for the early Late Pleistocene gives new insights into the temporal context of wetter climate phases in Northeast Africa for AMH dispersal. Thereby, speleothems records, marine records, sea level changes, and variations in solar insulation are presented for the time between 140 - 40 ka (figure 44). This represents the most important periods for the different possible migration scenarios (early - late - multiple) of AMH Out of Africa (see chapter 2.1).

All dated speleothem growth phases from Saquia Cave correlate with human presence at the nearby Sodmein Cave, based on the dating of heated flint from the lowermost stratigraphic layer J (Mercier et al. 1999, Schmidt et al. 2015). The results from thermoluminescence dating have a comparable large error which does not allow direct correlations to a distinct phase of speleothem growth at Saquia Cave, but all dates are within their errors in phase.

Figure 44 (next page): Palaeoenvironmental archives for the early Late Pleistocene in Northwest Africa. A) new Th/U-ages for speleothem growth phases at Saquia Cave B) speleothem growth in the SAD (I) Sannur Cave (Osmond & Dabous 2004; El-Shanaway et al. 2018), (II) Ma'ale-ha-Cave, (III) Even-Sid Caves, (IV) Ashalim Cave, (V) Ma'ale-Ktora, (VI) Hol-Zakh Cave, (Burns et al. 1998, Burns et al. 2011; Vaks et al. 2010), (VII) Mukalla Cave , (VIII) Hoti Cave (Fleitmann et al. 2003, 2011); C) Thermoluminescence dating of heated artefacts from Layer J (Mercier et al. 1999, Schmidt et al. 2015); D) AMH fossils in at Taramsa (Van Peer et al. 2010) and estimates for population densitiy in the Nile Vally in Upper Egypt (Vermeersch & Van Neer 2015); E) Nile discharge and African Humid Periods 2-5 (Ehrmann et al. 2016), F) North-African Humid periods (Grant et al. 2017), G) Insolation at 25°N (Berger & Loutre 1991); H) Red Sea Level (Grant et al. 2012); Marine Isotope stages (MIS) are indicated at the top and bottom according to Railsbeck et al. 2015



ka 50 60 70 80 90 100 110 120 130
MIS 3 4 5a 5b 5c 5d 5e 6
A) New U/Th-ages Saquia Cave
B)
I)
II)
III)
IV)
V)
VI)
VII)
VIII)
C)
D)
Taramsa fossil
very low
population density
Nile valley
in Upper Egypt
decreasing population density
E)
Hiatus
1,5
1
Kaolinite / (Illite + Chlorite)
AHP 2
AHP 3
AHP 4
AHP 5
F)
wet
dry
G)
[m bsl]
0
- 20
- 40
- 60
- 80
- 100
exposed
Gulf of Suez
H)
500
480
460
440
MIS 3 4 5a 5b 5c 5d 5e 6
ka 50 60 70 80 90 100 110 120 130

The general pattern of an increase and northward migration of the African monsoon during MIS 5, strongly associated with a summer insolation maximum in North Africa, is well established. These changes are proved on a regional to local scale by speleothems deposits (this study, Burns et al. 1998, 2011; Vaks et al. 2010; Fleitmann et al. 2003, 2011) but also on an over-regional scale with a strong northward shift of the monsoon and a high Nile discharge, recorded in the marine records during peaks of insolation at the beginning of MIS 5e. Sapropel formation (e.g. S5 during MIS 5e in the eastern Mediterranean) is generally linked to enhanced freshwater influx during a strong African monsoon and correlated with insolation maxima (Rohling et al. 2015).

Various other marine records proof the existence of a strong African monsoon during MIS 5e, e.g. based on high Nile discharge (Ehrmann et al. 2016, Grant et al. 2017). The average $\delta^{18}O$ value of -11.6 ± 0.8‰ for the speleothem at Sannur Cave in Egypt also indicates a distal/ monsoonal origin of the moisture during MIS 5e, where a long distance transport of moisture lead to depletion of heavier ^{18}O in comparison to lighter ^{16}O (El-Shenawy et al. 2018). However, there is no direct correlation for the amplitude of a northward migration of the monsoon into Egypt and the overall intensification. Regional differences, e.g. between the Western Desert and the Eastern Desert, cannot be derived from marine records in the Mediterranean Sea, as they present the cumulative climate situation in Northeast Africa. Thus, they represent only the overall mainly monsoon driven south-north gradient of precipitation in Northeast Africa. This is important for the interpretation and correlation of different marine records from the Eastern Mediterranean and different proxy data. Revel et al. (2010) used a detailed Fe record from a marine core in the Nile delta as proxy for the intensification of the African Monsoon over Ethiopia and associated peaks in Nile discharge throughout the last 100ka. Highest discharge occur during MIS 5c, 5a, and the Mid-Holocene. Older sediments dating back to MIS 5e are not reached by this record. This record cannot be directly correlated with wetter climate in Egypt during peaks of discharge. The main geochemical investigations in this study are the detailed Fe record as indication of runoff of the Blue Nile and Strontium with Neodymium as Aeolian input from the Sahara (Revel et al. 2010). A more precise record of enhanced precipitation in Northeast Africa is given by Ehrmann et al. (2016), who investigate the Kaolinite/

Smectite ratio in an East Mediterranean marine record. Kaolinite is absent in the surface geology of the Nile catchment apart from some regions in Egypt e.g. in the Eastern Desert but also on the Sinai Peninsula. Thus, an increase in Kaolinite input in the eastern Mediterranean Sea is associated with enhanced wadi discharge into the Nile in Egypt, respectively in the Mediterranean Sea, and can be linked to increase rainfall in these areas. Peaks of enhanced Kaolinite input during the Late Pleistocene occurred between 132 to < 126 ka, 116 to 99 ka, and 89 to 77 ka (Ehrmann et al. 2016). The speleothem deposits from Saquia Cave also indicate the presence of wetter climate conditions during phases of less insolation during MIS 5, when marine records indicate more dry conditions. This can be attributed to the various sources of enhanced precipitation in the Eastern Desert, not only due to the northward shift of the monsoon, but also due to the southward shift of the Mediterranean winter rainfall zone and the activation of the Red Sea Through and tropical plums.

Wetter climate phases in Northeast Africa after MIS 5 during MIS 4 are less pronounced and evidences exist so far only based on marine climate records form the Eastern Mediterranean Sea. The kaolinite based indicates a wetter period in Northeast Africa during MIS 4 between 69-65 ka, with a similar magnitude as the interglacial wet periods and during a phase of strong increase in insolation (Ehrmann et al. 2016). The composite dry-wet index for North Africa based on the compilation of geochemical proxies for dry (aeolian dust record) and wet (detrial input associated with monsoon run-off, conditions in Mediterranean Sea records) show also enhanced wetter climate during beginning of MIS 4 (Grant et al. 2017). Both proxies do not indicate a distinct wetter period during MIS 3, and peaks for more humid climate in North Africa during MIS 3 do not exceed the peaks during the wet phase of MIS 4. This is in contrast to general global climate reconstruction, as MIS 4 represents a glacial period, normally associated with dry climate in North-Africa and MIS 3 as Interglacial, associated with wetter climate in North-Africa. However, late Pleistocene wetter climate in North Africa apart from MIS 5 is still not fully understood. Sufficient climate records for this time period are still scarce and particular feedback mechanism, e.g. the rapid onset of Heinrich event 6 during MIS 4 need further investigations for a better understanding of climate variabilities during MIS 4 and 3 (Ehrmann et al. 2016, Grant et al. 2017).

