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Rapid Tectonic Evolution of the Levant during the Pleistocene and Its Implications for Topography and Local Lake Formation and Disappearance: Factors Affecting Human Migration and Settlement

Abstract

During the Pleistocene human migration and settlement took place in Jordan when the topography and hydrology were very different from their present conditions. The elevation of the mountains east of the Jordan Rift during the Middle Pleistocene was ~500 masl, compared to the present ~1000 masl. On the Plateau area of Jordan, a series of freshwater lakes and wetlands such as Al Jafr, Gharandal, Al H̲asa, Al Qaṯrānah, and Suwāqah formed and disappeared as a result of the interplay of tectonics, sedimentation, and erosion. The existence and disappearance of these bodies seems to have played a major role in human migration from Africa, because these aquatic bodies served as water and food providers and settling sites. They developed a belt of green vegetation attracting animals which were hunted by early men. Ancient humans produced tools for hunting and food preparation from flint and assembled them next to the shores of former aquatic bodies. The shapes of these flint tools allow coarse dating and documents the arrival of humans a hundred thousand years ago and of modern men between 80,000 and 50,000 years ago. But with time, these lakes turned into swamps, then into drainage channels, and lastly into dry riverbeds which must have threatened the existence of these humans and caused their migration elsewhere in search of water, food, and shelter. In this article, the topographic and hydrologic evolution of the area during the Pleistocene is discussed and the role of the interplay between tectonics and erosion on the formation and disappearance of lakes and wetlands illustrated.

Introduction

Lengthy records are available for the numerous aquatic bodies that existed and then disappeared in the highlands of Jordan and in the Jordan Valley-Dead Sea basin (Bender 1968, 1974; Huckriede and Wiesemann 1968; Clark 1984; Schuldenrein and Clark 1994; Yasin 2001; Moumani *et al*. 2003; Petit-Maire *et al*. 2010; Mischke *et al*. 2015) (TABLE 1). These water bodies have different deposits of fossil and lithic remains, the sizes and ages of which reflect the prevailing environments during their lifetimes. The water bodies include the Samra and Lisan Lakes, Jurf Ad Darawīsh and Ṯawīl water courses, Gharandal oases, Al Mudawwarah, Ḫalat ʿAmmār, Al Jafr, Al Ḫasā (Jinz), Al Qaṯrānah, Suwāqah, and Al Azraq swamps and ponds (FIG. 1). They are small or large, deep or shallow, and of salt water or freshwater environments. These water bodies are distributed randomly on highlands or lowlands from 400 to 1000 masl.

Many studies have been carried out on these Quaternary aquatic deposits to investigate and reconstruct the historic climate conditions (Torfstein *et al*. 2008; Stein and Goldstein 2006). Ancient aquatic bodies attracted early humans during Pleistocene times, as indicated by the presence of stone artifacts along their shores, which helped researchers to relatively date them and understand some of the history of hominin habitation around these aquatic bodies and their migration routes.

The formation, development, and disappearance of the lakes took place during the Pleistocene as a result of the interplay of tectonic forces, erosion, and sedimentation processes in the Levant area. During the Pleistocene, different human species appeared in Africa and migrated northward, and in northern Egypt they then migrated east- and westward and found in the Levant lakes, food, and shelter. This article will concentrate on the formation, development, and disappearance of the lakes and their role in human migration across the Levant.

History of the Pleistocene Aquatic Bodies

During the Late Tertiary, the Levant began its uplift (epeirogenic movements), emerging from the retreating Tethys Sea which prior to that had flooded most of the land there. The Tethys Sea withdrew in northwestern, northern, and eastern directions. The water drainage of Jordan followed the shores of the retreating Tethys Sea in a westerly and northerly direction, where a series of river courses developed, such as Al Jafr, Al Ḫasā, Al Mūjib, Al Wālah, Al Kafrayn, Shuʿayb, Az Zarqā', Al Yabis, and Al Yarmūk. They all poured into the retreating Tethys Sea, the ancestor of the Mediterranean Sea.

