Hominin occupation and landscape evolution during the Middle and Late Pleistocene at the Druze Marsh site in northeast Jordan

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ABSTRACT

The Druze Marsh is a spring-fed wetland in northeast Jordan that, due to years of over-pumping the aquifer, dried out completely in the 1980s. This study combines detailed stratigraphic and sedimentological analysis of seven test pits and one controlled excavation in the exposed marsh bed, with artifact analysis and radiometric dating, to reconstruct the changing landscape since the Middle Pleistocene and relate hominin use of the area to environmental change. The results show that there are extensive hominin occupations in the Druze Marsh from the Late Lower Paleolithic through the Epipaleolithic that correspond to relatively dry environments when the wetland was reduced in size, suggesting the Druze Marsh acted as a desert refugium for hominins during adverse climatic conditions, with important implications for regional population continuity, turnover, and/or extinctions. Separating these occupations are extended periods when the wetland increased in size and depth, becoming a shallow lake that drowned land previously available for hominin occupation and forcing these populations into the surrounding river channels that flow into the central basin. Positioned at the north end of a string of paleolakes that connects the Levantine Corridor to the west and central Arabian Peninsula to the southeast, river networks around the Druze Marsh may have provided an additional inland route for hominins dispersing between Africa, Eurasia, and the Arabian Peninsula during wetter climates. Establishing the full significance of the Druze Marsh and other desert paleolakes for hominin survivorship and dispersal during the Middle and Late Pleistocene requires additional joint paleoenvironmental and archaeological research.

RÉSUMÉ

Situé dans nord-est de la Jordanie, le Marais Druze est une région marécageuse alimentée par une source complètement asséchée depuis les années 1980 à cause de pompages excessifs qui ont abaissé sa nappe phréatique. Afin de reconstruire l'évolution du paysage depuis le Pléistocène moyen jusqu'à aujourd'hui et d'établir la nature des liens entre la présence des hominidés et des changements environnementaux dans la région, la présente étude combine les analyses stratigraphiques et sédimentologiques de sept sondages géologiques et d'une fouille effectuée dans le lit du marais, l'analyse d'artéfacts archéologiques et la datation radiométrique des dépôts archéologiques. Les résultats de ces analyses indiquent que les hominidés occupèrent à plusieurs reprises et d'une manière soutenue le marécage entre la fin du Paléolithique inférieur et l'Épipaléolithique, pendant des intervalles climatiques arides durant lesquelles l'étendue du marais était considérablement réduite. Ces données se complémentent pour suggérer que le marais ait servi de zone de refuge pour les hominidés quand les conditions climatiques se détérioraient dans la région. En ce qui concerne la continuité des populations régionales et leurs extinctions localisées, les résultats de cette étude impliquent notament que les populations préhistoriques occupaient le marais quand le climat était moins clément et l'abandonnait quand le climat s'améliorait et que le basin se remplissait, devenant parfois un lac peu profond qui les repoussait le long des rivières qui se déversent dans le bassin. Étant donné leur situation à l'extrémité nord d'une chaîne de paléolacs reliant le Corridor Levantin à l'ouest et le centre de la Péninsule Arabique au sud-est, ces rivières entourant le marais pourraient ainsi avoir fourni une route intérieure additionnelle pour les migrations humaines entre l'Afrique, l'Eurasie et l'Arabie pendant les périodes humides du Pléistocène. La juste importance du Marais Druze, d'autres paléolacs et des déserts dans le contexte de l'histoire des populations humaines du Pléistocène moyen et supérieur du Proche-Orient reste néanmoins à être étoffée par de futures études paléoenvironnementales et archéologiques plus poussées.

PREFACE

As long as I can remember, history and travel have sparked my interest. I transferred into Anthropology during the second year of my undergraduate studies at the University of British Columbia simply because I enjoyed learning about different cultures, both past and present. I did not know where these studies would lead. I certainly did not expect it would result in me completing a doctorate in Anthropology. In fact, I was hesitant about graduate studies after my Bachelor's degree, and jumped at the chance to work at the Museum of Anthropology in Vancouver. Helping to design and populate a new digital database for their entire archaeological collection, predominantly from the northwest coast of North America, exposed me to a breadth of archaeological remains across time and space that I would never have understood from textbooks and journal articles alone. As a result, I slowly became interested in the historical processes and mechanisms that produced the variation I was observing, and how and why it changed over time. These questions, combined with the encouragement of Dr. Susan Rowley at the University of British Columbia, landed me in a Master's program in Anthropology at McGill University in 2007. During this degree, I compiled a large list of well-dated sites from the southwest coast of British Columbia and analyzed how the artifact assemblages changed through time and space. In addition to the conclusions concerning the prehistory of southwest British Columbia, my research highlighted the limitations of large comparative projects – specifically that the context of artifact assemblages controls the resolution at which comparisons can be made. This is when I first understood that the dirt surrounding the artifacts is critical for establishing the context of archaeological remains, and that without this context the artifacts from one site cannot be productively compared to those from other sites. With the benefit of hindsight, I see it was in fact my Master's research that pushed me toward geoarchaeology.

The topic of my doctoral dissertation resulted by chance. I was not actively seeking a project in Jordan; the country was not even on my radar. My interests were in regional scale comparisons and change over time in prehistory, specifically in southwest British Columbia. I had developed competency in a number of techniques to facilitate this type of research, which included operating a total station and Geographic Information Systems. Thanks to this skill set, I was hired by Professor Michael Bisson at McGill University to accompany the Druze Marsh Archeological and Paleoecological Project in Jordan during the 2008 field season. It began as a summer job, but after witnessing the stratigraphy and seeing a prehistory that extended back in time by orders of magnitude more than my previous experience, I was hooked. It was an opportunity for me to overcome the challenges I faced in my Master's research by actually studying the dirt to better understand the archaeological remains and how and why they changed over time. After discussing my ideas with Dr. April Nowell, the project director, and Dr. Carlos Cordova, the project geoarchaeologist, it was official: my doctoral research would analyze the Druze Marsh stratigraphy to establish the relationship between paleoenvironmental change and its rich archaeological record that dates back to the Lower Paleolithic.

The archaeological periods involved and the geographic location of such a project inevitably overlap with fundamental paleoanthropological questions of human dispersals out of Africa and potential interactions between archaic and anatomically modern humans. These topics are pervasive in the recent literature and are being approached from paleoanthropological, archaeological, genetic, and paleoenvironmental perspectives, among others. Taken together, the data present a complex pattern of hominin demography in the Levant and Arabian Peninsula with multiple waves of dispersal out of eastern Africa at different times, interspersed with hominin range expansions, contractions, and possible extinctions. The details are unclear.

The research presented in this dissertation examines the Druze Marsh stratigraphy and associated sequence of hominin occupation in order to help with clarifying this complex demographic pattern. Detailed sedimentological analysis demonstrates that the Druze Marsh spring sites were a desert refugium for hominins during adverse regional climates, identifying it as potential location where archaic humans survived and potentially interbred with anatomically modern humans during successive dispersal events. Moreover, wetter conditions allowed hominins to expand their ranges out of the Druze Marsh proper along river networks that extend west toward the Levant and southeast into the Arabian Peninsula, placing the Druze Marsh at the intersection of a possible inland migration corridor connecting the Levant to the Arabian Peninsula during wet climatic episodes. Although this study addresses a number of questions concerning hominin occupation in the Druze Marsh, many remain. It demonstrates that a geoarchaeological approach is critical to understanding the impact of landscape evolution on hominin settlement dynamics. The results also point toward the eastern Levantine desert and the north Arabian Peninsula as promising regions for future research on hominin dispersal and demography.

CONTRIBUTION OF AUTHORS

The research presented in this thesis is a work of original and independent scholarship. However, as a member of a collaborative research team many parts of my PhD research benefitted from the research and field work of others. In addition, a number of sections of this dissertation are the foundation for a co-authored article, of which I am lead author, titled “Paleoenvironmental change and settlement dynamics in the Druze Marsh: results of recent excavation at an open-air Paleolithic site,” which is currently in press with *Quaternary International*. For transparency purposes, the various research and field work contributions, as well as the sections related to the co-authored article, are outlined below. For a full list of people who helped guide this research to completion, please refer to the acknowledgments section.

Data collection for this thesis is based on three field seasons in 2008, 2009, and 2011. The 2008 and 2009 field seasons were funded and organized by Dr. April Nowell at the University of Victoria and director of the Druze Marsh Archaeological and Paleoecological Project (DMAPP). During these two field seasons, in which I participated, many sediment samples were collected by the project – mostly by Dr. Carlos Cordova – which I ultimately analyzed and interpreted for this dissertation. Moreover, I worked closely with Dr. Cordova to describe and interpret the stratigraphic profiles during the 2008 and 2009 field seasons. I am solely responsible for organizing and conducting the 2011 field work, which was funded by fellowships and grants I obtained independently. During the 2011 field work, I performed all descriptions and interpretations and collected all sediment samples. Nevertheless, because much of the field work was conducted in a team environment, I will use third person plural (i.e. we and us) when detailing the field work and previous research. I will refrain from using the first person singular unless specifically referring to an event I conducted in isolation from other team members.

Following fieldwork, I organized and conducted all laboratory analyses for this research, which includes the analysis of samples collected by Dr. Cordova. The only samples I did not analyse myself are the radiometric age samples (see

Appendix D). Typological classification and analysis of the condition and alteration of the artifacts was conducted by Professor Michael Bisson from McGill University, but I conducted all other post-classification analyses of the artifacts, which include spatial data manipulation and correlation with the sedimentological data. In the dissertation a number of radiometric age estimates are discussed. DMAPP had Dr. Regina DeWitt (East Carolina State University) analyze the optically stimulated luminescence (OSL) dating samples. The values reported in the thesis are from the unpublished report she provided to DMAPP (see Appendix D). All Uranium/Thorium (U/Th) age estimates were conducted by Dr. Bassam Ghaleb at the Université du Québec à Montréal. The U/Th age estimates have been published prior to this thesis and are cited appropriately throughout the text (see Appendix D). I am responsible for integrating and interpreting the various data, and produced all figures and tables unless otherwise noted in the caption.

While writing this dissertation I also produced an article on behalf of DMAPP for submission to the journal *Quaternary International*. It was submitted for publication on March 8, 2013 and was accepted for publication on April 16, 2013. A number of sections of this thesis were the foundation for the co-authored article, they include: paragraph 1of section 1; modified versions of sections 3.1, 8.1, and 8.3; summarized versions of sections 3.3, 5, 6.1.1, 7.1, and 7.2. I am responsible for the analysis and initial writing of the article, aside from a short section written by Dr. April Nowell that is not included in this thesis. I received valuable editorial assistance from the co-authors, and because the writing was derived from my dissertation, their comments subsequently assisted with the editing of my dissertation as well. However, all of the writing in this thesis is my own, based on original and independent laboratory research and post-field work analysis. Although none of the work in this dissertation is explicitly collaborative, permission was obtained from all members of the co-authored article to ensure transparency. It must also be noted that paragraph 4 in section 3.2 is a modified version of a paragraph that is part of a chapter I submitted to an edited volume (see Ames and Cordova, In Press). Figure 7.3 is reproduced from the same article. Permission has been obtained from the co-author, Dr. Carlos Cordova.

1. INTRODUCTION

Fluctuating cycles of wet and dry conditions over the past 2 million years in the eastern Mediterranean region provided windows of opportunity for hominins and other animals to move along the Levantine Corridor between Africa and Eurasia (Bar-Yosef, 2000; Lahr and Foley, 2003; Goren-Inbar and Speth, 2004; Belmaker, 2010; Bar-Yosef and Belmaker, 2011; Bar-Yosef and Belfer-Cohen, 2013) and/or between Africa and the Arabian Peninsula via a number of possible migration routes (Parker, 2009; Armitage et al., 2011; Petraglia, 2011; Rosenberg et al., 2011; Drake et al., 2013; Groucutt and Petraglia, 2012). One potential route between the Levant and Arabia is a string of paleolake basins that follows the Wadi Sirhan depression from eastern Jordan into the north-central Arabian Peninsula (Figure 1.1). The Greater Azraq Oasis Area (GAOA), one of these paleolake basins and the regional focus of this study, sits on the eastern Jordanian Plateau between the Levantine Corridor to the west and at the northern end of the Wadi Sirhan depression (Figure 1.2), making it an important crossroads for hominin dispersals into Eurasia and Southwest Asia (Petraglia and Alsharekh, 2003; Rose and Petraglia, 2009; Armitage et al., 2011; Petraglia et al., 2011; Rosenberg et al., 2011; Cordova et al., 2013; Groucutt and Petraglia, 2012).

When the Pleistocene environment transitioned from wet to dry conditions, the springs in Azraq would have continued to flow for several thousands of years due to recharge of the aquifer during previous wet conditions (Noble, 1998; Jones and Richter, 2011; Cordova et al., 2013), turning the GAOA into a pocket of concentrated resources in an otherwise harsh and potentially inhospitable environment.

Evaluating the role of the Azraq springs for hominin occupation, survival, and/or extinction in the eastern Levantine desert is the goal of the Druze Marsh Archeological Project (DMAPP), specifically asking if the GAOA acted as a desert refugium for hominins during times of adverse climatic conditions throughout the Pleistocene (Ames and Cordova, In Press; Cordova et al., 2009, 2013). As a contribution to DMAPP, the research presented in this study is a geoarchaeological analysis of the stratigraphic succession at one of the former spring locations in the GAOA, the Druze Marsh, to determine how the archaeological sequence relates to the history of local environmental change and to better understand the chronology, depositional context, and post-depositional alteration of the archaeological horizons.

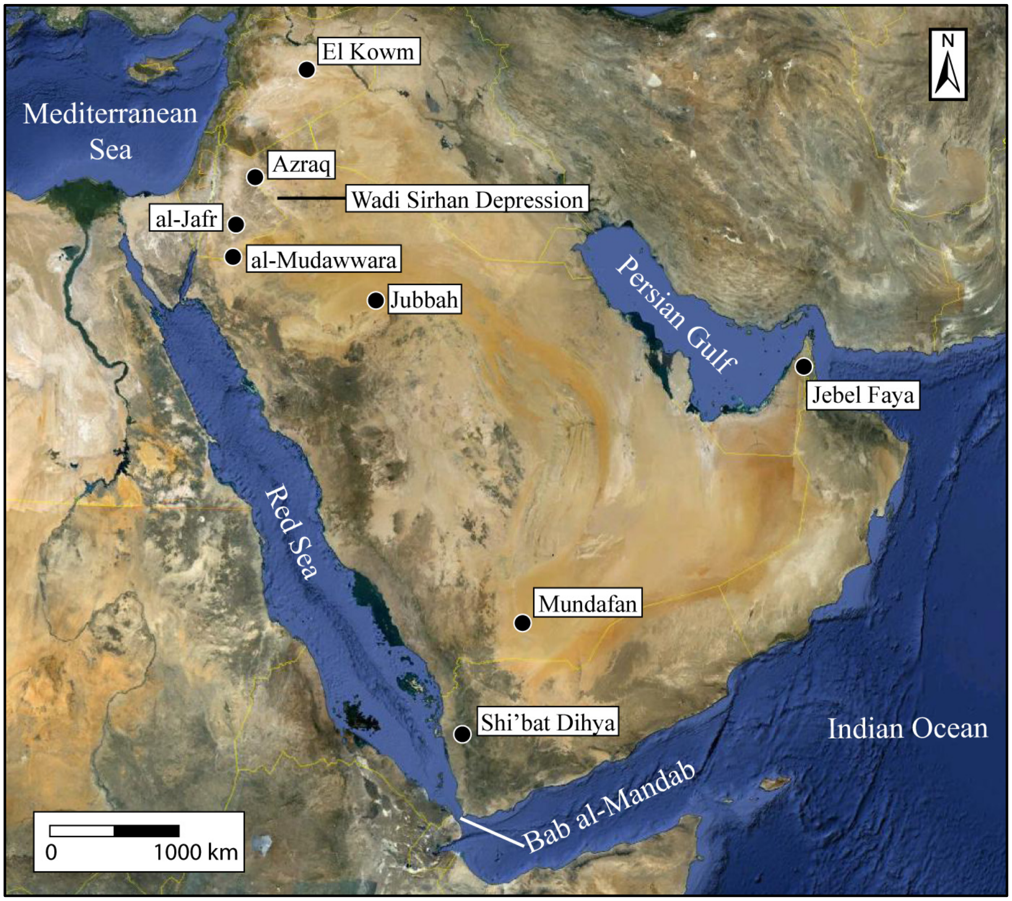

Figure 1.1 Map of Middle East with locations and features mentioned in the text (base map: Google Earth, 2013).

The Druze Marsh is a spring-fed wetland located approximately 80 km east of Amman, the capital city of Jordan, which dried out completely in the late 1980s after pumping of the aquifer lowered the water table (El-Naqa, 2010). The falling water table caused the marshes to dry out and, in response, the local residents began to dig wells. In the process of digging wells, Paleolithic tools were exposed, suggesting that prehistoric occupations are contained in the marsh deposits, which previous surveys did not report because they were underwater at the time. In the spring of 2008, the Department of Antiquities of Jordan granted our team a permit to investigate the potential Paleolithic occupations in the Druze Marsh. When our team arrived at the Druze Marsh in June of 2008, we encountered construction of the Azraq Children's Park that was encroaching onto the dry marsh bed. Three large foundation pits for the park's toilet facilities and septic tanks had exposed deeply stratified deposits embedded with Paleolithic artifacts spanning the Lower through Epipaleolithic. The imminent refilling of the pits compelled our team to carry out rapid salvage work in order to recover as much information as possible about the stratigraphy and any archaeological horizons.

The preliminary salvage work indicated that throughout the Middle, Upper, and Epipaleolithic, cycles of marsh and/or lake activity were interrupted by drier environments, causing a reduction in the wetland area (Ames and Cordova, In Press; Cordova et al., 2009, 2013). In response to the rich record encountered, the team obtained permission to open three trenches on the adjacent property and dug five shallow test pits along a trench near channels that flowed into the historic marsh. We observed a similar stratigraphic succession and archaeological sequence as that which was identified in the construction pits. The relationship between this fluctuating wetland and the history of hominin settlement at the Druze Marsh needed to be refined – a project that became the foundation of the dissertation research presented here. The team returned to the Druze Marsh in 2009 to conduct a 2 x 1 m excavation extending from the south wall of one of the trenches opened during the 2008 season. We also opened an additional trench near the northwestern perimeter of the former marsh to expand our spatial understanding of the stratigraphic succession. I returned independently to the study location in 2011 to deepen the original shallow test pits from the 2008 season and collect additional samples.

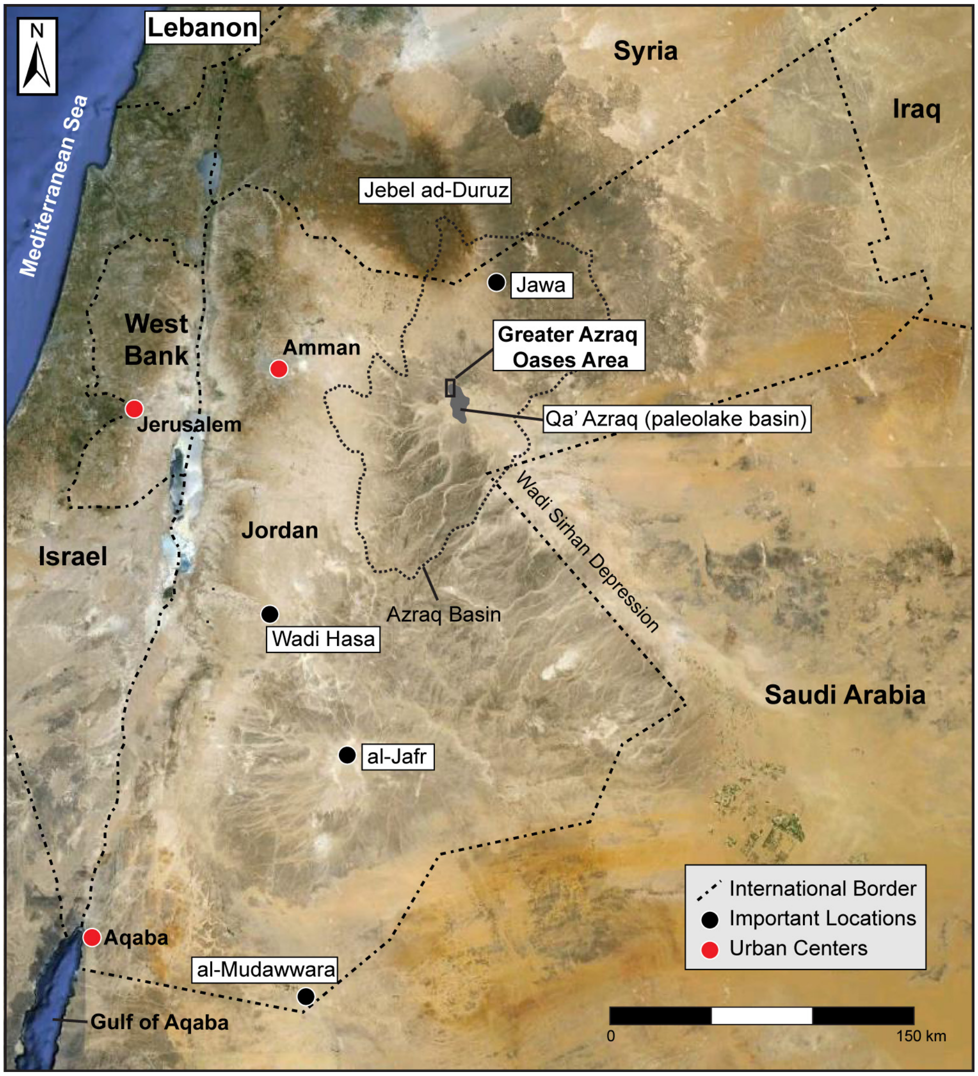

Figure 1.2 Regional context of the Greater Azraq Oasis Area (base map: Google Earth, 2013).

Based on data collected during the 2008, 2009, and 2011 field seasons, the present research combines detailed stratigraphic and sedimentological analysis from one controlled excavation and multiple geological test pits in the former marsh bed with artifact analysis to reconstruct the changing landscape throughout the Middle and Late Pleistocene, and then relate the sequence of hominin settlement in the Druze Marsh to environmental change.

This dissertation begins by outlining the questions that must be answered to establish the relationship between the stratigraphic succession and the sequence of archaeological occupation in the Druze Marsh. The questions are followed by a series of expected test implications for this relationship if the Druze Marsh did act as a desert refugium for hominins during times of adverse regional climatic conditions. An introduction to the study area follows, before briefly placing the Druze Marsh in the broader paleoanthropological context of hominin dispersals, population turnovers, and the possibility of interaction between Anatomically Modern Humans (AMH) and Neanderthals in the Levant. Detailed description of the field and laboratory methods follows and precedes the presentation of the results. Subsequently, the discussion is divided into two sections. The first discussion section presents the stratigraphic correlation of the Druze Marsh sequences and the reconstructed history of Paleolithic settlement. This first section also contextualizes the results within similar local and regional archaeological and paleoenvironmental records to highlight the impact of fluctuating paleoenvironments on Paleolithic settlement dynamics in the GAOA. The second discussion section addresses the future of research at the Druze Marsh, specifically the unique opportunity such a large open-air site offers for expanding our understanding of the range of environments exploited by hominins, as well as and how their mobility patterns were affected by local, regional, and global environmental fluctuations. In open-air contexts, however, the distribution of buried and surface archaeological remains is greatly affected by geomorphic processes that acted on the landscape throughout the Pleistocene and Holocene. By outlining the interpretive constraints of large open-air sites, I show that a robust understanding of the Paleolithic settlement history of the Greater Azraq Oasis Area since the Middle Pleistocene (ca. 780 ka), and subsequently its importance as a desert refugium along a possible dispersal corridor, can only be achieved by reconstructing the regional history of landscape change and evaluating the influence of landscape change on the visibility, integrity, and spatial distribution of the archaeological material.

2. QUESTIONS, HYPOTHESES, AND RESEARCH OBJECTIVES

2.1. Questions

The goal of this study is to establish the relationship between the Middle (ca. 780-125 ka) and Late (ca. 125-12 ka) Pleistocene stratigraphic succession and the sequence of archaeological occupation in the Druze Marsh. To understand this relationship, several issues need to be addressed: sediments and depositional environments, artifacts and occupation horizons, and paleoenvironmental and cultural chronologies. These issues can be framed into three research questions:

1) What sedimentary units are present, and what depositional environments or geomorphic landforms do they represent?
2) What is the nature of the archaeological material, their associated depositional environments, and what post-depositional alteration has affected their integrity?
3) What is the chronology of sedimentary deposition and paleoenvironmental change? What temporal window can we attribute to the archaeological occupations and paleoenvironmental changes?

2.2. Hypotheses

As discussed in the introduction, the overarching question of the DMAPP project asks if the Azraq oasis functioned as a locus of hominin activity during adverse regional climatic conditions. If this is the case, there should be increased hominin activity in the Druze Marsh at times of increasing regional aridity as indicated by shrinking or drying of the wetland area. This produces a number of expected outcomes or test implications for the nature of the relationship between the wetland stratigraphy and the occurrence of archaeological material, which are stated in the following hypotheses:

1) Cultural material should be found in deposits or at stratigraphic breaks that indicate a shrinking or drying of the wetland, which include erosional surfaces, aeolian deposits, or shallow seasonal wetland deposits.

2) As occupation does not occur underwater, artifact accumulations will not occur in deposits that indicate a large perennial wetland or lake, which include lacustrine and palustrine sediments.
3) As an extension of hypothesis 2, lacustrine and palustrine deposits that do contain embedded cultural material may indicate seasonal fluctuation in water availability that left the marsh or lake bed exposed for periods of time, which is a common phenomenon in dryland environments. Another possibility is that the artifacts are in secondary context, which will be apparent in the artifact angles of repose, signs of damage or abrasion, and/or variations in patination.

2.3. Objectives

In order to address my primary research questions and evaluate my hypotheses, the primary objectives of this study are to:

1) Map all DMAPP test pit locations in the bed of former Druze Marsh and record their stratigraphy.
2) Analyze the stratigraphy of the controlled excavation at ~10cm intervals and correlate it with the stratigraphy from other test pit locations throughout the Druze Marsh.
3) Correlate specific depositional environments with the archaeological sequence in the controlled excavation and assess the nature and integrity of the cultural horizons.
4) Reconstruct the landscape evolution in the former Druze Marsh and produce a chronology of events using stratigraphic correlation, available radiometric dates, and artifact classification.
5) Compare the reconstructed landscape evolution and history of hominin occupation with other sedimentary sequences in the Greater Azraq Oasis Area and relevant paleolake basin sites in the Levant and Syro-Arabian Desert.

3. STUDY AREA

3.1. Geographic Setting

The GAOA is located approximately 80 km east of Amman on the northwest corner of Qa' Azraq, a 75 km^2 salt mudflat marking the lowest point of the ca. 12,750 km^2 endorheic Azraq Basin (Figures 1.2 and 3.1). The GAOA sits at the contact between the Miocene-Pliocene basalt flows to the north and the Maastrichtian and Eocene limestone deposits to the south (Figure 3.2), the latter of which are blanketed by Quaternary deposits grouped into the Azraq Formation (Ibrahim, 1996). Although not fully studied or dated, a number of Pleistocene-age deposits have been described in the GAOA and throughout the Azraq Basin. These deposits include Middle Pleistocene sandstones (Turner and Makhlouf, 2005), upland lacustrine terraces (Abed et al., 2008), lacustrine deposits in the center of the Qa' (Davies, 2000, 2005) and near the spring-fed wetlands (Cordova et al., 2009, 2013; Jones and Richter, 2011), and terraces along a number of the ephemeral rivers – wadis – that flow into the Qa' (Bescançon et al., 1989).

The present climate in the GAOA is hot and arid. Temperatures in the summer can exceed 45˚C with an average July temperature of 27˚C. The average temperature in January is 12˚C with lows dropping below freezing (El-Naqa, 2010). The center of the GAOA receives less than 50 mm/year of highly seasonal precipitation, predominantly falling in storms between January and March (El-Naqa, 2010). Historically, groundwater was accessible via two spring-fed wetlands, both associated with modern communities (Figure 3.1). The town of Azraq Shishan, or South Azraq, is adjacent to the Shishan Marsh and Azraq ad-Duruz, or North Azraq, is adjacent to the Druze Marsh. Water over-extraction throughout the second half of the 20th century led to dramatic drops in the local water table, causing both major wetlands to dry out by the late 1980s and early 1990s (Fariz and Hatough-Bouran, 1998; Al-Kharabsheh, 2000; El-Naqa, 2010). Conservation efforts by the Royal Society for the Conservation of Nature (RSCN) have helped reclaim and maintain the south marsh, although the wetland area is greatly reduced in size compared to historic times (France, 2010). The Druze

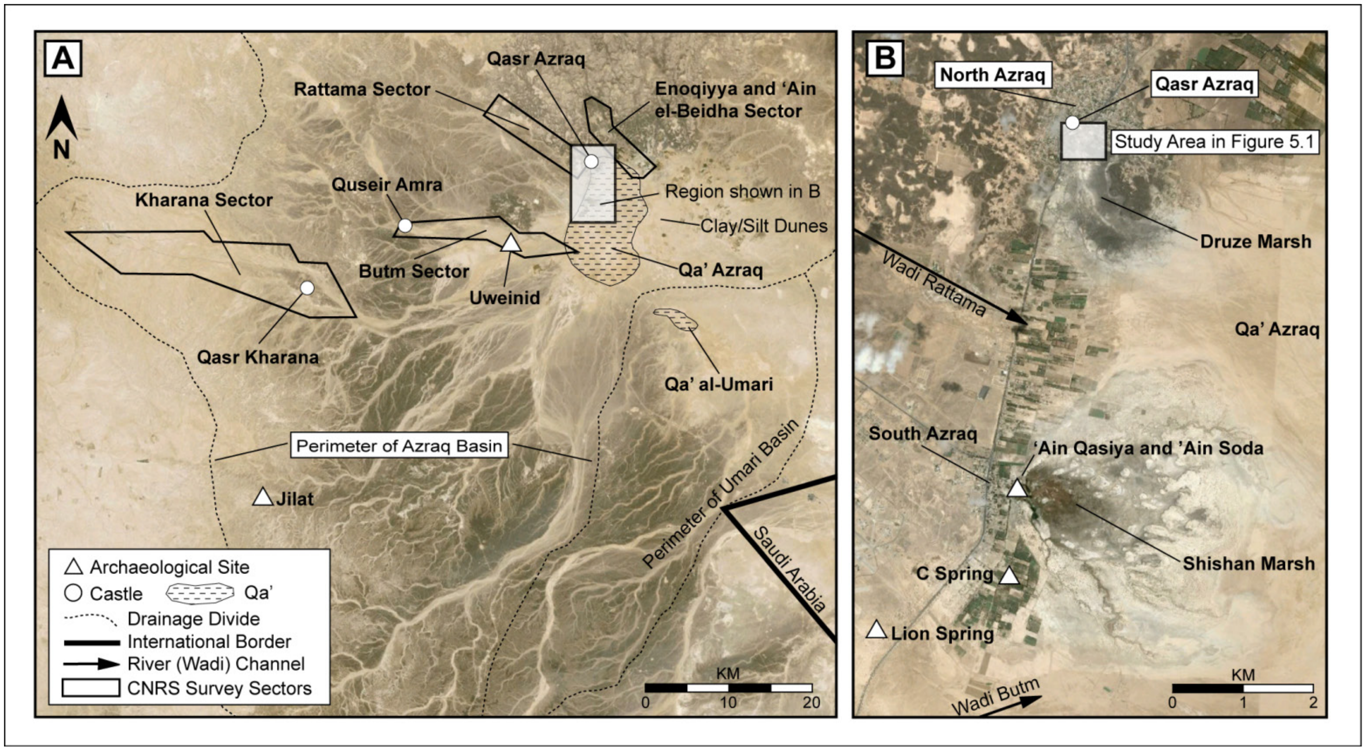

Figure 3.1 Map of the central Azraq Basin (A) and Greater Azraq Oasis Area (B) with locations discussed in the text (base map: Google Earth, 2012).

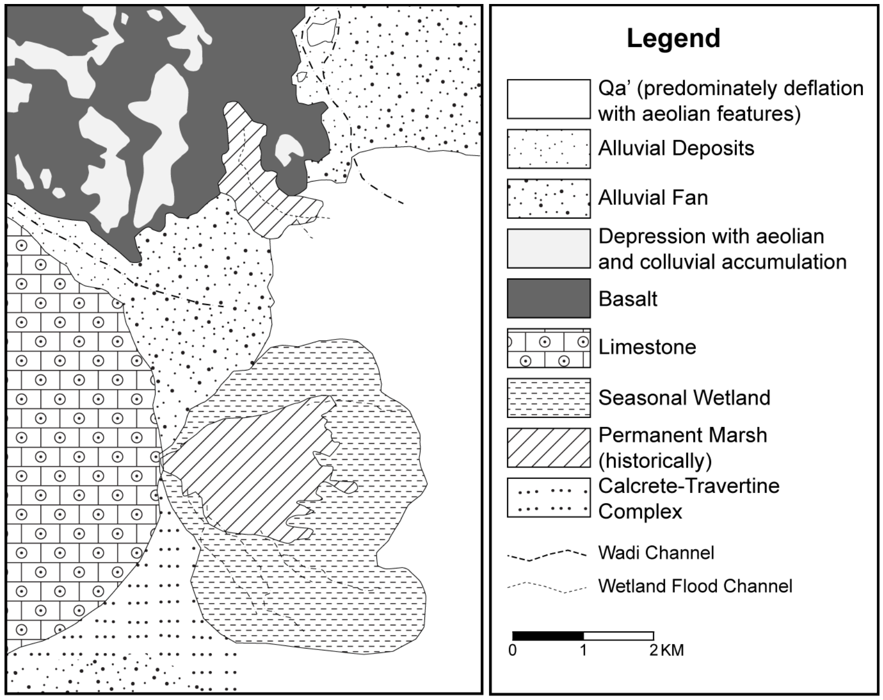

Figure 3.2 Geological Map of the Greater Azraq Oasis Area. The areal extent matches Figure 3.1B (adapted from Cordova et al., 2013, Figure 2B)

Marsh dried out completely in the late 1980s and remains that way today (El-Naqa, 2010). The remnant of the former marsh bed covers approximately 2 km^2 and is the focus of this study (Figure 3.1B). Additional detail on the geology and geography is available from a number of sources (see Nelson, 1973; Bender, 1974; Bescançon et al., 1989; Ibrahim, 1996; El-Naqa, 2010; Jones and Richter, 2011; Cordova et al., 2013)

3.2. Hydrological Setting

The Azraq Basin is one of the most important sources of ground and surface water in northeast Jordan, and second only to Palmyra in the Syro-Arabian Desert (Kennedy and Riley, 1990). Most of the Azraq Basin is situated within Jordan's borders (94%); the remainder extends into Syria (5%) and Saudi Arabia (1%) (El-Naqa, 2010). Water pumped from the basin currently supplies the capital city of Amman, and other large urban centers of Zarqa and Irbid (Al-

Kharabsheh, 2000). It is said that one out of every four glasses of water in Amman comes from the Azraq Basin (France, 2010). Moreover, water quality and yield measurements from the Azraq aquifer complex are superior to other basins in the region (El-Naqa, 2010). The name Azraq (الأزرق) means 'blue' in Arabic, highlighting the importance of the high quality freshwater available year round in what is otherwise a harsh, arid environment.

The Azraq Basin aquifer system contains three primary aquifers: an upper, middle, and lower (Al-Kharabsheh, 2000). The upper aquifer, or the Shallow Aquifer System, resides in Quaternary and Tertiary Formations that include recent alluvium, basalt, and weathered and argillaceous limestone. It is the source of the high quality freshwater and is the main target of substantial pumping, putting it at risk of salinization due to over-exploitation (El-Naqa, 2010). It is estimated that water in this aquifer ranges between 20-5 ka (Al-Kharabsheh, 2000); and before the wetlands dried out in the 1990s, it was only a few metres below the surface in the central basin. It primarily discharged via four springs: the Aura and Mustadehma springs in Azraq ad-Duruz, and the Sawda and Qasiyya springs in Azraq Shishan (Al-Kharabsheh, 2000). Marls and chalks with low permeability separate the middle limestone aquifer, containing brackish water, from the upper aquifer; the lower aquifer is located in deep sandstone and is poor quality with low yields (Al-Kharabsheh, 2000; El-Naqa, 2010).

The aquifer system is primarily recharged by rainfall to the north, northeast, and northwest (El-Naqa, 2010). Average annual precipitation in the Jabal ad-Duruz area of southern Syria is ~350 mm (Figure 1.2) (Fariz and Hatough-Bouran, 1998). Estimates of aquifer recharge vary substantially between the wet and dry seasons, but on average 35 x 10^6 m^3 of water infiltrates into the system yearly. After accounting for the 9 x 10^6 m^3/year lost to evapotranspiration, the net recharge is approximately 25 x 10^6 m^3/year (Al-Kharabsheh, 2000). As of 2010 it was estimated that >900 wells extract roughly 60 x 10^6 m^3/year (El-Naqa, 2010), not accounting for potential clandestine wells (Cordova et al., 2013). Such over-extraction has caused a gradual drop in the water table since at least the early

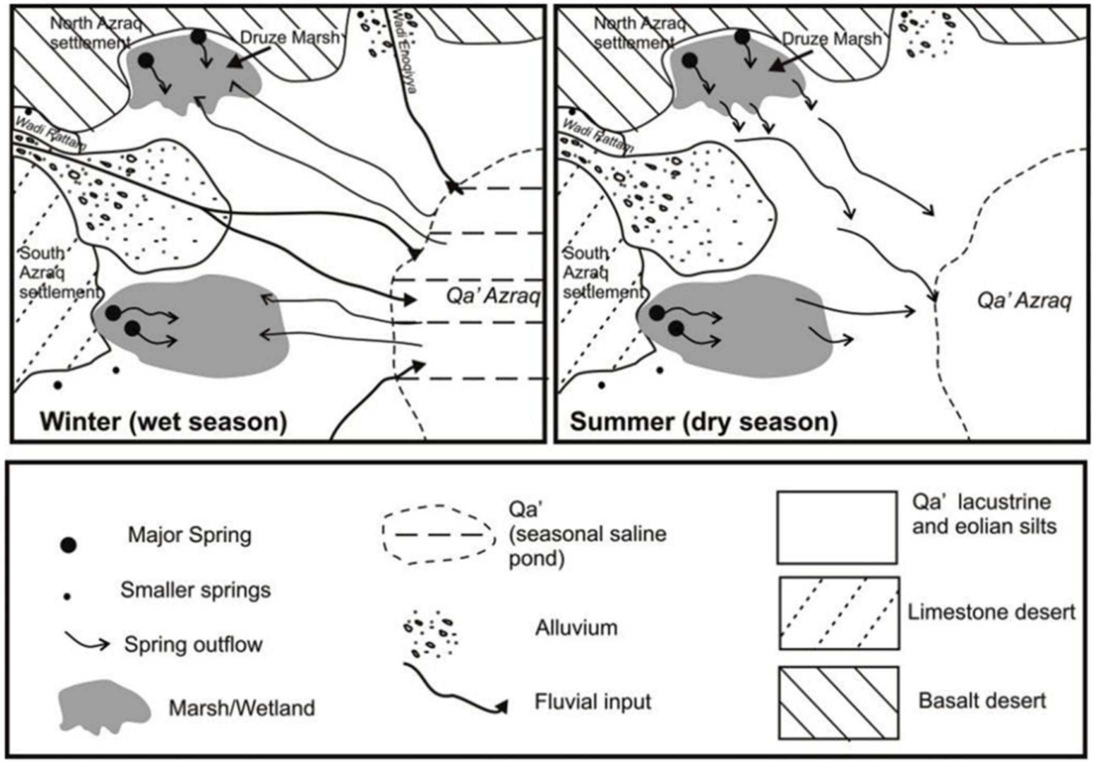

Figure 3.3 Historical hydrological cycle of the Azraq marshes (Reprinted from *Quaternary International* 300 (2013), Carlos E. Cordova, April Nowell, Michael Bisson, Christopher J.H. Ames, James Pokines, Melanie Chang, Maysoon al-Nahar, Interglacial and glacial desert refugia and the Middle Paleolithic of the Azraq Oasis, Jordan, 94-110, Copyright (2013), with permission from Elsevier).

1980s (El-Naqa, 2010) and is the reason why the Azraq springs stopped flowing in the early 1990s.

Prior to a reduction in the water table, the Azraq wetlands were a seasonal hydrological system characterized by seasonal changes in the quality and amount of water in the marshes due to spring flow and fluvial input (Nelson, 1973). The system of seasonal water flow involved exchanges of water between the marshes and the Qa' (Figure 3.3). At the onset of the rainy season, or winter, when the water levels were low after a long dry season, high intensity storms would fill the wadis and flow into the center of the basin. The increased water level in the seasonal pond would rise, and when high enough, would breach the low sill that separates the Qa' from the marshes, forcing water and suspended sediment to flow through channels toward the marshes, where it would mix with and increase the depth of the wetland. By the end of the rainy season the flow from the marsh would equal the flow from the Qa' itself, recharging the springs for the dry season. During the dry season, or summer, the fluvial influx from the wadis to the central basin stopped and high temperatures would increase evaporation. The recharged springs would maintain pools in the marshes and flow through the same channels into the central basin, but water would quickly evaporate, leaving a salt mudflat or sabkha. Results discussed in this study, in conjunction with previous research, suggest that a similar pattern functioned throughout the late Holocene, but acted on a larger scale at times during the Quaternary (Ames and Cordova, In Press; Copeland, 1988; Garrard et al., 1988; Rollefson et al., 1997; Abed et al., 2008; Frumkin et al., 2008; Jones and Richter, 2011).

3.3. Paleolithic Archaeology of the Azraq Basin

Evidence for Paleolithic occupation of the Azraq Basin was first identified in the early half of the 20th century (Maitland, 1927; Rees, 1929). These initial findings consisted of surface material of unknown age, but the discovery of impressive Lower Paleolithic artifacts during construction of an irrigation system in 1956 (Kirkbride, 1989) solidified Azraq as an important Paleolithic landscape. In the nearly 60 years since this original discovery, a body of research has accumulated to show that the region was occupied during every major Paleolithic time period since the Middle Pleistocene (Rollefson, 1983, 1984; Garrard et al., 1987; Copeland and Hours, 1989a; Rollefson et al., 1997; Jones and Richter, 2011; Cordova et al., 2013).

Initial discovery of the rich Paleolithic archaeological record in the Azraq Basin happened by chance when Mr. R.R. Panell of the Baker & Harza Engineering Company recognized Paleolithic artifacts in the dredging buckets during construction of the Azraq Irrigation Project in 1956. A series of visits to the location by archaeologists ensued (Zeuner et al., 1957; Kirkbride, 1989). The artifacts collected from 'Ain el-Assad during these short visits – now commonly referred to by its English translation of Lion Spring – were examined by Copeland (1989a, 1989b). The artifacts are almost exclusively Lower Paleolithic types, dominated by bifacial cleavers, suggesting to Copeland that the material dates to the Late Acheulean.

The archaeological potential of the Azraq Basin brought a team of researchers led by A. Garrard (Garrard et al., 1988; Turnbull, 1989) to the area beginning in the mid-1970s. The goal was to study the development of sedentism and plant and animal domestication immediately following the Last Glacial Maximum. Their initial survey focused on three locations: Wadi el-Jilat and Wadi el-Uweinid to the west of the Azraq wetlands, and the immediate vicinity around the Shishan Marsh, specifically the area near C Spring that was identified by Zeuner and Kirkbride during the Baker & Harza construction (Kirkbride, 1989). Their preliminary results identified surface artifacts spanning the Lower Paleolithic through the Neolithic in a variety of geomorphic contexts, although Upper Paleolithic material was scarce (Garrard et al., 1988) (Table 3.1). Of particular note, the small 3 x 1 m sounding at C Spring produced a Lower Paleolithic deposit with approximately 2700 pieces of worked flint (Hunt and Garrard, 1989). Copeland's analysis of the retouched tools clearly identified the assemblage as Late Acheulean and similar to the material found at Lion Spring 25 years earlier (Copeland, 1989c). The high prevalence of bifacial cleavers led her to classify it as a unique tool-kit called the Late Acheulean of Azraq facies, a designation that seems appropriate considering the high numbers of bifacial cleavers also found at the nearby Lion Spring (Copeland, 1989a, 1989b) and 'Ain Qasiyya (Rollefson et al., 1997; Cordova et al., 2008). Rollefson conducted two seasons of excavation at Lion Spring in 1980 and 1981 in attempt to relocate the rich Lower Paleolithic layers (Rollefson, 1983). Although unsuccessful in this goal, his team identified *in situ* Pre-Pottery Neolithic deposits (Rollefson, 1983; Turnbull, 1989), adding to the wealth of archaeological material beginning to be known throughout the basin.

Following their initial results, Garrard and his students continued research on the Epipaleolithic and Neolithic sites (Garrard et al., 1994; Richter, 2009), while Copeland and Hours were invited by Garrard to examine the Lower and Middle Paleolithic occupations in the Azraq Basin and place them in chronological and regional context (Copeland and Hours, 1989b). Between 1982 and 1986, Copeland and Hours, under the auspices of the Centre National de la Recherche Scientifique (CNRS) at the Université Lumière in Lyon, undertook a detailed archaeological and geomorphological survey of four sectors along major wadi channels flowing into the central Azraq Qa' (Copeland and Hours, 1989a) (Figure 3.1A). Each sector produced Lower and Middle Paleolithic artifacts on the surface, but buried archaeological deposits were more variable. Although well known for the Epipaleolithic site of Kharaneh IV (Muheisen, 1988; Maher et al., 2012), the Kharana sector produced very few Lower and Middle Paleolithic artifacts in buried context, and when they were encountered, they were in redeposited alluvial terraces and heavily damaged (Copeland and Hours, 1989b) (Table 3.1). Acheulean artifacts were ubiquitous in the Rattama sector, while Middle Paleolithic finds were less common. The Butm sector provided similar results. Although they recognized the potential long time frame represented by the Lower Paleolithic artifacts in the Kharana, Butm, and Rattama sectors, the considerable typological similarity, regardless of geomorphic context, led Copeland and Hours (1989b) to designate the entire Lower Paleolithic collection as Desert Wadi Acheulean (DWA), specifically to separate it from the Late Acheulean assemblages found near the springs. The DWA is less evolved than the

Late Acheulean from the springs, and likely older, but the proto-Levallois debitage and the generally refined nature of the bifaces suggest it also falls into the Late Acheulean (Copeland and Hours, 1989b). The Middle Paleolithic was also identified in the Kharana, Butm, and Rattama sectors, but due to the small sample size it was difficult to draw any conclusions. This contrasts with the data from the Wadi Enoqiyya sector, which produced predominately Middle Paleolithic artifacts that typologically match the Levantine Mousterian (Hours, 1989). Despite collecting more than 7000 pieces, all finds in the Enoqiyya sector were from surface contexts. The ‘Ain Beidha region on the northeast corner of the GAOA also produced surface finds from a number of time periods, but the area was not subject to a systematic study and remains a promising location for future work (Copeland, 1989d).

Table 3.1 Previous archaeological material identified in the Azraq Basin and associated geomorphic contexts.

