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Paleovolcanic model for the evolution of the basement complex of the central part of Egyptian Eastern Desert

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Relevance of the work. This article emphasizes the geological history of the accumulation of a thick volcanic, volcano-sedimentary, and sedimentary sequence around the Meatiq metamorphic core, the emplacement of its magmatic intrusions and the influence of tectonics during its formation. This study will help in expanding the natural resource base in the Egyptian Eastern Desert.
Purpose of the work. To clarify the geological setting of the studied territory, give an interpretation for its evolution and establish specific directions for exploration its ore deposits, based on our research results and previous works.
Methodology of research. Firstly, methods of comparative analysis of paleovolcanic structures were used to identify the sequence of orogenesis. Secondly, the study of stratigraphy, geological mapping, the spatial distribution of rock units, the form of fault systems distribution, and structural analysis. Thirdly, the creation of a model with schematic illustrations of geological sections.
Results of the work. The results of the study clearly indicate the long duration of geological processes that continued for at least two main tectono-magmatic epochs (Cadomian – with a duration of 120 Ma, and Salairian – 110 Ma).
Area of work application. The results of this paper can be used to identify several economic deposits, such as volcanic massive sulfides, copper porphyry deposits, etc.
Conclusions. The rock assemblage of the area around Meatiq dome represents a huge Archean-Neoproterozoic paleovolcanic structure. This structure is composed of gneissic cores intruding in an older platform cover of metasediments and upper two main successive tectonic-magmatic cycles which rejuvenated the lower older gneisses.

Keywords: Meatiq, paleovolcanic structure, tectono-magmatic cycle, Eastern Desert, stratigraphy, magmatism, Egypt.

Introduction

The basement complex of the Eastern Desert is located within a large platform structure known as the Arabian-Nubian Shield (ANS) which represents the northern extension of the East African Orogen (EAO). Previous studies divided this complex into two main tectonostratigraphic units [1–3]. The lower structural unit, or infrastructure, consists of metamorphic rocks (gneiss, schists, amphibolites, etc.), grouped in dome-shaped structures, such as the Migif, Meatiq and Sibai domes. Above there are rocks of the upper structural unit or superstructure, represented by metasediments, and metavolcanic rocks which called ophiolitic mélange [4]. The tectonic evolution of the ANS has been discussed by many authors produced the following proposed models, summarized by Hamimi et al. [5].

(1) Infracrustal orogenic model, that considered the high-grade gneisses and migmatites as an old craton that were over thrusted by ophiolites and island arc volcanics and volcaniclastics, and remobilized equivalents during the Neoproterozoic time [1, 6, 7, 8].

(2) Turkic-type orogenic model, that considered much of the ANS formed in broad fore-arc complexes that involved the growth of a subcontinent-size subduction-accretion complexes, into which magmatic arc axes commonly migrate and thus enlarge their attached continent [9].

(3) Hot-spot model, that considered much of the ANS formed due to the accretion of the oceanic plateau by upwelling mantle plumes [10].

(4) Arc accretion (arc assembly) model, that considered the EAO as a juvenile crust that was generated around and within a Pacific-sized ocean (Mozambique Ocean). This model was proposed first by [11, 12], and modified by [13].

Here we present a new interpretation for the development of the basement complex around the Meatiq dome based on the model of the paleovolcanic structure. The theoretical concepts of this model are presented in details by [14, 15]. This territory in the central Eastern Desert of Egypt, is favorable for the reconstructions paleovolcanic structure. Here it was possible to identify a huge Archean-Neoproterozoic paleovolcanic structure with the center is located in the area of the Meatiq dome, forming an oval shape measuring about 60*30 km (Fig. 1).

Stratigraphy

A thick old platform cover of various metamorphosed terrigenous deposits outcrop within the whole area of the Eastern Desert. Hashad [18] considered it the oldest rock unit of the Egyptian basement except for some highly metamorphosed gneisses (Table). They form an oval shape around the gneiss dome of Meatiq (Fig. 1, 2, a). According to Sabet et al., [19], fine-grained types predominate to the northwestern part from the Meatiq dome, while in the southeastern part, coarse-grained clastics to conglomerates are the main types, where the transition between them is gradational. This platform cover separates the planetary stage represented by the highly metamorphosed rocks from the geologic stage represented by all the above laying units. The gneisses are exposed in gneiss domes as a result of subsequent intensive erosion across the EDSZ "Eastern Desert Shear Zone" [20] and considered as erosion windows in the metamorphosed platform cover. Based on their structural and stratigraphic position, El Gaby et al., [1, 21] considered