With the start of the tectonic downward movement along what later became the Jordan Rift Valley a new base level for the different river courses and wadis formed and the wadis began discharging into that rift valley (FIG. 2). After that, in the later Tertiary, the eastern and western sides of the Jordan Rift Valley depression started gradually to rise relative to the other parts of the Levant because of taphrogenic uplifts (Graben tectonics). Gradually, the elevations of the Shoulder Mountains of the Jordan Rift Valley started to exceed the elevations of the land lying further east on the Plateau area of Jordan. The erosion rates along the wadis draining the area westward had been lower than the uplift rate of the Shoulder Mountains, which resulted in the formation of local base levels for the surface and groundwater in the form of highland lakes such as Al Jafr,

Table 1. Paleo-Pliocene to Pleistocene water bodies in Jordan (information is derived from Huckriede and Wiesemann 1968; Winer 2010; Mischke *et al*. 2012; Mischke 2015, Ginat *et al.* 2017; Rech *et al.* 2017, Al-Saqarat *et al*. 2020; Mischke *et al.* 2021; and others.)

Formation	Lithology	Fossils and Trace Fossils	Age	Environmental Deposition
Jurf Ad Darāwīsh	Gravel, massive clay (yellowish-brown), and grayish-green clayey	Ostracod (*Potamocypris, Ilyocypris, Pseudocandona*), aquatic and terrestrial gastropod shells, charophyte gyrogonites, and root traces. Human artifacts ca. 85 to 65 kya.	Pleistocene during MIS 5–4	In-stream wetland
Wādī GHarandal	Sand intercalated with laminated carbonates and gravel deposits	Gastropod shell fragments and ostracod valves, including *Herpetocypris brevicaudata, Ilyocypris bradyi, Heterocypris salina, Candona neglecta, Scottia pseudobrowniana, Herpetocypris* sp., and *Psychrodromus* sp. Lithic artifacts	Pleistocene ~125–70 kya	Freshwater of riverine wetland oasis
Al Jafr Basin	Green mudstones and white marls	Ostracode (*Ilyocypris* cf. *bradyi, Candona neglecta, Heterocypris salina, Fabaeformiscandona fabaeformis, Pseudocandona* sp., and *Herpetocypris brevicaudata*), gastropod (*Gastrocopta Vertigo, Vallonia*), and bivalve, charophyte algae, and root traces	Late Pleistocene, during MIS 3	Shallow freshwater to slightly oligohaline pond, stream, and swamp wetlands.
Wādī Al Hasā	Marls, green mudstone, and poorly sorted conglomerates	Gastropods, bivalves, ostracode microfauna, charophyte algae and root traces. Palaeolithic artifacts	Late Pleistocene ~70–20 kya	Wetland or palustrine
Al Mudawwarah (Hālat ʿAmmār)	Fine-grained, green-yellow sand, coquina with gravel covered by marl with evaporate (halite, gypsum), and conglomerate	Ostracodes (*Cyprideis torosa* (Jones) and *Candona* gr. *neglecta*), bivalve (*Cerastoderma glaucum, Brachidontes* cf. *pharaonis*, and *Abra* sp.), gastropods (*Hydrobia* sp. and *Melanoides tuberculata*), benthic foraminifera (*Ammonia beccarii/tepida* Linné and *Elphidium excavatum terquem*)	Early or middle Pleistocene MIS 5 130–70 kya?	Brackish to saline wetland or springs
Al Azraq	Sandstone, conglomerates, limestone and gypsum	Gastropod shells (*Bythinia* sp., *Hydrobia* sp., *Gyraulus* sp.), *Cardium* bivalve, ostracodes (*Cyprideis torosa),* benthic foraminifera (*Ammonia beccarii)* and charophyte gyrogonite algae. Palaeolithic artifacts.	Pleistocene MIS 9 at 330 kya?	Fresh to brackish wetland or springs

Al Hasā (Jinz), Al Qaṯrānah, Suwāqah, and others (FIG. 2). The former wadis draining the Plateau areas and the eastern parts of the developing Shoulder Mountains into the Jordan Rift Valley were then dissected into two parts, one ending in the highland lakes and the other draining only the Shoulder Mountains' western parts which discharged into the Rift Valley.

