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Paleoclimates of the Cenozoic of Egypt: Evidence from Fossil Plants

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Abstract

Paleoclimatology is the study and reconstruction of past climates for which direct measurements were not taken. Paleoclimatologists, paleobotanists and geologists use a number of proxies to study the past climatic changes and to understand the natural variation and evolution of the current situation; as climate change in the 21st century has been regarded as a threatening issue. Paleoclimate interpretation using fossil plants is one of the most important contributions of paleobotany to earth sciences, as they are considered as reliable indicators of long-term climatic changes, especially during the Cenozoic era; which encompassed a wide range of climates. Research work on the fossil flora of Egypt has started 150 years ago; with paleoclimate inferences being displayed in the different references. Thus, this review collates all the Egyptian paleobotanical and paleopalynological data to reconstruct the Cenozoic climate in Egypt. Spanning through the epochs of the Cenozoic era; woods, leaves, fruits, seeds, pollen and spores have been recorded from different sites. Apparently, the paleoenvironments differed but a tropical to subtropical climate was prevalent during the Cenozoic in Egypt. However, the usage of different proxies, other than fossil plants will reveal a better picture of the past climate.

Keywords: Paleoclimate, Fossil plants, Cenozoic era, Egypt

Introduction

Paleoclimatology is the study of ancient climates taken on the scale of the entire history of Earth. Understanding the possible impacts of global change is not possible without studying the past climates (Uhl et al. 2006). Paleoclimate reconstruction, therefore, can provide a long-term baseline for understanding modern and future conditions.

Prior to the widespread availability of instrumental records, paleoclimatology uses a variety of proxy methods from Earth and life sciences to obtain data previously preserved in tree rings, locked in the skeletons of tropical coral reefs, sealed in glaciers, boreholes, shells and fossils. The past climate interpretations range from simple qualitative assumptions to quantitative assessments; including computer-based process simulations. All approaches to paleoclimatic reconstruction rely on understanding the relationship between climate and the source of evidence (Shuman 2007). Paleoclimatic data is therefore useful to help assess the dangerous level of human interference with the atmosphere and the climate; especially that climate change is the predominant scientific, economic and political issue of the 21st century (Hansen 2009).

Paleoclimate estimates derived from the fossil record are important to give the current climate a historical perspective and serve as a test for global circulation models which are used to estimate future climate (Pan 2007). All types of fossils are useful in “reading the rock record”, elucidating the Earth’s history. Thus, they are among the most important proxies for scientists attempting to learn about past climates and environments, a major focus of research in Earth and environmental sciences, motivated in part by concerns over future climate change (Seyfullah 2012).

Fossil plants in particular can be useful for archiving past climate signals. Terrestrial plants have a unique degree of dependence on the environment to which they are committed by their sedentary habit, thus plants have a direct relationship with their environment and climate change is encoded in physiognomic change. These changes have been decoded by various workers (such as Wheeler & Baas 1991, 1993; Wiemann et

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al. 1998, 2001; Poole 2000) to reconstruct past climates and climatic changes. Detailed information on environmental and climatic conditions in the past can be provided by all types of fossil plant remains i.e. wood, leaves, fruits, seeds and propagules (Bergen & Poole 2002).

There are two main methods in which fossil plants can contribute evidence that will help to reconstruct past climates: The first method is based on finding the systematic affinities of the fossil taxa to reconstruct the paleoclimate using climatic requirements of the presumed living analogue or Nearest Living Relative (NLR). This method assumes that the fossil taxon had a similar climatic tolerance and habitat to its nearest living relatives (Bamford 2011). The second method does not require a precise identification of fossil specimens (Sakala 2007). This method takes into account the correlation between climate and selected features of the plant structure such as; leaf and wood physiognomy, paleodendrology and stomatal index.

