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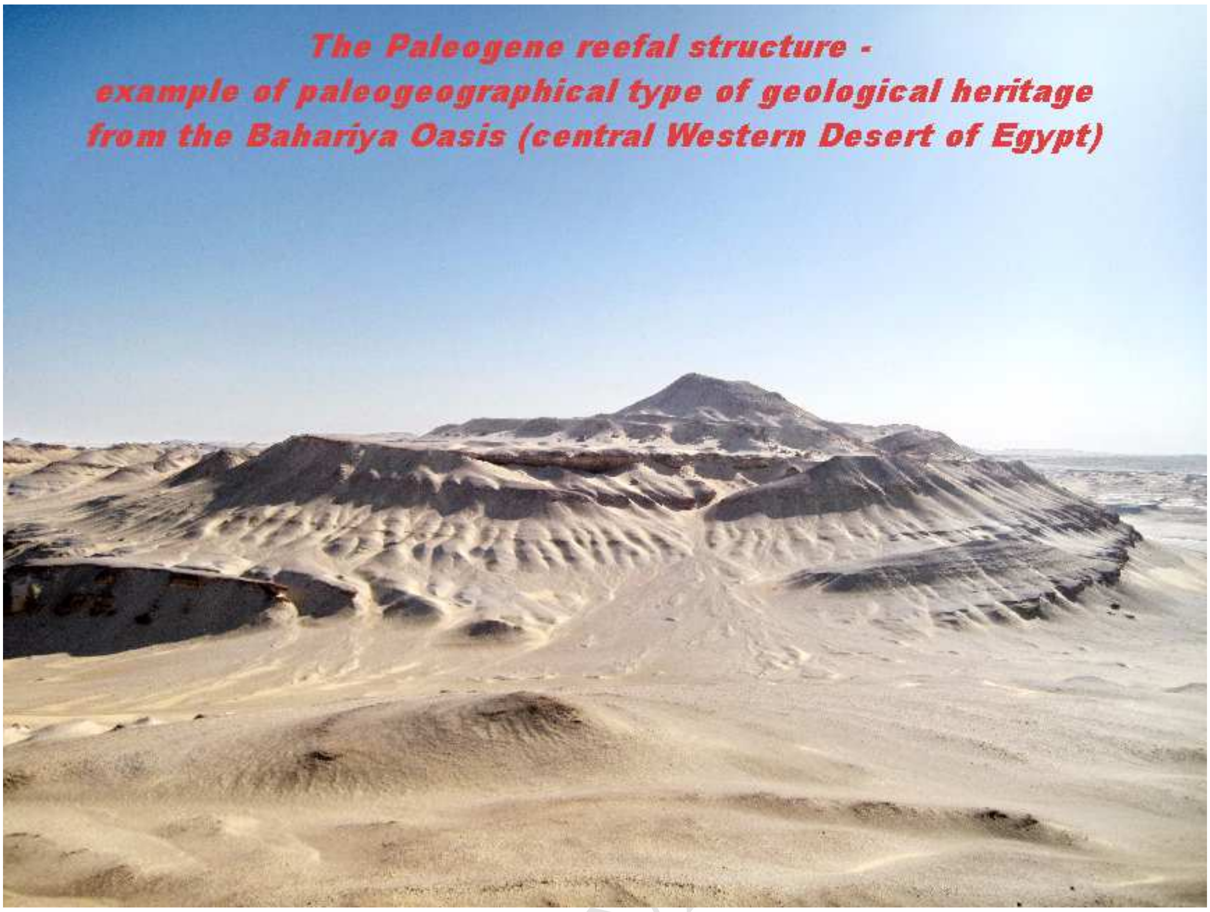
The Paleogene reefal structure -
example of paleogeographical type of geological heritage
from the Bahariya Oasis (central Western Desert of Egypt)

Geological heritage of the Bahariya and Farafra oases, the central Western Desert of Egypt

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ABSTRACT

Archaeological and cultural heritage of Egypt is world-known, but its geological heritage is yet to be revealed. Investigations in the central Western Desert of Egypt permitted finding a lot of unique features that can be assigned to this heritage. In the Bahariya Oasis, 10 geological heritage types are established, namely stratigraphical, paleontological, sedimentary, igneous, mineralogical, economical, paleogeographical, geomorphological, hydrological and hydrogeological, and pedological types. In the Farafra Oasis and vicinities, only geomorphological and hydrological and hydrogeological types are found. On the area between these oases, sedimentary, mineralogical, paleogeographical, and geomorphological features are established. Chalk and nummulitic limestones, invertebrate and dinosaur localities, paleoreefs and paleokarst, iron ore deposit, and peculiar landforms occur on the study territory. Taken together, these features constitute a highly diverse geological heritage that can be judged global (even if the rank of individual objects is often relatively low). This heritage is well suitable for the purpose of geotourism; for instance, thematic excursions explaining the geological evolution during the last 100 Ma are possible. Participants of such excursions can also see different facies. A geopark in the central Western Desert of Egypt would facilitate geoconservation and geotourism activities.

Keywords: Geological heritage; Geotourism; Geomorphology; Upper Cretaceous; Cenozoic; Western Desert; Egypt.

