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Chapter

An Overview on the Classification and Tectonic Setting of Neoproterozoic Granites of the Nubian Shield, Eastern Desert, Egypt

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Abstract

Granites constitute the main rock components of the Earth's continental crust, which suggested to be formed in variable geodynamics environments. The different types of granitic rocks, their compositional characteristics, tectonic settings and magma sources are outlined. Mineralogical classification of granites includes four rock types: tonalites, granodiorites, granite (monzogranite and syenogranites) and alkali-feldspar granites. Alphabetical classification subdivided granites into: I-type, S-type, A-type and M-type granites. Moreover, formation of granitic magmas requires distinctive geodynamic settings such as: volcanic arc granite (Cordilleran); collision-related granites (leucogranites); intra-plate and ocean ridge granites. The Eastern Desert of Egypt (ED) forms the northern part of Nubian Shield. Both older and younger granites are widely exposed in the ED. Old granites (OG) comprise tonalites and granodiorites of syn- to late-orogenic granitoid assemblages. They are calcalkaline, I-type, metaluminous and display island arc tectonic setting. Younger granites (YG) on the other hand, include granites, alkali-feldspar granites and minor granodiorites. They are of I- and A-type granites and of post-orogenic to anorogenic tectonic settings. The majority of the YG are alkaline, A-type granite and of within-plate tectonic setting (WPG). The A-type granites are subdivided into: A2-type postorogenic granites and A1-type anorogenic granites. Granite magma genesis involves: (a) fractional crystallization of mafic mantle-derived magmas; (b) anatexis or assimilation of old, upper crustal rocks (c) re - melting of juvenile mafic mantle – derived rocks underplating the continental crust. Generally, older I-type granitoids were interpreted to result from melting of mafic crust and dated at approximately 760-650 Ma, whereas younger granites suggested to be formed as a result of partial melting of a juvenile Neoproterozoic mantle source. Moreover, they formed from anatectic melts of various crustal sources that emplaced between 600 and 475 Ma.

Keywords: granitoid rocks, neoproterozoic, granites, Nubian shield, Eastern Desert, Egypt, older and younger granites, tectonic setting

1. Introduction

Granitoid rocks are the most abundant plutonic rocks in the continental crust, which are diverse and their magma sources have long been debated. There is a tectonomagmatic connection, where each granite type is related to definite tectonic settings, and all magmatism is tectonically motivated, so that such a division is simply a matter of emphasis [1]. Using the QAP diagram (Figure 1) granites are classified into four granite domains: tonalite, granodiorite, granite (monzogranite, and syenogranite) and alkali feldspar granites according to IUGS [2]. Genetic alphabetical classification includes: I-type granites (I = igneous); S-type granites (S = sedimentary); M-type granites products of mantle melts (M = mantle) and A-type (A = anorogenic) [3]: A = type granites were referred as alkaline or anorogenic granites [4]. The granitic rocks show an obvious alumina saturation from metaluminous, through peraluminous to peralkaline [5, 6]. Peraluminous granites have $Al_2O_3 > CaO + Na_2O + K_2O$; Metaluminous: $A_2O_3 < CaO + Na_2O + K_2O$ and $Al_2O_3 > Na_2O + K_2O$ and peralkaline $Na_2O + K_2O > Al_2O_3$. Chemically, S-type granites are equivalent to peraluminous granites, and I-type granites are equivalent to metaluminous granites. Whalen et al. [7] used the contents of Zr, Ce, Y and Nb (normalized to Ga/Al) to discriminate between A-type granites and both I- and S- type granites. A more comprehensive descriptive basis for chemically subdividing granitoids was given by Frost et al. (2001), in which they subdivided granitic rocks based on the so - called *Fe* - number (whole– rock Σ FeO/[Σ FeO + MgO] into ferroan and magnesian rocks.

Granites formed in a variety of tectonic settings around the world, either at plate margins or intraplate. They are subdivided according to their tectonic environments into four main groups—ocean ridge granites (ORG), volcanic arc granites (VAG), within plate granites (WPG) and collision granites (COLG) using trace element Y-Nb, Yb-Ta, Rb-(Y + Nb) and Rb— (Yb + Ta) diagrams [8]. Harris et al. [9] recognized four groups of collisional zone granites: (1) Pre-collision calc-alkaline (volcanic-arc) intrusions which are mostly derived from mantle modified by a subduction component; (2) Syn-collision peraluminous intrusions (leucogranites) which may be derived from the hydrated bases of continental thrust sheets; and



Figure 1.