The above processes allow the conclusion that during the Pleistocene, wetlands and lakes formed in the Levant area as a result of the interaction of Graben tectonics along the Jordan Rift Valley, with the uplift of the Graben Shoulders and its accompanying erosion, sedimentation, and river course reversals (FIG. 2). After the formation of the highland lakes, headward erosion along the westerly draining wadis and sedimentation in the lakes gradually led to capturing the lakes' water and diverting it to discharge into the Jordan Rift Valley again. Only the Al Jafr depression still forms an exitless playa collecting floodwater, which either evaporates or infiltrates down into the underlying aquifers (FIG. 2). The ultimate fate of the water on that playa is to be captured by the Al Hasā drainage or by southeasterly draining wadis. The Sirhan depression had historically drained northwestward into the Jordan Rift Valley through what is now called the "Harrat Ash Shām basalts." The basalt eruptions and the accumulation of their weathering products in the Sirhan Depression blocked the flow of the depression and a lake formed at the interface of the basalt front and the sediments coming along the Depression from the southeast (Salameh and Al Farajat 2006). Until before forty years ago, Azraq Lake collected fresh floodwater and spring water, but artificial overdraft of its water has since resulted in its dryness.

Summary of Tectonics, Erosion, and Sedimentation That Led to the Formation and Disappearance of the Highland Lakes

Tectonics

With the formation of the Jordan Rift Valley, its shoulders started to rise relative to the valley bottom and relative to the eastern part of the country. That caused the land in Jordan to tilt toward the east, which was accompanied by reversals of the drainage pattern from being oriented west towards the Tethys Sea, instead to be oriented toward the east, where the water accumulated between the rising Graben Shoulder Mountains in the west and the eastern elevated escarpment of Jordan, separating the Plateau drainage from Wadi Sirhan drainage in the east (FIG. 2). The accumulated water formed lakes that existed year-round, such as Al Jafr, Jinz, Al Qaṯrānah, and Swāqah, among others.

Sedimentation

The highland lakes received flood water carrying sediment loads which settled in the lakes and raised their bottoms. This in turn created higher water levels in these lakes which then overflowed into nearby wadis, accelerating the headward erosion of westerly draining wadis that captured the lakes' water and drained it back into the Jordan Rift Valley.

Erosion

The wadi courses, which used to drain the land of Jordan in a westerly direction toward the retreating Tethys Sea before the formation of the Rift Valley and uplift of the Graben Shoulders, started their headward erosion in an easterly direction and gradually reached the highland lakes and started draining them west into the forming Rift Valley. These lakes gradually turned into wetlands, then into playas with temporary water collection during the rainy season, and then into wadi beds draining west. With that, the presence of the highland lakes was terminated.

The lifetime of these lakes during the Pleistocene coincided with the migration from Africa of humans, who used the lakes' water for drinking and for hunting animals drawn to the water and used the shores for shelter and other necessities of human settlement.

Al Jafr playa is still an intermittent lake, holding water only during the wet season. Headward-eroding wadis have not yet captured it, but it will ultimately be absorbed by either the Wādī Al H̲asā draining into the Rift Valley or by the easterly draining wadis into Wādī Sirhan. The uplift along the Jordan Rift Valley Shoulder Mountains in the northwestern area of the Wādī Sirhan Depression allowed for the formation of several lakes along that Depression, which runs SE-NW over an original length of ca. 400 km. However, the basalt accumulation from the volcanic eruptions of H̲arrat ash Shām in the northwestern part of the Depression gradually blocked its drainage, allowing in Jordan the formation of the Azraq Lake (Oasis), which dried up during the 1980s.