1. Introduction

Geological heritage has attracted a lot of attention since the beginning of the 1990s. Its inventory deems essential for conservation (geoconservation) and use for the purposes of tourism development (geotourism) (Wimbledon, 1996, 1999; Wimbledon et al., 1998; Prosser et al., 2006, 2011; Gray, 2008, 2013; Dowling and Newsome, 2010; Ruban, 2010; Ruban and Kuo, 2010; Dowling, 2011; Henriques et al., 2011; Hose and Vasiljević, 2012; Wimbledon and Smith-Meyer, 2012; Erikstad, 2013; Prosser, 2013; Bradbury, 2014; Ruban, 2015). Although most research is concentrated in Europe, geological heritage of other parts of the world is of equal importance. For example, Henriques et al. (2013), Enniouar et al. (2014), Zangmo Tefogoum et al. (2014), Errami et al. (2015), and Henriques and Neto (2015) have shown its unprecedented richness in Africa. Geological heritage of Egypt is of special interest because of three reasons. First, the diversity of geological features known from this country and the complex nature of its geological evolution (Issawi, 2002, 2005; Guiraud et al., 2005; Tawadros et al., 2006; Issawi et al., 2009; Tawadros, 2011) make it very promising for inventory, conservation, and tourism use. Second, geological research in Egypt has been intense for many decades, and the available information is rigorously systematized. For instance, stratotypes of many units are sufficiently established and described (e.g., El Kelani et al., 2003) making them ready to be evaluated as geological heritage sites. Third, the cultural heritage of Egypt (e.g., pyramids) is well-known, and it is clear how effictively cultural heritage facilitates the promotion and tourism utility of geological heritage (Migon, 2009; Last et al., 2013; Woo et al., 2013; Gontareva et al., 2015; Moroni et al., 2015).

Unfortunately, very few sites have been declared as parts of the geological heritage of Egypt. One example is Wadi Al-Hitan ("Whale Valley"), which is located in the Fayium Depression (~90 km southwest of Cairo). It is included in the list of the UNESCO World Heritage Sites (see on-line at http://whc.unesco.org/en/list/1186). Some geological heritage sites along the Mediterranean coast of Egypt are described by El-Asmar et al. (2012). In the present paper, we attempt to fill the noted gap. Field investigations in the central Western Desert of Egypt and, particularly, in the Bahariya and Farafra oases permitted the recognition of numerous unique features that when taken together can account for an important geological heritage. Their characteristics are presented in this paper.

2. Geologic setting

The Bahariya and Farafra depressions lie on the Uweinat-Bahariya-Port Said arch (Issawi et al., 2009). The Bahariya Oasis is located in the central part of the Western Desert of Egypt (between 27^{o}48'-28^{o}30' N and 28^{o}35'-29^{o}10' E) (Fig. 1). It is oval in shape stretching NE-SW by ~94 km (the width of the depression is ~42 km). The Bahariya Oasis was a subject of many geological studies aimed at structural geology, stratigraphy, iron ore deposits, sedimentology, paleontology, geoarchaeology, etc. (Ball and Beadnell, 1903;

Stromer 1914, 1936; Lebling, 1919; Weiler, 1935; El-Akkad and Issawi, 1963; Said and Issawi, 1964; Soliman et al., 1970; Slaughter and Thurmond, 1974; Khalifa, 1977; El Aref et al., 2006; Catuneanu et al., 2006; Khalifa and Catuneanu, 2008; Tanner and Khalifa, 2010; Salama et al., 2012, 2013, 2014; Afify et al., 2015a, b). The Bahariya Formation (Cenomanian), which is composed of ferruginous sandstones and shales, outcrops on the bottom of the depression. The siliciclastic beds of the Bahariya Formation are weathered into black conical-like hills, mesas, and buttes. The black conical hills, which are distributed on the southern part of the Bahariya Depression, are known as "the Black Desert". Most of these hills are capped by basalt sills, giving them a characteristic black color. The Campanian, Maastrichtian, and lower Eocene rocks outcrop on the flanks of the Bahariya Depression; the Paleocene is totally missing there (Issawi, 2009) (Fig. 1). The Bahariya depression superposes the Bahariya anticline that stretches from Gebel Ghorabi in the north, passing through the central hills of the depression to the southern part of the oasis, and extends southward to include the Farafra Oasis.

The Farafra Oasis is located ~140 km southwest of the Bahariya Oasis in the central part of the Western Desert (between 26°45'-27°40' N and 27°00'-28°50' E) (Fig. 1). Similarly to the Bahariya Oasis, the Farafra Oasis occupies an oval-shaped depression with an area of ~10,000 km^2. On the bottom of the Farafra Depression, the Dakhla Shale (Maastrichtian) is outcropped, and it is intertonguing laterally into the Maastrichtian Khoman Chalk in the central and northern parts of the oasis (Hermina, 1990; Issawi et al., 2009). The Farafra Depression is surrounded by high escarpments, and its bottom rises gradually to the general level of the surrounding desert southwards (Beadnell, 1901; Said, 1962; Issawi et al., 2009). The scarps of the Farafra Depression are composed of the Tarawan Formation (Paleocene) overlain by the Esna Shale (Paleocene-lower Eocene) and the Farafra Limestones (lower Eocene) (Issawi et al., 2009; Orabi and Zaky, 2016). The eastern part of the depression is covered by sand sheets, and the depression is bounded to the west by the Great Sand Sea (Fig. 1). The Farafra Depression forms a dome structure, which represents the southern extension of the Syrian Arc System (Omara et al., 1970). Its axis stretches in the NE-SW direction.