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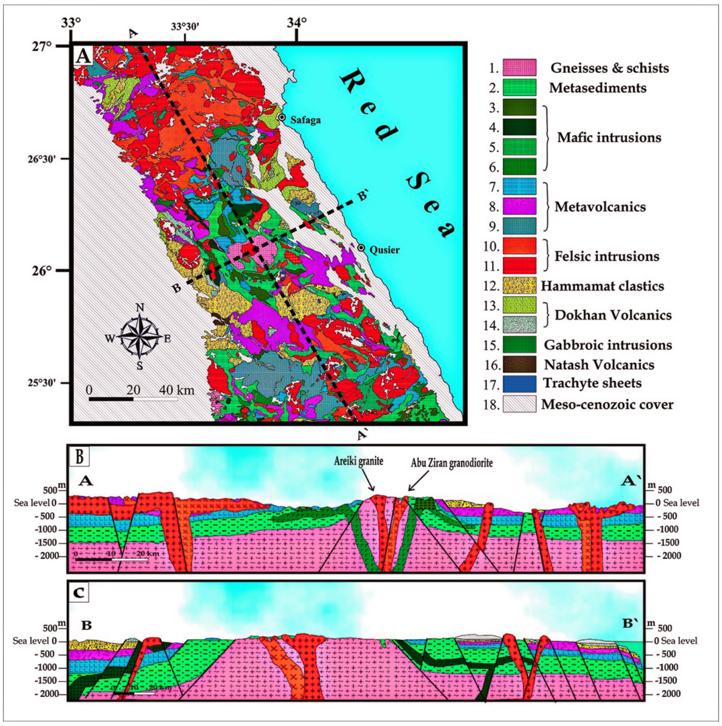

Figure 1. Meatiq paleovolcanic structure. a – Geological map of the territory around Meatiq dome (After [16]); b, c – schematic geological cross section across the Meatiq dome (After [17]). 1 – Mostly melanocratic, medium to high grade gneisses and schists» 2 – metasediments (metamorphosed shelf sediments with pyroclastics); 3 – Serpentinites, talc-carbonate and related rocks; 4 – Metagabbro; 5 – Metagabbro to metadiorite undifferentiated; 6 – Intrusive Metagabbro to metadiorite; 7 – basic metavolcanics; 8 – felsic to intermediate metavolcanics with metapyroclastics; 9 – undifferentiated metavolcanics; 10 – Older granitoids (Calc-alkaline quartz diorite to granodiorite); 11 – Younger granitoids (alkaline alkali-feldspar granite); 12 – Hammamat clastics (Molasse-type conglomerates to siltstone); 13 – Andesitic Dokhan volcanic; 14 – Rhyolitic Dokhan volcanics (or post-Hammamat felsite); 15 – fresh gabbro, norite and troctolite; 16 – Post-Hammamat felsite, felsite porphyry and quartz porphyry; 17 – trachyte plugs and sheets; 18 – Meso-Cenozoic sedimentary cover.

Рисунок 1. Палеовулканическая структура Митик. а – геологическая карта территории вокруг купола Митик (по [16] с редактированием); б, в – схематические геологические разрезы (по [17] с редактированием). 1 – в основном меланократовые гнейсы и сланцы средней и высокой степени метаморфизма; 2 – метаосадки (метаморфизованные шельфовые отложения); 3 – серпентиниты, тальк-карбонат и родственные породы; 4 – метагаббро; 5 – нерасчлененные метагаббро–метадиорит; 6 – интрузивные метагаббро–метадиориты; 7 – основные метавулканиты; 8 – кислые к среднными метавулканитами с метапирокластиками; 9 – нерасчлененные метавулканиты; 10 – более старые гранитоиды (известково-щелочные кварцевые диориты до гранодиоритов); 11 – младшие гранитоиды (щелочной полевой шпат гранит); 12 – обломочные породы группы Хаммамат (типа моласса от конгломератов к алевролитам); 13 – андезитовые вулканиты Дохан; 14 – риолито-доханские вулканиты (или постгаммаматский фельзит); 15 – свежие габбро, нориты и троктолиты; 16 – фельзиты постхаммамата, фельзитовый порфир и кварцевый порфир; 17 – пробки и листы трахита; 18 – мезокайнозойский осадочный чехол.

gneiss domes as pre-Neoproterozoic structures. However, the gneisses show younger absolute ages than overlaying metasediments and metavolcanics (Table). Stern [22] explained it due to the partial melting “rejuvenation” of gneisses during the deformation of the upper units. Andresen et al. [23] considered these younger ages to represent the main deformation event at Meatiq of 610–605 Ma.

