Implementations of karstology in Egypt

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The Egyptian Phanerozoic Carbonate rocks cover about 54 % of Egypt's area and represent extremely valuable raw materials versatile of all industrial rocks and minerals. The different Egyptian Phanerozoic carbonate sequences (ranging in age from Carboniferous to Recent) are obviously punctuated and truncated by paleokarst surfaces (fossilized, rejuvenated and surface karst) of different magnitudes and time gaps, representing intermittent carbonate exposing events and breaks of sedimentation. Such paleo-surfaces and the related features have been recently documented, recognized and deeply studded by the present author and his coauthors and students during the last four decades, since 1976. The contributions are based on a vey systematic way of observations, from field scale down to hand specimen, microscopic and crypto-scopic scales as well as geochemical examinations and textural (chemical and or biogenic) evolution. Quantitative morphometric identification of some Egyptian karst related landforms at various scales and resolutions are also implemented, using field, remotely sensed data and geographic information utilities. The outcropped carbonate sequences and the included paleokarst surfaces exhibit also an amazing surface paleokarst morphologies developed during Oligocene-Quaternary time span and may led to partial or extensive denudation of older features and karst rejuvenation forming astonishing denuded karst. In Egypt karst morphosites together with arid products and features in several single places form an outstanding compilation of hyper-arid and humid landforms. The economic potentiality of the recognized paleokarst systems are accentuated by the concentration of potential ore deposits such as Mn, Fe ,Pd ,Zn ,Ba , Sr, Cu, U, S,….. etc), underground storage of water (ex. Farafra and Siwa kasrt aquifers), oils and gases (in underground sites) and development of karst geomorphsites as a potential for tourism attraction. The just recorded paleokarst events and surface karst morphologies and the related products are addressed in a simplified chronologic classification aiming to help in: a) determining sequence boundaries and paleoclimate, b) detection of the paleo-topography, paleo-watertable and paleo-drainage configuration pattern and evolution, as well as the paleo-geography of the paleo-shoelines, c) detection of surface water paleo-environments, porosity evolution and recognition of the post-diagenitic (supergenesis) processes (telogenesis and pedogenesis), and d) using in every urban development, land use planning and hazards assessment (AHA).

The recognized great hiatus and major and minor paleokarst surfaces are defined as follows:

I. Inter-formational fossilized major sequence boundaries displaying break in sedimentation during periods of relatively long-lived exposure and sea level fall, with intensive paleokarstification along paleohighs.
II. Inter-formational and Intra-formational fossilized minor paleokarst intervals delineating some rock unit bounders during relatively short-periods of exposures.
III. Intra-formational fossilized (depositional) micro paleokarst surfaces, and
IV. Exposed karst landforms, responsible for the sculpturing and development of the characteristic exposed karst features of the Egyptian Sahara and development of amazing karst landscape, karst economic products as well as fantastic karst remnants.

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Determining the beginning and the end of the life of a karst system is a substantial problem. In contrast to most of living systems development of a karst system can be „frozen“ and then rejuvenated several times (polycyclic and polygenetic nature). The principal problems may include precise definition of the beginning of karstification (e.g. inception in speleogenesis) and the manner of preservation of the products of karstification. Karst evolution is particularly dependent upon the time available for process evolution and on the geographical and geological conditions of the exposure of the rock. The longer the time, the higher the hydraulic gradient and the larger the amount of solvent water entering the karst system, the more evolved is the karst. In general, stratigraphic discontinuities, i.e. intervals of nondeposition (disconformities and unconformities), directly influence the intensity and extent of karstification. The higher the order of discontinuity under study, the greater will be the problems of dating processes and events. The order of unconformities influences the stratigraphy of the karst through the amount of time available for subaerial processes to operate. The end of karstification can also be viewed from various perspectives. The final end occurs at the moment when the host rock together with its karst phenomena is completely eroded/denuded. In such cases, nothing remains to be dated. Karst forms of individual evolution stages (cycles) can also be destroyed by erosion, denudation and abrasion without the necessity of the destruction of the whole sequence of karst rocks. Temporary and/or final interruption of the karstification process can be caused by the fossilisation of karst due to loss of its hydrological function. Such fossilisation can be caused by metamorphism, mineralisation, marine transgressions, burial by continental deposits or volcanic products, tectonic movements, climatic change etc. Known karst records for the 1st and 2nd orders of stratigraphic discontinuity cover only from 5 to 60 % of geological time. The shorter the time available for karstification, the greater is the likelihood that karst phenomena will be reserved in the stratigraphic record. While products of short-lived karstification on shallow carbonate platforms can be preserved by deposition during the immediately succeeding sea-level rise, products of more pronounced karstification can be destroyed by a number of different geomorphic processes. The longer the duration of subaerial exposure, the more complex are those geomorphic agents.