A ternary QAP plot showing the relative modal proportions of quartz (Q), alkali feldspar (A) and plagioclase (P) defining the IUGS fields for granitic rocks (after Streckeisen, 1976).

(3) Late or post-collision calc-alkaline intrusions which may be derived from a mantle source but undergo extensive crustal contamination and (4) A fourth category, distinguished by Sylvester [10], consists of Alkaline granites in post orogenic continental settings and fall within the A - type or *anorogenic* category of granitoids. Figure 2 shows the different types of granitoid rocks related to various tectonic settings [11–14]. Sources of magma include two proposed processes: (i) fractional crystallization of mantle - derived basic magma; and (ii) partial melting of old sialic continental crust, leading either to the formation of anatectic plutons or to the contamination of mantle - derived magmas. The Cordilleran-type granites form in arc environments are characterized by magnesian compositions dictated by early crystallization of magnetite [15]. In contrast, ferroan granites are characteristic of extensional environments, where they form by partial melting or extreme differentiation of basaltic magma. *Island arc granitoids* (I-type granites) are produced above subduction zones, which characterized by large masses of batholiths made of diorites, quartz diorites, tonalites, granodiorites and minor granites. They are calc alkaline with small to high K contents and their Sr. initial ratio (Sr_i) are in the range 0.704–0.705 [16]. S-type granites in continental collision span compositions from granodiorites to granite, peraluminous granites without magnetite. Collision - related leucogranites of the High Himalayan have high (87 Sr./ 86 Sr) ratios in the range 0.743–0.762) and enriched in Rb and K but are depleted in Sr., Zr and LREE compared to Cordilleran granitoids [17]. Intraplate (within *plate) granites* can be subdivided based on tectonic criteria into intraoceanic, intracontinental and attenuated continental lithosphere. A-type granites are commonly alkali feldspar granites or syenogranites and often associated with syenites; these granites were defined by Loiselle and Wones [4] as alkaline or *anorogenic* granites. They are rich in silica and having high contents of LILE, HFSE (Zr, Ce, Nb, Hf, Ta, etc.), REE, K and Zr, but low in trace elements compatible in mafic silicates (Co, Sc, Cr, Ni) and feldspars (Ba, Sr., Eu) relative to the I-type ones. Intraplate A-type granitoids have significantly higher Fe/Mg ratios (*Fe* – number) than typical Cordilleran granitoids and accordingly fall in the "ferroan" granitoid category. Eby [18] divided A-type granites into two categories according to their Y/ Nb ratios: a group have low Y/Nb ratios and generally low initial 87 Sr./ 86 Sr. ratios that formed by differentiation of basaltic magmas of OIB - like (plume) mantle sources; the second group of A-type granitoids characterized by higher Y/Nb ratios (1.2–7) and highly variable initial 87 Sr./86 Sr. ratios. This group shows a complex petrogenetic history as having a significant mantle component or may be totally of crustal origin. **M-type granites** (plagiogranites) can be subdivided tectonically into subduction-related and subduction-unrelated on the basis of the chemistry of their associated basalts. Plagiogranites are characterized by normalized and REE patterns with a notable depletion in the most highly incompatible large-ion



Figure 2.

A classification of Granitoid rocks based on tectonic setting (according to pitcher, 1993; Barbarin, 1990; winter, 2001).

lithophile (LIL) elements Rb, Ba and K, greater enrichment in Th, Nb and prominent negative anomalies in P and Ti.