Times of enhanced precipitation during MIS 5 and MIS 4 serve as possible windows of opportunities for AMH occupation in the SAD and a possible dispersal through it. In contrast to MIS 5 and 4, the over regional marine records do not show the presence of more humid conditions between 60-40ka at the beginning of MIS 3. All records indicate an increase in aridity from MIS 5 to 3 with the exception of the short wet phase during MIS 4. This is in phase with reconstruction of human population density in the Nile valley. A decrease in population density is estimated from MIS 5 to MIS 4 and MIS 3, and characterised with only very low population density (Vermeersch & Van Neer 2015). Therefore, based on the given chronology for the palaeoenvironment in Northeast Africa, the possible dispersal phases need to be re-discussed.

The so far only AMH fossil found on the Arabian Peninsula at Wadi Al Wusta dates back to around 95-86ka (Groucutt et al. 2018). It is located on similar latitude as Saquia Cave (Wadi Al Wusta 27°25'N, Saquia Cave 26°19'N). Wetter climate in the Eastern Desert derived from speleothem growth during MIS 5b may also been mirrored at the eastern side of the Red Sea at Wadi al Wusta. It is still questionable, if the proposed early phase of AMH dispersal onto the Arabian Peninsula during MIS 5 is associated with the northern or southern migration route. Sea level low stands in the southern Red Sea at Bab el-Mandeb might serve as a possible migration route towards the Arabian Peninsula (*cf.* Armitage et al. 2011). Detailed investigations of sea level changes and the palaeogeography of submerged islands in this area do not provide a finale resume for or against sea crossings (Lambeck et al. 2011). Comparative analysis of stone tool technologies in Northeast Africa and the Arabian Peninsula are considered to reflect possible exchanges between both regions. The Nubian Complex technology is one of the regional manifestation of the MSA in Northeast Africa, but also on the Arabian Peninsula during MIS 5 (Van Peer 2016). The Nubian Complex technology is found in the eastern Sahara, the Nile valley and in the Eastern Desert at Sodmein Cave. The archaeological site of Jebel Faya at the eastern side of the Arabian Peninsula represent also findings of Nubian Complex dating back to MIS 5e, and technological patterns indicate similarities with sites in East and Northeast Africa (Armitage et al. 2011). However, the far distance between Jebel Faya and the northern and southern route does not imply any specific probability of both routes. The only site which is geographical more connected to the southern Route with Nubian Complex technology is found at Dofar, Oman (Rose et al. 2011). Palaeolithic occupation at the Jubba palaeolakes in central Arabia during MIS 5 represent stone tool technologies similar with patterns from the African Stone Age and the Levantine Middle Palaeolithic technologies and the direction of reaching the regions is discussed either from the Sinai Peninsula and Levant, the Mesopotamian plains and Euphrates basins or the Persian Gulf (Petraglia et al. 2012). Therefore, the given archaeological evidences and regional distribution of the Nubian Complex technology also do not imply an exclusive southern or northern migration route into the Arabian Peninsula. However, even though sea crossing via the Bab el-Mandeb was possible and humans did cross the southern Red Sea, the extensive environmental conditions in Northeast Africa during MIS 5 and the full terrestrial route via the Sinai Peninsula seems to provide much better conditions for large scale migration Out of Africa during an MIS 5.

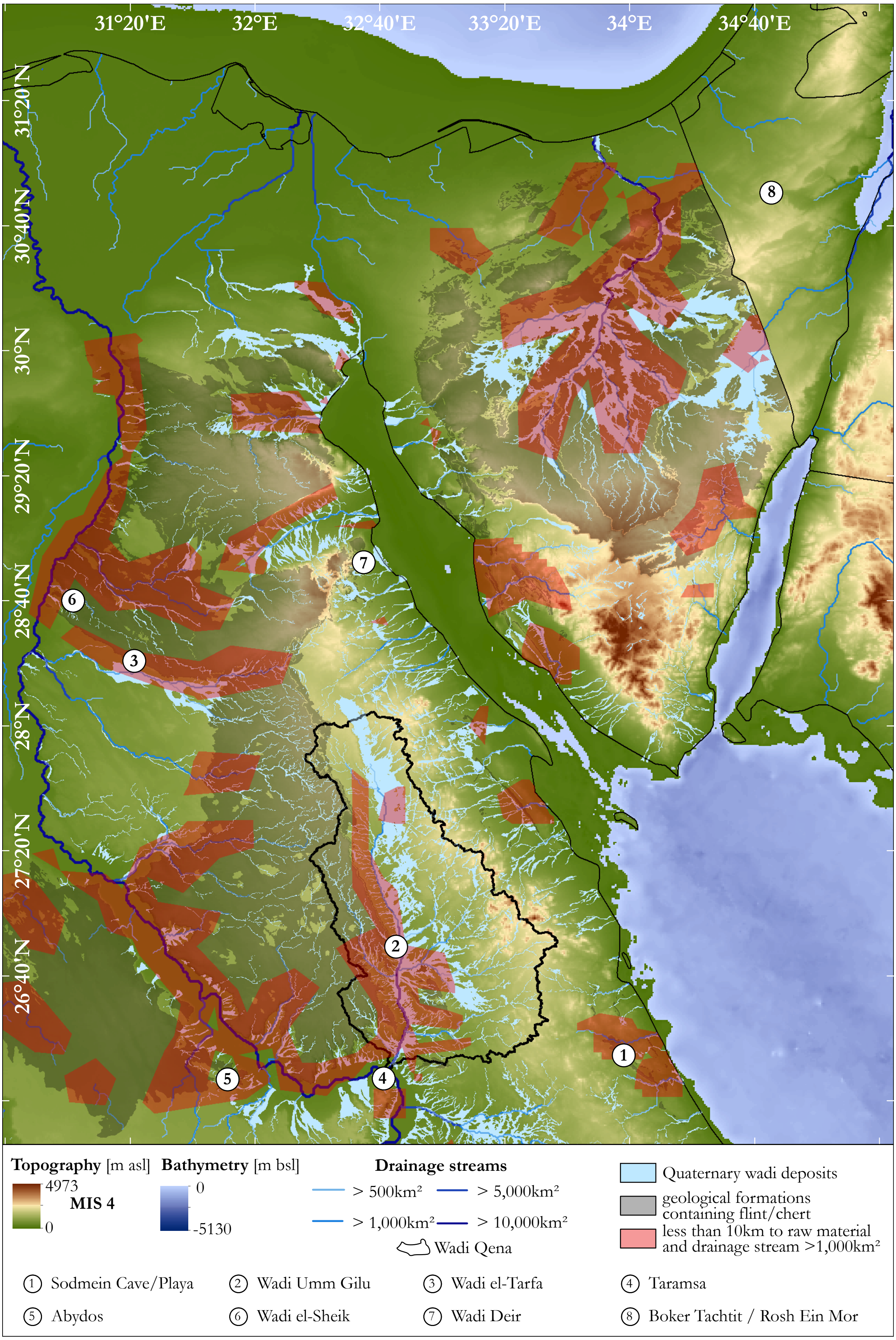
Global dispersal models have been focused on MIS 4 and 3 for a late/second major dispersal of AMH Out of Africa. The variations of the late dispersal model focus on the southern dispersal route and a coastal dominated dispersal towards Asia during MIS 4 or a northern dispersal during MIS 3 with proposed wetter climate at this time (Groucutt et al. 2015). This might also be revised, as the latest results for wetter climate conditions in Northeast Africa are shown to be present during MIS 4. This is in disagreement with global scenarios, where MIS 4 as a glacial period is often interpreted as dry climate in northern Africa in comparison to the Interglacial period of MIS 5 and 3. However, MIS 4 represents also the time, where the so far oldest fossil of AMH in Northeast Africa was found at Taramsa Hill located in the Nile valley. Its burial is dated to 68.6 ±8 ka and thus indicates human presence during MIS 4 (Van Peer et al. 2010). Based on this perspective, the separation of an early dispersal phase during MIS 5 and a later dispersal phase during MIS 3 is not supported. It seems, that favourable climate conditions for an dispersal of AMH in Northeast Africa are rather one time span with more favourable climate conditions (even though discontinues) from MIS 5 to 4. This possibility was already stressed out with the findings from Asia and an early occupation of regions outside of Africa (Bae et al. 2017), but so far had only limited direct evidences from the northern African continent. Main lack of evidences for human dispersal during MIS 4 are still outstanding archaeological sites at the northern migration route apart from the Nile valley. So far, evidences for human presence during the Late Pleistocene at Sodmein Cave in the Eastern Desert exist only during MIS 5. The stratigraphic layers I, G, and F, overlying the MIS 5 dated layer J, are so far undated and have only a minimum age at the limit of radiocarbon dating > 44.5 ka (Moeyersons et al. 2002). OSL-dating of these layers are in progress. The thick accumulation of layer G, positioned between the oldest layer J dated to MIS 5 and the top of layer D securely dated to around 25ka (Moeyersons et al. 2002) reveals a high potential for the possible proof of human occupation at Sodmein Cave during MIS 4. The distinct technological analysis of stone artefacts from the undated Middle Palaeolithic layers in comparison to the final dating results will give important insights into the temporal, but also technological human occupation in the Eastern Desert of Egypt and can fill a gap of knowledge in this area. Thereby, the established palaeoenvironmental synthesis for the early Late Pleistocene will help to understand better the human-environment interaction in this region.