Since the beginning of the Late Cretaceous, the evolution the Bahariya-Farafra platform was influenced greatly by eustatic fluctuations and the tectonic activity along the Syrian Arc fold system (Aram, 1990; El Emam et al., 1990; Sehim, 1993; Moustafa et al., 2003). During the Cenomanian, the Bahariya-Farafra platform was located on a passive continental margin (El Emam et al., 1990). This was followed by a phase of tectonic folding (Said, 1962). Throughout the Turonian-Santonian, the northern part was tectonically uplifted, while the southern part was subsiding (El Emam et al., 1990). Folding took place later, and the anticline became even more pronounced (Sehim, 1993; Moustafa et al., 2003). In the Maastrichtian, the western and southern parts of the Bahariya Oasis and the northern part of the Farafra Oasis were covered by sea (El Emam et al., 1990). During the Paleocene, the Bahariya structure was uplifted to become an island, and the Tarawan chalky limestones and the overlying Esna Shale were deposited on the area of the present-day Farafra Oasis (Issawi et al., 2009). In the early Eocene, the whole territory submerged (Said and Issawi, 1964; Issawi et al., 2009). The last phase of the Eocene deposition took place in the Bartonian-Priabonian, when thick-bedded mollusc-rich siliciclastic-carbonate sediments of the Hamra Formation were deposited (Said and Issawi, 1964; Issawi et al., 2009). Seaward shoreline shift continued in the Oligocene, and many river systems were developed: a fluviatile cross-bedded sandstone and grit sediments were accumulated (the Radwan Formation) (Said and Issawi, 1964). Later, extensive volcanic eruptions (Mandisha’s basalt) and hydrothermal activity took place on the study territory (Meneisy and El Kalioubi, 1975; El-Etr and Moustafa, 1978; Morsy, 1987; Meneisy, 1990; El Aref et al., 1999).

The formation of the many oases in the Western Desert is related to the thickness of the hard limestones above the clastic beds and also to the level of the underground water table. Geological structure is very important in the formation of depressions. In all known oases in the Western Desert, the successions include relatively thin limestones above a thick succession of clastics. An uplift of the area of the Bahariya double-plunging anticline "cracked" the thin limestone, and wind deflation coupled with rainfall completed "hewing" of the clastics beneath the limestone. Erosion continued to the level of the underground water. The same occurred with the Farafra Oasis, which is located on a high basement arch known as the Uweinat-Bahariya-Port Said Arch (Issawi, 2009), where sediments are thin above the basement complex.

3. Methods

The geological heritage of the central Western Desert of Egypt was established on three areas, namely the Bahariya Oasis, the Farafra Oasis and vicinities, and the area between the noted oases (chiefly along the road connecting these oases). Field investigations (by the second author) supported by the analysis of literature sources permitted the delineation of unique geological features. Numerous photos of the latter were taken. The uniqueness of each feature is determined by its rarity or, in contrast, very typical appearance that can be established on the local, regional, national, or global scale. All heritage objects can be further employed for scientific, educational, and tourism purposes. This information permits the delineation of the geological heritage significance of the above-mentioned three areas (each taken entirely). It was not necessary to emphasize on particular geological heritage sites (geosites) within these areas, because of three reasons: 1) these areas are relatively small in size, 2) some features occupy large areas and intersect spatially with one another, and 3) the "density" of unique features is sufficient in all areas. It is better to consider each area as a large geosite.

The analysis of the geological heritage requires distinction of unique features by their essence. For this purpose, various classifications (Wimbledon et al., 1998; Prosser et al., 2006; Ruban, 2010; Ruban and Kuo, 2010; Bradbury et al., 2014) have been proposed. In this work, the classification proposed by Ruban (2010) and Ruban and Kuo (2010) is used. It necessitates the presence of about two dozens of types of geological features (stratigraphical, paleontological, sedimentary, igneous, metamorphic, mineralogical, economical, geochemical, seismical, structural, paleogeographical, cosmogenic, geothermal, geocryological, geomorphological, hydrological and hydrogeological, engineering, radiogeological, neotectonical, pedological, and geohistorical). Ruban (2010) underlined that many geosites are essentially complex with many types co-occurring in each given object. For instance, in an outcrop of sedimentary rocks, not only sedimentary, but also stratigraphical, mineralogical, paleogeographical, and, probably, paleontological features can be identified. To solve this problem, Ruban (2010) suggested to pay attention to the dominant types that determine the uniqueness of any given object. It should be also added that the types may differ by their rank in a given geosite or on a given area (local, regional, national, or global) (Ruban, 2010). For the three areas of the study territory, the dominant geological heritage types were established, and the rank was assigned to them tentatively.

4. Results

4.1. Bahariya Oasis

In the Bahariya Oasis, numerous peculiar geological features were established (Fig. 2). These belong to 10 dominant geological heritage types (Table 1), and some representative examples are given below.

Stratigraphical type. Gebel El Dist (Fig. 2a) exhibits a section of the Bahariya

Formation (Cenomanian, Upper Cretaceous) and the Naqb Formation (Ypresian, lower Eocene) that can be used for the stratigraphical correlation purposes. An angular unconformity between these formations is well visible (Fig. 2h, i). This is an important, but "ordinary" stratigraphical section, and, therefore, this is a kind of local geological heritage.

Paleontological type. The same Gebel El Dist (Fig. 2a) is a famous fossil locality, from which Cretaceous and Eocene bivalves, silicified wood, leaf imprints, remains of sharks, and bones of dinosaurs were reported (Ball and Beadnell, 1903; Stromer, 1914; Said, 1962; El Akkad and Issawi, 1963; Smith et al., 2001; Schweitzer et al., 2003). With regard to the noted paleobiodiversity, this can be judged as national geological heritage.

Sedimentary type. The snow-white nummulitic chalky limestones of the Qazzun Formation (Ypresian, lower Eocene) reported from several places, including Gebel El Gar El Hamra (Fig. 2l), are of special interest because such rocks are rare in the geological record. Of course, the Bahariya Oasis is not the only place to observe them, and the rank of this feature is regional at maximum.

Igneous type. Although the geology of the Bahariya Depression is dominated by sedimentary rocks, some magmatic (volcanic) formations are also known there. The so-called "Mandisha's basalt" (Oligocene) is represented by a combination of columnar and pillow-like basalts that comprise a sill that caps some hills nowadays (Fig. 2d, e). The noted lava structures are well-known, but their very typical appearance is established in this oasis, where outcrops are also large and well accessible. This implies a national rank of this geological heritage type.