Global climate during the beginning of the Cenozoic era (65 million years ago) (Table 1) continued in the warm mode that persisted before, in the Cretaceous period. The early Cenozoic was symbolized by an almost complete absence of continental ice, in addition to small temperature gradients between low and high latitudes. The global temperatures were also higher than today (Mudelsee et al. 2014). By the end of the Eocene, temperatures had dropped drastically and seasonality had returned. The climate became cool, dry and seasonal in the Oligocene and Antarctica, for the first time in the Cenozoic, was covered extensively with glaciers. Warmer conditions prevailed in the first half of the Miocene. However, in the latter half; cooler temperatures, decreased rainfall and increased seasonality overruled (Zachos et al. 2008). Following the late Miocene; the first half of the Pliocene was warmer than today and during the last half, temperatures dropped again. Finally, the Pleistocene was a time of global cooling and warming with ice ages and interglacial periods occurring every 100,000 years. During the course of the Cenozoic era, significant changes in Africa's physical setting contributed to ecosystem evolution, as did the local and regional effects of global climate change and biotic interactions (Jacobs et al. 2010).

The aim of this paper is to use the paleobotanical and paleopalynological evidences compiled in El-Saadawi et al. (2020) to gain insight into the prehistoric past and to reconstruct the Cenozoic climates in Egypt.

Table (1). Simplified geological timescale.

Eon	Era	Period	Epoch	Millions of Years	Taxa recorded
Phanerozoic	**Cenozoic**	Quaternary	Holocene	0.0117	
			Pleistocene	2	*Phragmites australis*
		Neogene	Pliocene	5	
			Miocene	23	*Bombacoxylon owenii*
		Paleogene	Oligocene	34	Leaf impressions of Dipterocarpaceae,Cyperaceae and Poaceae
			Eocene	56	Leaves of *Ficus stromeri*, *Litsea engelhardti*,*Maesa zitteli*
			Paleocene	65	*Palaeowetherellia schweinfurthii*, *Nypa*
	Mesozoic	Cretaceous		145	
		Jurrasic		201	
		Triassic		252	
	Paleozoic	Permian		298	
		Carboniferous		358	
		Devonian		419	
		Silurian		443	
		Ordovician		485	
		Cambrian		541	

Paleocene epoch (65-56 mya):

Palaeowetherellia schweinfurthii (Heer) Chandler fossil fruits were described by Chandler (1954) from the Paleocene of Farafra and Quseir (El-Saadawi et al. 2020). Its exclusive record from marine sediments infers that this plant represents a coastal or mangrove environment and it was suggested that the fruit is of tropical nature. The disappearance of *Palaeowetherellia* (Heer) Chandler from the Egyptian flora coincides with a change from marine to terrestrial depositional environments (Mazer &Tiffney 1982).

Chandler also reported *Nypa* Wurmb fruits from Quseir (El-Saadawi et al. 2020). *Nypa* plant thrives in the mangrove environment, favoring brackish water environments such as quiet estuaries or shallow lagoons (El-Soughier et al. 2011). Nowadays, the mangrove palm *Nypa* is confined within the Indo-West-Pacific region. In this region, the climate is tropical with mean temperatures above 18°C all over the year with seasonal variations of precipitation (Moreno-Dominguez et al. 2016).

Eocene epoch (56-34 mya):

El-Saadawi et al. (2018) reported from the late middle Eocene of Wadi El-Hitan casts and moulds of massive rhizomes comparable to those of the extant mangrove-associate palm *Nypa fruticans* Wurmb. The paleoclimate that have been interpreted for the presence of fossil *Nypa* remains have been tropical-subtropical and characterized by low seasonal variation; taking in consideration that this genus grew under similar conditions to its modern counterpart (El-Saadawi et al. 2020).

Furthermore, a summary of earlier publications on fossil plants of Fayum area was given by El-Saadawi (2006): leaves of *Ficus stromeri* Engelhardt (Moraceae), *Litsea engelhardti* Kräusel (Lauraceae), *Maesa zitteli* Engelhardt (Myrsinaceae), ?*Nymphaeites* sp. (Nymphaeaceae) and a fruit of *Securidaca tertiaria* Engelhardt (Polygalaceae) were described from the upper Eocene of north Dimé. It was concluded that the recorded taxa has many nearest living relatives growing in the tropics and many other growing in monsoon climate with alternating wet and dry periods.

Oligocene epoch (34-23 mya):

Leaf impressions of Dipterocarpaceae, Cyperaceae and Poaceae were described by Darwish et al. (2000) from the lower Oligocene of Farafra Oasis. They all indicate a humid climate. Species of Dipterocarpaceae constitute forest trees of the humid tropics or subtropics and species of Cyperaceae are known to be chiefly marsh plants. Poaceae taxa also grow in swamps (El-Saadawi et al. 2020).

