Can The Odds of Hominin Fossil Site Discoveries Be Improved
Through The Use of GIS?

A thesis submitted in partial fulfillment of the requirements
For the degree of Master of Arts in Anthropology

By

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Abstract

Can The Odds of Hominin Fossil Site Discoveries Be Improved Through The Use of GIS?

By
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Master of Arts in Anthropology

Hominin fossil finds have been a source for scientific discoveries and debate for many years. Debates include whether our own species, *Homo sapiens*, evolved entirely in Africa, or if interaction between early *Homo sapiens* and other *Homo* groups existed. While genetic research has provided important contributions to our understanding of human evolution, continued field discoveries are critical to this ever growing body of knowledge, as they provide both the materials to perform the genetic tests, as well as the necessary contextual information needed to understand the hominins’ surrounding environment. Unfortunately, fossil discoveries are limited, with fossils found either by chance discovery or focusing efforts on already known fossil areas.

What if we could use technology to increase our chances? It would save time and money knowing in advance what areas to focus field research on. The answer is simple, we can. This ability is readily available in the form of geographical information system (GIS) spatial mapping to focus on areas sharing attributes of known fossil locations.
Serving as an example, naturally occurring hominin fossil sites found in Northern Africa (Morocco and Algeria) were used to create spatial maps highlighting potential fossil sites to allow one to better predict where to find fossils.
Section 1

Research Objectives and Previous Contributions

Preparation is of the utmost importance when beginning any project. Preparation includes a thoroughly researched topic, and gathering and utilizing the proper tools for the project. With advances in technology, available tools have been refined and are now more adept for researching and analyzing data. These technologic tools, specifically GIS spatial mapping, allow one to hone in on areas that are more likely to contain fossil bearing zones prior to entering the field. Preparing a spatial map that can highlight potential fossil bearing localities based on a set of shared site similarities not only saves time and money, but is also good preparation. GIS is a readily available tool to be used, and much like a paleoanthropologist would use a trowel in the field, GIS should be a tool used prior to fieldwork.

Modern GIS began in the 1960s first as a measuring tool, closely followed by its use of mathematical and geometric concepts to tackle difficult geographic and cartographic questions, such as planning and predicting; however, it has gone through several phases before arriving at its current state of “user dominance…of what a GIS should do and look like” (Coppock and Rhind, 1991:21; Kvmme, 1999, 2005; Longley et al., 2001; Hessler, 2013). GIS has since become an invaluable tool often used in private and academic settings for modeling purposes. GIS has been used effectively to capture, store, manipulate, analyze, and display geographic information in numerous disciplines and professional research, including such disciplines as ecology (Luk, N.d.; MacLeod, 2011),
economics (Reid et al., 2009), health (Gatrell and Löytönen, 1998), history (von Lünen and Travis, 2012), oceanography (Valavanis, 2002), and urban studies (Greene and Pick, 2011). GIS has the ability to “pull together very different data types and allow quantitative analysis at the scale of landscapes or entire regions [in order] to handle [very] complex analyses at large geographic scales, [and thus] has become an indispensable tool” (Sisk, N.d.). GIS allows researchers to create multiple layers (or views) of data, and spatially analyze the data in both two- and three-dimensions. In addition, many researchers and institutions are now posting GIS downloadable data (sharing data) online for all to use.

In archaeology, the modern tradition of analyzing site distributions is usually linked to Gordon Willey’s Virù Valley Project, in which he mapped settlement patterns found in Virù Valley, Peru in 1946 (Willey, 1953). Since site relationship mapping first began, the maps have become more complex and detailed, especially as new technology emerged, such as GIS. Prior to GIS software, archaeological statistical analysis predictions, commonly done for the Bureau of Land Management, were completed through a laborious and time-consuming process involving hand measuring environmental variables on various maps and then calculating estimated probabilities of site densities (Kvamme, 2005). With the advancement of GIS, archaeology can now analyze and predict site patterns with ease and in less time, as well as providing the ability to manipulate and store the data. For example, GIS is being used to spatially display multiple sites, allowing one to look at differences and patterns, as well as act as a digital archive for a single site (Katsianis et al., 2008). An example of this more streamlined process creating more
complex and detailed archaeological maps using GIS can be seen in the intra-site study of Paliambela Kolindros in Greece (Katsianis et al., 2008). In this example a time component was added to the GIS model in order to display a three-dimensional image of the site, thus allowing one to observe the site digitally excavated, as well as provide a database to store and link data (Katsianis et al., 2008).

Early paleoanthropologists were typically archaeologists or medical doctors employing archaeological methods and techniques while conducting fieldwork in what has been called a “single investigator approach” (Anemone et al., 2011). Current paleoanthropologists have a more diversified background, trained in such fields as biological anthropology, paleontology, morphologic and genetic biology, and paleoecology; and, with current research typically done in collaboration with other disciplines such as geology, paleontology, biology, and biochemistry, new approaches are constantly being introduced to the discipline, such as CT scanning (Anemone et al., 2011). Now, much like in archaeology, GIS is utilized in paleoanthropology to visualize and analyze spatial relationships; however, it has only recently been thought of for analyzing the landscape to identify areas with a greater percentage of yielding future fossil sites. For example, one project (The Role of Culture in Early Expansions of Humans) utilizes GIS to spatially trace transportation of raw materials as well as spatially display stone tool technology site distributions (ROCEEH.net). Another example of GIS in paleoanthropology is the Swartkrans site-specific analysis visualizing the spatial relationship and context of the artifact’s, fossil’s, and geologic material’s original deposition in South Africa (Nigro et al., 2003). Finally a third example, discussed further
in Section 4, is the “fossil prospecting” study conducted in the Uinta Basin in Utah, in which the researchers successfully used a spectral signature model to identify other likely fossil locations within the Uinta Basin based on a list of attributes (Conroy et al., 2012).

With ideas and theories regarding the emergence and spread of *Homo sapiens* constantly changing each time new fossil evidence is discovered, and with such little fossil evidence available, there is a great need to increase our hominin fossil data. This project combines both geology and GIS, much like the Uinta Basin study, to aid in the prediction of future hominin fossil sites. The project focuses on Northwest Africa during the Pleistocene (approximately 1.8 million years ago to 11,477 years before present), which can tell us about hominin life during the time and place of the emergence of *Homo sapiens*. The project allows four important research questions to be brought to the forefront:

1) What tools and technology are available to improve fossil site discoveries in paleoanthropology, and how can they be used;
2) Do hominin fossil sites contain similarities that can be applied to identifying potential fossil locations;
3) Why have hominin fossil sites in Morocco and Algeria only been found along the coast; and
4) Why has there only been one hominin fossil site found in Algeria.

Furthermore, the goal of this project, to increase fossil finds in Northwest Africa, can lead to an increase in our knowledge about the emergence of *Homo sapiens*. This
increased knowledge can help paleoanthropologists tackle such questions as whether a possible ancient crossing of the Strait of Gibraltar had occurred.

The specifics of the project include focusing on hominin fossil sites found in Morocco and Algeria (Figure 1) to seek similarities in age, surficial geology, hypsography (topography), land coverage, physiography (physical geography), and drainages (including rivers, streams, springs and waterholes). With so many questions regarding the emergence of *Homo sapiens*, the role that Northwest Africa played in this emergence, and with so few sites found in this region, this project was designed to focus on the few sites found in Morocco and Algeria (see Section 2). The site similarities, or attributes, were input into ArcGIS® version 10.1 to create spatial maps showcasing the existing fossil locations while highlighting other areas in the same region matching the known sites' attributes, but that have yet to be explored. As mentioned previously, this method of "fossil prospecting" has been used successfully for the Great Divide Basin Project in Utah where approximately 7,000 mammalian fossils, ten percent of which were primates, have been found (Conroy et al., 2012). Currently, the known hominin fossil locations in Northwest Africa are found along the coastline; however, using ArcGIS® 10.1 to analyze the region, it can then be determined whether venturing away from the coastline would be worth the chance or not.
Figure 1. Overview Map Of Africa Highlighting The Project Focus Area (Morocco And Algeria).
Section 2
Regional Setting and Importance

Northwest African geology is very diverse, complex, and spans much of the geologic time scale, with granitic basement rocks dating back to the Precambrian. The area has a long history of heavy mining, specifically with Morocco exporting phosphates and Algeria exporting crude oil (El Source Book, 2013). Algeria consists of three tectono-stratigraphic domains: the West African Craton located in the south and west portions of Algeria, the Tuareg Shield located further south in Algeria, and the Alpine Chain located in the north portion of Algeria. Within the Alpine Chain are the Atlas Tellian Mountains, located in Northern Algeria along the southern side of the Mediterranean Basin (Harbi et al., 1999). Since the early Cenozoic, the Atlas Tellian Mountains have undergone folding and faulting, and have affected young Quaternary deposits (Harbi et al., 1999). It is in the Atlas Tellian Mountains that the Algerian hominin paleontological and archaeological sites have been found. Morocco, the Africa-Atlantic-Mediterranean Triple Junction is characterized by crustal extension, compression, uplift, and subsidence, and consists of four domains (from south to north): the Anti-Atlas, the Meseta, the Atlas belt, and the Rif (Michard et al., 2008). The hominin paleontological and archaeological sites found in Morocco are found within close proximity to the Atlantic Ocean, primarily within the middle to late Quaternary deposits (see Section 3).

Another geologic feature Algeria and Morocco both share are karsts, which are “terrain usually characterized by barren, rocky ground, caves, sinkholes, underground rivers, and
the absence of surface streams and lakes. It results from the excavating effects of underground water on massive soluble limestone” (Encyclopædia Britannica, 2014). Limestone outcrops are not common in Africa; however, a considerable amount of limestone and an abundance of karsts are found in Northwest Africa, specifically in Algeria and Morocco (Gunn, 2004). It is important to note that eleven known hominin fossil sites in Morocco are found within karsts (see Figure 4 in Section 4).

Northwest African paleontology and archaeology have been studied continuously since the 1930s, with sites found along the coastlines or slightly inland from the coast (Geraads et al., 1986; Hublin et al., 2001; Geraads, 2002; Raynal et al., 2010; Dibble et al., 2012). Of concern is the past and current turmoil surrounding Algerian politics, which poses hindrance to research conducted within the country. The Algerian Revolution, from which Algeria won its independence from France and divided the country, occurred from 1954 to 1962 (Evans, 1991). Although the area stabilized during the 1980s, the tension did not fully dissipate, and the current civil war began December 1991, and remains ongoing (BBC News Africa, 2013).

Although there have been numerous archaeological sites discovered in this region, only a few of these sites have contained hominin fossils. These Pleistocene fossil sites vary in age from approximately 55,000 years ago (El Harhoura II) to approximately 700,000 years ago (Tighenif), with some sites containing multiple occupations over the years, and are important to human evolution with respect to the emergence and dispersal of *Homo sapiens* and modern human behavior (Geraads et al., 1986; Hublin et al., 2001; Geraads,
2002; Raynal et al., 2010; Jacobs et al., 2011, 2012; Dibble et al., 2012). In particular, this region could illuminate whether there was genetic and technological information being shared between the early Western European and Northwest African populations during the Pleistocene (Raynal et al., 2010).