The old pre-Neoproterozoic platform cover was exposed to main two cycles of tectono-magmatic activity. The first cycle is represented by the eruption of lava that formed the metavolcanic sequence and their tuffs. This cycle occurred in Archean-late Neoproterozoic during the Cadomian Orogeny. The main eruption center of this cycle is located in the Central Eastern Desert in the Meatiq dome. The Arieki and Abu Ziran granitoids (Fig. 1, a–c) in the central part of the Meatiq dome filled the place of the vent channels. The Meatiq formation is composed of two members: a) Umm Ba’anib granitic gneiss, and b) Abu Fannani metasediments including different types of quartz-feldspar and pelitic schists that reach several hundred meters thick. The metamorphic rocks of the Meatiq formation are covered by a thick succession of metavolcanic rocks along their northwestern part. Along the contact of Abu Fannani metasediments with the basic metavolcanics lies a 30 m thick basal horizon of the conglomerates, with pebbles from the lower underlying metamorphic rocks [24]. The Metavolcanics formation which is composed of two sheets a) The lower mafic sheet, which is associated with serpentinites (called Older Metavolcanics) and followed by b) The upper intermediate and acidic metavolcanic sheet (called Younger Metavolcanics, by Stern [25]) which is intercalated with tuffs and pyroclastics. These Metavolcanics and pyroclastics represent the development area of both distant and slope facies (Fig. 2, b). This first tectono-magmatic cycle was ended by the emplacement of the Older granitoids.

All the above-mentioned formations are uncomfortably covered by the second cycle of tectono-magmatic activation of the Salairian Orogeny. It began with the deposition of non-metamorphosed clastic “molasse-type” sediments called the Hammamat group; range from conglomerate to siltstone forming a major unconformity surface represented. Akaad and Noweir [6] subdivided the Hammamat group into the lower Igla Formation, consisting of sandstone, siltstone, and mudstone with a basal conglomerate, followed by the El Shihimiya Formation composed of conglomerate, greywacke, and sandstone.

The volcanic activity is represented by a stratified succession of lava flows of a wide spectrum of silica content called “Dokhan Volcanics Formation”. It comprises two main rock suites: (a) Lower minor intermediate volcanic suite, composed of lower basaltic andesite, andesite, dacite sheet, and their associated pyroclastic rocks called “Older Dokhan Volcanics”; and (b) Upper thick felsic volcanic suite composed of dacite, rhyodacite, rhyolite, ignimbrite and rhyolitic tuffs collectively called “Younger Dokhan Volca-

Table. The geological history of the formation of Meatiq paleovolcanic structure.
Таблица. Геологическая история формирования палеовулканической структуры Митик.

Tectono-magmatic cycle	Formation	Member	Thickness, m	Lithology	Isotopic ages, Ma		Associated intrusives
					Min.	Max.	
Saliarian	Dokhan	Younger Dokhan	1200 (max.)	Rhyolite, dacite, tuffs	465 [26]	630 ± 6 [27]	Younger granitoids
		Older Dokhan		Basalt, basaltic andesite	–	–	
	Hammamat group	Fine-grained Hammamat	150–500	Greywackes, mudstone and siltstone with chert bands	585 ± 13 [28]	585 ± 15 [29]	
		Coarse-grained Hammamat		Conglomerate, sandstone, and breccia with basalt and andesite	–	–	
Cadomian	Metavolcanics	Younger Metavolcanics	1000–1500	Metarhyolite, metadacite, metaandesite and acidic tuffs	622 ± 6 [30]	1078 [31]	Older granitoids
		Older Metavolcanics	1500–2000	Metabasalt, metabasaltic andesite, metaandesite	640 [32]	2730 [32]	
Old platform cover	Metasediments	Fine-grained metasediments	3000	Tuffaceous sandstone, siltstone, gravel and conglomerate	1150 ± 60 [18]	2765 [32]	Serpentinites, amphibolites, and metagabbro-diorite complex
		Coarse-grained metasediments	1000	Medium to coarse-grained schists, greywackes, tuffs	–	–	
Pre-Neoproterozoic	Meatiq	Abu Fannani	1500	Pelitic and quartzo-feldspathic schists	595.9 ± 0.5 and 588.2 ± 0.3 [33]		
		Umm Ba'anib	> 550	Granitic gneiss	596 ± 15 [34]	779 ± 4 and 1150 for amphibolite xenoliths [35]	