The Cairo Petrified Forest (CPF) is considered as the most famous petrified forest in Egypt, with the most diverse Oligocene assemblage. A comprehensive overview of all the paleobotanical data about the CPF was presented in El-Saadawi et al. (2017). It has to be mentioned that three monocot woods are reported from the CPF in addition to the 27 dicot woods reported from there (El-Saadawi et al. 2020). Families Arecaceae, Combretaceae, Ebenaceae, Fabaceae (its three subfamilies are represented), Fagaceae, Malvaceae *s.l.*, Monimiaceae and Moraceae are reported from the CPF. The main physiognomic features of the woods of the CPF prove that the paleoclimate of their growth environment was subtropical to tropical with well-defined seasons and rainfall seasonality. Moreover, the paleoclimate of the recorded *Palmoxylon* species supports the tropical or subtropical nature, based on the comparison with the climates under which modern palms live today (Kamal El-Din et al. 2013).

The macrofossil flora (wood, leaves, fruits and seeds) of Gebel Qatrani Formation indicates a tropical forest vegetation and mangrove swamps. Thus, it was suggested by El-Saadawi (2006) and Nour-El-Din et al. (2018) that in the Oligocene, the Fayum area was coastal and subtropical to tropical in climate regime.

Miocene epoch (23-5 mya):

Detarioxylon aegyptiacum (Unger) Louvet (Fabaceae) was described by Kamal El-Din & Refaat (2001) from the lower Miocene Rudeis Formation in southern Sinai. The xylotomical features of the species indicate tropical low-land habitat accompanied by seasonal climatic changes.

Pollen palynoflora from the Miocene of the Gulf of Suez was studied by El-Beialy et al. (2005). The nearest living relatives for the recorded taxa is the palynofloras of southeastern Asia and North America, where the modern counterparts in these regions grow in a fairly warm, mild subtropical area. Thus, the recorded palynoflora deduced a subtropical to warm temperate climate.

Twenty-one dicot species and 14 monocot species (all are *Palmoxylon* species) were listed by El-Saadawi et al. (2014). The woods with wide vessels are compatible with the warm humid climate suggested for the early Miocene in the region in general. It was assumed that a drier and more seasonal climate in the middle Miocene till the Pleistocene followed the early Miocene climate of North Africa (Salard-Cheboldaeff 1979; Morley & Richards 1993; El-Saadawi et al. 2020).

Kamal El-Din et al. (2015) described *Bombacoxylon owenii* (Carruthers) Gottwald (Malvaceae *s.l.*), *Cynometroxylon* sp. cf. *holdenii* (Gupta) Prakash & Bande (Fabaceae), *Dipteroxylon africanum* Bancroft (Dipterocarpaceae) and seven *Palmoxylon* species (Arecaceae) (Kamal El-Din et al. 2013) from the lower Miocene Moghra Formation in Siwa Oasis. The fossil wood taxa of

Siwa Oasis reveal a warm tropical climate with minor seasonality in precipitation.

Three species of *Terminalioxylon* namely, *T. edwardsii* (Mädel-Angeliewa & Müller-Stoll), *T. geinitzii* (Mädel-Angeliewa & Müller-Stoll) and *T. primigenium* (Mädel-Angeliewa & Müller-Stoll) were described by El-Noamani (2020) from three lower Miocene sites in the northern part of the Western Desert of Egypt viz., Gebel El-Khashab, Wadi Natrun and Cairo-Bahariya desert road. It was inferred from their xylotomical features that the *Terminalioxylon* species are a part of tropical vegetation; either dry deciduous forests or savannas.

Pleistocene and Holocene epochs **(2-0.0117 mya):**

Gardner (1935) recorded angiosperm stems, leaves and fruits from the Quaternary strata of Kharga Oasis (El-Saadawi et al. 2020). It was concluded from the physiognomic characters of the recorded taxa that there was a deficiency of rainfall; although groundwater was provided by the springs.

El-Saadawi et al. (1975, 1987) reported silicified rhizomes of *Phragmites australis* (Cavanilles) Trinius ex Steudel and silicified roots of *Tamarix* sp. from Pleistocene deposits at Dimé. It was noted that these plants grew in swamps around the old Moeris lake. El-Saadawi et al. (1978) also reported 41 species of fossil diatoms from the same deposits. The majority was centric and freshwater forms; which indicates that old Moeris lake was once a freshwater lake.