The emergence of modern humans is an ongoing debate. Part of the debate includes whether modern humans evolved entirely in Africa and then dispersed outward onto other continents replacing archaic groups (“out of Africa”); whether archaic humans dispersed out of Africa first and then evolved into modern humans simultaneously, maintaining gene flow (multiregional); or whether modern human evolution was rather the result of a combination of the two, involving an assimilation or trellis model, which contains gene flow between the groups (Cann et al., 1987; Templeton, 1997; Wolpoff et al., 2000). Another part of the debate is the role Africa played in the early Western European populations (Raynal et al., 2010; Hublin et al., 2012). Morocco’s close proximity to Western Europe, separated from Spain only by the Strait of Gibraltar, makes it an ideal location to investigate whether there was an ancient crossing into Western Europe, and whether there was interaction between the early Homo groups (Raynal et al., 2010:380). In addition, Morocco’s Pleistocene hominin record provides a useful niche in analyzing the Acheulian evolution separated from its eastern origins (Raynal et al., 2010).

Some researchers have found that some hominin fossils from Morocco and Algeria feature plesiomorphic characteristics (ancestral traits), yet lack Neandertal characteristics, leading them to believe that the Mediterranean Sea acted as a barrier, as well as the
Saharan desert at times (Hublin et al., 2001). Others believe that there was an early crossing of the Strait of Gibraltar that potentially contributed to the Western European population (Raynal et al., 2010). Early stone tools have been found in Morocco and Algeria, such as the Oldowan stone tools found at the Ain Hanech site in Algeria that are similar to ones found in East Africa, supporting the idea that there was a westward expansion at approximately 2.5 million years ago, believed to be followed by a northern migration from Northwest Africa into Western Europe (Sahnouni et al., 2010). A good amount of the research conducted and the evidence produced in Morocco has come from the Thomas Quarry I site, which the primary researcher, Raynal, has stated "is one of the very rare key African sites for studying individuals and techno-economic behaviors which relate to a crucial period of human evolution during which North African and European populations, facing each other on both sides of the Mediterranean and potentially exchanging genes and technics, started to diverge biologically” approximately 500,000 years ago (Raynal et al., 2010). Increasing the number of sites found, along with quantity of fossils to compare would allow for a clearer understanding of human evolution during the Pleistocene.

In addition, until recent there has been little research in human ecology in this region, with most of the work focused on Southern Africa (Steele, 2012). Current studies have been conducted in both Morocco and Algeria looking at faunal remains, such as suids (members of the Suidae family, which include pigs), gazelles, and rhinoceros, to determine the landscape and ages of the sites (Bocherens et al., 1996; Sahnouni et al., 2010; Campmas, 2012). For example, isotope analyses of faunal remains from Ain
Hanech (Algeria) demonstrated a change in the climate as well as the landscape during the Pleistocene. They noted a transition from C₃ plants (needing moderate temperatures and abundant groundwater) dominating the landscape to a C₃/C₄ mixed landscape (with C₄ plants better suited to higher temperatures and drought) (Bocherens et al., 1996; Sahnouni et al., 2010). Additional studies have been conducted on “Saharan-derived dust in marine sediments” in which isotopic analysis indicates wet periods resulting in a C₃ plant favored environment, megalakes, and extended river channels approximately 110,000 to 120,000 years ago (Hublin et al., 2012).

This project will provide researchers the opportunity to visually identify the different areas containing similar depositional environments, by focusing on the similar surficial geology and topography. This visualization allows researchers to focus efforts on potential sites that can, in turn, lead to more data, thus providing glimpses into the past environment to better understand Algeria and Morocco's role in the emergence of modern humans, as well as better understand the early human ecology and subsistence (Dibble et al., 2012).
Section 3

Site Selection and Descriptions

Fossil sites of relevance to this study have been defined according to several criteria. First, the project only focused on hominin fossil sites associated with the emergence of anatomically modern humans; however, since the transition between archaic humans and anatomically modern humans is not completely understood, and the oldest known hominin site in the focus area dates to approximately 700,000 years ago, the hominin sites focused on in this project included any site dating to younger than 700,000 years ago. Furthermore, only sites containing hominin fossils preserved by the natural fossilization process were included. Thus, sites containing hominin fossils caused by human influence, specifically burials, were excluded from the project, as this meant human influence (human choice or preference for burials) caused the preservation of the fossils, which was not a shared attribute of the earlier sites. Based on the above criteria, thirteen hominin fossil sites were chosen, twelve in Morocco and one in Algeria. Below is a summary of each site chosen.

Included in the summaries for each hominin fossil site chosen, are: 1) the site name(s); 2) geographic location (latitude and longitude coordinates in decimal degrees or dd, and any other geographic identifier, including situation relative to current sea level in meters above sea level or m asl); 3) the estimated ages of the sites based on dating obtained through various dating techniques, such as Optically Stimulated Luminescence (OSL; used for sediment associated with the fossil), Electron Spin Resonance (ESR; used on
teeth found), thermoluminescence (TL; used on artifacts), Uranium/Thorium (U/Th) radiometric dating, biochronology and paleomagnetism; 4) the dates the sites were discovered or first described and by whom; 5) the fossil remains found (i.e. specific skeletal parts such as teeth or isolated bones); 6) the genus and species of the hominin fossils found; 7) associated artifacts found; 8) paleoenvironment information, discussing the environment at the time of the deceased specimen’s deposition; 9) the current environment the fossil was discovered in, including the Köppen-Geiger climate classification (Kottek et al., 2006) and annual precipitation in millimeters (mm); 10) the geology of the fossil site; 11) the hydrology, identifying the nearest modern day fresh water sources, distance from the modern day shoreline, and current drainage pathways; 12) the past sea level/shoreline (ancient sea levels; data only available from 20 kya to 140 kya, as older data is less accurate); and 13) references. In addition, the site attributes are also presented as Table 1.

Morocco

Site: Aïn Maarouf (also known as El Hajeb)

Geographical location: underwater: estimated 36.08 km inland; estimated latitude: 33.72 dd, estimated longitude: -6.61 dd

Age: not available, but estimated to be slightly younger than the Tighenif site based on associated faunal remains

Discoverer/Original Descriptor(s) and Date: Choubert and Sittler, 1957

Remains found: left femoral shaft
Genus and species: *Homo erectus*

Associated artifacts: Acheulian

Paleoenvironment: open air

Current environment: underwater

Geology: geology associated with fossil find is unknown

Hydrology: currently underwater

Past Sea Level/Shoreline based on site ages: unavailable

References: Geraads et al., 1992; Hublin, 1992; McBrearty and Brooks, 2000; Geraads, 2002

Site: Dar es Soltane II

Geographical location: approximately 162.20 m inland, 24 m asl, latitude: 33.98 dd, longitude:-6.90 dd; approximately 6 km SW of Rabat, west facing cave

Age: 90 kya; associated Aterian, TL, OSL

Discoverer/Original Describer(s) and Date: A. Debénath, 1975

Remains found: partial remains of several individuals, including an adult male cranium, infant calvarium, and mandible of an adolescent

Genus and species: *Homo sapiens*

Associated artifacts: Aterian

Paleoenvironment: marine, coastal setting with wetter periods and combination of C\textsubscript{3} and C\textsubscript{4} plants
Current environment: semi-arid coastal setting, Köppen-Geiger classification Csa (warm temperate environment with hot and dry summers), average annual temperature of 17.8 degrees Celsius, annual precipitation is 508 mm

Geology: dune sandstone karst deposit; surficial geologic unit: Holocene; rock type: sandstone (bedrock); top/predominant soil(s): sand

Hydrology: approximately 260 meters east of the Atlantic Ocean, Bou Regreg River is approximately 6 km NE

Past Sea Level/Shoreline based on site ages: as low as -130 m to as high as 0 m (based on studies conducted in England, Norway, Sweden, Canada, Southeast Asia, Barbados, and Australia); as low as -120 m to as high as 0 m (based on studies conducted in South Africa)

References: Climate-Data.org; Lambeck and Chappell, 2001; Ramsay and Cooper, 2002; Schwartz and Tattersall, 2003; Kottek et al., 2006; Takeru, 2007; Barton et al., 2009; Rightmire, 2009; Jacobs et al., 2011

Site: Djebel Irhoud

Geographical location: 47.04 km inland, 508.71 m asl, latitude: 31.93 dd, longitude: -8.87 dd, located in a barytes mine near Chemaia, approximately 60 km East of Safi

Age: 90-190 kya; ESR (on associated mammalian teeth)

Discoverer/Original Descruber(s) and Date: M. ben Fatmi, 1961 (Irhoud 1); M. ben Fatmi and C. Coon, 1963 (Irhoud 2); E. Ennouchi, 1968 (Irhoud 3); J. Tixier and R. Bayle des Hermens, 1969 (Irhoud 4)
Remains found: adult cranium with teeth missing (Irhoud 1); adult calvaria (Irhoud 2); juvenile (approximately eight years old) mandible (Irhoud 3); juvenile humerus (Irhoud 4)

Genus and species: *Homo sapiens*

Associated artifacts: Levalloiso-Mousterian

Paleoenvironment: dry, open, shrubby cover

Current environment: hot semi-arid environment, Köppen-Geiger classification BSh (hot arid steppe environment), average annual temperature of 19.6 degrees Celsius, annual precipitation is 250 mm

Geology: fissure fill in Precambrian limestone (originally a small subterranean solution cavity that had filled from above) surficial geologic unit: Cambrian; rock type: sandstone; top/predominant soil(s): sand and clay

Hydrology: Ourika River is located approximately 30 km to the south

Past Sea Level/Shoreline based on site ages: as low as -140 m to as high as +5 m (based on studies conducted in England, Norway, Sweden, Canada, Southeast Asia, Barbados, and Australia); as low as -45 m to as high as +5 m (based on studies conducted in South Africa)

References: Climate-Data.org; McBrearty and Brooks, 2000; Lambeck and Chappell, 2001; Geraads, 2002; Ramsay and Cooper, 2002; Schwartz and Tattersall, 2003; Kottek et al., 2006; Takeru, 2007

Site: Contrebandiers Cave (also known as Smugglers’ Cave and Grotte d’Oulad Bouchiha/Ouled Bouchikha)
**Geographical location:** 15.62 m inland, 11.33 m asl, latitude: 33.90 dd, longitude - 7.01 dd, 17 km SW of Rabat, 53 km NE of Casablanca.

