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Mineral Chemistry and Genesis of Emerald and Beryl Mineralization in the south Eastern Desert of Egypt

F. M. Khaleal [1]*, D. R. Lentz [2]; D. C. Hall [3]

[1] *Nuclear Materials Authority, P.O. 530. El Maadi, Cairo, Egypt*
[2] *Department of Earth Sciences, University of New Brunswick, Fredericton, NB, Canada*
[3] *Microscopy and Microanalysis, University of New Brunswick, Fredericton, NB, Canada*

Abstract

Beryl mineralization in Egypt occurs in the south Eastern Desert and Sinai, occurring in two geologic environments. In the first environment, beryl occurs in phlogopite schist next to contacts with discontinuous muscovite leucogranite and linked to cogenetic pegmatites. Their spatial distribution is a well-defined NW-SE trend district extending ~45 km long and ~9 km wide. This extensive district coincides with the major Nugrus thrust and linked strike-slip shear-zone system. Zabara-Um Addebaa district (Z-UD) resembles this type and the schist hosting emerald in the south Eastern Desert of Egypt is confined to this district. In the second geologic environment, beryl occurs within pegmatite (lenses, bodies, and veins), quartz veins, and disseminated form in alkali feldspar granite; the Homret Akarem-Homret Mukpid district (HA-HMD) resembles this type. In Z-UD, the averages of Al_2O_3, K_2O, CaO, TiO_2, V_2O_3, and Cr_2O_3, in emerald of phlogopite are higher than those of green beryl either in phlogopite or in quartz veins. It is sodium-rich beryl, as Na_2O ranges between 1.74 and 1.96 wt.%. In the studied emerald and beryls, the concentrations of Cr, V, and Fe^{+2} control the beryl coloration (chromophore). In HA-HMD, the beryl mineralization of Homret Akarem is a whitish and pale green color, while beryl of Homret Mukpid is of pale blue color. The averages of Na_2O, MgO, Al_2O_3, K_2O, CaO, MnO, NiO, and Cs_2O in Homret Akarem are higher than those of Homret Mukpid. Conversely, the averages of TiO_2, V_2O_3, Cr_2O_3, and FeO of Homret Akarem are less than those of Homret Mukpid. The pale blue color of Homret Mukpid is attributed to the high content of Fe^{+2}, Cr, and V, whereas the whitish color of Homret Akarem beryl is due to the deficiency of these elements. The genesis of beryl mineralization in Z-UD district is interpreted as a result of the interaction between highly evolved felsic magma (muscovite leucogranite and associated pegmatite) and the pre-existing mafic-ultramafic rocks embedded in mélange matrix (schists). These processes involve the addition of the elements characteristic of a highly evolved granitic assemblage (Be, F, B, P, alkalis) to the ultramafic assemblage that is quite high in Mg, Ti, Cr, Ni, and Cu. Consequently, phlogopite (K-metasomatism) formed at the expense of earlier actinolite (Mg, Ca metasomatism), which released Cr and (or) V giving the green to deep green color. The genesis of beryl mineralization in HA-HM district is attributed to metasomatism by emanation of volatiles exsolved from a deep-seated highly evolved felsic magma source.

Keywords: Type your keywords here, separated by semicolons ;

1. Introduction

Beryl is a beryllium alumino-silicate mineral with the chemical formula $Be_3Al_2(Si_6O_{18})$. Normal beryl is colorless but the presence of various trace impurities gives the gemstone varieties of this mineral their distinctive colors (chromophore): green emerald, blue to bluish green aquamarine, pink morganite, red bixbite, and yellow to yellowish-orange heliodor [1]. Beryl occurs as elongated crystals with a hexagonal cross-section. It has a Mohs scratch hardness of 7.5-8, which is exceeded by only a few other gemstones such as chrysoberyl at 8.5, ruby and sapphire corundum at 9, and diamond at 10 [2].

Although 28 minerals are known in which beryllium is an essential constituent, only two are found in sufficient quantity and concentration to allow commercial extraction. These are beryl ($Be_3Al_2Si_6O_{18}$) with 14% BeO and bertrandite [$Be_4Si_2O_7(OH)_2$] with 15% BeO. Deep green, transparent beryl is an extremely valuable gemstone (emerald). In emerald, up to 2% Cr + V may replace Al in the crystal lattice. The pale, greenish-blue color of aquamarine is due to content of 0.1–0.3% Fe^{+2}. Exploitable beryllium ores have minimum concentrations from 0.1 to 2% BeO, depending on grain size, purity, texture and co-products [3]. It is estimated that about 65% of beryllium consumption is in the form of beryllium-

copper or other master alloys, about 15% in the oxide form, and the remainder in the metal form. Beryllium has been used in material test reactors, in the construction of mobile reactors, and also in defense applications [4]. Emerald, the green gem variety of beryl, is the third most valuable gemstone (after diamond and ruby [5].

Emerald deposits are mostly common in association with pegmatites, granitic dykes, and hydrothermal veins worldwide [6, 7]. Emerald deposits can be subdivided into two different categories [8], the predominant deposit type is associated with pegmatites and granites (also known as glimmerite type), while the rare but probably the most valuable deposit type is associated with thrusts and shear-zones (also known as telethermal type).

Beryllium is present in crustal granites and associated dyke swarms of pegmatites, aplites, and quartz veins. These highly evolved felsic rocks (FELSR), with more than 70% SiO_2, are mainly intrusive into the upper continental crust, and less so extrusive, with the highest Be concentration occurs in granites and rhyolites (~5 ppm) [9]. The two-mica granites have concentrations between 5 and 10 ppm, whereas specialized granites have more than 200 ppm [9]. Beryllium is carried by Be-minerals, but also by feldspar and micas. Chromium and V are more highly concentrated in mafic to ultramafic rocks (M-UMR) of the oceanic lithosphere that contain less than 50% SiO_2. These rocks, which are generally termed peridotites, are often metamorphosed into serpentinites containing up to 14 wt.% H_2O or into talc-chlorite-carbonate schists. Chromium is dominantly sourced from chromite and V is sourced from V-bearing magnetite or coulsonite ($Fe^{2+}V^{3+}_2O_4$). Nevertheless, Cr, V, and Be can be present in sedimentary rocks and are highly concentrated in shale [9].. Indeed, the weathering and erosion of M-UMR and FELSR on the continents delivers to the sea fine-grained clastic sediments composed of mud with Cr-V-Be-bearing grains and organic matter, as well as tiny fragments of quartz and calcite [9].

Beryl mineralization in Egypt occurs in the south Eastern Desert (SED) and Sinai (Fig. 1). In the SED, beryl mineralization occurs in two main districts; namely Zabara-Um Addebaa district (Z-UD) and Homret Akarem- Homret Mukpid district (HA-HMD); [10-16]. It was also recorded in milky quartz veins and lenses of the Igla area in the central Eastern Desert [17-20] and in the southeastern Sinai; in Wadi (W.) Ghazala area [21] as well as minor amounts in the southwestern Sinai in W. Sedri area [22].