The Nubian Shield (NS) consists mainly of juvenile Neoproterozoic crust, where the ED of Egypt constitutes its northern part. Four main rock assemblages characterize the NS, namely: a gneiss assemblage [19–24], an ophiolite and island arc assemblages [25–29], igneous intrusions and unmetamorphosed Dokhan volcanics and Hammamat molasse sediments. The Eastern Desert (ED) of Egypt include three domains: (a) the Northern Eastern Desert (NED), (b) Central Eastern Desert (CED) and (c) Southern Eastern Desert (SED), where the igneous activity began prior to 765 Ma and ended by 540 Ma [30–31]. Granitoid rocks, which are common in the Egyptian Eastern Desert (ED) and Sinai were emplaced between (*820 to 570 Ma) at various tectonic settings [32]. The granitoid rocks of the ED include both older granites, which constitute about 27% of the basement outcrop [33] and younger granites constituting approximately 30% of plutonic assemblages in Egypt [34]. The reconstruction of this chapter is based on a compiled data of published and previous geological, geochemical and geochronological studies. This to reviews and discuss the general geochemical characteristics, and classification of granitic rocks in general and in the ED of Egypt too. This could be helpful in understanding their compositional variation, tectonic environments and magma evolution.

2. Neoproterozoic granites of the Eastern Desert of Egypt

2.1 General outlines

Granites are of wide distributions between the different rock units of the Egyptian Neoproterozoic rocks, constituting approximately 60% of its plutonic assemblage [35]. The main exposures of granitic masses are concentrated in the ED of Egypt, where a huge masses of granite plutons intruded into the pre-existing country rocks (**Figure 3**; based on the Geological map of Egypt 1981; [36]). Granitoid rocks of the ED are classified into older (750–610 Ma) and younger (620–540 Ma) granites based on their composition, color, and relative age [37]. They further classified as: (1) Subduction-related older granites; (2) suture-related or Post-orogenic younger granites and (3) intraplate anorogenic younger granites [35]. The Older granites (OG) comprise mainly tonalites and granodiorites, and minor trondhjemite and quartz diorites. The Younger granites (YG) classified according to their geological setting and petrography [38] into: (i) phase I granodiorites with minor monzogranites, (ii) phase II (monzogranites and syenogranites), and phase III (alkali feldspar granites). Recently, part of the Younger granites (commonly phase III) is classified as A-type granites [39]. Stern and Hedge [31] proposed a major tectonic transition from a compressive to an extensional regime at 600 Ma. They concluded that the Egyptian granites are belonging to two main phases of the Pan-African Orogeny: (1) The older group (715-610 Ma) comprises syn- to late-tectonic granites forming batholithic masses that exhibit wide compositional variations (trondhjemites to granodiorites with minor granites), and (2) The younger group (600–540 Ma) comprises post-tectonic pluton to stock-sized granitic bodies, generally rich in K-feldspars and sometimes associated with rare metal mineralization. Bentor [32] classified the granites of the Arabian Nubian Shield into two groups: an older Syn- to late-orogenic granites (880–610 Ma), and younger post-orogenic to anorogenic granite (600–475 Ma. Loizenbauer et al. [40] identified three magmatic pulses in the Central Eastern Desert, dated as: 680 Ma; (2) 620 Ma; and (3) 585 Ma.



Figure 3.

Distribution of older and younger granites in the Eastern Desert of Egypt (based on the geological map of Egypt 1981; Asran, 2021).

2.2 Geological setting

The older granites of the ED constitute about 27% it's basement outcrops [33]. They occur as low relief igneous mountains (**Figure 4a**). They intrude the oldest rock types such as metavolcanics, and metasediments and have commonly have foliated margins concordant to wall rock structure. The granites include rounded to subrounded microgranular mafic enclaves of variable sizes (few cm up to meter (**Figure 4b**). The rocks are of gray to whitish gray colors, medium to coarse grained and composed mainly of tonalites and granodiorites. Examples of such granites are: Abu Ziran granites in the Central Eastern Desert and the Shaitian granite in the southern Eastern Desert.

The Younger granites are of wide distribution across the ED, where they form high relief bold mountains (**Figure 4c**). They intrude the earlier exposed rocks with sharp contacts and they commonly possess steep walls and oval or elongated outlines. They enclose mafic xenoliths, enclaves and roof pendants of country rocks with sharp contacts with the enclosing granitic rocks (**Figure 4d**). The rocks are of pink and red colors, medium to coarse grained and comprise monzogranites,



Figure 4.

Photographs showing the field observations of the Egyptian granites: (a) low relief older granite; (b) mafic enclaves with gradational contacts with the host older granite; (c) high relief younger granite (back); (d) angular xenoliths within host younger granites with sharp contacts.

syenogranite and alkali feldspar granites, even granodiorites are seldom reported. They are classified according to their geological setting and petrography into: (i) phase I granodiorites with minor monzogranites, (ii) phase II (monzogranites and syenogranites), and phase III (alkali feldspar granites) [38]. Examples of younger granites are El Sibai granite in the Central ED and Gattar granite in the northern ED.

