Evolution of the Nile River Through Time

Bahay Issawi and Sherif Farouk

Abstract

The Nile River, which receives its water from the Ethiopian Highlands and the Central African lakes, is often considered as the world's longest South-North river. The purpose of this chapter is to produce an updated overview of the stages of the formation of the Nile drainage system. It is based on bringing together all of the available data concerning the stratigraphy and paleoenvironments which prevailed during the evolution of the Nile River from the Ethiopian Highlands to the Mediterranean Sea. During the Messinian Salinity Crisis (MSC) in the whole Mediterranean, river systems were deeply down-cut and extended throughout most of North Africa and South Europe. The Qena River, which had its catchment area in the Southern Galala Plateau and the surrounding desert before the Nile, was Egypt's master stream before the Nile, a south-west ward drainage. It has been proposed that waters from the Qena River continue to flow to the Atlantic Ocean, which is known as the Trans African Drainage System (TADS). The earliest Nile sediment deposited by a river flowing into Egypt from Ethiopia on its way to the Mediterranean is considered to be the Dandara Formation. The presence of an Ethiopian heavy mineral suite within the Middle Pleistocene Dandara Formation, which has been extensively documented on both banks of the Nile River in Upper Egypt, distinguishes Nile sediments from those found in other riverine systems.

Keywords

Nile River • White Nile • Blue Nile • Nile evolution • Africa • Egypt

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1 Introduction

The Nile is generally regarded as the world's longest river with a total length of about 6800 km and one of the most notable geomorphological characteristics in Africa. Its drainage basin is shared by eleven countries (Fig. 1): Tanzania, Rwanda, Uganda, Burundi, Kenya, the Democratic Republic of the Congo, Eritrea, Ethiopia, South Sudan, the Republic of Sudan, and Egypt (Liu et al., 2009). By measure of the volume of water flowing annually, the Nile is one of the smallest of the main world rivers. It has two main tributaries that meet at Khartoum: the White Nile, which starts from the Lake Victoria basin, and the Blue Nile, which starts from the Ethiopian Plateau. The Nile River is the primary source of water supply for Egypt and Sudan, besides both renewable and non-renewable groundwater. The Holocene Nile is regarded to be of significant archaeological importance, since ancient communities in Egypt were largely dependent on it for drinking water and irrigation. Most Egyptians lived along the Nile banks, and the Nile has played an important role in establishing one of the planet's earliest civilizations. Today, the most important problems facing many African countries north of the equator in achieving sustainable development are the scarcity of fresh and clean water, which is combined with a rapid increase in the population, and extreme climate change (Issawi et al., 2016). Egypt is one of the most drought-stricken countries in the world due to its location in the arid belt of North Africa. The previous evolution of the Nile River and the shifting tectonic and climate factors over time are not well understood until now (e.g., Fielding et al., 2018; Macgregor, 2012; Woodward et al., 2015).

Our knowledge of the geological and geomorphological evolution of the integrated drainage system of the Nile come from the early and pioneering contributions of Issawi (1976), Said (1981, 1993), and McCauley et al. (1982, 1986) which dealt with the physiography of the Nile in modern times. These studies were followed by more detailed reviews which

Z. Hamimi et al. (eds.), *The Phanerozoic Geology and Natural Resources of Egypt*, Advances in Science, Technology & Innovation, https://doi.org/10.1007/978-3-030-95637-0_17

Fig. 1 The drainage system of the Nile River (after The World Bank, 2000)

have been recently published over the past decade (e.g., Abdelsalam, 2018; Faccenna et al., 2019; Fielding et al., 2017, 2018; Talbot & Williams, 2009; Woodward et al., 2015).

The Eastern Sahara is presently the driest place on Earth with arid to hyper arid climate. Although presently covered by sand sheets of sand dunes, such extensive blanket of Aeolian deposits buries a large number of channel courses indicative a previous pluvial conditions and wetter climate dominating the region. It is probable that the Earth's equator during the Late Eocene or Oligocene was situated at the latitudes of Chad and Sudan in the present-day, which would have resulted in pluvial conditions throughout North Africa (Abdelkareem et al., 2012). However, the northward drift of Africa during the Late Miocene in counterclockwise direction caused the formation of new valleys and abandonment of old valleys and channels in the Sahara. These channels are impossible to be identified during field expeditions or by using aerial photography, therefore, space data surveys are the best way to locate and identify buried older channels with reasonable costs.