Note: the given isotopic ages and method used are as the following techniques: [34] Rb–Sr, [35] ^{207}Pb/ ^{206}Pb single zircon, [3] ^{40}Ar/^{39}Ar Muscovite, [18] Rb/Sr, [32] U–Pb SHRIMP, [30] Rb–Sr, [31] Pb–Pb Galena, [28] SHRIMP U–Pb, [29] Rb–Sr whole-rock, [26] K–Ar, [27] SHRIMP U–Pb zircon.

nics” [36]. The post-Hammamat felsites are tensely associated with Dokhan volcanics. They are composed of rhyolite flows and tuffs [37]. Here it is considered to belonging to the Younger Dokhan volcanics. The Dokhan volcanics are intensively eroded and the present occurrences represent only a few remains (Fig. 2, d).

The time relation between Hammamat formation and the Dokhan volcanics is debated. El-Gaby et al., [1] and Akaad [38] established that the deposition of the Hammamat sediments was after the eruption of the Dokhan volcanics. Moghazi et al., [39] stated that the Hammamat sediments and Dokhan volcanics were formed contemporaneously. At many localities, however, an interfingering relationship between the two lithologies can be observed [40]. Multiple transport directions and closely spaced lateral facies changes in the Hammamat Group are common. The eruption of Dokhan volcanics apparently was probably synchronous with deposition of at least the upper units of the Hammamat Group and emplacement of the alkali Younger Granites. This second tectono-magmatic was ended by the extensive intrusion of granitic massifs. Unfortunately, we have no detailed data on the facial composition of volcanogenic and volcanogenic-sedimentary strata. Consequently, conducting a facies analysis today is unrealistic.

Small exposures of young Mesozoic and Cenozoic volcanics (200–300 Ma) of mainly trachytic composition (Trachyte sheets and plugs) are recorded in the studied territory, due to further reactivation of older fracture zones. Here they aren’t discussed, because they don’t play a vital role in the development of Meatiq paleovolcanic structure. The stratigraphic section ends with Meso-Cenozoic terrigenous sediments, which constitute a thick platform cover to west from the paleovolcanic structure.

Magmatism

Three periods of emplacement of magmatic intrusions that covered a large area of the Eastern Desert define the ends of each tectonic epoch. These intrusions range in composition from ultramafic to felsic.

The gneisses and upper platform metasedimentary cover were intruded by ultramafic and mafic intrusions including serpentinite, gabbroic, gabbro-dioritic complexes; in many places, serpentinites thrust over the whole sequence.

The end of the first tectono-magmatic cycle is characterized by the emplacement of huge felsic calc-alkaline masses of a mainly granodioritic composition formed the so-called Older “or grey” Granite. They bound along the outer contour of the metavolcanic sheet with small masses intruding the metasediments and gneisses in the central parts of the palevolcanic structure (Fig. 1).

The end of the second tectono-magmatic cycle is characterized by the emplacement of alkaline intrusions of granitic composition composed the Younger “or red” granite. They outcrop mainly along the outer contours of the Older Granitoids as in the Northern Eastern Desert (Fig. 1), with prominent higher relief relative.

The emplacement of the Younger granite is most likely predated the deposition of the Hammamat molasses as observed in many areas like Wadi Igla and Wadi Quieh. However, the long period of deposition of the Hammamat molasses to make it overlapped in a few areas. For example, in Wadi Zeidoun E the Younger granite form 5 m contact zone with Hammamat sediments, sending apophyses in them indicating younger ages of granite [41].