**Age:** 90-120 kya; OSL (quartz grain)

**Discoverer/Original Descriptor(s) and Date:** Roche, 1955

**Remains found:** one adult mandible with dentition, maxillary teeth, occipital, frontal, and parietal fragments

**Genus and species:** *Homo sapiens*

**Associated artifacts:** Aterian/Mousterian

**Paleoenvironment:** coastal dry shrubland environment

**Current environment:** Köppen-Geiger classification Csa (warm temperate environment with hot and dry summers), average annual temperature of 17.8 degrees Celsius, annual precipitation is 508 mm

**Geology:** calcarenite cave deposit; surficial geologic unit: Holocene; rock type: calcarenite (bedrock); top/predominant soil(s): silty sands

**Hydrology:** approximately 270 meters east of the Atlantic Ocean, Bou Regreg River is approximately 17 km NE

**Past Sea Level/Shoreline based on site ages:** as low as -70 m to as high as +5 m (based on studies conducted in England, Norway, Sweden, Canada, Southeast Asia, Barbados, and Australia); as low as -45 m to as high as +5 m (based on studies conducted in South Africa)

**References:** Climate-Data.org; McBrearty and Brooks, 2000; Lambeck and Chappell, 2001; Ramsay and Cooper, 2002; Kottek et al., 2006; Takeru, 2007; Jacobs et al., 2011; Dibble et al., 2012
Site: El Harhoura I (Zouhra)

Geographical location: 124.13 m inland, approximately 18 m asl, latitude: 33.95 dd, longitude -6.93 dd

Age: >100 kya; TL, OSL, U/Th, ESR

Discoverer/Original Desciiber(s) and Date: 1976 Debénath

Remains found: mandible with left P4-M3 and right M1-M3

Genus and species: *Homo sapiens*

Associated artifacts: Aterian

Paleoenvironment: semi-arid and open

Current environment: Köppen-Geiger classification Csa (warm temperate environment with hot and dry summers), average annual temperature of 17.8 degrees Celsius, annual precipitation is 508 mm

Geology: cave deposit, karst environment; surficial geologic unit: Holocene; rock type: calcarenite (bedrock); top/predominant soil(s): sand, silt, and clay

Hydrology: approximately 124.13 meters east of the Atlantic Ocean, Bou Regreg River is approximately 13.74 km NE

Past Sea Level/Shoreline based on site ages: as low as -70 m to as high as +5 m (based on studies conducted in England, Norway, Sweden, Canada, Southeast Asia, Barbados, and Australia); as low as -45 m to as high as +5 m (based on studies conducted in South Africa)

References: Climate-Data.org; Debénath 1979-1980, 1992, 2000; Lambeck and Chappell, 2001; Ramsay and Cooper, 2002
Site: El Harhoura II

Geographical location: 261.14 m inland, 18 m asl, latitude: 33.95 dd, longitude -6.93 dd

Age: 55-110 kya; ESR-U/Th (Bovine teeth) and OSL (sediment)

Discoverer/Original Descriptor(s) and Date: Debénath, 1977

Remains found: isolated remains: “vertebrae, clavicle, rib, short bones” in level 3 and a “vertebral body” in layer 9

Genus and species: Homo sapiens

Associated artifacts: Aterian,

Paleoenvironment: humid and arid alternating periods

Current environment: Köppen-Geiger classification Csa (warm temperate environment with hot and dry summers), average annual temperature of 17.8 degrees Celsius, annual precipitation is 508 mm

Geology: calcarenite cave deposit, karst environment; surficial geologic unit: Holocene; rock type: calcarenite (bedrock); top/predominant soil(s): sand, silt, and clay

Hydrology: approximately 261.14 meters east of the Atlantic Ocean, Bou Regreg River is approximately 12.59 km NE

Past Sea Level/Shoreline based on site ages: as low as -75 m to as high as -10 m (based on studies conducted in England, Norway, Sweden, Canada, Southeast Asia, Barbados, and Australia); as low as -50 m to as high as +5 m (based on studies conducted in South Africa)

References: Climate-Data.org; Lambeck and Chappell, 2001; Ramsay and Cooper, 2002; Jacobs et al., 2011; Stoetzel et al., 2011, 2014; Campmas, 2012
Site: El Mnasra

Geographical location: 623.93 m inland, 14 m asl, latitude: 33.93 dd, longitude -6.95 dd

Age: 75-110 kya; OSL (sediment)

Discoverer/Original Describer(s) and Date: Roche, 1956

Remains found: isolated human remains: mandible and cranial fragments (occipital, partial parietals, and right frontal bone fragment

Genus and species: Homo sapiens

Associated artifacts: Aterian

Paleoenvironment: humid and arid alternating periods

Current environment: Köppen-Geiger classification Csa (warm temperate environment with hot and dry summers), average annual temperature of 17.8 degrees Celsius, annual precipitation is 508 mm

Geology: cave deposit, karst environment; surficial geologic unit: Holocene; rock type: calcarenite (bedrock); top/predominant soil(s): sand, silt, and clay

Hydrology: approximately 623.93 kilometers east of the Atlantic Ocean, Bou Regreg River is approximately 16.37 km NE

Past Sea Level/Shoreline based on site ages: as low as -70 m to as high as -10 m (based on studies conducted in England, Norway, Sweden, Canada, Southeast Asia, Barbados, and Australia); as low as -35 m to as high as +5 m (based on studies conducted in South Africa)

References: Climate-Data.org; Debénath 2000; Lambeck and Chappell, 2001; Ramsay and Cooper, 2002; Jacobs et al., 2011; Campmas, 2012; Stoetzel, et al., 2014
Site: Kébibat (also known as Rabat I and Mifsud-Guidice Quarry)

Geographical location: 15 km inland, 4.88 m asl, latitude: 34.03 dd, longitude -6.85 dd, on the coastal cliff SW of Rabat

Age: 200-350 kya; $^{230}\text{Th}/^{234}\text{U}$

Discoverer/Original Describer(s) and Date: M. Alenda, 1933

Genus and species: Homo erectus

Remains found: 23 fragments of an adolescent male (aged 14-15 years old) cranium, left maxilla with 2I, C, 2P, M$^{1-2}$, and left mandibular fragment with 2I, C, P$_3$-M$_1$, right I$_1$, P$_3$-M$_3$.

Associated artifacts: Acheulian

Paleoenvironment: beach setting

Current environment: Köppen-Geiger classification Csa (warm temperate with hot and dry summers), average annual temperature of 17.9 degrees Celsius, annual precipitation is 523 mm

Geology: cave deposit; surficial geologic unit: Tertiary; rock type: sandstone; top/predominant soil(s): sand

Hydrology: Approximately 15 km east of the Atlantic Ocean and the City of Rabat is located at the mouth of the Bou Regreg River.

Past Sea Level/Shoreline based on site ages: unavailable

References: Climate-Data.org; Stearns and Thurber, 1965; Kottek et al., 2006; Takeru, 2007
Site: Littorina Cave (aka Sidi Abderrahman)

Geographical location: 1.70 km inland, 55.78 m asl, latitude: 33.58 dd, longitude: - 7.67 dd, 6 km SW of Casablanca

Age: 200 kya; associated fauna, geomorphology

Discoverer/Original Describer(s) and Date: P. Biberson, 1955

Remains found: young adult male fragmented mandible with the right M₁, M₂, and M₃, and left P₃

Genus and species: Homo erectus

Associated artifacts: Acheulian

Paleoenvironment: coastal beach setting

Current environment: Köppen-Geiger classification Csa (warm temperate with hot and dry summers), average annual temperature of 17.7 degrees Celsius, annual precipitation is 412 mm

Geology: Karstic cavity, Tensiftian stage; surficial geologic unit: Holocene; rock type: sandstone (Great Dune Formation); top/predominant soil(s): sand

Hydrology: Atlantic Ocean approximately 1.7 km west of the site, Oued Bouskoura seasonal creek located in Casablanca (6 km NE), and Oum Er-Rbia River approximately 70 km south-east of Casablanca

Past Sea Level/Shoreline based on site ages: unavailable

References: Climate-Data.org; Howell, 1960; Hublin, 2001; Raynal et al., 2001; Kottek et al., 2006; Takeru, 2007

Site: Salé
**Geographical location:** 1.5 km inland (from coast of el-Hamra, Douar Caid bel Aroussi, Morocco), 38.41 m asl, latitude: 34.07 dd, longitude - 6.77 dd

**Age:** 389-455 kya; ESR (associated bovid tooth enamel)

**Discoverer/Original Describer(s) and Date:** J.-J. Jaeger, 1971 (discovered by Quarry workers)

**Remains found:** base and rear of braincase, partial left maxilla, and a natural endocranial cast

**Genus and species:** Archaic *Homo sapiens*

**Associated artifacts:** None

**Paleoenvironment:** sand dune, coastal environment

**Current environment:** sand dune, Köppen-Geiger classification Csa (warm temperate with hot and dry summers), average annual temperature of 17.9 degrees Celsius, annual precipitation is 530 mm

**Geology:** dune (Aeolian sands) karst deposit, associated with maximum marine transgression (probably Anfatian, approximately +25-30 m); surficial geologic unit: Quaternary; rock type: sandstone; top/predominant soil(s): sand

**Hydrology:** Atlantic Ocean is approximately 1.5 km east of the site; the city of Salé is located on the right bank of the Bou Regreg River

**Past Sea Level/Shoreline based on site ages:** unavailable

**References:** Climate-Data.org; Hublin, 2001; Schwartz and Tattersall, 2003; Kotték et al., 2006; Takeru, 2007

**Site:** Thomas Quarry I
**Geographical location:** within Casablanca, 1.37 km inland, 38.1 m asl, Thomas Quarry Complex: latitude: 33.5 \( \text{dd} \), longitude: -7.75 \( \text{dd} \)

**Age:** 391 kya (OSL measurement of sediment) to 501,000 years ago (Uranium-series and ESR dating from a fragment removed from the upper third premolar ThI 94 OA 23-24)

**Discoverer/Original Describer(s) and Date:** P. Beriro, 1969

**Remains found:** adult left mandibular ramus and four isolated teeth: two right upper third premolars (ThI 94 OA 23-24 and 95 SA 26 n°89), left upper first incisor (ThI 95 SA 26 n°90), and left upper fourth premolar (ThI 2005 PA 24 n°107)

**Genus and species:** *Homo erectus*

**Associated artifacts:** Acheulian

**Paleoenvironment:** dry, open woodland environment

**Current environment:** located in the Chawiya plain along the Atlantic coast, notable mild climate with little seasonal variation, Bouskoura forest consists of Eucalyptus, Pine, and Palm trees planted in the 20th Century, Köppen-Geiger classification Csa (warm temperate with hot and dry summers), average annual temperature of 17.7 degrees Celsius, annual precipitation is 412 mm

**Geology:** calcareous Aeolian sandstone fissure fill cave deposit; surficial geologic unit: Holocene; rock type: sandstone; top/predominant soil(s): sand and clay

**Hydrology:** Atlantic Ocean approximately 1.4 km west of the site, Oued Bouskoura seasonal creek located in Casablanca, and Oum Er-Rbia River approximately 70 km south-east of Casablanca

**Past Sea Level/Shoreline based on site ages:** unavailable
References: Climate-Data.org; Raynal et al., 2001, 2010; Schwartz and Tattersall, 2003; Kottek et al., 2006; Takeru, 2007

Site: Thomas Quarry III (also known as Oulad Hamida I, part of the Thomas Quarry Complex)

Geographical location: within Casablanca, 1.38 km inland, 44.81 m asl, Thomas Quarry Complex: latitude: 33.5 dd, longitude: -7.75 dd

Age: part of the Thomas Quarry complex, believed to be within the same age range as Thomas Quarry I: 391 kya (OSL measurement of sediment) to 501 kya (Uranium-series and ESR dating from a fragment removed from the upper third premolar Thl 94 OA 23-24 from the Thomas Quarry I site)

Discoverer/Original Describer(s) and Date: Ennouchi, 1972

Remains found: adult female or young adult calotte and left partial maxilla with upper left lateral incisor, canine, third and fourth premolars, and three molars (with the M³ erupting)

Genus and species: Homo erectus

Associated artifacts: Acheulian

Paleoenvironment: dry, arid environment along the Middle Pleistocene shoreline during a lower sea level

Current environment: located in the Chawiya plain along the Atlantic coast, Bouskoura forest consists of Eucalyptus, Pine, and Palm trees planted in the 20th Century, Köppen-Geiger classification Csa (warm temperate with hot and dry summers), average annual temperature of 17.7 degrees Celsius, annual precipitation is 412 mm
**Geology:** Calcite concretions cave deposit, Anfatian marine transgression; surficial geologic unit: Holocene; rock type: sandstone; top/predominant soil(s): sand and silt

**Hydrology:** Atlantic Ocean approximately 1.4 km west of the site, Oued Bouskoura seasonal creek located in Casablanca, and Oum Er-Rbia River approximately 70 km south-east of Casablanca.