Shuttle Radar Topography Mission (SRTM) images provide valuable information on the geological attributes of the Earth's surface. The images expose remnants of paleochannels and give details of paleodrainage systems which are covered with sand sheets. The shuttle images obtained from the Columbia spaceship showed a large network of hidden buried river channels below the covered sand. These images started a long-lasting debate on whether a north-flowing pre-Messinian 'Blue Nile' with connecting tributaries from southern Egypt reached the Mediterranean or Egypt was drained by a significant drainage system prior to the Nile.

In investigating the relation between the Messinian Nile canyon east of the Nile Delta and the Quaternary Nile channels, Egypt, Said (1981) stated that it was one river with different names which flew from south to north across Egypt heading to the Mediterranean Sea and there were five river phases that succeeded each other: Eonile (Late Miocene), Paleonile (Late Pliocene), and the Pleistocene Proto-, Pre-, and Neo-Niles. These river phases are separated from one another by long periods of recession and great unconformities. However, Issawi et al. (2009) disagreed with this theory and suggested that the term "Nile" should be applied only to the south-north-flowing river which gets its water from the Ethiopian Plateau and Central African lakes. He also advocated that the previous rivers that were running during the Oligo-Miocene and the Late Miocene should be considered independent systems. Those rivers that antedated the modern Nile are generally of east–west slope that flew from the eastern part of the Egypt including most of the Eastern Desert to the present-day Western Desert.

During the Late Mesozoic, the maximum north–south transgression of the Tethys took place, covering most of Egypt's surface. This was followed by a retreat of the shoreline during the Early Eocene up until the Oligocene north of Fayoum depression (Issawi et al., 2009). The opening of the Red Sea and the uplift of the Red Sea Mountains in the Eastern Desert started with the retreat of the Tethys shorelines during the Late Eocene (Priabonian) and terminated in the final pulse at about 21 Ma, the boundary between the Aquitenian and the Burdigalian (Early Miocene) (Omar & Steckler, 1995). The initiation and evolution of the Nile River is the result of contribution of several events: regional tectonics (the opening of the Red Sea and East African Rift System accompanying with uplifting of the Red Sea Hills) (Issawi & Osman, 2008), local structures (the presence of Cretaceous and younger faulting), and climate change (the MSC, the emergence of the Sahara and the alternation of wet and dry climate) (Butzer & Hansen, 1968; Said, 1993).

2 Stages of the Nile Evolution

The rise of African swells and Ethiopian Plateau have had an impact on shaping of the Nile Basin which result to change in river patterns and caused the drainage systems to switch northward to initiate the current Nile system and form the modern catchment. This must have caused climatic changes accompanied by increased precipitation and runoff. It is questionable whether this increase of runoff was sufficient to provide permanent integrated river system or each river ended in a separate delta. To answer this question much work has been done on the source to sink relationships to determine the nature and timing of the connection between the Egyptian Nile and the Blue Nile. There is no agreement on when the river first initiated; periods ranging from the Oligocene (Fielding et al., 2018; Gani et al., 2007; MacGregor, 2012; Said, 1981; Steinberg et al., 2011) to the Pleistocene (Issawi et al., 2009; Shukri, 1950) have been proposed for when the Nile trunk river first drained as far south as the Ethiopian Highlands.

2.1 Early Origins of the Oligocene to Late Miocene Nile (North-Flowing Pre-Messinian Nile)

Evidence collected by Issawi and Osman (2008) suggested that there was no Nile till the end of the Miocene but there were many major rivers flowing over Egypt (Fig. 2). The uplift of the southern Galala Bridge led to the formation of north-flowing rivers to the Mediterranean (Ur-Nil River and Bown-Kraus River) and the south-flowing main master stream which had a N-SW direction forming the beginning of the Qena system and he Gilf river, which ran from south to north and during an earlier history (Late Eocene–Oligocene) formed a westerly channel of the rivers which dominated Egypt's surface.