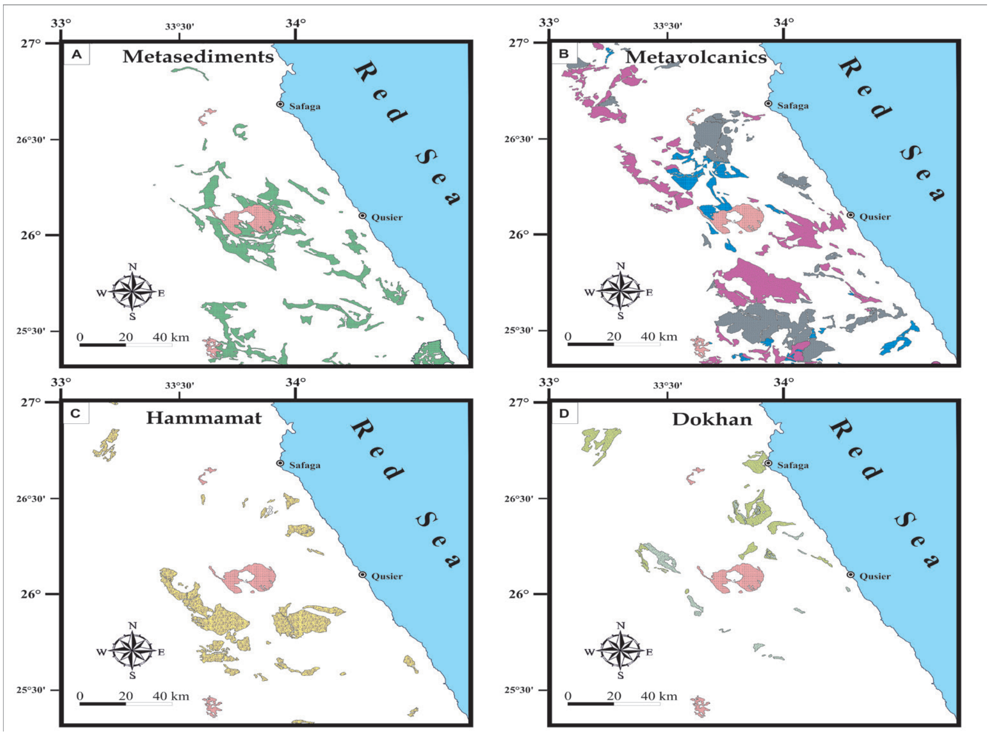

Figure 2. Geological maps illustrating the spatial distribution of a – Metasediments; b – Metavolcanics; c – Hammamat clastics, Dokhan volcanics around Meatiq gneiss core and other gneiss exposures (After [16]).

Рисунок 2. Геологические карты, иллюстрирующие пространственное распределение. a – метаосадков; b – метавулканитов; c – обломочных пород Хаммамат; d – вулканитов Дохан вокруг гнейсового ядра Митик и других обнажений (по [16] с редактированием).

Tectonics

The fault system in this territory represents two cycles of development, (a) Older Fault System (OFS) was formed at the earlier stages of the development of the paleovolcanic structure. It is expressed by fragments of radial faults of different directions directed from the center of the Meatiq structure, and fragments of concentric faults encircling the Meatiq structure and later magmatic intrusions (Fig. 3). They are most likely correspond to the time of doming of the gneisses and after the introduction of granitoids. The radial faults served as channels for the introduction of dikes and also areas of later hydrothermal solutions. Around the center of the Meatiq structure, volcanogenic-sedimentary, volcanogenic, and sedimentary strata were accumulated along these concen-