The two main beryl districts (i.e., Z-UD and HA-HMD) are related to the Pan-African event based on Rb/Sr isochron ages between 700 and 677 Ma from granitic gneisses of the Sikait S-type leucogranite [23], 550±100 Ma [24], and K/Ar age 548±6 Ma of phlogopite from beryliferous pegmatites [25].
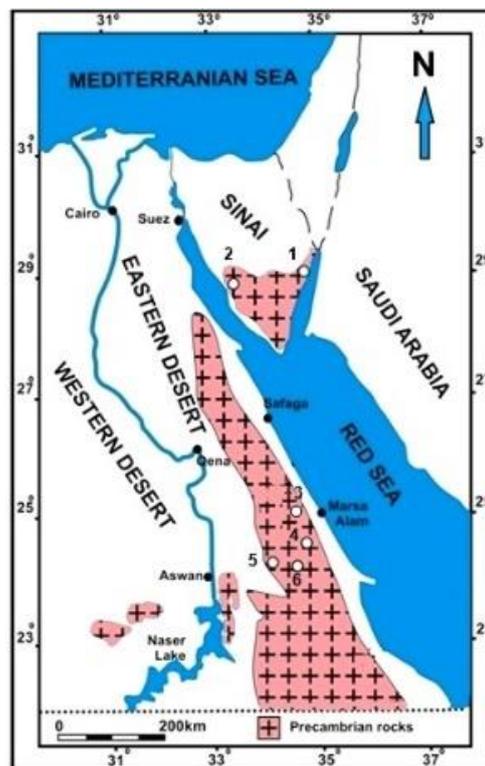

Fig. 1. Location map of the beryl mineralization occurrences in Egypt:1- W. Ghazala; 2- W. Sedri, Sinai Peninsula; 3- Igla area; 4- Zabara-Um Addebaa district; 5- Homret Akarem; 6- Homret Mukpid, ED, Egypt.

Beryl mineralization has been known in Z-UD since the Pharaonic times, and were exploited for gemstones since that time until the 1930's [10]. This district is a Precambrian basement terrain that is located ~70 km SW of the coastal town of Marsa Alam on the Red Sea and extends ~45 km in NW-SE direction (~9 km wide) from Zabara in the north to Um Addebaa in the south. This district coincides with the well-known deep-seated tectonic zone, which follows the NW-SE trend of the Red Sea.

The Z-UD comprises many ancient localities of exploited emerald mines and quarries since the Pharos and Roman time. The workings that were excavated in the softer phlogopite schist, with flat–edged chisels and pointed picks, are mostly shallow open–cut trenches following the quartz veins and pegmatite dykes. Some workings continue as much as 100 metre depth underground and are still largely unexplored [26].

The main emerald and beryl localities along this district comprise: W. Zabara, W. Sikait, W. Abu Rusheid, W. Nugrus (Ancient Madinat Nugrus), W. Um Solimat, W. Um El Kheran, W. Um Kabu, and W. Um Addebaa. The mining workings resulted in huge mine dumps, which contain significant amounts of discarded non-gem beryl crystals. Moreover, the nearby W. deposits contain

abundant fragments of beryl that can easily be hand–picked due to its characteristic green color [14].

Many authors studied the geology and (or) emerald and beryl mineralization in the Z-UD [2, 11, 14, 25, 27-37]. In Homret Akarem-Homret Mukpid (HA-HMD), the beryl mineralization was first discovered by [12.13]**.** In HA-HM District (70 km²), the beryl mineralization occurs as pockets, lenses, and disseminations in greisens and albitized granites [38]. Few authors studied the beryl mineralization in this district [12-14, 25, 34, 38]. The poor quality of Egyptian beryl has been attested repeatedly in both the ancient and modern literature **[1].**

This study enables a better understanding the genesis of the Emerald and other beryls mineralization in the SED of Egypt.

2. Geologic setting

2.1. Zabara-Um Addebaa District (Z-UD):

Zabara-Um Addebaa area is located at ~70 km SW of the town Marsa Alam on the Red Sea coastal plain and extends ~ 45 km long (and ~9 km) wide in NW-SE direction and coincides with major Nugrus thrust and linked strike-slip shear-zone system or so called deep-seated tectonic zone [14] or the so called Nugrus major shear zone [34]. On the basis of geologic environments, Z-UD can be sub-divided into three geologic sub areas; Zabara area, Nugrus-Sikait area, and Um Kabu-Um Addebaa area (Fig. 2). Generally, the rocks exposed in Z-UD include: Ophiolitic rocks [metamorphosed ultramafic rocks (mainly serpentinite)], ophiolitic metagabbro, schistose mélange matrix of volcanogenic metasediments, orthogneiss, gneissose granite, muscovite leucogranite, and cogenetic pegmatites and biotite pink granite (Fig. 2**)**. This district is dissected by post orogenic dykes (lamprophyres, dolerites, pegmatites, aplites) and quartz veins (& quartz zones in pegmatite).

In the Zabara area, pegmatites and metagabbro are not observed, whereas in Nugrus-Sikait area all the rock units mentioned above were recorded. In Um Kabu-Um Addebaa area, orthogneiss and biotite gneissose granite were not recorded, but may be hidden as some fragments of them were recorded within the ancient dumps resulted from beryl mine workings [14]. The pink granite was recorded in Nugrus-Sikait area at the upper stream of W. Sikait.

The metamorphosed ultramafic rocks are mainly comprised of serpentinite, which is the principal rock unit of Gebel Sikait. In many parts, the serpentinite is altered to talc carbonate rocks. The metagabbro is composed mainly of plagioclase and hornblende with relics of clinopyroxene. The schistose rocks can be sub-classified into graphite-biotite schist, garnet-hornblende-biotite schist, and quartzo-feldspathic schist. The orthogneiss is composed mainly of quartz, plagioclase, and biotite and minor amount of kyanite, cordierite, and is locally uraniferous. The muscovite leucogranite is composed mainly of potash feldspar, plagioclase, quartz, and muscovite with garnet and zircon as accessory minerals. The pink biotite granite has potash feldspar, plagioclase, and quartz with only minor biotite. Beryl crystals in pegmatite-related veins are medium grained, high relief, and pale green in color, whereas in quartz veins they are corroded by quartz and characterized by cracking which is filled by quartz. Emerald crystals in phlogopite schist show hexagonal prismatic crystals with deep green color that sometimes are fractured and locally those fractures are filled by phlogopite.

The ophiolitic mélange is highly foliated and deformed, whereas gneissose granite is strongly lineated. The granitic rocks have a regional NW-SE trend coincides with the major Nugrus thrust and linked shear zone. The ophiolitic mélange rocks are thrusted over the orthogneiss. The contact between the gneissic rocks and the overlying ophiolitic rocks is marked by a low-angle thrust, trending NW-SE and dipping 30SW. The age of thrusting plausibly falls between 682 Ma (the time of emplacement of the older granitoid) and 600 Ma, the upper time limit of intrusion of the younger granites [39].