7.2 A possible corridor for AMH migration from the Eastern Desert via the Sinai Peninsula into the southern Levant

The distinct regional context at the gateway Out of Africa between the Eastern Desert, the Sinai Peninsula and the southern Levant, represents a possible corridor for AMH migration (figure 45).

As shown for the overall environmental context, several possible opportunities existed for humans to occupy the Eastern Desert. The latest phase is associated to wetter climate during MIS 4, as MIS 3 tend to be drier in comparison to MIS 5 and 4. It is of particular importance for the northern Eastern Desert, that the short wet phase in Northeast Africa during MIS 4 falls in a time of global glaciation, in which the level of the Red Sea decreases. Due to the so far neglected possible migration of AMH during MIS 4, the exposed landmass of the Red sea is mapped for the situation of MIS 4, where the Red sea level drops under -74 m below present sea level (Grant et al. 2012) and an exposed Gulf of Suez.

Figure 45 (next page): Synthesis of the Eastern Desert Sea as possible migration corridor for AMH. Sea level and exposed landmass during MIS 4. Digital elevation model based on SRTM-data and Batymetry data according to the GEBCO-dataset 2014. (Weatherall et al. 2015). References of the archaeological sites are given in the text. Wadi deposits and Flint and chert bearing strata after Conoco 1987. Analysis and Cartography Henselowsky


31°20'E
32°E
32°40'E
33°20'E
34°E
34°40'E
31°20'N
30°40'N
30°N
29°20'N
28°40'N
28°N
27°20'N
26°40'N
Topography [m asl]
4973
MIS 4
0
Bathymetry [m bsl]
0
-5130
Drainage streams
> 500km²
> 5,000km²
> 1,000km²
> 10,000km²
Wadi Qena
Quaternary wadi deposits
geological formations containing flint/chert
less than 10km to raw material and drainage stream >1,000km²
1 Sodmein Cave/Playa
2 Wadi Umm Gilu
3 Wadi el-Tarfa
4 Taramsa
5 Abydos
6 Wadi el-Sheik
7 Wadi Deir
8 Boker Tachtit / Rosh Ein Mor

Although, the northern migration is the only full terrestrial dispersal route, which continuously existed over the time since AMH first appeared in Africa independently from sea level changes, these changes in available landmass could have an effect. The Gulf of Suez is exposed during sea levels below 70-80 m of present sea level and is the only region, where such sea level changes have an impact to the land-sea distribution at larger scale. All other coastal regions have a comparable steep shelf and a drop in sea level do not causes large-scale exposition of landmass. The enlarged landmass during MIS 4 increases the width of the corridor between the Eastern Desert and the Sinai Peninsula up to 400 km, in contrast to a width of less than 150km during sea level high stands. The impact of sea level variations and exposed or submerged coastal areas are discussed in the literature for the potential activation of freshwater springs in dependency of fast sea level fluctuations. This could led to coastal oasis, where freshwater springs occur on exposed shorelines. Coastal water table steeped at exposed shorelines during fast sea level fall and freshwater spring appeared on emerged continental shelves (Faure et al. 2002). This might be an important water sources for human dispersal along the coastline area also during phases of more arid climate conditions (Beyin 2011). No MSA sites in Egypt are found so far in association with coastal areas and no evidences exit about the use of marine resources in the people's subsistence. The only sites, where coastal adaptions during the MSA are found north of the Sahara, are located in North West Africa (Morocco), in North Africa (Libya and Tunisia), and in East Africa (Eritrea) (compare review of Will et al. 2019). Underwater archaeology in the Red Sea has been conducted in the southern Red Sea, which shows the possible relevance of todays submerged palaeocoasts for a coastal adaption of humans during the MSA. These areas are neither uniformly attractive nor unattractive and show a high temporal and spatial variability (*cf.* Bailey et al. 2015). So far, no detailed information exist about human presence near the Gulf of Suez. However, absence of evidences is criterion for exclusion of human occupation in this region, as it is still not well studied respectively all possible evidences are today below sea level. However, due to the specific context of MIS 4 in Northeast Africa, where groundwater and surface runoff in the area could be enhanced due to the wetter climate conditions, it does not exclude the possibility of an increase importance of coastal areas.