2.2 The Late Miocene Nile (the Messinian Nile Canyon)

The Messinian breaking near the end of the Miocene ($\sim$ 5.8 Ma) of the connection between the Atlantic Ocean and the Mediterranean Sea led to the desiccation of the sea into a number of isolated lakes (Hsü et al., 1973). The dramatic sea-level fall during the Messinian salinity crisis and the nearly empty Mediterranean Sea caused a phase of acute degradation and produced canyons along the course when the rivers were emptying their waters into the sea as they carved their channels at least 2–3 km deep to reach the new base level, the floor of the Mediterranean Sea. The Nile carved a deep bedrock canyon (Fig. 3), which extended for 1200 km from the Mediterranean Sea to just north of Aswan (Chumakov, 1967). This canyon was deeper and longer than the Grand Canyon of the Colorado River. Approximately 80,000 km^2 of rock and sediment were eroded from the canyon during the Messinian and replaced by Pliocene deposits. The Late Miocene Nile generated a number of fans further downstream in the area of the North Delta Embayment.

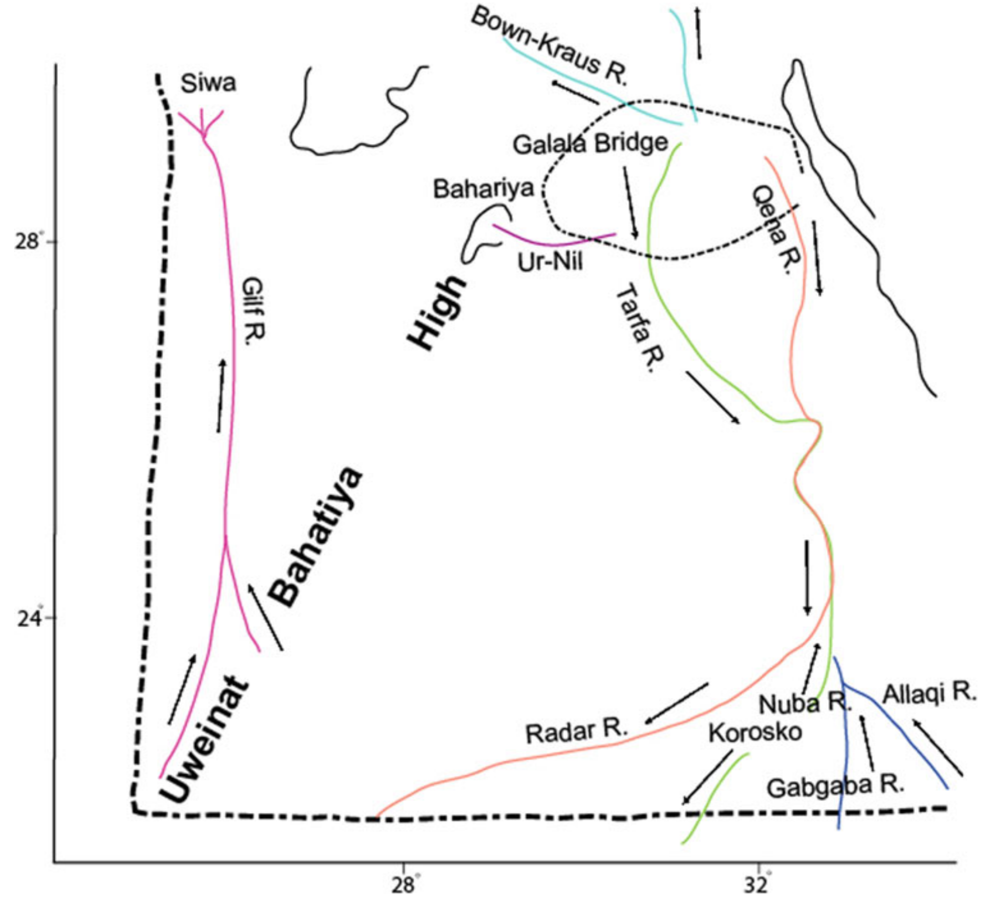

Fig. 2 Egypt during the Late Oligocene–Miocene (after Issawi & Osman, 2008)