Mineralogical type. Iron minerals are known from the Bahariya oasis (Fig. 2r). The relevant minerals are represented mainly by goethite, hematite, and siderite with manganese oxides intercalations (Said and Issawi, 1964; Salama et al., 2012, 2013; Afify et al., 2015 a, b; Baioumy et al., 2014, Baioumy, 2015). This is a kind of local geological heritage.

Economical type. Iron ore is mined directly in the oasis (Fig. 2r), which is an important mining site in Egypt. The iron ore lies at the basal part of the Naqb Formation (Ypresian, lower Eocene) replacing carbonates. The origin of the Bahariya iron ore has been discussed by several workers since the early work of Ball and Beadnell (1903) who considered the iron ore as Oligocene lacustrine deposits. Gheith (1955) suggested that the origin of the Bahariya iron ore is due to replacement processes in the post-Eocene time. Nakhla (1961) attributed the iron ore of the Ghorabi mine to metasomatic replacement of the lower Eocene carbonates, whereas El Shazly (1962) proved that the ore was formed as a primary sedimentary deposit in lagoons during late Eocene-Oligocene times. El Akkad and Issawi (1963) attributed the origin of the iron ore to the replacement of the carbonate rocks after their direct deposition in shallow depressions in early-middle Eocene. Said and Issawi (1964) suggested that the ore is of diagenetic origin. They believed that the iron ore was deposited together with the early Eocene Naqb carbonates. The small basins, where this deposition took place, were converted into shallow lagoons during the gradual regression. In these lagoons, iron minerals concentrated due to leaching of the ferruginous layers of the Bahariya high (Said and Issawi, 1964). Irrespective of what point of view is correct, the disputed origin of this mineral deposit (Ball and Beadnell, 1903; Alling, 1947; Gheith, 1955, 1959; Nakhla, 1961; El Shazly, 1962; El Akkad and Issawi, 1963; Said and Issawi, 1964; El Bassyouny, 2004; Salama et al., 2012, 2013; Afify et al., 2015a, b; Baioumy et al., 2014, Baioumy, 2015) makes it very interesting. The rank of this heritage feature is regional.

Paleogeographical type. Different facies are known from this area. Probably, the most interesting amongst them is linked to the paleoreefs of the Hamra Formation (Lutetian-Priabonian) (Fig. 2m-j). These carbonate buildups were produced by bivalves and gastropods, communities of which flourished on the sea bottom (Said and Issawi, 1964; Issawi et al., 2009). The reefal constructions dip inward, i.e., concentrically toward the center of the structure with angles of 40°, and form saucer-like structures. It appears that such paleoreefs are rare on the global scale, and, therefore, global rank should be assigned to this type of the geological heritage.

Geomorphological type. A lot of peculiar landforms occur in the Bahariya Oasis. The most interesting are black conical hills in the south of the oasis (Fig. 2f), ball-like concretions (average diameter 50-60 cm) of hard siliceous dolomitic limestones (so-called "melon fields") (Fig. 2j, k), and spectacular sand dunes (Fig. 2t, u). These forms are so unusual and impressive that their rank should be judged as national (at least) or global (most probably).

Hydrological and hydrogeological type. Thermal mineral springs are known in the oasis, and these are used already for the purposes of recreation and spa therapy (Fig. 2v). The rank of these heritage objects is local.

Pedological type. Middle-late Eocene paleosols have been found above the iron ore in the Bahariya iron ore mine (Fig. 2s). However, these are rather "ordinary" features that can be judged as only local.

4.2. Farafra Oasis and vicinities

In the Farafra Oasis and in its vicinities, peculiar geological features are also numerous (Fig. 3). However, these belong to the only two dominant geological heritage types (Table 1). Examples of unique features are given below.

Geomorphological type. Diverse geomorphological features are reported from this area. These include "melon fields" (like those in the Bahariya Oasis), peculiar landforms, and, paleokarst phenomena (Fig. 3). The latter are of special interest. The Maastrichtian (Late Cretaceous) chalky limestones karstified intensively in the Miocene (Pickford et al., 2010), and the results of these processes created a very unique landscape (Fig. 3b-e). The number of the co-occurrence of all these geomorphological features permits judging the rank of the relevant geological heritage as national.

Hydrological and hydrogeological type. Thermal mineral springs are known in the oasis, and these are used already for the purposes of recreation and spa therapy. The rank of these heritage objects is local, similarly to the Bahariya Oasis.

It should be added that some micropaleontological finds that permit interesting taphonomic judgements has been made in the Farafra Oasis recently (Orabi and Zaky, 2016). However, it is questionable whether this indicates any paleontological and paleogeographical types of geological heritage on this area.

4.3. Area between the Bahariya and Farafra oases

On the area between the oases, some peculiar geological features also occur (Fig. 4). These belong to 5 dominant geological heritage types (Table 1) that are illustrated with some examples below.

Sedimentary type. The Khoman Chalk Formation (Maastrichtian, Late Cretaceous) is represented on this area by distinctive snow-white chalk and chalky limestones with abundant chert bands and thin shale beds at top. This formation is 25-30 m in thickness, and it overlies conformably the Hefhuf Formation (Campanian, Late Cretaceous) and underlies the Tarawan Formation (Paleocene). Although this chalk is peculiar, it is very well distributed both in Egypt and other places of the world, and, therefore, this is the only local geological heritage.

Mineralogical type. Large calcite crystals (also in the form of speleothems) are known from the so-called "Crystal Hill" (Fig. 4e). These would attract potentially the attention of visitors, although this is the only local geological heritage.

Paleogeographical type. The Khoman Chalk was deposited under open marine, outer shelf environmental conditions (Issawi et al., 2009). These rocks are rather specific, but very common in many regions of the world. If to treat the outcrops of the Khoman Chalk in terms of paleogeographical heritage, its rank would be only local.