2.3 Petrography

The Older granites are composed mainly of tonalite and granodiorites. They are consisting of quartz, plagioclase and K-feldspar as essential minerals as well as variable proportions of biotite and hornblende. Quartz occur as anhedral crystals, whereas plagioclase forms tabular, lamellar oligoclase and is occasionally zoned (**Figure 5a, b**). K-feldspar occurs as tabular microcline and/or Carlsbad orthoclase. Hornblende forms long prismatic crystals of green or yellowish green colors. Biotite occur as platy crystals of yellow or yellowish-brown colors.

The younger granites comprise monzogranite, syenogranite and alkali feldspar granite. They are composed of quartz, k-feldspar and plagioclase as essential minerals, together with subordinate biotite, muscovite, hornblende, riebeckite and arfvedsonite (**Figure 5c, d**). Quartz occurs as anhedral large crystals interstitial to other mineral constituents. Potash-feldspars include tabular orthoclase and microcline perthite crystals. Primary K-feldspar minerals are usually altered to sericite and clay minerals and corroded by quartz and plagioclase. Plagioclase is represented by subhedral tabular crystals with distinct albite-lamellar twining of albite to oligoclase composition and occasionally intergrown with the K-feldspar forming perthitic texture (**Figure 5c**). In alkali feldspar granite, quartz is actively



Figure 5.

Photomicrographs of the Egyptian granites: (a) tonalite consists of quartz, plagioclase, K-feldspar and biotite. Together with iron oxides; (b) granodiorite with the plagioclase showing zoning; (c) syenogranite with perthitic texture; (d) myrmekitic and micrographic textures in alkali feldspar granite (pl = plagioclase; k-f = feldspar; Q = quartz; Bi = biotite).

intergrowth by adjacent feldspar leaving blebs of quartz inside the replacing alkali feldspar forming micrographic and myrmekitic textures (**Figure 5c, d**). Biotite is subordinate and occurs as subhedral flaky or platy crystals with inclusions of zircon, apatite and sphene.

2.4 Geochemical characteristics

Compiled data of whole-rock major, trace and REE of representative granitic samples from different occurrences are presented [24, 41–44]. The OG are metaluminous to slightly peraluminous, and have calc-alkaline affinity, whereas most of YG have a peraluminous character and slightly metaluminous and peralkaline [24, 45]. According to Frost et al. [15], the majority of OG analyses fall within the magnesian field, while analyses of YG plot in ferroan field with few exceptions (Figure 6). The younger granites are either of calc-alkaline character, LILE-enriched, highly fractionated I-type granites, or alkaline rocks of A-type character. Commonly, the trace element characteristics for YG are marked by enriched contents of K, Rb, Ta, Th, Nb and Zr and depletion in Sr., Ba, P and Ti. They are enriched in the HFSE, Nb, Ta, Zr, Hf, Y, U, Th and total REEs and relatively depleted in Ba, Sr. with LREE-enriched to almost flat and prominent negative Eu anomaly. Noweir et al. [46] classified younger granites into four groups: (1) Group I of calc-alkaline to weakly alkaline I-type granites; (2) Group II alkaline A-type monzogranite to syenogranite; (3) Group III strongly alkaline alkali feldspar A-type granites; and (4) Group IV apogranites, enriched in Na₂O. The Phase I younger granites of Samadi and Um Rus are calc alkaline, I-type and formed in a compressional regime or continental arc setting [47].



Figure 6. Plot of Σ FeO/(Σ FeO + MgO) versus SiO₂ content (after frost et al., 2001; redrawn from Abd El Naby, 2021).

The phase-III younger granitoids (A-type) are characterized by higher SiO₂, Rb, Y, Nb and REE and lower CaO, MgO, Sr., and Ba contents than other phases of younger granites [45]. They are classified as alkaline, and peralkaline to mildly peraluminous A-type granites [48]. Commonly, the calc-alkaline rocks of YG are enriched in Sr. and Ba, but relatively depleted in Zr, Nb, Y, Zn and K in comparison with the alkaline suite granitoids (A-type granites). They are considered as fractionated I-type to A-type granites, magnesian and peraluminous to metaluminous, whereas the alkaline suite ones (A-type) are ferroan and commonly peralkaline.