Location (see Figure 3.1)	**Archaeological Periods Identified**	**Geomorphic Context**	**References**
Kharana Sector	Lower Paleolithic Middle Paleolithic Epipaleolithic Neolithic	Surface and reworked terrace deposits Surface and alluvial terrace deposits Buried, in situ Surface, in situ	Copeland and Hours, 1989b; Maher et al., 2012; Muheisen, 1988
Butm Sector	Lower Paleolithic Middle Paleolithic Epipaleolithic	Alluvial conglomerate Surface Surface, in situ, and buried aeolian deposits	Copeland and Hours, 1989b; Garrard et al., 1988
Rattama Sector	Lower Paleolithic Middle Paleolithic Epipaleolithic	Surface and alluvial gravels Surface and alluvial gravels Surface and wadi bank	Copeland and Hours, 1989b
Enoqiyya Sector	Middle Paleolithic Upper Paleolithic Epipaleolithic Neolithic	Surface, wadi Surface, wadi Surface, wadi Surface, wadi	Hours, 1989

Lion Spring	Lower Paleolithic Pre-Pottery Neolithic	Buried, sand and gray clay Buried, grayish brown silty clay	Kirkbride, 1989; Copeland, 1989a, 1989b; Rollefson, 1983
C Spring	Late Lower Paleolithic Epipaleolithic Neolithic	Buried, blue-gray silt Buried, silty clay and silt dunes, and surface Buried aeolian silts and silt dunes	Copeland, 1989c; Garrard et al., 1988; Hunt and Garrard, 1989
Wadi Uweinid	Lower Paleolithic Epipaleolithic	Surface Buried aeolian deposits	Garrard et al., 1988; Rollefson, 1994
‘Ain Beidha	Lower Paleolithic Middle Paleolithic Upper Paleolithic Epipaleolithic	Surface Surface Surface Surface	Copeland, 1989d
‘Ain Qasiyya and ‘Ain Soda	Lower Paleolithic Middle Paleolithic Epipaleolithic Neolithic	Surface, disturbed and buried, uncertain Surface, disturbed and buried, silty clay with large clasts Surface, disturbed, and buried, in situ Surface, disturbed, and buried, in situ	Jones and Richter, 2011; Rollefson et al., 1997
Wadi Jilat	Middle Paleolithic Upper Paleolithic Epipaleolithic Neolithic	Alluvial conglomerate Alluvial deposits Colluvial/alluvial deposits and aeolian deflation surface Surface	Garrard et al., 1988

Previous research in the Azraq Basin clearly demonstrates the importance of the region as a locus of prehistoric occupation since at least the Late Lower Paleolithic. Surface and buried remains, although in considerably different quantities, appear in every area of the basin that has been tested (Figure 3.1; Table 3.1). Substantial erosion has impacted the integrity of much of this record (Bescançon et al., 1989), but that does not mean it should be ignored, especially considering the traces of artifact-bearing alluvial deposits that have been identified (Copeland and Hours, 1989b). Integrating the record from the wadi channels with the known Paleolithic occupations at Lion Spring, C Spring, and

‘Ain Qasiyya provides an opportunity to improve our understanding of prehistoric settlement in the Azraq Basin since the Late Lower Paleolithic. Recent research by the Druze Marsh Archaeological and Paleoecological Project (Cordova et al., 2009, 2013) and the research presented in this study add to the growing body of knowledge on prehistoric occupation in the Azraq Basin. Of particular importance is the buried *in situ* Middle Paleolithic occupation surface identified during the 2009 excavation (Cordova et al., 2013). Although present at a number of locations on the surface, the Middle Paleolithic is a time period for which few buried contexts are known from the Azraq Basin.

4. THE PALEOANTHROPOLOGICAL CONTEXT

Both fossil and genetic evidence indicate that *Homo sapiens* originated in sub-Saharan Africa approximately 200 ka (McBrearty and Brooks, 2000; Macaulay et al., 2005; McDougall et al., 2005, 2008; Tishkoff et al., 2009; McEvoy et al., 2011). Today, however, humans cover the globe and successfully occupy a wide range of environments. The detailed path and timing of human dispersal out of Africa is highly uncertain and hotly debated, but the geographic limitation of their starting point means they had to cross either the Saharan or Arabian desert to enter Eurasia (Drake et al., 2013). Possible routes include the Nile Corridor (Van Peer, 1998), the Red Sea Coast (Stringer, 2000), the Green Sahara (Drake et al., 2011), or across the Bab al-Mandab strait into the southern Arabian Peninsula and then along the southern coast or through the center of the peninsula during wetter climatic events (Petraglia and Alsharekh, 2003; Petraglia, 2011; Petraglia et al., 2012) (Figure 1.1). Early AMH fossil remains outside of Africa and genetic evidence for relatively recent population divergence combine to produce a complex demographic pattern of multiple dispersal events at times when paleoenvironmental change opened ‘windows of opportunity’ for early humans to move along these multiple dispersal routes (Gunz et al., 2009; Parker, 2009; Armitage et al., 2011; McEvoy et al., 2011; Rosenberg et al., 2011; Drake et al., 2013; Groucutt and Petraglia, 2012; Richter et al., 2012; Soares et al., 2012; Bar-Yosef and Belfer-Cohen, 2013).

Fossils discoveries from Skhul, Qafzeh, and Zuttiyeh Cave indicate that early AMH dispersed into the Levant by at least 120 ka and perhaps earlier (Schwarcz et al., 1988; Grün et al., 2005; Millard, 2008). A contemporaneous dispersal of AMH into the southern Arabian Peninsula is also possible, as suggested by strong affinity between the 125,000 year old artifact assemblage from Jebel Faya in the United Arab Emirates and contemporaneous assemblages from the east African Middle Stone Age (Armitage et al., 2011). Petraglia (2011) urges caution with this interpretation, as no early AMH fossil remains are known in Arabia, and there is a contemporaneous archaic *Homo* species present in the Indian subcontinent who is equally likely to be the maker of the Jebel Faya assemblage. Nevertheless, the time frame matches a known expansion of AMH into the Levant, and the MIS 6/5e transition would have provided climatic conditions favourable for movement across the Bab al-Mandab strait or along the Red Sea coast into southern Arabia (Stringer, 2000; Bailey, 2009). This question remains open, however, and is fueling a rapidly growing body of research on Middle and Late Pleistocene hominin occupation and paleoenvironmental change in the Arabian Peninsula (Groucutt and Petraglia, 2012).

The picture becomes increasingly messy after the initial AMH dispersal out of Africa (Bar-Yosef and Belfer-Cohen, 2013). Early AMH continue to occupy the Levant until the onset of MIS 4 (~75 ka), at which point they disappear from the record until roughly 45 ka. During this hiatus only Neanderthal remains have been identified in the eastern Mediterranean region (Shea, 2008a). Shea (2008a) argues that population contraction into small, circumscribed cold weather refugia led to the extinction of early Levantine AMH populations between 80-75 ka when the climate became colder, perhaps due to the Mount Toba super-eruption in Indonesia (Haslam et al., 2010) . Shea posits that the recently depopulated Levant was then occupied by Neanderthals moving south from Central Europe until 50-45 ka when another bout of cold conditions associated with Heinrich Event 5 (H5) repeated the extinction scenario, after which the Levant was repopulated with AMH from Africa. Meanwhile in the Arabian peninsula, the period between the initial occupation at the MIS 6/5e transition and the onset of MIS 4 is marked by hominin expansion into the center of the peninsula during the humid episodes of MIS 5e, 5c, and 5a, but range contraction back to the coast or depopulation during the intervening stadials (Walter et al., 2000; Petraglia et al., 2011, 2012; Rosenberg et al., 2011; Delagnes et al., 2013).

In both the Levant and the Arabian Peninsula hominins were able to expand out of Africa into new environments during relatively humid periods of MIS 5, but climatic changes placed significant stress on the populations, forcing them to contract into small, circumscribed resource refugia. The emergence of regionally distinct archaeological lithic traditions in the southern Arabian Peninsula during MIS 3 has led some to argue for the survival of isolated populations in coastal refugia (Groucutt and Petraglia, 2012; Delagnes et al., 2013), whereas in the Levant, the incursion of Neanderthal populations from the North has produced an interpretation of early AMH extinction at this time (Shea, 2008a).

A reduction and possible extinction of the early AMH populations outside Africa near the end of MIS 5 and into MIS 4 aligns well with the genetic evidence, which indicates a recent split between the African and Eurasian lineages at approximately 70 ka (Macaulay et al., 2005; Soares et al., 2012). However, the demographics within the Levant and the Arabian Peninsula are less clear following this final major dispersal event. Shea's complete extinction and depopulation scenario is unlikely in light of recent DNA evidence. Sequencing of the Neanderthal genome determined that Neanderthals are more closely related to Eurasian populations than to African ones, and that between 1-4% of Eurasian DNA is derived from Neanderthal populations (Green et al., 2010). Perhaps some of the contracting Neanderthal populations survived in the Levant at particularly productive environmental refugia and interacted with AMH as they dispersed out of Africa. Mitochondrial DNA analysis of southeast Asian populations agrees with a dispersal out of Africa between 80-70 ka, but it documents a brief period of

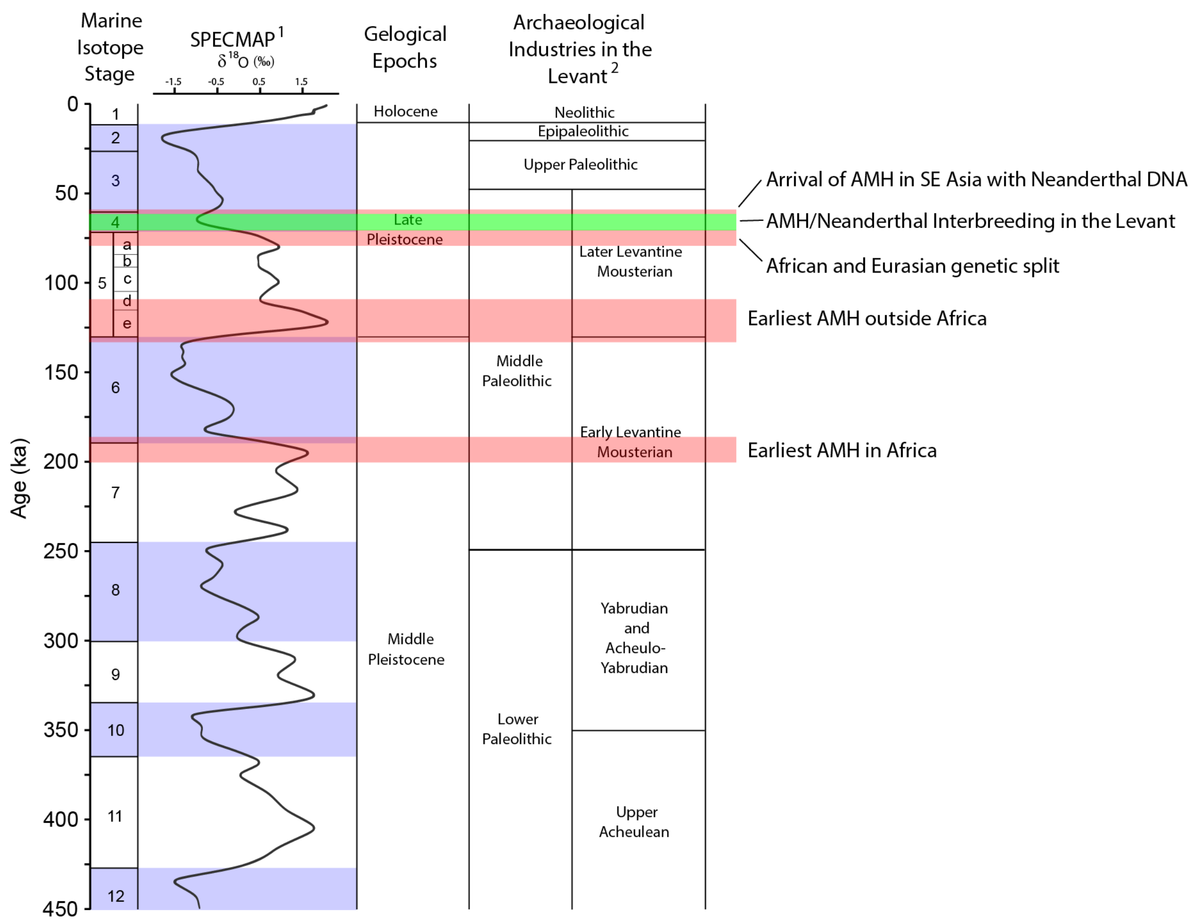

Figure 4.1 Important dates and events discussed in the text in relation to the marine isotope chronology. 1: Imbrie and McIntyre, 2006; 2: Shea, 2008b

mutation and drift before a rapid coastal dispersal at ~65 ka around the Indian ocean into southeast Asia and, ultimately, Australia (Macaulay et al., 2005). The exchange of genetic material between AMH and Neanderthals must have occurred outside of the African continent after the recent dispersal between 80-70 ka, but before dispersal into southeast Asia by 60 ka, as southeast Asian populations also contain the 1-4% Neanderthal DNA (Figure 4.1). This makes the Arabian Peninsula and the Levant prime candidates for where this interaction occurred.

Although Neanderthal fossil remains are well documented along the Levantine coast (see Shea, 2008a; Richter et al., 2012; Bar-Yosef and Belfer-Cohen, 2013), there is a paucity of fossil remains associated with the Paleolithic sites in the eastern Levantine desert and the Arabian Peninsula. Moreover, despite substantial progress in archaeological exploration and research in the Arabian Peninsula (Groucutt and Petraglia, 2012), this work is primarily relegated to the southern portion of the peninsula, particularly concentrated on the Red Sea and southern coast (Walter et al., 2000; Petraglia and Rose, 2009; Armitage et al., 2011; Petraglia, 2011; Petraglia et al., 2011, 2012; Rosenberg et al., 2011; Beyin, 2013; Bretzke et al., 2013; Delagnes et al., 2013). At present, there is limited archaeological and paleoenvironmental research in the Rhub al-Khali and the Nefud Deserts in the interior of the Arabian Peninsula. What little that has been conducted shows that during interglacials there was enough precipitation to produce lakes in some of the desert basins, which subsequently attracted hominin populations (Petraglia et al., 2011, 2012; Rosenberg et al., 2011). Therefore, it is not only the Red Sea coast that is a potential dispersal corridor and location for the interaction between dispersing AMH and Neanderthals, but also the interior of the Arabian Peninsula during periods of wetter conditions. Particularly important for a potential dispersal route into the Arabian Desert would be a string of paleolakes that follows the Wadi Sirhan depression from eastern Jordan into north-central Arabia (Cordova et al., 2013).

Assorted surface scatters are known from the northern Arabian Peninsula and have been ambiguously attributed to the Middle Paleolithic, but stratified sites are lacking and only limited attempts to reconstruct the paleoenvironmental contexts have been made as of yet (Petraglia and Alsharekh, 2003; Groucutt and Petraglia, 2012). Located at the northern end of the Wadi Sirhan depression is the Greater Azraq Oasis Area, the regional focus of this study and an area with hominin occupation dating from the Late Lower Paleolithic to historic times (Garrard et al., 1988; Copeland and Hours, 1989a; Jones and Richter, 2011; Cordova et al., 2013). In addition to its position at the northern end of a potential corridor connecting the eastern Levant to central Arabia during humid climatic periods, the hydrology of the Azraq springs may have buffered local hominin populations from adverse climatic periods when the surrounding desert was dry and relatively inhospitable (Ames and Cordova, In Press; Cordova et al., 2009, 2013). Just as pockets of the south coast of Arabia acted as environmental refugia during MIS 4 (Delagnes et al., 2013), the GAOA might have acted in a similar manner for hominin populations that had extended their range into the north-central portion of Arabia or eastward from the Levantine coast. Therefore, deciphering the history of hominin settlement and paleoenvironmental change in the GAOA and assessing its role as a desert refugium throughout the Pleistocene will contribute to fundamental questions of hominin dispersals, the complex demographic pattern of the Middle East during the Middle Pleistocene, as well as the potential interaction between Neanderthals and AMH. The study presented below takes a first step toward this larger research agenda by establishing the relationship between the stratigraphic succession and the archaeological sequence at one of the GAOA spring locations, the Druze Marsh, and evaluating the impact of paleoenvironmental change on the Paleolithic settlement dynamics in the surrounding basin. The final section addresses the required next steps to continue on this research trajectory and fully evaluate the importance of the GAOA for human origins.

5. METHODOLOGY

The methodology relevant to this study can be divided into three parts: field methodology, artifact analysis, and laboratory analysis. The field methods and sampling were carried out by various members of the DMAPP team, the artifact typological and taphonomic classifications were conducted by Dr. Michael Bisson and Dr. April Nowell, and I conducted all other artifact analyses and the sedimentological laboratory analyses. Refer to the "Contribution of Authors" section above for more detailed information on the portions of this research that were collaborative and those conducted solely by the author. Much of the field work was conducted in a team environment; therefore, I will use first person plural (i.e. we and us) when detailing the field work and previous research. I will refrain from using the first person singular unless specifically referring to an event conducted by myself in isolation from other team members.

5.1. Field Methodology

The Druze Marsh Archaeological and Paleoecological Project (DMAPP) conducted field seasons in 2008, 2009, and 2011(Ames and Cordova, In Press; Cordova et al., 2009, 2013). During the 2008 field season, three large construction pits (DM-1, DM-1X, and DM-1Y) presented deeply stratified deposits containing Paleolithic artifacts from multiple time periods (Figure 5.1). In response to the rich record encountered, we obtained permission to open three additional geological trenches on the adjacent property (DM-7, DM-8, and DM-9) and recorded the top 40-60 cm of test pits DM-2A, DM-3, DM-4, DM-5, and DM-6. We recorded the stratigraphy, the 3-dimensional location of artifacts embedded in profile walls, and collected representative bulk sediment samples from each stratigraphic unit in DM-1, DM-8 and DM-9.

Based on the 2008 results, we returned in 2009 and opened an additional geological trench near the main road (DM-11) following the same procedure as in 2008. We also recorded the stratigraphy of an open trash pit (DM-10). Our primary work during the 2009 season was a 2 x 1 m excavation extending from the south wall of DM-8; detailed analysis of the stratigraphy and artifacts from this excavation forms a large portion of this study. We recorded the 3-dimensional

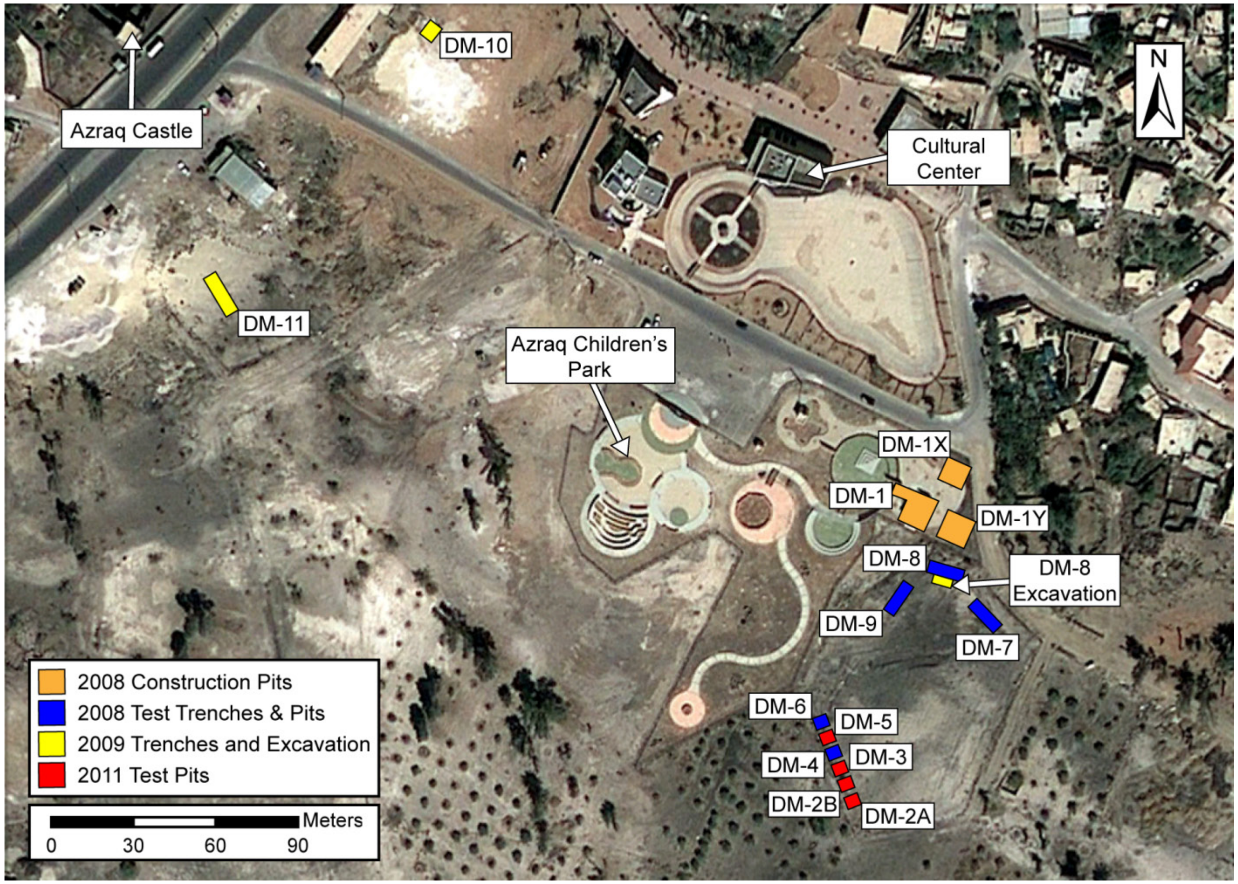

Figure 5.1 The Druze Marsh study area and locations of stratigraphic profiles discussed in the text (base map: Google Earth, 2011).

location of all artifacts >2 cm using a Leica total station, and for artifacts with an obvious long-axis we recorded both end points in order to calculate the angle of repose. The team recorded detailed stratigraphic properties of the excavation profile and collected sediment samples at ~10 cm intervals for laboratory analysis, or at smaller intervals when necessary to ensure all sedimentary units were represented.

Led by Dr. Cordova, the sedimentary succession was first divided into zones, which were later numbered as sedimentary units or layers (i.e. 1b, 2a, 3a, 3d, 4a, etc.). The soil and sedimentary properties for each unit were described according to the United States Department of Agriculture classification system (Schoenenberger et al., 2002), as modified by Birkeland (1999) and Holliday (2004). The in-field colour was recorded using a Munsell soil colour chart (Munsell Color, 2000). We also recorded the sediment unit boundaries and sample depths with the total station in laser mode to ensure consistent depth measurements when comparing the stratigraphy and artifact assemblages. Sediment samples were split for various sedimentological analysis and paleoenvironmental proxies. I conducted all sedimentological analyses at McGill University, while the pollen and phytolith analysis are under the direction of Dr. Carlos Cordova at Oklahoma State University. This dissertation addresses the research I conducted concerning the sedimentological analyses.

I returned to the Druze Marsh in 2011 and removed the backfill from the shallow pits DM-2A, DM-3, and DM-5, extending them to a depth of approximately 250 cm, each roughly 15 m apart. I opened a new test pit halfway between DM-2A and DM-3, labeled DM-2B, and sampled a modern dune for comparison with the buried sedimentary units. I documented the stratigraphy in each test pit following the methods outlined above for the 2008 and 2009 field seasons, and I took bulk sediment samples from each stratigraphic unit.

5.2. Artifact Analysis

The classification of lithic material recovered from the Druze Marsh was conducted by Dr. Michael Bisson (McGill University) and Dr. April Nowell

(University of Victoria) and their students. In areas tested to date, over 5000 pieces of chipping debris have been recovered from various sedimentary contexts. Artifacts were classified using the Bordes typological system (Bordes, 1968; Debénath and Dibble, 1994). The technological and taphonomic attributes of each specimen were also recorded according to the methodology of Bisson (2000). In addition to the artifact angle of repose, which I calculated using the total station data, Dr. Bisson recorded the condition and alteration of the artifacts. Condition refers to post-depositional damage of the edges and/or surface of the artifact (Table 5.1). Undamaged specimens have sharp edges and flake-scar ridges that appear fresh and exhibit no microflaking, crushing, or abrasion. Moderately damaged pieces show evidence of microflaking, abrasion, or edge crushing that is discontinuous but extensive, as opposed to slightly damaged pieces that only show traces of these features. The severely damaged category refers to pieces with substantial damage on all edges. Rolled specimens are characterized by extensive crushing and abrasion on all edges and surfaces, while wind-abraded pieces may have intact edges with polished and rounded flake scar ridges. Alteration refers to patination and other chemical alterations to the artifact surface colour. Slightly patinated pieces have an altered surface colour but the natural colour is still evident, although patchy. Moderate patination refers to a colour change on the entire surface of the piece; while heavy patination means the artifact is bleached white. De-silicified pieces show evidence of chemical dissolution of the artifact surface, leaving a chalky texture and appearance. Thermal damage is indicated by pot-lid fractures on the artifact surface.

5.3. Laboratory Methodology

Bulk sediment samples were subject to a series of laboratory analyses to test properties such as colour, magnetic susceptibility, pH, % organic carbon, % inorganic carbon, and particle size distribution. I conducted all analyses at a number of laboratory facilities where the appropriate equipment was available. Air-drying, sequential Loss-on-Ignition (LOI), and the HCl pretreatment were conducted at the Archaeology Wet Lab in the Department of Anthropology at

Table 5.1 Possible variable states for artifact condition.

Condition	Description
Undamaged	Sharp edges and fresh flake scar ridges
Slightly Damaged	Sparse evidence of microflaking, crushing, or abrasion on edges and flake scar ridges
Moderately Damaged	Discontinuous but extensive evidence of microflaking, crushing, or abrasion on edges and flake scar ridges
Severely Damaged	Substantial microflaking, crushing, or abrasion on all edges
Rolled	Extensive crushing and abrasion on all edges and surfaces
Wind Abraded	Intact edges with polished and rounded flake scar ridges

McGill University; magnetic susceptibility was measured at Dr. Gregory-Eaves' Lab in the Department of Biology at McGill University; pH measurements and hydrogen peroxide (H_2O_2) pretreatments were performed at the Pedology Lab in the Department of Geography at McGill University; laser diffraction particle size distribution analysis was carried out at the Analytical Instruments Lab in the Materials Engineering Department at McGill University; separation of the fine fraction (<2 mm) was completed at both the Lux Luminescence Lab and the Sedimentology Lab at the Université du Québec à Montréal depending on whether the sample could be dry sieved or needed to be wet sieved, respectively.

After collection in the field, samples were packaged in air-tight plastic bags and shipped to McGill University. Sedimentological analysis involved gently disaggregating each sample with a mortar and pestle as necessary, after which the samples were separated into coarse and fine fractions using a 2 mm sieve. Disaggregated sediments were dry sieved and strongly aggregated sediments, particularly the clayey silts, required wet sieving. After sieving, the samples were left to air dry in foam bowls for seven days before recording the air-dry colour using a Munsell soil colour chart (Munsell Color, 2000). 7 ml subsamples were taken from the air-dry fine fraction for low frequency magnetic susceptibility measurement using a Bartington MS2B sensor (Dearing, 1999a, 1999b) (Figure 5.2). An additional 10 g were taken for pH analysis following the procedures outlined by Hendershot et al. (1993) (Figure 5.3). After completion of the magnetic susceptibility measurements the same subsamples were used for sequential Loss-on-Ignition (LOI) to estimate the proportions of organic and inorganic carbon (Dean, 1974; Heiri et al., 2001; Santisteban et al., 2004). The method used for sequential LOI involved weighing clean, dry ceramic crucibles to four decimal places using a Mettler Toledo AB104-S digital balance and then adding 1-5 g subsamples before recording the combined weight. The samples were then placed in a muffle furnace at 105˚C for 12 hours to remove all remaining moisture then cooled in a desiccator (Figure 5.4) and reweighed before returning to the muffle furnace at 550˚C for 4 hours. Again they were cooled and weighed. The percentage weight loss after this ignition (LOI_{550}) is an estimate of the organic carbon content. The final ignition was at 950˚C for two hours after which the samples were cooled and weighed for the final time; the percentage weight loss (LOI_{950}) is proportional to the inorganic carbon content, whose source we can assume is from $CaCO_3$ (Dean, 1974; Jones and Richter, 2011). Values are presented as percentage weight loss in this study.

Preparing the samples for particle size analysis required removing carbonates and organic matter (Sheldrick and Wang, 1993). To remove the carbonates, 3 g subsamples of the <2 mm fraction were placed in 50 cc centrifuge tubes and pretreated with 3M HCl in successive 5 ml aliquots while stirring with a glass rod until the effervescing ceased (Figure 5.5). After completion of the reaction, each tube was filled with deionized water (DI) and placed in a centrifuge for 5 minutes at 3000 rpm before decanting. This step was repeated a minimum of four times or until the pH of the supernatant tested neutral. The remaining sediment pellet was then transferred to a tall glass vial using DI water. The glass vials were placed in a conventional oven at 100˚C until dry. Once the samples were dry, organic matter was removed by adding 10 ml of 30% H_2O_2 to each sample at room temperature. If a violent reaction occurred, successive 5 ml aliquots were added until the frothing subsided. 95% ethanol was sprayed onto violently reacting samples to keep them from spilling over the top of the tubes. When the reaction of the cold treatment was complete, each tube was then placed on a hot plate set to 80˚C and allowed to continue reacting. Additional 5 ml aliquots of H_2O_2 were added until all organic matter was removed, as determined by the colour of the sediment and the rate of the reaction. The tubes were left on the heat for 45 minutes after the final addition of H_2O_2 to ensure the reaction was complete and evaporate excess H_2O_2. The tubes were then removed from the hot plate and allowed to cool before being transferred back to 50 cc tubes and undergoing the same centrifuging procedure as was described for the HCl pretreatment.

Figure 5.2 Measuring magnetic susceptibility using a Bartington MS2B sensor.

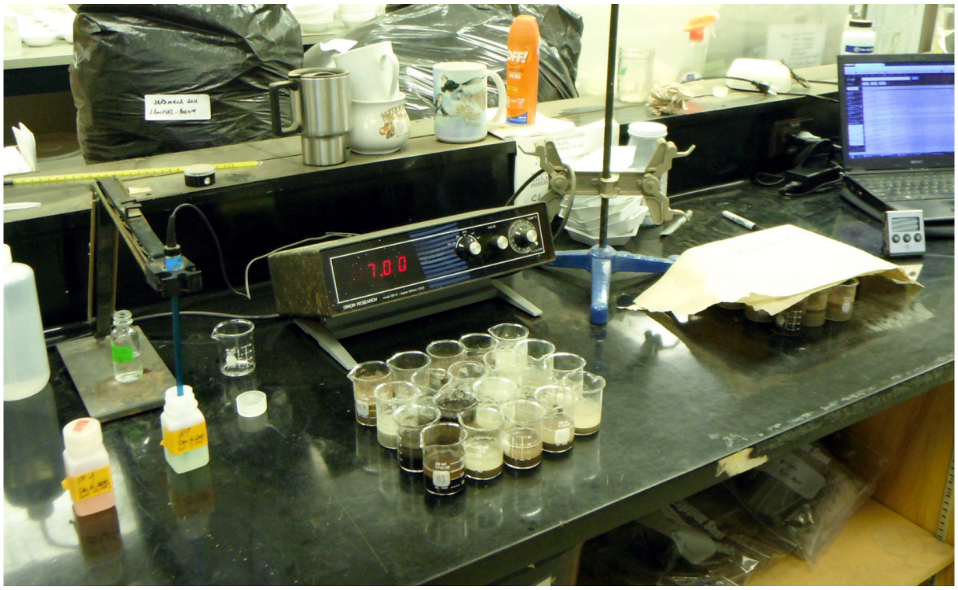

Figure 5.3 Calibrating the pH meter prior to measurement.

Figure 5.4 Crucibles cooling in the desiccator with the muffle furnace in the background under the fume hood.

Figure 5.5 Preparing the fume hood for the HCl pretreatment.

Figure 5.6 HORIBA Laser Scattering Particle Size Distribution Analyzer LA-920.

The particle size distribution (PSD) of each pretreated sample was determined using a HORIBA Laser Scattering Particle Size Distribution Analyzer LA-920 (Figure 5.6). This technique calculates the percentage by volume of different particle sizes in suspension by measuring how light is scattered as it passes through the sample. The HORIBA LA-920 has a measurement range of 0.022-2000 μm and all samples were processed in a circulating 0.1% sodium hexametaphosphate ($(NaPO_3)_6$) solution with ultrasonication to ensure deflocculation. Once measurement is complete for a sample, a frequency distribution output is generated by the machine that separates the sample into 85 size groups or bins that increase in size exponentially (Figure 5.7A) (Appendix C). All PSDs in this study are presented as frequency profiles on a logarithmic particle size scale to improve visualization and give more equal weight to the smaller size particles (Figure 5.7D). Moreover, because the area under the curve for the frequency profiles always equals 100% of the sample by volume, the y-axis is not labeled on PSDs presented in the results section (Figure 5.8). Numerical values for the proportions of sand, silt, and clay are presented in Appendix B.

PSD statistics were calculated using GRADISTAT v.8 (Blott and Pye, 2001), and the particle size boundaries and terminology used in this study follow the recently proposed scheme of Blott and Pye (2012). Following a thorough review of the wide range of particle size scales and descriptive systems currently in use across numerous disciplines, Blott and Pye (2012) present a revised system based on the well known Wentworth (1922) scale that systematizes the divisions between and within particle size classes, both for the phi scale (φ) or when measured in metric units (μm) (Figure 5.9). They also created a new descriptive system based on the proportions of sand, silt, and clay in which each descriptive term (i.e. silty, slightly silty, or very slightly silty) has an associated range of proportions that is equivalent for each particle size category (Figure 5.10). For example, very slightly sandy slightly clayey silt indicates that the sediment is predominantly silt, between 34-100%, with 5-20% clay and 1-5% sand. The new descriptive system of Blott and Pye (2012) provides a higher resolution and easier comparability between samples than those previously in use and is therefore used in this study.

A number of radiometric ages are presented in the results and discussion sections that follow. Two techniques were attempted with the Druze Marsh sediments – optically stimulated luminescence (OSL) and uranium series (U-series). OSL age determinations rely on the fact that quartz and silica grains accumulate energy in “traps” that is released from those “traps” when exposed to heat or light. In this respect, the amount of energy stored in the “traps” of buried quartz and silica grains is proportional to the length of time since the deposit was

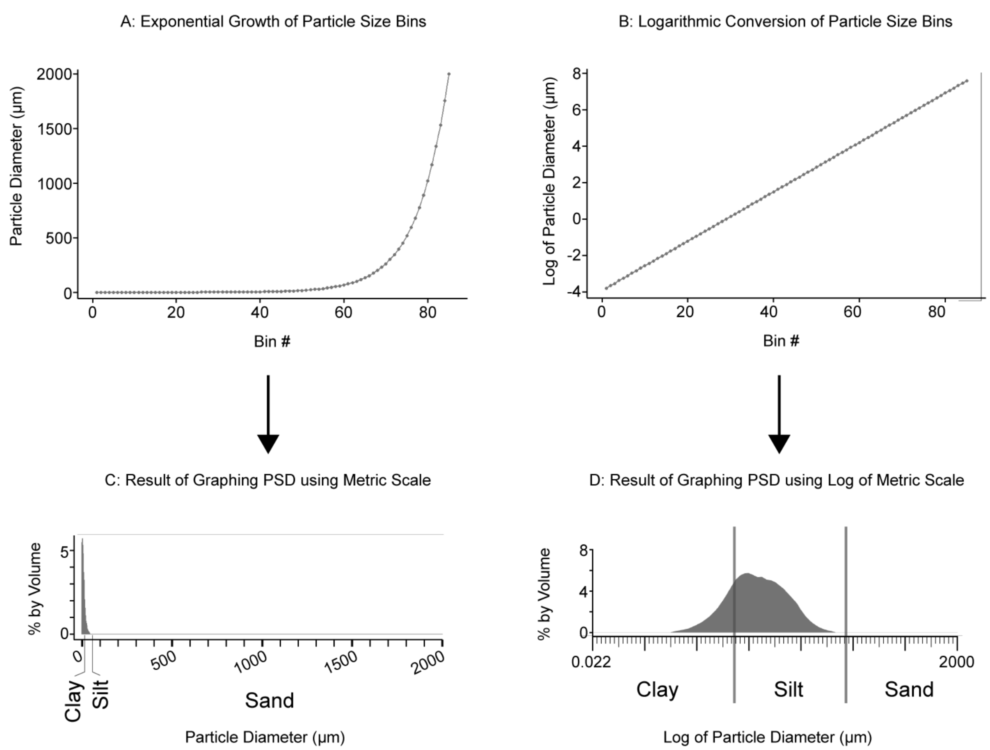

Figure 5.7 Exponential increase in the particle size bins that are output by the HORIBA LA-920. It is more useful to visualize the PSDs using a logarithmic conversion for the particle diameters. The same silt dune sample is plotted in graph C using a metric scale for particle diameter and in graph D using a log of the particle diameter.

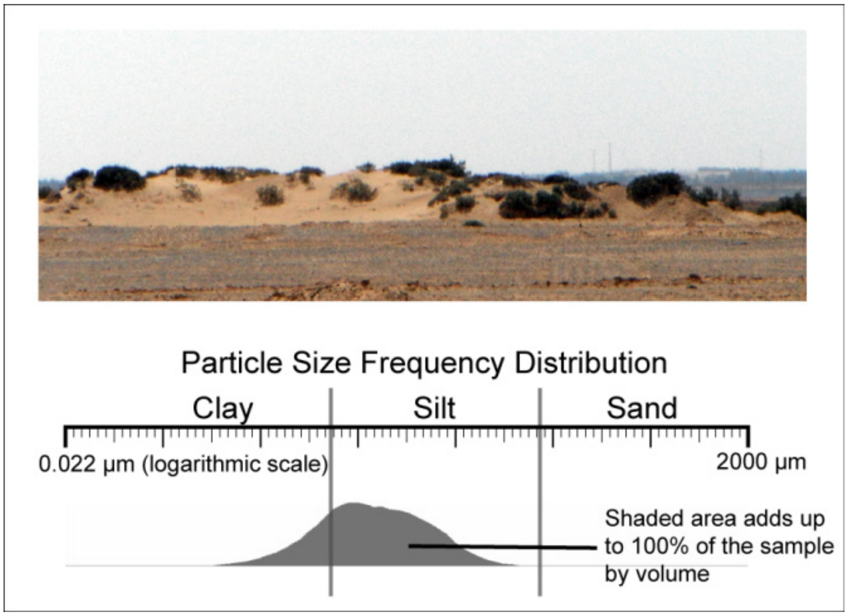

Figure 5.8 Example of the PSD frequency curves presented in this study. The example is of a silt dune from the lunettes east of Qa' Azraq (photo facing west with North Azraq on the horizon in the background). The y-axis of the PSD is % by volume and the area under the curve shaded in dark gray equals 100%. The y-axis will not be included in PSDs presented in this study, as they are each internally consistent. Details of the PSDs, including the proportion of sand silt and clay, are presented in Appendix B, and the raw output of the HORIBA laser diffraction PSD analyzer are provided in Appendix C.

Size Class Terminology	Phi (φ)	Metric (µm)
	-1.00	2000.0
Very Coarse Sand		
	0.00	1000.0
Coarse Sand		
	1.00	500.0
Medium Sand		
	2.00	250.0
Fine Sand		
	3.00	125.0
Very Fine Sand		
	4.00	62.50
Very Coarse Silt		
	5.00	31.25
Coarse Silt		
	6.00	15.63
Medium Silt		
	7.00	7.813
Fine Silt		
	8.00	3.906
Very Fine Silt		
	9.00	1.953
Very Coarse Clay		
	10.00	0.977
Coarse Clay		
	11.00	0.488
Medium Clay		
	12.00	0.244
Fine Clay		
	13.00	0.122
Very Fine Clay		
	14.00	0.061

Figure 5.9 Particle size class terminology and corresponding scale in phi (φ) and metric units (µm) (adapted from Blott and Pye, 2012: Figure 5).

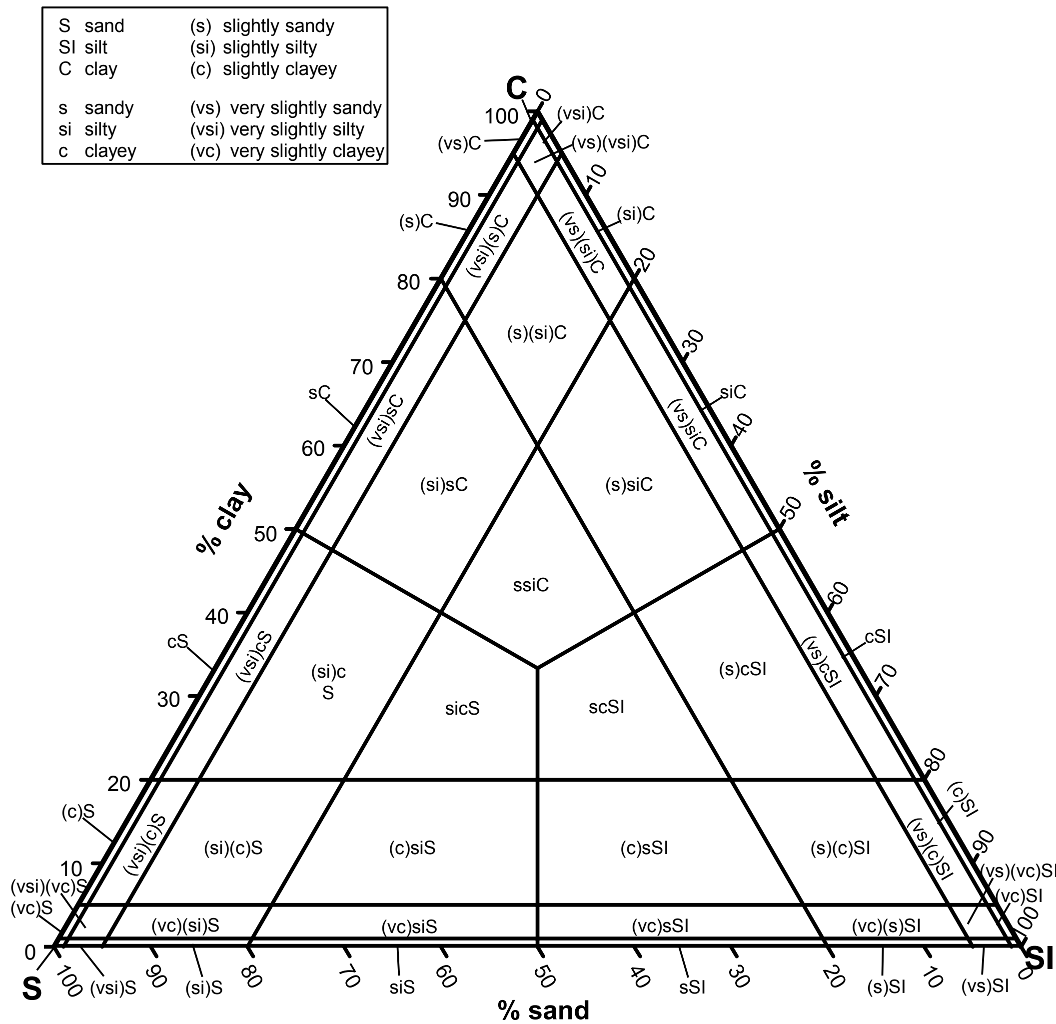

Figure 5.10 Fine fraction (<2mm) particle size distribution classification scheme used in this study. The ternary diagram was produced using the Particle Size Classification software developed by Blott and Pye (2012). It is available online at http://www.kpal.co.uk/particle_size.html.

buried, assuming that prior to deposition the “traps” of a particular grain are fully emptied by exposure to sunlight. Collecting a sample without exposing it to light allows the amount of “trapped” energy to be measured under controlled conditions in the laboratory (Duller, 2008). OSL age determinations were conducted by Dr. Regina DeWitt in 2009 at facilities in the Department of Physics at Oklahoma State University (see Appendix D).

Uranium series techniques use the ^{230}Th-^{234}U-^{238}U decay chain to date the age of carbonate formation in various contexts. The technique measures the amount of ^{230}Th accumulated in a carbonate sample since precipitation from soil water. The primary assumption is that at the time of precipitation the carbonate contains only uranium because uranium is highly soluble in water; whereas thorium is relatively insoluble in water. However, most samples are contaminated by detrital thorium (^{232}Th) and produce dates that are too old unless a mathematical correction is applied (Ludwig and Paces, 2002). Uranium series analyses and calculations were carried out in the fall of 2008 by Dr. Bassam Ghaleb at the Centre de Recherche en Géochimie et Géodynamique (GÉOTOP) at the Université du Québec à Montréal. Additional detail on the specific analytical procedures as well as a summary of the laboratory results for the U-series and OSL age estimates are presented in Appendix D.

6. RESULTS

Of the 16 total sedimentary sequences examined in the bed of the former Druze Marsh, I subjected eight to detailed sedimentological analysis: DM-1, DM-2A, DM-2B, DM-3, DM-5, DM-8, DM-9, and DM-11. The DM-8 geological trench profile recorded in 2008 is described in Cordova et al. (2013) and will not be discussed in detail here. However, the controlled excavation extending from the south wall of DM-8, what is referred to as the DM-8 excavation, is discussed extensively. The stratigraphic sequence of the DM-8 excavation was sampled at ~10cm intervals and the 3-dimensional location of all artifacts >2 cm were recorded, making it the foundation for assessing the relationship between the sedimentary and archaeological data. The DM-8 excavation data are therefore presented first. Test pits and trenches other than the DM-8 excavation were dug for sedimentological purposes, specifically to understand the stratigraphic relationships throughout the bed of the former marsh. Bulk sediment samples were taken from each sedimentary layer in these geological test pits and the artifacts were assigned to their layer of origin, unless they were identified in the profile, in which case the 3-dimensional location was recorded.

The stratigraphic results are grouped into three areas: Areas A, B, and C. Overlaying the test pit locations on a 1978 aerial photo of the historic marsh provides a set of expectations for the geomorphic relationship between the three areas (Figure 6.1). Area A is close to the historic spring pools where water would be more abundant. It includes the DM-8 excavation and the surrounding test trenches of DM-1, DM-1X, DM-1Y, DM-7, and DM-9. Area B is a short transect of test pits dug into a pre-existing ditch approximately 90 m south-southwest of the DM-8 excavation. It runs parallel to the western perimeter of the historic marsh along a channel that would carry water into the marsh from the central basin (see Figure 3.3 for explanation of this process). Six test pits were opened along the ditch, they are: DM-2A, DM-2B, DM-3, DM-4, DM-5, and DM-6. According to the 1978 aerial photo, DM-2A, DM-2B, DM-3, and DM-4 fall outside the historic marsh boundary, and DM-5 and DM-6 within the perimeter. This fits with the laboratory results presented below, as the stratigraphy of DM-5 indicates wetter conditions at all times relative to other Area B sequences. Of the six test pits, DM-4 and DM-6 are shallow profiles, less than 1 m below surface, and are not discussed. The remaining four pits were re-opened in 2011 and extended to approximately 2.5 m below the surface and sampled for laboratory analysis. Area C has one profile, trench DM-11. It is approximately 300 m west-northwest of the DM-8 excavation. This area is the northwestern edge of the historic marsh and at the farthest point that the historic marsh extended from the central basin.

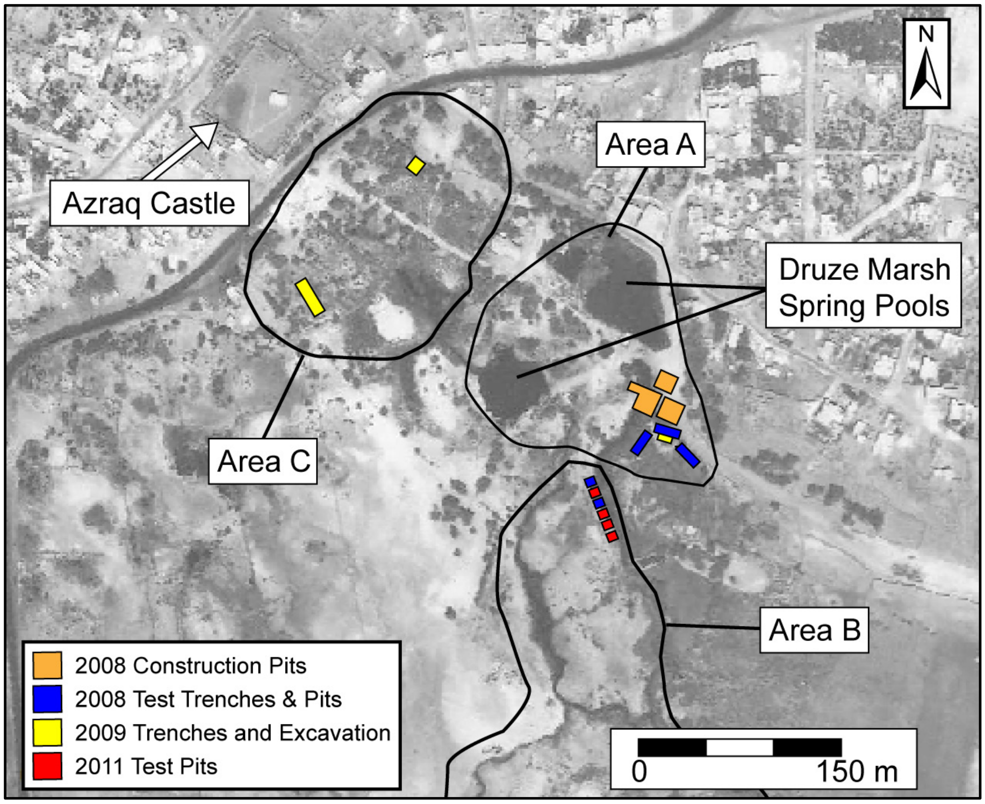

Figure 6.1 Test pit locations relative to the 1978 marsh; see Figure 5.1 for test pit labels. Aerial photo from the Royal Jordanian Geographic Centre in Amman; the specific date of the photo is uncertain but the low water levels suggest it was taken during the dry season.