Geomorphological type. On the study area, there are paleokarst features similar to those described above in the Farafra Oasis. However, there is a feature that deserves close attention. The well-arranged crystals of calcite form large, medusa-shaped body (Fig. 4f) that is so unusual and spectacular that can be assigned to the national geological heritage.

5. Discussion

5.1. Diversity of the geological heritage and its rank

The three study areas differ by the diversity of geological heritage features, and the number of the dominant types is the largest in the case of the Bahariya Oasis (Table 1). However, in all cases, the most common are geomorphological features. These include the peculiar landforms mentioned above ("natural sculptures", "melon fields", and paleokarst features), as well as the "Black Desert" and the "White Desert" taken entirely. The White Desert (El-Sahara El-Beida in Arabic) is located ~45 km to the north of the Farafra Oasis, and it has a total area of 3010 km^2. It has been declared as a natural protectorate in 2002. The White Desert is called so because of the white color dominating its whole landscape. The Black Desert (El-Sahara El-Soda in Arabic) lies between the White Desert in the south and the Bahariya Oasis in the north. It is located ~50 km southwest of the Al-Bawetii City. It is called “the Black Desert” because of many widely-spaced black conical hills and the black sheets of gravels and rock fragments strewn on the floor of this desert giving it a characteristic rough physiography. These hills vary in their forms and height.

A central idea in the modern understanding of geological heritage is geodiversity that can be characterized either quantitatively or qualitatively (Gray, 2008, 2013; Ruban, 2010;

Knight, 2011; Crawford and Black, 2012). As demonstrated above, the geological features of the study territory are chiefly of intermediate to low ranks (local or regional). However, the co-occurrence of diverse features by itself increases the overall rank of their entity (such a situation was discussed by Ruban (2010)). Rare places of the world can boast by such a diversity of peculiar geomorphological and geological features as the Bahariya and Farafra oases and the area in between them. If so, the entire geological heritage of the study territory, i.e., the central Western Desert, can be ranked as global.

5.2. Geotourism perspectives

The geological heritage of the central Western Desert of Egypt seems to be very suitable for the purposes of geotourism development because of its diversity and uniqueness (Table 1). Individual tourists and tourist groups can reach there easily via luxury tourist buses or four-wheel safari cars owned by tourism enterprises. Travellers to the Bahariya and Farafra oases may visit particular geological features to learn about the general geology and geomorphology. Moreover, thematic excursions, as explained by Plyusnina et al. (2015), provide another opportunity to learn about the geological history of a given area. In the case of the study territory, visitors can learn about the last 100 Ma of the geological history (Late Cretaceous-Present) seeing different facies, fossils, and other relevant features (Table 2). Importantly, some of these features are not only typical for the Western Desert, but they also characterize the general scheme of geological evolution. For instance, there are specific formations like chalk and nummulitic limestones, paleoreefs, invertebrate and dinosaur localities. As the discussed geological heritage is concentrated on rather small area restricted to two oases and their vicinities (Fig. 1), the potential for such a thematic (paleogeographical) excursion seems to be large.

The geological heritage, especially when it is ranked globally, should be employed for tourism purposes in good balance with conservation (e.g., Prosser et al., 2006, 2011; Gray, 2008, 2013). Two possibilities for this exist in the central Western Desert. First, the Natural Protectorate of the White Desert has been designated in 2002 to include the hills of El-Dist and El-Maghrafa and the Black Desert, and it is managed now by the Egyptian Ministry of the Environment. The most activities offered at this protectorate include Safari trips, camping inside the desert, and sand boarding on the sand dunes. This kind of protected area can itself work for the purposes of geotourism. Second, a geopark that will become further a member of the global geopark network (http://www.unesco.org/en/natural-sciences/environment/earth-sciences/geoparks/some-questions-about-geoparks/where-are-the-global-geoparks/) can be established on the basis of the diverse and abundant geological heritage features of the Bahariya and Farafra oases and the area between them. Experience from many other places of the world (Farsani et al., 2012; Henriques et al., 2012; Fukami, 2013; Palacio Prieto, 2013; Lazzari and Aloia, 2014; Sun, 2014; Wang et al., 2015) suggests that such a geopark may facilitate the joint geoconservation and geotourism activities. However, establishment of geopark requires significant efforts from the national geological community in Egypt.

6. Conclusions

The present study underlines the importance of geological heritage inventory in Egypt. The diverse geological features of the Bahariya and Farafra oases are essential part of the geological heritage. The latter is represented by 10 dominant types, of which the geomorphological features are the most common. This geological heritage is of global importance because of the diversity of features co-occurring on a rather restricted territory. The Bahariya and Farafra oases and the area between them are well suitable for geotourism development. The already established natural protectorate and the possible geopark can contribute substantially to both geoconservation and geotourism.

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FIGURE CAPTIONS

Fig. 1. Geological map of the study territory (modified from Geological Survey of Egypt, 1981).

Fig. 2. Geological heritage of the Bahariya Oasis: a-c - Gebel El Dist (Cenomanian siliciclastics overlain by Lower Eocene nummulitic limestones), d, e - the Mandisha's basalt (Oligocene), f - the Black Desert (black hills consisted of Cenomanian siliciclastics topped by basalts), g - Quaternary paleolake deposits, h, i - Lower Eocene dolomitic limestones overlying Cenomanian strata with angular unconformity, j, k - ball-like concretions (average diameter 50-60 cm) of hard siliceous dolomitic limestones ("melon field"), l - Gebel El Gar El Hamra (landmark conical-hill buildup, type section of the Qazzun and Hamra formations, paleoreefs and other deposits), m - Lutetian-Priabonian semi-circular reefal structure), n, o - Middle Eocene saucer-like reefal

structures, p, q - pedestal rocks, r - Bahariya iron ore mine (origin of ore is debatable), s - cross-bedded paleosols highly pierced by root casts, t - asymmetrical ripple marks, u - sand dunes of Ghard Ghorabi, v- thermal mineral spring equipped with a kind of bath.