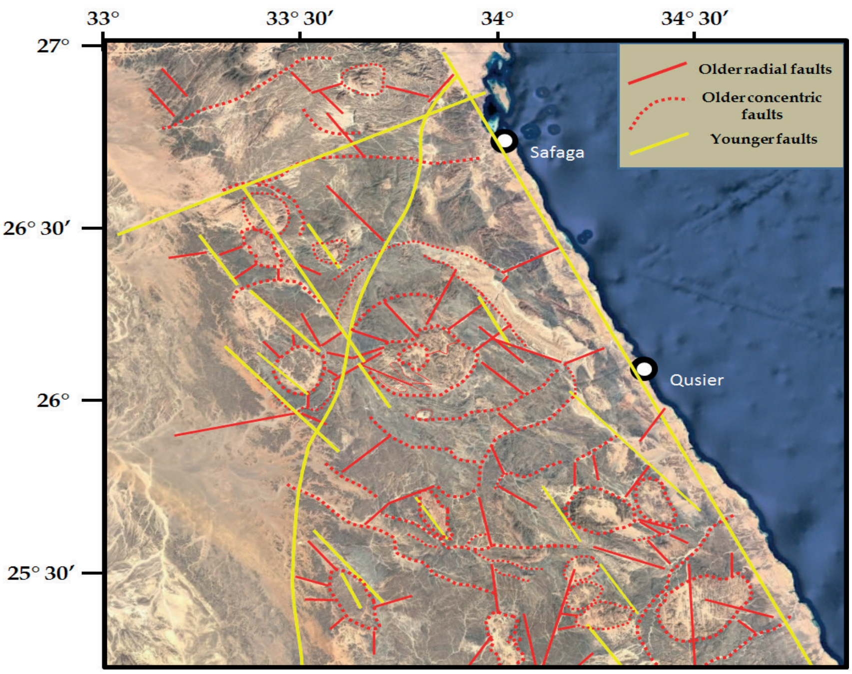

Figure 3. Older and younger fault systems of the studied territory.
Рисунок 3. Старые и молодые системы разломов изучаемой территории.

tric faults (Fig. 1–3). (b) Younger Fault system (YFS), represented by large faults of the NW strike and perpendicular to them that called the Najd Fault System. The Najd Fault System started after at the end of the formation of the paleovolcanic structure that equivalent to the Alpine Orogeny. The manifestation of YFS interrupted the radial and concentric faults led to the creation of a complex-folding mosaic block structure dominated by the vertical movement of large-sized blocks.

Many other items interrupted this paleovolcanic structure and hide many its features including, the extensive emergence of the granitic intrusions, Mesozoic and Cenozoic volcanics, and the thick Phanerozoic sedimentary cover. The study of the litho-stratigraphic sequence with the spatial distribution of rock units, field relations, previously recorded ages, etc. helps to construct this proposed model.

Summary

The rock assemblage of the area around Meatiq dome represents a huge Archean-Neoproterozoic paleovolcanic structure. According to the stratigraphic position, the oldest rock unit in the studied territory is represented by Umm Ba'anib granitic gneisses and Abu Fannani schists. The gneisses are covered with a thick platform cover of metasediments that was intruded by many mafic and ultramafic intrusions represented by metagabbro and serpentinites. The Meatiq gneisses were domed and rejuvenated during two subsequent tectono-magmatic cycles. The first cycle resulted in the formation of two metavolcanic sheets. The lower sheet has a basic composition which represents the development area of distant facies. The upper sheet has intermediate to acidic composition and intercalated with pyroclastics representing the development area of slope facies. The Older granitoids were emplaced at the end of this cycle. The second cycle is represented by the Dokhan volcanic series and separated from the first cycle by a major unconformity surface represented by the Hammamat group clastics. This cycle was ended with the intrusion of Younger granitoids. Radial and concentric faults developed around the Meatiq paleovolcanic structure and interrupted by more younger well-developed NW Najd Fault system faults and perpendicular to them.

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Палеовулканическая модель эволюции фундаментального комплекса центральной части Восточной пустыни Египта

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Актуальность работы. В данной статье подчеркивается геологическая история накопления мощной последовательности вулканических, вулканоосадочных, осадочных пород вокруг метаморфического ядра Митик, внедрение ее магматических интрузий и влияние тектоники во время их формирования. Это исследование поможет в расширении базы природных ресурсов на территории Восточной пустыни Египта.
Цель работы: на основании результатов собственных исследований и анализа фондовых материалов уточнить геологическое строение исследуемой территории, дать новую интерпретацию ее эволюции и установить конкретные направления для разведки ее руд.
Методология исследования. Впервые использованы методы сравнительного анализа палеовулканических структур для целей выявления исторической последовательности орогенезов. Во-вторых, изучение стратиграфии, геологического картирования, пространственного распределения породных единиц, формы распределения систем разломов и структурного анализа. В-третьих, создание модели со схематическими иллюстрациями геологических разрезов.
Результаты выполненных исследований однозначно свидетельствуют о длительности геологических процессов, продолжавшихся как минимум на протяжении главных двух эпохи тектогенеза (Кадомская – протяженностью 120 млн лет, Салаирская – 110 млн лет).
Область применения работы. Результаты, описанные в статье, позволяют надеяться на выявление нескольких промышленных месторождений, таких как колчеданные, медно-порфировые и т. д.
Выводы. Породная ассоциация вокруг купола Митик представляет собой огромную палеовулканическую структуру архея–неопротерозоя. Эта структура состоит из гнейсовых ядер, внедряющих в более старый платформенный чехол метаосадков и двух верхних последовательных тектономагматических циклов, которые омолаживали нижние древние гнейсы.

Ключевые слова: Митик, палеовулканическая структура, тектономагматический цикл, Восточная пустыня, стратиграфия, магматизм, Египет.

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