A preliminary analysis of the sand, silt, and clay proportions of sediments from these three areas follows the expected geomorphic pattern, and suggests the historic facies relationship between them extends back into the Pleistocene as water levels fluctuated over time (Figure 6.2). Area A contains the widest range of sediment types. It is also the only area in which the stratigraphy contains clayey silts, which are open water deposits. This matches the expected pattern for a location near the spring source. Area B sediments are noticeably absent from the lower right hand corner of the ternary diagram and highly concentrated below the 5% clay line with varying proportions of sand and silt. Area C sediments are, for the most part, in the lower right hand corner of the diagram with silt values above 80%. They fill an intermediary zone between the clayey silts of Area A and the concentration of relatively coarse deposits in Area B. These differences represent facies transitions throughout the Druze Marsh in response to changing water availability over at least the past 250,000 to 300,000 years. This age estimate is based on the typological characteristics of the artifacts – something that will be elaborated upon in the discussion section. First, however, the details of each stratigraphic succession are presented. The sedimentological data used to produce the figures in section 6 are available in the appendices.

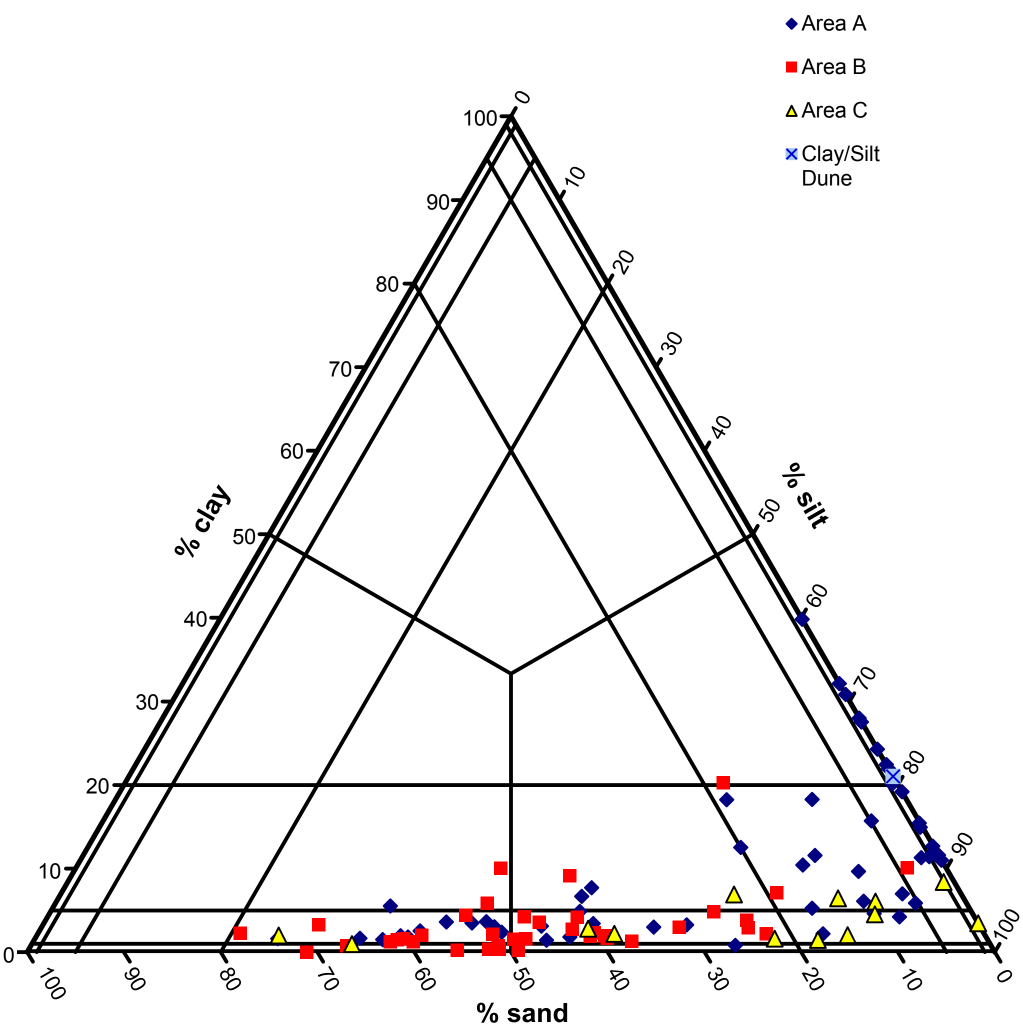

Figure 6.2 Sand, silt, and clay ternary diagram for all samples from the Druze Marsh. Produced using software developed by Blott and Pye (2012)

6.1. Area A Stratigraphic Profiles

6.1.1. The DM-8 Excavation

6.1.1.1. Stratigraphy

The 2 x 1 m DM-8 excavation extends in a southwest direction from the south wall of the original DM-8 geological trench opened in 2008. Not surprisingly, the excavation profile is very similar to the trench profile published previously (Cordova et al., 2009, 2013). To ensure consistency, this study continues to use the original sedimentary unit designations used in the aforementioned publications, but the new laboratory data provides additional detail about the depositional history of the area. To avoid confusion I have produced a table comparing the new data to the previous descriptions in Cordova et al. (Cordova et al., 2009, 2013) (Table 6.1).

Table 6.1 Description of sedimentary units in the DM-8 excavation and associated depositional environments.

Sedimentary Unit	Description in Cordova et al., 2009, 2013	Description in this Study	Depositional Environment
6	Calcified organic deposits	Light gray slightly sandy slightly clayey silt high in carbonate content with a slightly basic pH	Drying of the historical/Holocene marsh
5	Soft peat mat with distinguishable roots and plant fragments	Very dark gray very slightly clayey slightly sandy silt with a basic pH	Historic/Holocene marsh with permanent water
4b	Calcified, organic mudflow deposit	Dark gray very slightly clayey silty sand with a neutral pH	Channel fill, mudflow
4a	Peat with signs of burning	Black, organic-rich slightly sandy slightly clayey silt grading up to a slightly clayey silty sand, with an acidic pH	Shallow marsh edge environment
3e	Black organic-rich clay with vertical cracks and few pedogenic carbonates near the upper boundary	Dark gray slightly sandy slightly clayey silt with large vertical cracks, columnar structure, and basic pH	Shallow marsh with permanent water
3d	Green clay with vertical cracks capped by a thick layer of pedogenic carbonates	Pale olive clayey silt capped by nodular carbonates with vertical cracks and columnar structure, and basic pH	Deep marsh or lake with perennial water
3b and 3c	Green clay with vertical cracks	Dark greenish gray to olive gray slightly clayey silt with a few vertical cracks and an acidic pH	Marsh or shallow lake with dry episodes, perhaps seasonal drying

3a	Organic-rich green clay with few vertical cracks near the upper boundary	Dark greenish gray slightly clayey silt with an acidic pH and organic bands	Deep marsh or lake with perennial water
2b	Organic-rich clay loam	Thin layer (<5 cm) of very dark gray very slightly sandy slightly clayey silt with an acidic pH	Transition from playa to marsh
2a	Aeolian silt and sand	Thin layer (<5 cm) of gray very slightly clayey silty sand with an acidic pH	Playa with aeolian accumulation
1e	Intradunal pond	Light brownish gray, organic-rich very slightly clayey slightly sandy silt with an acidic pH	Intradunal pond
1d	Aeolian deposit of fine silt and sand, intradunal pond	Light gray silty sand with an acidic pH	Aeolian accumulation
1c	Light green silty clay with sugary consistency formed by sand-sized pellets of the green lacustrine clay	Pale yellow very slightly clayey silty sand with a sugary consistency and an acidic pH	Aeolian accumulation, perhaps a lunette
1b	Light green silty clay; lacustrine sediment	Pale olive very slightly clayey slightly sandy silt with an acidic pH that grades upward to a very slightly clayey sandy silt	Deep marsh or lake, transitioning to arid conditions
1a	Light green silty clay with orange stains	Light gray slightly sandy slightly clayey silt with orange stains similar to 0b and an acidic pH	Aeolian accumulation
0b	Yellowish-green aeolian sand and basalt regolith	Pale yellow slightly sandy slightly clayey silt with an acidic pH and orange mottles	Aeolian accumulation, oxidation of underlying basalt

The excavation profile is characterized by thick deposits of lacustrine and palustrine clayey silts, intercalated with erosional unconformities, aeolian silty sands, and pedogenic carbonate concretions (Figures 6.3, 6.4, 6.5, 6.6). The DM-8 profile can be divided into three major zones. The lower zone of the profile (sedimentary units 0b to 2a) is dominated by silt with the proportion of sand increasing upward until the depositional gap at the contact between layers 1c and 2a (Figure 6.6). This suggests increasingly dry conditions, culminating with an extended period during which erosion dominated in the Druze Marsh. The middle zone (units 2b to 3d) represents a return to moist conditions and the development of deep marshes and lakes characterized by a suite of greenish gray clayey silts, ultimately capped by nodular carbonates at the top of unit 3d, which indicates the return of dry conditions. The upper zone of the profile (units 3e to 6) marks a transition to a shallow marsh followed by the gradual drying of the Druze Marsh to its current conditions. The upper zone is dominated by dark, organic-rich silt deposited by a shallow wetland, units 3e and 5, which is eventually capped by the modern calcified marsh deposits, unit 6.

Figure 6.3 South wall of the DM-8 excavation.

The DM-8 excavation reached bedrock slightly over 3 m below the surface. The basal deposit (unit 0b) of the profile is slightly sandy slightly clayey silt. The pale yellow to brownish yellow colour is likely caused by the oxidation of the underlying basalt. Its high magnetic susceptibility value is the result of high iron content (Figure 6.5). Caution must be taken when interpreting the PSD of unit 0b, as the weathering indicated by the oxidation can break down larger grains into silts and clays. Overlying 0b is unit 1a, a gray deposit that is texturally

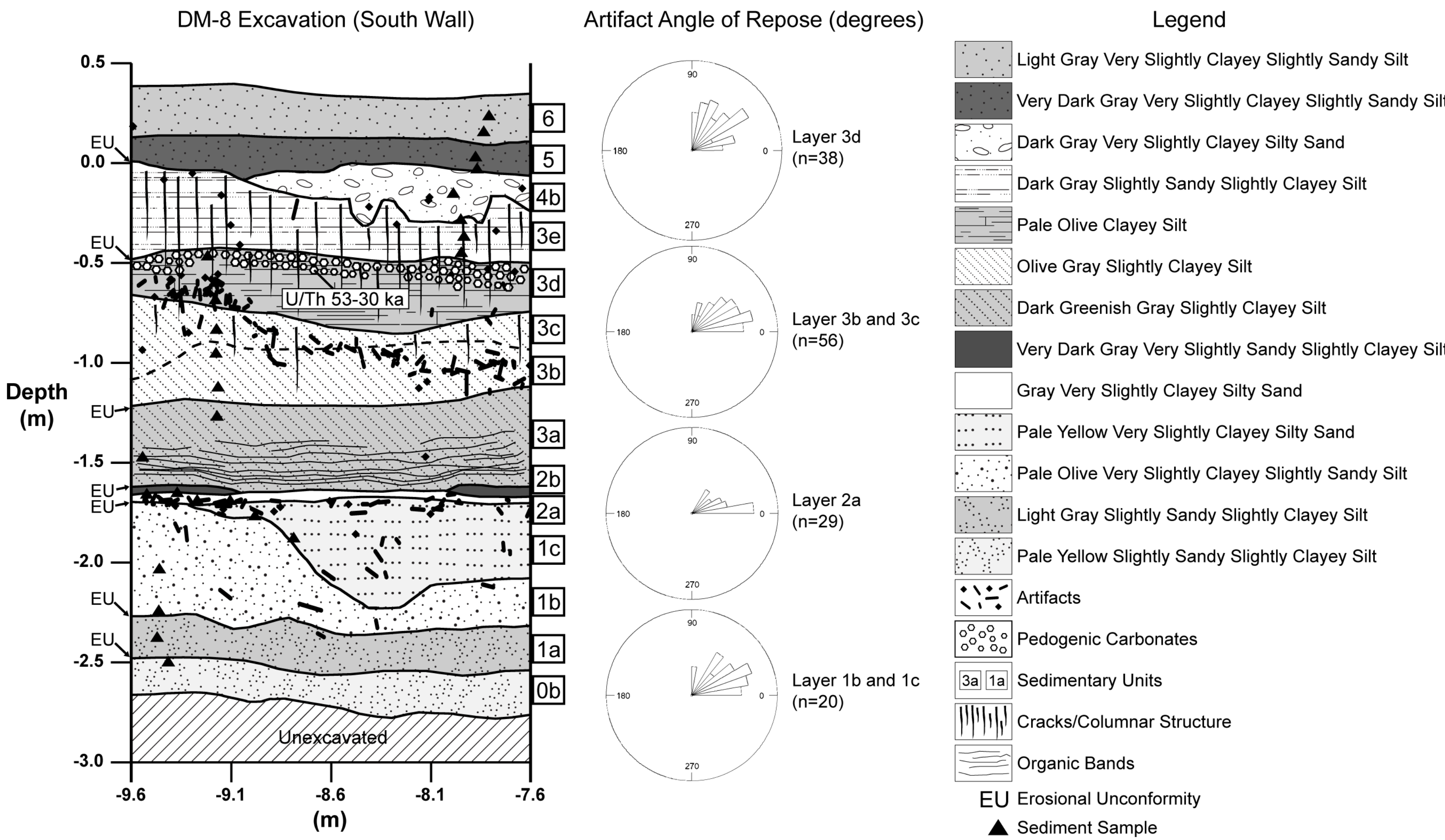

Figure 6.4 Stratigraphic drawing of the DM-8 excavation profile.

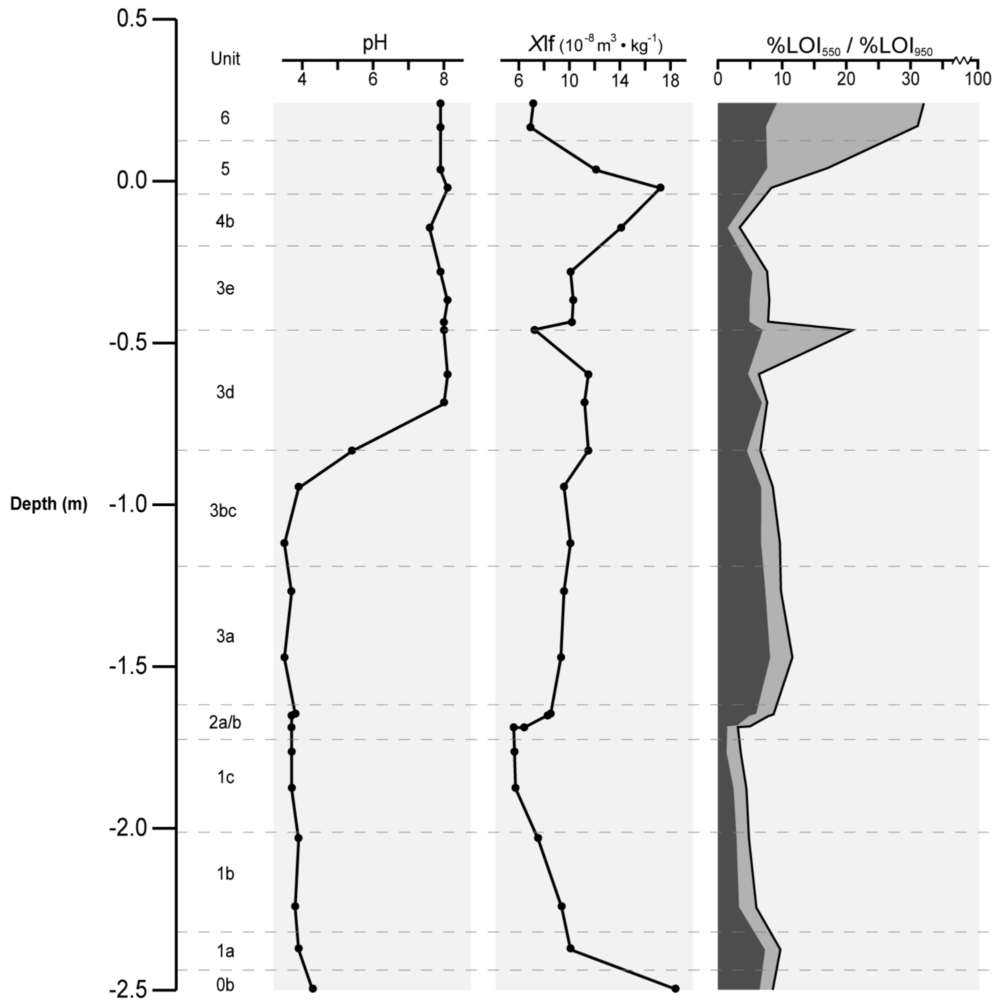

Figure 6.5 Sedimentological data from the DM-8 excavation profile.

similar to 0b and is not influenced by oxidation of the underlying basalt. As expected, the magnetic susceptibility is lower than the underlying unit (Figure 6.5). Based on particle size analysis, it is likely that unit 1a is a lacustrine deposit with some aeolian input.

Unit 1b, which conformably overlies unit 1a, has a similar particle size distribution as its underlying unit, and the pale olive colour is the result of gleying caused by waterlogged conditions. This is an open water deposit with a secondary peak of fine sand in the PSD that suggests aeolian input. The substantial increase in sand content in the upper portion of 1b forecasts the transition to drier conditions. In fact, 1b is truncated by pale yellow, very slightly clayey silty sand

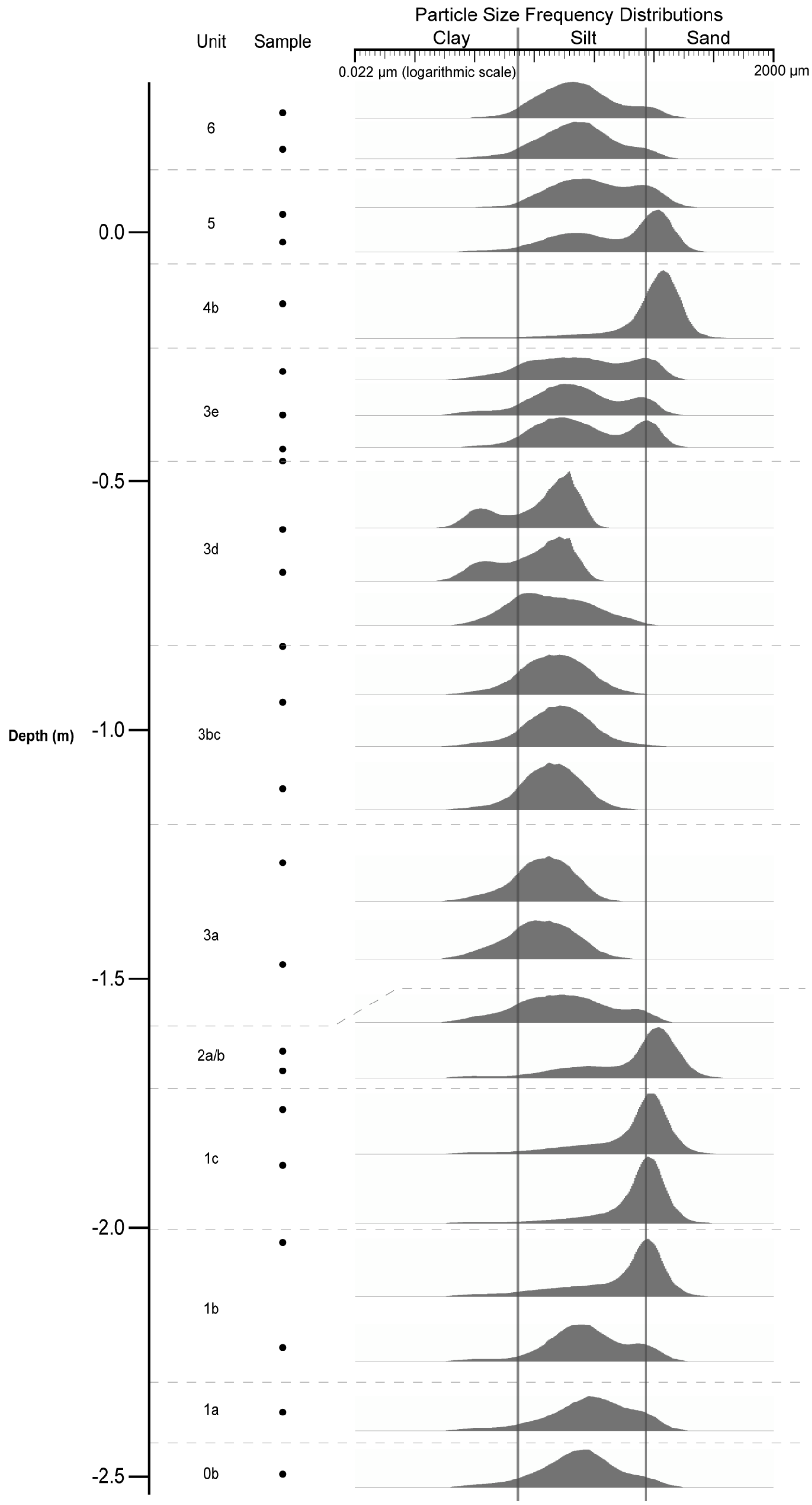

Figure 6.6 Particle size data from the DM-8 excavation profile.

with a sugary consistency, labeled unit 1c. The sugary consistency implies aeolian re-deposition. This occurred as local conditions became more arid and deflation began to predominate in the area. It is possible this deposit is part of a nebkha or silt dune on the leeward side of a seasonal marsh or playa. This period of arid conditions culminates with unit 2a, a thin lens of very slightly clayey silty sand, and an erosional unconformity at the 1c/2a transition. The gradual decrease in LOI_{550} and magnetic susceptibility of units 1b and 1c also indicate erosion and overall increased regional aridity (Figure 6.5).

The basal age of the DM-8 section and the length of time represented by this erosional unconformity at the boundary of layer 1c/2a are currently unknown. Attempts to date quartz grains from layers 0b and 2a from DM-8 using optically stimulated luminescence (OSL) produced saturated age estimates of >38 ka and >29 ka respectively (Appendix D). The deposits contain an unusually high concentration of uranium and have high dose rates, resulting in rapid saturation of the quartz samples. The saturated estimates provide 'older than' dates. We are confident, however, that these deposits are much older due to the Lower and Middle Paleolithic artifacts they contain, which will be described in the next section. Moreover, pedogenic carbonates capping unit 3d formed between 53-30 ka (see below), which also suggests the lower deposits are older than the saturated OSL age estimates. It is possible that the depositional hiatus at the 1c/2a boundary more closely corresponds to the drying episode documented by the accumulation of pedogenic carbonates in DM-2A (see below), which produced a uranium series age estimate of 160-133 ka (Cordova et al., 2013). This relationship will be addressed further in the discussion section. Obtaining radiometric dates from the lower layers in the Druze Marsh is a primary concern for future research. Unfortunately, radiometric age estimates are currently unavailable for the lower zone of the Druze Marsh sequence.

The accumulation of silty sand in layer 2a is conformably overlain by very dark gray, very slightly sandy slightly clayey silt that is also associated with an increase in organic matter content (Figure 6.5, 6.6). This unit, 2b, represents the onset and transition to wet conditions in the Druze Marsh, as evidenced by the thick accumulation of clayey silts that lie immediately above. Unit 3a is dark greenish gray slightly clayey silt that is distinguished from the overlying units by the organic bands visible in its lower half. Units 3b and 3c were originally considered separate during field description based on a slight difference in colour, but were ultimately deemed to be the same unit (Cordova et al., 2009). This conclusion is supported by the laboratory analyses and the unit will be referred to as 3bc in this study (Figures 6.4, 6.5, 6.6), which is dark greenish gray to olive green slightly clayey silt. Overlying 3bc is unit 3d, a pale olive clayey silt capped by a layer of pedogenic carbonates. It is at this point in the stratigraphic profile where the pH becomes relatively neutral (Figure 6.5). All deposits below this point are extremely acidic, making the preservation of faunal remains highly unlikely. Moreover, the PSDs from unit 3d are markedly bimodal (Figure 6.6). The secondary mode is dominated by clay between 0.7-0.8 μm and the dominant mode by fine to medium silt, between 6.0-8.5 μm (Appendix B). It implies two depositional processes. The pale olive colour denotes waterlogged conditions and relatively deep, calm water that allowed clay particles to settle. The silts could be aeolian dust that settled on the water's surface, or they could have been deposited when the wetland was reduced in size during the dry season and DM-8 was closer the shoreline of a small shallow lake. The thick carbonates capping unit 3d already point to the eventual drying of the lake and it is reasonable to expect that increased seasonal or year to year fluctuations in water availability most likely preceded the eventual complete drying. A combination of a high water table and high temperatures could create this pattern (Cordova et al., 2013). The high water table would create perennial standing water via the Druze Marsh springs, whereas high evapotranspiration would cause deflation in the areas surrounding the Druze Marsh that did not receive water from the springs. The substantial deposition of nodular carbonates capping unit 3d occurred as the water table dropped in conjunction with high evapotranspiration (Cordova et al., 2013).

Due to the absence of artifacts in 3a and because the presence of artifacts in 3d can be explained by post-depositional disturbance (see below), I believe these deposits were produced by a perennial deep marsh or shallow lake. A U-series age estimate from the pedogenic carbonates at the top of unit 3d suggests that the local transition from wet to dry conditions occurred between 53-30 ka (Cordova et al., 2013). It also implies that the greenish gray silty clays of layer 3d, and all layers below, were deposited prior to the carbonate formation; perhaps they correspond to the latter part of MIS 5 (MIS 5a and 5c) that is known to have been wet in the eastern Jordanian desert (Frumkin et al., 2008) and in southern Jordan (Abed et al., 2008; Petit-Maire et al., 2010).

The transition to dry conditions that began with the carbonates capping unit 3d persisted for an unknown length of time. Eventually wetter conditions returned and deposited unit 3e, a dark gray clayey silt with abundant roots. This is a return to moist conditions, but not nearly as wet as the previous thick clayey silt deposits of 3a through 3d, which is evidenced by the increase in the particle sizes compared to the greenish gray clayey silts. The dark colour, relatively high organic matter content, and bimodal particle size distribution suggest this was a shallow and probably seasonal marsh (Figures 6.4, 6.5, 6.6). The predominant particle sizes are fine to medium silts, with a secondary process depositing a considerable amount of very fine sand. It could be the result of continued high regional evapotranspiration and the constant input of fine aeolian sand from surrounding regions, or variations caused by seasonal runoff into the center of Qa' Azraq during the wet season that ultimately flowed into the marshes (see Figure 3.3). It is most likely a combination of both.

The shallow marsh of unit 3e is truncated by unit 4b, which is very slightly clayey silty sand. This unit is the coarsest deposit identified in the Druze Marsh stratigraphy, which is reason to believe it is a channel flow deposit, likely laid down in a single mudflow event (Cordova et al., 2009). The notable increase in magnetic susceptibility could reflect increased fluvial influx and watershed erosion. Petraglia et al. (2012) suggest a similar phenomenon in the Jubbah paleolake deposits in the Nefud Desert in north-central Arabia. The top two deposits, units 5 and 6, are associated with the historic wetland and its gradual drying. Unit 5 is very dark gray, very slightly clayey slightly sandy silt with abundant roots and bimodal PSD reminiscent of unit 3e (Figure 6.6). Embedded

Roman pottery in some localities suggests that unit 5 is the historic marsh deposit. An increase in carbonate content appears in the upper portion of unit 5, marking the beginning of the historic drying of the Druze Marsh (Figure 6.6). The carbonate is produced as the water table lowers in conjunction with high evapotranspiration. The carbonate content continues to increase into unit 6 (Figure 6.5), a light gray slightly sandy slightly clayey silt, that is the dry, calcified historic marsh deposit.

6.1.1.2. Artifacts

A total of 193 artifacts >2 cm were recovered, recorded, and analyzed from the DM-8 excavation (Figure 6.7). Artifacts were grouped according to the sedimentary unit in which they were found (Table 6.2). When plotted against the stratigraphic profile, and in conjunction with field notes, the artifacts clearly cluster into four major groups. Artifact clusters occur in layer 3d, layer 3bc, layer 2a, and scattered throughout layer 1b and 1c (Figure 6.4). Artifacts are sparsely scattered in unit 5 and 3e but the sample sizes are too small to warrant detailed analysis (Table 6.2). Throughout the Druze Marsh, units 5 and 6 consistently produced Epipaleolithic and Neolithic material mixed with Roman-Byzantine period ceramic and glass. Our test pits suggest that layer 3e dates to the Upper Paleolithic/Epipaleolithic, but a larger sample and better chronological control is needed to confirm this hypothesis (Cordova et al., 2009, 2013).

The predominance of blades, blade cores, the endscraper on a blade, and the twisted debitage in layer 3d suggest that the assemblage dates to the Upper Paleolithic. Moreover, the carbonate nodules capping unit 3d formed between 53-30 ka, meaning the sediment of unit 3d was deposited prior to this time frame. The majority of artifacts in 3d were found resting at angles greater than 45˚ from horizontal (Figure 6.4). I suspect that this cluster originated as an Upper Paleolithic occupation on the surface of layer 3d and as the environment transitioned to arid conditions, the clayey silts of layer 3d dried out and shrank causing the artifacts to fall through large vertical cracks. This provides an

Figure 6.7 Example of artifacts recovered during the DM-8 excavation. (A: Layer 3d Upper Paleolithic; 1-endscraper; 2-endscraper; 3-complete double backed bladelet; 4-double backed bladelet fragment. B: Layer 2a-b Middle Paleolithic; 1-Mousterian point; 2-elongated Levallois point; 3-retouched Levallois point; 4-denticulate; 5-Levallois point core; 6-elongated triangular biface; 7-convergent scraper-denticulate. C: Layer 1b-c Lower Paleolithic; 1-partial cordiform biface; 2-heat damaged amygdaloid biface; 3-discoid biface; 4-small bifacial cleaver; 5-cleaver tranchet flake; 6-retouched Levallois point; 7-déjeté scraper; 8-scraper-denticulate; 9-Levallois core) (photo credit: Melanie Chang).

Table 6.2 Summary of artifacts recovered from the DM-8 excavation.

Artifact Type	Sedimentary Unit						Total
	1b & 1c	2a & 2b	3b &3c	3d	3e	5	
Levallois Flake	1	1	0	0	0	0	**2**
Levallois Point	0	2	2	0	0	0	**4**
Mousterian Point	0	1	2	0	0	0	**3**
Endscraper	0	0	1	0	0	0	**1**
Endscraper on Blade	0	0	0	1	0	0	**1**
Burin	0	0	0	0	1	0	**1**
Perçoir	0	0	0	1	0	0	**1**
Naturally-Backed Knife	0	1	0	0	0	0	**1**
Notch	1	0	0	0	0	0	**1**
Denticulate	1	1	0	0	1	0	**3**
Miscellaneous	0	1	0	0	1	0	**2**
Flake and Flake Fragments	9	16	18	18	5	5	**44**
Blade and Blade Fragments	0	1	32	20	5	2	**87**
Twisted Bladelet	0	0	1	0	0	0	**1**
Levallois Blade	0	4	0	0	0	0	**4**
Angular Fragment	3	3	2	4	0	0	**12**
Biface Retouch Flake	1	0	0	0	0	0	**1**
Double Backed Bladelet	0	0	1	0	0	0	**1**
Single platform Core	0	2	3	2	0	0	**7**
Polyhedral Core	0	0	1	0	0	0	**1**
Levallois Core	1	1	0	0	0	0	**2**
Blade Core	0	0	3	2	0	0	**5**
Bladelet Core	0	0	1	1	0	0	**2**
Bladelet Core Tablet	0	0	0	0	1	0	**1**
Discoid Core	1	0	0	0	0	0	**1**
Core Fragment	1	0	0	0	0	0	**1**
Handaxe and Handaxe Fragments	2	0	0	0	0	0	**2**
Azraq Cleaver	1	0	0	0	0	0	**1**
Total	**22**	**34**	**67**	**49**	**14**	**7**	**193**

explanation for why the cluster appears embedded in the bottom half of layer 3d, which is a thick clayey silt deposited by a perennial deep marsh or shallow lake. Moreover, the angle of repose suggests a heavily disturbed assemblage but nearly all of the artifacts are in pristine condition (Table 6.3), meaning whatever disturbed the orientations must have been a relatively gentle process. Although the vertical cracks in the DM-8 profile become less dramatic and less frequent in layer 3bc they still occur, meaning there is a chance some artifacts from 3d have fallen below the 3bc/3d boundary and are incorporated into the underlying cluster of artifacts. However, the artifacts in layer 3bc are predominantly tilted at angles less than 45˚ (Figure 6.4). If artifacts have been incorporated into the 3bc cluster from above, it appears to have been very few, as we would expect them to show up as severely tilted artifacts in the distribution of angles of repose.

Layer 3bc was deposited by a deep marsh or shallow lake. The distribution of artifacts suggests the marsh or lake may have dried out occasionally, allowing prehistoric populations to move onto the exposed lake bed in search of water or food for short periods of time. However, the unimodal PSD does not indicate multiple geomorphic inputs, but this may be a product of the sampling resolution. Another possibility is that the artifacts were deposited either at the 3bc/d transition and have sunk or were trampled into the underlying deposit, or they were deposits at the 3a/3bc transition and have been compressed upward during shrink swell episodes. Massive and complete displacement of the 3bc assemblage upward is highly unlikely. The artifacts occur in a linear thin band dipping to the west and the angles of repose are predominantly between 0 and 45˚ from horizontal (Figure 6.4). Most likely the lake dried out for short periods allowing the lakebed to be occupied by hominins. The combination of moderately tilted artifacts (Figure 6.4) with pristine edges (Table 6.3) results from artifacts sinking or being trampled into the soft clayey silts or perhaps slight disturbance as the clayey silts experienced seasonal cycles of shrink and swell. Typologically, the 3bc assemblage is difficult to classify. It is dominated by blades and blade fragments, but the presence of a Levallois flake, two Levallois points, and a Mousterian point clearly indicate Middle Paleolithic technology. Because the deposit represents a seasonally fluctuating marsh over an unknown length of time, it could be a palimpsest of Middle and Upper Paleolithic occupations. This assemblage is the only one with two prominent types of patination, whereas all others are dominated by one particular category (Table 6.4). However, because the carbonates at the top of layer 3d date to 53-30 ka, the assemblage must be older, meaning that, at least with the present data, it more likely dates to latter part of the Middle Paleolithic near the transition to the Upper Paleolithic, which could account for the combination of tool types observed. Until we have both a larger sample and better chronological control, this question remains unanswered.

Table 6.3 Artifact condition from the DM-8 excavation.

Artifact Condition	Sedimentary Unit						Total
	1b & 1c	2a & 2b	3b &3c	3d	3e	5	
Undamaged	14	26	61	48	8	4	**161**
Slightly damaged	6	2	1	0	5	2	**16**
Moderately damaged	0	2	2	2	1	1	**8**
Heavily damaged	1	4	1	0	0	0	**6**
Rolled	1	0	0	0	0	0	**1**
Wind Abraded	0	0	1	0	0	0	**1**
Total	**22**	**34**	**66**	**50**	**14**	**7**	**193**

Table 6.4 Artifact alteration from the DM-8 excavation.

Artifact Alteration	Sedimentary Unit						Total
	1b & 1c	2a & 2b	3b &3c	3d	3e	5	
Unpatinated	0	0	0	0	1	2	**3**
Slightly Patinated	0	0	18	41	6	3	**68**
Moderately Patinated	0	0	3	6	5	2	**16**
Heavily Patinated	2	2	2	0	1	0	**7**
Double Patinated	1	1	0	2	0	0	**4**
De-Silicified with Thermal Damage	0	0	1	0	0	0	**1**
Patinated with Thermal Damage	5	5	3	0	1	0	**14**
Black and White Patina	0	1	32	1	0	0	**34**
Black Patina	14	25	7	0	0	0	**46**
Total	**22**	**34**	**66**	**50**	**14**	**7**	**193**

The cluster of artifacts found in unit 2a is a Middle Paleolithic occupation surface in primary context. The artifacts are lying horizontally (Figure 6.4) in nearly pristine condition (Table 6.3) on the aeolian silty sands of layer 2a at the transition with layer 2b, which marks the return to wet conditions in the Druze Marsh. The length of time represented by this erosional unconformity and aeolian deposition is unknown, but the elongated Mousterian point and prevalence of laminar Levallois technique (Figure 6.7 and Table 6.2) matches well with other early Levantine Mousterian assemblages in the Near East (Shea, 2008b).

Below layer 2a the artifacts are scattered and diffuse, appearing predominantly in layers 1c and 1b (Figure 6.4). This assemblage is very small but is the only cluster of artifacts to produce large handaxes and a bifacial cleaver (Table 6.2), typical of the Late Lower Paleolithic. Until a larger sample is obtained we preliminarily classify the basal deposits at DM-8 as Late Acheulean, likely to be contemporaneous with the Late Acheulean of Azraq facies deposits identified in the Shishan Marsh to the south (Copeland, 1989a, 1989b, 1989c; Rollefson et al., 1997). Taphonomically the artifacts are undamaged or only slightly damaged (Table 6.3) and the pattern of the angle of repose matches the 3bc assemblage (Figure 6.4). Layer 1b represents a similar depositional marsh or lake environment as layers 3bc, although with a larger mean particle size suggesting shallower water closer to the shoreline, and layer 1c is aeolian sandy silt (Figure 6.6; Appendix B). We suspect this collection of artifacts accumulated slowly and was gently buried by a seasonal marsh and aeolian deposits – possibly the remains of a lag deposit that has since been reburied. The slightly different pattern of patination for artifacts from layers 1c and 1b compared to those from the thick clays suggests a different post-depositional environment (Table 6.4) and perhaps a longer exposure on the surface during the aeolian accumulation. Although only speculation at this point in time, the only other assemblage with a similar breakdown of patination categories is layer 2a, which is also an aeolian accumulation.

6.1.2. The DM-1 Construction Pit

In 2008, the DMAPP team arrived in North Azraq to find three large foundation pits exposed in the bed of the former Druze Marsh (DM-1, DM-1X, DM-1Y) (see above for more detail). We obtained permission to document the stratigraphy and salvage what artifacts we could from DM-1 over the period of a few short days. The choice of recording DM-1 as opposed to DM-1X or DM-1Y is directly the result of accessibility. DM-1 was large, more than 160 m^2, and had a graded earth ramp allowing easy access (Figure 6.8). DM-1X and DM-1Y were also large, but their vertical walls made access difficult and slow. Because of our time limitations, we chose to concentrate on obtaining as much information as possible from DM-1.

Located only 25 m to the northwest of the DM-8 excavation (Figure 5.1), it is of no surprise that the stratigraphic sequences are considerably similar between the two locations. DM-1 can be divided into the same three zones as the DM-8 excavation profile: a lower zone with increasing aridity upward, a middle zone dominated by wet conditions, and an upper zone that documents the gradual drying of the historic marsh. The lower zone is dominated by silty sand that culminates with an erosional unconformity. Overlying the unconformity is the middle zone: thick – 60-80 cm in places – massive clayey silt deposited most likely in open water, probably from a relatively deep marsh or shallow lake. The upper zone documents the eventual drying of the Druze Marsh, but the specific sedimentary units are slightly different than those observed in the DM-8 excavation, particularly the substantial Epipaleolithic occupation horizon identified at the base of layer 4a, which, at present, is exclusive to DM-1 (Figure 6.8 and Table 6.5). Due to the general similarity with the DM-8 excavation profiles, the stratigraphic unit designations developed by Cordova continue to be used (Cordova et al., 2009, 2013) (see Table 6.1).

DM-1 did not reach bedrock (Figure 6.8 and 6.9). The lowest deposit exposed is pale yellow, very slightly clayey silty sand with a sugary consistency labelled unit 1c, which is an aeolian deposit that accumulated during relatively dry conditions. This interpretation is supported by the relatively low proportions of organic and inorganic carbon (Figure 6.9). Dry conditions increased above unit 1c, leaving an erosional unconformity until deposition began anew with a thin, very dark gray, slightly clayey sandy silt (unit 2a) that grades upward into a slightly sandy slightly clayey silt (unit 2b). This marks the onset of moist conditions, particularly demonstrated by the increase in organic matter and the proportions of clay and silt sized particles (Figure 6.9). As we only had a limited time to study DM-1, the data collection was necessarily rushed and artifacts were

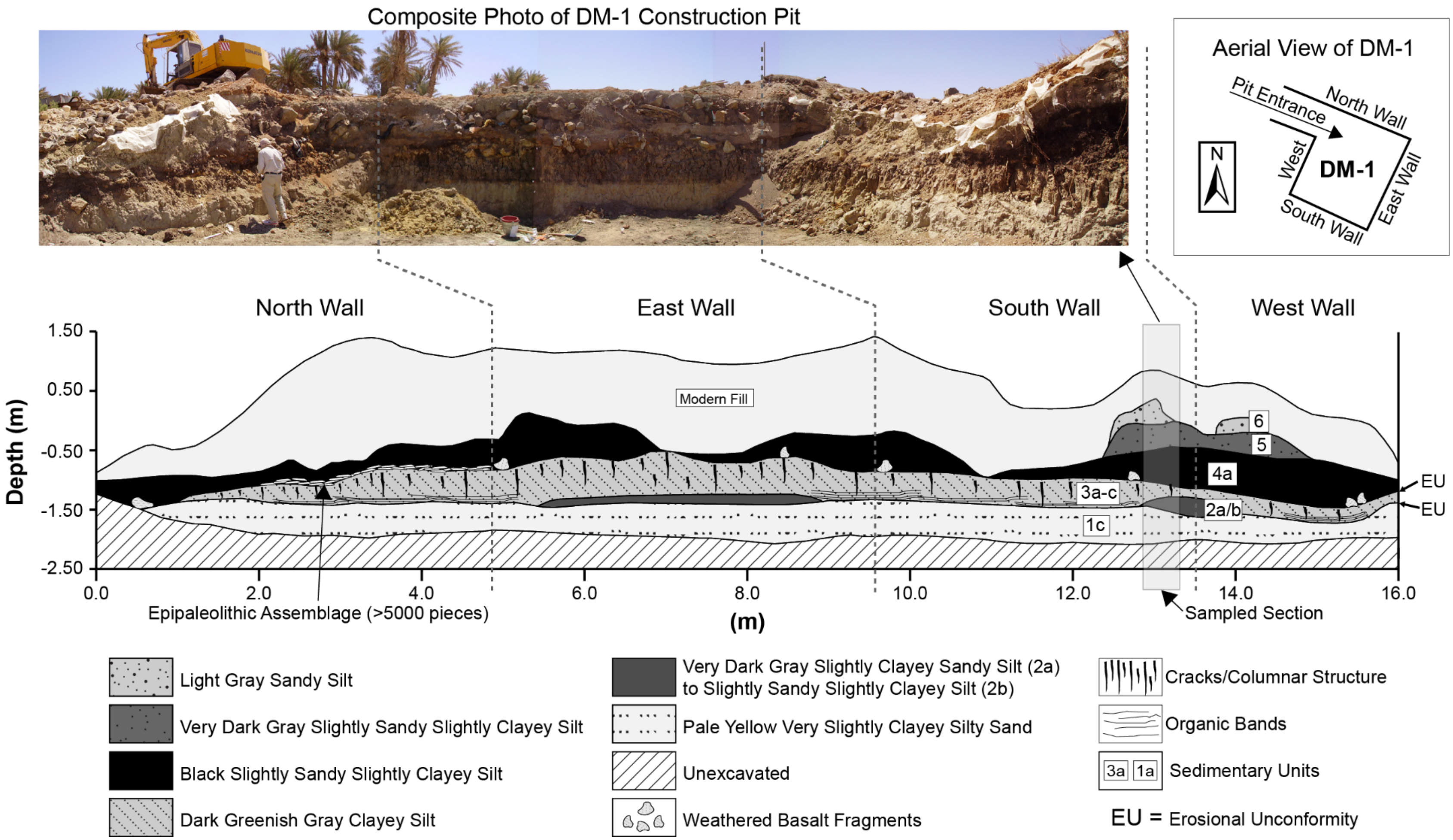

Figure 6.8 Composite photo and stratigraphic drawing of the DM-1 construction pit (photo credit: Carlos Cordova).

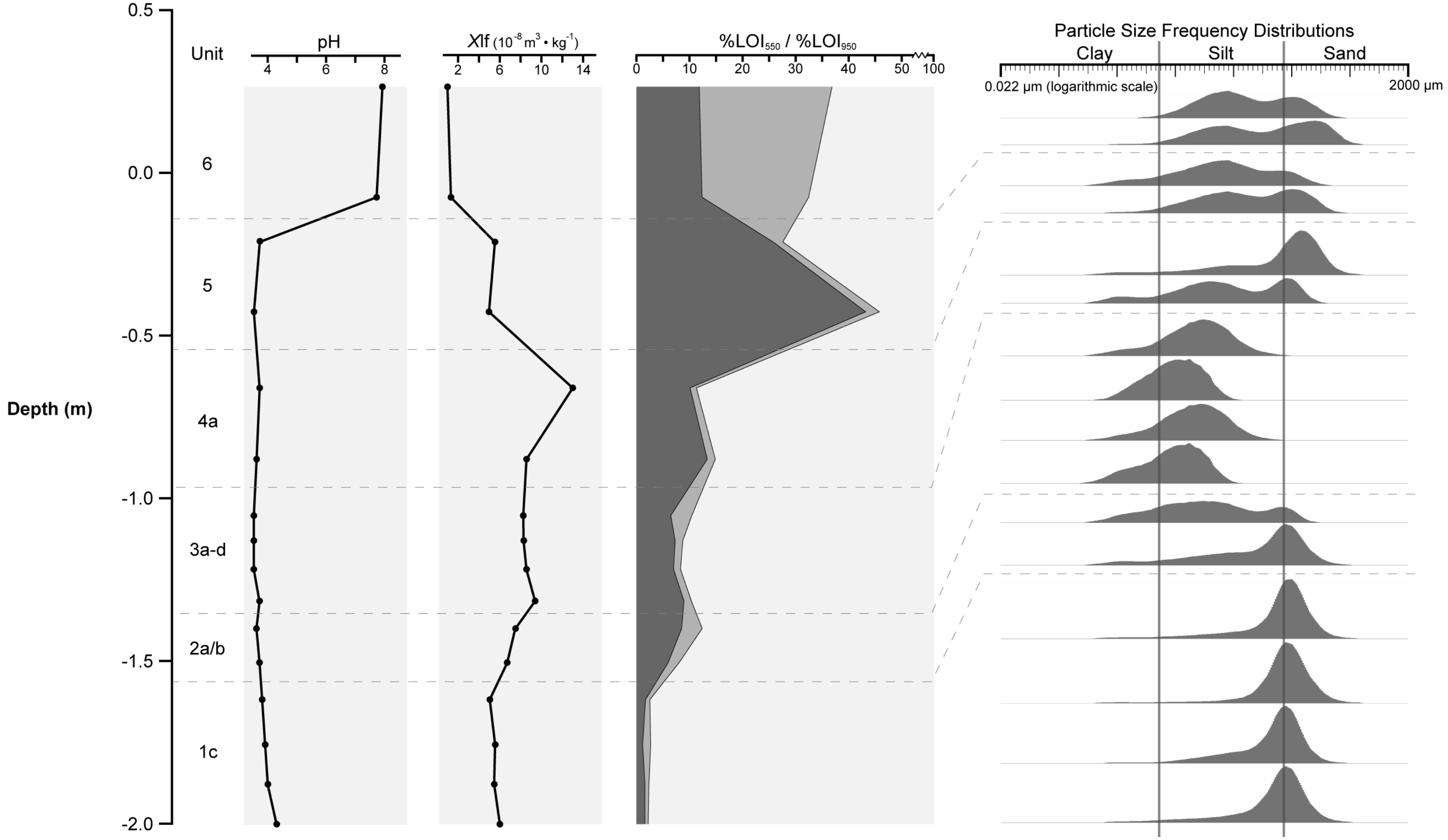

Figure 6.9 Sedimentological data from the DM-1 stratigraphic profile.

not recorded in 3-dimensions. Nevertheless, a careful search of the deposits removed from the three construction pits, and an expedient test pit into the floor of DM-1, produced Late Acheulean type artifacts from this lower portion of the profile. The formal tools include handaxes, minimally retouched scrapers, Levallois points, and Mousterian points (Table 6.5). Beyond the sedimentary unit of origin, it is difficult to discuss the artifacts recovered from the construction pits and the geological trenches in detail. Moreover, aside from the Epipaleolithic horizon (unit 4a), the sample sizes are generally small, making behavioural conclusions tenuous at best. A more thorough discussion of the cultural material will follow in the discussion section.