Fig. 3. Geological heritage of the Farafra Oasis and vicinities: a-i - paleokarst (Miocene?) features, j - "melon field" of Quaternary sediments, k-n - peculiar landforms.

Fig. 4. Geological heritage of the area between the Bahariya and Farafra oases: a-d - Crystal Hill (brecciated structure on c, d reflects the collapsed cave roof), e - calcite crystals from the Crystal Hill, f - medusa-shaped (umbrella-shaped) body consisting of well-arranged crystals of calcite.

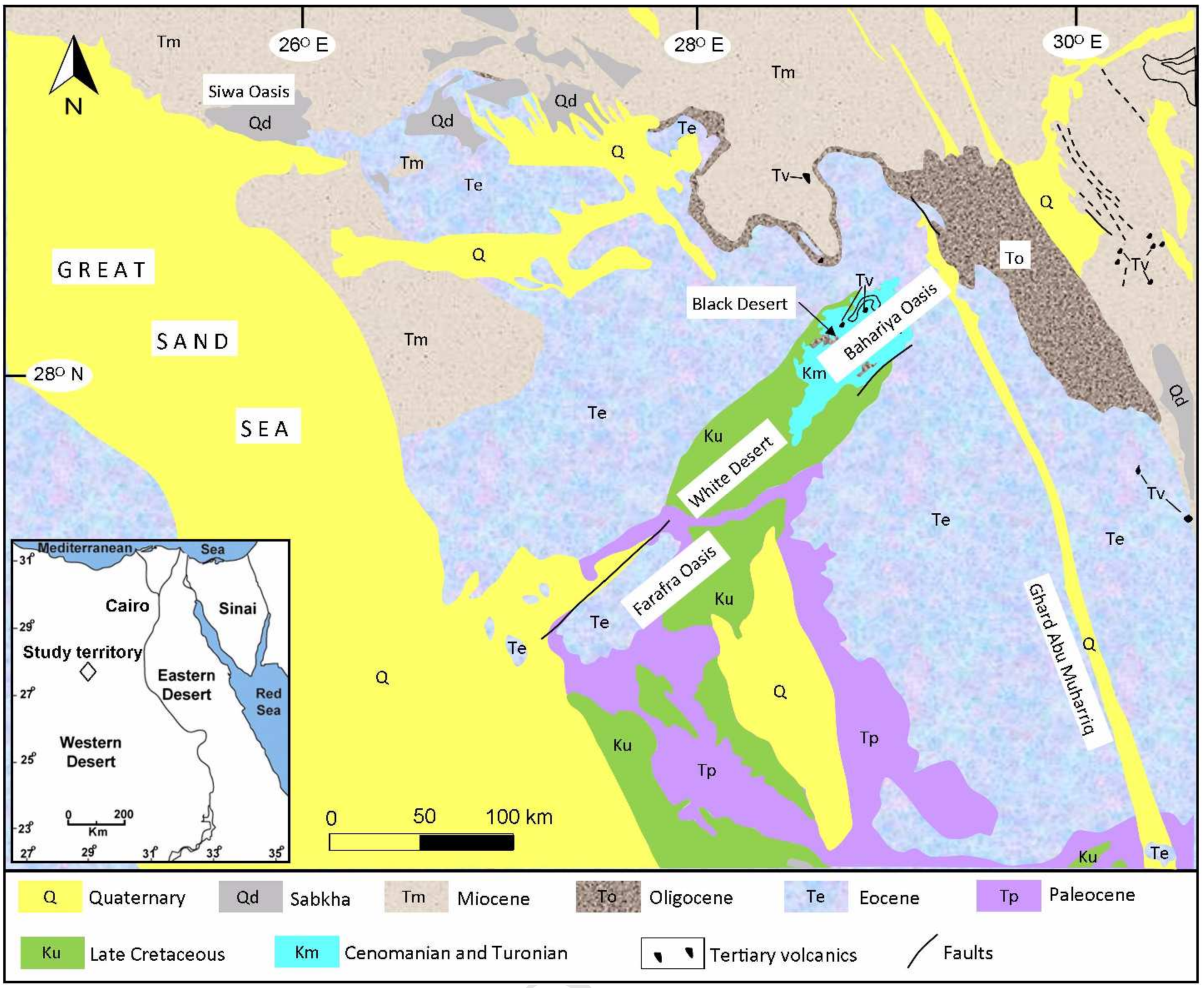
Table 1. Geological heritage types in the study territory. Typology is based on Ruban (2010) and Ruban and Kuo (2010).

Area	Dominant types																				
	ST	PL	SE	IG	MT	MI	EC	GC	SI	SR	PG	CO	GT	GY	GM	HY	EN	RA	NE	PE	GH
Bahariya Oasis	X	X	X	X		X	X				X				X	X				X	
Farafra Oasis and vicinities															X	X					
area in between of oases			X			X					X				X						

Types abbreviations: ST – stratigraphical, PL- paleontological, SE – sedimentary, IG – igneous, MT – metamorphic, MI – mineralogical, EC – economical, GC – geochemical, SI – seismical, SR – structural, PG – paleogeographical, CO – cosmogenic, GT – geothermal, GY – geocryological, GM – geomorphological, HY - hydrological and hydrogeological, EN – engineering, RA – radiogeological, NE – neotectonical, PE – pedological, GH – geohistorical.

Table 2. Paleogeographical features in the geological heritage of the study territory. Typology is based on Bruno et al. (2014).