**Past Sea Level/Shoreline based on site ages:** unavailable

**References:** Climate-Data.org; Raynal et al., 1993, 2001, 2010; Schwartz and Tattersall, 2003; Kottek et al., 2006; Takeru, 2007; Sahnouni, 2012

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**Algeria**

**Site:** Tighenif, Algeria (also known as Ternifine)

**Geographical location:** 56.04 km inland, 606.55 m asl, latitude: 35.5 dd, longitude 0.33 dd, Quarry near Palikao approximately 20 km E. of Mascara, Algeria

**Age:** 700 kya; associated fauna, paleomagnetism

**Discoverer/Original Descriptor(s) and Date:** 1872 (during the building of a village); excavations in 1954 (Tighenif 1 and 2) and 1955 (Tighenif 3 and 4) by C. Arambourg and R. Hoffstetter

**Remains found:** Tig 1: adult mandible, Tig 2: young adult hemimandible, Tig 3: adult male mandible, Tig 4: young adult parietal fragment (may be associated with Tig 2) and isolated teeth: Rdm¹, LM¹, Ldm², LM¹, RM¹, LI, RI¹, and LC¹

**Genus and species:** *Homo erectus*
**Associated artifacts:** Acheulian

**Paleoenvironment:** lake bed

**Current environment:** Köppen-Geiger classification Csa (warm temperate with hot and dry summers), average annual temperature of 16.9 degrees Celsius, annual precipitation is 449 mm

**Geology:** surficial geologic unit: Tertiary; rock type: sandstone; top/predominant soil(s): sandy and clayey beds

**Hydrology:** Mediterranean coast north of site, previous artesian springs/pond that has since dried up (1980s)

**Past Sea Level/Shoreline based on site ages:** unavailable

**References:** Climate-Data.org; Geraads et al., 1986; Schwartz and Tattersall, 2003; Kottek et al., 2006; Takeru, 2007
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<tr>
<th>Sites</th>
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<th>Long (deg)</th>
<th>Distance inland From Current Shoreline</th>
<th>Distance To Current Freshwater Source</th>
<th>Current Elevation (asl)</th>
<th>Current Environment</th>
<th>Site Age (kya)</th>
<th>Dating Method</th>
<th>Fossil Remains Found</th>
<th>Genus and Species</th>
<th>Work Type/Redist</th>
<th>Surficial Deposit Age</th>
<th>Site Specific Ecology</th>
<th>Paleoenvironment</th>
<th>Past Sea Level</th>
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<td>7.01</td>
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<td>360-560 m</td>
<td>sandstone</td>
<td>Quaternary</td>
<td>44.81 m</td>
<td>OSL</td>
<td>unpaired teeth, partial mandible, partial maxilla, left second upper incisor</td>
<td>Homo</td>
<td>Csa</td>
<td>Csa</td>
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<td>humid and arid alternating periods ; Cessation of C3 and C4 vegetation; increased soil erosion</td>
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<td>7.01</td>
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<td>360-560 m</td>
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<td>Quaternary</td>
<td>44.81 m</td>
<td>OSL</td>
<td>unpaired teeth, partial mandible, partial maxilla, left second upper incisor</td>
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<td>Csa</td>
<td>Csa</td>
<td>-130 m to 0 m</td>
<td>humid and arid alternating periods ; Cessation of C3 and C4 vegetation; increased soil erosion</td>
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<tr>
<td>El Harhoura I</td>
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<td>38.1 m</td>
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<td>sandstone</td>
<td>Tertiary</td>
<td>623.93 m</td>
<td>U/Th</td>
<td>isolated human remains: mandible, partial maxilla, and left frontal bone fragment</td>
<td>Homo</td>
<td>Csa</td>
<td>Csa</td>
<td>-130 m to 0 m</td>
<td>humid and arid alternating periods ; Cessation of C3 and C4 vegetation; increased soil erosion</td>
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<tr>
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<td>sandstone</td>
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<td>623.93 m</td>
<td>U/Th</td>
<td>isolated human remains: mandible, partial maxilla, and left frontal bone fragment</td>
<td>Homo</td>
<td>Csa</td>
<td>Csa</td>
<td>-130 m to 0 m</td>
<td>humid and arid alternating periods ; Cessation of C3 and C4 vegetation; increased soil erosion</td>
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<td>isolated human remains: mandible, partial maxilla, and left frontal bone fragment</td>
<td>Homo</td>
<td>Csa</td>
<td>Csa</td>
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<td>Tertiary</td>
<td>623.93 m</td>
<td>U/Th</td>
<td>isolated human remains: mandible, partial maxilla, and left frontal bone fragment</td>
<td>Homo</td>
<td>Csa</td>
<td>Csa</td>
<td>-130 m to 0 m</td>
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<td>Tertiary</td>
<td>623.93 m</td>
<td>U/Th</td>
<td>isolated human remains: mandible, partial maxilla, and left frontal bone fragment</td>
<td>Homo</td>
<td>Csa</td>
<td>Csa</td>
<td>-130 m to 0 m</td>
<td>humid and arid alternating periods ; Cessation of C3 and C4 vegetation; increased soil erosion</td>
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<td>sandstone</td>
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<td>U/Th</td>
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<td>Csa</td>
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<td>623.93 m</td>
<td>U/Th</td>
<td>isolated human remains: mandible, partial maxilla, and left frontal bone fragment</td>
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<td>Csa</td>
<td>Csa</td>
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<td>Thomas Quarry II</td>
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<td>U/Th</td>
<td>isolated human remains: mandible, partial maxilla, and left frontal bone fragment</td>
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<td>Csa</td>
<td>Csa</td>
<td>-130 m to 0 m</td>
<td>humid and arid alternating periods ; Cessation of C3 and C4 vegetation; increased soil erosion</td>
</tr>
</tbody>
</table>

**Table 1. Summary Of Select Moroccan And Algerian Hominin Fossil Sites’ Attributes.**

**Notes:**
- **Air Maounif** location is approximate based on a map from a dissertation by Emilie Campmas, 2012
- Koppen and Geiger classification Csa is identified as having a warm temperate with hot and dry summers
- Koppen and Geiger classification BSh is identified as having a hot arid steppe environment
- **lat** = latitude
- **long** = longitude
- **m** = meters
- **asd** = above sea level
- **kya** = thousand years ago
- **km** = kilometers
Section 4

Methodology

The crux of the project is the determined attributes of the hominin fossil sites. At the start of the project, available information regarding the known hominin fossil sites detailed in Section 3 was entered into a spreadsheet for ease of comparison (Table 1). A detailed description of these attributes, as well as the GIS methodology used, is discussed in this section.

GIS has become a valuable tool for many disciplines, and much of the research done today benefits from the use of GIS, as discussed in Section 1; however, there are still research projects that could benefit from the use of GIS, but do not utilize or are in the early stages of utilizing this tool. Locating potential fossil sites in paleoanthropology is one such research area that could benefit from using the GIS tool.

The GIS predictive modeling tool was best demonstrated as a means to predict potential fossil locations within the field of paleontology by a team consisting of two anthropologists and one geographer in 2011 and 2012, when they successfully used ArcGIS® 10 to create a spectral signature model in order to analyze the Uinta Basin in Utah, where previous mammalian fossils have been found (Conroy et al., 2012). Through the use of the spectral signature model, the researchers essentially “trained” the computer program to identify other likely fossil locations within the Uinta Basin based on attributes
that included elevation, vegetation, and surface sediments (Conroy et al., 2012). The researchers were then able to contact paleontologists working in the Uinta Basin to verify if their predictions were accurate (Conroy et al., 2012). The results of the Uinta Basin study revealed fossils located within areas the computer predicted with 98-percent certainty that fossils would be found. Using a very similar process in a separate study on another continent will only enhance and refine the model, as well as showcase the possibilities of utilizing such technology and combined disciplinary efforts.

The overall process of creating a spatial map highlighting potential hominin fossil sites is quite involved. There are four main phases of completing the map: Phase I: identify data needed and site attributes through research; Phase II: download available or create GIS recognizable data files, insert data into GIS (using arc catalog), and filter data using GIS; Phase III: identify other possible fossil locations; and Phase IV: interpret results. Phases III and IV include analyzing the data, interpreting results, noting issues/problems that arose in the study, and suggesting future studies needed, which are discussed in the next two sections (Section 5 “Results and Interpretations”, and Section 6 “Conclusions, Limitations, and Recommendations for Future Research”).

**Phase I**

The first phase entails identifying the data needed. This was done by researching all known naturally occurring hominin fossil sites in Algeria and Morocco, and detailing their attributes (see Section 3). These attributes were analyzed to determine which ones
were the most prevalent, which ones likely contributed to the fossil preservation, and which ones contributed to the fossil being discovered at the respective site. Below is a brief overview of characteristic proportions shared between the hominin fossil sites, followed by figures visually displaying the attributes found among the hominin fossil sites.

A total of thirteen hominin fossil sites met the criteria described in Section 3, deeming them naturally occurring hominin fossil sites, and are the focus of this project. Of these thirteen hominin fossil sites, six are associated with remains of Homo erectus, one is associated with remains of Archaic Homo sapiens, and six are associated with remains of Homo sapiens (Figure 2).

Figure 2. Proportion Of Hominin Species Found At The Studied Sites.

Of particular interest in analyzing the hominin fossil species found at the sites are the ages of the fossils, associated artifacts, and sediments (site age during the fossilized species occupancy). Overall, the sites vary in age from 55,000 years ago to 700,000 years ago. Of the naturally occurring hominin fossil sites found within the study area, 46-
percent are younger than 200,000 years. The proportion of sites correlating to the ages of the hominin fossils discovered is shown below in Figure 3.

![Figure 3. Proportion Of Studied Sites According To The Age Ranges Of The Hominin Fossils They Have Yielded.](image)

Tool technology is a characteristic of the different hominin groups and their respective ages. The Acheulian industry dates to the Lower Paleolithic, approximately 2.5 million years ago to 300,000 years ago (Conroy, 1997). The Middle Paleolithic dates from approximately 300,000 years ago to 40,000 years ago, and includes the Mousterian and Levallois technology (Conroy, 1997). Below is the proportion of tool technology found at the sites in association with the hominin fossils (Figure 4).
Figure 4. Proportion Of Tool Technologies Found Associated With The Hominin Fossils At The Studied Sites.

Based on Figures 2 through 4, it was noted that the age ranges of the hominin fossils found in which nearly half are younger than 200,000 years, and the species of hominin fossils found which are equally divided between Homo erectus and Homo sapiens and a few Archaic Homo sapiens, reinforces the claim that Northwest Africa can provide important clues about the emergence and dispersal of modern Homo sapiens and modern human behaviors (Geraads et al., 1986; Hublin et al., 2001; Geraads, 2002; Raynal et al., 2010; Jacobs et al., 2011, 2012; Dibble et al., 2012). In addition, and more specific to this project, these figures show the primary age range of the geologic deposits to focus on, as all the sites date to the Pleistocene Epoch in the Quaternary Period.

Additionally, factors affecting the fossilization process or locations were also noted, such as drainage pathways that may have moved the fossil to a secondary location and karst locations that typically trap individuals and preserve the remains (fossils). Figure 5 below
shows the proportion of hominin fossil sites per their geologic environment. It is worth noting that eleven out of thirteen sites have been found within karst environments.

Figure 5. Proportion of Geologic Environments Of The Hominin Fossil Sites From the Focus Study Area.