The middle portion of the DM-1 stratigraphic profile indicates a return to moist conditions. As in the DM-8 excavation, this is marked by the units 2a and 2b. In DM-1, however, both units are very dark gray, making it difficult to distinguish unit 2a from 2b in the field. Nonetheless, the transition is clear in the particle size distribution data (Figure 6.9). Moreover, unit 2b is bimodal, with one mode of fine to medium silt and a shorter peak the straddles the sand/silt boundary at 62.5 μm (Appendix B). This means that despite the onset of much wetter conditions in unit 2b, there is still an aeolian input of fine sand during the deposition of the shallow marsh. The sand contribution ends, however, with the transition at the upper boundary to a dark greenish gray, massive clayey silt. As with the DM-8 excavation, this middle zone of the sequence is produced by a relatively deep marsh or shallow lake. The gleyed colour indicates waterlogged conditions, and substantial deposition of clay implies relatively calm open water. Macroscopically, there are no transitions within the massive clayey silts, leading me to label this unit 3a-d. However, the PSDs show vertical fluctuations in the mean particle size. The bottom of the deposit has a mean particle size of 3.9 μm; it grades upward to a mean 7.6 μm then back to a mean of 3.9 μm before it increases again to 8.5 μm (Figure 6.9 and Appendix B). This represents a facies transition at the DM-1 location through time as the deep marsh or shallow lake contracted and expanded in response to local environmental conditions. A smaller mean particle size represents deeper water, whereas a larger mean particle size represents slightly shallower water, or a location closer to the shoreline and the influence of fluvial input. The wet conditions end at DM-1 with an erosional unconformity at the 3a-d/4a boundary.

Table 6.5 Combined list of artifacts found in DM-1, DM-2B, DM-3, DM-7, and DM-9.

Artifact Type	Sedimentary Units								Total
	0b-1c	2a-2b	3a	3bc	3d	3e	3?	4a	
Levallois Flake	14	3	0	1	0	0	2	0	**20**
Levallois Point	5	1	0	1	0	0	0	0	**7**
Mousterian Point	2	0	0	0	0	0	1	0	**3**
Single and Double Scrapers	4	0	0	3	0	0	1	0	**8**
Endscraper	1	0	0	0	1	0	4	2	**8**
Simple Endscraper on Blade	1	0	0	1	1	0	2	2	**7**
Burin	2	0	0	1	0	0	1	1	**5**
Blade and Blade Fragments	3	1	1	18	3	2	34	610	**672**
Naturally Backed Knife	2	2	0	0	0	0	1	0	**5**
Notch	1	2	0	1	0	0	0	0	**4**
Denticulate	2	0	0	0	0	1	1	0	**4**
Denticulate and Notch	2	0	0	0	0	0	0	0	**2**
Flake and Flake Fragments	11	19	1	35	7	0	54	3767	**3894**
Tayac Point	1	0	0	0	0	0	0	0	**1**
Naturally Backed Blade	1	0	0	0	0	0	1	0	**2**
Levallois Blade	2	2	0	0	0	0	5	0	**9**
Angular Fragment	1	1	0	0	0	0	0	0	**2**
Biface Retouch Flake	6	0	0	0	0	0	0	0	**6**
Core Tablet (+ Crested Blade in 4a)	1	0	0	1	0	0	0	49	**51**
Single Platform Core	1	2	0	2	0	0	3	0	**8**
Two Platform Core	1	0	0	1	0	0	0	0	**2**
Polyhedral Core	2	0	0	0	1	1	0	0	**4**
Levallois Flake Core	1	3	0	0	0	0	0	0	**4**
Blade Core	1	0	0	4	0	0	1	8	**14**
Bladelet Core	0	0	0	0	0	0	0	11	**11**
Levallois Blade Core	1	0	0	0	0	0	1	0	**2**
Core on Flake	3	0	0	0	0	0	1	0	**4**
Trapezoidal Microlith	0	0	0	0	0	0	0	1	**1**
Bladelet	0	0	0	0	0	0	0	692	**692**
Backed, Diagonally Truncated Bladelet	1	0	0	0	0	0	1	200	**202**
Truncated Bladelet	0	0	0	0	0	0	0	2	**2**
Discoid Core	2	0	0	0	0	0	0	0	**2**
Handaxe and Handaxe Fragments	7	0	0	0	0	0	2	0	**9**
Azraq Cleaver	1	0	0	0	0	0	0	0	**1**
Divers	2	0	0	0	0	0	0	0	**2**
Total	**85**	**36**	**2**	**69**	**13**	**4**	**116**	**5345**	**5670**

Unit 4a, which was not present in the DM-8 excavation, marks the beginning of the upper zone of the stratigraphic sequence in DM-1. It is a black, organic-rich deposit of irregular thickness that grades upward from slightly sandy slightly clayey silt to slightly clayey silty sand (Figure 6.9). Despite the high organic matter content, the PSD for the bottom part of unit 4a is very poorly sorted and trimodal. It has a primary mode of very fine sand (72.4 µm), an almost equivalent peak of medium silt (9.5 µm), and a third small peak of coarse clay (0.7 µm) (Figure 6.9 and Appendix B). This peaty deposit is a marsh edge environment with abundant vegetation that was subject to seasonal inundation of varying depths depending on yearly variations in precipitation. The result is a palimpsest of geomorphic processes over time. The upper portion of Unit 4a transitions to a PSD dominated by fine and very fine sand. This documents drying environmental conditions accompanied by increased aeolian deposition and reduction in the size of the wetland. Because the deposit maintains a relatively high organic carbon content while the conditions are drying, the water table must have been high at this time to support plant growth and soil formation. The spike in the magnetic susceptibility at the top of unit 4a supports increasingly dry conditions as well. It coincides with a similar spike in DM-8, and is likely the result of greater fluvial influx due to increased watershed erosion, a phenomenon also observed in the Jubbah paleolake deposits in north-central Arabia (Petraglia et al., 2012).

Culturally, unit 4a is a significantly rich deposit. During only a few short days of salvage work in DM-1, wall scrapings from layer 4a produced a >5000 piece Epipaleolithic assemblage. The assemblage is dominated by chipping debris (>3700 pieces), blades (n=610), bladelets (n=692) and backed, diagonally truncated bladelets (n=200) (Table 6.5). The backed, diagonally truncated bladelets make up 96.2% of all retouched tools (n =208). It is typologically Early Kebaran and is reminiscent of assemblages recovered from 'Ain Qasiyya to the south that date between 24-19 ka (Richter et al., 2007, 2010; Jones and Richter, 2011). As a marsh edge environment, unit 4a would have been an attractive location for resource acquisition.

The drying of Unit 4a is followed by another return to wet conditions. Overlying unit 4a is very dark gray, very slightly clayey sandy silt that grades upward into slightly sandy slightly clayey silt. This is unit 5, the historic marsh deposit. And again, although wet conditions have returned, the PSDs suggest arid conditions were still predominant (Figure 6.9). The bottom portion of unit 5 has a bimodal distribution with a primary peak at 83.0 μm and a slightly lower peak at 14.2 μm. This pattern reverses in the upper portion of the deposit with a primary mode of 14.2 μm and a secondary mode of 63.2 μm, suggesting increasingly wet conditions through time (Figure 6.9; Appendix B). The corresponding increase in carbonate content indicates high evapotranspiration and pedogenic carbonate formation, a trend that continues through the topmost deposit, unit 6, which is light gray, very slightly clayey sandy silt to sandy silt. Unit 6 is the dried and calcified historic marsh deposit, which is capped by a thick fill of modern construction debris and garbage.

6.1.3. The DM-9 Trench

Using a backhoe, trench DM-9 was opened in 2008 to contextualize the finds made during the salvage work at DM-1 (Figure 6.10). It is located roughly 30 m south of the large construction pit and approximately 15 m southwest of the DM-8 excavation (Figure 5.1). Not surprisingly, the stratigraphic succession is similar to both the DM-8 and DM-1 sequences. The same three zones used to divide DM-8 and DM-1 apply to DM-9, but an additional fourth zone must be added to the bottom of the sequence. A number of artifacts were recovered from the DM-9 deposits, but their 3-dimensional coordinates were recorded only when the artifacts were found in the profile wall (Figure 6.11). The stratigraphic unit designations developed by Cordova (Cordova et al., 2009, 2013) apply to the DM-9 sediments and are used in the following descriptions (see Table 6.1).

Trench DM-9 reached bedrock just over 3 m below the surface. The stratigraphic succession can be divided into four zones from bottom to top: a lower zone indicating moderately wet conditions; a zone dominated by a deep marsh or shallow lake; a zone characterized by drying to the point where erosion predominates; and, in the topmost zone, a return to wet conditions before the subsequent drying of the historic marsh. The most noticeable difference between the DM-9 sequence and the other two profiles in Area A is that the deep deposits of DM-9 have neutral pH values (Figure 6.12). In every other profile examined, including Areas B and C, the basal deposits have extremely acidic pH values.

Figure 6.10 East wall of the DM-9 geological trench.

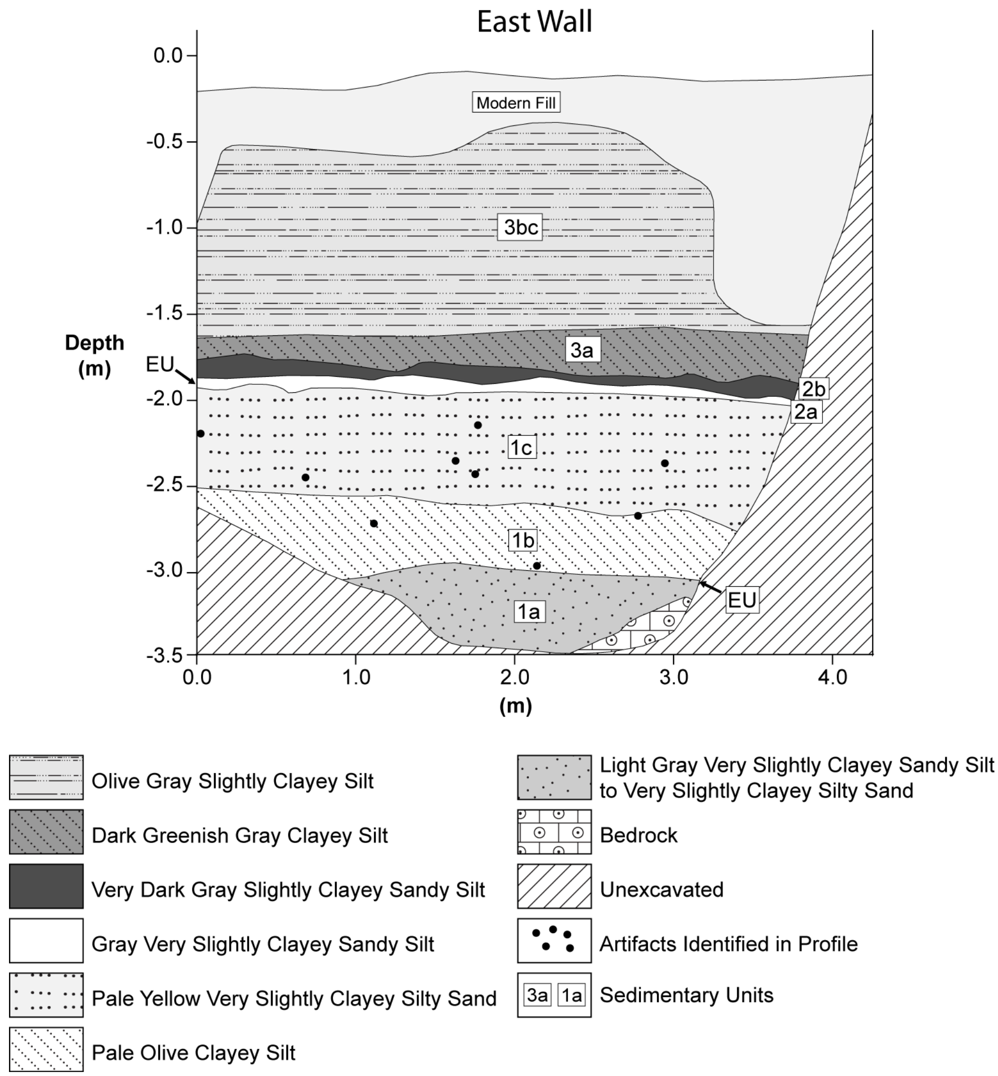

Figure 6.11 Stratigraphic drawing of the DM-9 geological trench.

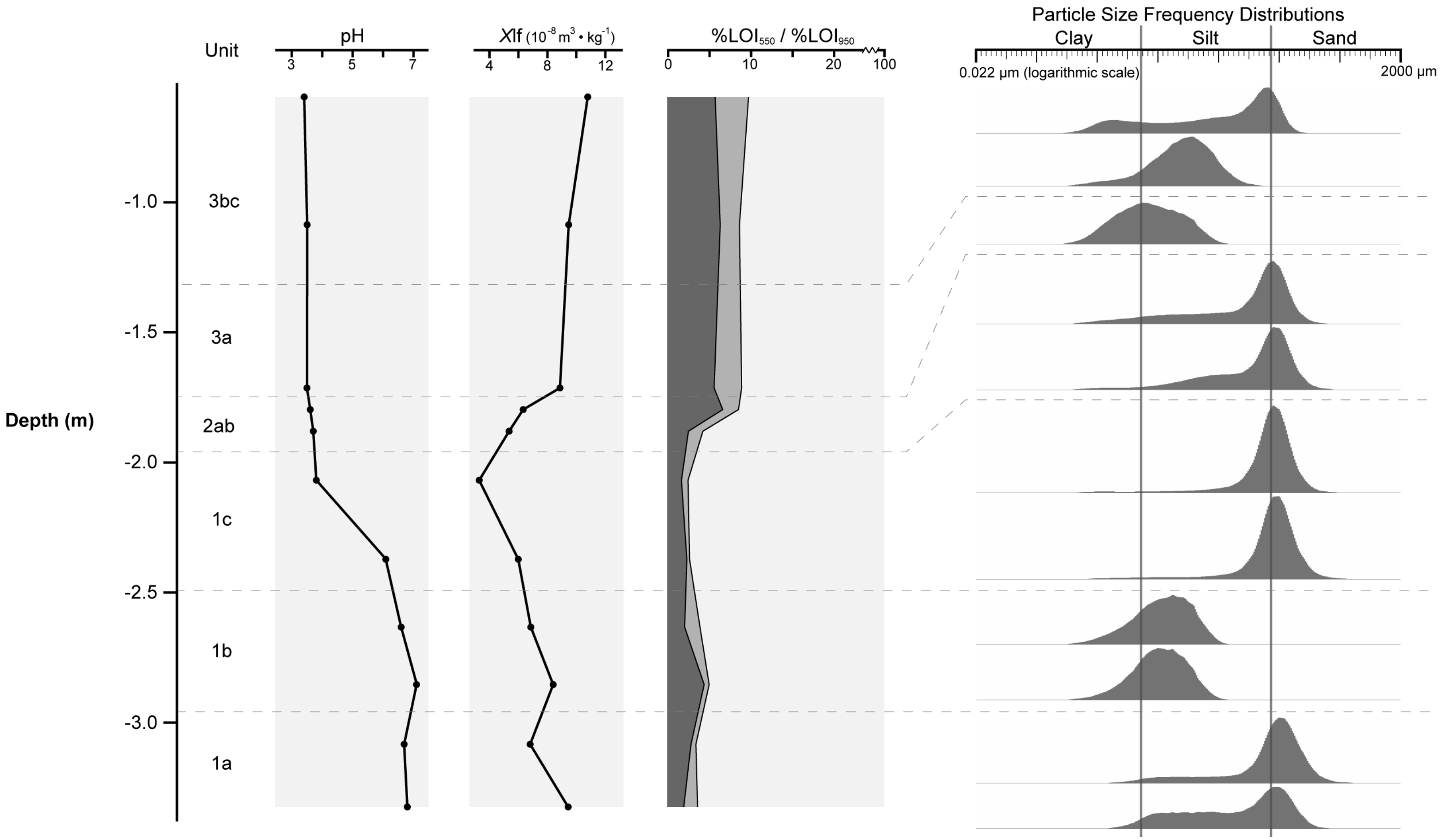

Figure 6.12 Sedimentological data from the DM-9 stratigraphic profile.

The lowest deposit in the stratigraphic profile is unit 1a. It is light gray, very slightly clayey sandy silt. At the base of this unit the PSD displays a prominent peak of very fine sand with a heavily left skewed tail of silt and coarse clay (Figure 6.12). The tail of fine particles diminishes in the upper portion of unit 1a, and the peak of very fine sand is much more prominent. The limited organic carbon content and the sand and coarse silt dominated PSD suggests this is predominantly an alluvial deposit laid down as water flowed into the marsh during the wet season. Occasional standing water during particularly wet years is likely responsible for the finer particle sizes observed, but there is no evidence to suggest this was a waterlogged deposit. The decrease in fine particles near the upper boundary means episodes of inundation became less frequent over time.

The arid conditions represented by unit 1a culminate in an erosional unconformity. It is followed by the deposition of unit 1b, which is pale olive clayey silt. The colour suggests waterlogged conditions and the fine silt implies relatively calm, open water. Unit 1b transitions gradually upward to pale yellow, very slightly clayey silty sand with a sugary texture. This is an aeolian sand deposit, unit 1c, that accumulated during a period of increased regional aridity and shrinking of the Druze Marsh. It is capped by an erosional unconformity. The depositional gap signifies a period when deflation dominated the Druze Marsh. Nearly all artifacts recovered from DM-9 came from unit 1c, with a few identified in 1b (Table 6.5). Mostly the artifacts were scattered throughout the aeolian deposit, as can be seen by the few artifacts identified in the profile wall (Figure 6.11). The majority of artifacts are flakes and flake fragments, but a number of handaxes and a few Levallois pieces were recovered, which point to a Late Acheulean occupation; as drier conditions took over in the region hominins were most likely drawn into the center of the marsh where the isolated springs pools would have provided a source of water in an otherwise dry environment.

Above unit 1c, wet conditions return to DM-9 with the deposition of a thin gray layer of very slightly clayey sandy silt. It transitions to an equally thin, very dark gray layer of slightly clayey sandy silt with an increase in organic carbon content. These two layers correspond to units 2a and 2b, respectively. The PSDs of units 2a and 2b are very similar at DM-9, but the latter has a slight increase in clay and organic carbon content. It is more appropriate to label these two deposits as one unit, unit 2ab, and distinguish it from the clearly differentiated units of 2a and 2b at the DM-1 and DM-8 locations. Furthermore, 2ab in DM-9 seems not to represent a shallow or seasonal marsh, which is what 2b represents in the other stratigraphic sections. Immediately overlying unit 2ab is dark greenish gray clayey silt deposited by a perennial shallow lake, which is labeled unit 3a. The fine particle size distribution, with a mean of 3.5 μm and a mode of 2.1 μm (Figure 6.12; Appendix B), indicates that DM-9 is an offshore location. It grades upward into dark greenish gray, slightly clayey silt, labelled unit 3bc. This documents a slight reduction in the size of the shallow lake as the DM-9 location becomes closer to the shoreline and accumulates slightly coarser sediments. At this point, however, the gleyed colour and overall fine particle size distribution indicate continued open water at this location. A more detailed understanding of water level fluctuations within sedimentary units would be possible with finer sampling resolution and micromorphological analysis. The upper most intact portion of unit 3bc is olive gray, slightly sandy slightly clayey silt. Clay and fine silt particles are present in the PSD signifying that deep, calm water was present at times. The prominent, very coarse silt peak may signify fluctuating water levels or increased aeolian silt settling onto the water's surface. I suspect, however, that the thick layer of modern construction fill may have introduced silt and sand into the top of the underlying deposits. The historic marsh deposits are not present in DM-9.

6.2. Area B Stratigraphic Profiles

In 2008, five narrow and shallow geological test pits (DM-2A, DM-3, DM-4, DM-5, and DM-6) were dug into the south bank of a pre-existing ditch approximately 80 m south-southwest of Area A. Due to time constraints, the test pits were dug to only 40 cm below the surface. In 2011, I reopened and extended DM-2A, DM-3, and DM-5, which are spaced at 15 m intervals. Upon completion, in attempt to better understand the differences between the stratigraphic sequences of DM-3 and DM-2A, I opened DM-2B halfway between them.

Despite visible similarities among the stratigraphic sequences in Areas A and B, the laboratory data demonstrates that they are substantially different. Evidence of fluctuating wetter and drier conditions exists in Area B, but the sedimentary units are dominated by coarse silts and very fine sands. Thick clayey silts indicative of relatively deep standing water in Area A are not present in Area B. These differences make it difficult to directly apply the stratigraphic unit designations used by Cordova (Cordova et al., 2009, 2013) to the Area B sedimentary units. Although in many instances the Area B sedimentary units show macroscopic similarities with those in Area A, the laboratory data indicate that conditions in Area B were drier and contained shallower water at all times compared to Area A. As a result, the stratigraphic sequences of DM-2A, DM-2B, DM-3, and DM-5 will be presented with the most appropriate stratigraphic designation from Cordova's scheme followed by the prime symbol (i.e. 1c′ or 3d′) to emphasize that it represents a facies transition and/or that the same unit in area A and B may not be temporally linked. The stratigraphic correlation of the sequences from each area will be presented in the discussion section.

6.2.1. The DM-2A Test Pit

Geological test pit DM-2A extends ~240 cm below the surface (Figure 6.13 and 6.14). No artifacts were found in DM-2A. The lowest deposit is a moist, greenish gray, very slightly clayey silty sand with red iron stained root voids. The iron staining suggests proximity to an oxidized layer, which we know lies on top of the basalt bedrock in the DM-8 excavation. This unit is overlain by a relatively thin, light greenish gray and very slightly clayey silty sand deposit. These two units combined are labelled unit 1b′, as they indicate a period of waterlogged conditions near the edge of a shallow lake where coarser sediments would accumulate. It is overtaken by massive dark bluish gray silty sand. The dark colour suggests high organic matter content but the LOI_{550} measurement is low (Figure 6.15). The lack of fine particles in the PSD tells us that standing water was not present in this part of the Druze Marsh at this time, although intermittent flooding causing ponding during the wet season is likely responsible for the small proportions of clay and fine silt. Rather, the sand was deposited by aeolian processes in the dry season or more likely as alluvium during flood events in the wet season when the Qa' filled and flowed into the Druze Marsh, heading for the low spots where pools would form (see Figure 3.3). Regardless, there must have been enough water available in the region via the water table to support soil formation, producing the dark colour. As a result, this deposit is labelled unit 1b-c′ because it represents continued groundwater presence and also documents the transition to arid conditions marked by the erosional unconformity on top of it.

Deposition began anew above the erosional unconformity with unit 3a-c′, which is a greenish gray, slightly clayey silty sand. The greenish gray of the parent material is difficult to see in the profile, as the entire sedimentary unit is overtaken by pedogenic carbonate formation – evidenced by the noticeable white colour in the profile picture (Figure 6.13) and the dramatic LOI_{950} spike in the lab data (Figure 6.15). The carbonates are most dense at the upper boundary, but there is no indication of laminar structure. The nodules are distinct, as are carbonate casts in numerous root voids. Based on a U-series age estimate, the onset of dry conditions causing the carbonate development began sometime between 160-133 ka (Cordova et al., 2013), in the latter part of MIS 6. Macroscopically the greenish gray parent material appears uniform, but the PSDs are markedly bimodal with the silt proportion increasing upward (Figure 6.15). The PSD for the lower half of this sedimentary unit is dominated by a prominent peak of very fine sand (72.4 μm) and a short, broad mode of 4.8 μm (Appendix B). The upper half of the deposit is still dominated by fine sand, but the fine silt mode, between 4.7-6.3 μm, is almost equal in height at this point in time. The bimodal distribution implies two different geomorphic inputs, with the input of fine silt increasing through time. It appears that as conditions improved, the depth of water in the Druze Marsh still fluctuated. During wetter conditions DM-2A was a nearshore environment, depositing fine silt; when conditions were drier, it was a shoreline where very fine sands were deposited. The colour of the deposit indicates gleying

Figure 6.13 West wall of the DM-2A test pit.

and confirms waterlogged conditions, yet the predominance of roots suggests relatively shallow water. The wetter conditions end sometime between 160-133 ka with the dramatic development of pedogenic carbonates. Unit 3a-c′ therefore represents one of the wettest periods in the Druze Marsh and corresponds to the thick clayey silt deposits in the Area A stratigraphic sequences, although it is possible the deposit only corresponds to unit 3a, which represents the wettest conditions and deepest water in Area A near the spring source.

The erosional unconformity that caps the carbonate indicates a period of time, at least in the vicinity of DM-2A, when deflation was the primary geomorphic process. I am unsure how long this dry period lasted, perhaps until the latter part of MIS 5e (130-120 ka), or more likely until one of the more recent

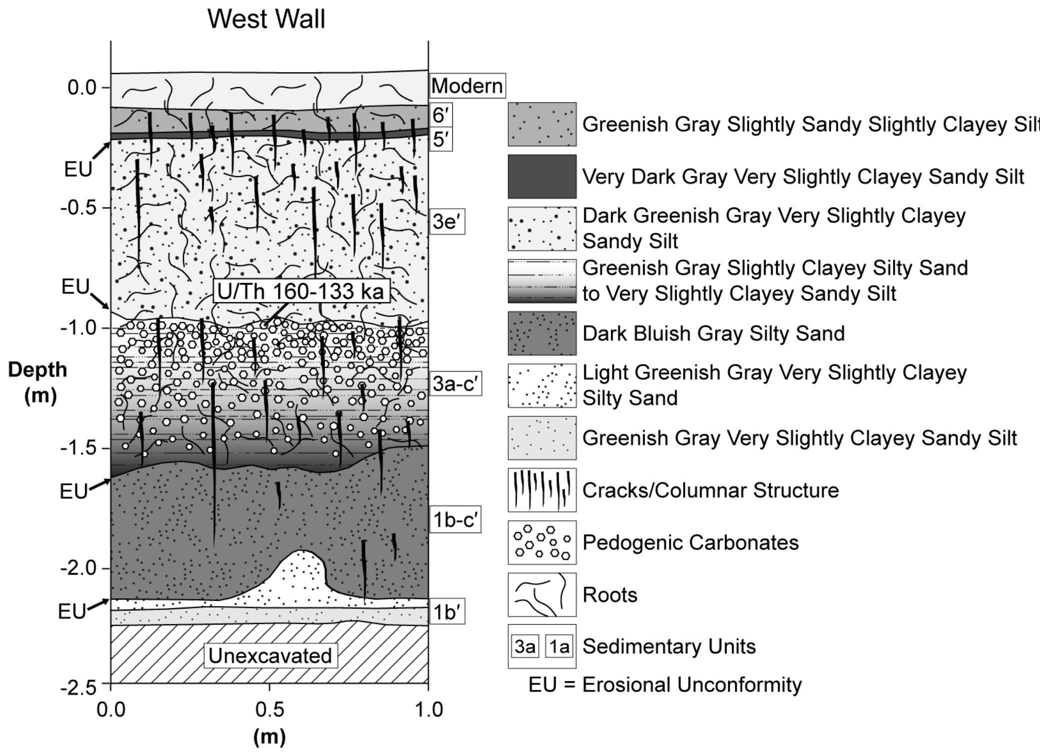

Figure 6.14 Stratigraphic drawing of the DM-2A test pit.

stadials – either MIS 5c (105-100 ka) or 5a (82-78 ka), which are known to be periods of increased moisture on the eastern Jordanian basalt plateau (Frumkin et al., 2008), as well as in other localities in the Jordanian Desert (Abed et al., 2000), and the Madaba Plateau (Cordova et al., 2011). Deposition returns above the unconformity with dark greenish gray, very slightly clayey sandy silt. The PSD is dominated by fine sand, but is skewed toward silt-sized particles. The increase in the organic carbon content suggests the return of wetter conditions and soil formation, but the prevalence of roots, the dark colour, and the fine sand-dominated PSD imply a seasonal wetland, reminiscent of unit 3e in the DM-8 excavation profile. Overlying this unit is a thin layer of very dark gray, very slightly clayey sandy silt accompanied by a further increase in organic carbon content. It signals a slight amelioration in the conditions, which is unit 5, before the historic drying of the marsh identified by calcified light gray, very slightly clayey sandy silt. The bimodal distribution of this top-most deposit matches unit 6 in DM-1, suggesting the deposition of fine particles during wet periods and coarse

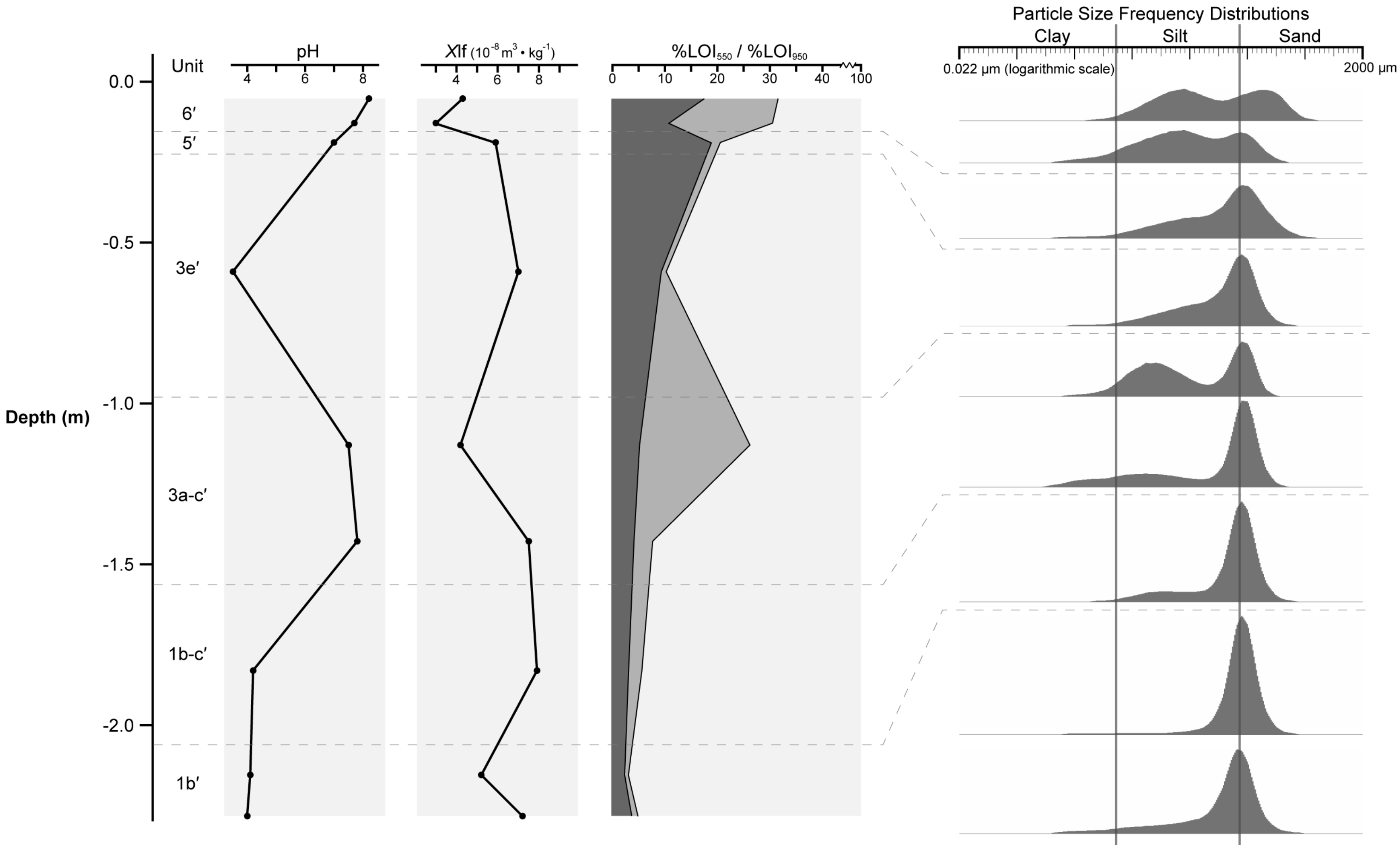

Figure 6.15 Sedimentological data from the DM-2A stratigraphic profile.

particles during dry periods. This is likely due to fluctuations in the water level of the historic marsh and the accompanying geomorphic environments of the wetter and drier periods until, eventually, the complete drying of the marsh.

6.2.2. The DM-2B Test Pit

Test pit DM-2B is situated approximately 8 m north-northwest of pit DM-2A. The profile is dominated by very fine sands and coarse silts. There is overall very little evidence for clay and fine silt sized particles in the stratigraphic sequence. Two artifacts were found while digging DM-2B and will be discussed in relation to the relevant depositional units.

The base of the DM-2B geological test pit extends ~245 cm below the surface (Figures 6.16, 6.17). The lowest deposit, unit 1b′, is very dark grayish brown, slightly clayey sandy silt with yellow stained root voids. It is trimodal (Figure 6.18). The most prominent peak in the PSD for unit 1b′ is very fine sand (~72.4 μm). The subsequent medium silt (14.2 μm) and coarse clay (0.6 μm) modes decrease in proportion respectively (Appendix B). Although not stratigraphically linked, the environmental conditions of unit 1b′ are reminiscent of the lower portion of unit 4a in trench DM-1. It is a relatively organic-rich deposit that was subject to varying geomorphic processes responsible for depositing different particle sizes. Combined with the plentiful root voids visible in the profile, it implies a shallow wetland environment that was subject to short-term fluctuations. Lying horizontally on the surface of this deposit was a >20 cm long Azraq cleaver (Figure 6.19). It typologically matches many of the Late Acheulean artifacts found at other locations in the Druze and Shishan Marshes.

Overlying this basal deposit is a depositional hiatus followed by a thin sequence of four deposits, sedimentary units 1d through 2b (Figure 6.17). From bottom to top, the sequence begins with a light yellowish brown, very slightly clayey silty sand of aeolian origin and corresponding drop in the organic carbon content, which suggests dry conditions. It is labelled unit 1d and corresponds to a similar deposit from Area C (see below). This unit is overlain by a light olive

Figure 6.16 West wall of the DM-2B test pit.

gray, very slightly clayey silty sand and an increase in the organic carbon content, implying a moderate return of wet conditions and vegetation. This is unit 1e and may be a shallow intradunal pond deposit, which is also present in DM-11 in Area C. On top of unit 1e is a brown silty sand (unit 2a), which is associated with a decrease in the organic carbon content, indicating that the local environment transitioned back to drier conditions. Overlying unit 2a is unit 2b, a peaty, black sandy silt with many roots, high organic carbon content, and well developed sub-angular blocky soil structure. As was the case in the DM-8 excavation profile, units 2a and 2b mark the transition back to wetter conditions.

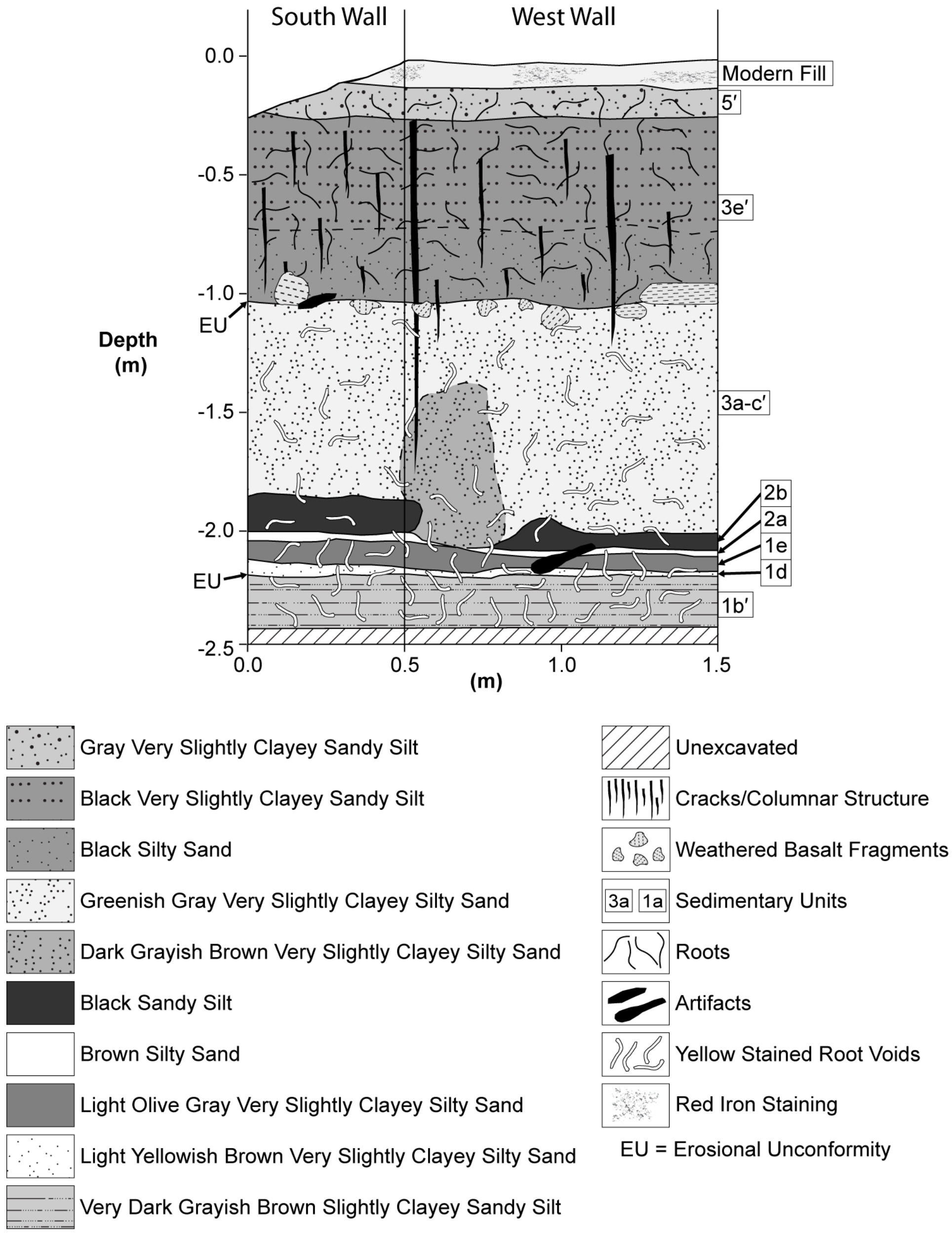

Figure 6.17 Stratigraphic drawing of the DM-2B test pit.

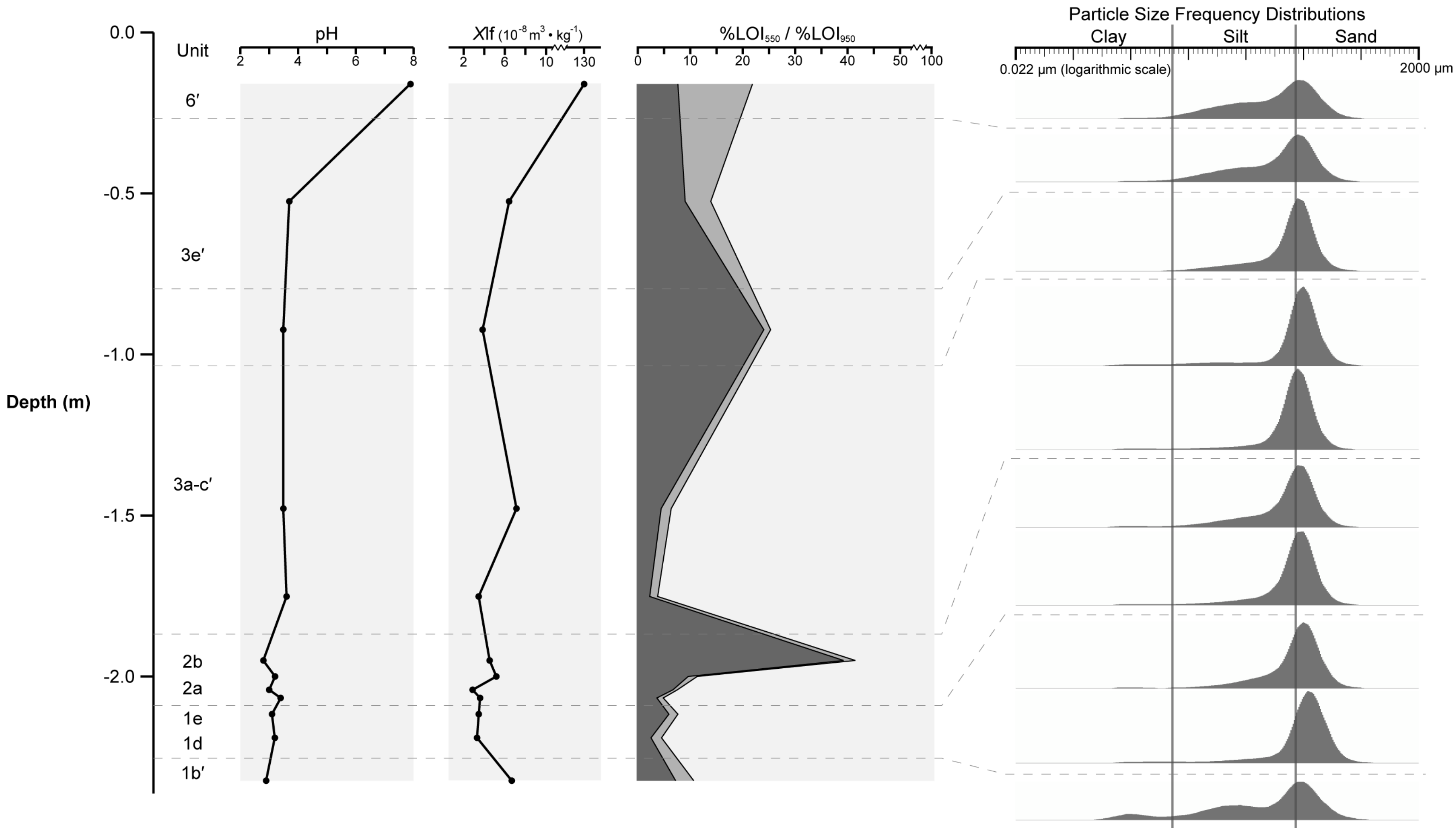

Figure 6.18 Sedimentological data from the DM-2B stratigraphic profile.

Unit 2b grades upward into a nearly metre thick greenish gray very slightly clayey sandy silt with many yellow stained root voids that are more concentrated near the lower and upper boundaries, but less common in the center of the deposit. This is labelled unit 3a-c′. Also apparent in this greenish gray deposit is an intrusive feature with a distinct texture and colour. Truncating the black, peaty deposit in the left hand side of the west wall is dark grayish brown, very slightly clayey silty sand. It contains less fine silt and clay than the greenish gray deposit (Appendix C) and has pockets of light yellowish brown silt, probably an erosional channel that is infilled with younger and coarser deposits. The PSD of unit 3a-c′ does not change much from the underlying unit 2b deposit, but the gley-like colour of unit 3a-c′ implies waterlogged conditions. However, the lack of fine particles in the PSD suggests that it was located relatively close to the edge of a shallow lake, forming a nearshore open water deposit.

Unit 3a-c′ is capped by an erosional unconformity lined with a row of decaying stones. Lying on the unconformity was a 7 cm retouched flake that is typologically ambiguous, as it could relate to a number of Paleolithic industries (Figure 6.19). This erosional unconformity likely corresponds to the deposition of pedogenic carbonates in DM-2A. The reason carbonates were not deposited at this location only 8 m away is somewhat unclear. Either the hydrological conditions were different at DM-2B and pedogenic carbonates did not develop at this location, or they were deposited and then eroded by a combination of fluvial action and deflation. The rocks lining the surface of this deposit are an indication of high energy fluvial deposition, and are perhaps all that remains of a deflation surface that created the erosional unconformity at the top of unit 3a-c′.

Deposition returns above the erosional unconformity with a black silty sand that grades upward into black, very slightly clayey sandy silt. These two deposits are considered unit 3e′ and document the onset of wet conditions. The bottom deposit of unit 3e′ is peaty and has a high organic carbon content and abundant roots. The PSD is dominated by very fine sands, but enough water was available to support soil formation. It is a marsh edge environment that was rarely covered by deep enough water to deposit large amounts of clay and silt. The proportion of silt increases upward in unit 3e′, yet there continues to be abundant roots. The associated environmental conditions change very little, but the increased proportion of clay and fine silt particles implies more short-term inundation. Above this point in the stratigraphic succession, the inorganic carbon value increases and is the first indicator of the historic drying of the marsh. It culminates with the top-most deposit, unit 5′, which is gray, very slightly clayey sandy silt. The PSD matches the underlying deposit, but the gray colour is caused by calcification. There are numerous large red iron stains, which are responsible for the dramatic spike in magnetic susceptibility at the surface of DM-2B.

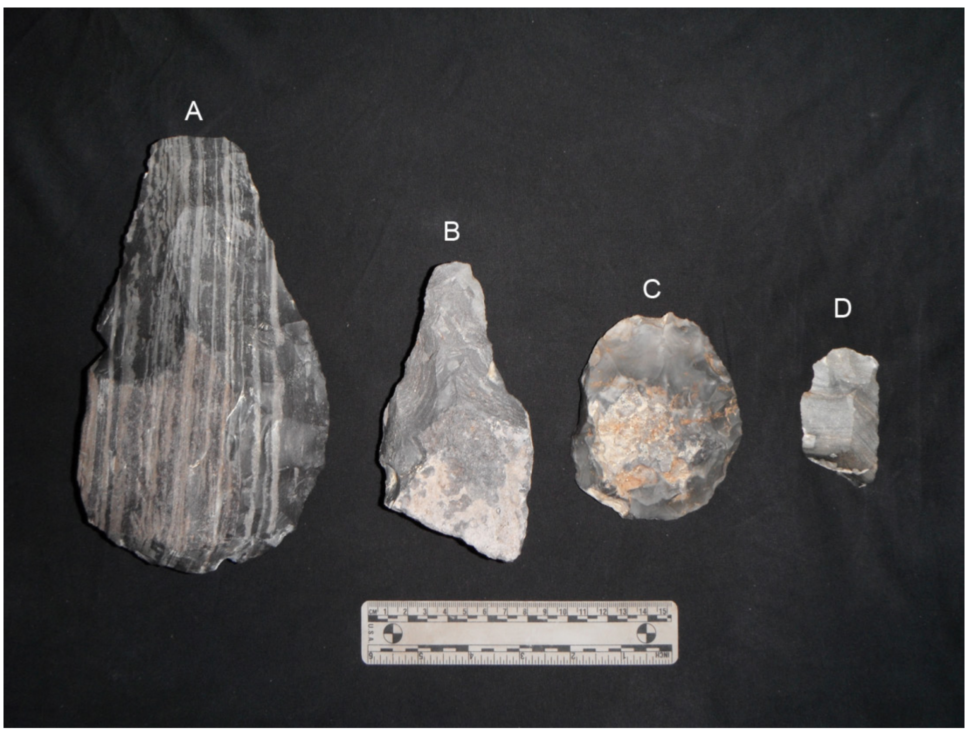

Figure 6.19 Artifacts recovered from the DM-2B and DM-3 test pits. (A: Azraq Cleaver from layers 1d-1e in DM-2B; B: Micoquian Handaxe from the layer 1b′/1b-c′ transition in DM-3; C: Ovate Biface from the layer 1b′/1b-c′ transition in DM-3; D: Undiagnostic Retouched Flake from the 3a-c′/3e′ transition in DM-2B).

6.2.3. The DM-3 Test Pit

Test pit DM-3 is situated ~7 m north-northwest of pit DM-2B along the same pre-existing ditch mentioned previously. The top 30-40 cm were examined in 2008, and in 2011 the pit was extended to approximately 255 cm below the surface (Figure 6.20, 6.21). The profile is dominated by fine sands and coarse silts, quite similar to DM-2B. The profile shows little evidence for the presence of deep marshes or shallow lakes at this location (Figure 6.22), but it does show fluctuations between wetter and drier conditions, suggesting that DM-3 was peripheral to areas of relatively deep pools or shallow lakes documented in the sedimentary units in Area A.

The bottom of test pit DM-3 did not reach bedrock. The lowest deposit encountered is restricted to the bottom left-hand corner of the pit and is a massive, pale olive, very slightly clayey silty sand with few yellow stained root voids, considered part of unit 1b′. The gley colour suggests waterlogged conditions, but the presence of root voids points to a relatively shallow water level, as does the PSD dominated by fine sand to coarse silt (Figure 6.22). The sample still contains approximately 4% clay and nearly 15% very fine to medium silt (Appendix B), suggesting there were times when the water was deep and calm enough to allow fine particles to settle out of suspension. This deposit most likely represents a nearshore environment of a relatively deep marsh or shallow lake. The upper boundary is a clear transition with the overlying very dark gray, very slightly clayey sandy silt. The darker colour is associated with a corresponding increase in organic carbon content and the deposit contains many yellow stained root voids. This is a shallow marsh or marsh edge environment that promoted the development of a wetland soil. Both the nearshore open water deposit and the shallow marsh deposit are considered unit 1b′. Lying on the upper boundary of unit 1b′ were two typologically Acheulean artifacts. One is a Micoquian shaped handaxe (Figure 6.19B) and the other is an ovate biface (Figure 6.19C); both were laying one on top of the other. This landscape of a relatively large wetland surrounding a shallow lake would have provided Lower Paleolithic hominins plenty of opportunity to prey on large mammals coming to the water source, or on the aquatic resources themselves.