The northern Eastern Desert and the Sinai Peninsula are rich in geological formations with flint and chert, and access to raw-material is no limiting factor in these areas. Wadi Qena is of specific interest in the northern Eastern Desert, as it is the largest catchment and the north-south orientation of the catchment represents a morphometric corridor towards the Sinai Peninsula. Wadi Qena drained northwards towards during the Tertiary into the Tethys Sea and reversed its direction into a drainage from north to south during a later tectonic uplift of the north-western part of the Red Sea Mountains (Abdelkareem & El-Baz 2015). This reversal marks an important morphological change, as the watershed at the northern edge of the catchment is comparable flat and the headwaters of Wadi Qena towards the northern Wadi el-Tarfa are free of any morphological barrier. It has also a large amount of quaternary wadi deposits and tributary of Wadi Qena drain the Maaza limestone plateau with abundant high quality flint of the Thebes formation. The dense drainage systems and large amounts of quaternary wadi deposits enable an abundant use of flint and chert cobbles from secondary geological context. This interplay has been seen during the geoarchaeological survey of Wadi Qena, at Wadi Umm Gilu, and Wadi el-Tarfa, but also at other MSA sites in the Eastern Desert at Sodmein Playa (Kindermann et al. 2018), Wadi Deir (Dittmann 1990) or Wadi el Sheik (Köhler et al. 2017). It provides evidence, that such locations seem to be very promising areas for archaeological sites, even though they occur mostly as surface sites without stratigraphic context. Thus, they are not directly comparable due to local differences of the site context. A counter-argument would be that it needs to be proofed, that no (less) artefacts are found at wadi terraces, which are not draining flint bearing areas. However, field work (respectively funding proposals) need to focus in general on areas where expectations are high to find further archaeological sites, rather than to survey a region where no sites are expected. Therefore, future studies need to be focus on the area where the interaction of drainage systems with distinct geological formations is high.

The complex topography of the Eastern Desert reveals several ecological niches within a heterogeneous landscape. As this landscape is influenced by more variables in comparisons with homogeneous landscapes, e.g. the large plains in the Western Desert, the environmental knowledge of hunter-gatherer might differ between these landscapes. Wren & Costopoulos (2015) investigated Agent Based Modelling for the relation of environmental knowledge and hominin dispersal. Their results indicate that agents with high environmental knowledge tend to focus on known environments in comparison to agents with less environmental knowledge, which have a higher mobility and show higher exploration of new territories. In conclusion, agents with less environmental knowledge, influenced by a higher degree of environmental heterogeneity, have a higher dispersal potential (Wren & Costopoulos 2015). The Eastern Desert provides a study area, where such hypothesis could be analysed in more detail. It offers the opportunity, that the diverse landscape of the Eastern Desert triggered human dispersal Out of Africa, in this case to explore new landscapes possible via the Sinai Peninsula into the southern Levant.

From an archaeological point of view, the sites at Boker Tachtit, Boker, and Rosh Ein Mor in the southern Levant serve as a first archaeological anchor point Out of Africa in relation to the archaeological sites in the Eastern Desert. The site complexes of Boker Tachtit and Boker are also associated with an interplay between wadi terrace deposits and slope pediment deposits of the local bedrock (Goldberg 1983). Importantly, the local limestone bedrock also includes rich flint deposits in several geological strata and Wadi Zin drains these formations, which leads to the occurrence of abundant flint noodles in the wadi terraces and humans have collected the majority of their raw material from these wadi deposits (Goder-Goldberger et al. 2017). A comparable site, Rosh Ein Mor, is located less than two kilometres downstream to the sites of Boker Tachtit and Boker and located in the same landscape setting. Only two direct chronometric ages for Middle Palaeolithic occupation at Boker Tachtit exist, which points to a minimum age of 48.3 ±1.8 ka to 50.6 ±2.2 ka (Kuhn & Zwyns 2014). Oldest settlements at Rosh Ein Mor are dated to MIS 4 (Goder-Goldberger & Bar-Matthews 2019). Thus, the presence of humans in the southern Negev Desert during MIS 4 are likely in phase with the wetter climate phases in Northeast Africa during MIS 4. Current in-depth studies of the lithic artefacts from Sodmein Cave and datings in progress will provide new information about the possible exchange between the Eastern Desert and the southern Levant. The presence of two Emireh points from Middle Palaeolithic level 1 at Sodmein Cave already point to strong south-western Asian contacts and possible similarities with the site of Boker Tachtit (Van Peer et al. 1996). The Emiran represents a fusion of Mousterian in the southern Levant and Afro-Arabian Nubian Levallois reduction strategy with its origin presumable at the interface of Northeast

Africa, northern Arabia, and southern Levant between 100 and 50 ka (Rose & Marks 2014). This supports a close interaction of these regions during the late Pleistocene.

All of these evidences of human behaviour and dispersal from Northeast Africa into the southern Levant cannot be studied by a one-way perspective, but also needs to recognise possible re-migration from the Levant into Northeast Africa. Genetic studies based on analyses of the mDNA macrohaplogroup L3 basal lineages suggest a re-migration of AMH from southwest Asia into North Africa at around 70 ka (Cabrerea et al. 2018). This is in phase with the wetter climate during MIS 4 and the interlink between the southern Levant and Northeast Africa during this time. In summary, the possible migration corridor in the Eastern Desert is not only visible in the environmental context, but preserve also indications from an archaeological point of view or insights from genetics. Nevertheless, the very sparse data background with all uncertainties, advantages, and disadvantages of each parameter and the different research perspectives are just at the beginning for an integrated better understanding of the distinct factors of AMH dispersal in this region. Thereby, the environmental reconstruction and the given landscape perspective for the possible corridor for AMH migration in the Eastern Desert is an important additional proxy.

One of the important conclusions, resulting out of the proposed PalaeoMap and the Eastern Desert as possible migration corridor, is the use of the given data into subsequent modelling approaches. A very simplified model for human dispersal from East Africa into the Levant via Egypt is a least cost path model given by Beyin et al. (2019). Here, topographic roughness, drainage density, and elevation is used as an input parameter to calculate a route of least costs in Northeast Africa, which favours the Nile valley and adjacent regions as optimal pathway for human dispersal (Beyin et al. 2019). However, this perspective is very limited, as only morphometric parameters of the landscape are integrated under the assumption of least costs (=least energy) to disperse throughout the landscape. Similar least cost path analysis was done by Field & Laher (2006) to model human dispersal. Their results follow strictly the Nile Valley in Egypt as an area of least costs based on a topographic perspective. These outcomes are in strong disagreement with the given advantages of a complex topography, as these areas result in higher travel costs and are excluded in the approach of least costs. More sophisticated modelling approaches are given by means of Agent Based Modelling. Here, acting entities (agents) environmental parameters and rules of interactions are used to calculate different scenarios of human-environment interaction, e.g. for modelling human dispersal (*cf.* HÖLZCHEN et al. 2015). Both, the presented dataset for the PalaeoMap of Egypt and the regional interpretation of different landscapes in the Eastern Desert can provide the environmental background for such models in future. Here, the impact of different landscapes can be transferred into rules of interaction, and particular important into models of hunter-gatherer behaviour, where for instance parameters of spatial foresights, environmental knowledge, and hominin cognition are integrated into Agent Based Modelling (WREN et al. 2014, WREN & COSTOPOLOUS 2015). Such Agent Based Modelling approaches lead finally into the integration of natural and social sciences, where a geographical perspective and the perspective of "everything is interaction" (HUMBOLDT 1808) is a precondition for the requirements for a successful model.