Leaves of angiosperms (dicots and monocots) were described by Darwish (2003) from Quaternary tufa deposits at Bir Dungal, southwestern Desert of Egypt. It was inferred that the climate was humid in this region due to the presence of plant families such as Cornaceae, Moraceae and Salicaceae; thriving today in temperate climates.

Ziada (2018) identified 57 Holocene palynomorphs from the Fayum depression. They included three spores of bryophytes and 12 spores of pteridophytes (Ziada et al. 2018). According to El-Saadawi & Shabbara (2007), *Sphagnum* Linnaeus is extinct, at present, from Egypt. It was reported from the Holocene strata of Fayum and its presence refers to the prevalence of moist acidic soils of swamps or river margins (Freitas et al. 2015). The presence of *Blechnum* Linnaeus, *Lycopodium* Linnaeus and *Selaginella* Palisot de Beauvois in the Holocene strata of Fayum is an indication that the paleoclimate of the region was more humid than today and the temperature during the summer did not exceed 25-30°C. The rise in summer temperatures today is the reason behind the complete elimination of the majority of the recorded pteridophytes (Ziada et al. 2018).

Ziada (2018) also reported *Pinus* Linnaeus, *Betula* Linnaeus and *Quercus* Linnaeus pollen grains from the Holocene of Fayum depression. Their presence is an indication that the climate at that time was cooler than the present. *Pinus* is a constituent of temperate floras and if present in the tropics; it is generally found on elevated regions, suggested to be Jebel Qatrani. The extinction of *Pinus* from the present-day flora of Egypt could be attributed to the resin found in *Pinus* tissues; which raises the temperature of the plant than its surroundings if subjected to heat. Moreover, *Betula* and *Quercus* are not present in the today Egyptian flora according to Boulos (1995) and El-Hadidi (2000). Both arborescent genera are mainly found in the Northern hemisphere where the climate is temperate. Furthermore, the existence of *Erica* Linnaeus pollen grains furtherly supports that the climate in the Holocene was much cooler than today (Ziada *et al.* 2018).

From the 42 recorded fossil gymnosperm and angiosperms by Ziada (2018), only 16 genera still exist to date in Egypt (supposing that the fossil pollen grains were not transported from other sites) whilst 26 genera are extinct. More than half of the recorded genera are herbs (27 taxa) whereas the trees and shrubs are only represented by 15 genera. This fact pinpoints to the progressive water stress and lack of heavy rainfall that affected the climate of Egypt, as perennial trees were mostly found in the Cretaceous and Early Cenozoic. The domination of the herbaceous forms in the Quaternary is a recent adaptation to overcome the water stress (El-Saadawi et al. 2017).

Finally, it can be concluded from the latter Holocene pollen assemblage that the paleoclimate was tropical to subtropical. However, some types (*Pinus*, *Betula*, *Quercus*, *Blechnum*, *Lycopodium* and *Selaginella*) indicate cooler and more humid climate. They probably lived on elevated montane areas.

Conclusion

The Cenozoic era, the time of extinction of the dinosaurs at the end of the Cretaceous period (David & Gautam 2021), illustrates the huge magnitude of natural climate change; and because climate change is a threatening issue which is impacting human lives; it is essential to try to reconstruct the paleoclimate using different proxies.

According to the preceding paleobotanical and paleopalynological data, it can be deduced that a tropical to subtropical climate prevailed during the Cenozoic era in Egypt (considering that the fossil record is still incomplete). However, the oscillating global changes in temperature during the Cenozoic were also documented in Egypt and were the justification for the extinction of certain taxa and rather whole plant families from the Egyptian floras; attributed to changes in the environmental conditions, which became unfavorable for their natural growth. Progressive water stress and lack of heavy rainfall affected the climate of Egypt extensively, and this was the main reason behind the domination of annual herbaceous forms. It is also the cause of the elimination of the mosaic of halophytic, swampy and marshy habitats which covered areas of Egypt.

Documentation of the Cenozoic paleoclimate of Egypt continues to improve with each and every new locality being discovered and taxa being recorded. Continued exploration will fill the gaps in the fossil record to become a more complete narrative for past climates and environments. However, data from fossil plants must be compared with records based on marine organisms and chemical isotopes to offer the most robust model for the paleoclimates and paleoenvironments.

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