Figure 6.20 West wall of the DM-3 test pit.

The shallow marsh deposit gradually transitions upward to unit 1b-c′, which is very dark grayish brown, slightly clayey silty sand with many roots. This is a shallow wetland with increased vegetation, as evidenced by the organic matter content and the increase in large root voids. Overall, the PSDs are very similar in the bottom three depositional units of DM-3. There was a shift from perennially waterlogged conditions at the bottom of the profile to the shallow marshland of unit 1b-c′, with little overall change in the geomorphic inputs. The change was instigated by increased aridity, which is evidenced by a drop in the proportion of fine particles in the PSD of the uppermost dark grayish brown deposit (unit 1b-c′), and ultimately the depositional gap at its upper boundary. Unit 1b-c′ represents a period of wetter conditions followed by the eventual onset of dry conditions.

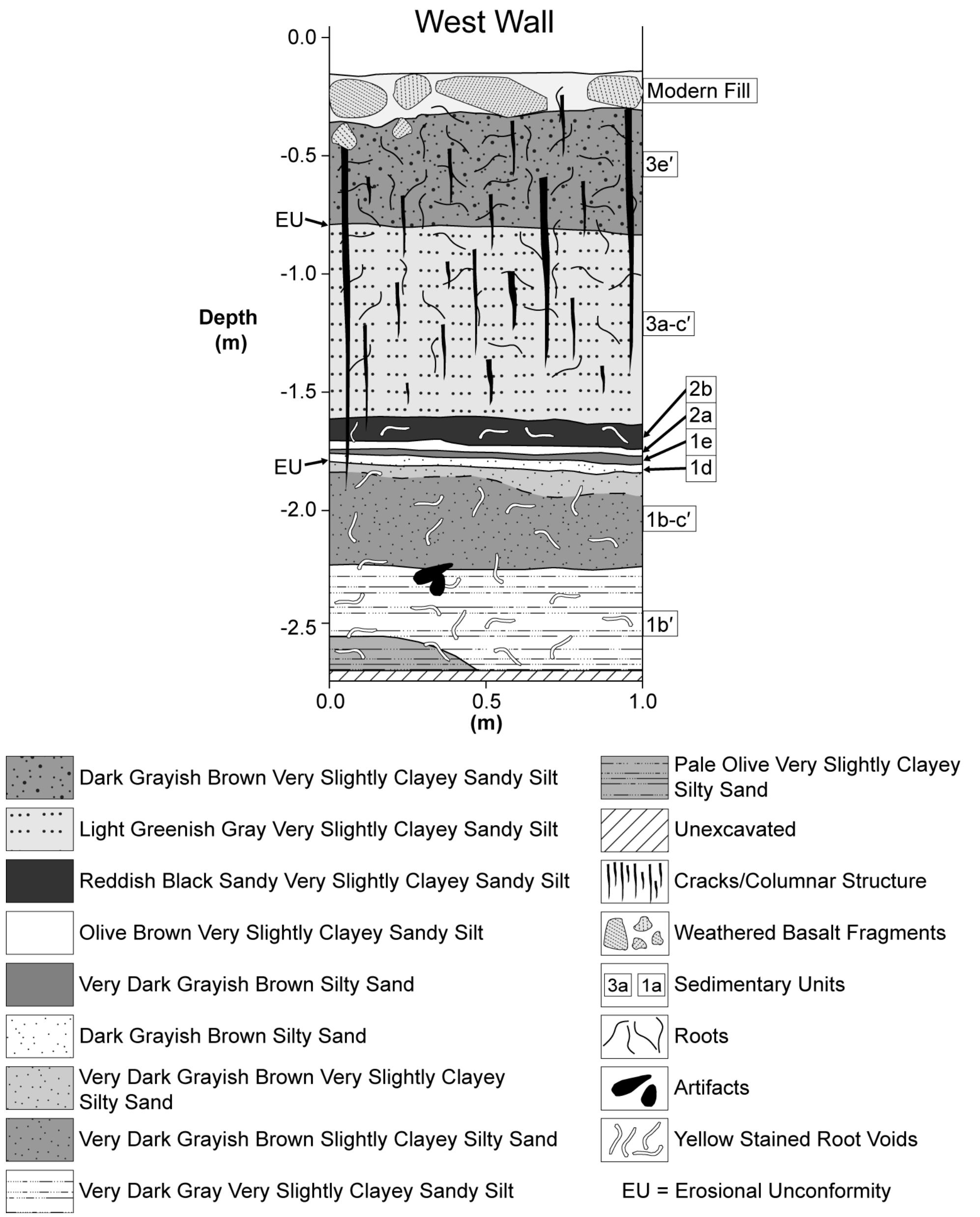

Figure 6.21 Stratigraphic drawing of the DM-3 test pit.

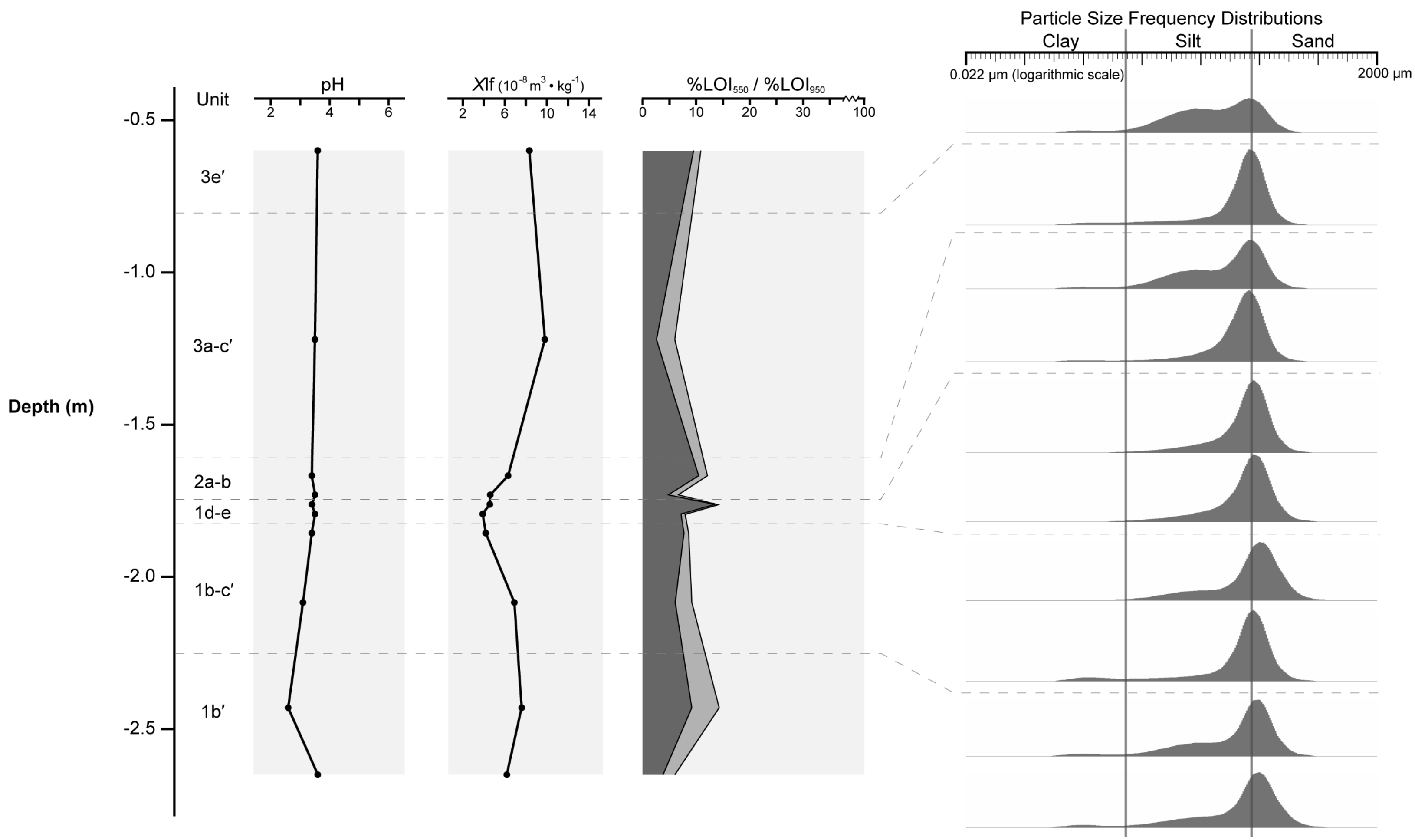

Figure 6.22 Sedimentological data from the DM-3 stratigraphic profile.

Above the erosional unconformity on top of unit 1b-c′, deposition resumes with a thin sequence of aeolian and organic-rich deposits, which are units 1d through 2b. This sequence of four sedimentary units is very similar to the thin sequence observed in DM-2B. Rather than beginning with an aeolian deposit, however, the bottom of this sequence in DM-3 is very dark grayish brown, very slightly clayey silty sand that looks very much like the underlying shallow wetland deposit of unit 1b-c′. It could be an intradunal pond deposit or the return of a widespread shallow wetland. Capping the shallow wetland deposit is a thin layer of dark grayish brown aeolian silty sand deposited during a period of increased aridity, which is unit 1d. Wet conditions return, however, depositing very dark grayish brown, silty sand with a substantial spike in organic carbon content. This is unit 1e, an intradunal pond deposit. It is sandwiched between the underlying aeolian deposit and a thin layer of olive brown, aeolian, very slightly clayey sandy silt on top, which is unit 2a. The aeolian silt of unit 2a is overlain by organic-rich, reddish black, very slightly clayey sandy silt with many root voids, labeled unit 2b. This wetland soil was deposited under marshy conditions, probably similar to the one that existed in historic times.

The reddish black deposit of unit 2b transitions into a thick, massive to columnar, light greenish gray, very slightly clayey sandy silt, labelled unit 3a-c′. The colour implies gleization caused by waterlogged conditions. However, the almost absent clay portion of the PSD indicates a shallow water body. Unit 3a-c′ at this location suggests a nearshore or shoreline environment when the water table was high and evapotranspiration relatively low, forming relatively deep marshes or a shallow lake in the Druze Marsh. The fine sand and coarse silt were likely brought in by fluvial action that filled the central basin and then flowed into the marsh seasonally. Although only one representative bulk sample was taken from the middle of this deposit, it may represent deeper water at its base, transitioning to shallower conditions upward. The evidence for this is that it sits conformably on top of the reddish black unit that marks a clear return of wet conditions; there are no roots in the lower half of the sedimentary unit, implying relatively deep water, and the gleyic colouration is a clear indication of waterlogged conditions. The increase in the density of roots in the upper portion of the profile indicates a reduction in water depth. The drying trend continues upward, resulting in an erosional unconformity that separates the gleyed deposit of unit 3a-c′ from the overlying unit. This sedimentary unit, layer 3e′, is dark grayish brown, very slightly clayey sandy silt that marks the final return to wet conditions, which is accompanied by a relatively high organic carbon content and abundant roots. The calcified deposit that signifies the historic drying of the marsh – unit 6 in other profiles – is not present at DM-3. Due to the relatively thick modern fill capping the test pit, the absence of the calcified historic marsh deposit is probably the result of modern construction and/or farming activities. The modern fill is light gray loose sand embedded with numerous large rocks.

6.2.4. The DM-5 Test Pit

Test pit DM-5 is situated approximately 15 m to the north-northwest of DM-3 (Figure 5.1). The stratigraphic succession of DM-5 is considerably different from the other test pits dug along the pre-existing ditch. The sedimentary transitions in DM-5 are all gradual, with no evidence for major depositional gaps (Figures 6.23 and 6.24). The sediments fluctuate between clayey silts and silty sands, associated with fluctuations between wet and dry conditions respectively. An examination of historical aerial photographs shows the DM-5 falls within the boundary of the historic marsh, which, as previous stratigraphic profiles have shown, was relatively reduced in size compared to the Pleistocene wetlands and lakes (Figure 6.1). It is no surprise then, that the deposits in DM-5 represent wetter depositional environments than identified in the other Area B sequences. No artifacts were recovered from DM-5.

DM-5 extends 255 cm below the surface but did not reach bedrock (Figure 6.24). The lowest deposit encountered, unit 1b′, is a pale olive, very slightly sandy slightly clayey silt (Figure 6.24). The colour indicates waterlogged conditions and the silt dominated PSD suggests standing water (Figure 6.25). However, the water was not deep enough to prohibit plant growth, as shown by the many yellow stained root voids. The deposit is reminiscent of the massive silty clays

Figure 6.23 West wall of the DM-5 test pit.

encountered at the base of the DM-8 excavation that represent a perennial marsh or shallow lake in the Druze Marsh, and is labelled unit 1b′ accordingly. This unit grades upward to grayish green before giving way gradually to very dark grayish brown, slightly sandy clayey silt. This deposit, unit 1b/c′, is at least trimodal, with a relatively prominent very fine sand mode, followed by a medium silt mode, and a clay mode (Figure 6.25). The increased proportion of sand and the spike in inorganic carbon content in this sedimentary unit imply increasingly dry conditions, but the deposition of clay and silt point to the continued presence of a wetland, as does the organic matter content. The multiple modes suggest a wetland that experienced different geomorphic inputs, depending on fluctuations in water availability. This sedimentary unit suggests that at the time of deposition, the area was inundated with deep, calm water that allowed clay and silt particles to settle, whereas at other times, fluvial input would deposit fine sand. The right half of this layer has a noticeably different texture; it is a very slightly clayey sandy silt, and slightly lighter in colour – a light olive brown. At 85% coarse silt to very fine sand (Appendix B), this represents a facies transition at the shallow edge of a marsh, perhaps as it is drying. This explains the spike in inorganic carbon for the trimodal sample, as increasingly dry conditions promote the precipitation of carbonate in soil in arid environments (Machette, 1985; Cordova et al., 2011). However, there is no corresponding spike in the sample for the right hand side of the sedimentary unit. The left hand side of the unit is a marsh bottom deposit. The right hand portion is very fine sand deposited when fluvial flood waters reached existing wetland and slowed. The remaining suspended fine particles were carried out into the deeper portion of the marsh. As dry conditions prevailed and exposed the marsh bed, evapotranspiration promoted the formation of pedogenic carbonate in the saturated marsh bed deposit, or the left hand side of the layer, but not in the sandy shoreline deposit, which is the right hand side of the layer. To accommodate this deposit that contains a lateral facies transition, it is labelled unit 1b′/c′.

Despite the evidence for increasingly arid conditions in unit 1b′/c′, there is no clear erosional unconformity between it and the overlying deposit. Rather, there is a gradual transition to massive, olive gray, very slightly clayey sandy silt with many yellow stained root voids. This deposit, unit 3a′, is dominated by very fine sand and very coarse silt, but is left skewed with a long tail of particles finer than coarse silt, comprising roughly 20% of the distribution. This does not mean that deposition continued at a uniform rate. It is likely that deposition slowed during the period of dry conditions, but the continuous presence of abundant root voids tells us that water was still available to support vegetation and soil formation. It is possible there was an erosional episode between unit 3a′ and the underlying layer and is now obscured by more recent bioturbation, which

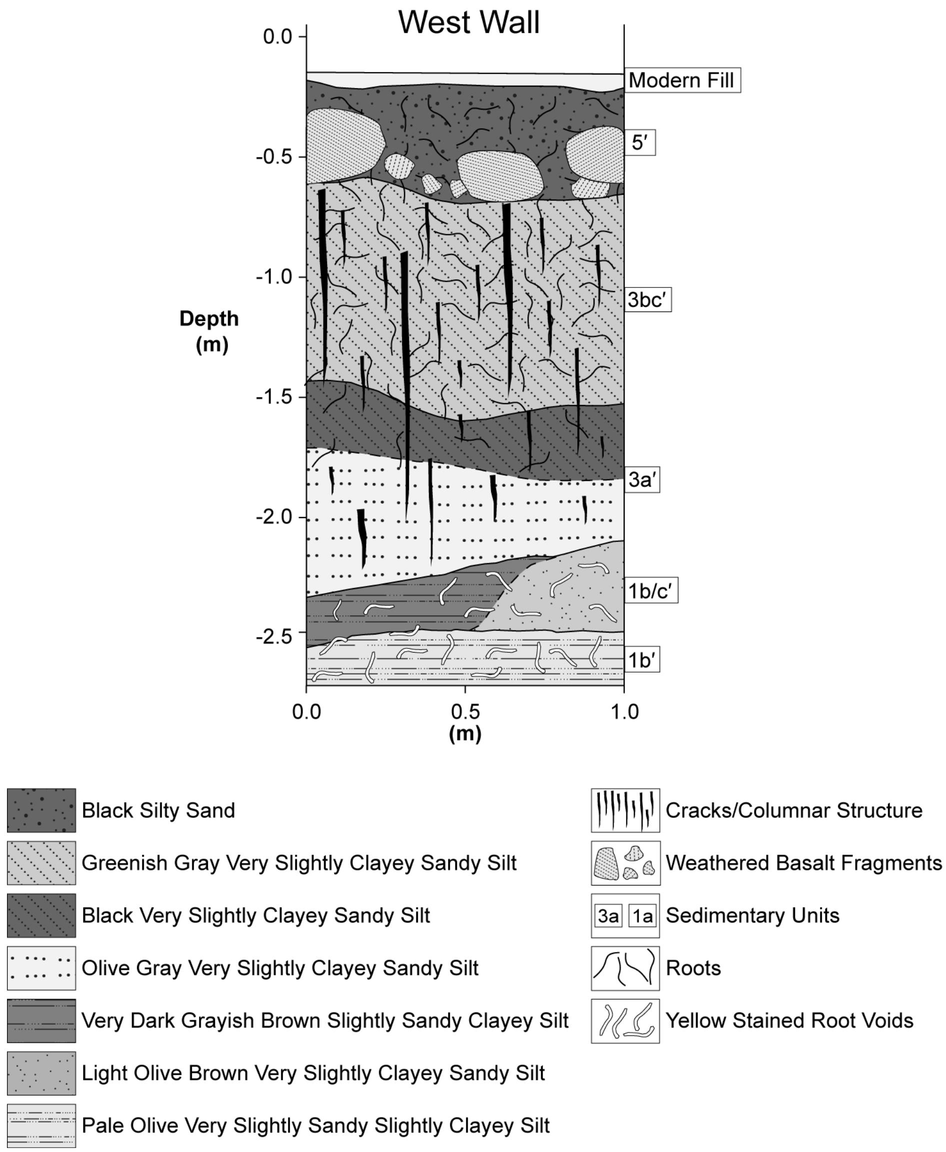

Figure 6.24 Stratigraphic drawing of the DM-5 test pit.

is indicated by the abundance of root voids throughout the lower portion of the stratigraphic sequence, clearly crossing sedimentary transitions. Regardless, the depositional environment changed at this time in DM-5. Clay-sized particles almost completely disappear, yet despite the lack of fine particles, the pale olive colour suggests waterlogged conditions. Water availability is also indicated by the abundant root voids. However, the predominance of fine sand deposited in unit 3a′ suggests a nearshore or foreshore environment, not deep water conditions

(Figure 6.25). Unit 3a′ gradually transitions to black, very slightly clayey sandy silt. The PSD is bimodal with one peak of very fine sand at 72.4 μm and an equivalent in size peak of medium silt at 8.3 μm (Figure 6.25; Appendix B). This is a transition to an inundated shallow marsh environment and is considered part of unit 3a′ as it is drying, which we tentatively correlate with the formation of pedogenic carbonates in unit DM-2A. During wetter periods the area would be flooded as the Qa' filled and breached the sill that separates it from the Druze Marsh, and thereby allowing silt sized particles to settle. During drier conditions the shallow marsh would shrink, leaving the DM-5 location to dry out and collect fluvial input of very fine sand until the onset of the next wet period and increase in water depth, inundating DM-5 once again. The darker colour of the upper part of unit 3a′ supports fluctuating water levels, as waterlogged conditions were not persistent enough to cause gleization. Thus, although water was still available to promote soil formation and vegetation growth, the conditions at DM-5 switched from a relatively stable waterlogged nearshore environment producing gleyed very fine sands to intense differences between wet and dry periods; this allowed two different geomorphic processes to act on a marsh edge environment over time.

The same pattern of water level fluctuations is present in the overlying greenish gray, very slightly clayey sandy silt of unit 3bc′. This deposit has an almost identical bimodal PSD as the underlying black deposit of unit 3a′ (Figure 6.25). However, the medium silt mode is more prominent in unit 3bc′, and the deposit is gleyed (Figure 6.24). The interpretation is generally the same as for unit 3a′, except now the marsh is overall deeper, placing the DM-5 location within the waterlogged portion of the wetland. Water level fluctuations still occur, but now DM-5 transitions between an area of relatively deep water in the wet season to a shallow or nearshore environment during the dry season. Overlying unit 3bc′ is the historic marsh deposit, unit 5′, with a noticeable increase in organic carbon content. Unit 5′ is black, silty sand with medium to coarse sub-angular blocky soil structure and a loose consistence. The PSD is dominated by sand. The complete lack of clay and silt sized particle is unexpected, but the deposit may be

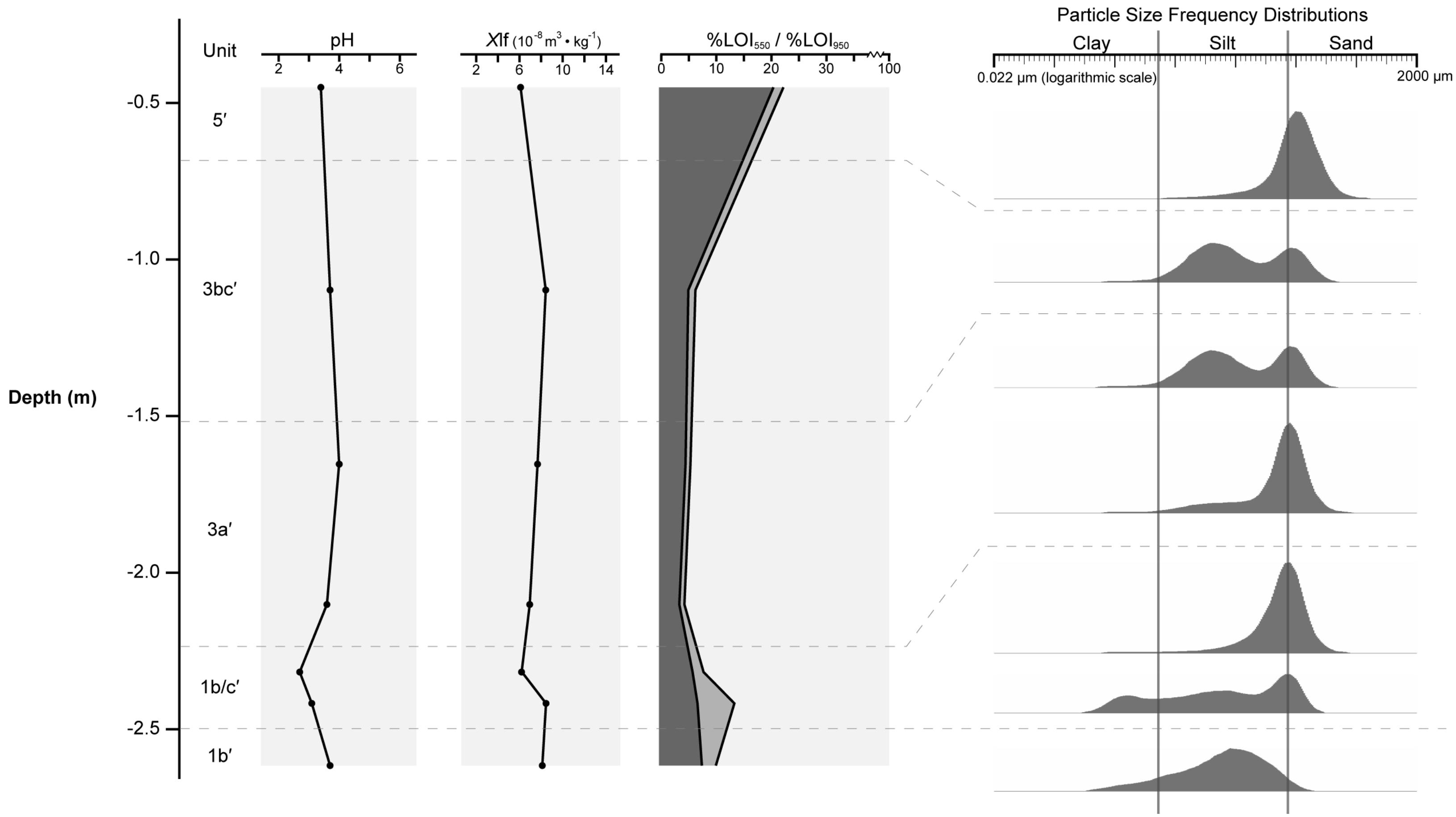

Figure 6.25 Sedimentological data from the DM-5 stratigraphic profile.

disturbed by modern construction or farming. The large rocks present in the layer are similar to those found in the modern fill at DM-3. The dry and calcified historic marsh deposit, unit 6 in other profiles, is not present at DM-5, which suggests that the area may have been under water at this time.

6.3. Area C Stratigraphic Profile

6.3.1. The DM-11Trench

DM-11 is a backhoe trench located across the road from Azraq Castle, roughly 300 m to the west-northwest of the DM-8 excavation (Figure 5.1). The stratigraphic succession combines characteristics observed in areas A and B (Figures 6.26 and 6.27). In general terms, the lower zone of the profile is defined by gradual drying capped by an erosional unconformity. Deposition resumes when wet conditions return in the middle zone of the profile. The onset of wetter conditions begins with alternating thin bands of very fine sand and organic-rich silt until massive clayey silt takes over. The upper zone of the profile documents a return of drier conditions and the eventual drying of the historic marsh. Some macroscopic details of the DM-11 stratigraphic succession have been published by Cordova et al. (2013), but the new laboratory data presented below provides additional detail and clarification. To maintain consistency with the previously published data, the same stratigraphic unit designations will be used in the following descriptions (see Table 6.1). DM-11 produced 71 artifacts (Table 6.6). Only seven of these were identified in the profile wall, and subsequently had their 3-dimensional location recorded (Figure 6.27). The rest were found in the loose sediment while monitoring the digging of the trench. These artifacts, therefore, can only be associated with a particular sedimentary unit – nothing more precise. Artifacts will be discussed when relevant during the following description of the DM-11 stratigraphic sequence.

The DM-11 trench reached basalt bedrock approximately 3.5 m below the surface. Resting on top of the basalt is unit 0b, which is pale yellow, very slightly clayey slightly sandy silt, probably of aeolian origin. The yellow and orange iron staining is produced by oxidation of the basalt bedrock, which is responsible for

Figure 6.26 West wall of the DM-11 trench (see profile drawing for scale).

the elevated magnetic susceptibility measurement (Figure 6.28). Unit 0b gradually gives way at its upper boundary to light gray, slightly sandy slightly clayey silt, which is unit 1a. It is almost identical to the underlying deposit except it lacks the iron staining, and, correspondingly, it has a lower magnetic susceptibility value. This is a continuation of the aeolian deposit, but it is not influenced by the basalt regolith. The upper boundary of 1a is difficult to discern. It gradually transitions to a pale olive, slightly clayey sandy silt that is reminiscent of unit 1b in the DM-8 excavation profile. The upper boundary of this unit is equally obscure as the unit gradually grades upward again, this time into a pale yellow, very slightly clayey

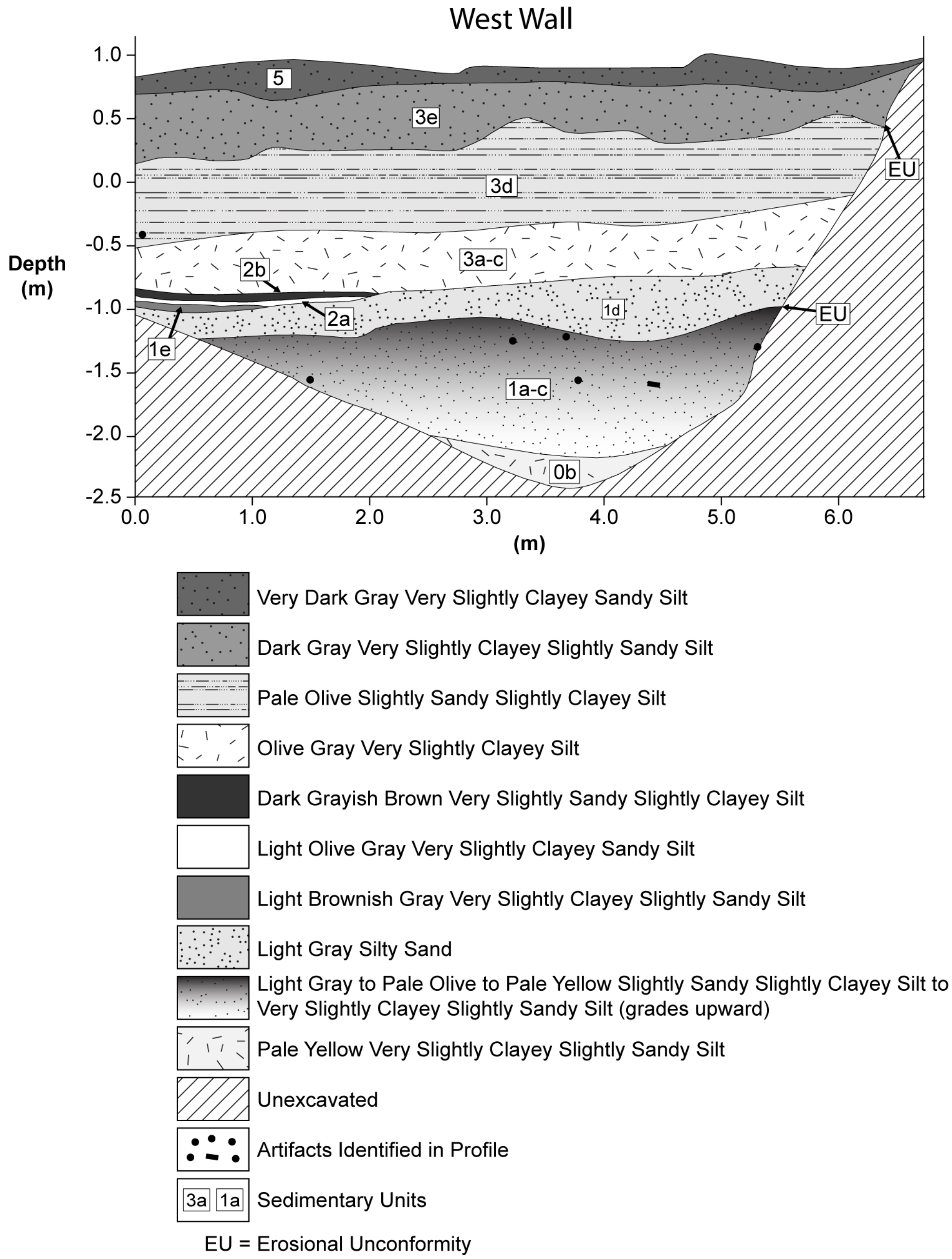

Figure 6.27 Stratigraphic drawing of the DM-11 trench.

sandy silt, similar to unit 1c in DM-8 and DM-1. It is capped by an erosional unconformity. Due to the difficulty identifying the boundaries between these separate sedimentary units, the entire sequence is referred to as unit 1a-c. It represents a transition from the basal aeolian deposits to waterlogged conditions, inferred from the gleyed colour in the middle, followed by gradual drying and the return of aeolian conditions, finally ending when erosion takes over as the dominant geomorphic process. Out of the 71 total artifacts found in DM-11, 61 of them originated from unit 1a-c, including six of the seven artifacts identified in the profile wall (Table 6.6). The artifacts are dominated by flakes and flake fragments (n=28), but more diagnostic are the handaxes of various shapes (n=10), and the Levallois flakes, blades, and cores (n=1, n=3, n=4, respectively) (Figure 6.29; Table 6.6). The assemblage is Late Acheulean, and if the general location of these six artifacts found in the profile wall is any indication, most of them are from the upper half of the unit when aeolian conditions predominate (Figure 6.27). This provenience correlates with the provenience of Late Acheulean finds in the DM-8 excavation and the DM-1 and DM-9 trenches.

Lying immediately above the erosional unconformity is light gray, aeolian, silty sand, which is unit 1d. In some parts of the profile unit 1d transitions to a thin layer of light brownish gray, very slightly clayey slightly sandy silt, labelled unit 1e. This organic-rich layer signifies a return of wet conditions in the Druze Marsh, perhaps as an intradunal pond. Dry conditions and aeolian deposition return, however, with a thin layer of light olive gray, very slightly clayey sandy silt. This is unit 2a. It is the same unit that contained the Middle Paleolithic occupation surface in the DM-8 occupation. Only one blade fragment was found in this layer at DM-11 (Table 6.6). Unit 2a is overlain by unit 2b, a dark grayish brown, organic-rich, very slightly sandy slightly clayey silt. It marks the return of long-standing wet conditions in the marsh, first as shallow wetland that allowed an organic-rich soil to form. Unit 2b transitions upward into unit 3a-c, an olive gray, very slightly clayey silt. This gleyed deposit signifies fully waterlogged conditions. The medium to fine silt implies calm standing water of a deep marsh or shallow lake, most likely an offshore area. It appears to comprise

Table 6.6 Artifacts recovered from the DM-11 trench.

Artifact Type	Sedimentary Units				Total
	1a-c	2ab	3a-d	3e	
Levallois Flake	1	0	0	0	**1**
Scraper	1	0	0	0	**1**
Denticulate	0	0	0	1	**1**
Endscraper	0	0	0	1	**1**
Flake and Flake Fragments	30	0	3	1	**34**
Levallois blade fragment	3	0	0	0	**3**
Blade Fragment	1	1	2	0	**4**
Angular Fragment	4	0	0	0	**4**
Biface Retouch Flake	1	0	0	0	**1**
Single Platform Core	1	0	0	0	**1**
Two Platform Core	1	0	0	0	**1**
Levallois Core	3	0	1	0	**3**
Blade Core	0	0	1	0	**1**
Levallois Blade Core	1	0	0	0	**1**
Core on Flake	3	0	0	0	**3**
Handaxe	8	0	0	0	**8**
Azraq Cleaver	3	0	0	0	**3**
Total	**61**	**1**	**6**	**3**	**71**

both units 3a and 3bc identified in the DM-8 excavation. The upper boundary is difficult to identify, as it gradually transitions upward to pale olive, slightly sandy slightly clayey silt, labelled unit 3d. Although still a gleyed deposit, this transition to unit 3d documents a change in the availability of water. The bimodal PSD is reminiscent of unit 3d from the DM-8 excavation. The colouration denotes continued waterlogged conditions, and the clay and fine silt suggest that, at least at times, DM-11 was an area covered by calm standing water. However, the substantial proportion of very coarse silt and very fine sand indicate one of two options. Either at times the shallow lake would shrink, putting DM-11 closer to the shore where coarser fluvial sediments were deposited, or increasing regional aridity caused higher amounts of aeolian silt and sand that would then settle onto the water's surface and ultimately onto the lake bottom. Six undiagnostic lithics were found in units 3a-c and 3d (Table 6.6).

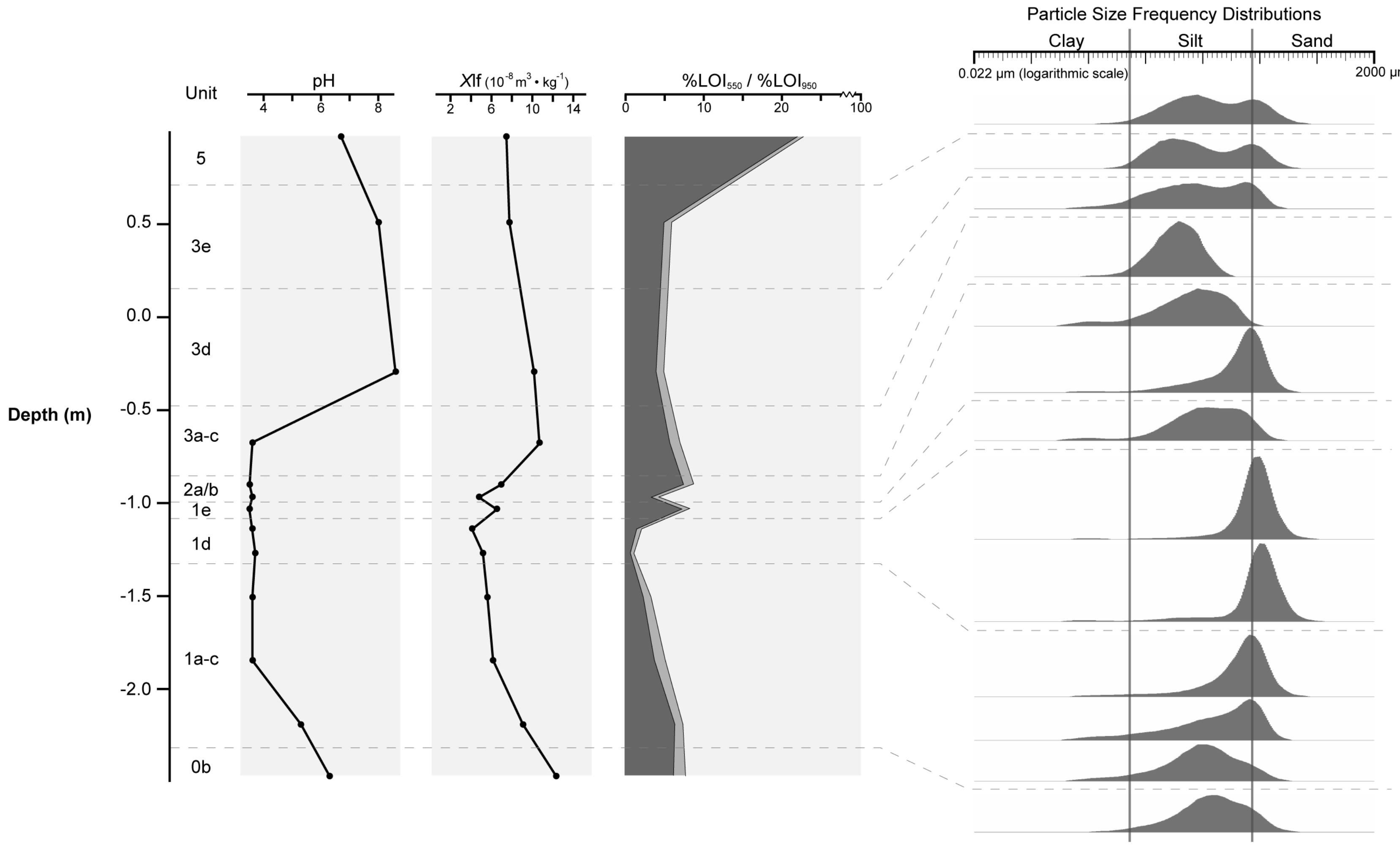

Figure 6.28 Sedimentological data from the DM-11 stratigraphic profile.

Figure 6.29 Examples of artifacts recovered from unit 1a-c in DM-11 (1-sub-cordiform biface; 2-lanceolate biface with broken tip; 3-sub-cordiform biface; 4- Levallois blade core; 5-denticulate) (photo credit: Melanie Chang).

The drying trend continues as unit 3d transitions into unit 3e, which is dark gray, very slightly clayey slightly sandy silt with abundant roots. The darker colour and lack of evidence for waterlogged conditions, combined with the bimodal PSD, suggest that unit 3e is a shallow marsh or marsh edge environment that was intermittently flooded. During flood times, fine silt and clay particles would settle from the standing water. At other times, perhaps when the area was dried out from a long dry season, fluvial inflow from the Qa' or sheet-wash off the western slope at the onset of the wet season would deposit very fine sand. Capping unit 3e is the historic marsh deposit, labeled as unit 5. This unit is very similar to 3e, except for the substantial increase in organic carbon content, which corresponds with the increase in the amount and size of roots. It also has a more friable, crumbly consistency. It is not associated with an increase in the inorganic carbon content that signifies the onset of arid conditions in other test pits. It suggests that this area of the Druze Marsh was covered by modern fill before full drying of the marsh in the late 1980s. The proximity of DM-11 to the road combined with the substantial development that has taken place in the past few decades reinforce this idea. The area is currently used for dumping construction debris and may have been used in a similar way in the recent past as well.

7. DISCUSSION

7.1. Stratigraphic Correlation and Landscape Evolution in the Druze Marsh

There are traces of Lower through Epipaleolithic occupations embedded in the Druze Marsh stratigraphy. Generally, the natural and cultural components of the stratigraphy show that occupations correspond to relatively dry paleoenvironments, when the wetland area was reduced in size. Occupations also occur on aeolian deposits and in shallow marsh or marsh edge environments. Separating these occupations are extended periods of time when the wetland increased in size and depth, becoming a shallow lake and drowning the land previously available for hominin occupation. Although DM-8 is at present the only detailed excavation, the stratigraphic and archaeological sequences recorded from various test pits throughout the former marsh bed confirm the general occupation sequence identified in the DM-8 excavation (Figure 7.1). The most striking observation is that the Middle Paleolithic occupation surface identified by layers 2a and 2b appears in almost all test pits examined, suggesting there is a buried, well preserved, and *in situ* early Middle Paleolithic occupation surface beneath most of the bed of the former Druze Marsh, at least across the area tested thus far. Lower Paleolithic occupation below this stratigraphic marker is also confirmed throughout the area by numerous large bifaces found in DM-1, DM-9, and DM-11, a >20 cm long Azraq cleaver found in DM-2B, and two handaxes in the lower parts of DM-3. Although the length of time represented by the erosional unconformity at the unit 1c/2a transition is currently unknown, it is possible that the Late Lower to Middle Paleolithic transition is documented in the Druze Marsh

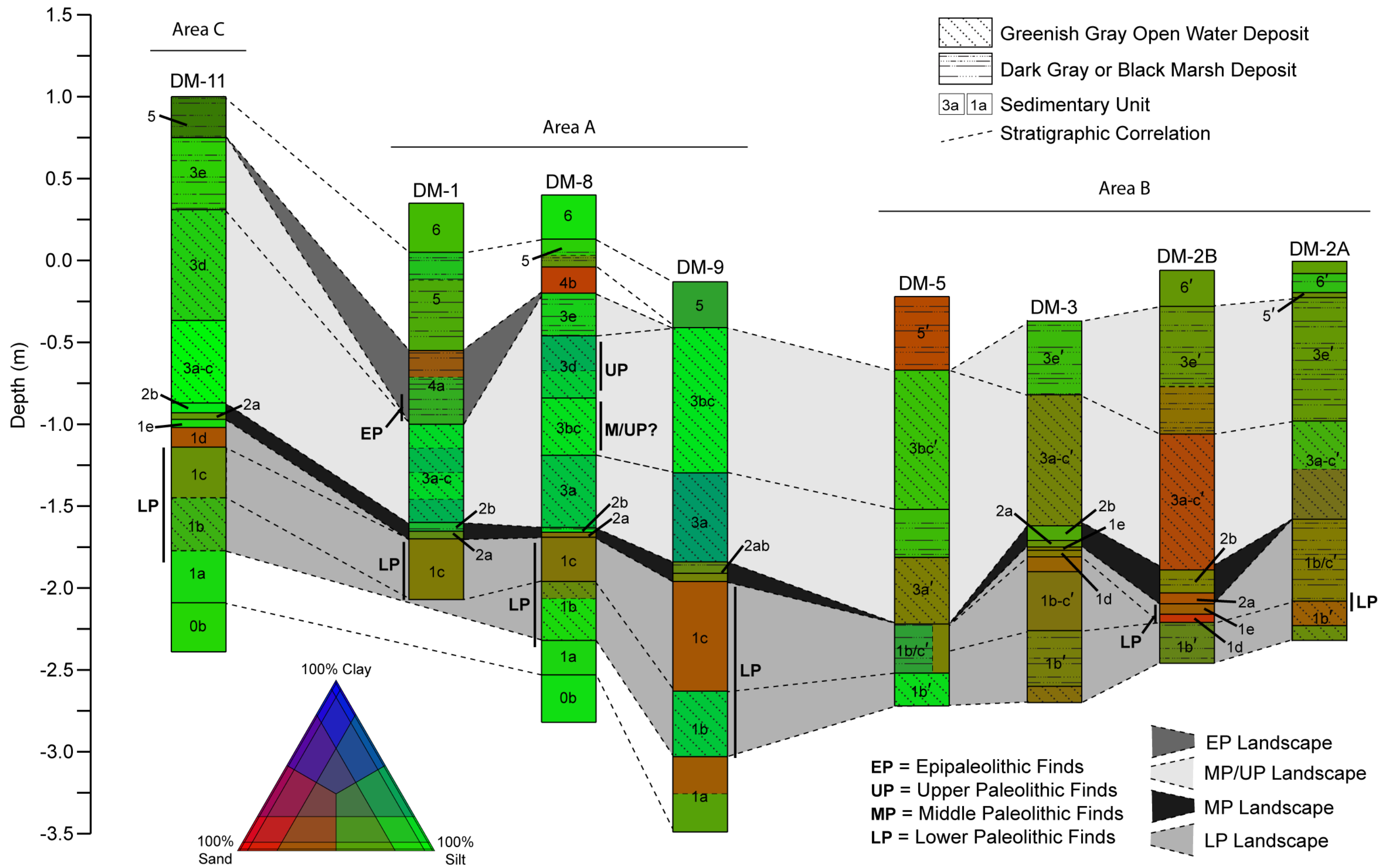

Figure 7.1 Stratigraphic correlation of the Druze Marsh sequences.

stratigraphy. The Upper Paleolithic occupation is slightly more difficult to correlate, but the deposits are present in numerous profiles. Until more archaeological material associated with the Upper Paleolithic is identified, we cannot assess whether or not the Middle to Upper Paleolithic transition is well documented in the Druze Marsh. An Epipaleolithic occupation has also been identified, but it is spatially restricted compared to the Lower and Middle Paleolithic evidence.

Stratigraphic correlation of the Druze Marsh sequences sheds light on the paleotopography of occupation surfaces and on how paleoenvironmental fluctuations impacted the settlement dynamics of hominins living in the GAOA (Figure 7.1). The erosional unconformity underlying the early Levantine Mousterian occupation in sedimentary unit 2a is a clear stratigraphic marker that can be traced throughout the three areas examined. In some test pits (DM-2B, 3, and 11), the depositional gap that precedes the deposition of layers 2a and 2b contains an additional set of layers, designated layers 1d and 1e. Layer 1d is a light gray silty sand of aeolian origin that is overlain by layer 1e, a grayish brown silt or sandy silt with a slight increase in organic matter that represents an intradunal pond during relatively arid conditions. These thin layers only appear in areas that are outside the core spring flow of Area A, and likely represent minor fluctuations between wet and dry conditions as water was returning to the Druze Marsh, which is represented by unit 2b in the Area A sediments. The onset of wetter conditions in Area B and C would be delayed in comparison with Area A. This dynamic is confirmed by the facies transition between Areas A and B that shows the greenish gray and pale olive clayey silts and silty clays become coarser grained greenish gray and pale olive sandy silts or silty sands (Figure 7.1). This facies transition is related to the proximity of the stratigraphic profiles to the paleoshoreline of the marsh or lake, with coarser sediments being deposited closer to the shoreline and higher concentrations of clay in the deeper parts. This means that evidence of open water deposition in Area B would relate to the deepest water deposits in Area A, and that as drier conditions prevail in the basin, the impact would be observed first in Areas B and Area C as water contracted back toward the spring sources of Area A and topographic low spots.