The thrust contact is characterized by strong folding resulting in the folding of the metamorphosed ultramafics of the ophiolitic mélange. The contact between the gneisses and the overthrusted ophiolitic mélange rocks acts as a zone of weakness or pathway for the intruding felsic magma (i.e., muscovite leucogranite and its cogenetic pegmatites); the beryliferous zone at Zabara–Um Addebaa district is confined to this contact that follows the major Nugrus thrust and related shear zone. Several ancient mine workings were observed along this zone. More than 204 ancient tunnels (emerald mine workings) were recorded along Z-UD [40], for example, in Zabara mines area (Fig. 3 A), in Um Addebaa mine area (Fig 3 B), and in Sikait mines area (Fig 3 C). The Sikait emerald mine is the oldest emerald mine in the world and the Sikait temple (Fig. 3 D) is the main cult building on the Sikait mines area, i.e. for prayers and worshipers.
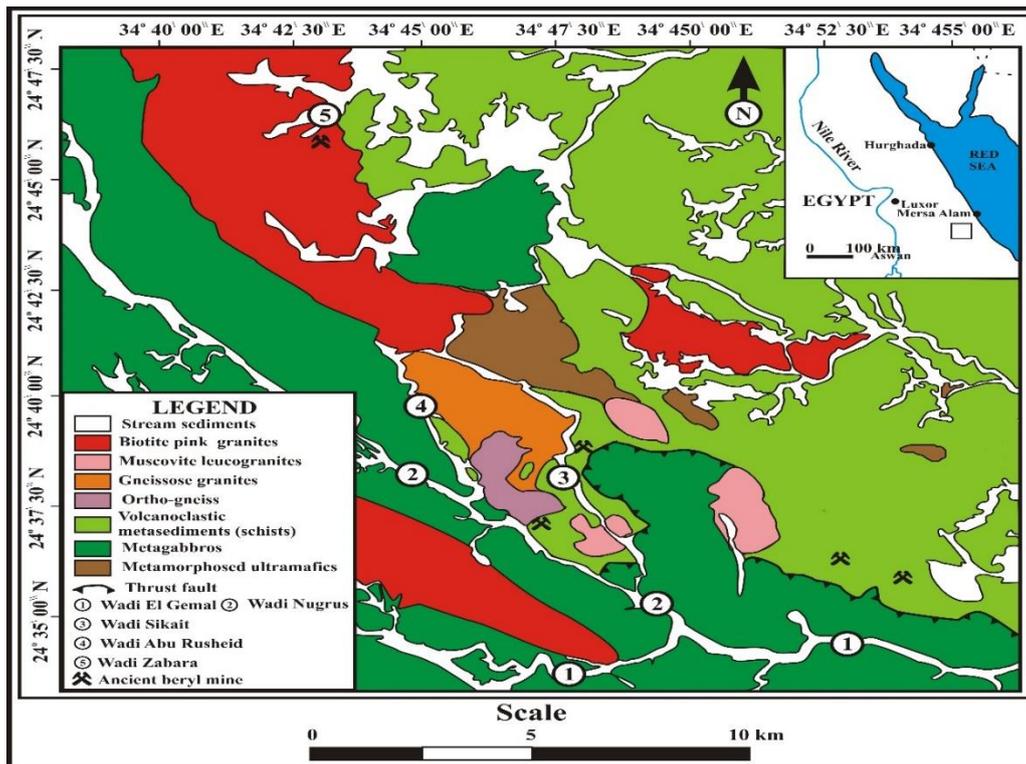
Fig. 2. Geologic map of Zabara-Um Addebaa district (Z- UD), SED, Egypt.

Fig. 3. A: Ancient mines in Zabara area (The photo looks to the SE), B: Ancient quarries working in Um Addebaa area (The photo looks to the E), C: Ancient mine shaft at Sikait emerald mine (The photo looks to the W) and D: Sikait Temple (The photo looks to the W); Z-UD, SED, Egypt.

All the rock units date to the Late Proterozoic era (roughly 550 to 900 million years ago) and belong to the Pan-African Series except the granite–granodiorite gneiss, which is older and dates to an earlier part of the Proterozoic or possibly even the preceding Archean eon [41]. The beryl occurs either in phlogopite schist and its related quartz stringers or in pegmatite and (or) in quartz veins related to the muscovite leucogranite. These veins

generally vary from a few centimeters up to one meter in thickness, having intruded all older rock units in the area. The veins are now considerably deformed and so commonly appear as discontinuous lenticular bands and pods. The occurrence of beryl is intimately linked with these Be-enriched veins, especially those of milky quartz, which are the most plentiful [26].

Although beryl occurs in the quartz/pegmatite veins, it could not have been extracted from these hard rocks without considerable effort and large losses of crystals through breakage. Given this as well as the generally inferior color of the beryl in the veins, the ancient miners were probably interested only in the phlogopite schist-hosted gems, which would have been easier to extract. From the great piles of fine–grained tailings around many of the workings, it appears that the removal of beryl crystals from the schist was done at the mine site [2]. The good quality of beryl with green grass color (emerald) could be found in phlogopite schist. In all these localities, beryl occurs in the same setting, which implies a similar petrogenetic origin [16]; i.e. that emerald and other green beryls occur within the contact zone between phlogopite schist and intrusive quartz and pegmatite veins. This district is extensively intruded by discontinuous muscovite leucogranite bodies and cogenetic pegmatites and quartz veins. At the contacts of the muscovite leucogranite with the biotite schists, there are abundant pockets composed of three rock types. These are black mica (phlogopitic), actinolitic rock composed totally of large crossed prismatic crystals of actinolite, and talc-carbonate rock. Some quartz veins are also associated with these pockets. Beryl occurs in this association disseminated both within the phlogopite and the quartz stringers. Ancient mining workings are located along contacts in these pockets. This association is commonly encountered for most of the beryl occurrences in the mapped area and, for all these localities, beryl occurs in the same setting, which suggests a similar petrogenetic origin.

A black-wall zone was observed along the contacts between the mafic – ultramafic rocks and the muscovite leucogranitic intrusive rocks. This zone developed by mixed varieties of metasomatization; B-metasomatism (tourmaline), K-metasomatism (phlogopite), Mg-Ca-metasomatism (actinolite), and CO_2-metasomatism (talc-carbonate) where the CO_2 is derived from the surrounding schists.