Surficial geology found at the sites consisted of sands, clays, and silts dating to the Precambrian, Tertiary, Quaternary (undivided), and Holocene (see Section 3). The surficial geology data was downloaded from the USGS website (United States Geological Survey, 2013), which lists ages as: 4 billion years ago to 542 million years ago (Precambrian), 533.2 million years ago to 65.5 million years ago (Tertiary), 1.806 million years ago to present (Quaternary), and 11,477 years ago to present (Holocene). A geologic timescale reference for the ages discussed in this project is included as Table 2 below. The USGS Africa World Geology surficial geologic units legend is included as Figure 6 to give the explanation of the abbreviations used for the units in subsequent maps.
<table>
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<th>PERIOD</th>
<th>SERIES/EPOCH</th>
<th>BEGINNING AGE (estimated in mega-annum [Ma] unless noted otherwise)</th>
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<td>Holocene 11.477 +/- 85 yr</td>
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<td>Pleistocene</td>
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<td>Pliocene</td>
<td>5.332 +/- 0.005</td>
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<td>Upper/Late</td>
<td>161.2 +/- 4.0</td>
</tr>
<tr>
<td></td>
<td>Middle</td>
<td>175.6 +/- 2.0</td>
</tr>
<tr>
<td></td>
<td>Lower/Early</td>
<td>199.6 +/- 0.6</td>
</tr>
<tr>
<td>Triassic</td>
<td>Upper/Late</td>
<td>228.0 +/- 2.0</td>
</tr>
<tr>
<td></td>
<td>Middle</td>
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</tr>
<tr>
<td></td>
<td>Lower/Early</td>
<td>251.0 +/- 0.4</td>
</tr>
<tr>
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<td>Permian</td>
<td>Upper/Late 260.4 +/- 0.7</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Guadalupian 270.6 +/- 0.7</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Cisuralian 299.0 +/- 0.8</td>
</tr>
<tr>
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<td>(Pennsylvanian)</td>
<td>Upper/Late 306.5 +/- 1.0</td>
</tr>
<tr>
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<td>(Pennsylvanian)</td>
<td>Middle 311.7 +/- 1.1</td>
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<tr>
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<td>(Pennsylvanian)</td>
<td>Lower/Early 318.1 +/- 1.3</td>
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<td></td>
<td>(Mississippian)</td>
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<td></td>
<td>(Mississippian)</td>
<td>Lower/Early 359.2 +/- 2.5</td>
</tr>
<tr>
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<td>Upper/Late</td>
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</tr>
<tr>
<td></td>
<td>Middle</td>
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</tr>
<tr>
<td></td>
<td>Lower/Early</td>
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</tr>
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<td>Pridoli</td>
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</tr>
<tr>
<td></td>
<td>Ludlow</td>
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</tr>
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<td></td>
<td>Wenlock</td>
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<td></td>
<td>Llandovery</td>
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</tr>
<tr>
<td>PRECAMBRIAN</td>
<td></td>
<td>Approximately 4000</td>
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Table 2. Geologic Timescale Reference Table. Modified After The Divisions Of Geologic Time Approved By The U.S. Geological Survey Geologic Names Committee (Orndorff et al., 2007).
### EXPLANATION

- **G**: Quaternary (undivided)
- **H**: Holocene
- **O**: Pleistocene
- **C**: Cenozoic
- **T**: Tertiary
- **M**: Mesozoic
- **TK**: Tertiary and Cretaceous
- **K**: Cretaceous
- **KJ**: Lower Cretaceous
- **KJ**: Cretaceous and Jurassic
- **J**: Jurassic
- **J**: Lower Jurassic
- **Jr**: Jurassic and Triassic
- **Tr**: Triassic
- **Th**: Lower Triassic
- **MP**: Mesozoic and Paleozoic
- **K**: Cretaceous through Carboniferous
- **JL**: Jurassic through Carboniferous
- **P**: Paleozoic
- **P**: Permian
- **TP**: Triassic and Permian
- **PC**: Permian-Carboniferous
- **C**: Carboniferous
- **CD**: Carboniferous and Devonian
- **D**: Devonian
- **DU**: Upper and Middle Devonian
- **DS**: Devonian and Silurian
- **S**: Silurian
- **SO**: Silurian-Ordovician
- **O**: Ordovician
- **OCa**: Ordovician-Cambrian
- **Ca**: Cambrian
- **P**: Precambrian (undivided)
- **Pc**: Paleozoic-Precambrian
- **Qu**: Quaternary extrusive and intrusive rocks
- **T**: Tertiary extrusive and intrusive rock
- **M**: Mesozoic extrusive and intrusive rock
- **Mes**: Mesozoic-Paleozoic extrusive and intrusive rock
- **P**: Paleozoic extrusive and intrusive rock
- **K**: Kimberlite
- **S**: Subsurface salt dome
- **I**: Internal Water Body

Figure 6. USGS World Geology of Africa Legend (United States Geological Survey, 2013).
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<tr>
<th>Symbols</th>
<th>Description</th>
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<th>Ages</th>
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<td>Quaternary (undivided)</td>
<td>1.806 +/-0.005 to current</td>
</tr>
<tr>
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<td>Holocene</td>
<td>Holocene</td>
<td>11,477 +/- 85 yr to current</td>
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<td>Pleistocene</td>
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</tr>
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<td>65.5 +/- 0.3 to current</td>
</tr>
<tr>
<td>Ti</td>
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<td>Tertiary-Cretaceous</td>
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</tr>
<tr>
<td>K</td>
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<td>Cretaceous</td>
<td>145.5 +/- 4.0 to 65.5 +/- 0.3</td>
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<tr>
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<tr>
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<td>199.6 +/- 0.6 to 65.5 +/- 0.3</td>
</tr>
<tr>
<td>J</td>
<td>Jurassic</td>
<td>Jurassic</td>
<td>199.6 +/- 0.6 to 145.5 +/- 4.0</td>
</tr>
<tr>
<td>Jl</td>
<td>Lower Jurassic</td>
<td>Jurassic</td>
<td>199.6 +/- 0.6 to 175.6 +/- 2.0</td>
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<tr>
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<td>Mesozoic</td>
<td>Triassic-Jurassic-Cretaceous</td>
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</tr>
<tr>
<td>JTr</td>
<td>Jurassic-Triassic</td>
<td>Jurassic-Triassic (undivided)</td>
<td>251.0 +/- 0.4 to 145.5 +/- 4.0</td>
</tr>
<tr>
<td>Tr</td>
<td>Triassic</td>
<td>Triassic</td>
<td>251.0 +/- 0.4 to 199.6 +/- 0.6</td>
</tr>
<tr>
<td>Trl</td>
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<td>Triassic</td>
<td>251.0 +/- 0.4 to 245.0 +/- 1.5</td>
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<td>Mesozoic</td>
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</tr>
<tr>
<td>P</td>
<td>Permian</td>
<td>Permian</td>
<td>299.0 +/- 0.8 to 251.0 +/- 0.4</td>
</tr>
<tr>
<td>TrP</td>
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<td>Permian-Triassic (undivided)</td>
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<td>Carboniferous-Cretaceous</td>
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<td>359.2 +/- 2.5 to 145.5 +/- 4.0</td>
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<td>Carboniferous-Permian</td>
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<td>Devonian</td>
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</tr>
<tr>
<td>Du</td>
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<td>Devonian</td>
<td>397.5 +/- 2.7 to 359.2 +/- 2.5</td>
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<tr>
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</tr>
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<td>Silurian</td>
<td>443.7 +/- 1.5 to 416.0 +/- 2.8</td>
</tr>
<tr>
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<td>Ordovician-Ordovician</td>
<td>488.3 +/- 1.7 to 416.0 +/- 2.8</td>
</tr>
<tr>
<td>O</td>
<td>Ordovician</td>
<td>Ordovician</td>
<td>488.3 +/- 1.7 to 443.7 +/- 1.5</td>
</tr>
<tr>
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<td>Cambrian-Cretaceous</td>
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<td>Cambrian-Ordovician</td>
<td>542.0 +/- 1.0 to 443.7 +/- 1.5</td>
</tr>
<tr>
<td>Pi</td>
<td>Paleozoic Igneous</td>
<td>Paleozoic</td>
<td>542.0 +/- 1.0 to 251.0 +/- 0.4</td>
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<td>Cambrian</td>
<td>542.0 +/- 1.0 to 488.3 +/- 1.7</td>
</tr>
<tr>
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<td>Precambrian</td>
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</tr>
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<td>PzPC</td>
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<td>Precambrian-Paleozoic</td>
<td>~4000 to 251.0 +/- 0.4</td>
</tr>
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<td>MiPi</td>
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<td>--</td>
</tr>
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<td>Kimberlites</td>
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<td>Salt Domes</td>
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<td>--</td>
</tr>
<tr>
<td>H2O</td>
<td>Water (River or Lake)</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>SEA</td>
<td>Sea</td>
<td>--</td>
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</tr>
<tr>
<td>oth</td>
<td>Areas outside of African Continent</td>
<td>--</td>
<td>--</td>
</tr>
</tbody>
</table>

Table 3. Surficial Geology Quick Reference Table. Table Incorporates USGS Symbology Used, Description, Epoch Or Period, and Age. Data Compiled From USGS World Geology of Africa Legend (United States Geological Survey, 2007) And Table 2 Modified After The Divisions Of Geologic Time Approved By The U.S. Geological Survey Geologic Names Committee (Orndorff et al., 2007).

The distribution of the focus area’s hominin fossil sites based on their bedrock is shown below in Figure 7. The known hominin fossil sites were found in either calcarenite or
sandstone, typical of karst environments. Below that, Figure 8 shows the distribution of the focus area’s hominin fossil sites and the respective geologic unit they were found in.

Figure 7. Proportion of Bedrock Types the Focus Study Area’s Hominin Fossil Sites Are Found In.

Figure 8. Proportion of Geologic Units the Focus Study Area’s Hominin Fossil Sites Are Found In.
During Phase I, it was determined that surficial geology, particularly the age of the surficial geologic deposits, and karst environments were the primary site attributes. Elevation and proximity to the coast were also used as site attributes; however, both elevation and proximity to the coast are likely due to researcher bias, selective locations of mining activities exposing the fossils, and/or restrictions in accessible areas causing research to be focused on select locations. Figure 9 below shows the distribution of sites found within various ranges of the modern day shoreline; however, it is important to note that the past shoreline fluctuated from approximately 5 meters above modern day shoreline to approximately 130 meters off the modern day coastline. Although the hominin fossil sites have been found within close proximity to the modern day shoreline, it must be noted that research has focused on these areas, limiting the potential of finding hominin fossils further inland. In addition, discoveries have typically been made during mining activities, and these sand quarries are primarily situated along the coast. Finally, the Atlas Mountains are a more challenging terrain, and thus research efforts have likely been focused on areas not only previously yielding hominin fossils, but that also provide a more easily accessible field area.
Figure 9. Distribution of the Focus Study Area’s Hominin Fossil Sites in Relation to Modern Day Shoreline.

Figure 10 below shows the distribution of sites found within various elevations. Figures 9 and 10 both show that sites have been found primarily close to the coast; however, as noted above, this is likely due to a researcher bias conducting further studies at known hominin fossil sites.

Figure 10. Distribution Of The Focus Study Area’s Hominin Fossil Sites Found Per Their Respective Elevations.
During Phase I, it was noted that the sites shared certain attributes; specifically, the sites were mainly found in Quaternary deposits (primarily sandstone or calcarenite), all were found within close proximity to the modern day coastline, and eleven out of the thirteen sites were located within karst environments. This meant the sites shared the same age range, depositional and ecological environments, and geographical positioning. These attributes were determined to be significant factors in assessing whether a location was a viable potential fossil locality. However, since previous research has been focused along the coastline, this attribute, although significant, likely represents the lack of studies conducted inland, and thus was not used as a main criterion in assessing potential hominin fossil locations. Since age, surficial geologic deposits, and karst environments were attributes shared among the hominin fossil sites found in Algeria and Morocco, these features, along with hypsography, land coverage, physiography, and drainages were used to create spatial maps in *Phase II: Figures*, noting other potential hominin fossil locations.