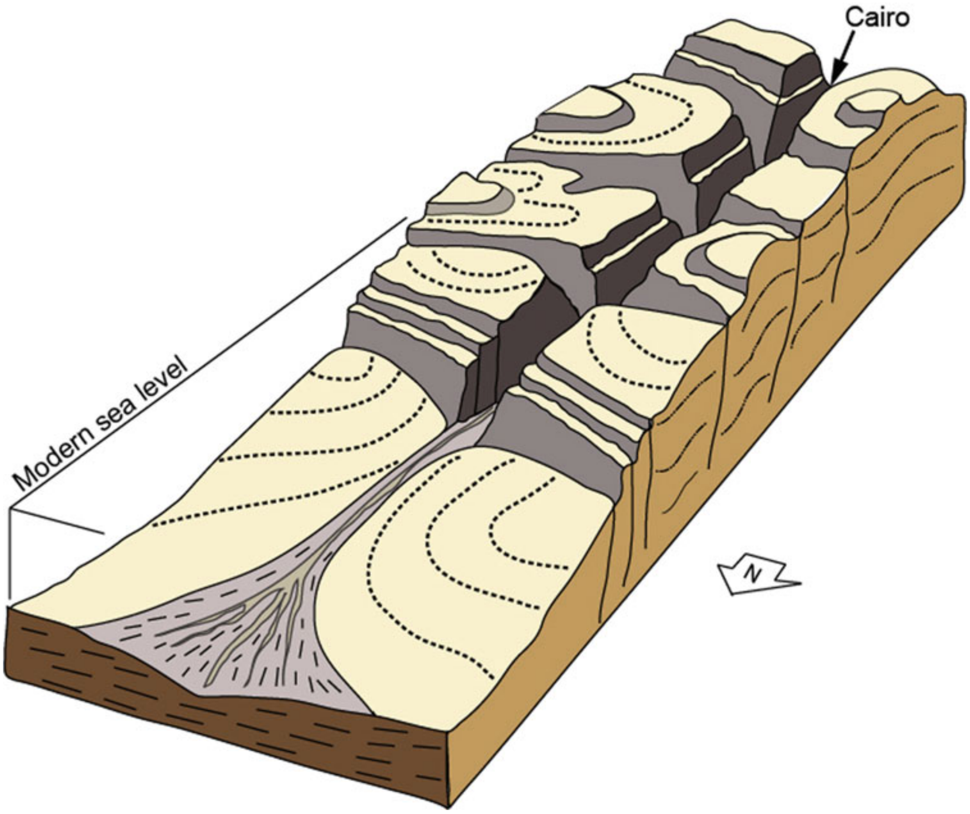

Fig. 3 Block diagram of the Nile Canyon (after Said, 1981)

2.3 The Pliocene and Quaternary Niles

By the end of the Miocene and the start of the Pliocene, the Mediterranean Sea and the Atlantic Ocean were connected again. Higher Pliocene sea-levels flooded the canyon, turning it into a narrow, long gulf that reaches Aswan in the south and filling about one-third of the depth with marine sediments (Chumakov, 1967). The sea water penetrated the Egyptian land, filling a wide area estimated to be 60 km wide (Issawi et al., 2001). During the Late Pliocene, the transgressive water changed into regressive water, resulting in a changed in lithofacies from marine to brackish deposited with a sediment load derived from local wadis of fine-grained clastics as the fluvial freshwater zone shifted progressively northwards toward the modern Mediterranean coastline. The deeper part of the gulf in the north contains a huge thickness of clay deposits, 1854 m in the subsurface Kafr El Sheikh Formation of the Delta (Issawi et al., 2005). Only drilling in the Aswan area has revealed the deep buried Pliocene marine facies. The filling of the gulf area continued through the whole Early Pliocene. During the Middle and Late Pliocene, the nearly empty gulf became a good burial place for the sediments brought by the Nile River. By the end of the Pliocene and the beginning of the Quaternary, the shoreline of the Mediterranean Sea nearly coincided with its present line. The drop of water level in the Mediterranean was a result of the building of thick ice sheets on both poles of the earth. In the upper Nile Basin, Late Quaternary climates have fluctuated between cold-dry and warm-wet conditions. Fluctuations in the climate in Africa during the Quaternary holds a great impact on the behavior of the Nile sediment system (Cockerton et al., 2015). El Mahmoudi and Gaber (2009) carried out geoelectric resistivity surveys in the eastern part of the Nile Delta and correlated between the Messinian canyons (wadis) and the Late Quaternary channels. It was revealed that above the Messinian canyons remained a negative geomorphic characteristic until the time of the channeling of the Nile historical branches into the Nile Delta.