As mentioned above, in Z-UD the beryl cystals occur either in quartz veins (Fig. 4 A), pegmatites (Fig. 4 B), phlogopite schist (Fig. 4 C), and some crystals of grass green color of gem quality (emerald) were recorded within phlogopite schist (Fig. 4 D). Beryl-bearing phlogopite schist occurs associated with the studied beryl – bearing quartz vein and the beryl occurs in the form of aggregates or individual crystals within the phlogopite. The beryl crystals and (or) aggregates are pale green in color. The schists-hosted emerald are almost monomineralic, consisting essentially of high-corrugated big flakes of phlogopite and characterized by a silky sheen surface in hand specimens. These rocks are highly tectonized and foliated with minor to major folds.
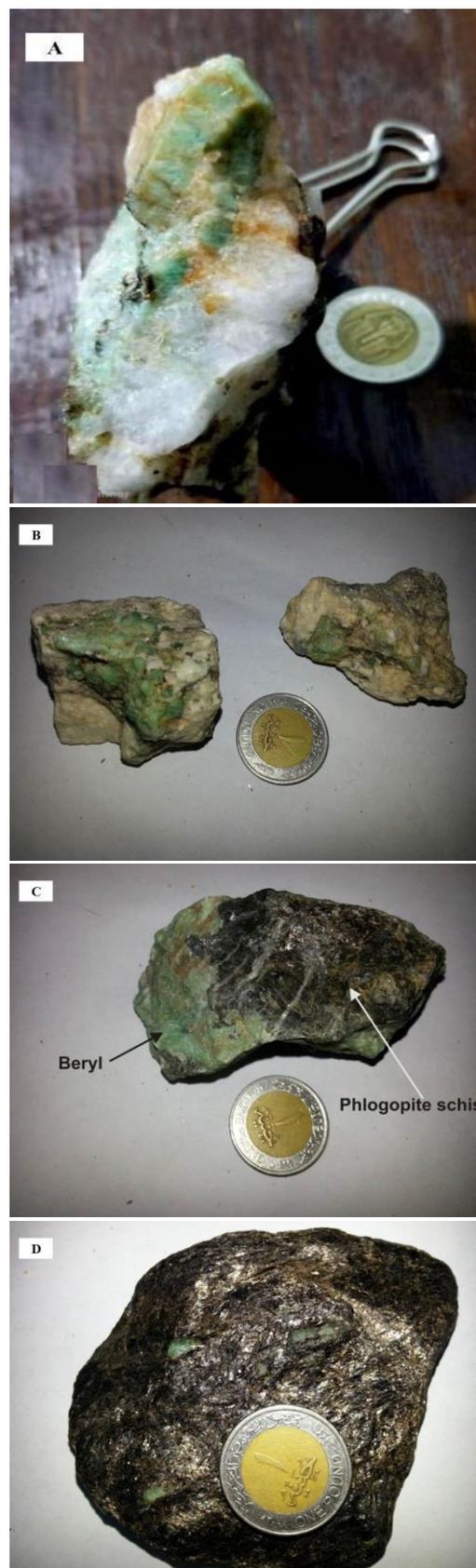

Fig. 4. A: Beryl in quartz; Abu Rusheid area, B: Beryl in pegmatite; Um Solimate area, C: Beryl in phlogopite schist; W. Nugrus area, and D: Emerald in phlogopite schist, W. Abu Rusheid area, Z-UD; SED, Egypt.

Most of beryl crystals present in ancient dumps and mines are almost destroyed due to fracturing of crystals and presence of inclusions, especially in the area around Sikait Temple (Fig 5 A). Grass green emerald crystals are also present especially in Um Addebaa area (Fig. 5 B). They occur in the form of idiomorphic six-sided prismatic crystals reaching 1 cm length, which may occasionally show longitudinal striations.

Beryl occurs mainly in the phlogopite schist and quartz/pegmatite veins, and is restricted to within tens of centimeters of their contact. It is found as individual crystals and, more often, as small clusters of crystals. Crystals can be up to 3 cm in length, but most are much shorter. The beryl in the quartz and quartz-hosted veins in pegmatite varies from colorless or white to light green, but in the phlogopite schist the color ranges from light to dark green. Given that the schist is a source of Cr, it is not surprising that this rock would have the greener beryl, including gem emerald [26]. The geologic occurrence of green beryl at W. Sikait is very similar to that at Regal Ridge in Canada. Here the green beryl, in which Cr is the chromophore, occurs within mica schist close to its contact with quartz veins spawned by a nearby granite intrusion [42]. The absence of metagabbro from the beryl mineralization zone in Zabara area supports the mafic schist as a source of chromium.

The orthogneiss rocks of Nugrus - Sikait area have the highest radioactivity in the Eastern Desert of Egypt [37].

Fig. 5. A: Green beryl from W. Sikait area, Z-UD. B: Emerald from Ancient Nugrus town area, Z-UD; SED, Egypt.

2.2. Homret Akarem-Homret Mukpid (HA-HM) District:

The Homret Akarem area (Fig. 6 A) includes metasediments, older granites, alkali feldspar granites, and muscovite-alkali feldspar granites. The metasediments are grayish black to greenish in color and contain interbedded amphibolites. The metasediments cover most of the mapped area and are intruded by the surrounding granitic rocks. A number of quartz veins striking NE-SW with cassiterite, molybdenite, chalcopyrite, and beryl cut the metasediments. The older granites occur in the northern part of the mapped area. They are grayish in color and medium- to coarse-grained granular in texture. The medium-grained, pink alkali feldspar granites outcrop forms an oval shape elongated in a NE-SW direction. They are invaded by several pegmatite, fluorite, and quartz veins. There are some parts of the alkali feldspar granite bodies affected by hydrothermal and metasomatic processes of albitization, greisenization, and silicification. Muscovite-alkali feldspar granite exposures are whitish in color and medium to coarse grained. They intrude the metasediments and contain some endo- and exocontact barren quartz veins.

The Homret Mukpid area comprises metasediments, quartz diorite, granodiorites, and pink alkali feldspar granites (Fig. 6 B). The quartz diorites and granodiorites are exposed in the southern part of the study area. The granodiorites are hard massive rocks of dark greenish grey color and medium to coarse grained. The granodioritic rocks exhibit cavernous, exfoliation, and block weathering. Fluorite veins, basic dykes, and alteration zones frequently crosscut the granodiorite plutons. The pink alkali feldspar granites are medium grained, porphyritic and locally highly deformed with cataclastic textures. They exhibit cavernous weathering and are characteristically highly jointed, where many of these joints are filled by mineralization and (or) by pegmatite dykes, vein-like dykelets, and bodies. Many of these pegmatite veins and bodies (lenses) contain beryl and fluorite mineralization. The northern part of the pluton is partly albitized and greisenized along tectonic zones, which cut the granitic body in different directions.

Beryl mineralization in Homret Akarem area is of white and pale green color (Fig. 7 A), whereas in Homret Mukpid are a blue color (Fig. 7b) and both occur in pegmatoidal lenses, quartz veins and dykes cutting the albitized and greisenized zones in alkali feldspar granites or as disseminated in the alkali feldspar granite itself.

In Homret Akarem area, beryl mineralization occurs as: pegmatoidal lenses of massive beryl in alkali feldspar granite, within selvage zones between the cassiterite-molybdenite-bearing quartz veins and the metasediments, and within pegmatite veins cutting across the alkali feldspar granite.
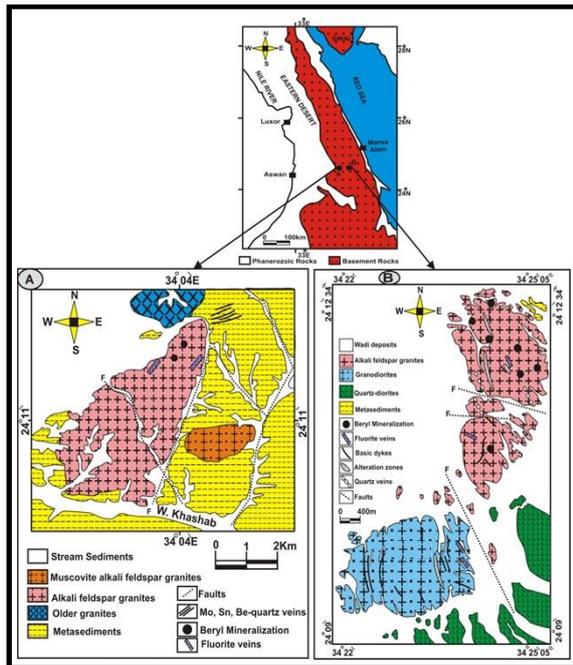
Fig. 6. Summary geological maps from: A) Gabel Homret Akarem area, B) Gabel Homret Mukpid area, SED, Egypt, (modified after [12, 13, 43].