8. Synthesis

The main perspective of this thesis was based on a fundamental integrative approach to overcome challenges in the combination of different research disciplines. The study of AMH dispersal is driven by a high complexity of involved subjects. Neither natural science nor natural science can provide sufficient input alone within the study for our own species history. Geography as tandem of natural and social sciences fulfils the potential to act as moderator for various perspective (*cf.* chapter 1). The examinations with variable temporal and spatial scales within geography represent one of the key issues in understanding past environmental changes with their impact to human behaviour. The applied geographical perspective about various spatial scales under the aegis of geomorphology is for itself not independent, but neither can any participating discipline claim their perspective as autonomous.

Therefore, the results of the study at hand are synthesised into the overall context for the importance of different relief scales, which might influenced human behaviour. This links the results into further sub-disciplines of the discussed research context with spatial scales in geoarchaeology and archaeogeomorphology. The main results point to an integration of environmental parameters and different types of landscapes into archaeological evidences for human behaviour and dispersal in Northeast Africa and the Egyptian Eastern Desert. No detailed studies about a distinct archaeological site (apart from Sodmein Playa) could be investigated. This reveals an archaeogeomorphological approach rather than a geoarchaeological perspective. The large-scale environment and landscapes represent the initial scale, where a top-down approach identifies different regional to local variabilities. The contrary approach would be the archaeological site a nucleus of investigations with a bottom-up approach in scale. This would represent a rather geoarchaeological point of view.

A schema for the impact of various relief scales is proposed based on the given archaeogeomorphological perspective and examined the first goal of this thesis (Goal I: Identification and definition of distinct spatial scales for Late Pleistocene human-environment interaction in Northeast Africa). Scales in geomorphology serve as background where resilient types of landforms can be investigated mostly quantitatively with distinct spatial definitions, e.g. based on the scale of relief types. Variable scales for different research objectives in archaeology exist for the reconstruction of daily activities, mobility, or migration of humans. The influence of scales is here mostly discussed qualitatively. However, the general framework can be integrated into quantitative spatial scales (figure 46).

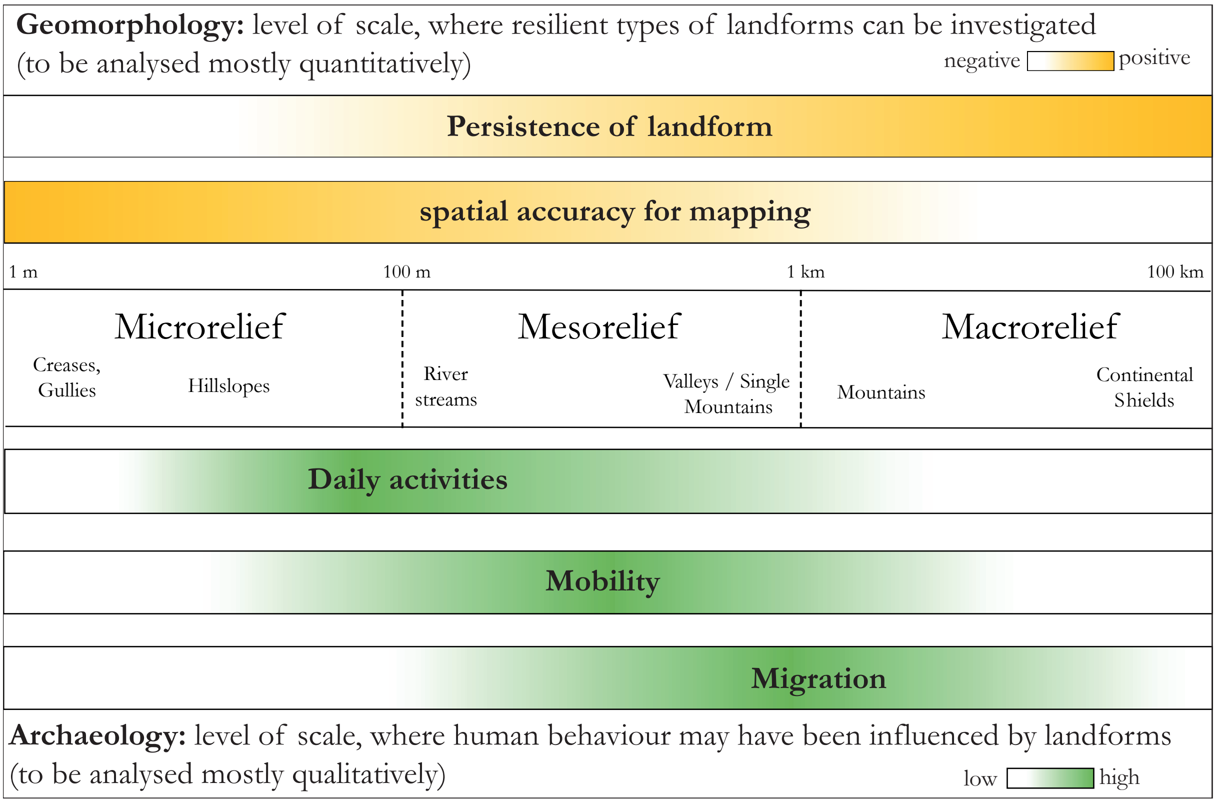


Figure 46: Synthesis of spatial scales and their context in geomorphology and archaeology. Relief scales according to Dikau 1988 (own design).

The spatial scales range from the micro- to macrorelief. Dimensions of the pico- to nano-relief (below 1 m) are excluded, as they represent in principle, not exclusively, the scale where geoarchaeological studies focusses, e.g. for site formation processes within a given stratigraphy (cf. chapter 2). As archaeogeomorphology aims to integrate the impact of different landscapes to human behaviour based on a geomorphological perspective, it is also reasonable to start the consideration of different landforms at the human scale of land surface. Evans (2012) sets the human scale at 1.5 m as starting point for the consideration about the definition of a landform. This threshold may not cover all aspects of geomorphology, as surface irregularities below an extent of 1.5 m are not considered, but it represents the scale of what humans in general - not straight geomorphologists - identify as a landform.

The highest spatial accuracy for the geomorphological mapping is achieved for the study area at Gebel Duwi by the given investigations on the wadi terraces. They represent the scale of the microrelief. These landforms have a comparable high possibility for accurate mapping, but have a relative low persistence. This is visible in the fact, that only few remnants of the terraces are still preserved (compare chapter 5.1). The coexistence between very young and active landforms represents typical landscape conditions in the highly erodible environment in the Eastern Desert of Egypt. The discussed special characteristics and complex landscape setting at Gebel Duwi are responsible that even the high-resolute remote sensing data cannot replace detailed field investigations, which produced more sophisticated results. The interpretation and implications for landscape processes and environmental changes at Gebel Duwi rely more on field-based evidences than on GIS-investigations. However, the integration of GIS-based mapping following the field-based evidences, e.g. the mapping of the terraces based on the high-resolution satellite image, allows an upscaling in space. Altogether, this relates to the second goal of this thesis (Goal II: Integration of field-based investigations and GIS-based investigations to provide a sufficient background for the landscape context at the archaeological site of Sodmein Cave and sites in the Central Eastern Desert in general).