The Nile today flows through a variety of strata, including the volcanic Ethiopian Highlands in the south, Precambrian foundation rocks of the Saharan Metacraton and Arabian–Nubian Shield, and a Phanerozoic successions cover that extends over much of its drainage area (Fig. 4). The Qena Sand (Said et al., 1970) is the oldest Quaternary deposit in the Nile Valley. It unconformably overlies, perhaps, the Pliocene (?) Muneiha or the Issawia formations. Both of these units represent the Late Pliocene's regressive phase; the Muneiha is a 14.5-m-thick clastic layer, while the Issawia is a 22-m-thick brecciated limestone. The Qena Formation at east Kom Ombo covers the plain of Burg El Makhazin between the embouchures of Wadi Kharit and Wadi Shait. The very interesting observation about the Qena Formation is that it stretches to the other west side of the river in a sloping sheet-like feature which is now cut by the Nile water. The sheet was deposited by a river running from east to west before the onset of the Nile. The Qena Formation represents the resumption of the E–W drainage system above the buried gulf channel after the regressive phase of the Late Pliocene. The chocking of the channel was very uneven, resulting (later when the current Nile used this channel) in an irregular floor of the river which obstructs the navigation routes at present.

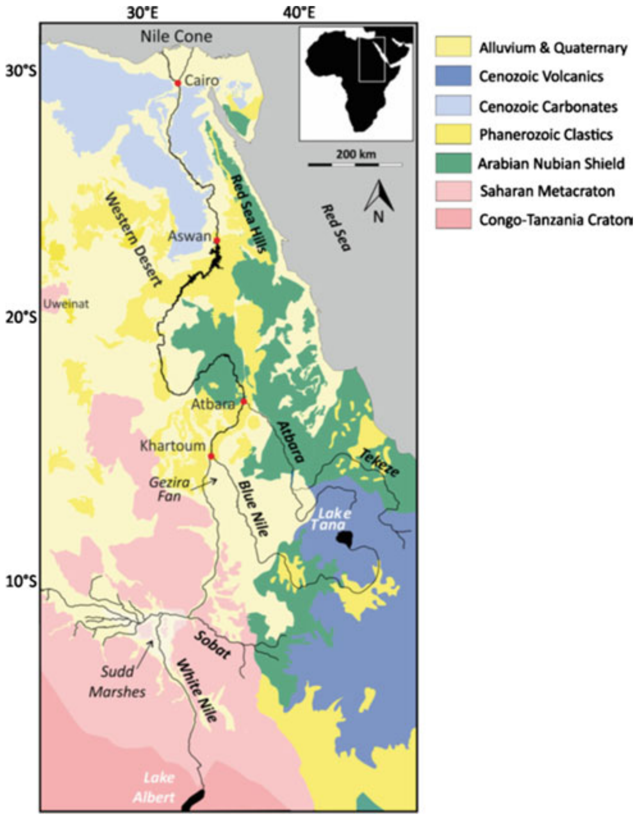

Fig. 4 Geological map of the Nile drainage (Fielding et al., 2018)

The important diagnostic characteristic distinguishing Nile sediments from other riverine systems is the inclusion of an Ethiopian heavy mineral suite. The sediments are rich in pyroxenes (mainly augite) and amphiboles, with an intermediate epidote content and strongly dwindled zircon and ZTR values; certainly indicating Ethiopian derivation. This suite is found in the silt of the Dandara Formation, which is well exposed in Upper Egypt on both banks of the Nile. It is believed that the Dandara is the first sediment deposited by a river coming into Egypt from Ethiopia heading toward the Mediterranean.