The REE patterns of the granodiorites of the OG (**Figure 7a**) show enrichment in the LREE relative to HREE with small negative Eu anomaly (average Eu/Eu^{*} = 0.674) [24]. The rocks display enrichment of LILE) HFSE, K, Sr., Rb, Ba, Th and Ta are, which are compatible with calc-alkaline trends found in island/continental arc settings. The alkali feldspar granites of the YG are characterized by LREE-enrichment or moderately fractionated LREE, flat heavy REE patterns (**Figure 7b**), and moderately to strongly negative Eu anomalies (Eu/Eu^{*} = 0.14–0.63) [49]. REE patterns for YG show high contents of total REE and are enriched in LREEs, and depleted in HREEs, with negative Eu/Eu^{*} [44]. Collision-related granites exhibited moderately negative Eu anomaly (Eu/Eu^{*} = 0.093–0.436) whereas pattern of within plate granites showed moderately to strong negative Eu/Eu^{*} values of approximately 0.026–0.211 for A1-type and 0.004–0.382 for A2-type (**Figure 6c, d**). Also, the calc-alkaline granites of the YG are characterized by higher Eu/Eu^{*} values (0.5–1), giving rise to shallow negative anomalies. The alkaline granites appear to be differentiated from the calc-alkaline granitoids by higher RREE and much lower Eu/Eu^{*} values [50].

2.5 Tectonic setting

Generally, the Egyptian granitoids can be classified into: (1) synorogenic calcalkaline granitoids, (2) late- to post-orogenic calc-alkaline granitoids, and (3) post-orogenic alkaline granites [51], or moreover, granitic rocks subdivided into (1) subduction-related granites, (2) collision-related granites, (3) A2-type intraplate granites and (4) A1-type intraplate granites. Petro et al., [52] constructed



Figure 7.

(a) REE of older granites and (b) REE of younger and A-type granites (from Basta et al., 2017); (c) and (d) chondrite-normalized REE patterns (normalizing values from McDonough and sun 1995). b trace element patterns normalized to the oceanic ridge granite (from Abd El Naby, 2021).



Figure 8.

(a) AFM diagram (after petro et al. (1979); (b) Nb-SiO₂ plot for the Egyptian granites (Pearce and Gale 1977; based on data from Abd El Naby, 2021).

the AFM triangular diagram to discriminate between granites formed in compressional (e.g., subduction related) and extensional regimes (e.g., intraplate environment). The data of the OG are plotted inclined to the AF side of the AFM diagram (**Figure 8a**) suggesting a compressional tectonic setting, while the data from the YG are plotted parallel to the AF line implying their extensional trend and that they formed in within plate environment. Pearce and Gale, [53] suggested Nb (ppm) versus SiO₂ (wt. %) diagram (**Figure 8b**) to discriminate tectonic environment of granites, in which the data of OG fall in the field of volcanic arc granites, whereas those of the YG plot in the field of the within–plate environment. The tectonic settings of the Egyptian granites can be deduced by using the discrimination diagrams of Pearce et al. [8]. In the Rb versus Y + Nb discrimination diagram (**Figure 9a**),



Figure 9.

(a) Yb + Nb versus Rb tectonic setting diagram of older and younger granitoid rocks of the ED of Egypt ((Pearce et al. 1984). Redrawn from El Bahariya, 2019); (b) Nb-Y-3 Ga ternary diagram (after Eby 1992). Redrawn from Abd El Naby, 2021.