**Phase II: Process**

Sources of data, such as site information, surficial geology, and karst locations came from journal articles, published books, and online databases. The search for data using online databases included first identifying where information was stored and available for downloading, and then whether the data was in the correct format to then be input into GIS. Re-formatting is a very involved process that includes creating polygon raster
datasets by tracing an overlay image, and then converting the raster data into a vector. Re-formatting was not needed for this project, so will not be further discussed; however, future research would benefit from digitizing additional geologic maps in vector format described above. For this project, three websites were identified as containing the information needed. These three websites are the USGS website (United States Geological Survey, 2013), which contained the surficial geology and the age of the surficial geology of Morocco and Algeria; the Geocommunity website (GeoCommunity, 2012), which contained most, however not all, drainage, hypsography, land coverage, ocean features, and physiography geospatial data for Morocco and Algeria; and the University of Auckland, New Zealand School of Environment website (The University of Auckland, New Zealand School of Environment, 2010). Geospatial data not available is discussed with each data map shown in this section.

All data downloaded was in the Geographic Coordinate System GCS WGS 1984, with a datum of D WGS 1984, using Greenwich as the prime meridian, and degree as the angular unit.

African surficial geology was available for downloading from the USGS website as a shapefile feature class in a polygon geometric shape, file titled “Surficial geology (geo7_2ag)” (United States Geological Survey, 2013).

Data downloaded from the Geocommunity website (GeoCommunity, 2012) is borrowed by the website, with permission, from US Defense Mapping Agency data by Environmental Systems Research Institute, Inc. (ESRI) to create the Digital Chart of the World. ESRI cautions that some assumptions for handling tiny polygons and
edgmatching were made (GeoCommunity, 2012). The available data downloaded included:

- **Morocco:**
  - digital terrain elevation data (DTED) in DTED format, 10 Deg Grid: N 20-30, W 0-10
  - hydrography (drainages as network and points, and ocean features as lines and points: DNNET, DNPOINT, DSPORT, OFPOINT, and OFLINE) in E00 format
  - hypsography (topography as network, points, and lines, and supplemental points and lines: HYPOINT, HYNET, HSLINE, and HSPOINT) in E00 format
  - land cover/land use (as points and polygons: LCPOLY and LCPOINT) in E00 format

- **Algeria:**
  - digital terrain elevation data (DTED) in DTED format, 10 Deg Grid: N 10-20, E 0-10
  - hydrography (drainages as network and points, and ocean features as lines and points: DNNET, DNPOINT, DSPORT, OFPOINT, and OFLINE) in E00 format
  - hypsography (topography as network, points, and lines, and supplemental points and lines: HYPOINT, HYNET, HSLINE, and HSPOINT) in E00 format
- land cover/land use (as points and polygons: LC POLY and LC POINT) in E00 format
- geology (physiography as lines: PH LINE) in E00 format

African karst data were available for downloading from the University of Auckland, New Zealand School of Environment website as a shapefile feature class in a polygon geometric shape, file titled “Africa_map.zip” (The University of Auckland, New Zealand School of Environment, 2010).

In addition, Digital Elevation Model data and World Imagery data was available and downloaded directly through ArcGIS® 10.1 by selecting arc online under the file tab, and adding 30 arc-second DEM of Africa and World Imagery by ESRI.

The downloaded data from the USGS, Geocommunity, and University of Auckland, New Zealand School of Environment websites were already formatted as feature classes recognized by ArcGIS® 10.1, and thus did not need to be converted. Originally, the 1969 International Quaternary Map of Africa (geologic map) was obtained to be used as a data layer in GIS; however, it was available only as a scan image which would need to be converted into a vector. Instead, the 1969 geologic map was used to cross check the surficial geology data, specifically the site specific surficial geology downloaded from the USGS website to ensure accuracy (see Figure 15).

Using the data downloaded from the websites noted above, subsets of data were created consisting of the data that intersected or was associated with the sites and within the
focus area. For example, a subset data of surficial geology only located within the focus area was created, which was then used to create another sub-dataset showing areas where surficial geology and karst data intersected or overlapped (Figures 24-26). In addition, each data set was then queried to only view relevant values/codes/items (Table 4). The data subsets were then added into ArcGIS® as individual data layers using arc catalog.

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<th>Code</th>
<th>Definition</th>
</tr>
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<td>Perennial inland water (perennial lakes, streams, estuaries, lagoons, unsurveyed perennial streams, reservoirs, and navigable canals)</td>
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<td>Inland water body shoreline</td>
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<tr>
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<td>Glacial limit</td>
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<td>Falls</td>
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<td>Rapids</td>
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<td>0 to 1,000 feet above mean sea level</td>
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<td>HYNET (HYLNVAL)</td>
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<tr>
<td>HYNET (HYLNVAL)</td>
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<td>Closed contour, approximate</td>
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<tr>
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<tr>
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<td>Spot elevation, questionable or doubtful location</td>
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<td>Depression contour</td>
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Table 4. Selected Queried Values/Codes/Items. Values/Codes/Items were taken from the Geocommunity website (GeoCommunity, 2012) and used for GIS project figures.

Once the data listed in Table 4 was input into ArcGIS®, the first step was to remove unnecessary views of duplicated data. In this step, all the “point” data was removed, so only line and polygon data was left. Polygon and line data are the preferred views, as they detail the area the data is associated with. The point view applies a point on the map without showing the boundaries of that data. The next step was to create subsets of the data to allow limited data to be shown at one time, which allows one to analyze each data set individually. The final step was to extrapolate data from each data set highlighting only areas containing the same attributes, thus highlighting potential hominin fossil locations. This was described above in the example of creating a sub-dataset showing areas where surficial geology and karst data intersected or overlapped (Figures 23-25).

**Phase II: Figures**

The GIS process discussed above produced the following figures, each displaying one data set in which to analyze. Following each data set figure is a discussion of the data displayed. Once the following figures were produced, the final step was to analyze each map, note areas in which the data sets overlapped, note data supportive and not supportive of identifying potential hominin fossil sites, note missing data, and then produce resulting maps highlighting areas where supportive overlapping data intersected, which are included in Section 5 (Results and Interpretation). The initial data set maps are shown below in Figures 11 through 20.
Figure 11. Region Overview Showing Known Hominin Fossil Site Locations.
Figure 11 contains a map of the focus area (Morocco and Algeria) showing all thirteen known hominin fossil site locations used for this project. The Aïn Maarouf site, located east of El Harhoura next to the northwestern coast of Morocco, is an approximate location based on a large-scale map of Morocco hominin coast sites, as this site was found below water and thus detailed information, including exact coordinates, is unavailable (Campmas, 2012). In addition, the shown locations of El Mnasra, El Harhoura I and II, Contrebandiers Cave, and Dar-es-Soltane are based off the Témara region sites map (Campmas, 2012), as this map proved to be a more accurate and detailed map, as opposed to the latitude and longitude coordinates provided on the Catalogue of Fossil Hominids Database (Takeru, 2007). The latitude and longitude coordinates of the sites focused on in this project were used to create a data layer from which GIS could extrapolate information, as opposed to plotting the locations on the map, which the layers cannot use as a data filter. The data layer allows one to filter information (turning on and/or off features) and focus or view individual data collectively or individually.
Figure 12. Focus Area Digital Elevation Model (DEM) Data and Location of the Known Hominin Fossil Sites.
Digital Elevation Model (DEM) data was available and downloaded directly through ArcGIS® 10.1 by selecting arc online under the file tab, and adding 30 arc-second DEM of Africa. The DEM data provides a detailed view of the elevation of the focus study area. Also shown on Figure 12 are the locations of the known hominin fossil sites found within the focus study area, which provide a visual aid in analyzing the potential relationship between the site locations and elevation.

Following the analysis of elevation, surficial geology was input into ArcGIS® to further analyze the relationship between surficial geology and hominin fossil sites (Figure 13).
Figure 13. Focus Study Area Surficial Geology Shown as Age of Deposits (United States Geological Survey, 2013). See Figure 6 for the explanation of the unit abbreviations and Table 2 for their ages.
Figure 13 shows a map of the focus area, hominin fossil locations used for the project, and the African surficial geology downloaded from the USGS website (United States Geological Survey, 2013). The USGS Geology 24K color scheme was used for both Figures 13 and 14. The sites are located within Quaternary undivided (Q), Holocene (Qe), Tertiary (T), and Cambrian (Cm) surficial geologic units, as shown in Figure 14. For a complete listing of units and ages, see Table 2; however, Figures 13 and 14 provide units and ages for the geologic units shown on those figures. The surficial geology data available for download only lists the age of the surficial geology; however, when compared to the 1969 International Quaternary Map of Africa in Figure 15, focusing on the surficial geology dated to the Quaternary undivided (Q), Holocene (Qe), Tertiary (T), and Cambrian (Cm) accurately represented the sites’ surficial geology the project intended to focus on, while providing GIS recognizable data.

This view demonstrates the value of filtering or querying the data to only show the data relevant to the project. Figure 13 also acts as a comparative figure to Figure 14, which has been narrowed down to show only the surficial geology found at the sites, and other areas within the focus study area where the same surficial geology can be found.
Figure 14. Site Specific Surficial Geology Found Within the Focus Study Area, Shown as Age of Deposits. See Figure 6 for the explanation of the unit abbreviations and Table 2 for their ages.
Figure 14 shows a map of the focus area with site specific surficial geology (shown by age of deposit), and other locations where similar surficial geologic deposits are found. The values shown are: Q (Quaternary undivided), Qe (Holocene), T (Tertiary), and Cm (Cambrian).

The method employed consisted of:

- using the selection tab; clicking on selection by location;
- selecting the feature from the target layer
  - in this case it was the African surficial geology layer that was targeted;
- selecting the source layer from which the feature originated from
  - in this case it was the focus area, as this was the only area the feature was needed to be viewed in; and
- selecting the spatial selection method for the target layer feature
  - in this case it was having their centroid in the source layer feature.

This method was employed for each subset layer of data listed in the following figures.
Figure 15. Focus Area Overlaid By the 1969 International Quaternary Map of Africa.
The 1969 International Quaternary Map of Africa is prepared by the Sub-Commission of INQUA for the Quaternary Map of Africa under the aegis of the National Center of Scientific Research (Paris).

Overlaying the 1969 International Quaternary Map of Africa in GIS involved adding the map into GIS by adding a data layer function, and then geo-referencing points on the 1969 International Quaternary Map of Africa to points on the GIS base map.

The sites are primarily found in the marine consolidated dune deposits or fluvial deposits, with the exception of three sites (Aïn Maarouf, Tighenif, and Djebel Irhoud), which are all three found in pre-Quaternary rocks not covered by essential Quaternary deposits. By comparing Figure 14 (Site Specific Surficial Geology) to Figure 15 (The 1969 International Quaternary Map of Africa), it supports the accuracy of the surficial geology used for the project.

Once surficial geology was analyzed, figures highlighting karst environments were prepared using ArcGIS®, and are shown below as Figure 16.
Figure 16. Focus Study Area Karst Environments Shown With DEM Data And Known Hominin Fossil Sites.
Figure 16 is a map of the focus study area with digital elevation model data highlighting all the known karst environments in the focus area (Morocco and Algeria). Figure 16, along with the enlarged view of where the Moroccan hominin fossil sites are found, highlight the fact that all but two sites are found within karst environments. Ain Maarouf (which is an approximate location and possibly incorrectly estimated) and Tighenif are the two sites not found within karst environments. The selection method described for the previous figures was employed for the karst data layer as well, and is outlined below.