The silt beds below the Dandara Formation are known as the Ghawanim Formation (Omar, 1996), and include both

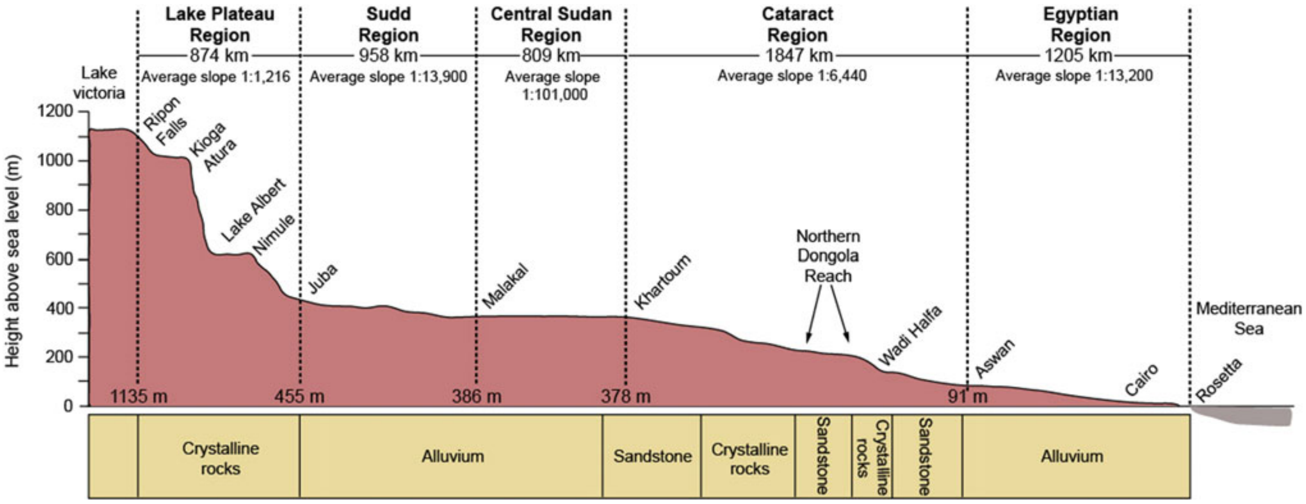

Fig. 5 Long profile of the Nile from the White Nile headwaters to the Mediterranean Sea (after Said, 1981)

Egyptian and, to a lesser extent, Ethiopian minerals. Thus, it seems that the beginning of the Nile in Egypt was a weak flowing drainage while the Qena System was still active, hence the mixture of the two suites of minerals. Since the Dandara Formations includes only Ethiopian minerals, a cessation of Egyptian waters into the old river systems is indicated. Radiocarbon dating of the upper Dandara Formation gives an age of 213 ± 14 ka (Issawi & McCauley, 1992), which indicates even an older age for the lower part of the Dandara and the Ghawanim formations. The presence of seventy species of nilotic fishes and crocodile remains in the Tarfawi–Sahara area, 300 km west of the Nile, demonstrates a link between the Nile and the faunal location (Wendorf & Schild, 2014). The fauna is 174 ka at elevation of about 247 m above sea-level. The various and extensive playas south of Sin El Kaddab, as well as the Bir Tarfawi–Bir Sahara stretch as well as the playas along the Darb El Arbain, Kharga, and Dakhla scarps are all less than 200 m above sea-level, meaning that during the Late Pleistocene, Nile waters flowed into these depressions.

2.4 The Modern Nile

The White Nile supplies only about 30% of the water and 3% of the sediments to the Nile System because most of the sediment load is trapped in the Sudd marshes. The Blue Nile, which flows in a northwest direction and joins the White Nile at Khartoum, supplies the Nile System with about 57% of its water and about 60% of its sediment load. The Tekeze–Atbara River contributes an additional ~ 22% of water and ~ 25% of sediments to the Nile System (Garzanti et al., 2015). The Nile flows through six discrete regions which display differences in their geologic history, geomorphological features, and environment. These regions were described by Said (1981) (Fig. 5) as:

1. The Lake Plateau at the southern headwaters of the White Nile in equatorial Africa.
2. The Sudd swampy areas and Central Sudan regions with larger channel belts and low-gradient floodplains.
3. The Highlands of Ethiopia form the headwaters of the Blue Nile and the Atbara River.
4. The Cataracts region extends from northern Egypt at Cairo to Sudan at Khartoum.
5. The Egyptian Nile delta is a low-gradient complex in the Mediterranean Sea.