the data of OG (tonalities, granodiorites) and phase I of younger granites plot within the volcanic-arc granite, while most obtained data of phase II and phase III of YG plot in the within-plate granite field. So, the YG include highly fractionated calc-alkaline I-type volcanic arc granites (postorogenic or collision-related) as well as A-type, intraplate granites. In other words, the younger granites, except phase I exhibit within plate tectonic setting. Most of the geochemical data of the A-type granites of the ED are generally consistent with a within-plate tectonic settings (**Figure 9a**). However, the majority of A-type granites such as El Atawi, Homrit are classified as A2 types with crustal sources, whose ratio Y/Nb is above 1.2 (**Figure 9b**) and appear to be formed mainly in a post-collisional setting., while A1-type granites such as Gattar, Abu Harba and Um Ara granites show Y/Nb ratio less than 1.2 and is characterized by continental intraplate environment [44]. Alkaline granites form mostly in intraoceanic system ocean islands or intracontinental rifts near the divergent boundaries of lithospheric plates in post-tectonic stage around 540 Ma [54]. The chemical characteristics of the A2-type intraplate granites indicate that they were derived from transitional stage between orogenic and anorogenic regimes, i.e., post-collision calc-alkaline granites. The change from compressional volcanic arc settings to extensional intraplate setting is likely to have occurred around 650-630 [55].

2.6 Origin and source of magma

Previous studies on granitoid rocks of Egypt suggested several models and scenarios for the sources of magmas in different tectonic sites. Some workers favor fractional crystallization of mantle-derived mafic magma [56]. Others suggested instead partial melting of various crustal sources [57] or combine mantle and crustal source components [58, 59]. Moreover, Lundmark et al. [54] also suggested three magmatic pulses with refined age brackets at 705–680, 660 and 635–630 Ma.

The older granites are classified as I-type granites and of volcanic-arc-granite tectonic setting [60]. Two contrasting petrogenetic models have been proposed for the origin of the OG: (1) magmas generation by partial melting of mantle sources previously metasomatized by slab-derived fluids through fractionation from mantle-derived, LILE-enriched basaltic melts in subduction settings with some crustal contamination [61-64]; (2) Fractional crystallization of mafic crustal melts generated by partial melting of amphibolite and mafic to intermediate igneous of lower crust [57]. However, the parental magmas may instead reflect mixing of

mantle and crustal melts. The intermediate magma derived, by partial melting of the lower crust may promoted by heat from mantle-derived mafic melts producing a hybridized intermediate magma, that form tonalite and granodiorite by fractional crystallization during its ascent and cooling [65]. This metaluminous magnesianrich magma eventually produce subduction-related granites (diorites, tonalities, granodiorites and minor monzogranites). Hassan and Hashad [34] proposed that emplacement of subduction-related granites was linked to three magmatic pulses at 850–800 Ma, 760–710 Ma and 630 Ma.

The magma of *the younger granites* appears to be derived by high degree of partial melting of crustal materials including: mafic lower crustal rocks [48], middle crust granodiorites-tonalites [66], metasedimentary protolith [67]. Alternatively, others-maintained mixing/mingling; of juvenile mantle-derived magma with felsic crustal melts [58]. *Post-collisional granites* of alkaline affinity are dominated at the final stages of the Pan-African orogeny [59]. The hot asthenosphere and crustal uplift causing extensive decompression melting and basaltic underplating and the heat promote partial melting of the lower crustal rocks to form the post-collisional calc-alkaline magma [68].

The alkaline A-type granites are considered as the product of either extensive fractional crystallization of mantle-derived mafic magmas [69] or partial melting crustal sources [70]. The A2-type intraplate granites appear to be derived from transitional stage between orogenic and anorogenic regimes. The A1-types are considered to be derived from differentiation of melts similar in composition to oceanic island basalts. Most of the A2 granites present in anorogenic environments and plot in the field of crust-derived A-type granites, which originate from a wide range of sources. However, the A2-type granites can also form at the sites of convergent (collision) plate boundaries [71]. Formation of A1-type intraplate granites is related to faulting [72] or magma is suggested to be produced by a melting process of lower crustal rocks in extension setting [73].

2.7 Age dating of granitoid rocks

Ages obtained for Older Granites from the Eastern Desert are younger than 750 Ma [74]. Stern and Hedge [31] gave Rb/Sr. whole-rock age of 674 ± 13 Ma for the time of intrusion of Wadi El-Miyah gray granites; and U/Pb zircon age 614 ± 8 Ma for the age of emplacement of Abu Ziran tonalite and granodiorite. Crystallization age for granodioritic batholiths from Humr Akarim and Humrat Mukbid, Eastern Desert of Egypt, is 630–620 Ma [75]. A comparable crystallization age (643 ± 9 Ma) of the Um Rus tonalite-granodiorite was determined by Zoheir et al. [76] although it is classified as phase I younger granite [38, 47].