The scale of the area around Sodmein Cave and Sodmein Playa can be seen as possible daily activity areas of humans. This area is a prime example, where the integration of a long-lasting archaeological stratigraphy in a cave - Sodmein Cave - can be integrated with open-air sites and archaeological findings outside of the cave at Sodmein Playa in context of presumable old wadi terraces. The palaeoenvironmental implications from the sediment sequence at the central part of Sodmein Playa can be correlated with human occupation at the nearby Sodmein Cave and Tree Shelter for times of the Holocene during wetter climate. However, the surface findings on top of the terraces indicate a correlation between archaeological findings dating back to the LIG. This is shown by the usage of the open-air site at Sodmein playa as raw-material procurement site related to the flint pebbles in wadi deposits and access to water, whereas Sodmein Cave could be used for shelter purposes.

In addition to the geomorphological studies at Gebel Duwi, a new important climate archive was first investigated with the Th/U-dating for speleothem deposits at Saquia Cave. It enhances the availability of a regional climate archive in the Eastern Desert, but also enlarges the terrestrial climate record in the SAD in space and time. Due to the proximity of Saquia Cave located in the same limestone ridge as Sodmein Cave, evidences of climate changes in the Eastern Desert and human occupation in the area is no longer only correlated with large-scale climate reconstructions. The different speleothem growth phases during MIS 5 show environmental changes associated with wetter climate conditions and vegetation growth for carbonate solution with enhanced water availability and soil CO_2. This occurred not only during times with a strong increase in insolation as one of the main trigger for a northward shift of the monsoon, but also during times of low insolation. Therefore, Saquia Cave mirrors a more detailed climate archive apart from marine records, where the impact of different possible sources of precipitation (Red Sea Through, tropical plums) and the larger extent of the Mediterranean climate in northern Egypt are not always identified. The presence of speleothem deposit over all substages of MIS indicates, that the Eastern Desert of Egypt might serve as humid corridor during the LIG, as the different sources of rainfall lead to the chance to encounter extensive possibilities for rainfall throughout different times of the year (summer rainfall, winter rainfall, and year round rainfall) in comparison to other regions in Egypt. Initial test measurements of the carbon and oxygen composition within the samples from Saquia Cave were done, but no further in-depth analyses are available. One of the main reasons is the so far lacking detailed age-depth model of the samples due to the complex internal stratigraphy, and the results can only be interpreted as the absence or presence of speleothem deposits indicating climate changes. Detailed investigations of the ^{18}O record from Saquia Cave in future have the possibility to give more insights into different sources of precipitation, as the $\delta^{18}O$ value is among other variables very sensitive to the distance between moisture source and precipitation area.

The identified indications for climate changes throughout the Late Pleistocene from Saquia Cave combined with the GIS-based investigations of the PalaeoMap represent the third goal of this thesis (Goal III: Establishment of a better identification of environmental and climate changes in the study area during the Late Pleistocene). Thereby, the analyses of the climate model, the derived Köppen-Geiger climate, and semi-quantitative calculation of ecozones present regional differences in Egypt during the LIG. The Köppen-Geiger climate is comparable to the scale of global biomes, where modelling approaches exist so far. The presented semi-quantitative transfer of today's ecozones and total annual precipitation into ecozones in Egypt during the LIG is up to now the only approach to gain insights into regional scales. Although, this cannot be modelled in a pure quantitative way, a qualitative integration is of high importance, as the ecozones differ significantly between the regions in Egypt. The regional variabilities of ecozones in Egypt during the LIG provide a heterogeneous environment, where no comprehensive and singular impact for human behaviour per se can be attributed.

The synthesis of the PalaeoMap (chapter 7) provides a better spatial understanding of the landscape context in Egypt during the LIG, which had to be crossed by humans following the northern migration route Out of Africa. The scale of the PalaeoMap represents one of the most challenging one, as it is neither purely based on a quantitative approach for palaeoenvironmental reconstruction at larger scale, nor able to include all local variabilities and influence parameters at smaller scale. However, it fills the important spatial gap while integrating local sites into their large-scale context. Apart from the general wetter climate conditions at large scale, the identification of distinct sources for raw-material procurement and the variability of landforms are additional important factors influencing human behaviour. This is shown at the overall scale of Egypt and the more detailed investigation of a possible migration corridor in the Eastern Desert.

The scale of the possible corridor between the Eastern Desert and the southern Levant is an important link between Northeast Africa and the southern Levant, and a key region for the discussion of the northern migration route Out of Africa. This reflects the fourth goal of this thesis (Goal IV: Infer possible attractive corridors for AMH migration Out of Africa). The region represents possible mobility pathways influenced by the distinct type of landscapes. It is still an unanswered question, if either a homogeneous or a heterogeneous landscape, or the strong mobility triggers a higher foraging radius. The chance to encounter favourable environmental conditions in a heterogeneous environment is influenced by more parameters in comparison to a homogeneous environment. However, humans in the Eastern Desert may not be specialised in only one resources (e.g. the strong correlation of archaeological sites in the Western Desert in dependency to the large palaeolakes), but had a variable use of resources in such a heterogeneous environment. This would lead to a surpassing mobility, which accumulate in migration and dispersal patterns at larger scale (compare chapter 7.2). Relief types vary between the mapping of drainage streams, and the identification of larger valley and mountainous areas. This scale represents the transition between the mesorelief and macrorelief, which persists through time, and the nowadays topography can be interpreted as the relief of the LIG at this scale. The only regions where larger relief changes between today and the LIG exist are coastal areas due to varying sea levels and nowadays large sand sea, e.g. the Great Sand Sea. As these changes are regional very variable, this implies once again the importance of field mapping, and local to regional case studies at smaller scale, as these features are mainly in the range of the micro- to mesorelief.

It is a general challenge, that the integration of all discussed parameters (climate, ecozones, drainage systems, topography, and geology) and their potential influence to human behaviour into the PalaeoMap might have a given uncertainty, in contrast to more detailed reconstruction of only one parameter. However, the impact of environmental factors to human behaviour is better achieved with such a cumulative approach of parameters, although it has more uncertainties in comparison to highlight one detailed investigated parameter. It avoids a one-way interpretation, where only one parameter (e.g. large scale rivers) is seen as the main trigger for human dispersal, e.g. in nowadays arid environments. This perspective would prevent other variabilities like relief types or geology to play an important role, even in areas where no for example large scale rivers exist.

Although the classification of landforms can be set to defined spatial scales within the proposed schema, they cannot be set to distinct thresholds for human behaviour. It is evident, that hunter-gatherer societies are very mobile and their distinct foraging radius represents no fixed area and the break-up into distinct scales for considering daily activities, mobility, and migration interacts with each other. Thereby, the temporal scale cannot be integrated at this stage. Not only the pace of dispersal is very challenging to calculated based on the sparse data available, but also seasonal behaviour have most likely a very important impact on human behaviour in an environment as proposed for Egypt during the LIG. Hunter-gatherer groups at Bir Tarfawi within the large plains of the Western Desert might have a total different behaviour as hunter-gatherer groups in the complex topography of the Eastern Desert, e.g. in the surrounding of

Sodmein Cave. This needs to be discussed with all involved disciplines. Here, not only archaeology, but also ethnology is an important discipline to be included. Thereby, the displayed categorisation can serve as a background for a better exchange between different disciplines involved to get a common implication of spatial scales.