The method employed consisted of:

- using the selection tab; clicking on selection by location;
- selecting the feature from the target layer
  - in this case it was the karst environments layer that was targeted;
- selecting the source layer from which the feature originated from
  - in this case it was the focus area, as this was the only area the feature was needed to be viewed in; and
- selecting the spatial selection method for the target layer feature
  - in this case it was having their centroid in the source layer feature.

In addition to DEM data showing the varying elevations found within the focus study area, hypsography data downloaded from the Geocommunity website was also used to analyze the relationship between the hominin fossil site locations and elevation.
Figure 17. Focus Area Showing Elevation (Hypsography – Hynet) Data As Polygons And Known Hominin Fossil Site Locations.
Figure 17 shows a map of the focus area with hypsography (elevation) data shown as polygons and arc. In arc view one can see the elevation lines, while in polygon view one can see the area that falls within a set elevation range. This map view shows areas of varying elevations, specifically the elevations at which the sites have been found (0-1,000 ft asl, and 1,000-3,000 ft asl). Each color represents an area of a certain elevation. Although DEM data is more specific and detailed, with the amount of detail shown on the final maps, both detailed DEM data and the wider range elevation data (polygons) are shown in the results (Section 5).

The selection method described in the previous figures was employed for the hypsography data layer as well. It is important to note that higher elevations do not necessarily rule out potential hominin fossil locations, as it is possible hominins migrated over the Atlas Mountains, and, as shown in Figure 16, karst locations are found in the higher elevations, indicating these areas are warrant further investigation.

Following the analysis of hypsography, drainage pathways were analyzed to help identify potential secondary depositional environments, and are shown below in Figure 18.
Figure 18. Focus Area Showing Drainage (DNNET) Data As Arc Lines In Relation To Known Hominin Fossil Site Locations.
This map of the focus area (Figure 18) shows the drainages in blue, which can potentially be transport pathways transporting fossils to secondary locations, depending on the volume of the flow. There is a function in ArcGIS® to analyze watersheds, which would include filtering for high volume flowing watersheds; however, this function is not available with a home use subscription, and would best be used on a site-specific level. On Figure 18, in addition to the blue drainage pathways, the purple locations highlight a body of water, such as a lake. Future research should look at lake deposits dating from the same time period as the deposition of the known hominin fossils, as these are potential fossil locations.

A preliminary drainage investigation was conducted for this project, which entailed projecting all possible drainage pathways into GIS; however, due to the large focus area, a more in depth analysis of possible drainage pathways leading from primary potential hominin fossil locations would need to be conducted prior to fieldwork in order to focus efforts on drainages that: 1) drained from an area containing the same geologic depositional environment as the known hominin fossil sites, and 2) contained enough volume (flow) to transport fossils from a primary deposition to a secondary deposition.

In addition to drainage pathways, and with much of the hominin fossils found exposed and discovered during mining activities, it is important to look into other mines for either potential future discoveries or past undocumented discoveries.
Figure 19. Focus Area Showing Land Coverage (LCPOLY) Data As Polygons And Arc Lines In Relation To Known Hominin Fossil Site Locations.
Figure 19 is a map of the focus area with land coverage data shown as polygons (complete areas) and arc lines. As described in Table 4, the land coverage features include quarry and mining areas. Because several of the known hominin fossil locations were discovered during quarry and mining activities specifically related to sand deposits which all the sites have in common, highlighting other quarry and mining localities is important to note as areas of potential finds; however, the data did not decipher between sand quarry or mining activities and other types of mining activities, so caution must be taken when using this data. In addition, none of the known hominin fossil site locations intersected the land coverage data, as evident by Figure 19 showing all site locations found outside the land coverage polygon areas, and thus was not determined to be an attribute. The selection method described for previous figures was employed for the land coverage polygon data layer as well.

In addition to the land coverage, physical geography (physiology) was also analyzed and is presented in Figure 20 below.
Figure 20. Focus Area Showing Physiography (PHLINE) Data As Arc Lines In Relation To Known Hominin Fossil Site Locations.
Figure 20 is a map of the focus area with physiography (physical geography) data shown as arc lines. Physiography data was downloaded from the Geocommunity website, and was only available for Algeria and only in arc view. This figure demonstrates the need for caution when using available data not personally collected, as Table 4 states physiography includes earthquakes; however, areas within the focus area known for recent faulting, such as Northern Algeria, do not show up in this data. None of the known hominin fossil sites intersected the available physiography data, as evident by the hominin fossil sites not found in association with the physiography arc lines in Figure 20, and thus it was determined to not be an attribute.
Section 5

Results and Interpretations

Topography (physiography), land coverage, drainage pathways, surficial geology, karst environments, and elevation (hypsography) were all comparatively analyzed between the known hominin fossil sites in Northwest Africa. This comparison was done by analyzing each map noting whether the known hominin fossil sites were found within the parameters of the data presented, and if so, how many sites were found in correlation with the data. After analyzing the site attributes and visually assessing the individual data maps produced in the methodology section (Figures 12 through 20), it has been determined that the areas with the greatest chance of discovering hominin fossils correspond to areas containing both the same surficial geology as the known hominin fossil sites and karst environments. Surficial geology provides the geologic units exposed during the hominin occupancy. In addition, certain environments are more conducive to fossil preservation, so narrowing in on similar geologic environments provides a better chance of yielding the same hominin fossils. Karst environments are not only conducive to fossil preservation, but also likely provided shelters, thus increasing the draw to these areas and the likelihood of the hominin dying and fossilizing in the same location. Therefore, it was determined that surficial geology and karst locations were the most important attributes. A discussion of each attribute analysis is presented below, starting with the most important attributes, surficial geology and karst environments.

As mentioned above, surficial geology provides the geologic units exposed during the time of the hominin occupation. With the sites primarily found in sandstone and
calcarenite, it is important to focus on these geologic beds. In addition to focusing on surficial geology, karst environments provided caves that were used as shelters, as well as environments that preserved fossils, which proves valuable when identifying areas likely to contain hominin fossils. Just as the sites were primarily found in the same surficial geology, most also shared the same karst environments. The combination of providing shelter for the living individual, and an environment that preserves the fossilized remains of the individual produces a greater chance of yielding fossils altogether. Due to the greater chance of karst environments yielding hominin fossils, all karst areas in Morocco and Algeria have been highlighted in the final GIS maps (Figures 23 and 24) as potential hominin fossil sites; however, it is the karst areas combined with the surficial geology that is found at the known hominin fossil sites that have the greatest potential of yielding hominin fossils. Figures 20 and 21 below show a closer view of the known hominin fossil sites of Morocco and Algeria, respectively, with surrounding areas highlighted in red showing locations of higher probability of yielding hominin fossil locations.
Figure 21. Morocco Known Hominin Fossil Sites Shown With DEM Data And In Relation To Karst Environments And Karst Environments Intersecting Surficial Geology.
Figure 21 is an enlarged image of the known hominin fossil sites found in Morocco. With the exception of one site, Aïn Maarouf, all the sites fall within karst environments shown on the figure in red.

Aïn Maarouf is an approximate location, as the hominin fossil specimen, a left femoral shaft, was found during irrigation channel digging, and is now underwater. This site would benefit from further study to determine the associated geology and hydrology, specifically to determine if water was present at the surface (i.e. could this have been a water source for the hominins associated with this site?) and what type of fossil preservation environment was present, and then compare it with the environments listed in this project to either confirm the determined environmental attributes, or add to the list of attributes.

Of the twelve known naturally occurring hominin fossil sites in Morocco, five were found in active mines, and one (Aïn Maarouf) was found during irrigation digging activities. This fact highlights the importance of looking at known mining locations for potential future discoveries should the surficial geology match the known hominin fossil sites, or for previously discovered fossils that have not been documented.
Figure 22. Algeria Known Hominin Fossil Site Shown With DEM Data And In Relation To Karst Environments And Karst Environments Intersecting Surficial Geology.
Figure 22 shows an enlarged image of the one hominin fossil site in Algeria, the Tighenif site, as well as the karst environments in red. The Tighenif site was found in an ancient lake bed. Data of ancient lake beds is not readily available, and requires one to geologically map and interpret the area. Since this information was not available for the project focus area, ancient lake beds, which are conducive to preserving fossils, were not included in the site attribute list, and thus not displayed on the figures.

In addition, elevation and proximity to the coast are important attributes as well, as hominins likely spent more time in the lower elevations and along the coastline as a greater variety of food sources were present in these areas. However, these hominins likely migrated over the Atlas Mountains (higher elevations), and did have access to food and water sources inland during the Pleistocene, so these areas are still of concern, thus highlighting potential areas inland and at greater elevations as long as the areas contained the same surficial geology and karst environments. Numerous archaeological sites have been found in the Atlas Mountains, within karst environments, signifying potential fossil discoveries to be made.

Drainages are also important to consider, as they can transport fossils to secondary locations. This is important when determining an area to conduct field research in, as one would want to investigate higher volume drainage pathways (watersheds) leading away from their site. This demonstrates the need to prepare a GIS watershed map on a site-specific scale in order to highlight secondary deposition locations. A preliminary drainage investigation was conducted for this project, which entailed projecting all possible drainage pathways into GIS, and is shown in Figures 19 and 26. Due to the large focus area, a more in depth analysis of possible drainage pathways leading from primary
potential hominin fossil locations would need to be conducted prior to fieldwork in order to focus efforts on drainages that: 1) drained from an area containing the same geologic depositional environment as the known hominin fossil sites, and 2) contained enough volume (flow) to transport fossils from a primary deposition to a secondary deposition. This can be done through a watershed analysis function in GIS; however, it would require a smaller focus area in order for it to be beneficial.

Based on the above criteria, there are several potential locations in Morocco and Algeria which should be considered for future research, most notably inland in both Algeria and Morocco where not as much research has been conducted. It is again important to note the lack of fossil locations in Algeria compared to Morocco. Fossil locations do exist in several locations throughout Algeria; however, the fossils found in Algeria are dinosaur fossils dating to the Mesozoic Era, primarily found along the southern border, most notably along the southern borders of Morocco and Niger (Currie and Padian, 1997). This is not surprising, since the surficial geology map indicates older outcrops are present in these areas, making these areas unlikely to find hominin fossils.

The lack of hominin fossil sites found in Algeria could also represent a lack of investigation; which is likely the result of two factors: 1) the political tension and violence during the Algerian Revolution from 1954 to 1962 (Evans, 1991) and the current civil war beginning December 1991 which remains on-going (BBC News Africa, 2013); and 2) the current inland temperatures range from approximately -10 degrees Celsius in the Sahara desert to extreme highs of approximately 49 degrees Celsius (Encyclopedia of the Nations: Africa: Algeria, 2014).
As discussed above, the GIS data maps have indicated that the main attributes likely affecting the location of hominin fossil sites are the surficial geology and karst environments, especially due to the shelters they provide and the possibility of collapses preserving the fossil remains. This reinforces the need to focus efforts on environments in which fossil preservation was possible. The areas most likely to contain hominin fossils, primarily due to their preservation environments, surficial geology and karst environment, are shown on Figures 14 and 16.
Figure 23. Areas (In Red) Most Likely To Contain Hominin Fossils Within The Focus Area Shown As Polygons.
In Figure 23, the red areas, as indicated in the legend, are areas that contain both the same surficial geology found associated with the known hominin fossil sites and karsts environments. It is these dark red areas that represent the locations that have the highest probability of yielding hominin fossils.