The wettest conditions in the Druze Marsh are indicated by sedimentary unit 3a in DM-1, DM-9 and the DM-8 excavation. This wet period corresponds to the nearshore open water deposits in Area B. At this time, the Druze Marsh was likely connected to the central Qa', forming a relatively shallow lake that made the central basin and the Druze Marsh uninhabitable for hominins. A shrinking of the Druze Marsh, and perhaps a separation from the central Qa', is indicated by the pedogenic carbonate development in DM-2A and erosional unconformities in the other Area B test pits. A uranium series age estimate places the onset of this reduction of the size of the shallow lake between 160-133 ka, which corresponds well with aeolian deposition dated to 163 ka in a sediment core from the center of Qa' Azraq (Davies, 2000) (Figure 7.2). This means the wet conditions responsible for the deposition of unit 3a occurred prior to 160-133 ka, likely associated with the end of MIS 7 or the MIS 7/6 transition. This timing aligns with speleothem deposition in Khsheifa Cave near the ancient city of Jawa on the eastern Jordanian basalt plateau (Frumkin et al., 2008), lacustrine coquina deposits in the Mudawwara depression in southern Jordan (Petit-Maire et al., 2010) and lacustrine deposits at the Jubbah paleolake in the central Nefud Desert in north-central Arabia (Petraglia et al., 2012) (see Figures 1.1. and 1.2), which confirm a humid MIS 7 in the region (Figure 7.2). However, caution is required to match the wet period indicated in the Druze Marsh directly with the age of MIS 7. The hydrological setting of the Azraq springs make it likely that there is a delay in spring discharge as the aquifer recharged during the onset of periods with increased precipitation. Moreover, there would be a corresponding delay in the onset of arid conditions as the recharged springs continued to flow into glacial periods before the aquifer was depleted (Jones and Richter, 2011; Cordova et al., 2013). It is thus assumed, until better chronological control is obtained, that wet periods correspond to the latter part of interglacial periods and initial parts of glacial periods, whereas dry periods correspond to the latter part of glacial periods and the initial stages of interglacial periods. Therefore, the sedimentary unit 3a

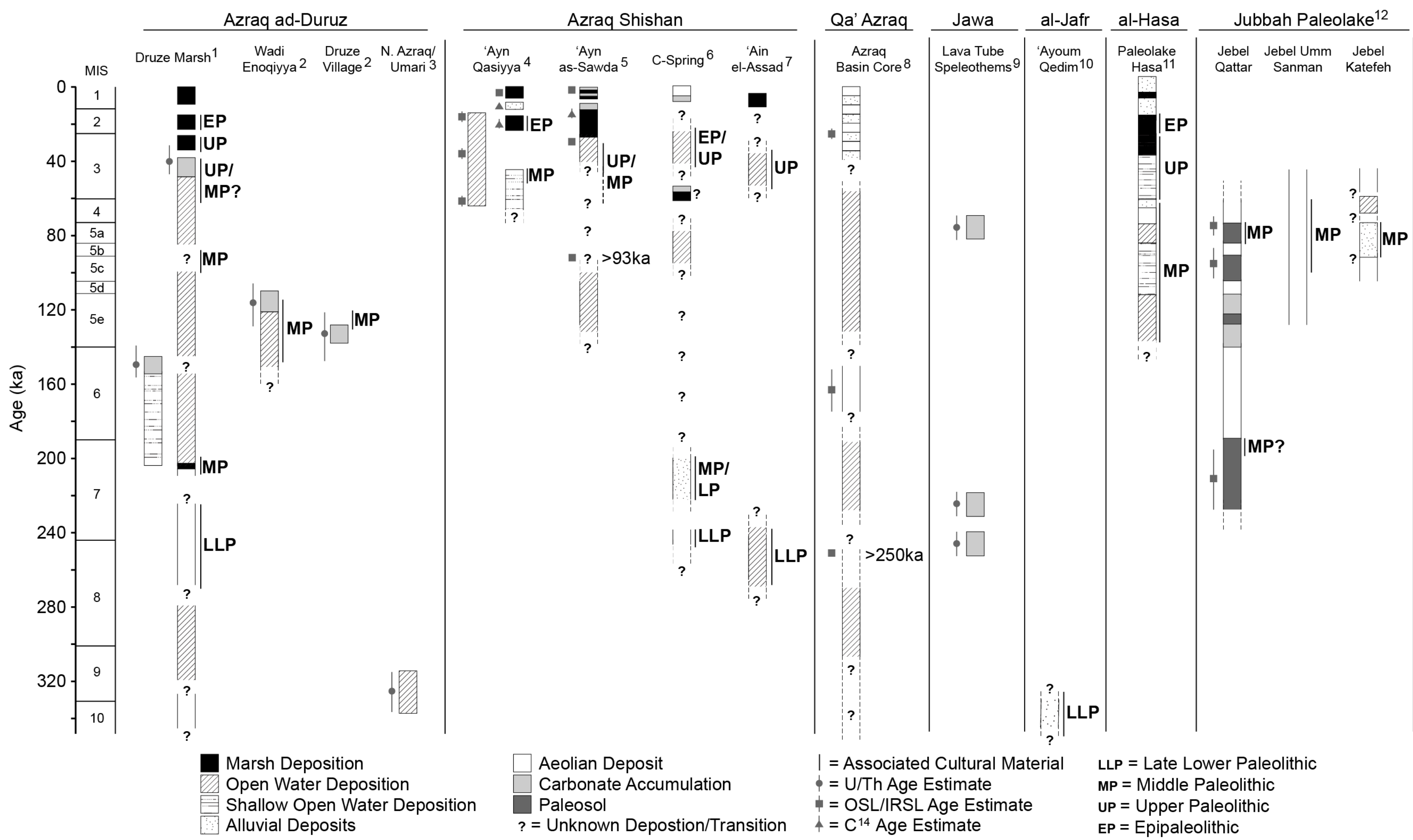

Figure 7.2 Comparison of sedimentological records from similar sites in the region. For the locations of places mentioned in

this figure and the associated text refer to Figures 1.1, 1.2, 3.1, and 5.1., and 6.1. 1: this study, Cordova et al. (2009); 2: Cordova et al. (2013); 3: Abed et al. (2008); 4: Jones and Richter (2011); 5: Cordova et al. (2008) ; 6: Copeland (1989c), Hunt and Garrard (1989); 7: Rollefson (1983), Copeland (1989a), (1989b), Kirkbride (1989); 8: Davies (2000); 9: Frumkin et al. (2008); 10: Rech et al. (2007); 11: Schuldenrein and Clark (2001, 2003); 12: Petraglia et al. (2012).

wet period is best associated with the latter part of MIS 7 and early part of MIS 6 (Figure 7.2). The placement of this wet period fits with the attribution of the underlying *in situ* Middle Paleolithic occupation to the early Levantine Mousterian that spans 250-130 ka at nearby sites in the Middle East (Shea, 2008b). If the onset of wet conditions associated with the MP occupation surface occurred near the middle or in the latter half of MIS 7, then a reasonable assumption for the timing of the MP occupation surface is in the vicinity of 200 ka, which is roughly contemporaneous with the early MP occupation at the Jubbah paleolake (Petraglia et al., 2012) (Figure 7.2). Moreover, the earliest MP occupation at Hummal in the El Kowm basin to the north are dated to approximately 250 ka (Richter et al., 2012). The depositional gap underlying the MP occupation at Druze Marsh therefore can be associated with the latter part of MIS 8 or early MIS 7.

Below the erosional unconformity at the 1c/2a sediment boundary is another sequence of wet and dry fluctuations. Attempts to date the basal deposits in the Druze Marsh have so far been unsuccessful, making it a challenge to place the events on a rough chronological timeline. However, the few dates available combined with the age constraints imposed by the cultural material allow for reasonable speculation. A thick *Cardium* shell horizon has been documented approximately 5 km to the north of the Druze Marsh – the Azraq Locality – and 45 km to the southeast, near the Umari border crossing with Saudi Arabia – the Umari Locality. Uranium series age estimates for the shells suggest that conditions in the Azraq Basin were much wetter during MIS 9 (Abed et al., 2008) (Figure 7.2). Whether this represents a large lake spanning the entire basin or a patchwork of smaller lakes and marshes is unclear (Abed et al., 2008). Stratigraphic correlation of the Druze Marsh sequences suggest a similar facies relationship existed for unit 1b as did for unit 3a. Deposit 1b in area A represents an open water environment, but in Areas B and C, the data suggests shallow nearshore or shoreline environments. At present, a conservative interpretation is that during MIS 9, the central Azraq Basin was filled with a patchwork of lakes that may have expanded during the wet season into a large, shallow lake. A very wet MIS 9 aligns with a saturated infrared stimulated luminescence date Davies (2000) obtained from a sediment core in the center of the Azraq Qa'. The date suggests the wettest periods in the Azraq Basin occurred prior to 250 ka (Figure 7.2.). Therefore, the open water conditions of unit 1b corresponds to the MIS 9 wet period, or the latter half of MIS 9 once the aquifer was recharged and the springs began to flow. This places the overlying aeolian deposit of unit 1c somewhere between the middle half of MIS 8 and the early part of MIS 7, a timing that is appropriate for the substantial collection of Late Acheulean artifacts it contained. Although the Late Acheulean finds in the Shishan Marsh are undated, they are typologically consistent and likely date to the same time period, somewhere in the range of 300-250 ka. It also suggests that the Desert Wadi Acheulean, which Copeland and Hours (1989b) believe predates the Late Acheulean at the spring sites, is associated with the MIS 9 wet period, when the wadi channels would have provided an attractive habitat for hominins surrounding a relatively large lake or patchwork of lakes in the center of the Azraq Basin.

The correlation of the stratigraphic sequences above the 1c/2a stratigraphic marker is more complex. As discussed, unit 3a in the Area A sediments represent the wettest conditions in the Druze Marsh since the Late Lower Paleolithic. These deposits are correlated with nearshore and shoreline deposits in the Area B sequences. However, as Area B dries out between 160-133 ka, wet conditions continue in Area A with continued deposition of gleyed clayey silts until they are capped by another set of pedogenic carbonates dated to 53-30 ka (Cordova et al., 2009). These thick clayey silts, deposits 3bc and 3d, represent environmental conditions that span MIS 5e through the first half of MIS 3. They suggest an environment with relatively deep pools or shallow lakes around the springs, which are surrounded by wetlands and not necessarily connected to the central Qa', except perhaps during seasonal flood events. Erosional unconformities between the thick clayey silts correspond to dry conditions when the spring flow diminished. The timing of the depositional gaps is uncertain.

The collection of MP artifacts embedded in the top half of unit 3bc in the DM-8 excavation is not large enough to allow systematic typological comparisons with other sites, but it does provide a minimum age of roughly 40 ka, and perhaps older, as unit 3d is capped by carbonates that date to 53-30 ka. The 3bc/3d depositional hiatus is best associated with one of the MIS 5 stadials, perhaps 5d or 5b, which would make the 3bc MP occupation roughly contemporaneous with similar paleolake occupations surrounding the Jubbah paleolake (Petraglia et al., 2012) and the paleolake deposits in Qa' al-Mudawwara in southeast Jordan (Abed et al., 2000; Petit-Maire et al., 2010). This interpretation is consistent with the deposits in Wadi Enoqiyya as well. Pedogenic carbonates capping greenish gray clayey silts in the banks of Wadi Enoqiyya suggest there was a regional dry period beginning between 146-93 ka (Cordova et al., 2009); whether it is associated specifically with MIS 5d or 5c is unknown at present (Figure 7.2). These deposits also imply that the more than 7000 Middle Paleolithic artifacts collected in Wadi Enoqiyya in the 1980s (Hours, 1989) are likely associated with the wet conditions prior to the onset of this carbonate formation – either MIS 5e or 5c – when the Druze Marsh was dominated by large spring pools. Evidence for speleothem deposition in Khsheifa Cave near the ancient city of Jawa to the north of Azraq during MIS 5c (Frumkin et al., 2008) makes it the most likely time period for high water levels during the middle of the Middle Paleolithic in the Azraq Basin (Figure 7.2).

Historically, Wadi Enoqiyya also contained a small wetland with pools of water fed by springs similar to the Druze Marsh (Copeland, 1988). It would have been an important location for MP occupation when open water conditions prevailed in the Druze Marsh proper and high water levels in the central basin backed up into the lower reaches of the wadi. Evidence of paleoshorelines eroded into the basalt in Wadi Enoqiyya and around the Druze Marsh confirms this idea (Figure 7.3). It is believed that lake wave action may have created these shoreline marks during high lake levels, but whether the paleoshorelines correspond to lake high stands during MIS 9, 7, 5e, 5c, 5a, or during all of them is still unclear.

The erosional unconformity and carbonate formation that caps the uppermost open water deposit in Area A, deposit 3d is dated to 53-30 ka. It marks the end of open water deposition in the Druze Marsh, and the exposed playa

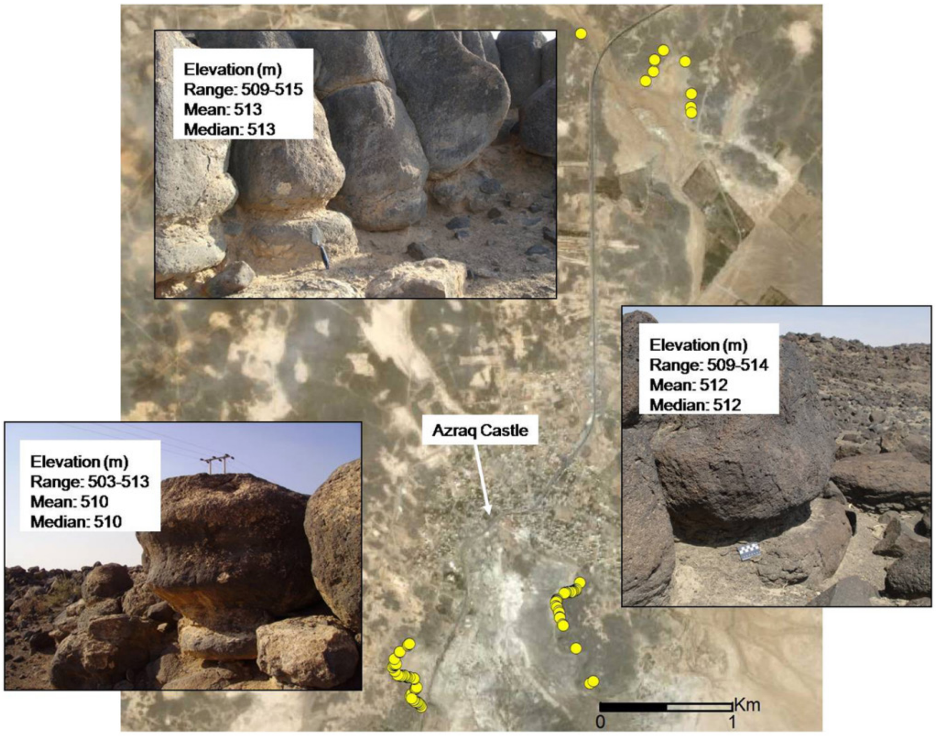

Figure 7.3 Locations of paleoshorelines eroded into the basalt flanking the Druze Marsh and Wadi Enoqiyya. Yellow circles are GPS points associated with evidence for paleoshorelines (reproduced from Ames and Cordova, In Press, Figure 7).

surface was occupied by Upper Paleolithic hominins. However, UP evidence is relatively scarce in the basin (Table 3.1) and our sample from the DM-8 excavation is very small. Any detailed conclusion about the status of the UP in the Druze Marsh is too speculative with the available data. The timing of pedogenic carbonate formation, particularly the recent end of the range, corresponds with the onset of drier conditions in the sediment core from the Qa'(Davies, 2000). A radiocarbon date from aeolian deposits at the top of the sediment column indicates that basin-wide arid conditions pre-date 24 ka, and that deflation has been the dominant geomorphic process in the basin since at least the Last Glacial Maximum. This implies that the dark wetland deposits of units 3e, 4a, and 5 were primarily supported by spring discharge and seasonal flood events. These flood events are responsible for the bimodal distributions that dominate the dark gray and black marsh deposits.

Overall conditions since the Last Glacial Maximum were drier than previous interglacials, producing a patchwork of marsh deposits and restricted open water pools in the Druze and Shishan Marshes. Jones and Richter (2011) have dated the upper portion of greenish gray open water clayey silts at ‘Ain Qasiyya to 16 ka (Figure 7.2). It is possible that upper portions of the thick clayey silts in the Area A stratigraphic profiles of the Druze Marsh, such as sedimentary units 3bc and 3d, represent isolated spring pools that extend into MIS 3 and 2. The surrounding Druze Marsh landscape was covered by shallow and seasonally inundated marshlands, indicated by the prevalence of dark gray and black silts with high organic matter content. There is also strong evidence for a depositional hiatus between 16-10.5 ka in the ‘Ain Qasiyya sediments (Jones and Richter, 2011). This is probably represented in the Druze Marsh by the erosional unconformity between the unit 3e marsh and the Holocene marsh of unit 5 (Figures 7.1, 7.2). The Holocene in both the Shishan and Druze Marshes is dominated by a dark gray to black marsh deposit, ultimately capped by calcified bimodal marsh deposits and aeolian sand indicative of the historic drying.

7.2. The Druze Marsh Sequence and Paleolithic Settlement Dynamics in the GAOA

Local paleotopographic variations may have had a significant influence on the potential areas available for hominin occupation and exploitation at various times in the past, a full understanding of which can only be attained through a detailed study of the local landscape evolution (Ames and Cordova, In Press). The importance of understanding the location and size of water sources is highlighted by layer 4a, which only appears in DM-1, DM-1X, DM-1Y, and DM-10 (Figure 5.1). Layer 4a is a black, organic-rich deposit that grades upward from a silt loam to a silty sand. As mentioned in the results, during only a few short days of salvage work layer 4a produced over 5000 Epipaleolithic artifacts (Cordova et al., 2009). The assemblage is typologically Early Kebaran, and, based on comparison with Early Epipaleolithic occupations in the Shishan Marsh, it likely dates between 24-19 ka (Jones and Richter, 2011) (Figure 7.2). The deposit represents a spatially isolated marsh edge environment that is at least partially contemporaneous with the shallow marsh deposits of layer 3e in DM-8. This means that DM-8 was not occupied during the Epipaleolithic because it was flooded for a large portion of the year, whereas the marsh edge only a dozen meters away to the north and west was heavily exploited. This example can be projected back in time to ask what part(s) of the Azraq Basin were the Lower, Middle, and Upper Paleolithic inhabitants occupying while the deep marshes and shallow lakes were depositing layers 1b, 3a, 3bc, and 3d. The evidence from the Druze Marsh proper is not able to answer this question directly. The spatial distribution of the data is restricted to the wettest part of the former wetland, meaning only hominin occupation during the driest periods can be directly observed. This data is very important for demonstrating that the Druze Marsh springs did act as a locus of hominin activity during regionally dry episodes, but it does not provide detailed information about where hominins were living at times when the wetland was large or the when the basin was filled with a large lake. Fully evaluating the question of where hominins were living, and the importance of the Druze Marsh for hominins during wet periods, requires additional testing in areas that would have been the at or near the edge of the expanded wetland. Nevertheless, enough previous research has been conducted that integrating the results from the Druze Marsh with the regional record of archaeological occupation and paleoenvironmental change sheds considerable light on the impact of paleoenvironmental change on the settlement history of the Azraq Basin.

Comparing a number of sites throughout the Middle East, Shea (2008b) dates the Upper Acheulean between the 550-350 ka and the Acheulo-Yabrudian between 350-250 ka. As a result, a conservative estimate for the Late Acheulean found at the Azraq spring sites is somewhere in the vicinity of 300-250 ka. This places the occupation in the latter half of MIS 8 glacial, an interpretation that matches with the shrinking wetlands that are indicated by the increase in aeolian deposition in the Area A sedimentary sequences, specifically layer 1c. In the wadis surrounding the GAOA, Copeland and Hours (1989b) identified a typologically different and earlier Lower Paleolithic occupation (Table 3.1). Substantial occupation of the wadis would require wetter conditions than at present. Dates from upland *Cardium* shell deposits indicate that MIS 9 was a considerable wet episode in the eastern Jordanian desert (Abed et al., 2008), and sediments from the center of the Azraq Basin indicate substantial expansion of lacustrine environments prior to 250 ka. The Desert Wadi Acheulean is most likely associated with MIS 9, when wetter regional conditions would have made the wadi channels more hospitable, surrounding a central basin dominated by a large shallow lake or patchwork of lakes. Although chronological control is limited for the basal deposits in the GAOA, it is clear that two different hominin tool kits are associated with different paleoenvironmental contexts. When conditions were generally wet in the Azraq Basin during MIS 9 and perhaps earlier, LP hominins – probably *H. erectus/ergaster* – occupied the wadis feeding into Qa' Azraq. At the onset of more arid conditions during MIS 8, the large shallow lake(s) in the central basin began to retreat. Based on evidence of Late Acheulean occupations near springs in the center of the basin, hominins may have moved into the central basin to occupy the newly exposed land around the Azraq springs, and to access the water and other resources in the small wetland. Exactly what happened during the depositional gap that follows the LLP occupation of the spring sites is unclear. Future research on this gap is critical, as it corresponds to the LLP/MP transition.

Occupation and slightly wetter conditions return together in the Druze Marsh sequence sometime near the later part of MIS 6 or early MIS 5. The onset of wetter conditions is associated with the early Levantine Mousterian occupation surface identified in the DM-8 sequence. Whether this represents continuity with the LLP or an episode of extinction and repopulation is unclear, but contextualizing this MP occupation with other known MP finds in the GAOA demonstrates that the changing paleolandscape had important ramifications for settlement and land use during the Middle Paleolithic. The early MP occupation of the Druze Marsh is associated with relatively dry conditions when the spring pools were small and a wetland was forming. Just as was the case in the Late Acheulean, the MP hominins moved into the Druze Marsh proper to exploit the wetland resources. This occupation corresponds to MIS 6 (Figure 7.2), which matches the early Levantine Mousterian association of the artifacts. According to Shea (2008b), this archaeological tradition dates between 250-130 ka. As conditions improved in the Druze Marsh, the spring sites were inundated with deep marshes and shallow lakes. Wetter conditions were not limited to the two historic spring sites in Azraq. Green silty clays, similar to those observed in the Druze Marsh stratigraphy, were identified in the banks of Wadi Enoqiyya to the north (Cordova et al., 2013). They are capped by carbonate nodules that formed sometime between 146-93 ka (Cordova et al., 2009), suggesting the open water deposits accumulated during MIS 5e or 5c. It is during this wet period that the MP occupation of Wadi Enoqiyya documented by Hours (1989) most likely occurred. There is also evidence to suggest that during wetter conditions MP hominins were occupying the uplands that are now behind the Azraq Castle (Cordova et al., 2013) (see Figures 3.1, 5.1, and 6.1). MP artifacts were observed lying above a pedogenic carbonate horizon that correlates with a similar layer exposed in a nearby section in the North Azraq village from which the carbonates were dated to 137-126 ka (Cordova et al., 2009, 2013). The MP material occurred on top of this horizon, and is therefore more recent. It may correspond in time to the Wadi Enoqiyya occupation during MIS 5e or 5c, but it could also relate to MIS 5a (Figure 7.2). The timing of speleothem deposition to the northwest of Azraq suggests that MIS 5a was a regionally wet period in the eastern desert as well (Frumkin et al., 2008) (Figure 7.2). Although the full timing of events is still unclear, the result of our excavation at DM-8 and research in the surrounding areas demonstrate that paleoenvironmental fluctuations had a substantial influence on the land available for MP occupation, and played a key role in how settlement patterns in the GAOA changed throughout the Middle Paleolithic. Moreover, the evidence suggests a continuous occupation of the region during the Middle Paleolithic, perhaps dating back to 200 ka.

Table 7.1 The timing of reconstructed paleolandscapes in the GAOA and associated settlement dynamics.

Reconstructed GAOA Paleolandscape	MIS Stage(s)	Associated Settlement
Large shallow lake or patchwork of lakes in the central Azraq Basin	9, 7/6 transition	LP in the wadis; possible MP occupation in wadis
Small shallow lake around springs and possibly large shallow lake during the wet season	5e, 5c, 5a, 4, early 3	MP occupation in Wadi Enoqiyya; possibly other wadis (Table 3.1)
Perennial spring pools surrounded by a seasonally inundated wetland	6/5e transition, 5d, 5b, 4	MP and UP occupations in the Druze and Shishan Marshes
Isolated spring flow with aeolian deposition	mid 8-mid7, possibly 10	LP occupation in the Druze and Shishan Marshes
Seasonal wetland with isolated spring pools	end 7, end 3, early 2, 1	Early MP in the Druze Marsh; UP, EP and Neolithic in the Druze and Shishan Marshes
Playa surface around springs dominated by deflation and alluvial input	mid 7, mid 3	LP and UP in the Druze and Shishan Marshes; presence of LP/MP and MP/UP transitions uncertain

Results discussed in this study imply that hominin occupation in the GAOA extends at least back 300 ka to the Late Acheulean (i.e. LLP) (Figure 7.2). During this time the Azraq springs and surrounding areas experienced a number of different paleolandscapes and paleoenvironments that forced hominins to adjust their settlement systems and patterns of land use (Table 7.1). During MIS 9 considerable wet conditions filled the central Azraq Basin with either a large lake or a patchwork of smaller lakes (Abed et al., 2008). The surrounding wadis provided a rich resource landscape for Lower Paleolithic hominins both within the wadis, the steppe in between, and the perimeter of the expanded Azraq lake(s). As conditions became more arid during MIS 8, populations congregated around the Azraq spring locations, both in the Druze Marsh and Shishan Marsh, adapting new technologies to accommodate their new circumstances, suggested by the differences between the Desert Wadi Acheulean and the Late Acheulean of Azraq facies (Copeland and Hours, 1989a). A depositional gap near the end of MIS 8 or early in MIS 7 makes it unclear if the Lower to Middle Paleolithic transition is recorded in the GAOA or if there was local population extinction. Nevertheless, the onset of wet conditions near the end of MIS 7 brings with it an early Middle Paleolithic occupation around a shallow wetland and perhaps small spring pools in a predominantly arid environment. As wetter conditions predominate and inundate the Druze Marsh, and most likely the Shishan Marsh as well, MP hominins were probably forced out of the central basin and alongside the surrounding wadis, particularly Wadi Enoqiyya to the north. During intermittent dry episodes throughout MIS 5 and 4, MP and possibly UP hominins returned to the central basin to exploit resources surrounding what was likely a patchwork of small, yet relatively deep pools around the springs surrounded by a seasonal wetland. The deep pools continued to dry and were replaced by an extensive marshland during MIS 3, 2, and 1. This is the landscape exploited by Epipaleolithic and Neolithic populations, and was an environment that persisted until the dramatic drop in the water table in the late 1980s. Since then the wetland has dried out and calcified (Table 7.1).

7.3. The Druze Marsh in Broader Context

The context of hominin occupation in the GAOA is reminiscent of the sites of Hummal, Nadaouiyeh Aïn Askar, and Umm El Tlel surrounding the El Kowm basin in central Syria (Ploux and Soriano, 2003; Le Tensorer et al., 2007; Hauck, 2011). El Kowm is located at the northern end of the Syro-Arabian desert, approximately 450 km to the north-northeast of Azraq. Despite the general similarities with Azraq, in terms of hominins congregating around a water source in an otherwise dry and harsh environment, the sedimentological settings between the Azraq and El Kowm spring sites are considerably different. The El Kowm basin springs emerge from fractures in the underlying bedrock as artesian wells that create large phreatic mounds around the spring vents (Copeland, 1988; Hauck, 2011). This leads to deep and highly complex stratigraphy (Le Tensorer et al., 2007; Hauck, 2011) that is very different from the relatively shallow Druze Marsh stratigraphy. Despite a well developed typological sequence, thanks to large numbers of artifacts, there are limited radiometric dates available from the El Kowm sites.

Unfortunately, we have limited artifact collections from the Druze Marsh excavation and meaningful techno-typological comparisons cannot be made as of yet. Moreover, the Late Acheulean of Azraq facies was given such a specific designation by Copeland (1989a, 1989b, 1989c) because it was different from what she had previously encountered in both Jordan and Syria, including work in the El Kowm Basin (Copeland and Hours, 1983). This distinction is not trivial. Regional artifact variation has been used to argue for population contraction and subsequent isolation into desert refugia along the southern coast of Arabia at Shi'bat Dihya in Yemen (Delagnes et al., 2013) and Jebel Faya in United Arab Emirates (Armitage et al., 2011). If the Late Acheulean of Azraq facies does roughly correspond temporally to the Acheulo-Yabrudian layers at Hummal and Nadaouiyeh, roughly 300-250 ka during MIS 8 (Le Tensorer et al., 2007), then perhaps a similar phenomenon of range contractions and material culture divergence is occurring in the Syrian desert as well. Until larger artifact collections are obtained from Azraq and better chronological control is established, such claims will unfortunately remain speculative; however, these claims do provide valuable hypotheses to help guide future research.

The GAOA and the El Kowm Basin demonstrate the importance of spring sites for Paleolithic hominins in the driest parts of the Levant. While most other sites in the desert regions produced intermittent occupation predominantly associated with wetter conditions during periods of increased precipitation (see Rech et al., 2007; Petit-Maire et al., 2010; Petraglia, 2011; Rosenberg et al., 2011; Petraglia et al., 2012; Delagnes et al., 2013), both the GAOA and El Kowm appear to be continuously occupied throughout at least the Middle Paleolithic thanks to unique hydrological circumstances that provided a water source even during regionally dry periods; these water sources likely played a substantial role in hominin survival or extinction in the eastern Levantine desert since the Middle Pleistocene. Future more detailed comparisons between the Azraq Oases and the

El Kowm basin will be fruitful, but the different stratigraphic contexts and the current data available make them premature at this time.

Other sites confirm the relationship between spring sites and Pleistocene hominin occupation in other localities in Jordan's Eastern Deserts. At 'Ayoum Qedim in the al-Jafr Basin 200 km to the south-southwest of Azraq, Rech et al. (2007) demonstrate that a suite of Lower Paleolithic surface sites were occupied during the Middle Pleistocene when wetter conditions would have made it a magnet for hominins in the region. No radiometric dates are available, but a techno-typological comparison with other sites, including the Shishan Marsh finds, suggests that the bulk of the Lower Paleolithic artifact assemblage accumulated during the early Late Acheulean, roughly 450-350 ka (Rech et al., 2007). The geomorphic context is quite different from Azraq, however. The hydrological system is karstic, and precipitation would enter the subsurface through sinkholes or fractures and flow through a series of karstic conduits before discharging at the base of the escarpment (Rech et al., 2007: 272–273). It is around these discharge points that the early Late Acheulean sites cluster. Because the al-Jafr Basin spring discharge would respond directly to increased or reduced precipitation, the occupations most likely are associated with the MIS 9 interglacial known to be relatively moist in the Eastern Desert (Davies, 2000; Abed et al., 2008). Although the surveys by Rech et al. (2007) did not identify lacustrine deposits, Davies (2005) identified lacustrine deposits in the lower section of a sediment core from the center of the al-Jafr Basin. Radiometric dates were not obtained for the lacustrine deposits, but an overlying radiocarbon date of 24,470 ± 240 BP places the lacustrine environments before the LGM, which matches the results obtained for the Azraq Basin. If the early Late Acheulean at 'Ayoum Qedim falls into MIS9, it is probably contemporaneous with the Desert Wadi Acheulean in the areas surrounding the Azraq Springs. One problem with establishing the chronology of the Acheulean sites in the al-Jafr Basin is that they occur on deflated surfaces (Rech et al., 2007), leaving the lithic material out of stratigraphic context.

Detailed research in the Wadi al-Hasa drainage basin in central Jordan, situated approximately 135 km southwest of Azraq, has also identified a strong connection between Pleistocene lacustrine deposits and hominin settlement dynamics. The first three years of survey along the south bank of Wadi al-Hasa (1979, 1981, and 1982) identified 1074 archaeological sites (MacDonald, 1988). This was complemented by two more years of survey on the north bank in 1992 and 1993 that identified another 531 sites (Olszewski and Coinman, 1998). The entire collection of sites spans the Lower Paleolithic through the Ottoman period. To examine the Paleolithic through Neolithic settlement system in the Hasa drainage system, Clark (1998) divided the survey results from 222 sites into typologically based chrono-units and analyzed their spatial distribution across the landscape. The results demonstrated that locally changing lacustrine environments were responsible for changes in the distribution of archaeological assemblages through time, specifically the development of the paleolake Hasa at approximately 70 ka, and its drying and replacement by a pond/marsh biome at the end of the Upper Paleolithic ca. 25-20 ka (Schuldenrein and Clark, 1994, 2001, 2003). The large area surveyed, combined with detailed geomorphic and stratigraphic analysis, demonstrated that fluctuations between lake, marsh, and erosional landscapes correspond to different mobility strategies. Wetter conditions allowed Paleolithic populations to maintain higher site densities and more permanent home bases with a radiating mobility pattern to access seasonal resources. During drier times site densities are lower suggesting a seasonally circulating pattern of occupation.

Similar changes in mobility pattern may have existed in the GAOA as well. When the springs were inundated and resources generally abundant, hominin populations could establish more permanent home bases, such as the high density of middle MP finds in the Wadi Enoqiyya during high water levels. During drier conditions, on the other hand, populations would circulate throughout the GAOA based on the seasonal availability of resources, ultimately congregating around the springs during extremely dry times. As research continues in the GAOA and such hypotheses are tested, comparison with the behavioural model surrounding paleolake Hasa will be highly productive and will help evaluate the role of springs and lacustrine basins for hominin survival and expansion throughout the eastern deserts of the Levant.

The importance of paleolake basins for Near Eastern hominins is not restricted to the eastern Mediterranean region. The Jubbah paleolake, approximately 600 km to the southeast of the GAOA, in the central Nefud Desert, offers another promising comparison to the Druze Marsh sequence. At Jebel Qattar in the Jubbah area, Petraglia et al. (2011, 2012) have identified three distinct MP occupations associated with paleosols surrounding the Jubbah paleolake basin. Occupations date to MIS 7, 5c, and 5a. Based on less secure dates and technological comparisons they have also attributed an MP occupation on aeolian deposits overlooking a paleolake basin at Jebel Umm Sanman to the recent part of MIS 5. A third occupation in alluvial deposits at Jebel Katefeh also flanks the paleolake, but its timing is less secure, although it is thought to be contemporaneous with other MIS 5 MP occupations (Figure 7.2). The Jubbah paleolake is a series of depressions on the leeward side of large sandstone outcrops. Water availability in the basins is controlled by precipitation and evapotranspiration. The importance of this comparison rests in the potential for the string of paleolakes that follow the Wadi Sirhan depression to be a migration corridor for hominins moving between Africa, Eurasia, and the Arabian Peninsula during wet climatic conditions. The GAOA is located at a junction between the Levantine Corridor to the west and the northern end of the Wadi Sirhan depression that extends into the center of the Arabian Peninsula (Figures 1.1, 1.2). The fact that the MP occupations at Jubbah coincide with the MP occupations in the Druze Marsh suggest that during wetter episodes in the Eastern Desert, hominins were able to extend their range eastward from the Levantine coast into the Eastern Desert and possibly move along drainage networks into what were usually marginal environments, perhaps connecting the Levant to the Arabian Peninsula via the string of paleolakes that developed along the Wadi Sirhan Depression. If this is the case, the Wadi Sirhan Depression provides an additional dispersal corridor and a possible location where Neanderthals and AMH interacted, something we know happened prior to the rapid dispersal of AMH into southeast Asia, which occurred approximately 65 ka along the south coast of the Arabian Peninsula and around the Indian Ocean (Macaulay et al., 2005; Green et al., 2010). The question that remains is: What happened to those hominin populations that extended into the north-central Arabian Peninsula as conditions worsened and survival in these marginal environments became extremely difficult? The same question applies to the al-Jafr Basin and Lake Hasa. In Azraq and the El Kowm basin, continued spring flow would allow small populations to congregate around the isolated water sources and possibly survive environmental downturns until the return of wetter conditions. In areas like Jubbah, such springs are not available and hominins must have moved or, if not, they most likely perished. It is possible that both the GAOA and the southern coast of Arabia were the locations where hominins sought refuge from the deserts of central Arabia.

This study has shown that during regionally arid conditions, Middle and Late Pleistocene hominins were congregating around the spring sites in the GAOA, potentially offering them a refuge from the harsh regional environment. When conditions improved they would expand outward into the many wadi channels feeding into the basin and potentially further into the Syro-Arabian desert and other parts of Eurasia. Further interdisciplinary research at individual paleolake basins, including an assessment of their role as possible Pleistocene desert refugia, will shed more light on interregional pattern of hominin dispersal in this part of the world (Shea, 2008a; Parker, 2009; Petraglia, 2011; Cordova et al., 2013; Groucutt and Petraglia, 2012; Richter et al., 2012; Delagnes et al., 2013). The full implication of desert paleolakes for hominin survivorship and extinction, and ultimately the potential for interaction between modern humans migrating out of Africa and Neanderthals remains to be tested. The possibility for survival in refugia like the GAOA, the El Kowm Basin, and southern Arabia is now established, however, and will only be elucidated with additional archaeological and paleoenvironmental research that attempts to compare and contrast these locations. Finding hominin fossils and reconstructing the history of settlement and land use in paleolake basins is critical to furthering our understanding of these issues. Unfortunately, finding hominin fossils is largely a matter of preservation and luck. Reconstructing the Paleolithic settlement history in paleolake basins is possible, but requires acknowledging the unique challenges of such large open-air sites. The next section will use the Druze Marsh as a case study to discuss the various challenges and interpretive limitations of large open-air sites, as well as the opportunities for future research.

8. CHALLENGES AND OPPORTUNITIES OF OPEN-AIR SITES

8.1. Challenges for Reconstructing Paleolithic Settlement Dynamics in the Druze Marsh and the GAOA

In addition to understanding the paleotopography and landscape evolution of the Druze Marsh, piecing together the prehistoric settlement history and land use of the area depends on identifying and accounting for a variety of post-depositional alterations. Artifact assemblages documented in the DM-8 excavation, although mostly in pristine condition, ranged from an *in situ* occupation surface to substantially displaced assemblages due to the shrink-swell of clayey sediments (Figure 6.4). It can be assumed that similar phenomena occur across the Druze Marsh paleolandscape; most likely, the pattern of disturbance is spatially variable, and at best concomitant with paleotopographic variations.

In addition to the potential disturbances of artifact assemblages, a second challenge presented by the Druze Marsh is that no faunal material was recovered from stratified context during our test pits or the DM-8 excavation. The highly acidic pH of the deposits in the Druze Marsh makes the preservation of bone and teeth highly unlikely. The pH profile from the DM-8 excavation demonstrates the general pattern for the entire Druze Marsh (Figure 6.5). Deposits close to the surface and near layers capped by pedogenic carbonates, such as layer 3d, have a relatively neutral or slightly basic pH. All other sedimentary units, especially the deeper deposits, have a pH between 3.0 and 4.0. A set of pH samples from ‘Ain

Soda in the Shishan Marsh (Pokines et al., In Press) show a similar pattern of neutral values near the surface and highly acidic deposits at depth. The one exception is that the deepest tested deposit at ‘Ain Soda, approximately 2.75m below the surface and associated with the Late Acheulean (Rollefson et al., 1997; Cordova et al., 2008), has a pH between 6.0 and 7.0 (Pokines et al., In Press). The Late Acheulean layers at C Spring and ‘Ain Soda have produced a rich faunal record, including extinct rhinoceros specimens (*Dicerorhinus hemitoechus*) that date from the Middle to Late Pleistocene (Clutton-Brock, 1989; Rollefson et al., 1997). Pollen has also been obtained from deposits in South Azraq, at both Lion Spring (Kelso and Rollefson, 1989) and ‘Ain Soda (Cordova et al., 2008). The degradation of recovered pollen from the Druze Marsh has made identifications difficult, but phytoliths are well preserved (C.E. Cordova, personal communication).

Reconstructing the settlement history of the Azraq Basin ultimately depends on integrating all of the relevant information from the central basin, the spring sites, and the surrounding wadis (Table 3.1). This requires understanding the Azraq Basin as a large open-air archaeological landscape. However, there are a number of constraints to such an endeavour, which must be understood and overcome before a robust picture of hominin behaviour can assembled. The next two sections discuss the difficulties of taking such a broad landscape approach, as well as what opportunities future research in the Azraq Basin can offer.

8.2. The Interpretive Constraints of Large Open-Air Sites

In 1981 Robert Foley published a now seminal article, “Off-site archaeology: an alternative approach for the short-sited,” arguing that a strictly site-based perspective of the archaeological record imposes considerable interpretive limitations on past behavioural systems. Foley perceives the formation of the archaeological record as a two step process of artifact discard and subsequent post-discard geomorphological disturbance. For Foley (1981: 59), the accumulation of human debris is non-discrete and “archaeological discard is a continuous process through time.” Length of time and the nature of occupancy govern the spatial distribution of the artifacts. Furthermore, he recognizes that occupation location is part of a regional system that can only be understood with regional-scale analysis. He explains his approach to the archaeological record as a two step process: "Firstly the archaeological record of mobile peoples should be viewed not as a system of structured sites, but as a pattern of continuous artifact distribution and density. And, secondly, information on land use patterns may in some cases be better obtained through the study of non-discrete artifact distributions in specific zones than from orthodox site distributions" (Foley, 1981: 163).

Beyond the complex spatial patterns of artifact discard and accumulation, Foley articulately demonstrates the confounding influence of geomorphic processes on the temporal and spatial variability in the archaeological record. For Foley (1981: 158), the archaeological record is behaviour filtered by geomorphic process, making it the job of the archaeologist to reconstruct the original behavioural pattern. As with Schiffer (1976, 1987), Foley's approach is to disentangle the post-depositional distortion of the archaeological record, whether caused by natural or cultural transformations.

Dunnell (1992) takes Foley's argument one step further. For him, the notion of 'site' is explicitly an archaeological construct and, although often done, should not be treated as something to be discovered and observed. He highlights the problem that site identification is based on an arbitrary density threshold; the value selected has a significant impact on the derived variables of site size, site density, and subsequent population estimates. Dunnell's argument is valid, especially for mobile populations like Paleolithic hunter-gatherers, and the individual artifact is a more appropriate basic unit of survey. However, sites do in fact exist, insofar as people occupy particular places intensely and others seldom or not at all. As Binford (1992) argues, sites are useful analytical units as long as the constructed nature of the concept is understood. Sites, in this respect, are more akin to the patches of Glynn Isaac's scatter and patches approach employed at Koobi Fora (Isaac and Harris, 1980; Stern et al., 1993; Stern, 1994). Foley (1981:

166) was aware of this, observing that "[n]either on-site or off-site theory alone can account for the extent and nature of archaeological variability."

At approximately the same time Foley presented his ideas on the nature of regional archaeological records, a number of papers related to challenges in the formation of the archaeological record were published. Geoff Bailey (1983, 1987) tackled palimpsests and the role that time plays in producing spatial and temporal patterns of artifact assemblages and Lewis Binford (1980, 1981, 1982) began to address the issue of inter-site variability through ethnoarchaeological observations. They all agree that the temporal resolution of archaeological data places considerable constraints on interpretations of prehistoric behaviour and the reconstruction of settlement systems. For Foley (1981: 178) it is a "question of how much temporal resolution may acceptably be lost to obtain increased spatial information." This trade-off between temporal resolution and spatial information underscores a fundamental and often overlooked component of regional studies – that of establishing contemporaneity between variables. As the spatial parameters increase, often so does the envelope of time that encompasses the behavioural evidence. Binford argues that under such circumstances it is impossible to reconstruct a prehistoric ethnography because the time frame is inappropriate. He notes that, "[r]ates of deposition are much slower than the rapid sequencing of events which characterizes the daily lives of living peoples; even under the best of circumstances, the archaeological record represents a massive palimpsest of derivatives from many separate episodes" (Binford, 1981: 197). Bailey's work (Bailey, 1983, 1987, 2007, 2008) focuses in detail on this palimpsest nature of the archaeological record, suggesting that rather than try to disentangle the various types of palimpsests (cf. Schiffer, 1976, 1987; Foley, 1981), archaeologists need to recognize that palimpsests form the majority of archaeological data and develop techniques and models for understanding the behavioural significance of this unique data set.

These initial works have spawned a growing body of literature trying to develop such techniques, referred to as a Time Perspectivist approach (Rossignol and Wandsnider, 1992; Stein and Linse, 1993; Stern et al., 1993; Stern, 1994;

Lock and Molyneaux, 2006; Bailey, 2007, 2008; Brown, 2008; Holdaway and Wandsnider, 2008). The fundamental argument behind this approach is that the often-applied ethnographic models, which are structured in terms of dynamics playing out at scales of days, years, or decades, are inappropriate for the temporal resolution at which the archaeological record is created – a criticism that is particularly important for the study of the Pleistocene archaeological record. The degree with which each proponent eschews ethnographic interpretation varies. Some (Stern et al., 1993; Stern, 1994, 2008; Bailey, 2007) argue for the complete abandonment of ethnographic analogy, whereas others recognize that ethnoarchaeology has much to offer archaeological interpretation as long it is not seen as a source of direct analogues. Rather, "it serves to establish inferential constants or fixed reference points, which in turn permit researchers to identify and measure behavioral variation manifest in the archaeological record" (Arnold III, 2008: 162). Although much of this literature takes a negative tone toward ethnographic analogy, archaeological contexts do exist, such as Ötzi the Ice Man and the catastrophic burial of Pompeii, when ethnographic scale interpretations are appropriate. Nevertheless, the criticisms against the wide-spread application of ethnographic-scale interpretations are warranted. High temporal resolution finds are the exception to the rule. The bulk of the archaeological record is represented by artifact discard, accumulation, and burial over periods of hundreds and thousands of years, especially during the Lower, Middle, and Upper Paleolithic.

Despite internal variability in how each Time Perspectivist perceives the applicability of ethnographic time to the past, they agree that formational processes (behavioural, depositional, and post-depositional) determine the temporal resolution of the archaeological record and the questions that can be productively asked of it. Time Perspectivism can be viewed as merging a formational approach to the archaeological record with a recognition and acceptance that "[p]alimpsests are neither exceptions, nor inconveniences, nor oddities that need to be transformed into something else before they can be interpreted and understood" (Bailey, 2007: 209). Such a conception of the archaeological record is directly applicable to the Azraq Basin, because its archaeological materials span the entire Paleolithic and it is distributed unevenly across multiple geomorphic contexts (Table 3.1). Therefore, not only must these limitations be accepted if we are to best understand the settlement history of the GAOA, but they provide an opportunity to develop techniques and models for squeezing the most behavioural information possible out of an archaeological occurrence that is ubiquitous throughout arid and semi-arid regions.

8.3. Future Directions: Reconstructing Paleolithic Settlement in the GAOA

Combining the previously known Paleolithic finds in the Azraq Basin with the new results from the Druze Marsh produces a spatially continuous but compositionally heterogeneous distribution of artifacts across the GAOA landscape (Figures 3.1, 7.2; Table 3.1). Paleolithic artifacts from all time periods are known from a variety of geomorphic contexts in both buried and surface contexts. Developing a chronology of prehistoric settlement and land use in the region, therefore, requires establishing methodological and analytical techniques that can integrate the archaeological remains found in different geomorphic contexts and account for post-depositional alterations similar to those observed in the Druze Marsh. Traditionally, the reconstruction of Paleolithic settlement patterns has relied on site distribution data from large scale survey with only minimal excavation. Sites are identified based on flexible criteria of artifact densities, assigned to temporal periods spanning millennia using diagnostic features of stone tools, and their spatial distribution is correlated with various landscape features to determine prehistoric settlement patterns through time. However, as discussed in the previous section, the applicability of the site concept for the open-air Paleolithic archaeological record has been heavily criticized (Thomas, 1975; Foley, 1981; Binford, 1992; Dunnell, 1992; Ebert, 1992), and the relationship between landscape variables (e.g. slope, geology, etc.) and the distribution of surface artifacts is known to change through time and space, requiring more sensitive spatial analyses that consider multiple scales of analysis (Bevan and Conolly, 2009). In reality, the Pleistocene open-air archaeological record is a constellation of material culture interspersed throughout a 3-dimensional space of sedimentary history (Foley, 1981; Butzer, 1982; Stafford, 1995; Goldberg and Macphail, 2006), making the distribution of artifacts on the contemporary landscape a product of the spatial distribution of artifact discard, the length of artifact accumulation, as well as sedimentary deposition, erosion, and land surface stability (Foley, 1981; Bailey, 1983, 1987, 2007, 2008; Schiffer, 1987; Rossignol and Wandsnider, 1992; Stern et al., 1993; Stein and Linse, 1993; Stern, 1994; Holdaway and Wandsnider, 2008). In this respect, I suggest that reconstructing the settlement patterns and hominin behaviours that took place in the Azraq Basin necessitates an approach that incorporates landscape evolution as a critical component of understanding the spatial distribution and variability in the archaeological record.