In Homret Mukpid area, beryl mineralization occurs in: disseminated forms in alkali feldspar granite, within pegmatites in granite, in quartz veins or veinlets in granite, and in quartz-beryl veinlets filling foliation planes of metasediments in close contact to alkali feldspar granite [14]. A number of fluorite veins (Fig. 7 C) with cassiterite, Nb-Ta mineralization, galena, and associated alteration zones were observed. The pegmatite bodies, quartz veins and dykes vary in thickness, but often range from a few centimeters up to one meter. The occurrence of beryl is intimately linked with these beryllium enriched veins, especially those with abundant quartz [26].

2.3. Igla area:

The Igla area (Fig. 1) is located in the central Eastern Desert of Egypt (north of the study area) at the intersection of Lat. 25° 28′ 28″ N and Long. 34° 38′ 50″ E. The beryl mineralization was first reported among a group of tin-tungsten mineralization in the central Eastern Desert [17, 18]. Later [44,45].reported the discovery of beryl-bearing quartz vein swarms in greisenized zones of the contact between an albitized portion of the post-kinematic biotite granite (Igla Al-Ahmer) and the country rocks. These milky white quartz vein swarms and lenses form an elongated lens-like stock work zone of 440×100m. These veins are beryl-bearing and are introduced into brecciated rhyolite and porphyritic dolerites [19].
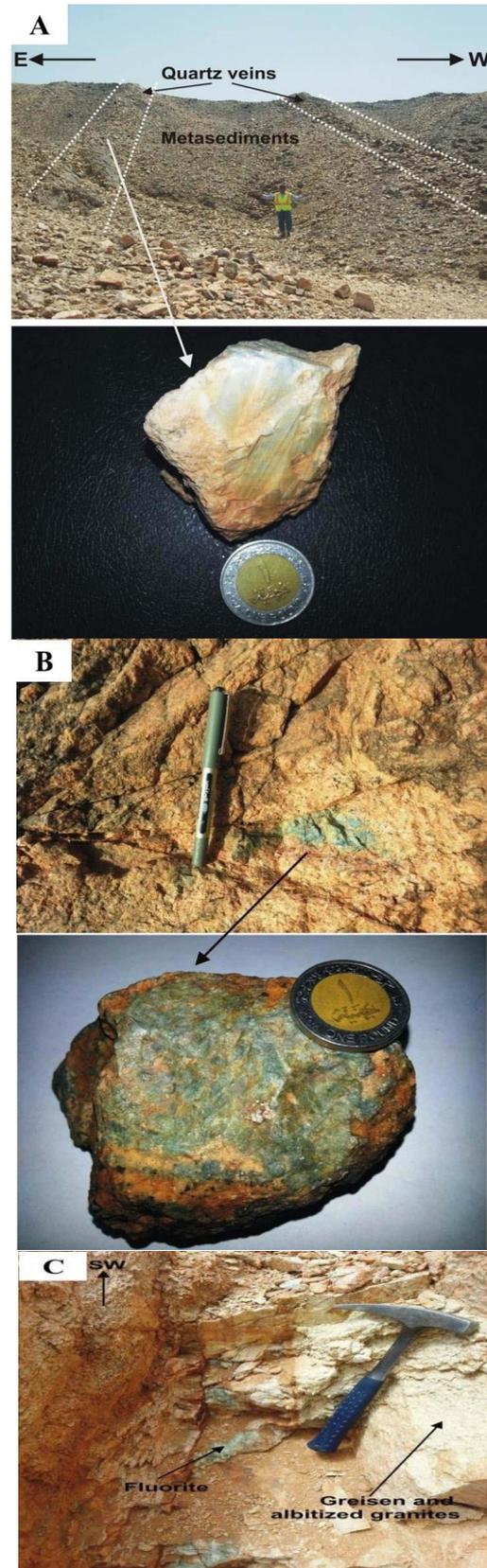
Fig. 7. Beryl minerals of Egypt; A) whitish to pale green color in quartz vein at Homret Akarem, B) Blue color at Homret Mukpid, SED, and C) in fluorite vein cutting pink alkali feldspar granites, Homret Akarem area, SED, Egypt.

3. Methodology

Mineral compositions were determined on the JEOL JXA-733 Superprobe at the Microscopy and Microanalysis Facility, University of New Brunswick (UNB), Fredericton, New Brunswick, Canada. Operating conditions were 15 kV, with a beam current of 30 nA, and peak counting times of 50 seconds for all elements. The standards used were jadeite (for Na), olivine (for Mg), corundum (for Al), augite (for Si, Ca), orthoclase (for K), ilmenite (for Ti), vanadium metal (for V), chromium metal (for Cr), bustamite (for Mn), hematite (for Fe), NiO (for Ni), and pollucite (for Cs). All Fe was calculated as Fe^{2+}.

Eight (8) grains from Z-UD district were analysed; 3 grains of beryl hosted in quartz vein, one grain of beryl hosted in phlogopite schist, and 4 grains of emerald hosted in phlogopite schist. In addition, two grains of beryl from HA-HMD were analysed; one from each stock.

4. Mineral chemistry

4.1. Beryl in Zabara-Um Addebaa District:

The compositions of the studied beryl samples from W. Abu Rusheid area (Z-UD) are listed in Tables 1-3 for beryl hosted in quartz vein, Table 4 for beryl hosted in phlogopite schist, and Tables 5-8 for emerald in phlogopite schist. The average compositions of the studied samples are listed in Table 9 for comparison with those of Wadis Um Kabu and Sikait of the same district. The average values of V_2O_3 wt. % and Cr_2O_3 wt. % in

emerald of Abu Rusheid phlogopite schist are greater than those of beryl found in W. Abu Rusheid, W. Sikait, and W. Um Kabu. The average value of Na_2O wt.% of beryl in quartz vein is more than that of all studied phlogopite schist and of W. Um Kabu and nearly the same at W. Sikait. The average of FeO_t wt.% in quartz vein is greater than that of emerald and beryl of phlogopite schist of W. Abu Rusheid, W. Sikait, and less than that of W. Um Kabu. The average of MgO wt.% in quartz vein is more than that of emerald and beryl of phlogopite schist of W. Abu Rusheid, and less than that of Wadis Um Kabu and Sikait. The average values of K_2O and MnO wt.% in emerald are more than that of beryl in quartz vein and phlogopite schist of W. Abu Rusheid, and the same of W. Um Kabu and less than that of W. Sikait. The average of Al_2O_3 wt.% in emerald is more than that of beryl in quartz vein, and phlogopite schist of W. Abu Rusheid, W. Sikait, and of W. Um Kabu. The average of CaO wt.% of beryl in quartz vein is more than that of emerald and beryl of phlogopite schist of W. Abu Rusheid, W. Sikait, and that of W. Um Kabu. All the Egyptian emeralds from the Eastern Desert are sodic beryl according to the scheme of [46].