The beginning and the end of karst is clearly associated with conformities, unconformities and disconformities. Esteban (1991) in an excellent review following the sequence stratigraphic approach outlined the role of nondepositional events (stratigraphic discontinuities) in karst evolution. Different ranks of stratigraphic discontinuity represent the differing time gaps in deposition that have been available for dissolution (karstification; see also Moore 1991, pp. 247-264).

Karst period defines long-lasting times of groundwater circulation and continental weathering,

which were terminated by an ensuing marine transgression. They are recognised by higher order unconformities or disconformities (= interregional karst of Choquette and James (1988). Their karst features can usually be divided into several

Interregional (paleo)karst and products of karst periods can be linked with composite unconformities of the 1st and 2nd orders sensu Esteban (1991). Such products can be correlated over extensive regions, e.g., post-Kaskadia and post-Variscan karstifications in North America and Europe, respectively (G.azek 1989a). Local (paleo)karst and products of type 1 of karst phases (sen

su G.azek 1989a) are common products during single unconformities and syntectonic unconformities, i.e. of the 3rd order.It can be readily asserted that the shorter the time available for karstification, the greater is the probability of preservation of the karst phenomena in the stratigraphic record. While products of short-lived karstification on shallow carbonate platforms can be preserved by deposition during the sea-level rise following immediately after, products of more pronounced karstification may be destroyed by a variety of geomorphic processes. The longer is the duration of subaerial exposure, the more complex are those geomorphic agents. Further, individual long periods of subaerial exposure (stratigraphic discontinuities of the 1st and 2nd orders – karst periods) may coalesce, being separated only by a short interruption (e.g., marine transgression/ ingression).

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Quaternary sediments and landforms related to humid climate

Lacustrine (Playa) sediments
Pleistocene Lacustrine sediments
Holocene playas
Alluvial deposits
. Radar Rivers

The term “Radar Rivers” refers to almost fully aggraded Tertiary basins and valleys that lie beneath the sand sheet in southern Egypt and northern Sudan. These features were first recognized when radar images produced by the imaging radar (SIR-A) experiment aboard the November, 1981 flight of the space shuttle Columbia (McCauley et al. 1982). Radar Rivers have been described under different synonymy; e.g. Radar Rivers and Subsurface Valleys (McCauley et al. 1982, 1986; Ghoneim et al. 2007); Paleo-rivers (McHugh et al. 1988); Paleo-drainages (McCauley et al. 1986; Schaber et al. 1997) and Paleo-channels (El-Baz et al. 1998).

Inverted Wadis

Solution and karstic features (Tufa and Spleothem deposits)
3.3.1. Karstic landforms

The karst landforms of the Western Desert exist on three erosion surfaces. Each is characterized by its geomorphic, lithological and archaeological characteristics (El-Aref et al., 1987; Hamdan and Lucarini; 2013):

Absolute dating of the karstification in Egypt is not possible. U/Th dating of spleothem deposits in the caves (see below) gives only the age of last stage of karstic processes. However, the age of initial karst stages are given from terrestrial fossils associated with terra rossa in solution cavities in both the Western and Eastern Deserts. The karstic shafts in the limestone of Bahariya-Farafra Depressions contain small vertebrate fossils dated back to late Miocene (Pickford et al. 2006; Mein and Pickford 2010). In Khasm El-Raqaba limestone quarry (Eastern Desert), small fossil vertebrates representing snakes, rodents and bats, have been recovered from karst fissure-fill deposits intrusive into the Eocene limestone (Gunnell et al. 2016). These fossil assemblages indicate mixed subtropical and more arid microhabitats and dated to late middle Miocene.

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The contributions are based on a very systematic way of observations, from field scale down to handspecimen, microscopic and crypto-scopic scales as well as geochemical examinations and textural (chemical and or biogenic) evolution. Quantitative morphometric identification of Egyptian karst related landforms at various scales and resolutions are also recently implemented, using field, remotely sensed data and geographic information utilities. The outcropped carbonate sequences and the included paleokarst surfaces exhibit also an amazing surface paleokarst morphologies developed during Oligocene-Quaternary time span and may led to partial or extensive denudation of older features forming astonishing denuded karst. In Egypt karst morphosites together with arid products and features in several single places form an outstanding compilation of hyper-arid and humid landforms.

The economic potentiality of the paleokarst systems are accentuated by the concentration of potential ore deposits (Mn, Fe ,Pd ,Zn ,Ba , Sr, Cu, U, S,….. etc) , underground storage of water (ex. Farafra and Siwa kasrt aquifers), oils and gases (in underground sites) and development of karst geomorphsites as a potential for tourism attraction

It is highly recommended to intensively examine such paleosurfaces as a guide for further exploration and also the related soil products (*in situ* or transported) as a good environment for concentration of an amble of trace ore major elements. Furthermore, the study results emphasize the importance of all types of unconformities as potential sites for ore exploration, some recoded examples are addressed, and detailed survey and detailed investigations should be given to the Pre

-Cambrian basement complex and the overlaying Phanerozoic sequences