Highlands Lakes: Their Sediments, Fossils, and Artifacts

According to Al-Nahar and Clark (2009), Lower Paleolithic sites in Jordan are located in three areas: the Jordan Rift Valley north of the Dead Sea on the northern Jordanian Plateau; the Azraq Basin on the southern Jordanian Plateau; and in the Al Jafr Depression. The following gives a short account about some of the ancient lakes, their sediments, fossil contents, ages, artifacts and other human remains, which indicates their role in human migration from Africa across the Levant.

Al Jafr

The Al Jafr Pleistocene lake (*ca.* 1.0–1.8 km^2) contains deposits composed of fine sediments in the center of the basin (*Qā'*), while alluvial sheet-wash deposits cover the basin margins (Bandel and Salameh 2013; Moumani 2005; Huckriede and Wiesemann 1968; Bender 1968). The sediments contain ostracods and mollusk fossils represented by gastropods (*Bithynia opercula*, *Gyraulus,* and *Valvata* spp.), bivalves and ostracods (including *I.* cf. *bradyi*, *C. neglecta*, *Fabaeformiscan dona fabaeformis*, *Pseudocandona* sp., *H. salina* and *Herpetocypris brevicaudata*) (Huckriede and Wiesemann 1968; Mischke *et al*. 2015 and 2017. Huckriede and Wiesemann (1968) suggested that during the Würmian pluvial period the Al Jafr Basin was covered by a freshwater lake. According to Mischke *et al*. (2015), Al Jafr sediments were deposited in shallow freshwater to slightly oligohaline ponds, streams, and swamp environments. Lower Paleolithic artifacts have been found widespread in the Al Jafr Basin, indicating a Late Acheulian occupation by *Homo erectus* populations, with favored locations for butchering large game animals, while artifacts of Middle and Upper Paleolithic sites are rarely found in the basin (Rech *et al*. 2007).

Al Azraq

The historic lake of Al Azraq (*ca.* 600 km^2) formed, according to Salameh and Al Farajat (2006), as result of the blockage of Wādī Sirhan's northwestern extension by basaltic eruptions from Jabal Drūz and associated sediments composed of clastic and chemical sediments, including gypsum covering the margins of the ancient lake. The Pleistocene lake sediments are about 330 kya based on U/Th measurements on fossilized *Cardium* (bivalve) shells (Garrard *et al*. 1977; Abed *et al*. 2008; Ahmad and Davies 2021). Fossils of gastropods, bivalves, ostracods, and plant remains are found in the lake sediments. Paleolithic artifacts have been documented, which indicates the long history of humans inhabiting the area (Rees 1929; Kirkbride 1989; Rollefson *et al*. 2001; Mischke *et al*. 2012). Late Acheulian artifacts assigned to the late Middle Pleistocene, associated with remains of elephants, lions, equids, and rhinoceros, are documented in the lake sediments. They were hunted by Pleistocene humans (Nowell *et al*. 2016; Pokines *et al*. 2019). Recently, Ames *et al*. (2022) concluded that since the late Middle Pleistocene, the central Al Azraq Basin has had three local wet-dry cycles affected by freshwater resources, which in turn affected Paleolithic inhabitants.

Al Ḫasā (Jinz) Lake

In the central part of the Wādī Al Ḫasā catchment, lake deposits have been found indicating that a large freshwater lake occupied parts of the Wadi Al Ḫasā at a maximum level of 815 masl during Late Pleistocene (*ca*. 70 to 20 kya) (Moumani *et al.* 2003; Macumber 2008; Schuldenrein and Clark 1994), though recently, other researchers have reconsidered the Al Ḫasā lake sediments to be an in-stream wetland environment (Rech *et al*. 2017). Lake Al Ḫasā may have existed from Upper Paleolithic times around 26 kya into the Epi-Paleolithic period about 19 kya. According to Schuldenrein and Clark (1994, 2001, 2003) and Clark *et al.* (1987), the Lake Al Ḫasā had cultural deposits near its shore including a rich vertebrate fauna of gazelle, horse, wolf, fox, aurochs, hare, badger, and tortoise. Pollen from *Typha*, *Salix*, *Alnus* (alder), *Quercus,* and other plants of lake/marsh environments were found there. The lake shores were settled by people who camped there. Winer (2010) documented radiocarbon ages from bulk organic sediments, plant macrofossils, and charcoal found *in situ* from archaeological hearths within a unit of the wadi deposits ranging from 32.475 ± 190 to 26.905 ± 150 kya.