The temporal resolution at which landscape change unfolds, however, places constraints on the interpretation of regional settlement history and land use (Binford, 1981; Foley, 1981; Bailey, 1983, 1987, 2007, 2008). For example, in northwest Jordan, Edwards (Edwards, 2004) observed that both rolled and fresh Middle Paleolithic artifacts occur in the same stratigraphic context. This suggests that some small stone tool scatters were buried quickly, preserving them in primary context, while other scatters were left exposed for long periods of time before being buried. The temporal resolution in this stratigraphic unit is variable, meaning some artifact occurrences represent relatively brief moments in time, but others could theoretically span the entire Middle Paleolithic. In addition, research in central Australia (Fanning and Holdaway, 2004; Fanning et al., 2008, 2009; Holdaway and Fanning, 2008) demonstrates that surface geomorphology in arid and semi-arid environments is surprisingly discontinuous; and that artifact clusters that appear very similar can be substantially different in age, and can have accumulated over significantly different lengths of time. Together, these and other case studies (Stern et al., 1993; Barton et al., 2002; Bettis and Mandel, 2002; Rech et al., 2007; Fanning et al., 2009; Maher, 2011; Sitzia et al., 2012) demonstrate that the spatial distribution of artifacts across the landscape, whether buried or on the surface, is not a simple proxy for prehistoric behaviour, but one filtered and interpretively constrained by the history of landscape change. Therefore, a robust understanding of the Paleolithic settlement history of the Azraq Basin, and subsequently its importance as a desert refugium along a possible migration corridor, can only be achieved by reconstructing the regional history of landscape change and evaluating its influence on the visibility, integrity, and spatial distribution of the archaeological material. Only then can the remains from diverse archaeological contexts be incorporated into a unified history of settlement and land use.

In 1984 Clark (1984: 225) noted that "most Paleolithic sites so far recorded [in Jordan] consist of deflated surface finds where industries from a number of different periods are mixed together in an archaeological composite (or palimpsest) without contextual evidence of any kind." Although many more sites have been identified since 1984, some in good stratified context (e.g. Henry, 1995; Coinman, 1998, 2000), the landscape is still dominated by artifact scatters on deflated surfaces. Impressive cave and rockshelter sites do exist in the Eastern Mediterranean (see Hovers, 2009: 247–249 for a comprehensive list), but detailed accounts of buried or stratified open-air contexts are rare, making their investigation at locations such as the Druze Marsh, and others in the Azraq Basin, critical for broadening our knowledge of Pleistocene hominin behaviour and dispersal, and the range of environments hominins exploited. Nevertheless, both buried and surface contexts are remnants of prehistoric behaviour and are thus crucial for deciphering regional settlement histories. We must acknowledge that surface accumulations are not second-rate datasets. Most buried and stratified open-air sites started as surface deposits, meaning that they were subject to the same suite of post-depositional processes that are often used to argue for the second-rate nature of surface data (Dunnell, 1992). Regional investigations of settlement patterns therefore require integrating both lines of evidence, something that Butzer (2008) sees as a primary challenge confronting the future contribution of geoarchaeology to paleoanthropological research.

9. CONCLUSION

The research presented here combined detailed stratigraphic and sedimentological analyses from multiple test pits and one controlled excavation in the Druze Marsh in combination with artifact analysis and radiometric dates with the purpose of reconstructing the changing landscape throughout the Middle and Late Pleistocene. The goal of this study was to relate the sequence of hominin occupation to particular depositional environments and establish the relationship between hominin settlement and paleoenvironmental change. The results identified Lower Paleolithic through Epipaleolithic occupation horizons embedded in a stratigraphic succession characterized by cyclical aggradations of lacustrine or palustrine clayey silts indicative of wet periods and aeolian sand and erosional unconformities indicating arid conditions. Evidence of substantial Lower, Middle, and Upper Paleolithic occupation at times when the Druze Marsh was reduced in size indicates that the GAOA functioned as a desert refugium for hominins at times of adverse climatic conditions, with important implications for regional population continuity, turnover, and/or extinctions at critical times during the Pleistocene. In contrast, Middle and Late Pleistocene humid periods caused substantial increases of the water level in the GAOA, forcing hominins out of the central basin into the areas along wadi drainages, which likely had an impact on their mobility patterns.

Positioned at the northern end of the Wadi Sirhan depression between the Levantine Corridor and the Arabian Peninsula, this observed relationship between fluctuating paleoenvironments and hominin settlement dynamics makes the GAOA an important location for the dispersal of hominins between Africa, Eurasia, and the Arabian Peninsula. Perhaps small Neanderthal populations were able to survive at particularly productive resource refugia like the Druze Marsh during harsh climatic conditions, providing an opportunity for them to interbreed with AMHs as they dispersed out of Africa into Eurasia for the final time via the Levant and Arabian Peninsula between 70-50 ka. Moreover, the early AMH dispersals out of Africa ~120 ka present a complex demographic pattern of archaic and anatomically modern humans in the Levant and Arabia prior to this 'final' dispersal event. Because of the ~70 ka genetic bottleneck in the human population (see section 4 above), the dispersal and demography between 120-70 ka can only be elucidated by continued archaeological research (Groucutt and Petraglia, 2012). Evaluating the importance of the GAOA at critical points in human prehistory, therefore, requires building on the results of this study to reconstruct a detailed history of Paleolithic settlement and land use. This can only be accomplished by integrating the large body of archaeological remains distributed across varying geomorphic contexts and subject to inconsistent post-depositional alterations. Deciphering the behavioural patterns of such a large open-air landscape requires accepting landscape evolution as a critical component contributing to the spatial distribution and variability in the archaeological record, specifically acknowledging that the distribution of artifacts throughout the landscape is not a simple proxy for prehistoric settlement patterns, but one filtered and interpretively constrained by the history of landscape change. It is more appropriate to speak of open-air archaeological landscapes, rather than sites in the traditional sense. If such challenges are embraced, future research at the GAOA is poised to make a considerable contribution to the study of human origins and, relevant to our current concerns of global climate change, how human ancestors adapted to regional-scale environmental change in the past.

10. APPENDICES

Appendix A: Sedimentological Data

Table 10.1 Basic sedimentological properties for all samples from the Druze Marsh.

Pit	Sample	Depth (m)	pH	Xlf	LOI_{550}	LOI_{950}	Field Colour	Air Dry Colour
1	105	0.27	7.9	1.0	11.9	25.0	5Y 7/2 (light gray)	2.5Y 7/1 (light gray)
1	104	-0.07	7.7	1.3	12.4	20.1	5Y 7/2 (light gray)	2.5Y 7/1 (light gray)
1	103	-0.21	3.7	5.5	25.8	1.8	2.5Y 3/1 (very dark gray)	2.5Y 4/1 (dark gray)
1	102	-0.43	3.5	5.0	43.3	2.5	2.5Y 3/1 (very dark gray)	7.5YR 2.5/1 (black)
1	101	-0.66	3.7	13.0	10.2	1.2	5Y 2.5/1 (black)	10YR 4/2 (dark grayish brown)
1	100	-0.88	3.6	8.6	13.4	1.4	5Y 2.5/1 (black)	2.5Y 4/2 (dark grayish brown)
1	99	-1.05	3.5	8.3	6.5	4.0	5GY 4/1 (dark greenish gray)	2.5Y 5/2 (grayish brown)
1	98	-1.13	3.5	8.3	7.4	1.4	5GY 4/1 (dark greenish gray)	5Y 6/1 (gray)
1	97	-1.22	3.5	8.6	7.1	1.2	5GY 4/1 (dark greenish gray)	5Y 6/1 (gray)
1	96	-1.31	3.7	9.4	9.0	1.3	5Y 3/1 (very dark gray)	2.5Y 5/1 (gray)
1	95	-1.40	3.6	7.5	8.6	3.9	5Y 3/1 (very dark gray)	10YR 3/1 (very dark gray)
1	94	-1.50	3.7	6.7	6.0	2.1	5Y 3/1 (very dark gray)	10YR 4/1 (dark gray)
1	93	-1.62	3.8	5.0	1.8	0.7	5Y 7/4 (pale yellow)	5Y 8/2 (pale yellow)
1	92	-1.76	3.9	5.6	1.2	1.4	5Y 7/4 (pale yellow)	10Y 8/1 (light greenish gray)
1	91	-1.88	4.0	5.5	1.6	0.7	5Y 7/4 (pale yellow)	10Y 8/1 (light greenish gray)
1	90	-2.00	4.3	6.0	1.8	0.5	5Y 7/4 (pale yellow)	10Y 8/1 (light greenish gray)
2A	1	-0.05	8.2	4.3	17.5	14.1	10YR 7/2 (light gray)	10YR 6/2 (light brownish gray)
2A	2	-0.13	7.7	3.0	10.8	19.7	5GY 6/1 (greenish gray)	10YR 5/1 (gray)
2A	3	-0.19	7.0	5.9	18.9	1.7	2.5Y 3/1 (very dark gray)	2.5Y 3/2 (very dark grayish brown)

2A	4	-0.59	3.5	7.0	9.3	1.0	10Y 3/1 (dark greenish gray)	5Y 2.5/1 (black)
2A	5	-1.13	7.5	4.2	5.2	21.0	N 8/1 (white)	2.5Y 8/1 (white)
2A	6	-1.43	7.8	7.5	4.1	3.6	10GY 6/1 (greenish gray)	10Y 6/1 (greenish gray)
2A	7	-1.83	4.2	7.9	3.1	2.5	10B 4/1 (dark bluish gray)	N 4/1 (dark gray)
2A	8	-2.15	4.1	5.2	2.4	0.6	10Y 8/1 (light greenish gray)	2.5Y 7/1 (light gray)
2A	9	-2.28	4.0	7.2	3.7	1.2	5G 5/1 (greenish gray)	5Y 6/2 (light olive gray)
2B	10	-0.16	7.9	130.6	7.1	14.3	2.5Y 6/1 (gray)	2.5Y 6/2 (light brownish gray)
2B	11	-0.53	3.7	6.4	8.5	4.9	10YR 2/1 (black)	5Y 2.5/1 (black)
2B	12	-0.92	3.5	3.8	23.5	1.4	10YR 2/1 (black)	7.5YR 2.5/1 (black)
2B	13	-1.48	3.5	7.2	3.9	1.9	5GY 5/1 (greenish gray)	2.5Y 6/2 (light brownish gray)
2B	14	-1.75	3.6	3.4	1.7	1.6	2.5Y 4/2 (dark grayish brown)	2.5Y 5/2 (grayish brown)
2B	16	-1.95	2.8	4.5	38.7	2.3	N 2.5/black (black)	7.5YR 2.5/1 (black)
2B	15	-2.00	3.2	5.2	9.1	1.7	7.5 YR 2.5/1 (black)	10YR 3/2 (very dark grayish brown)
2B	18	-2.04	3.0	2.9	6.2	0.8	10YR 4/3 (brown)	10YR 5/3 (brown)
2B	17	-2.06	3.4	3.6	3.1	1.3	10YR 4/3 (brown)	10YR 5/3 (brown)
2B	19	-2.12	3.1	3.5	5.4	1.6	5Y 6/2 (light olive gray)	10YR 5/3 (brown)
2B	20	-2.19	3.2	3.3	2.1	1.9	2.5Y 6/3 (light yellowish brown)	2.5Y 6/3 (light yellowish brown)
2B	21	-2.32	2.9	6.7	6.7	3.5	2.5Y 3/2 (very dark grayish brown)	10YR 5/3 (brown)
3	22	-0.60	3.6	8.3	9.5	1.5	10YR 4/2 (dark grayish brown)	2.5Y 4/2 (dark grayish brown)
3	23	-1.22	3.5	9.8	2.6	3.5	5GY 8/1 (light greenish gray)	5Y 6/2 (light olive gray)
3	24	-1.67	3.4	6.3	10.5	1.6	2.5YR 2.5/1 (reddish black)	10YR 3/2 (very dark grayish brown)
3	25	-1.73	3.5	4.6	4.8	1.9	2.5Y 4/3 (olive brown)	10YR 4/3 (brown)
3	26	-1.76	3.4	4.6	13.6	0.5	10YR 3/2 (very dark grayish brown)	10YR 3/2 (very dark grayish brown)
3	27	-1.80	3.5	3.9	7.2	0.8	10YR 4/2 (dark grayish brown)	10YR 4/2 (dark grayish brown)
3	28	-1.86	3.4	4.2	7.7	0.9	2.5Y 3/2 (very dark grayish brown)	10YR 3/2 (very dark grayish brown)

3	29	-2.08	3.1	6.9	6.1	3.1	2.5Y 3/2 (very dark grayish brown)	2.5Y 5/2 (grayish brown)
3	30	-2.43	2.6	7.6	9.2	5.2	7.5YR 3/1 (very dark gray)	10YR 4/2 (dark grayish brown)
3	31	-2.65	3.6	6.2	3.8	2.2	5Y 6/3 (pale olive)	2.5Y 7/2 (light gray)
5	32	-0.45	3.4	6.1	20.4	1.8	N 2.5/1 (black)	10YR 3/1 (very dark gray)
5	33	-1.10	3.7	8.4	4.9	1.2	5GY 6/1 (greenish gray)	5Y 6/2 (light olive gray)
5	34	-1.65	4.0	7.7	4.4	0.9	N 2.5/1 (black)	2.5Y 3/1 (very dark gray)
5	35	-2.10	3.6	7.0	3.3	1.0	5Y 5/2 (olive gray)	5Y 6/2 (light olive gray)
5	36	-2.32	2.7	6.2	5.7	2.1	2.5Y 5/3 (light olive brown)	10YR 5/3 (brown)
5	37	-2.42	3.1	8.4	6.6	6.7	10YR 3/2 (very dark grayish brown)	10YR 4/2 (dark grayish brown)
5	38	-2.62	3.7	8.1	7.4	2.6	5Y 6/3 (pale olive)	5Y 6/2 (light olive gray)
8	64	0.24	7.9	7.2	9.1	23.0	5Y 7/2 (light gray)	10YR 7/1 (light gray)
8	65	0.17	7.9	6.9	7.4	23.7	5Y 7/2 (light gray)	10YR 7/1 (light gray)
8	66	0.04	7.9	12.1	7.6	9.5	2.5Y 3/1 (very dark gray)	10YR 4/1 (dark gray)
8	67	-0.02	8.1	17.2	5.7	2.6	2.5Y 3/1 (very dark gray)	10YR 4/1 (dark gray)
8	68	-0.14	7.6	14.1	1.5	1.9	5Y 4/1 (dark gray)	2.5YR 5/2 (grayish brown)
8	69	-0.28	7.9	10.1	5.3	2.3	N 4/1 (dark gray)	2.5Y 3/1 (very dark gray)
8	70	-0.36	8.1	10.3	4.9	3.1	N 4/1 (dark gray)	5Y 4/1 (dark gray)
8	71	-0.44	8.0	10.2	4.8	3.0	N 4/1 (dark gray)	5Y 4/1 (dark gray)
8	72	-0.46	8.0	7.2	6.9	14.0	5Y 6/3 (pale olive)	2.5Y 7/3 (pale yellow)
8	73	-0.59	8.1	11.5	4.6	1.7	5Y 6/3 (pale olive)	5Y 6/3 (pale olive)
8	74	-0.68	8.0	11.2	6.8	0.8	5Y 6/3 (pale olive)	5Y 7/3 (pale yellow)
8	75	-0.83	5.4	11.5	4.5	2.1	5Y 4/2 (olive gray)	5Y 6/3 (pale olive)
8	76	-0.94	3.9	9.6	6.7	1.8	5GY 4/1 (dark greenish gray)	5Y 6/3 (pale olive)
8	77	-1.12	3.5	10.1	6.7	3.0	5GY 4/1 (dark greenish gray)	5Y 5/2 (olive gray)
8	78	-1.26	3.7	9.6	7.4	2.4	5GY 4/1 (dark greenish gray)	10Y 6/1 (greenish gray)

8	79	-1.47	3.5	9.3	8.1	3.5	5GY 4/1 (dark greenish gray)	10Y 5/1 (greenish gray)
8	81	-1.64	3.7	8.5	5.9	2.7	5Y 3/1 (very dark gray)	5Y 6/2 (light olive gray)
8	80	-1.65	3.8	8.3	4.9	2.9	5Y 3/1 (very dark gray)	2.5Y 6/2 (light brownish gray)
8	83	-1.68	3.7	6.4	2.9	2.1	5Y 6/1 (gray)	5Y 8/2 (pale yellow)
8	82	-1.68	3.7	5.6	1.4	1.7	5Y 6/1 (gray)	5Y 6/2 (light olive gray)
8	84	-1.76	3.7	5.6	1.3	2.2	5Y 7/4 (pale yellow)	5Y 8/2 (pale yellow)
8	85	-1.87	3.7	5.7	2.4	2.0	5Y 7/4 (pale yellow)	5Y 7/2 (light gray)
8	86	-2.03	3.9	7.5	2.9	1.9	5Y 6/4 (pale olive)	5Y 7/2 (light gray)
8	87	-2.24	3.8	9.4	3.2	2.7	5Y 6/4 (pale olive)	2.5Y 6/3 (light yellowish brown)
8	88	-2.37	3.9	10.1	7.3	2.4	5Y 7/4 (light gray)	10YR 7/6 (yellow)
8	89	-2.49	4.3	18.4	6.5	2.1	2.5Y 7/8 (pale yellow)	10YR 6/6 (brownish yellow)
9	50	-0.59	3.4	10.7	5.7	3.9	5Y 5/2 (olive gray)	5Y 6/2 (light olive gray)
9	49	-1.09	3.5	9.4	6.3	2.3	5GY 4/1 (dark greenish gray)	5Y 6/2 (light olive gray)
9	48	-1.63	3.5	9.0	6.2	2.4	5GY 4/1 (dark greenish gray)	5Y 5/1 (gray)
9	47	-1.71	3.5	8.8	5.6	3.4	5GY 4/1 (dark greenish gray)	5Y 5/1 (gray)
9	46	-1.80	3.6	6.3	6.6	1.9	5Y 3/1 (very dark gray)	2.5Y 4/1 (dark gray)
9	45	-1.89	3.7	5.3	2.5	1.7	5Y 6/1 (gray)	5Y 7/2 (light gray)
9	44	-2.07	3.8	3.3	1.6	0.8	5Y 7/4 (pale yellow)	5Y 8/2 (pale yellow)
9	43	-2.38	6.1	6.0	2.3	0.3	5Y 7/4 (pale yellow)	10Y 8/1 (light greenish gray)
9	42	-2.64	6.6	6.8	2.0	1.9	5Y 6/4 (pale olive)	5GY 8/1 (light greenish gray)
9	41	-2.86	7.1	8.4	4.4	0.6	5Y 6/4 (pale olive)	5GY 8/1 (light greenish gray)
9	40	-3.09	6.7	6.8	2.8	0.6	5Y 7/4 (light gray)	2.5Y 7/4 (pale yellow)
9	39	-3.33	6.8	9.4	1.9	1.7	5Y 7/4 (light gray)	5Y 7/3 (pale yellow)
11	63	0.81	6.7	7.5	22.0	0.8	2.5Y 3/1 (very dark gray)	7.5YR 2.5/1 (black)
11	62	0.39	8.0	7.8	5.0	1.0	N 4/1 (dark gray)	2.5Y 4/1 (dark gray)

11	61	-0.33	8.6	10.2	4.0	0.9	5Y 6/3 (pale olive)	5Y 7/2 (light gray)
11	60	-0.68	3.6	10.7	5.7	1.3	5Y 5/2 (olive gray)	5Y 5/2 (olive gray)
11	59	-0.87	3.5	7.0	7.4	1.3	10YR 4/2 (dark grayish brown)	10YR 4/2 (dark grayish brown)
11	58	-0.93	3.6	4.8	3.4	0.9	5Y 6/2 (light olive gray)	10YR 6/2 (light grayish brown)
11	57	-0.99	3.5	6.5	7.2	1.0	2.5Y 6/2 (light brownish gray)	2.5Y 4/2 (dark grayish brown)
11	56	-1.08	3.6	4.1	1.5	0.6	5Y 7/2 (light gray)	2.5Y 7/2 (light gray)
11	55	-1.20	3.7	5.2	0.7	0.4	5Y 7/2 (light gray)	2.5Y 7/1 (light gray)
11	54	-1.42	3.6	5.6	2.4	1.0	5Y 7/4 (pale yellow)	5Y 8/2 (pale yellow)
11	53	-1.72	3.6	6.2	3.8	1.4	5Y 6/4 (pale olive)	10YR 6/2 (light brownish gray)
11	52	-2.03	5.3	9.1	6.4	1.0	5Y 7/4 (light gray)	2.5Y 7/4 (pale yellow)
11	51	-2.28	6.3	12.3	6.2	1.5	2.5Y 7/8 (pale yellow)	10YR 6/6 (brownish yellow)
Dune	106	n/a	n/a	n/a	n/a	n/a	10YR 5/6 (yellowish brown)	10YR 5/6 (yellowish brown)

Appendix B: Particle Size Distribution Proportions and Classification

Table 10.2 Summarized particle size distribution data for all samples from the Druze Marsh.

Pit	Sample	Depth (m)	% Sand	% Silt	% Clay	Mean (µm)	Mode 1 (µm)	Mode 2 (µm)	Mode 3 (µm)	PSD Classification
1	105	0.27	26.4	72.8	0.8	46.1	14.2	83.0		sandy silt
1	104	-0.07	43.0	55.2	1.8	82.9	163.5	14.2		very slightly clayey sandy silt
1	103	-0.21	12.8	75.6	11.6	26.0	14.2	63.2		slightly sandy slightly clayey silt
1	102	-0.43	30.2	66.5	3.3	49.9	83.0	14.2		very slightly clayey sandy silt
1	101	-0.66	59.7	34.8	5.5	91.9	108.8	18.6		slightly clayey silty sand
1	100	-0.88	20.0	67.5	12.5	31.1	72.4	9.5	0.7	slightly sandy slightly clayey silt
1	99	-1.05	0.2	84.8	14.9	8.5	7.2			slightly clayey silt
1	98	-1.13	0.0	72.0	28.0	3.9	4.8	3.7		clayey silt
1	97	-1.22	0.1	84.5	15.4	7.6	6.3	4.8		slightly clayey silt
1	96	-1.31	0.0	69.2	30.8	3.9	4.8			clayey silt
1	95	-1.40	9.7	72.0	18.3	19.6	7.2	9.5	4.8	slightly sandy slightly clayey silt
1	94	-1.50	37.8	54.5	7.7	55.9	72.4			slightly clayey sandy silt
1	93	-1.62	58.1	39.3	2.5	78.2	83.0			very slightly clayey silty sand
1	92	-1.76	60.4	37.6	2.0	84.6	72.4			very slightly clayey silty sand
1	91	-1.88	45.6	53.0	1.4	63.3	72.4			very slightly clayey sandy silt
1	90	-2.00	49.8	47.8	2.4	69.7	72.4			very slightly clayey silty sand
2A	1	-0.05	36.8	61.8	1.3	70.1	14.2	142.8		very slightly clayey sandy silt
2A	2	-0.13	19.0	73.9	7.1	33.3	14.2	72.4		slightly sandy slightly clayey silt
2A	3	-0.19	42.3	55.0	2.7	67.3	72.4			very slightly clayey sandy silt
2A	4	-0.59	39.3	59.1	1.7	55.9	72.4			very slightly clayey sandy silt
2A	5	-1.13	26.7	68.5	4.8	36.1	72.4	6.3	4.8	very slightly clayey sandy silt

2A	6	-1.43	46.0	43.9	10.0	55.4	72.4	4.8		slightly clayey silty sand
2A	7	-1.83	50.9	48.3	0.8	65.1	72.4			silty sand
2A	8	-2.15	61.0	37.5	1.5	75.1	72.4			very slightly clayey silty sand
2A	9	-2.28	41.1	54.8	4.2	58.4	63.2			very slightly clayey sandy silt
2B	10	-0.16	39.3	58.7	2.0	60.1	72.4			very slightly clayey sandy silt
2B	11	-0.53	40.9	57.2	1.9	59.4	72.4			very slightly clayey sandy silt
2B	12	-0.92	55.5	44.3	0.2	71.1	72.4			silty sand
2B	13	-1.48	68.2	28.5	3.3	83.2	83.0			very slightly clayey silty sand
2B	14	-1.75	58.2	39.8	2.0	73.0	72.4			very slightly clayey silty sand
2B	16	-1.95	49.1	50.6	0.2	67.3	72.4			sandy silt
2B	15	-2.00	50.8	47.1	2.1	67.4	72.4			very slightly clayey silty sand
2B	18	-2.04	66.6	32.7	0.8	81.5	83.0			silty sand
2B	17	-2.06	60.3	38.2	1.6	75.8	83.0			very slightly clayey silty sand
2B	19	-2.12	61.9	36.9	1.2	81.1	83.0			very slightly clayey silty sand
2B	20	-2.19	76.9	20.9	2.3	102.3	95.0			very slightly clayey silty sand
2B	21	-2.32	39.3	51.5	9.1	59.3	72.4	14.2	0.6	slightly clayey sandy silt
3	22	-0.60	23.7	72.4	3.8	40.1	63.2	14.2		very slightly clayey sandy silt
3	23	-1.22	45.3	51.2	3.6	61.4	63.2			very slightly clayey sandy silt
3	24	-1.67	31.1	65.9	3.0	47.3	63.2	14.2		very slightly clayey sandy silt
3	25	-1.73	40.2	57.5	2.3	58.8	63.2			very slightly clayey sandy silt
3	26	-1.76	51.0	48.6	0.3	67.4	72.4			silty sand
3	27	-1.80	52.1	47.5	0.3	69.9	72.4			silty sand
3	28	-1.86	59.5	39.3	1.2	83.3	83.0			very slightly clayey silty sand
3	29	-2.08	49.5	44.6	5.9	65.5	72.4			slightly clayey silty sand
3	30	-2.43	46.5	49.3	4.3	62.5	83.0	18.6		very slightly clayey sandy silt
3	31	-2.65	52.5	43.1	4.4	73.5	83.0			very slightly clayey silty sand

5	32	-0.45	71.1	28.9	0.0	97.3	83.0			silty sand
5	33	-1.10	22.5	75.3	2.2	36.4	9.5	72.4		very slightly clayey sandy silt
5	34	-1.65	24.0	73.0	2.9	36.9	72.4	8.3		very slightly clayey sandy silt
5	35	-2.10	49.0	49.5	1.5	65.0	72.4			very slightly clayey sandy silt
5	36	-2.32	47.7	50.7	1.6	65.7	72.4			very slightly clayey sandy silt
5	37	-2.42	17.9	61.8	20.2	28.8	63.2	12.4	9.5	slightly sandy clayey silt
5	38	-2.62	4.0	85.9	10.1	18.8	14.2			very slightly sandy slightly clayey silt
8	64	0.24	7.7	88.0	4.2	19.6	9.5	55.2		very slightly clayey slightly sandy silt
8	65	0.17	5.3	88.9	5.9	17.4	9.5			slightly sandy slightly clayey silt
8	66	0.04	16.6	81.2	2.2	31.8	14.2	63.2		very slightly clayey slightly sandy silt
8	67	-0.02	39.8	56.8	3.4	55.8	95.0	9.5		very slightly clayey sandy silt
8	68	-0.14	73.3	25.1	1.6	102.9	108.8			very slightly clayey silty sand
8	69	-0.28	14.6	74.9	10.4	26.4	9.5	7.2	63.2	slightly sandy slightly clayey silt
8	70	-0.36	9.2	81.1	9.7	20.6	7.2	63.2		slightly sandy slightly clayey silt
8	71	-0.44	16.2	78.5	5.3	27.3	6.3	72.4		slightly sandy slightly clayey silt
8	72	-0.46	0.0	72.5	27.5	5.3	8.3	0.7		clayey silt
8	73	-0.59	0.0	67.9	32.1	4.4	6.3	8.3	0.8	clayey silt
8	74	-0.68	0.6	79.3	20.1	9.0	2.8	9.5		clayey silt
8	75	-0.83	0.1	87.3	12.7	8.0	6.3	4.8		slightly clayey silt
8	76	-0.94	1.0	87.5	11.4	9.6	6.3			very slightly sandy slightly clayey silt
8	77	-1.12	0.0	88.4	11.6	6.8	4.8	6.3		slightly clayey silt
8	78	-1.26	0.0	80.8	19.2	5.3	4.8			slightly clayey silt
8	79	-1.47	0.0	75.7	24.3	5.4	3.2	4.8		clayey silt
8	81	-1.64	4.9	79.4	15.7	15.2	7.2	4.8	9.5	very slightly sandy slightly clayey silt
8	80	-1.65	1.9	86.8	11.3	13.5	9.5	7.2		very slightly sandy slightly clayey silt
8	83	-1.68	54.9	41.5	3.6	79.3	95.0	14.2		very slightly clayey silty sand

8	82	-1.68	52.3	44.2	3.5	73.0	83.0	14.2	18.6	very slightly clayey silty sand
8	84	-1.76	50.7	45.6	3.6	68.6	83.0			very slightly clayey silty sand
8	85	-1.87	50.2	46.8	3.0	67.5	72.4			very slightly clayey silty sand
8	86	-2.03	40.4	54.7	4.9	56.5	72.4			very slightly clayey sandy silt
8	87	-2.24	10.2	85.2	4.6	23.9	12.4	55.2		very slightly clayey slightly sandy silt
8	88	-2.37	10.5	83.4	6.1	25.8	14.2			slightly sandy slightly clayey silt
8	89	-2.49	6.1	87.0	7.0	19.0	12.4			slightly sandy slightly clayey silt
9	50	-0.59	18.6	63.2	18.2	32.1	63.2	0.9		slightly sandy slightly clayey silt
9	49	-1.09	0.0	89.0	11.0	8.0	8.3			slightly clayey silt
9	48	-1.63	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
9	47	-1.71	0.0	60.2	39.8	3.5	2.1			clayey silt
9	46	-1.80	39.4	54.0	6.7	53.1	72.4	7.2		slightly clayey sandy silt
9	45	-1.89	45.3	51.6	3.1	60.5	72.4			very slightly clayey sandy silt
9	44	-2.07	59.7	38.4	1.8	75.2	72.4			very slightly clayey silty sand
9	43	-2.38	64.8	33.6	1.6	82.8	83.0			very slightly clayey silty sand
9	42	-2.64	0.0	78.1	21.9	4.6	4.8			clayey silt
9	41	-2.86	0.0	77.6	22.4	4.2	3.2	4.8		clayey silt
9	40	-3.09	62.5	36.0	1.5	85.7	83.0			very slightly clayey silty sand
9	39	-3.33	33.8	63.2	3.0	48.6	14.2	9.5	4.8	very slightly clayey sandy silt
11	63	0.81	21.9	76.4	1.6	39.1	14.2	72.4		very slightly clayey sandy silt
11	62	0.39	17.5	81.0	1.5	31.2	7.2	63.2		very slightly clayey slightly sandy silt
11	61	-0.33	13.0	80.6	6.4	26.9	55.2	14.2		slightly sandy slightly clayey silt
11	60	-0.68	0.0	96.6	3.4	9.3	8.3			very slightly clayey silt
11	59	-0.87	1.1	90.5	8.4	16.8	14.2			very slightly sandy slightly clayey silt
11	58	-0.93	38.2	59.6	2.2	55.3	63.2			very slightly clayey sandy silt
11	57	-0.99	10.1	85.4	4.5	27.9	18.6	14.2		very slightly clayey slightly sandy silt

11	56	-1.08	65.9	33.1	1.0	82.3	83.0		silty sand
11	55	-1.20	73.0	25.0	2.0	92.6	83.0		very slightly clayey silty sand
11	54	-1.42	40.6	56.6	2.8	59.2	63.2		very slightly clayey sandy silt
11	53	-1.72	23.5	69.6	6.9	38.9	63.2		slightly clayey sandy silt
11	52	-2.03	9.3	84.6	6.1	25.2	14.2	18.6	slightly sandy slightly clayey silt
11	51	-2.28	14.2	83.8	2.0	32.7	24.5		very slightly clayey slightly sandy silt
Dune	106	n/a	0.0	79.0	21.0	5.9	3.2	4.8	clayey silt

Appendix C: Raw Particle Size Distribution Data Expressed in % by Volume

Table 10.3 Raw particle size distribution data for samples 1 through 18.

Bin	Diameter (µm)	Sediment Sample ID																	
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1	0.022	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	0.026	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	0.029	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	0.034	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5	0.039	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6	0.044	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7	0.051	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8	0.058	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9	0.067	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10	0.076	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
11	0.087	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
12	0.1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
13	0.115	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
14	0.131	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
15	0.15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
16	0.172	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
17	0.197	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
18	0.226	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
19	0.259	0	0	0	0	0	0.11	0	0	0	0	0	0	0	0	0	0	0	0
20	0.296	0	0	0	0	0	0.172	0	0	0	0	0	0	0.11	0	0	0	0	0
21	0.339	0	0.141	0.103	0	0	0.259	0	0	0.137	0	0	0	0.148	0	0.115	0	0	0
22	0.389	0	0.195	0.129	0	0	0.368	0	0	0.179	0	0	0	0.19	0.125	0.143	0	0.112	0
23	0.445	0	0.251	0.15	0	0.107	0.479	0	0.11	0.217	0.105	0.109	0	0.223	0.148	0.162	0	0.127	0.109
24	0.51	0	0.317	0.172	0.11	0.14	0.613	0	0.123	0.26	0.118	0.124	0	0.258	0.173	0.18	0	0.142	0.117
25	0.584	0	0.38	0.185	0.121	0.179	0.711	0	0.131	0.29	0.126	0.134	0	0.273	0.185	0.184	0	0.146	0.117
26	0.669	0	0.439	0.194	0.129	0.223	0.789	0	0.136	0.314	0.133	0.142	0	0.278	0.19	0.181	0	0.145	0.113
27	0.766	0	0.494	0.198	0.135	0.27	0.844	0	0.14	0.332	0.138	0.146	0	0.274	0.19	0.172	0	0.141	0.108
28	0.877	0.112	0.558	0.206	0.143	0.334	0.876	0	0.142	0.348	0.148	0.153	0	0.265	0.183	0.163	0	0.134	0.101

29	1.005	0.136	0.634	0.219	0.155	0.418	0.903	0.108	0.143	0.365	0.164	0.164	0	0.257	0.174	0.156	0	0.129	0
30	1.151	0.17	0.715	0.238	0.171	0.518	0.914	0.123	0.144	0.382	0.188	0.181	0	0.249	0.164	0.153	0	0.124	0
31	1.318	0.223	0.841	0.27	0.197	0.676	0.962	0.147	0.148	0.415	0.225	0.209	0	0.25	0.158	0.156	0	0.124	0
32	1.51	0.301	1.001	0.32	0.237	0.89	1.023	0.184	0.152	0.456	0.281	0.252	0.105	0.259	0.155	0.167	0.113	0.128	0
33	1.729	0.426	1.236	0.404	0.301	1.214	1.139	0.247	0.16	0.521	0.375	0.325	0.131	0.284	0.16	0.195	0.141	0.14	0.101
34	1.981	0.584	1.476	0.497	0.375	1.599	1.234	0.323	0.165	0.581	0.484	0.409	0.159	0.307	0.164	0.224	0.172	0.152	0.109
35	2.269	0.777	1.721	0.613	0.47	2.027	1.333	0.422	0.169	0.642	0.62	0.518	0.199	0.338	0.174	0.269	0.215	0.171	0.122
36	2.599	0.998	1.937	0.732	0.571	2.468	1.398	0.536	0.171	0.692	0.772	0.637	0.244	0.366	0.182	0.317	0.263	0.19	0.135
37	2.976	1.245	2.146	0.866	0.69	2.906	1.458	0.664	0.172	0.74	0.941	0.777	0.301	0.398	0.196	0.38	0.323	0.215	0.152
38	3.409	1.479	2.314	0.994	0.809	3.209	1.485	0.78	0.172	0.774	1.095	0.915	0.363	0.427	0.212	0.452	0.387	0.243	0.172
39	3.905	1.722	2.472	1.122	0.932	3.436	1.493	0.887	0.173	0.806	1.252	1.056	0.431	0.452	0.231	0.531	0.459	0.275	0.195
40	4.472	2.074	2.732	1.302	1.103	3.831	1.545	1.036	0.176	0.857	1.47	1.254	0.521	0.487	0.253	0.637	0.554	0.315	0.223
41	5.122	2.285	2.857	1.411	1.219	3.758	1.494	1.078	0.18	0.883	1.598	1.372	0.59	0.496	0.276	0.725	0.636	0.355	0.253
42	5.867	2.615	3.094	1.578	1.388	3.845	1.487	1.156	0.188	0.931	1.793	1.549	0.683	0.516	0.303	0.843	0.748	0.405	0.29
43	6.72	2.878	3.282	1.717	1.539	3.715	1.439	1.181	0.2	0.98	1.949	1.691	0.766	0.522	0.333	0.954	0.86	0.458	0.331
44	7.697	3.087	3.364	1.815	1.66	3.474	1.345	1.171	0.204	0.99	2.059	1.797	0.844	0.515	0.356	1.06	0.968	0.508	0.371
45	8.816	3.316	3.572	1.978	1.84	3.24	1.302	1.181	0.235	1.088	2.226	1.946	0.935	0.521	0.399	1.18	1.111	0.58	0.429
46	10.097	3.425	3.617	2.073	1.969	2.896	1.209	1.153	0.261	1.142	2.317	2.034	1.011	0.511	0.435	1.283	1.24	0.645	0.484
47	11.565	3.538	3.683	2.19	2.122	2.6	1.134	1.139	0.297	1.223	2.429	2.141	1.099	0.507	0.481	1.398	1.392	0.724	0.552
48	13.246	3.608	3.722	2.31	2.284	2.319	1.068	1.133	0.346	1.325	2.54	2.25	1.194	0.506	0.538	1.521	1.563	0.816	0.631
49	15.172	3.407	3.521	2.334	2.364	1.993	0.999	1.129	0.42	1.429	2.542	2.278	1.274	0.513	0.614	1.61	1.705	0.913	0.72
50	17.377	3.252	3.366	2.385	2.474	1.727	0.94	1.138	0.513	1.559	2.575	2.332	1.369	0.522	0.704	1.716	1.877	1.028	0.824
51	19.904	3.018	3.146	2.412	2.566	1.491	0.891	1.165	0.645	1.717	2.579	2.37	1.469	0.539	0.82	1.814	2.052	1.158	0.945
52	22.797	2.814	2.977	2.494	2.721	1.352	0.892	1.272	0.855	1.977	2.645	2.477	1.626	0.591	1.006	1.968	2.292	1.344	1.112
53	26.111	2.602	2.826	2.618	2.928	1.304	0.961	1.496	1.197	2.376	2.76	2.652	1.86	0.7	1.316	2.188	2.603	1.61	1.343
54	29.907	2.432	2.746	2.839	3.251	1.401	1.165	1.948	1.78	3.015	2.979	2.963	2.255	0.932	1.878	2.55	3.06	2.032	1.701
55	34.255	2.308	2.731	3.168	3.728	1.69	1.605	2.768	2.759	3.971	3.304	3.437	2.915	1.398	2.871	3.125	3.722	2.706	2.271
56	39.234	2.279	2.816	3.66	4.467	2.256	2.463	4.157	4.369	5.325	3.778	4.142	4.032	2.302	4.521	4.047	4.717	3.81	3.236
57	44.938	2.366	3.001	4.322	5.519	3.155	3.925	6.179	6.759	6.977	4.406	5.082	5.769	3.89	6.855	5.408	6.101	5.499	4.819
58	51.471	2.523	3.215	5.05	6.725	4.317	5.992	8.59	9.724	8.589	5.096	6.118	8.011	6.278	9.571	7.09	7.694	7.699	7.068
59	58.953	2.722	3.385	5.682	7.751	5.498	8.255	10.645	12.373	9.559	5.706	6.994	10.205	9.144	11.823	8.722	9.073	9.956	9.68
60	67.523	2.929	3.429	6.028	8.145	6.226	9.798	11.39	13.484	9.39	6.062	7.394	11.408	11.542	12.649	9.701	9.682	11.453	11.826
61	77.339	3.115	3.278	5.968	7.622	6.031	9.765	10.42	12.48	8.095	6.031	7.118	10.955	12.395	11.679	9.544	9.189	11.489	12.519
62	88.583	3.268	2.924	5.527	6.319	4.873	8.161	8.246	9.953	6.2	5.598	6.23	9.091	11.398	9.421	8.284	7.765	10.049	11.408
63	101.46	3.383	2.417	4.833	4.681	3.25	5.817	5.782	7.018	4.315	4.854	4.995	6.664	9.173	6.77	6.404	5.915	7.751	9.034

64	116.21	3.47	1.85	4.059	3.169	1.806	3.654	3.717	4.53	2.819	3.963	3.731	4.462	6.679	4.458	4.506	4.156	5.397	6.376
65	133.103	3.499	1.31	3.302	2.004	0.852	2.078	2.251	2.751	1.775	3.057	2.629	2.807	4.509	2.749	2.943	2.747	3.465	4.109
66	152.453	3.419	0.859	2.612	1.211	0.352	1.094	1.312	1.607	1.102	2.233	1.767	1.701	2.876	1.62	1.821	1.742	2.096	2.476
67	174.616	3.189	0.528	2.017	0.718	0.135	0.55	0.756	0.927	0.691	1.557	1.151	1.018	1.77	0.936	1.094	1.084	1.227	1.435
68	200	2.787	0.309	1.517	0.429	0	0.272	0.441	0.542	0.449	1.046	0.739	0.617	1.074	0.543	0.653	0.673	0.714	0.823
69	229.075	2.24	0.176	1.106	0.263	0	0.137	0.267	0.329	0.305	0.683	0.475	0.384	0.653	0.325	0.396	0.424	0.423	0.478
70	262.376	1.62	0	0.772	0.167	0	0	0.169	0.209	0.216	0.436	0.307	0.248	0.402	0.202	0.246	0.273	0.258	0.286
71	300.518	1.046	0	0.513	0.111	0	0	0.113	0.139	0.159	0.275	0.2	0.166	0.252	0.132	0.159	0.181	0.165	0.178
72	344.206	0.617	0	0.329	0	0	0	0	0	0.12	0.175	0.135	0.117	0.165	0	0.108	0.125	0.112	0.118
73	394.244	0.352	0	0.212	0	0	0	0	0	0	0.117	0	0	0.116	0	0	0	0	0
74	451.556	0.209	0	0.145	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
75	517.2	0.136	0	0.109	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
76	592.387	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
77	678.504	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
78	777.141	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
79	890.116	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
80	1019.52	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
81	1167.73	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
82	1337.48	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
83	1531.91	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
84	1754.61	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
85	2000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 10.4 Raw particle size distribution data for samples 19 through 36.

Bin	Diameter (µm)	Sediment Sample ID																	
		19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36
1	0.022	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	0.026	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	0.029	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	0.034	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5	0.039	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6	0.044	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7	0.051	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8	0.058	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9	0.067	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10	0.076	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
11	0.087	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
12	0.1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
13	0.115	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
14	0.131	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
15	0.15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
16	0.172	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
17	0.197	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
18	0.226	0	0	0.104	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
19	0.259	0	0	0.172	0	0	0	0	0	0	0	0	0.105	0.116	0	0	0	0	0
20	0.296	0	0	0.279	0.14	0.101	0.103	0.103	0	0	0	0.149	0.155	0.171	0	0	0	0	0
21	0.339	0	0	0.431	0.194	0.138	0.141	0.133	0	0	0	0.221	0.22	0.241	0	0	0	0	0
22	0.389	0.119	0.116	0.611	0.249	0.18	0.181	0.163	0	0	0	0.313	0.292	0.315	0	0	0.126	0	0
23	0.445	0.131	0.138	0.752	0.285	0.216	0.21	0.183	0	0	0.101	0.4	0.344	0.365	0	0.106	0.147	0.109	0.113
24	0.51	0.143	0.162	0.903	0.32	0.257	0.24	0.202	0	0	0.112	0.503	0.396	0.415	0	0.122	0.17	0.118	0.133
25	0.584	0.141	0.178	0.919	0.322	0.28	0.248	0.203	0	0	0.115	0.554	0.399	0.414	0	0.134	0.185	0.121	0.145
26	0.669	0.135	0.192	0.884	0.311	0.295	0.245	0.198	0	0	0.114	0.578	0.383	0.394	0	0.143	0.195	0.122	0.153
27	0.766	0.126	0.204	0.805	0.291	0.301	0.233	0.187	0	0	0.109	0.575	0.352	0.36	0	0.148	0.2	0.12	0.157
28	0.877	0.116	0.211	0.699	0.272	0.299	0.221	0.174	0	0	0.105	0.537	0.314	0.32	0	0.159	0.211	0.122	0.156
29	1.005	0.107	0.216	0.606	0.261	0.297	0.213	0.163	0	0	0.103	0.489	0.282	0.287	0	0.177	0.23	0.127	0.153
30	1.151	0.101	0.216	0.533	0.262	0.293	0.212	0.155	0	0	0.104	0.436	0.259	0.263	0	0.205	0.26	0.137	0.149

31	1.318	0	0.218	0.488	0.275	0.299	0.221	0.15	0.104	0.104	0.11	0.402	0.248	0.251	0	0.25	0.309	0.153	0.148
32	1.51	0	0.217	0.476	0.313	0.311	0.247	0.152	0.118	0.117	0.123	0.377	0.253	0.255	0	0.327	0.391	0.182	0.149
33	1.729	0.11	0.217	0.519	0.394	0.34	0.307	0.165	0.141	0.14	0.152	0.376	0.287	0.286	0	0.467	0.54	0.234	0.156
34	1.981	0.119	0.213	0.556	0.487	0.365	0.374	0.176	0.166	0.166	0.184	0.369	0.32	0.316	0	0.648	0.725	0.293	0.16
35	2.269	0.136	0.21	0.644	0.629	0.397	0.481	0.195	0.199	0.202	0.235	0.38	0.384	0.37	0.114	0.91	0.987	0.373	0.17
36	2.599	0.154	0.205	0.727	0.786	0.422	0.601	0.214	0.235	0.24	0.292	0.383	0.451	0.422	0.127	1.229	1.295	0.462	0.178
37	2.976	0.179	0.203	0.855	0.995	0.451	0.767	0.239	0.279	0.287	0.37	0.398	0.548	0.495	0.145	1.639	1.686	0.566	0.191
38	3.409	0.211	0.204	1.009	1.228	0.475	0.959	0.27	0.326	0.339	0.46	0.417	0.663	0.579	0.165	2.072	2.095	0.667	0.208
39	3.905	0.249	0.21	1.177	1.484	0.497	1.173	0.304	0.378	0.395	0.56	0.437	0.792	0.669	0.187	2.53	2.524	0.766	0.228
40	4.472	0.297	0.219	1.403	1.84	0.53	1.472	0.348	0.446	0.469	0.697	0.464	0.963	0.79	0.214	3.203	3.151	0.902	0.253
41	5.122	0.352	0.24	1.571	2.086	0.547	1.68	0.395	0.506	0.533	0.798	0.488	1.103	0.88	0.242	3.532	3.452	0.963	0.289
42	5.867	0.423	0.264	1.796	2.439	0.576	1.973	0.456	0.587	0.618	0.936	0.521	1.288	1.004	0.278	4.055	3.927	1.058	0.332
43	6.72	0.504	0.297	1.968	2.724	0.606	2.2	0.526	0.67	0.705	1.049	0.557	1.444	1.112	0.317	4.341	4.169	1.114	0.388
44	7.697	0.594	0.329	2.126	2.98	0.612	2.412	0.59	0.748	0.786	1.161	0.575	1.601	1.207	0.355	4.561	4.351	1.142	0.442
45	8.816	0.707	0.38	2.217	3.216	0.675	2.567	0.706	0.861	0.905	1.249	0.64	1.722	1.314	0.413	4.562	4.297	1.189	0.543
46	10.097	0.825	0.427	2.26	3.37	0.715	2.666	0.817	0.963	1.012	1.318	0.686	1.817	1.392	0.468	4.433	4.129	1.201	0.646
47	11.565	0.964	0.481	2.289	3.528	0.774	2.761	0.959	1.086	1.141	1.388	0.748	1.909	1.478	0.535	4.279	3.935	1.225	0.78
48	13.246	1.124	0.542	2.298	3.666	0.854	2.839	1.139	1.23	1.293	1.454	0.828	1.993	1.565	0.615	4.065	3.692	1.257	0.952
49	15.172	1.268	0.598	2.203	3.596	0.958	2.793	1.348	1.368	1.435	1.472	0.925	1.998	1.603	0.703	3.599	3.246	1.283	1.156
50	17.377	1.437	0.658	2.122	3.568	1.088	2.771	1.609	1.535	1.608	1.5	1.043	2.015	1.655	0.807	3.218	2.876	1.323	1.415
51	19.904	1.604	0.715	2.009	3.475	1.262	2.715	1.932	1.72	1.798	1.516	1.193	2.003	1.692	0.927	2.812	2.493	1.38	1.735
52	22.797	1.797	0.78	1.951	3.45	1.551	2.742	2.399	1.979	2.062	1.574	1.43	2.036	1.775	1.089	2.513	2.221	1.519	2.175
53	26.111	2.006	0.857	1.959	3.465	2.024	2.863	3.063	2.334	2.412	1.684	1.803	2.12	1.91	1.305	2.295	2.044	1.781	2.765
54	29.907	2.272	0.982	2.106	3.587	2.823	3.181	4.031	2.871	2.915	1.907	2.417	2.326	2.156	1.624	2.213	2.023	2.277	3.571
55	34.255	2.649	1.211	2.433	3.809	4.076	3.743	5.329	3.673	3.624	2.295	3.375	2.714	2.566	2.107	2.266	2.178	3.131	4.614
56	39.234	3.297	1.665	2.995	4.161	5.869	4.606	6.951	4.894	4.663	2.95	4.79	3.407	3.242	2.893	2.481	2.55	4.496	5.973
57	44.938	4.395	2.521	3.782	4.602	8.021	5.681	8.691	6.6	6.107	3.965	6.637	4.502	4.274	4.129	2.858	3.146	6.36	7.643
58	51.471	5.947	3.914	4.674	4.996	10.09	6.707	10.14	8.572	7.801	5.304	8.663	5.921	5.597	5.817	3.315	3.859	8.44	9.358
59	58.953	7.796	5.895	5.477	5.179	11.31	7.301	10.70	10.24	9.325	6.799	10.24	7.389	6.986	7.73	3.744	4.512	10.06	10.53
60	67.523	9.465	8.199	5.955	5.017	11.05	7.143	9.995	10.88	10.09	8.092	10.67	8.401	8.025	9.374	4.003	4.846	10.52	10.58
61	77.339	10.31	10.19	5.955	4.479	9.377	6.211	8.228	10.12	9.739	8.773	9.721	8.49	8.327	10.23	3.973	4.676	9.599	9.411
62	88.583	9.956	11.21	5.505	3.671	6.985	4.817	6.032	8.269	8.36	8.634	7.824	7.586	7.806	10.13	3.627	4.02	7.735	7.454
63	101.46	8.535	10.95	4.749	2.764	4.665	3.376	4.008	6.01	6.441	7.753	5.661	6.031	6.67	9.202	3.019	3.074	5.61	5.338
64	116.21	6.604	9.654	3.88	1.929	2.878	2.189	2.478	3.983	4.54	6.445	3.777	4.346	5.288	7.777	2.28	2.106	3.756	3.529

65	133.103	4.682	7.737	3.022	1.256	1.685	1.344	1.461	2.464	2.979	5.008	2.379	2.896	3.949	6.17	1.554	1.304	2.373	2.198
66	152.453	3.093	5.675	2.256	0.772	0.962	0.802	0.843	1.459	1.857	3.669	1.447	1.823	2.817	4.613	0.959	0.742	1.445	1.319
67	174.616	1.943	3.848	1.627	0.457	0.551	0.477	0.489	0.85	1.127	2.561	0.872	1.11	1.947	3.269	0.542	0.396	0.868	0.781
68	200	1.183	2.444	1.14	0.265	0.326	0.289	0.293	0.501	0.681	1.718	0.531	0.669	1.315	2.207	0.288	0.204	0.526	0.468
69	229.075	0.712	1.48	0.779	0.154	0.203	0.182	0.184	0.305	0.418	1.118	0.333	0.407	0.874	1.43	0.148	0.105	0.327	0.289
70	262.376	0.43	0.866	0.519	0	0.133	0.12	0.122	0.193	0.264	0.71	0.216	0.252	0.573	0.895	0	0	0.211	0.186
71	300.518	0.263	0.501	0.34	0	0	0	0	0.129	0.173	0.444	0.146	0.162	0.372	0.548	0	0	0.142	0.125
72	344.206	0.168	0.296	0.222	0	0	0	0	0	0.119	0.28	0.104	0.109	0.244	0.338	0	0	0.102	0
73	394.244	0.117	0.188	0.152	0	0	0	0	0	0	0.186	0	0	0.167	0.219	0	0	0	0
74	451.556	0	0.133	0.112	0	0	0	0	0	0	0.135	0	0	0.124	0.155	0	0	0	0
75	517.2	0	0.106	0	0	0	0	0	0	0	0.107	0	0	0	0.123	0	0	0	0
76	592.387	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
77	678.504	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
78	777.141	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
79	890.116	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
80	1019.52	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
81	1167.73	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
82	1337.48	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
83	1531.91	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
84	1754.61	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
85	2000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 10.5 Raw particle size distribution data for samples 37 through 55.