As a final remark in the context of the study of AMH dispersal, the interlock and characteristics of different philosophies of science have a huge impact, where natural and social sciences bounce against each other. Derricourt raises the point of personality and research philosophy, and points an important statement in the research context of early human migration: "Both palaeoanthropology and the archaeology of early humans operate in a framework where the science is not experimental, data are sparse and hypotheses are not easily refutable and replicable. There are few other sciences where an isolated piece of evidence can support or change a broad scale interpretative model without itself being readily testable. In this framework, personality plays an important role the conservative thinker or the innovator, the dogmatist or the sceptic, the taxonomic splitter or the lumper." (Derricourt 2005: 119-120). For the study of environmental changes in a today hyper-arid region, not only social sciences as archaeology face the challenges of sparse data and hypotheses which are not easily refutable and replicable, but also natural sciences. Even though, the proposed results, e.g. the regional differences for the ecozones in Egypt are not fully testable or can be quantitative modelled, the sparse evidences that exist provide an important framework and provokes thoughts, which can be reworked and enhanced in future.

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Unpublished report of the OSL-dating of sediment samples from Sodmein playa
(Dr. Nicole Klasen)

Measurements were carried out on an automated Risø TL/OSL DA 20 reader equipped with a calibrated 90Sr beta source. Blue-light emitting diodes (470 nm, FWHM = 20) and a Hoya U 340 filter (7.5 mm) transmitting wavelengths of 330 ± 40 nm were used for optical stimulation and signal detection of the quartz multi-grain aliquots (8 mm diameter of the grain layer). The net OSL signal was obtained using the first 0.5 s of the stimulation and early background subtraction of the subsequent 1.3 s (Ballarini et al., 2007; Cunningham & Wallinga 2010). We used the single-aliquot regenerative-dose approach (SAR) for all measurements (Murray and Wintle, 2000, 2003) and measured the response to IR stimulation at the end of the SAR cycle (Duller 2003). For a preheat plateau test, we employed preheat temperatures between 180 and 280 °C for 10 s, a cut heat temperature of 20 °C below the preheat temperature and OSL stimulation for 40 s at 125 °C (8 mm, 3 aliquots each temperature). Additionally, we carried out dose recovery tests of the same samples (given dose: 15 Gy (1401P1-1) and 19 Gy (1401P1-2, P1-3, P1-4) after OSL stimulation for 100 s at room temperature) using a preheat temperature of 240 °C and a cutheat temperature of 220 °C (8 mm, 5 aliquots).
The radionuclide concentrations of the surrounding sediments were measured using high resolution gamma ray spectrometry. The dose rate was calculated using DRAC (Durcan et al., 2015) and included conversion factors of Guerin et al. (2011), attenuation factors of Brennan et al. 1991 and Brennan 2003, an a-value of 0.04 ±0.03 and an assumed water content of 5 ± 2 %. The cosmic dose rate was calculated following Prescott & Hutton (1994). The table summarize all measurements and calculated ages.

Sample	Sample	Sampling depth	Water content	n	Radionuclide concentration			Dose rate	RSD	De	Age
ID	name	[m b.s.]	[%]	accepted/ measured aliquots	U [ppm]	Th [ppm]	K [%]	[Gy/ka]	[%]	[Gy]	[ka]
C-L4479	1401 P1-1	0.35	3	49/49	2.50 ±0.12	8.59 ±0.43	0.80 ±0.02	1.96 ±0.04	13	14.9 ±0.27	7.61 ±0.20
C-L4480	1401 P1-2	0.8	3	31/32	2.43 ±0.11	8.79 ±0.44	0.61 ±0.01	1.74 ±0.03	23	16.0 ±0.66	9.19 ±0.42
C-L4481	1401 P1-3	1.2	3	33/33	1.89 ±0.09	6.30 ±0.33	0.61 ±0.01	1.45 ±0.03	9	14.3 ±0.24	9.88 ±0.23
C-L4482	1401 P1-4	1.45	3	41/42	2.71 ±0.10	7.51 ±0.38	0.57 ±0.01	1.68 ±0.03	28	17.3 ±0.76	10.3 ±0.49