Gharandal

Along the eastern course of the Wādī Gharandal, explosed wetland deposits were documented by Bender (1968, 1974, 1975) and Henry *et al*. (2001). These deposits were considered by some to be an ancient lake environment (Mischke *et al*., 2017; Ginat *et al*. 2018), while other researchers interpreted them as riverine wetland deposits (Cowardin *et al*. 1979, Henry *et al*. 2001; Braun 2015). They were dated ~125–70 kya based on OSL analyses (Al-Saqarat *et al*. 2021). The marl sediments contain ostracod assemblages (including *Ilyocypris bradyi, Heterocypris salina, Candona neglecta, Herpetocypris brevicaudata, Scottia pseudobrowniana, Herpetocypris* sp., and *Psychrodromus* sp.), gastropod shell remains, and root traces (Mischke *et al*., 2017; Braun 2015). Lithic artifacts embedded in the aquatic sediments were assigned an age of a minimum 74 ± 7 kya, in the Middle Palaeolithic (Henry *et al*. 2001; Henry 2017; Al-Saqarat *et al*. 2021). Also, other researchers have suggested that the artifacts belong to the Middle and early Upper Paleolithic (*ca*. 150–30 kya) (Bar-Yosef 1987; Henry *et al*. 2001). Gharandal Lake was later captured by the head erosion of Wādī Gharandal to drain into Wādī ʿAraba into the Jordan Rift Valley.

Jurf Ad Darawīsh

To the south of Jurf Ad Darawīsh village, lacustrine sediments of Quaternary age cover several square kilometers of flat topography. In these sediments, Mischke *et al*. (2021) reported different species of fossils including aquatic and terrestrial gastropod shells, ostracod valves (mostly *Potamocypris, Ilyocypris,* and *Pseudocandona*), and charophyte gyrogonites in addition to stem encrustations. Based on the fossils the sediments were interpreted as an in-stream wetland that formed during MIS 5–4 and that, later on, in MIS 3, was replaced by a vegetated alluvial environment. Artifacts found in the Jurf Ad Darawīsh area were assigned to the Lower Palaeolithic to Epipalaeolithic ages (85–65 kya). They indicate a relatively long record of human occupation of that area (Bender 1968; MacDonald *et al*. 2000 and MacDonald *et al*. 2001; Mischke *et al*. 2021). Lithified artifacts found within the lacustrine sediments date to the Paleolithic (Moumani *et al*. 2003). Without the presence of a wetland in that area ancient humans would not have found water, food, shelter, and other life necessities.

Mudawwarah

In the area southeast of Mudawwarah Police Station, close to the border of Saudi Arabia, lake sediments cover an area of around 7 km^2. The lake sediments consist of conglomerates, marls, and sands with surficial coquina deposits. The lake deposits belong to the Quaternary Halat ʿAmmār Formation (Masri 1988). The surficial coquina deposits are primarily composed of bivalve shells (mainly *Cerastoderma glaucum*). In addition, brachidontes, ostracods and shell of the small gastropod belonging to *Hydrobia* were found. The fossil assemblages reflect freshwater to brackish environments (Masri 1988; Petit-Maire *et al*. 2010). The age of the Mudawwarah aquatic deposits ranges between 170 ± 14 kya and 77 ± 8 kya based on U/Th dating, with a concentration of ages of about 125 kya (Petit-Maire *et al*. 2010).