Geological age	Dominant subtypes of paleogeographical type					
	Facies	Paleoecosystems	Ichnology	Taphonomy	Events	Geoarchaeology
Quaternary	paleolake		burrows and traces			artifacts
Miocene	karstic					
Oligocene	fluvial					
Eocene	shallow-marine	nummulites			gradual basin deepening	
	shallow-marine	reefs (bivalves and gastropods)				
Upper Cretaceous	chalk-dominated outer shelf	bivalves				
	deltaic, estuarine	bivalves, dinosaurs, flora		fossil wood, other fossilized remains		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28° N
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GREAT
SAND
SEA
Black Desert
Bahariya Oasis
White Desert
Farafra Oasis
Ghard Abu Muharriq
Tm
Qd
Q
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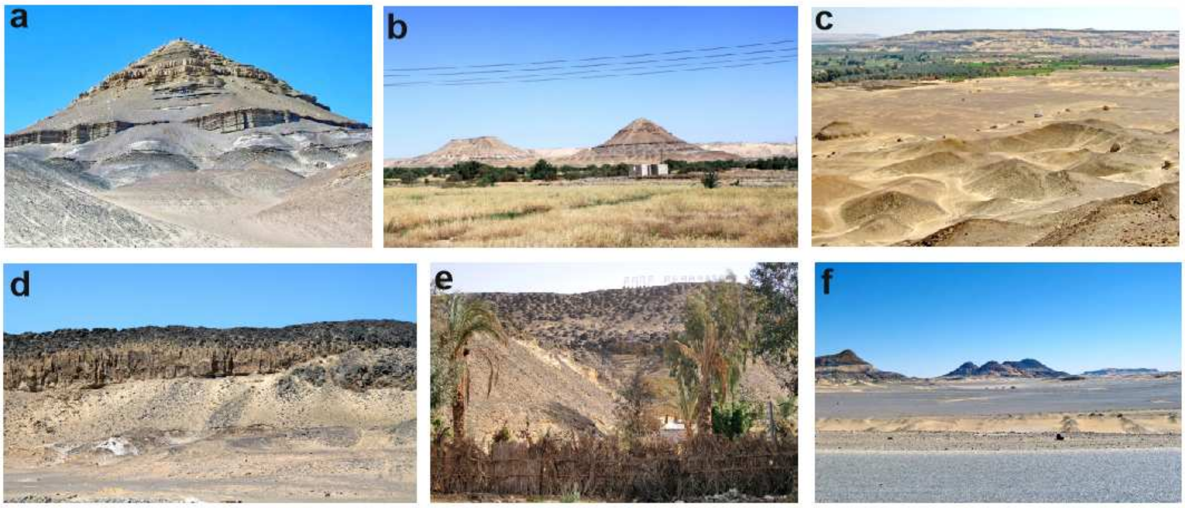
To
Tv
Km
Ku
Tp
0
50
100 km
Mediterranean
Sea
Cairo
Sinai
Study territory
Eastern Desert