The studied beryl within both quartz vein and phlogopite schist, and also emerald in phlogopite schist show negative correlations between Al_2O_3 and both Na_2O and FeOt (Figs. 8 and 9, respectively) indicating the substitution AlVI=Mg+(c)+Na, where (c)=channel position. In all three types, there are positive correlations between Na2O and MgO (Fig.10) and between Na (apfu) and Mg+Fe (apfu) (Fig. 11) indicating partial ionic substitutions of octahedral Al by Fe.

Table 1. Compositions of beryl (grain no. 1) in quartz vein of W. Abu Rusheid, SED, Egypt.

Pt#	1	2	3	4	5	6	7	8	9	10
Na_2O	1.5061	1.6655	1.6045	1.6849	1.7362	1.6652	1.6734	1.6692	1.6862	1.6057
MgO	2.3444	2.6359	2.5009	2.6941	2.6291	2.5505	2.5853	2.6563	2.6425	2.3463
Al_2O_3	15.13	14.42	15.04	14.61	13.95	15.2	14.67	15	15.14	15.13
SiO_2	65.54	64.6	65.14	65.38	62.9	66.5	64.66	66.01	65.83	65.61
K_2O	0.0396	0.0257	0.054	0.053	0.0276	0.0231	0.044	0.0656	0.0578	0.0415
CaO	0.0217	0.0239	0.0567	0.053	0.0341	0.038	0.0474	0.0601	0.0502	0.0333
TiO_2	0	0	0.0013	0.0074	0	0	0	0.0144	0	0.006
V_2O_3	0.0356	0.0322	0.042	0.0513	0.0065	0.0428	0.0183	0.0333	0.0156	0.0346
Cr_2O_3	0.1237	0.1145	0.1185	0.0729	0.0979	0.0941	0.0065	0.0282	0.0349	0.1841
MnO	0.0124	0.0045	0.0063	0.0271	0	0	0	0.0077	0.0066	0.0385
FeO	0.4225	0.4872	0.4324	0.4913	0.4791	0.4412	0.4464	0.4225	0.3979	0.5272
NiO	0	0.0048	0.0188	0	0	0	0	0	0.0062	0
Cs_2O	0	0.0077	0	0.0098	0.0057	0.0073	0.0044	0.0301	0.0077	0.0405
BeO	13.6	13.39	13.56	13.56	13.04	13.81	13.42	13.71	13.69	13.64
Total	**98.78**	**97.41**	**98.58**	**98.69**	**94.91**	**100.37**	**97.58**	**99.71**	**99.57**	**99.24**
No. Cation based on 18 oxygen of anhydrous formula										
Na	0.2681	0.3011	0.2866	0.3008	0.3224	0.292	0.3019	0.2948	0.2981	0.285
Mg	0.3208	0.3663	0.3434	0.3697	0.3753	0.3438	0.3585	0.3606	0.3591	0.3202
Al	1.6372	1.5846	1.6333	1.5856	1.5747	1.6201	1.6087	1.6102	1.6276	1.6323
Si	6.017	6.024	6.001	6.019	6.023	6.013	6.016	6.013	6.003	6.007
K	0.0046	0.0031	0.0063	0.0062	0.0034	0.0027	0.0052	0.0076	0.0067	0.0048
Ca	0.0021	0.0024	0.0056	0.0052	0.0035	0.0037	0.0047	0.0059	0.0049	0.0033

Ti	0	0	0.0001	0.0005	0	0	0	0.001	0	0.0004
V	0.0026	0.0024	0.0031	0.0038	0.0005	0.0031	0.0014	0.0024	0.0011	0.0025
Cr	0.009	0.0084	0.0086	0.0053	0.0074	0.0067	0.0005	0.002	0.0025	0.0133
Mn	0.001	0.0004	0.0003	0.0021	0	0	0	0.0006	0.0005	0.003
Fe	0.0324	0.038	0.0333	0.0378	0.0384	0.0334	0.0347	0.0322	0.0303	0.404
Ni	0	0.0004	0.0014	0	0	0	0	0	0.0005	0
Cs	0	0.0003	0	0.0004	0.0002	0.0003	0.0002	0.0012	0.0003	0.0016
Be	3	3	3	3	3	3	3	3	3	3
O	18	18	18	18	18	18	18	18	18	18

Table 2. Compositions of beryl (grain no. 2) in quartz vein of W. Abu Rusheid, SED, Egypt.

Pt#	11	12	13	14	15	16	17	18	19	20	21	22
Na₂O	1.9441	2.0673	1.986	1.7343	1.9724	1.9962	2.0037	2.0261	1.903	1.848	2.0458	1.9959
MgO	2.6065	2.7889	2.7463	2.2598	2.6206	2.7883	2.5951	2.6161	2.4859	2.3742	2.6049	2.5083
Al₂O₃	14.12	14.01	14.03	16.29	14.16	13.7	14.1	14.2	14.72	14.6	14.02	14.95
SiO₂	64.92	64.86	64.88	63.93	65.22	64.42	64.49	64.34	63.76	64.9	64.62	64.52
K₂O	0.0152	0.0402	0.027	0.019	0.0265	0.0409	0.0289	0.0257	0.0256	0.0169	0.0168	0.0262
CaO	0.0188	0.0467	0.0467	0.0334	0.0348	0.0386	0.0207	0.1445	0.1022	0.013	0.0251	0.037
TiO₂	0	0	0	0	0	0	0	0	0	0	0	0
V₂O₃	0.0409	0.0454	0.0631	0.0332	0.0477	0.0616	0.0383	0.047	0.0294	0.0416	0.0592	0.0394
Cr₂O₃	0.2064	0.1651	0.1508	0.1322	0.1042	0.1725	0.1245	0.0526	0.0812	0.0797	0.1576	0.0534
MnO	0.0003	0.001	0.0116	0	0.0021	0	0.0237	0.0017	0.001	0	0.0007	0.0031
FeO	0.5633	0.6321	0.5713	0.4106	0.5855	0.6639	0.5381	0.5434	0.5075	0.4337	0.5739	0.5007
NiO	0.001	0	0.0291	0.0041	0.0305	0.0166	0	0.0121	0.0041	0	0	0.0188
Cs₂O	0.0147	0	0	0.0087	0.0133	0.0067	0.0117	0.0189	0	0.002	0.188	0.0182
BeO	13.44	13.45	13.44	13.51	13.49	13.33	13.36	13.35	13.3	.13.44	13.38	13.47
Total	97.89	98.11	97.98	98.37	98.31	97.24	97.33	97.38	96.92	84.31	97.69	98.14
No. Cation based on 18 oxygen of anhydrous formula												
Na	0.3504	0.3723	0.3578	0.3107	0.354	0.362	0.3632	0.3674	0.3464	0.3328	0.3703	0.3588
Mg	0.3611	0.3861	0.3804	0.3113	0.0361	0.3895	0.3616	0.3646	0.3479	0.3287	0.3625	0.3467
Al	1.547	1.5338	1.5362	1.7746	1.5448	1.5133	1.554	1.565	1.6285	1.5986	1.5426	1.6339
Si	6.034	6.024	6.029	5.908	6.037	6.037	6.03	6.017	5.986	6.029	6.033	5.983
K	0.0018	0.0048	0.0032	0.0022	0.0031	0.0049	0.0034	0.0031	0.0031	0.002	0.002	0.0031
Ca	0.0019	0.0046	0.0047	0.0033	0.0043	0.0039	0.0021	0.0145	0.0103	0.0013	0.0025	0.0037
Ti	0	0	0	0	0	0	0	0	0	0	0	0
V	0.003	0.0034	0.0047	0.0025	0.0035	0.0046	0.0029	0.0035	0.0022	0.0031	0.0044	0.0029
Cr	0.0152	0.0121	0.0111	0.0097	0.0076	0.0128	0.0092	0.0039	0.006	0.0059	0.0116	0.0039
Mn	0	0.0001	0.0009	0	0.0002	0	0.0019	0.0001	0.0001	0	0.0001	0.0002
Fe	0.0438	0.0491	0.0444	0.0317	0.0453	0.052	0.0421	0.0425	0.0398	0.0337	0.0448	0.0388
Ni	0.0001	0	0.0022	0.0001	0.0023	0.0013	0	0.0009	0.0003	0	0	0.0014
Cs	0.0006	0	0	0.0001	0.0005	0.0003	0.0005	0.0008	0	0.0001	0.0007	0.0007
Be	3	3	3	3	3	3	3	3	3	3	3	3
O	18	18	18	18	18	18	18	18	18	18	18	18