Discussion

Epeirogenic uplift tectonic movements during the Late Tertiary period resulted in the regression of the Tethys Sea, causing the land of the Levant to start its emergence from that sea. This new land drained its water into the retreating Tethys Sea toward the north, west, and east. After that, another tectonic activity (taphrogenic activity) began to affect the area, leading to the formation of the Jordan Rift Valley as a major depression. Tectonic activity along the Rift Valley area began a few hundred million years earlier when it started to separate the Arabian Plate from the African Plate along the Red Sea Depression, which continues in a northerly direction through the Gulf of Al ʿAqaba, through Jordan, Syria, and Lebanon to Turkey. When the Rift Valley in the Levant started to break down, parts of the drainage of the Levant became directed into the forming Rift Valley Depression.

The formation of the Jordan Rift Depression was accompanied by gradual uplift of the Depression Shoulders, and the uplift due to taphrogenic tectonics was faster than the epeirogenic uplift that had led to the building of the western mountains of Jordan 1000–1730 masl, compared to the eastern Plateau of 600–850 masl. These tectonic activities led to the formation of different drainage patterns and base levels: inland lakes along the Plateau, lakes in the Rift Valley, and drainage toward the Mediterranean Sea. Sedimentation and erosion, especially headward erosion of the wadis draining the high mountains towards the Rift Valley, caused most of the Plateau lakes to be captured and diverted their drainage toward the Rift Valley again.

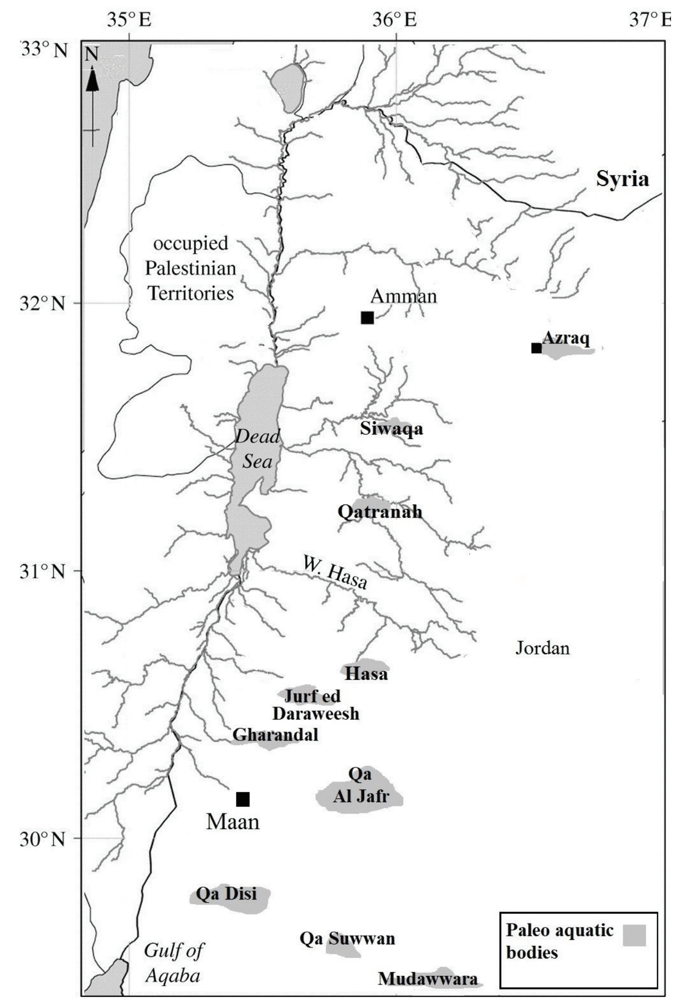
The short-lived Plateau lakes that existed for a few hundred thousand years during the Pleistocene gave human migration waves from Africa an opportunity to settle in spaces that had shelter, food, water, and other life necessities for survival and further migration. The fossils and isotopic age determination of the lake sediments and the artifacts found in their surroundings document the existence and disappearance of these lakes and their prominent role in the migration of different human species through the Levant.