Bin	Diameter (µm)	Sediment Sample ID																	
		37	38	39	40	41	42	43	44	45	46	47	49	50	51	52	53	54	55
1	0.022	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	0.026	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	0.029	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	0.034	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5	0.039	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6	0.044	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7	0.051	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8	0.058	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9	0.067	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10	0.076	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
11	0.087	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
12	0.1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
13	0.115	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
14	0.131	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
15	0.15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
16	0.172	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
17	0.197	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
18	0.226	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
19	0.259	0.134	0	0	0	0	0	0	0	0	0	0.148	0	0.114	0	0	0	0	0
20	0.296	0.241	0.139	0	0	0.113	0.139	0	0	0	0	0.257	0.153	0.198	0	0	0.138	0	0.108
21	0.339	0.418	0.208	0	0	0.172	0.215	0	0	0.115	0.133	0.432	0.227	0.332	0	0.14	0.199	0	0.138
22	0.389	0.685	0.296	0	0	0.258	0.325	0	0.117	0.153	0.188	0.694	0.318	0.532	0	0.195	0.272	0.121	0.165
23	0.445	0.998	0.39	0	0	0.372	0.467	0	0.135	0.186	0.25	1.037	0.412	0.777	0	0.252	0.341	0.146	0.178
24	0.51	1.415	0.503	0	0	0.528	0.658	0.107	0.154	0.224	0.327	1.52	0.522	1.112	0	0.321	0.42	0.174	0.19
25	0.584	1.715	0.601	0	0	0.732	0.884	0.124	0.163	0.247	0.401	2.045	0.617	1.395	0	0.379	0.477	0.197	0.183
26	0.669	1.942	0.691	0	0	0.977	1.139	0.139	0.167	0.261	0.47	2.614	0.7	1.643	0.114	0.431	0.522	0.217	0.17
27	0.766	2.069	0.771	0	0	1.271	1.424	0.152	0.166	0.265	0.535	3.216	0.769	1.832	0.136	0.476	0.554	0.234	0.154
28	0.877	2.041	0.848	0.148	0.114	1.645	1.75	0.164	0.161	0.264	0.592	3.766	0.847	1.891	0.165	0.517	0.579	0.249	0.137
29	1.005	1.949	0.929	0.228	0.152	2.102	2.123	0.175	0.156	0.262	0.647	4.266	0.944	1.873	0.202	0.56	0.606	0.264	0.125
30	1.151	1.785	1.001	0.34	0.199	2.562	2.466	0.182	0.151	0.261	0.687	4.529	1.054	1.751	0.246	0.597	0.628	0.275	0.117
31	1.318	1.708	1.122	0.526	0.27	3.259	2.988	0.194	0.15	0.271	0.758	4.982	1.237	1.7	0.311	0.663	0.676	0.295	0.113

32	1.51	1.643	1.261	0.776	0.36	4.013	3.538	0.206	0.152	0.292	0.831	5.274	1.494	1.623	0.392	0.742	0.738	0.315	0.116
33	1.729	1.683	1.467	1.095	0.471	4.945	4.256	0.222	0.162	0.337	0.936	5.623	1.918	1.607	0.503	0.869	0.84	0.344	0.13
34	1.981	1.677	1.65	1.482	0.598	5.848	4.924	0.234	0.169	0.383	1.026	5.774	2.379	1.55	0.624	0.986	0.93	0.367	0.144
35	2.269	1.741	1.832	1.773	0.694	6.511	5.49	0.243	0.181	0.452	1.108	5.75	2.933	1.525	0.753	1.125	1.027	0.388	0.169
36	2.599	1.752	1.97	2.045	0.785	6.978	5.901	0.249	0.19	0.519	1.161	5.531	3.473	1.459	0.883	1.247	1.1	0.402	0.195
37	2.976	1.821	2.114	2.196	0.838	7.256	6.259	0.253	0.202	0.61	1.21	5.317	4.075	1.435	1.021	1.398	1.179	0.417	0.231
38	3.409	1.897	2.242	2.212	0.849	7.201	6.438	0.254	0.214	0.713	1.234	5.069	4.618	1.426	1.157	1.564	1.253	0.432	0.271
39	3.905	1.977	2.384	2.202	0.85	6.991	6.524	0.256	0.226	0.827	1.251	4.813	5.124	1.43	1.313	1.758	1.332	0.453	0.316
40	4.472	2.111	2.61	2.284	0.879	7.155	6.944	0.261	0.242	0.982	1.304	4.785	5.918	1.467	1.534	2.032	1.454	0.483	0.374
41	5.122	2.198	2.812	2.225	0.858	6.408	6.62	0.266	0.257	1.107	1.306	4.42	6.167	1.511	1.761	2.319	1.559	0.524	0.416
42	5.867	2.34	3.117	2.262	0.867	6.007	6.583	0.276	0.276	1.28	1.345	4.237	6.689	1.589	2.083	2.718	1.718	0.579	0.471
43	6.72	2.451	3.444	2.282	0.869	5.056	5.922	0.291	0.3	1.436	1.374	3.751	6.834	1.68	2.454	3.156	1.893	0.655	0.512
44	7.697	2.491	3.68	2.191	0.834	4.423	5.566	0.293	0.314	1.583	1.347	3.443	6.905	1.71	2.815	3.583	2.013	0.712	0.553
45	8.816	2.594	4.12	2.31	0.875	2.924	3.925	0.332	0.359	1.731	1.42	2.466	6.472	1.87	3.347	4.12	2.287	0.861	0.577
46	10.097	2.593	4.398	2.288	0.872	1.953	2.807	0.359	0.396	1.844	1.427	1.779	5.902	1.948	3.818	4.561	2.478	0.993	0.593
47	11.565	2.6	4.717	2.313	0.888	1.215	1.86	0.399	0.447	1.96	1.457	1.197	5.279	2.054	4.362	5.03	2.716	1.169	0.608
48	13.246	2.597	5.018	2.341	0.911	0.691	1.122	0.451	0.512	2.069	1.5	0.739	4.567	2.174	4.933	5.467	2.976	1.39	0.62
49	15.172	2.476	4.932	2.279	0.93	0.303	0.512	0.523	0.6	2.091	1.524	0.355	3.448	2.233	5.142	5.43	3.106	1.627	0.625
50	17.377	2.376	4.902	2.246	0.958	0.132	0.231	0.611	0.71	2.125	1.563	0.168	2.627	2.312	5.411	5.434	3.277	1.924	0.63
51	19.904	2.243	4.721	2.204	0.998	0	0	0.73	0.857	2.124	1.612	0	1.887	2.375	5.498	5.219	3.402	2.274	0.633
52	22.797	2.17	4.529	2.227	1.085	0	0	0.915	1.083	2.164	1.737	0	1.321	2.51	5.508	4.936	3.572	2.74	0.66
53	26.111	2.155	4.25	2.305	1.236	0	0	1.204	1.436	2.25	1.964	0	0.884	2.729	5.337	4.518	3.744	3.323	0.726
54	29.907	2.263	3.936	2.489	1.504	0	0	1.673	2.014	2.462	2.385	0	0.574	3.123	5.059	4.071	3.967	4.066	0.884
55	34.255	2.515	3.555	2.794	1.953	0	0	2.424	2.935	2.868	3.079	0	0.36	3.731	4.706	3.628	4.243	4.956	1.221
56	39.234	2.949	3.145	3.267	2.691	0	0	3.621	4.373	3.603	4.15	0	0.219	4.581	4.415	3.284	4.658	6.049	1.907
57	44.938	3.538	2.705	3.923	3.815	0	0	5.405	6.422	4.767	5.587	0	0.132	5.538	4.215	3.043	5.226	7.309	3.17
58	51.471	4.145	2.233	4.675	5.306	0	0	7.708	8.905	6.263	7.178	0	0	6.305	4.004	2.821	5.783	8.497	5.154
59	58.953	4.554	1.734	5.375	6.971	0	0	10.041	11.152	7.774	8.435	0	0	6.443	3.695	2.557	6.078	9.185	7.706
60	67.523	4.523	1.247	5.821	8.404	0	0	11.554	12.238	8.733	8.786	0	0	5.674	3.244	2.216	5.853	9.002	10.146
61	77.339	3.96	0.825	5.845	9.174	0	0	11.614	11.668	8.659	8.003	0	0	4.208	2.673	1.811	5.03	7.916	11.572
62	88.583	3.017	0.506	5.407	9.089	0	0	10.305	9.763	7.544	6.406	0	0	2.627	2.062	1.385	3.811	6.274	11.527
63	101.46	1.977	0.29	4.567	8.227	0	0	8.213	7.277	5.806	4.555	0	0	1.394	1.49	0.987	2.533	4.523	10.192
64	116.21	1.11	0.157	3.497	6.874	0	0	6.013	4.933	4.015	2.933	0	0	0.642	1.015	0.657	1.485	3.017	8.167
65	133.103	0.537	0	2.408	5.338	0	0	4.119	3.102	2.547	1.747	0	0	0.266	0.658	0.41	0.779	1.894	6.02
66	152.453	0.23	0	1.495	3.884	0	0	2.69	1.852	1.524	0.989	0	0	0.105	0.413	0.245	0.376	1.145	4.133

67	174.616	0	0	0.849	2.68	0	0	1.707	1.077	0.888	0.549	0	0	0	0.258	0.144	0.174	0.683	2.68
68	200	0	0	0.452	1.776	0	0	1.069	0.626	0.518	0.307	0	0	0	0.163	0	0	0.411	1.668
69	229.075	0	0	0.234	1.148	0	0	0.671	0.373	0.312	0.178	0	0	0	0.107	0	0	0.255	1.016
70	262.376	0	0	0.122	0.727	0	0	0.425	0.23	0.196	0.108	0	0	0	0	0	0	0.165	0.613
71	300.518	0	0	0	0.456	0	0	0.273	0.15	0.129	0	0	0	0	0	0	0	0.112	0.371
72	344.206	0	0	0	0.29	0	0	0.181	0.104	0	0	0	0	0	0	0	0	0	0.232
73	394.244	0	0	0	0.195	0	0	0.129	0	0	0	0	0	0	0	0	0	0	0.155
74	451.556	0	0	0	0.143	0	0	0.101	0	0	0	0	0	0	0	0	0	0	0.115
75	517.2	0	0	0	0.115	0	0	0	0	0	0	0	0	0	0	0	0	0	0
76	592.387	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
77	678.504	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
78	777.141	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
79	890.116	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
80	1019.52	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
81	1167.73	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
82	1337.48	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
83	1531.91	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
84	1754.61	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
85	2000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 10.6 Raw particle size distribution data for samples 56 through 73.

Bin	Diameter (µm)	Sediment Sample ID																	
		56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73
1	0.022	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	0.026	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	0.029	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	0.034	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5	0.039	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6	0.044	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7	0.051	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8	0.058	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9	0.067	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10	0.076	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
11	0.087	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
12	0.1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
13	0.115	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
14	0.131	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
15	0.15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
16	0.172	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
17	0.197	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
18	0.226	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.115	0.158
19	0.259	0	0.122	0	0.143	0	0	0	0	0	0	0	0	0	0	0.128	0	0.211	0.279
20	0.296	0	0.18	0	0.22	0	0	0	0	0	0	0	0	0	0.102	0.199	0	0.398	0.491
21	0.339	0	0.254	0.127	0.323	0	0.125	0	0	0	0	0	0	0	0.153	0.296	0	0.723	0.823
22	0.389	0.115	0.329	0.158	0.439	0	0.168	0	0	0	0.123	0	0.103	0.118	0.22	0.405	0	1.207	1.277
23	0.445	0.126	0.375	0.178	0.53	0	0.213	0	0	0	0.158	0	0.13	0.134	0.296	0.498	0.125	1.742	1.742
24	0.51	0.135	0.416	0.197	0.624	0.115	0.266	0	0	0	0.2	0	0.162	0.149	0.391	0.598	0.162	2.408	2.311
25	0.584	0.133	0.407	0.197	0.659	0.139	0.318	0	0	0.124	0.248	0	0.191	0.151	0.489	0.653	0.205	2.742	2.652
26	0.669	0.128	0.381	0.189	0.666	0.163	0.37	0	0	0.16	0.298	0.104	0.218	0.149	0.59	0.686	0.25	2.875	2.873
27	0.766	0.12	0.341	0.176	0.649	0.187	0.419	0	0.103	0.204	0.351	0.122	0.241	0.142	0.694	0.699	0.299	2.816	2.964
28	0.877	0.111	0.304	0.163	0.63	0.225	0.482	0	0.124	0.268	0.422	0.151	0.269	0.134	0.814	0.718	0.365	2.558	2.913
29	1.005	0.103	0.277	0.153	0.623	0.279	0.561	0.101	0.153	0.357	0.513	0.191	0.303	0.128	0.957	0.754	0.452	2.282	2.827
30	1.151	0	0.265	0.149	0.632	0.352	0.65	0.152	0.192	0.47	0.619	0.246	0.343	0.125	1.1	0.81	0.558	2.013	2.7
31	1.318	0	0.266	0.151	0.673	0.47	0.787	0.241	0.253	0.648	0.78	0.333	0.406	0.126	1.322	0.911	0.725	1.869	2.684

32	1.51	0	0.292	0.163	0.757	0.651	0.966	0.391	0.343	0.89	0.991	0.46	0.494	0.133	1.579	1.076	0.954	1.814	2.735
33	1.729	0	0.361	0.193	0.928	0.956	1.23	0.646	0.487	1.244	1.302	0.662	0.637	0.15	1.93	1.371	1.306	1.981	3.009
34	1.981	0.104	0.438	0.225	1.104	1.355	1.516	1.023	0.67	1.675	1.651	0.92	0.797	0.167	2.268	1.687	1.722	2.09	3.202
35	2.269	0.113	0.568	0.276	1.345	1.879	1.809	1.481	0.901	2.133	2.025	1.227	0.994	0.193	2.558	2.079	2.185	2.42	3.55
36	2.599	0.121	0.713	0.331	1.58	2.494	2.081	2.056	1.166	2.608	2.394	1.574	1.198	0.218	2.779	2.467	2.659	2.72	3.811
37	2.976	0.133	0.918	0.404	1.864	3.228	2.34	2.641	1.474	3.079	2.775	1.949	1.431	0.248	2.944	2.89	3.132	3.203	4.224
38	3.409	0.146	1.167	0.485	2.15	3.955	2.54	3.086	1.772	3.451	3.106	2.279	1.647	0.279	3.01	3.26	3.477	3.834	4.69
39	3.905	0.161	1.454	0.574	2.446	4.702	2.717	3.466	2.082	3.794	3.432	2.598	1.857	0.309	3.052	3.595	3.755	4.547	5.152
40	4.472	0.179	1.857	0.692	2.862	5.826	3.011	4.063	2.535	4.348	3.938	3.075	2.166	0.349	3.205	4.108	4.225	5.602	5.915
41	5.122	0.197	2.185	0.786	3.148	6.364	3.109	4.125	2.798	4.539	4.205	3.284	2.302	0.377	3.192	4.249	4.229	6.299	6.123
42	5.867	0.219	2.646	0.912	3.576	7.276	3.333	4.396	3.215	4.948	4.664	3.658	2.538	0.416	3.295	4.558	4.419	7.302	6.561
43	6.72	0.244	3.066	1.032	3.958	7.772	3.485	4.437	3.535	5.179	4.999	3.908	2.677	0.452	3.35	4.659	4.391	7.52	6.242
44	7.697	0.264	3.491	1.139	4.249	8.232	3.509	4.309	3.79	5.264	5.224	4.045	2.755	0.479	3.265	4.63	4.215	8.37	6.372
45	8.816	0.304	3.892	1.287	4.685	8.006	3.691	4.283	4.05	5.351	5.43	4.253	2.813	0.529	3.38	4.557	4.075	6.264	4.437
46	10.097	0.341	4.225	1.414	4.956	7.597	3.695	4.051	4.166	5.205	5.419	4.28	2.773	0.568	3.311	4.31	3.763	4.9	3.208
47	11.565	0.387	4.57	1.565	5.265	7.052	3.734	3.868	4.284	5.057	5.386	4.328	2.734	0.617	3.28	4.074	3.491	3.454	2.1
48	13.246	0.446	4.894	1.74	5.556	6.295	3.759	3.672	4.352	4.832	5.259	4.337	2.668	0.675	3.24	3.809	3.212	2.167	1.229
49	15.172	0.522	4.89	1.896	5.424	4.715	3.578	3.297	4.104	4.237	4.687	4.059	2.46	0.732	3.028	3.341	2.801	0.969	0.526
50	17.377	0.616	4.945	2.089	5.38	3.592	3.448	3.007	3.914	3.753	4.215	3.85	2.288	0.801	2.863	2.96	2.469	0.427	0.221
51	19.904	0.737	4.877	2.3	5.196	2.541	3.274	2.716	3.638	3.222	3.653	3.579	2.09	0.88	2.665	2.569	2.149	0.156	0
52	22.797	0.92	4.854	2.62	5.039	1.706	3.182	2.536	3.413	2.78	3.158	3.382	1.952	0.996	2.538	2.289	1.939	0	0
53	26.111	1.202	4.815	3.072	4.801	1.045	3.138	2.436	3.198	2.391	2.693	3.212	1.863	1.158	2.454	2.094	1.82	0	0
54	29.907	1.663	4.815	3.747	4.479	0.569	3.194	2.457	3.058	2.1	2.321	3.117	1.876	1.392	2.454	2.032	1.839	0	0
55	34.255	2.415	4.796	4.681	3.952	0.261	3.328	2.584	2.993	1.894	2.04	3.074	2.013	1.724	2.522	2.091	2.009	0	0
56	39.234	3.644	4.755	5.931	3.214	0	3.546	2.821	3.051	1.785	1.869	3.11	2.333	2.219	2.671	2.269	2.364	0	0
57	44.938	5.515	4.612	7.414	2.326	0	3.799	3.136	3.233	1.761	1.786	3.219	2.887	2.969	2.892	2.51	2.889	0	0
58	51.471	7.97	4.28	8.823	1.5	0	3.962	3.434	3.45	1.764	1.72	3.328	3.643	4.017	3.117	2.702	3.463	0	0
59	58.953	10.491	3.702	9.61	0.848	0	3.894	3.609	3.617	1.751	1.615	3.362	4.538	5.362	3.268	2.724	3.895	0	0
60	67.523	12.163	2.926	9.31	0.419	0	3.499	3.561	3.647	1.677	1.429	3.256	5.416	6.901	3.249	2.486	3.952	0	0
61	77.339	12.262	2.095	7.927	0.184	0	2.81	3.256	3.49	1.511	1.151	2.977	6.046	8.407	2.987	2.01	3.521	0	0
62	88.583	10.822	1.362	5.963	0	0	1.997	2.744	3.156	1.257	0.823	2.551	6.212	9.565	2.483	1.428	2.722	0	0
63	101.46	8.481	0.811	4.013	0	0	1.251	2.123	2.685	0.948	0.513	2.031	5.782	10.012	1.82	0.892	1.819	0	0
64	116.21	6.036	0.449	2.471	0	0	0.697	1.511	2.152	0.639	0.28	1.497	4.829	9.538	1.155	0.497	1.062	0	0
65	133.103	3.981	0.237	1.427	0	0	0.352	0.993	1.624	0.385	0.137	1.019	3.592	8.191	0.631	0.252	0.552	0	0
66	152.453	2.486	0.123	0.797	0	0	0.167	0.61	1.159	0.21	0	0.646	2.383	6.33	0.301	0.121	0.264	0	0

67	174.616	1.503	0	0.445	0	0	0	0.358	0.79	0.108	0	0.389	1.427	4.433	0.132	0	0.122	0	0
68	200	0.899	0	0.255	0	0	0	0.204	0.518	0	0	0.227	0.786	2.846	0	0	0	0	0
69	229.075	0.543	0	0.155	0	0	0	0.117	0.33	0	0	0.132	0.411	1.711	0	0	0	0	0
70	262.376	0.335	0	0	0	0	0	0	0.207	0	0	0	0.211	0.982	0	0	0	0	0
71	300.518	0.214	0	0	0	0	0	0	0.129	0	0	0	0.112	0.554	0	0	0	0	0
72	344.206	0.144	0	0	0	0	0	0	0	0	0	0	0	0.32	0	0	0	0	0
73	394.244	0.105	0	0	0	0	0	0	0	0	0	0	0	0.199	0	0	0	0	0
74	451.556	0	0	0	0	0	0	0	0	0	0	0	0	0.139	0	0	0	0	0
75	517.2	0	0	0	0	0	0	0	0	0	0	0	0	0.11	0	0	0	0	0
76	592.387	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
77	678.504	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
78	777.141	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
79	890.116	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
80	1019.52	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
81	1167.73	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
82	1337.48	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
83	1531.91	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
84	1754.61	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
85	2000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 10.7 Raw particle size distribution data for samples 74 through 91.

Bin	Diameter	Sediment Sample ID																	
		74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91
1	0.022	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	0.026	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	0.029	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	0.034	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5	0.039	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6	0.044	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7	0.051	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8	0.058	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9	0.067	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10	0.076	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
11	0.087	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
12	0.1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
13	0.115	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
14	0.131	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
15	0.15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
16	0.172	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
17	0.197	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
18	0.226	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
19	0.259	0	0	0.11	0	0.129	0.131	0	0.119	0	0	0	0	0	0	0	0	0	0
20	0.296	0	0.106	0.166	0.115	0.202	0.216	0.138	0.191	0.124	0.125	0.107	0.117	0.127	0.114	0.108	0	0	0
21	0.339	0.155	0.155	0.242	0.163	0.305	0.341	0.204	0.293	0.167	0.17	0.146	0.152	0.173	0.164	0.155	0.143	0	0
22	0.389	0.238	0.218	0.33	0.221	0.435	0.512	0.286	0.424	0.212	0.217	0.188	0.187	0.223	0.22	0.211	0.199	0	0
23	0.445	0.351	0.292	0.416	0.284	0.575	0.711	0.373	0.562	0.243	0.25	0.223	0.21	0.265	0.266	0.267	0.259	0.121	0.107
24	0.51	0.51	0.385	0.513	0.358	0.743	0.966	0.475	0.729	0.274	0.283	0.261	0.233	0.309	0.316	0.33	0.329	0.145	0.117
25	0.584	0.714	0.492	0.596	0.442	0.907	1.22	0.572	0.876	0.282	0.292	0.28	0.238	0.337	0.341	0.379	0.393	0.165	0.122
26	0.669	0.96	0.608	0.671	0.531	1.07	1.476	0.665	1.013	0.281	0.289	0.289	0.238	0.356	0.351	0.421	0.452	0.182	0.123
27	0.766	1.255	0.735	0.736	0.628	1.233	1.729	0.755	1.138	0.271	0.278	0.291	0.232	0.369	0.348	0.454	0.505	0.197	0.121
28	0.877	1.606	0.9	0.821	0.765	1.432	1.996	0.861	1.27	0.261	0.267	0.289	0.227	0.382	0.346	0.488	0.561	0.211	0.12
29	1.005	2.012	1.108	0.936	0.95	1.678	2.292	0.992	1.42	0.256	0.261	0.289	0.225	0.4	0.351	0.528	0.626	0.228	0.122
30	1.151	2.373	1.341	1.077	1.18	1.948	2.558	1.135	1.565	0.257	0.263	0.292	0.227	0.422	0.367	0.57	0.694	0.244	0.128
31	1.318	2.918	1.699	1.299	1.533	2.365	2.987	1.358	1.8	0.268	0.275	0.306	0.237	0.462	0.404	0.641	0.803	0.27	0.138

32	1.51	3.432	2.146	1.614	2.012	2.89	3.462	1.641	2.082	0.295	0.304	0.331	0.256	0.517	0.474	0.735	0.945	0.302	0.158
33	1.729	3.998	2.771	2.112	2.718	3.646	4.118	2.055	2.493	0.35	0.365	0.381	0.293	0.606	0.614	0.887	1.168	0.348	0.194
34	1.981	4.474	3.441	2.665	3.528	4.418	4.709	2.479	2.874	0.407	0.429	0.428	0.328	0.692	0.775	1.035	1.397	0.393	0.233
35	2.269	4.706	4.064	3.274	4.33	5.126	5.179	2.887	3.214	0.486	0.518	0.489	0.371	0.783	1.018	1.211	1.667	0.438	0.29
36	2.599	4.768	4.61	3.866	5.106	5.723	5.472	3.234	3.46	0.565	0.608	0.544	0.41	0.862	1.285	1.373	1.92	0.477	0.351
37	2.976	4.711	5.062	4.446	5.769	6.183	5.649	3.533	3.654	0.662	0.718	0.608	0.453	0.937	1.644	1.562	2.217	0.515	0.429
38	3.409	4.521	5.309	4.88	6.151	6.36	5.621	3.722	3.745	0.763	0.832	0.67	0.494	0.999	2.049	1.756	2.514	0.545	0.514
39	3.905	4.332	5.469	5.231	6.388	6.396	5.512	3.872	3.802	0.867	0.947	0.732	0.535	1.056	2.495	1.971	2.832	0.574	0.607
40	4.472	4.31	5.871	5.834	6.931	6.716	5.629	4.175	4.001	1.011	1.107	0.818	0.59	1.146	3.144	2.28	3.304	0.618	0.733
41	5.122	4.137	5.763	5.853	6.683	6.315	5.296	4.222	3.969	1.101	1.205	0.876	0.63	1.189	3.574	2.557	3.651	0.647	0.831
42	5.867	4.116	5.897	6.115	6.731	6.183	5.18	4.433	4.078	1.232	1.348	0.961	0.688	1.268	4.213	2.953	4.172	0.695	0.964
43	6.72	4.061	5.789	6.061	6.386	5.676	4.852	4.554	4.1	1.334	1.458	1.039	0.746	1.336	4.689	3.354	4.622	0.746	1.085
44	7.697	3.842	5.526	5.866	5.936	5.156	4.445	4.5	3.967	1.413	1.542	1.091	0.783	1.358	5.141	3.72	5.016	0.771	1.195
45	8.816	3.85	5.221	5.516	5.248	4.288	3.936	4.65	3.989	1.502	1.634	1.195	0.877	1.468	5.358	4.17	5.343	0.87	1.326
46	10.097	3.646	4.726	4.994	4.478	3.47	3.355	4.562	3.811	1.55	1.679	1.262	0.945	1.519	5.434	4.496	5.49	0.939	1.432
47	11.565	3.481	4.259	4.492	3.775	2.747	2.827	4.51	3.663	1.604	1.729	1.346	1.034	1.594	5.452	4.835	5.594	1.034	1.553
48	13.246	3.294	3.759	3.959	3.096	2.093	2.317	4.424	3.495	1.654	1.771	1.441	1.142	1.682	5.364	5.131	5.587	1.152	1.684
49	15.172	2.89	2.992	3.176	2.268	1.389	1.686	4.026	3.128	1.647	1.736	1.505	1.251	1.739	4.835	5.007	5.067	1.275	1.778
50	17.377	2.563	2.409	2.573	1.677	0.928	1.237	3.715	2.827	1.653	1.717	1.587	1.384	1.816	4.397	4.925	4.627	1.427	1.894
51	19.904	2.214	1.864	2.012	1.186	0.583	0.864	3.346	2.504	1.644	1.675	1.669	1.539	1.899	3.861	4.673	4.052	1.612	2.008
52	22.797	1.928	1.437	1.581	0.834	0.358	0.594	3.045	2.26	1.682	1.669	1.807	1.776	2.057	3.406	4.402	3.518	1.89	2.195
53	26.111	1.674	1.089	1.237	0.577	0.211	0.396	2.754	2.067	1.774	1.693	2.01	2.119	2.31	3	4.063	3	2.288	2.479
54	29.907	1.466	0.822	0.988	0.402	0.123	0.26	2.494	1.962	1.983	1.79	2.341	2.649	2.739	2.717	3.744	2.579	2.879	2.951
55	34.255	1.269	0.608	0.804	0.28	0	0.167	2.217	1.923	2.365	1.99	2.856	3.431	3.403	2.548	3.456	2.251	3.693	3.685
56	39.234	1.061	0.437	0.67	0.197	0	0.104	1.919	1.943	3.022	2.38	3.672	4.574	4.395	2.507	3.26	2.033	4.79	4.786
57	44.938	0.829	0.3	0.57	0.14	0	0	1.601	1.975	4.032	3.055	4.879	6.108	5.704	2.559	3.147	1.9	6.153	6.243
58	51.471	0.598	0.196	0.482	0	0	0	1.274	1.947	5.335	4.02	6.387	7.849	7.12	2.604	3.029	1.785	7.61	7.819
59	58.953	0.39	0.121	0.398	0	0	0	0.949	1.796	6.714	5.212	7.889	9.326	8.208	2.561	2.835	1.644	8.773	9.032
60	67.523	0.226	0	0.314	0	0	0	0.649	1.496	7.778	6.407	8.868	9.944	8.481	2.367	2.516	1.45	9.208	9.362
61	77.339	0.117	0	0.234	0	0	0	0.402	1.097	8.156	7.264	8.896	9.398	7.763	2.018	2.08	1.204	8.724	8.629
62	88.583	0	0	0.164	0	0	0	0.225	0.698	7.744	7.523	7.969	7.92	6.339	1.575	1.589	0.932	7.51	7.123
63	101.46	0	0	0.108	0	0	0	0.116	0.388	6.713	7.127	6.441	6.03	4.685	1.124	1.12	0.669	5.94	5.334
64	116.21	0	0	0	0	0	0	0	0.192	5.399	6.254	4.79	4.237	3.206	0.739	0.73	0.445	4.39	3.695
65	133.103	0	0	0	0	0	0	0	0	4.084	5.134	3.336	2.8	2.073	0.453	0.444	0.278	3.078	2.412
66	152.453	0	0	0	0	0	0	0	0	2.937	3.971	2.212	1.776	1.293	0.265	0.257	0.165	2.08	1.514

67	174.616	0	0	0	0	0	0	0	0	2.028	2.908	1.422	1.102	0.795	0.151	0.146	0	1.378	0.935
68	200	0	0	0	0	0	0	0	0	1.354	2.018	0.897	0.682	0.491	0	0	0	0.906	0.578
69	229.075	0	0	0	0	0	0	0	0	0.882	1.332	0.564	0.428	0.31	0	0	0	0.598	0.365
70	262.376	0	0	0	0	0	0	0	0	0.561	0.837	0.355	0.274	0.201	0	0	0	0.396	0.237
71	300.518	0	0	0	0	0	0	0	0	0.351	0.505	0.225	0.179	0.135	0	0	0	0.264	0.159
72	344.206	0	0	0	0	0	0	0	0	0.221	0.302	0.147	0.123	0	0	0	0	0.18	0.111
73	394.244	0	0	0	0	0	0	0	0	0.146	0.188	0.103	0	0	0	0	0	0.129	0
74	451.556	0	0	0	0	0	0	0	0	0.106	0.128	0	0	0	0	0	0	0	0
75	517.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
76	592.387	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
77	678.504	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
78	777.141	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
79	890.116	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
80	1019.52	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
81	1167.73	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
82	1337.48	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
83	1531.91	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
84	1754.61	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
85	2000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 10.8 Raw particle size distribution data for samples 92 through 106.

Bin	Diameter	Sediment Sample ID														
		92	93	94	95	96	97	98	99	100	101	102	103	104	105	106
1	0.022	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	0.026	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	0.029	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	0.034	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5	0.039	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6	0.044	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7	0.051	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8	0.058	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9	0.067	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10	0.076	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
11	0.087	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
12	0.1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
13	0.115	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
14	0.131	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
15	0.15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
16	0.172	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
17	0.197	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
18	0.226	0	0	0	0	0.128	0	0	0	0	0	0	0	0	0	0
19	0.259	0	0	0.113	0.126	0.214	0.103	0	0.139	0.157	0.105	0	0.103	0	0	0
20	0.296	0	0	0.175	0.212	0.364	0.165	0	0.223	0.263	0.152	0	0.167	0	0	0.113
21	0.339	0.105	0.11	0.26	0.342	0.591	0.253	0.129	0.342	0.419	0.214	0	0.262	0	0	0.173
22	0.389	0.127	0.139	0.362	0.519	0.894	0.37	0.234	0.49	0.616	0.283	0	0.385	0	0	0.259
23	0.445	0.143	0.163	0.454	0.714	1.22	0.499	0.409	0.638	0.793	0.342	0.114	0.515	0	0	0.372
24	0.51	0.159	0.187	0.559	0.959	1.623	0.661	0.689	0.811	0.992	0.406	0.138	0.671	0.102	0	0.524
25	0.584	0.164	0.2	0.616	1.163	1.95	0.816	1.066	0.942	1.078	0.435	0.162	0.789	0.113	0	0.717
26	0.669	0.165	0.207	0.648	1.342	2.231	0.963	1.52	1.048	1.109	0.452	0.186	0.884	0.122	0	0.948
27	0.766	0.162	0.209	0.654	1.49	2.454	1.097	2.044	1.123	1.086	0.457	0.21	0.952	0.129	0	1.225
28	0.877	0.157	0.208	0.643	1.608	2.64	1.24	2.563	1.196	1.033	0.451	0.243	0.998	0.141	0	1.573
29	1.005	0.154	0.209	0.631	1.719	2.826	1.399	3.068	1.283	0.987	0.445	0.286	1.042	0.159	0	1.996
30	1.151	0.152	0.212	0.618	1.793	2.973	1.555	3.384	1.375	0.951	0.437	0.34	1.072	0.184	0.123	2.414
31	1.318	0.154	0.222	0.63	1.955	3.268	1.813	3.947	1.547	0.963	0.441	0.422	1.154	0.225	0.164	3.042

32	1.51	0.159	0.239	0.661	2.138	3.639	2.139	4.407	1.791	1.024	0.454	0.533	1.262	0.287	0.229	3.688
33	1.729	0.173	0.272	0.741	2.436	4.262	2.643	5.064	2.209	1.193	0.492	0.701	1.46	0.392	0.337	4.434
34	1.981	0.184	0.303	0.81	2.678	4.813	3.154	5.573	2.634	1.349	0.52	0.891	1.635	0.52	0.482	5.104
35	2.269	0.198	0.342	0.902	2.905	5.37	3.697	6.068	3.132	1.583	0.56	1.101	1.845	0.688	0.675	5.494
36	2.599	0.209	0.377	0.975	3.034	5.765	4.158	6.382	3.58	1.791	0.592	1.314	2.012	0.879	0.91	5.702
37	2.976	0.221	0.418	1.064	3.152	6.124	4.62	6.602	4.063	2.056	0.634	1.536	2.209	1.107	1.195	5.727
38	3.409	0.231	0.456	1.151	3.21	6.281	4.964	6.627	4.472	2.315	0.682	1.728	2.392	1.337	1.493	5.541
39	3.905	0.242	0.495	1.234	3.248	6.271	5.236	6.503	4.83	2.564	0.736	1.919	2.577	1.576	1.818	5.336
40	4.472	0.256	0.549	1.36	3.402	6.57	5.749	6.707	5.418	2.928	0.81	2.203	2.864	1.921	2.295	5.346
41	5.122	0.269	0.587	1.432	3.391	5.965	5.746	6.041	5.535	3.089	0.886	2.369	3.048	2.123	2.601	5.092
42	5.867	0.288	0.641	1.549	3.494	5.649	5.979	5.667	5.874	3.361	0.986	2.638	3.343	2.432	3.068	5.031
43	6.72	0.312	0.694	1.648	3.533	4.777	5.921	4.737	5.926	3.504	1.089	2.861	3.59	2.658	3.441	4.839
44	7.697	0.324	0.73	1.697	3.442	4.194	5.74	4.131	5.858	3.565	1.179	3.012	3.745	2.843	3.778	4.545
45	8.816	0.376	0.807	1.823	3.481	2.783	5.361	2.667	5.571	3.575	1.295	3.238	3.971	2.99	4.06	4.201
46	10.097	0.419	0.862	1.879	3.348	1.871	4.829	1.75	5.118	3.46	1.38	3.336	4.036	3.042	4.219	3.724
47	11.565	0.478	0.931	1.955	3.238	1.173	4.304	1.066	4.654	3.34	1.47	3.447	4.102	3.086	4.366	3.267
48	13.246	0.557	1.013	2.034	3.108	0.676	3.742	0.592	4.136	3.189	1.556	3.528	4.125	3.091	4.448	2.787
49	15.172	0.662	1.088	2.046	2.807	0.304	2.908	0.256	3.31	2.866	1.567	3.374	3.848	2.885	4.177	2.093
50	17.377	0.795	1.18	2.077	2.557	0.136	2.282	0.109	2.674	2.596	1.586	3.26	3.621	2.719	3.965	1.584
51	19.904	0.975	1.282	2.094	2.282	0	1.712	0	2.072	2.301	1.569	3.073	3.309	2.499	3.651	1.134
52	22.797	1.251	1.441	2.173	2.074	0	1.273	0	1.598	2.088	1.56	2.923	3.041	2.321	3.377	0.789
53	26.111	1.668	1.674	2.317	1.915	0	0.925	0	1.214	1.94	1.553	2.777	2.783	2.164	3.103	0.523
54	29.907	2.305	2.048	2.593	1.844	0	0.668	0	0.926	1.912	1.588	2.692	2.59	2.071	2.896	0.335
55	34.255	3.209	2.632	3.031	1.863	0	0.476	0	0.705	2.017	1.695	2.672	2.454	2.044	2.755	0.204
56	39.234	4.445	3.558	3.693	1.988	0	0.335	0	0.534	2.292	1.945	2.765	2.399	2.113	2.731	0.12
57	44.938	6.012	4.925	4.579	2.208	0	0.234	0	0.398	2.743	2.416	2.988	2.419	2.291	2.839	0
58	51.471	7.751	6.652	5.553	2.439	0	0.161	0	0.287	3.292	3.119	3.277	2.456	2.532	3.013	0
59	58.953	9.227	8.393	6.358	2.576	0	0.108	0	0.197	3.813	4.051	3.573	2.462	2.805	3.209	0
60	67.523	9.941	9.567	6.689	2.495	0	0	0	0.127	4.111	5.121	3.804	2.392	3.07	3.372	0
61	77.339	9.676	9.723	6.393	2.144	0	0	0	0	4.008	6.144	3.919	2.218	3.299	3.459	0
62	88.583	8.63	8.871	5.586	1.603	0	0	0	0	3.469	6.926	3.9	1.945	3.487	3.436	0
63	101.46	7.17	7.366	4.513	1.034	0	0	0	0	2.627	7.293	3.734	1.596	3.638	3.27	0
64	116.21	5.651	5.675	3.431	0.578	0	0	0	0	1.73	7.161	3.416	1.216	3.769	2.952	0
65	133.103	4.271	4.116	2.487	0.286	0	0	0	0	0.995	6.523	2.94	0.854	3.87	2.497	0
66	152.453	3.122	2.847	1.739	0.13	0	0	0	0	0.511	5.494	2.338	0.553	3.913	1.963	0

67	174.616	2.221	1.898	1.187	0	0	0	0	0	0.243	4.277	1.694	0.334	3.844	1.428	0
68	200	1.54	1.232	0.797	0	0	0	0	0	0.112	3.087	1.109	0.191	3.577	0.957	0
69	229.075	1.045	0.788	0.532	0	0	0	0	0	0	2.086	0.66	0.107	3.064	0.594	0
70	262.376	0.692	0.498	0.353	0	0	0	0	0	0	1.328	0.363	0	2.341	0.346	0
71	300.518	0.449	0.315	0.233	0	0	0	0	0	0	0.81	0.192	0	1.573	0.194	0
72	344.206	0.293	0.203	0.156	0	0	0	0	0	0	0.49	0.105	0	0.943	0.112	0
73	394.244	0.198	0.139	0.109	0	0	0	0	0	0	0.308	0	0	0.532	0	0
74	451.556	0.145	0.105	0	0	0	0	0	0	0	0.208	0	0	0.303	0	0
75	517.2	0.117	0	0	0	0	0	0	0	0	0.154	0	0	0.187	0	0
76	592.387	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
77	678.504	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
78	777.141	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
79	890.116	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
80	1019.52	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
81	1167.73	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
82	1337.48	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
83	1531.91	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
84	1754.61	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
85	2000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Appendix D: Radiometric Age Data

Two optically stimulated luminescence samples were collected from the DM-8 trench in 2008. The samples were collected from the trench profile at night under multiple layers of thick black plastic. The outer 15-20 cm of the profile was scraped away before taking a ~300 g sample and placing it in a pouch made of multiple layers of thick black plastic. Additional samples were obtained from the same layer, as well as the layers above and below, for dosimetry measurements and water content estimates. The samples were processed at the Radiation Dosimetry Laboratory at Oklahoma State University. The following procedures are summarized from an unpublished report prepared by Dr. Regina DeWitt for DMAPP in 2009.

Samples were sieved then treated with 3.75 % HCl and H_2O_2 to remove carbonates and organic matter, respectively. To remove the surface of grains affected by alpha-radiation, samples were treated 40% HF for 50 minutes followed by an HCl treatment to remove any fluoride precipitates that formed in the process. The samples were then rinsed with deionized water and dried. The quartz fraction was isolated by density separation using sodium polytungstate. Small aliquots of quartz grains were prepared for the most abundant grain size and fixed to stainless steel cups using silicone spray. OSL measurements were conducted using Risø TL/OSL-DA-15 reader from Risø National Laboratory, equipped with a bialkali PM tube (Thorn EMI 9635QB) and Hoya U-340 filters (290-370 nm). The built-in $^{90}Sr/^{90}Y$ beta source gives a dose rate of 105.7 mGy/s (error 4.1 %). Optical stimulation was carried out with blue LEDs (470 nm), delivering 45 mW/cm^2 to the sample. Infrared (IR) stimulation was from an IR LED array at 875 ± 80 nm with 36 mW/cm^2 power at the sample. The heating rate used was 5 °C/s. The measurement procedure was based on the single aliquot regenerative-dose (SAR) procedure described by Murray and Wintle (2000) and Wintle and Murray (2006).

The dosimetry samples were weighed, dried, and then weighed again in order to calculate the water content. The water content was 4-7%, and an error of

2% was used for calculation of the dose rate. The dry dosimetry samples were stored in air-tight plastic containers for 4 weeks and then the thorium, uranium, and potassium concentrations were measured using low level gamma spectrometry. An error of 5% was assumed for the cosmic dose rate. Samples had unusually large concentrations of uranium and since the saturation of the OSL signal only allows for a minimum age estimate (in calendar years before 2008); the maximum possible uranium concentration was used to calculate the dose rate.

Table 10.9 OSL Age Determinations

Sample	Minimum Equivalent Dose (Gy)	Dose Rate (Gy/ka)	Minimum Age (ka)
DM-8 unit 2a	242 ± 17	6.5 ± 1.3	> 29
DM-8 unit 0b	188 ± 18	4.36 ± 0.21	> 38

Two pedogenic carbonate samples were dated using Uranium series techniques in the Fall of 2008 by Dr. Bassam Ghaleb at the Centre de Recherche en Géochimie et Géodynamique (GÉOTOP) at the Université du Québec à Montréal. Results show that the uranium content varies from 1.50 to 2.00 ppm. The relatively high ^{232}Th concentrations (1.77 to 2.75 ppm) indicate the presence of a detrital fraction in all samples. The measured U and Th isotopes in the sample, therefore, are a mixture of detrital material inherited from the soil and authigenic material produced by uranium that was incorporated into the carbonate when it formed. As a result, a correction must be applied to the absolute ages to account for the detrital contamination. The U-series dates presented here and throughout this dissertation (Table 10.10) correspond to 0.0, 0.63, 1.00, and 1.70 of the ^{230}Th/^{232}Th ratio. The possible age ranges are used in the text and figures.

Table 10.10 Uranium and thorium values and U/Th ratios.

	Values (ppm)						
	^{238}U	^{232}Th	$^{234}U/^{238}U$	$^{230}Th/^{234}U$	$^{238}U/^{232}Th$	$^{234}U/^{232}Th$	$^{230}Th/^{232}Th$
DM-8 layer 3d	2.0006 ± 0.0099	1.7702 ± 0.2704	1.9182 ± 0.0179	0.4005 ± 0.0097	3.454 ± 0.055	6.625 ± 0.119	2.653 ± 0.073
DM-2A layer 3a-c′	1.4999 ± 0.0068	2.7515 ± 0.1923	1.8358 ± 0.0175	0.8408 ± 0.0345	3.477 ± 0.244	6.383 ± 0.451	5.366 ± 0.434

Table 10.11 Corrected Uranium Series Dates (Ages in ka).

	Correction Factor (proportion of $^{230}Th/^{232}Th$)			
	0.0	0.63	1.0	1.7
DM-8 layer 3d	53.2 ± 1.6	43.0 ± 1.5	36.5 ± 1.4	22.6 ± 1.2
DM-2A layer 3a-c′	160.3 (+14.0, -12.6)	151.3 (+12.7, -11.6)	145.6 (+11.9, -10.9)	133.7 (+10.4, -9.7)

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