The dark gray areas are the locations of karst environments. All karst environments have the potential of preserving fossilized remains, thus they are included on the map showing a higher probability of yielding hominin fossils.

The blue, green, cream, and orange highlighted areas on Figure 23 show ranges of elevation. The blue range (0 to 1,000 feet above sea level) is the range in which most of the known hominin fossil sites were found. The areas in which surficial geology intersects karsts found at elevations between modern day sea level and 1,000 feet above sea level represent the most likely areas to contain hominin fossils (red areas within the blue highlighted areas).

Figure 23 was completed using the intersect feature under the geoprocessing tab in ArcGIS®, in which one inputs features, designates an output feature class, and states the XY tolerance. For this project, input features included surficial geology and karst locations, were designated under a selected folder for the output class, and defined within a one-mile radius tolerance to include features that lay just on the country border.
Figure 24. Areas (In Red) Most Likely To Contain Hominin Fossils Within The Focus Study Area Shown With DEM Data.
Figure 24, like Figure 23, shows the areas most likely to yield hominin fossils in red. The gray areas show the karsts environments found in Morocco and Algeria. Figure 24 contains DEM data (a more detailed view) as opposed to the range in elevation presented in Figure 23.

As shown in Figures 23 and 24, Figure 25 highlights areas with a greater probability of finding hominin fossils, but also contains drainage data to show the numerous pathways leading from the potential sites that must be further evaluated as potential transport pathways. In Section 4, a preliminary drainage investigation to project all possible drainage pathways into GIS was discussed; however, it has been determined that due to the large focus area, a more in depth analysis of possible drainage pathways leading from primary potential hominin fossil locations would need to be conducted prior to fieldwork. A drainage analysis would consist of focusing on a smaller area and using the watershed function in ArcGIS® to identify drainages that: 1) drained from an area containing the same geologic depositional environment as the known hominin fossil sites, and 2) contained enough volume (flow) to transport fossils from a primary deposition to a secondary deposition.
Figure 25. Areas (In Red) Most Likely To Contain Hominin Fossils Within The Focus Area Shown With DEM Data And Drainage Pathways.
Section 6

Conclusions, Limitations, and Recommendations for Future Research

Conclusions

The purpose of this study was to identify attributes shared among the known hominin fossil locations in Algeria and Morocco, and to look for potential hominin fossil locations by focusing on these shared attributes. By analyzing a variety of data available for Morocco and Algeria, such as physiography, land coverage, drainage pathways, surficial geology, karst environments, and hypsography, a list of attributes were created in which it was determined that surficial geology combined with karst environments were the most important factors to be considered when deciding whether a location has a higher probability of yielding hominin fossil find. Surficial geology provides the sediments corresponding to the time period the hominins occupied the area, as well as provide details regarding the environment they lived in. Additionally, certain sediments and depositional environments are more conducive to fossil preservation. By focusing on these environments based on the surficial geology and karst environments, one has a greater chance of finding a hominin fossil. In addition, high volume (flow) drainages leading from the areas determined to most likely yield hominin fossils should also be studied, as these drainage pathways could potentially transport a hominin fossil to a secondary location. The final result maps (Figures 23 through 25) highlight potential locations that have a greater probability of finding hominin fossils, and indicate that venturing inland away from the coastline is worth the risk. The GIS spatial maps not only
highlight potential hominin fossil areas to consider, but also show transport pathways (drainages) that possibly transport fossils to secondary locations.

Unfortunately, it must be noted that additional factors are likely to affect fossil discoveries in this region. Current land uses and politics must be considered before fieldwork is undertaken. In both Morocco and Algeria, mining is a large part of their economies. For example, the fragments found at Kébibat (Rabat) might have originally formed a complete skull; however, the discovery was made during quarry blasting activities which fragmented the fossil (Howell, 1960). It is possible that heavy mining in these countries has already destroyed hominin fossil sites. In addition, as noted above, Algerian political violence has prevented research in this country.

In Section 1, four research questions were posed:

1. What tools and technology are available to improve fossil site discoveries in paleoanthropology, and how can they be used;
2. Do hominin fossil sites contain similarities that can be applied to identifying potential fossil locations;
3. Why have hominin fossil sites in Morocco and Algeria only been found along the coast; and
4. Why has there only been one hominin fossil site found in Algeria.
Also discussed in Section 1 was how the goal of this project, to increase the chances of finding hominin fossils in Morocco and Algeria, can increase our knowledge of early hominins. By focusing on Northwest Africa, we can increase our understanding of the emergence of *Homo sapiens*.

It is now clear that GIS is a valuable tool to view data and analyze potential focus areas. GIS should be used like any other tool, with a set purpose to help achieve a goal. The goal for this project is to locate areas of greater probability in which to find hominin fossils in order to maximize fieldwork time and money. Through this project it was demonstrated that fossil sites do in fact share attributes that can be used in GIS to determine other potential fossil locations. Surficial geology and karst environments are the most important attributes when looking for potential hominin fossil sites; however, looking at previous and current mines and construction projects within areas determined most likely to yield hominin fossils could lead to discoveries, as these projects likely expose fossils. Elevation and distance to modern day shoreline were attributes shared among the sites; however, this is likely due to a research bias of researching areas that have previously yielded hominin fossil finds. This project demonstrated a need to include inland areas, away from the coastlines, in future research. With numerous archaeological sites found in the Atlas Mountains, and knowing early hominins would have migrated from East Africa to the coast, focusing on other areas containing the surficial geology and karst environments that were deemed the most important attributes can potentially lead to new discoveries.
The project also discussed the need to analyze drainage pathways, as these areas can transport fossils to secondary locations. Drainage pathways should be analyzed on a site specific basis as transport flows vary, and on a large area, such as was done for this project, the varying flows do not show well visually. On a smaller scale, one can look at the volume of the flows to determine whether it was large enough to transport fossils from the primary deposition. Analyzing water flows is a function of GIS, further showing GIS as a useful tool to use prior to entering the field.

The project also mentioned the ongoing politics and war in Algeria hindering fieldwork. Safety is of concern when conducting fieldwork in Algeria due to the ongoing civil war, and as such, fieldwork should be put on hold until it is safe for researchers to enter.

The idea that early modern humans crossed the Strait of Gibraltar, leading to a population contribution in Western Europe originally posed an intriguing possibility; however, the idea of a land bridge is highly unlikely, as the “bridge” was submerged under the ocean. In searching through studies of past sea levels and looking at the current bathymetry to analyze paleocoastlines in Algeria and Morocco, the Strait of Gibraltar was noted to be rather deep, reaching depths greater than 800 meters below modern day sea level (Sanchez-Garrido et al., 2011). However, the Strait of Gibraltar bathymetry contains a ridge from Morocco to Spain approximately 250 meters below current sea level. Past sea level fluctuations show sea level in that area dropped, at most, to approximately 140 meters below modern day sea level. This still leaves approximately 110 meters of water covering the ridge. A land bridge in this area was not the case, leaving the only explanation of a possible crossing in this area by either swimming or boating across the Strait of Gibraltar. What the past sea level fluctuations and bathymetry do show,
however, is that the Moroccan coastal areas had approximately an additional 10 kilometers of land exposed during the lower sea level periods. This suggests further submarine investigation is needed in this particular area.

Northwest Africa still proves important in the emergence of anatomically modern humans, and as such should be studied further. With a map of potential hominin fossil locations, future research should focus efforts on these areas in attempt to gather more data in which to better understand the role Morocco and Algeria played in the emergence of *Homo sapiens*.

**Limitations and Recommendations for Future Research**

As with any project completed, areas of improvement are noted, and as with any project in science, more data is always needed. Some of the specific problems noted with this research are the very broad study area and limited available data. Additional data can be made available once it has been converted to vector data recognized by GIS as a data layer, such as the 1969 International Quaternary Map of Africa; however, this is a project all unto itself, and should be accomplished as a future project. This proved problematic when analyzing the few hominin fossil sites for attributes.

Some notable questionable data sources did arise, such as maps of sites showing different locations than what geographical positioning data was given from the Catalogue of Fossil Hominids Database website (Takeru, 2007), although locations were plotted based on published map locations, unless there was not a map available in which case the website
database was used. In addition, this demonstrates the possibility of inaccurate data used in this project, although not intentional; however, data was borrowed from a variety of sources, some of which could contain errors which could possible alter the results of this project.

The broad study area proved difficult in analyzing the drainage pathways, as there are features in ArcGIS®, specifically using arc toolbox, to analyze watersheds. This tool would allow one to focus on drainages leading from potential hominin fossil sites (not to) and drainages with enough water flow in which to carry hominin fossil remains (some watersheds have such minimal water flow, if any, that transport is unlikely). This feature would only be useful in close view of one site. This shows that this project is a first step in selecting an area to focus field research, and would need additional research once a site is selected in order to maximize field time and money.

In addition to analyzing watersheds on a site specific level, conducting GIS spectral model on a site specific level would be necessary once a location has been selected. This project was conducted on a larger scale to highlight other potential locations within two countries, Morocco and Algeria. Once a researcher has decided on a location within one of these countries, a site specific analysis could provide the same information, areas more likely to yield fossils, but on a much smaller scale, allowing one to know precise areas to focus on.

In addition, traveling to the area would have been extremely useful; however, this was not possible for this project. Another recommendation for future studies is to complete a
project from the initial prospecting steps detailed in this project through the stage of conducting field research. This would allow one to travel to the focus area and test the results of the study. This would also allow the process to become more refined and accurate by collecting more data from which others can use when beginning their projects (specifically knowing the ins and outs of what worked and what did not).

GIS also contains limitations, although many of these limitations are due to a lack of data. As discussed in Section 3, cave deposits can be potential fossil locations; however, although one can input known cave deposits into ArcGIS®, unless the criteria of locating additional cave deposits have been input into the program, it cannot determine potential cave deposits. Although caves in Algeria and Morocco are being studied, there are still caves that have not been explored or found (Gunn, 2004). Caves located in Algeria and Morocco must continue to be studied, and the data must then be input into ArcGIS® manually, which requires fieldwork to determine these locations. The same can be said of ancient lake deposits. Lake deposits are a great source of fossil preservation, and the Tighenif site was a direct result of this preservation environment. Future research should include mapping these ancient lake beds to later use in future GIS models, highlighting these areas as potential fossil locations based on their ages. Further exploration to increase and improve data sets is true of much of the data used in this project. This demonstrates the need of continuous data input from all fields into one database. ArcGIS® would be able to import data from a database and more accurate maps would then be available for research use. An all-inclusive shared database would also streamline the GIS process, allowing for potential location maps to be assembled relatively easily.
and quickly, saving more time and money for the field and post-field research.

Future research is not only necessary, but would also be extremely beneficial. Specifically, a multidisciplinary approach, consisting of several researchers, would provide much needed data to include as GIS layers from which to analyze the overall and site specific area. The multidisciplinary project should include a paleoanthropologist that provides hominin data (attribute list) to a GIS specialist, along with conducting test pits to refine the tool; a geologist that has conducted a thorough geologic study of the area; and, a GIS specialist that has a strong grasp of the ins and outs of the GIS program. A single continuously updated database containing all fossil site information would limit errors obtained from using multiple sources.

Finally, I cannot stress enough the need for a single database. A future project should be the start-up of such a database from which a GIS program can extrapolate data (have a linked GIS program and database). This would allow researchers access to all data necessary to analyze a project, and allow corrections be made to erroneous data, more importantly, before that erroneous data is used for another project.
Works Cited