Conclusions

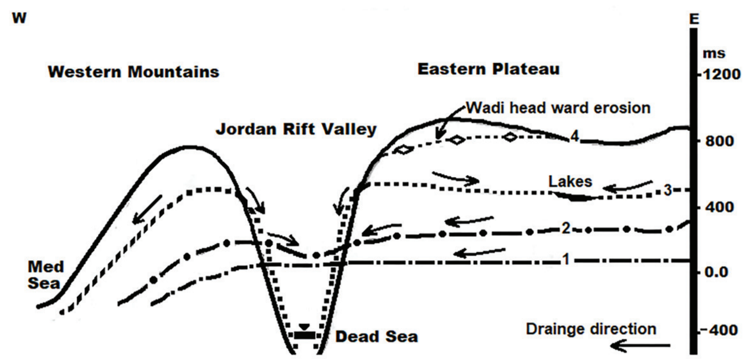
The Quaternary Period in the Levant was characterized by strong tectonic movements resulting from epeirogenic and taphrogenic uplifts and the formation of the Jordan Rift Depression. These uplift movements have been differential where, at times, the shoulders of the Rift Valley rose higher than the eastern Plateau of the country. That caused the original westward drainage system of the Levant area toward the retreating Tethys Sea to be reversed. Accordingly, the eastern parts of the Shoulder Mountains started to drain east and the western continued to drain west. The easterly draining water and the Plateau drainage itself collected along the flats of the Plateau and formed temporary lakes. These lakes collected suspended and chemical sediments from the incoming wadis. Headward erosion of the westerly flowing wadis towards the Rift Valley incised their courses deeper and deeper until they reached the lakes on the Plateau and started draining their water westward again. The interplay of tectonic movements, sedimentation, and erosion resulted in reversals of drainage, the formation of the highland lakes, and their disappearance.

During the Middle Pleistocene the Shoulder Mountains of the Jordan Rift Valley must have had an elevation of around 400–500 masl, as evidenced by, among other things, the Middle Pleistocene gravels deposited into the Red Sea which lay now at an elevation of some 500 masl. The Plateau with its lakes could have had elevations of only around 400 masl. The combination of relatively low topography and the presence of highland lakes as a provider of water, food, shelter, and other human necessities must have allowed migrating humans to settle. Most of these lakes have now disappeared.

The ages and lifespans of these lakes have been obtained from their faunal and floral fossil remains and from radioactive age determinations which helped to date the artifacts past humans left behind. It is believed that without the interplay of rapid tectonics, sedimentation, and erosion, the different waves of human migration and settlement from the Middle Pleistocene onward would have been more difficult or even impossible.



1. Pleistocene lake and wetland sites on the Plateau of Jordan (image by the authors).



2. Stages of the interplay of tectonic forces (epeirogenic and taphrogenic), sedimentation, and erosion that led to the formation and disappearance of the highland (Plateau) lakes and wetlands in Jordan (image by the authors):

1. Start of the emergence of Jordan and the Levant from the Tethys Sea during Middle Tertiary times (Epeirogenic Uplifts).
Further epeirogenic uplifts with beginning of break down along the Jordan Rift Valley that formed a new base level for the drainage.

2. Continued epeirogenic uplifts accompanied by stronger taphrogenic uplifts of the shoulders of the Rift Valley that led the drainage of the Plateau and of the eastern parts of the eastern Shoulder Mountains of the Rift Valley to collect in the center of the Plateau to form the highland lakes. The western parts of the eastern Shoulder Mountains kept draining into the Rift Valley.

3. Sediments carried with the incoming water deposited at the bottom of lakes, causing the levels of the lakes to rise.

4. Continued taphrogenic and epeirogenic uplifts. Wadis draining the eastern Shoulder Mountains into the Rift Valley incised their courses eastward and captured most of the Plateau lakes and drained their catchments again into the Rift Valley.

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