Table 3. Compositions of beryl (grain no. 3) in quartz vein of W. Abu Rusheid, SED, Egypt.

Pt#	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37
Na₂O	1.7	1.69	1.81	1.67	1.43	1.93	2.11	1.79	2.07	1.97	1.60	1.84	1.75	1.933	1.76
MgO	2.6	2.39	2.84	2.41	2.13	2.62	2.80	2.31	2.71	2.62	2.03	2.47	2.39	2.64	2.34
Al₂O₃	14.	15.2	14.1	14.8	15.2	14.8	14.2	14.9	14.2	14.3	15.2	14.6	15.4	14.3	14.8
SiO₂	63.	63.7	65.4	65.7	65.9	64.7	66.1	65.1	65.2	65.0	65.0	64.7	64.6	65.23	65.4
K₂O	0.0	0.05	0.08	0.02	0.04	0.02	0.05	0.00	0.03	0.03	0.04	0.05	0.08	0.083	0.01
CaO	0.9	0.10	0.08	0.01	0.02	0.04	0.05	0.02	0.02	0.02	0.03	0.06	0.07	0.040	0.11
TiO₂	0.0	0	0	0	0	0	0	0	0	0	0.00	0	0	0.005	0
V₂O₃	0.0	0.06	0.05	0.04	0.04	0.03	0.05	0.04	0.05	0.04	0.04	0.02	0.04	0.067	0.03
Cr₂O₃	0.1	0.08	0.14	0.10	0.05	0.01	0.16	0.16	0.16	0.14	0.01	0.05	0.02	0.065	0.10
MnO	0.0	0.00	0	0.00	0	0.00	0.02	0	0.02	0.00	0	0	0.00	0.006	0
FeO	0.5	0.50	0.59	0.45	0.47	0.56	0.57	0.45	0.61	0.56	0.51	0.46	0.49	0.534	0.40
NiO	0.0	0	0.01	0	0.01	0.00	0	0.01	0.00	0.00	0	0	0	0.008	0.00
Cs₂O	0	0.02	0.01	0	0.01	0	0	0.01	0	0.00	0.00	0.00	0.01	0.006	0.00
BeO	13.	13.3	13.5	13.6	13.6	13.4	13.7	13.5	13.5	13.4	13.5	13.4	13.5	13.51	13.5

Total	96.	97.3	98.8	98.9	99.1	98.2	99.9	98.4	98.6	98.3	98.0	97.7	98.5	98.43	98.6
No. Cation based on 18 oxygen of anhydrous formula															
Na	0.3	0.30	0.32	0.29	0.25	0.34	0.37	0.32	0.37	0.35	0.28	0.33	0.31	0.346	0.31
Mg	0.3	0.33	0.39	0.33	0.29	0.36	0.38	0.31	0.37	0.36	0.21	0.34	0.33	0.363	0.32
Al	1.5	1.68	1.53	1.60	1.64	1.61	1.53	1.62	1.54	1.56	1.66	1.60	1.68	1.558	1.60
Si	5.9	5.95	6.02	6.03	6.02	5.99	6.02	6.01	6.02	6.02	6.01	6.01	5.96	6.029	6.02
K	0.0	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.009	0.00
Ca	0.0	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.004	0.01
Ti	0.0	0	0	0	0	0	0	0	0	0	0.00	0	0	0.000	0
V	0.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.005	0.00
Cr	0.0	0.00	0.01	0.00	0.00	0.00	0.01	0.01	0.01	0.01	0.00	0.00	0.00	0.004	0.00
Mn	0.0	0.00	0	0.00	0	0.00	0.00	0	0.00	0.00	0	0	0.00	0.000	0
Fe	0.0	0.03	0.04	0.03	0.03	0.04	0.04	0.03	0.04	0.04	0.03	0.03	0.03	0.041	0.03
Ni	0.0	0	0.00	0	0.00	0.00	0	0.00	0.00	0.00	0	0	0	0.000	0.00
Cs	0	0.00	0.00	0	0.00	0	0	0.00	0	0.00	0.00	0.00	0.00	0.000	0.00
Be	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
O	18	18	18	18	18	18	18	18	18	18	18	18	18	18	18

Table 4. Compositions of beryl in phlogopite schist of W. Abu Rusheid, SED, Egypt.