Younger Granites (YG) include evolved island arc postorogenic and within plate anorogenic tectonic setting. The emplacement of the Egyptian late- to post-tectonic younger granites covers a time span between 600 and 550 Ma, [31] or 600 and 475 Ma [75]. The 635–580 Ma or 610 and 590 Ma period are characteristic for the postcollisional younger granite emplacement [77, 78]. They have been emplaced as two separates, but partially overlapping calc-alkaline and alkaline suites at 635– 590 Ma and 608–580 Ma, respectively [79]. The Um Had granite has a U–Pb zircon age of 590–3.1 Ma [74]. Alkaline A-type granites from the ED (such as Al-Missikat, Abu Harba, and Gattar) dated ca. ~600 Ma [58].

3. Concluding remarks

Granites of different types have variable magma sources and tectonic environments. The Egyptian granites of the ED are classified into older and younger granites. The overall geological settings, geochemical characteristics and tectonic setting of the granitoid rocks of the ED of Egypt are presented and summarized in **Table 1**. *The older granites* occur as low relief igneous plutons intruded over a very long period of time from >850 to 615 Ma. Geochemistry of older granites reveals

	Older granites	Youger granites		
Geological setting	Low releif mountains, gray coulur, with gradational contacts with the country rocks and have ellipsoidal enclaves with gradational contacts with the host granite	High relief, pink or yeloowish white coulour, have sharp contacts with the country rocks and their xenoliths and inclaves are irregular in shape and have sharp contacts with the host granite.		
		Phase I	Phase II	Phase III
Granite rock types	Tonalite, granodiorite	Granodiotite, monzogranite	Syenogranite, monzogranites	alkali feldspar granites, syenogranites
Mineral composition	Quartz, plagioclase, k-feldspar, hornblende, biotite	Quartz, k-feldspar, plagioclase, biotite, hornblende	Quartz, k-eldspar, plagioclase, biotite, muscovite	Quartz, k-feldspar, plagioclase, arvedsonite, rebiekite, aegerine.
Geochemical characteristics	low-to medium-K calc-alkaline; I-type granites; subduction- related magnesian, granitoids display enrichment of LILE relative to HFSE and clear negative anomalies in Nb and Ta.	Highly fractionated calc-alkaline granites;.	alkaline to peralkalin A-type; ferroan,	e granite,
			A2	A1
Tectonic setting and age dating	Compressional, Synorogenic; Volcanic arc granite or Magmatic arc/Active continental margin, *700–630 Ma (e.g., Lundmark et al. 2012; Ali et al. 2016)	Late-to post-orogenic, Collisional granite, or evolved volcani arc; Lundmark et al., 2012 590–610 Ma	Post-orogenic to anorogenic, Within plate 610 and 590 Ma (e.g., Ali et al. 2016; 590–540 Ma; Lundmark et al., 2012	Within plate, Anorogenic; 540 Ma Lundmark et al., 2012

Table 1.

Geological characteristics, geochemical features and tectonic setting of the granitoid rocks of the Eastern Desert of Egypt.

that they are metaluminous to slightly peraluminous, have calc-alkaline affinity, I-type granites and of volcanic-arc-granite tectonic setting. They are interpreted to result from melting of crustal rocks. Moreover, older I-type granites can form through fractionation from mantle-derived, LILE-enriched basaltic melts in subduction settings. *The younger granites* include highly fractionated calc-alkaline I-type granites as well as alkaline, A-type, granites. They are of peraluminous character and slightly metaluminous to peralkaline that have been emplaced as two suites: calc-alkaline (at 635–590 Ma) and alkaline (608–580 Ma) suites. Phase I younger granites (granodiorite and monzogranite) are suggested to be evolved island arc or post-orogenic subduction-related plutons, whereas Phase III and most of phase II exhibit within plate tectonic setting.

The diversity of granitoids rocks of the ED of Egypt and the variability of their chemical composition are controlled by the chemical composition of the source (crustal and mantle), P–T conditions, degree of partial melting, anatexis, as well as the extent of fractionation processes and crustal contamination. This implying various tectonic settings for the magma generation and emplacement. Granitic magmas formed during different tectonic regimes in compressional volcanic arc to extensional within-plate. Thus, the granitic rocks of the ED are geochemically diverse and their origin and tectonic evolution are still controversial.

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