Red Sea
Western Desert
200
Km
Quaternary
Sabkha
Miocene
Oligocene
Eocene
Paleocene
Late Cretaceous
Cenomanian and Turonian
Tertiary volcanics
Faults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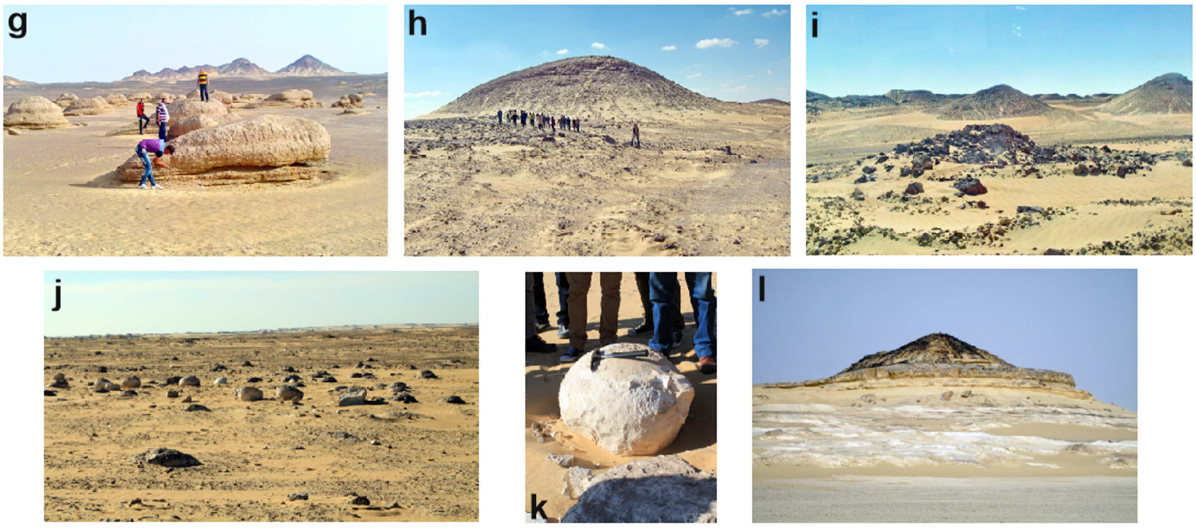
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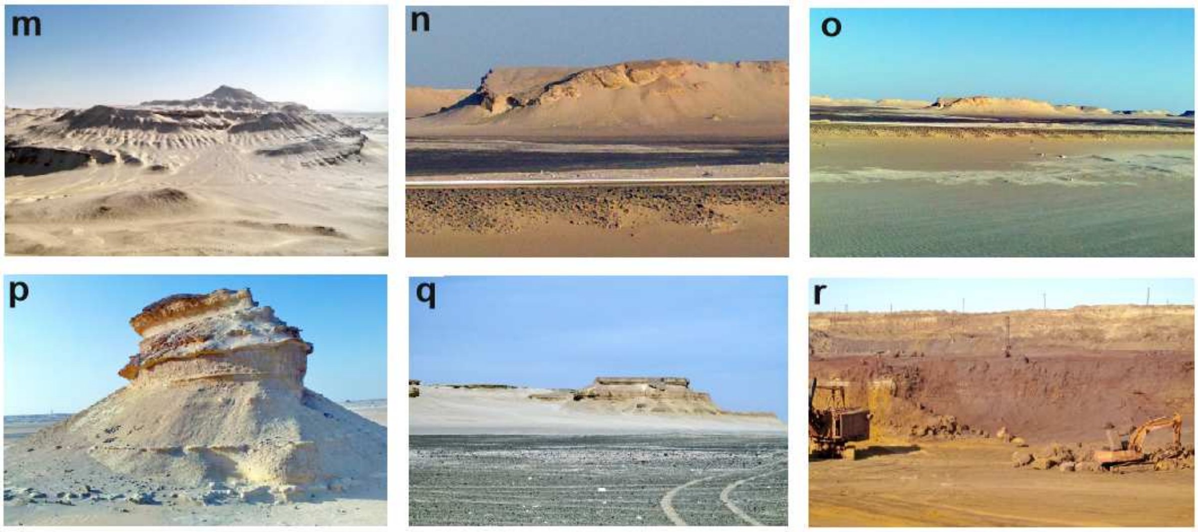
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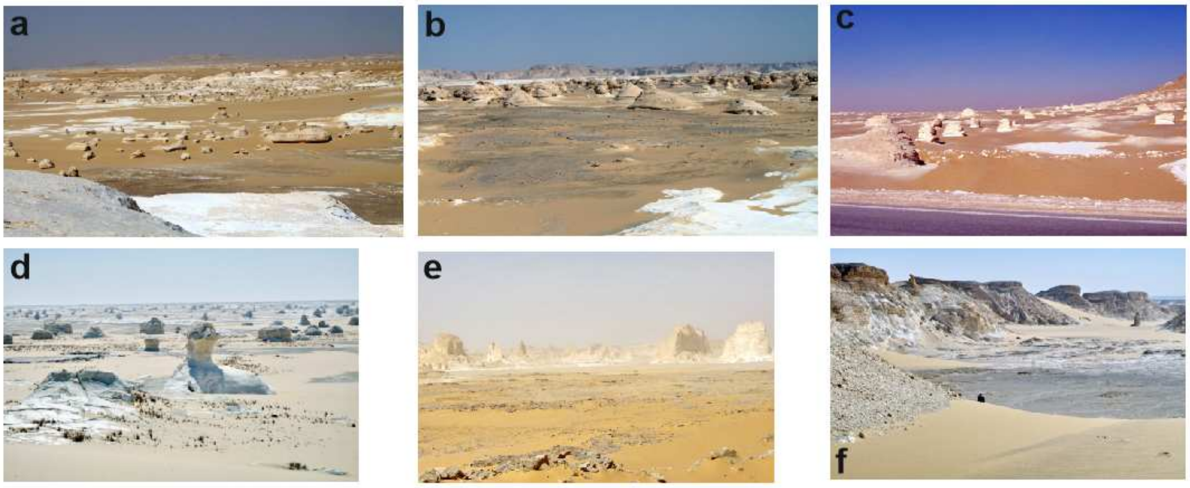
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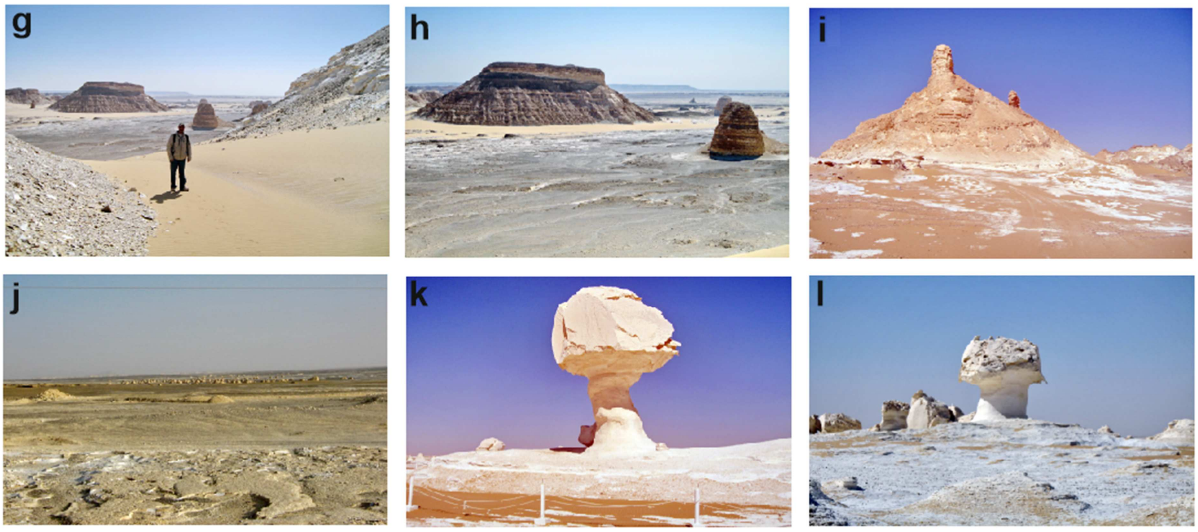
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Global-ranked geological heritage in central Western Desert of Egypt

Ten geological heritage types (geomorphological, igneous, paleogeographical, etc.)

Possibility for thematic geotourist excursions linked to geological history

Potential for geopark establishment in Bahariya and Farafra oases