3 The Nile's Water and Resources

The most significant concern facing many African countries north of the equator is the scarcity of freshwater, which when paired with rapid population increase, might lead to a shortage of water for irrigation and economic necessities. In comparison to the United States, which has a freshwater potential of about 10,000 m^3 per person per year, Egypt, west Sudan, east Libya, and east Chad have freshwater potentials of less than 700 m^3 per person per year, with Somalia having even less. Such scarcity of water inevitably leads to conflicts such as the Darfur tribal war and the Sudan–Chad confrontation, not to mention the dispute between Ethiopia and Sudan and Egypt over the construction of a massive dam on the Blue Nile just upstream from the Sudan border, in a seismically active region near the Ethiopian Rift. It is surprising, therefore, to realize that large amounts of water originating in central Africa and the Congo are lost in the wetlands of the Bahar El Gebeland and Bahar El Zaraf depressions in western South Sudan. This leads to the suggestion that the ancient Cenozoic river system, which flowed naturally from the south over what is now the Sahara Desert, may be exploited to bring freshwater to the populous areas of northern Africa at a comparatively modest cost. Some of the Congo River's northern feeders, such as those around Buta or Ueley further north, have modest gradients that might be reversed to allow water to flow into these natural collectors. Satellite imagery reveal river channels that could convey water from the sand-filled Gilf river channel or further west into the ancient Chad–Libya mega system. The main trunk of the rejuvenated channel would run from the swampy areas in western South Sudan to Darfur at El Fasher, then to the Wadi Magrur and Wadi Howar. A reservoir could be built at Merga, 100 km north, to supply two primary systems: the Paleo Gilf, which flows into Egypt across the Sudanese border east of Gebel Kamel, and the Paleo Kufra, which flows into north Chad and south Libya west of Gebel Uweinat. The proposed new canals would use the existing excavations made by the paleo river systems to establish new life in dead deserts. Gradient reversal can be done in recent streams, such as Uere and Uele, as well as in some of the underground channels and Wadi Howar, by elevating the water level through dams on the channels' courses. The dams would serve a variety of purposes including generating electricity, creating farmlands in currently desert areas, and generally increasing the amount of water available to residents in these thirsty places.

4 Conclusions

The evolution of the Nile drainage system remains poorly understood. Since the acquisition of the Shuttle Radar Topography Mission (SRTM) images, which has the capability of mapping paleodrainage systems, a debate has erupted concerning the nature and timing of the connection between the Blue Nile and the Egyptian Nile. We presented the geological arguments based on source to sink evidence supporting the idea that the Nile River was established as a main drainage system reaching from the Ethiopian Highland to the Mediterranean Sea around 30 Ma ago (Oligocene). The oldest Quaternary deposits in the Nile Valley are the Qena Sand, which has a suite of minerals specific to Egypt's Eastern Desert. The Ethiopian mineral suite is different and only recognized in the Ghawanim Formation and the overlying Dandara Formation. The Ghawanim Formation includes both Egyptian and Ethiopian suites, indicating that the Qena System was still partially active when the Ethiopian water reached Egypt. The top third of the Dandara is about 213 ± 14 ka, which gives an approximate age for the Ethiopian water with its special mineral suite of at least 1/2 million years; the age of the present Nile.

Within the population growth and water scarcity, we have no other source for water increase except to obtain water from the White Nile or the Congo River by digging a canal in the Sudan's Western Desert and through rejuvenating the old dry rivers in west Egypt (Gilf River) and in east Libya (Kufra River). Prosperous settings for people in south and west Sudan, east Chad, west Egypt, and east Libya will be possible.

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