Massspectrometer used for analysis	Dating performed	Lab. No.	sample ID	238U [ng/g]	err. ± [ng/g]	232Th [ng/g]	err. ± [ng/g]	[230Th/238U]1	err. ±	[230Th/232Th]1	err. ±	δ234U [‰]	err.	Age* [ka]	err.	Age ** ± ka	err. ± ka	δ234Ui [‰]	err. ± [‰]	depth [cm]
Thermion-Mass-Spectrometry [TIMS] MAT 262 RPQ 2012/13	2012/2013	IUP-5786	Saqia oben#5-2	429.460	0.860	19.950	0.140	0.5704	0.0092	37.87	0.63	63.00	4.90	84.40	2.00	83.20	2.10	79.40	6.40	2.2
	2012/2013	IUP-5787	Saqia oben#3	369.340	0.740	4.069	0.049	0.6660	0.0130	185.00	4.30	74.70	5.10	104.10	3.60	103.80	3.60	100.20	6.90	11.2
	2012/2013	IUP-5788	Saqia unten#11	1006.900	1.800	63.730	0.640	0.5830	0.0100	28.49	0.54	74.80	3.50	86.10	2.10	84.40	2.20	94.90	4.50	Top
	2012/2013	IUP-5911	Saqia oben#4o.	294.860	0.290	3.038	0.021	0.5795	0.0076	172.20	2.50	61.30	3.50	85.70	1.80	85.40	1.80	77.70	4.40	3.5
	2012/2013	IUP-5912	Saqia oben#4u.	483.770	0.480	24.920	0.220	0.6260	0.0100	37.43	0.65	57.80	6.60	98.10	2.60	96.70	2.70	76.00	8.70	7.5
	2012/2013	IUP-5913	Saqia unten#3	1380.100	1.400	85.080	0.580	0.7142	0.0073	35.64	0.41	63.10	4.10	121.30	2.30	119.70	2.40	88.20	5.90	Top
	2012/2013	IUP-5945	Saqia oben 5,8	326.230	0.650	11.675	0.050	0.6884	0.0061	59.04	0.55	52.10	5.70	115.50	2.20	114.50	2.20	72.00	7.90	5.8
	2012/2013	IUP-5946	Saqia oben 14,0	425.710	0.850	10.246	0.061	0.6613	0.0069	84.25	0.98	60.90	6.30	105.80	2.10	105.20	2.20	82.10	8.60	14.0
	2012/2013	IUP-6004	Saqia oben 4,5	403.240	0.810	13.644	0.081	0.6415	0.0087	58.23	0.83	66.70	4.40	100.00	2.30	99.10	2.30	88.20	5.90	4.5
Inductively Coupled Plasma Source Quadrupole Mass Spectrometer [ICP-Q-MS] Thermo Fisher Scientific iCAP-Q	2014	IUP-6435	Saqia1-1,7	512.300	0.750	116.980	0.610	0.6892	0.0053	10.15	0.09	55.40	3.50	133.50	2.00	127.20	3.50	79.40	5.10	1.7
	2014	IUP-6436	Saqia1-6,0	300.160	0.560	6.145	0.040	0.7306	0.0080	111.33	1.40	58.30	3.70	127.70	2.80	127.10	2.80	83.50	5.30	6
	2014	IUP-6437	Saqia1-11,5	387.360	0.540	5.588	0.028	0.7325	0.0052	158.06	1.34	69.50	2.70	124.90	1.80	124.50	1.80	98.80	3.80	11.5
	2014	IUP-6438	Saqia1-18,3	392.502	0.560	7.339	0.044	0.8646	0.0071	144.16	1.44	51.29	2.67	186.21	4.26	185.71	4.30	86.69	4.63	18.3
	2014	IUP-6439	Saqia1-23,7	494.734	0.503	14.517	0.141	0.8370	0.0084	89.24	1.24	48.17	3.27	174.83	4.63	174.05	4.60	78.78	5.44	23.7
	2014	IUP-6440	Saqia1-26,7	560.492	0.701	25.031	0.232	0.7989	0.0089	56.27	0.80	53.81	2.98	156.78	3.98	155.59	3.90	83.53	4.73	26.7
Multi-collector ICP-MS [MC-ICP-MS] Thermo Fisher Scientific Neptune Plus	2018	IUP-9173	NH1-7 Top	2097.750	0.290	6.725	0.018	0.8696	0.0014	830.70	2.60	127.37	0.41	153.59	0.44	153.51	0.57	196.56	0.71	Top
	2018	IUP-9177	Saqia2-1.0	454.900	0.023	15.407	0.029	0.7159	0.0019	64.92	0.21	57.80	1.30	121.41	0.70	120.57	0.75	81.20	1.80	1.0
	2018	IUP-9178	Saqia2-5.0	304.137	0.093	6.797	0.026	0.6725	0.0025	92.25	0.49	70.40	1.50	106.41	0.72	105.87	0.72	95.00	2.00	5.0
	2018	IUP-9179	Saqia2-10.0	406.824	0.018	10.090	0.023	0.6105	0.0014	75.55	0.25	72.35	0.84	90.84	0.35	90.23	0.45	93.40	1.10	10.0
	2018	IUP-9180	Saqia1-13.0	515.245	0.029	6.175	0.013	0.6889	0.0016	176.66	0.55	72.90	1.20	110.32	0.55	110.03	0.48	99.50	1.70	13.0
	2018	IUP-9181	Saqia1-15.0	1126.977	0.070	5.932	0.012	0.6871	0.0013	402.20	1.10	67.78	0.67	110.85	0.39	110.72	0.38	92.68	0.92	15.0
	2018	IUP-9182	Saqia1-17.0	976.018	0.037	14.395	0.030	0.5899	0.0015	122.92	0.40	75.12	0.62	85.84	0.28	85.48	0.40	95.65	0.80	17.0

1 Activity ratio

* uncorrected age

i initial $^{234}U/^{238}U$ ratio

** corrected age; orrected for detrital Th; ass. bulk Earth $^{232}Th/^{238}U$ weight ratio of 3.8 ± 1.9 for detritus and ^{234}U, ^{238}U and ^{232}Th in secular equilibrium

all errors 2σ

Marsa Matruh	J	F	M	A	M	J	J	A	S	O	N	D
Prec. [mm]	34	23	17	5	3	27	-2	72	15	14	25	30
Tmin [C°]	13.8	15.5	17.9	22.8	26.7	30.4	34	29.8	26.5	22.7	18.9	15.3
Tmax [C°]	6.1	7.1	8.7	11.7	16.2	22.2	27	24.9	19.4	16.2	11.8	8.5
Sannur Cave	J	F	M	A	M	J	J	A	S	O	N	D
Prec. [mm]	0	2	4	6	1	55	-1	76	7	0	1	1
Tmin [C°]	14	17.8	22.3	30.1	36.9	40.7	40.3	31.5	27.9	23.6	18.8	14.9
Tmax [C°]	3	4	6.7	11.2	16.7	21.8	26	20.9	17.3	13.1	8.6	5.4
Bir Tarfawi	J	F	M	A	M	J	J	A	S	O	N	D
Prec. [mm]	0	0	1	5	0	38	204	162	26	0	1	0
Tmin [C°]	17.6	21.4	29.5	36.1	42.3	46	33.5	20.3	30.2	28.8	21.6	16.8
Tmax [C°]	4.6	6.4	10.7	16	21.5	26.8	26.4	24.7	20.2	15.9	11	5.9
Sodmein Cave	J	F	M	A	M	J	J	A	S	O	N	D
Prec. [mm]	0	0	2	7	1	9	120	131	15	1	6	0
Tmin [C°]	16.3	19.2	23.7	28.5	34.2	40	33.3	21	26.6	23.9	19.1	16.6
Tmax [C°]	8.6	9.8	12.6	16.5	20.3	27	27.3	24.9	21.8	17.4	13.8	10.2

Curriculum vitae

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Erklärung

Ich versichere, dass ich die von mir vorgelegte Dissertation selbständig angefertigt, die benutzten Quellen und Hilfsmittel vollständig angegeben und die Stellen der Arbeit – einschließlich Tabellen, Karten und Abbildungen –, die anderen Werken im Wortlaut oder dem Sinn nach entnommen sind, in jedem Einzelfall als Entlehnung kenntlich gemacht habe; dass diese Dissertation noch keiner anderen Fakultät oder Universität zur Prüfung vorgelegen hat; dass sie – abgesehen von unten angegebenen Teilpublikationen – noch nicht veröffentlicht worden ist, sowie, dass ich eine solche Veröffentlichung vor Abschluss des Promotionsverfahrens nicht vornehmen werde. Die Bestimmungen der Promotionsordnung sind mir bekannt. Die von mir vorgelegte Dissertation ist von Prof. Dr. Olaf Bubenzer betreut worden.

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KINDERMANN, K., VAN PEER, P., HENSELOWSKY, F. **2018**. At the lakeshore – An Early Nubian Complex site linked with lacustrine sediment (Eastern Desert, Egypt). *Quaternary International* 485, 131-139.

YOUSIF, M. HENSELOWSKY, F., BUBENZER O. **2018.** Palaeohydrology and its impact on groundwater in arid environments: Gebel Duwi and its vicinities, Eastern Desert, Egypt. *CATENA* 171, 29-42.

HENSELOWSKY, F., ALMOAZAMY, A., FAWAZ, S., KHAIRY, H., KINDERMANN, K., EICHSTÄDTER, R., KLAHRE, N., SCHEPERS, C., LAMMERICH-LONG, D., KLASEN, N.,KEHL, M., BUBENZER, O. **2019**. Wadi Nakheil cave at the limestone hogback of Gebel Duwi: Interdisciplinary approaches to study palaeoenvironmental changes in the Central Eastern Desert of Egypt. *Annals of the Geological Survey of Egypt* 35, 389-392.