Pt#	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56
Na₂O	1.4946	1.6171	1.866	1.5953	1.6935	1.6513	1.6151	1.6234	1.7157	1.6837	1.6289	1.7466	1.6888	1.6103	1.595	1.7779	1.9682	1.7208	1.8436
MgO	2.1452	2.209	2.5732	2.2456	2.2813	2.2918	2.175	2.1212	2.3468	2.4153	2.6089	2.5938	2.4534	2.0543	2.0208	2.4194	2.5944	2.1893	2.4187
Al₂O₃	15.19	15.35	14.63	15.06	15.03	15.01	15.17	15.11	14.7	14.88	14.64	14.59	14.8	15.08	15.26	13.75	13.43	14.07	13.73
SiO₂	65.67	65.65	64.86	65.68	65.2	65.72	65.78	65.47	65.27	65.75	66.02	65.76	65.66	65.22	65.35	61.46	60.66	60.92	60.92
K₂O	0.0206	0.0311	0.0278	0.0316	0.0312	0.0371	0.0231	0.0167	0.026	0.0172	0.0285	0.0244	0.0274	0.0236	0.0242	0.0412	0.0565	0.0465	0.0443
CaO	0.0205	0.0282	0.0236	0.0236	0.0305	0.0161	0.0211	0.011	0.0258	0.0129	0.0187	0.0229	0.014	0.0144	0.028	0.0412	0.0523	0.0292	0.0313
TiO₂	0	0	0.0001	0.002	0	0.0025	0	0	0	0.0109	0	0.0061	0.0026	0	0.0003	0.0007	0	0	0
V₂O₃	0.0642	0.0446	0.0726	0.0572	0.0694	0.0666	0.0631	0.0426	0.0597	0.0838	0.0832	0.0457	0.0458	0.0491	0.0527	0.0328	0.0541	0.0267	0.057
Cr₂O₃	0.979	0.0642	0.04	0.0895	0.0835	0.0911	0.0857	0.0778	0.0424	0.0889	0.088	0.0505	0.044	0.069	0.0149	0.0389	0.0867	0.1466	0.0953
MnO	0.0046	0.001	0	0	0.0036	0	0	0	0	0	0	0	0.0086	0.0089	0.0036	0.0093	0.0011	0.0241	0
FeO	0.4819	0.2789	0.4716	0.3038	0.361	0.4965	0.3959	0.5847	0.5447	0.3219	0.4053	0.379	0.31	0.5942	0.4618	0.4777	0.5435	0.5122	0.5048
NiO	0	0.003	0	0.0216	0.0128	0.0083	0.0287	0.0083	0	0.0206	0	0.0032	0.0162	0	0.0114	0	0	0.0299	0.0099
Cs₂O	0	0	0	0	0.0007	0	0	0	0	0	0	0	0.0046	0.0137	0	0.0161	0.0262	0.0402	0.0047
BeO	13.61	13.63	13.47	13.6	13.53	13.62	13.63	13.57	13.51	13.62	13.65	13.6	13.59	13.52	13.55	12.75	12.62	12.69	12.67
Total	99.68	98.91	98.03	98.71	98.33	99.01	98.99	98.64	98.24	98.91	99.17	98.82	98.67	98.26	98.37	92.82	92.09	92.45	92.33
No. Cation based on 18 oxygen of anhydrous formula																			
Na	0.2659	0.2871	0.3354	0.284	0.303	0.2935	0.2868	0.2896	0.3074	0.2994	0.2889	0.311	0.3009	0.2884	0.285	0.3377	0.3777	0.3284	0.3523
Mg	0.2934	0.3016	0.3556	0.3073	0.3138	0.3131	0.297	0.2909	0.3233	0.3301	0.3557	0.355	0.3361	0.2828	0.2776	0.3533	0.3827	0.3212	0.3552
Al	1.643	1.6579	1.5983	1.6301	1.634	1.634	1.6381	1.6383	1.6009	1..6083	1.5787	1.5786	1.603	1.6414	1.6576	1.5873	1.5661	1.6318	1.5951
Si	6.025	6.015	6.013	6.03	6.016	6.016	6.025	6.023	6.032	6.029	6.039	6.039	6.035	6.024	6.023	6.021	6.004	5.997	6.005
K	0.0024	0.0036	0.0033	0.0037	0.0037	0.0037	0.0027	0.002	0.0031	0.002	0.0033	0.0029	0.0032	0.0028	0.0029	0.0051	0.0071	0.0058	0.0056
Ca	0.002	0.0028	0.0023	0.0023	0.003	0.003	0.0021	0.0011	0.0026	0.0013	0.0018	0.0023	0.0014	0.0014	0.0028	0.0043	0.0055	0.0031	0.0033
Ti	0	0	0	0.0005	0	0	0	0	0	0.0007	0	0.0004	0.0002	0	0	0.0001	0	0	0
V	0.0047	0.0033	0.0054	0.0042	0.0051	0.0051	0.0046	0.0031	0.0044	0.0062	0.0061	0.0034	0.0034	0.0036	0.0039	0.0026	0.0043	0.0021	0.0045
Cr	0.0071	0.0046	0.0029	0.0065	0.0061	0.0061	0.0062	0.0057	0.0031	0.0064	0.0064	0.0037	0.0032	0.005	0.0011	0.003	0.0068	0.0114	0.0074
Mn	0.0004	0.0001	0	0	0.0003	0.0003	0	0	0	0	0	0	0.0007	0.0007	0.0003	0.0008	0.0001	0.002	0
Fe	0.037	0.0214	0.0365	0.0233	0.0279	0.0279	0.0303	0.045	0.0421	0	0.031	0.0291	0.0238	0.0459	0.0356	0.0391	0.045	0.0422	0.0416
Ni	0	0.0002	0	0.0016	0.0009	0.0009	0.0071	0.0006	0	0.0247	0	0.0002	0.0012	0	0.0008	0	0	0.0024	0.0008
Cs	0	0	0	0	0	0	0	0	0	0.0015	0	0	0.0002	0.0005	0	0.0007	0.0011	0.0017	0.0002
Be	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
O	18	18	18	18	18	18	18	18	18	18	18	18	18	18	18	18	18	18	18

Table 5. Compositions of emerald (grain no. 1) in phlogopite schist of W. Abu Rusheid, SED, Egypt.

Pt#	57	58	59	60	61	62	63	64
Na₂O	1.7812	1.4884	1.5727	1.7002	1.8198	1.705	1.8406	1.9036
MgO	2.426	2.032	2.0957	2.3326	2.5055	2.3523	2.5582	2.5518
Al₂O₃	14.41	13.27	15.03	14.64	14.28	14.64	14.33	14.59
SiO₂	64.78	68.77	64.86	63.94	64.67	64.55	64.56	64.19
K₂O	0.0408	0.041	0.0429	0.0456	0.0502	0.0298	0.05	0.0277
CaO	0.0233	0.0281	0.0195	0.0456	0.0376	0.0263	0.1127	0.0364

TiO₂	0	0.0071	0.0138	0	0.0004	0	0	0.0002
V₂O₃	0.565	0.0475	0.0446	0.253	0.0479	0.0663	0.0728	0.0396
Cr₂O₃	0.0401	0.283	0.0233	0.0264	0.0653	0.039	0.0581	0.0652
MnO	0	0	0	0.0179	0.0038	0	0.0134	0.0189
FeO	0.4243	0.3689	0.3871	0.3805	0.4694	0.3888	0.4144	0.4809
NiO	0	0.0106	0.0129	0.0101	0.0025	0.0038	0.0187	0.0154
Cs₂O	0.0012	0.0153	0.0064	0	0	0	0.007	0.0049
BeO	13.4	13.82	13.44	13.27	13.38	13.37	13.38	13.36
Total	**97.89**	**100.18**	**97.55**	**96.66**	**97.33**	**97.17**	**97.42**	**97.28**
No. Cation based on 18 oxygen of anhydrous formula								
Na	0.3219	0.2609	0.2833	0.3102	0.3294	0.3087	0.333	0.3451
Mg	0.3371	0.2738	0.2903	0.3272	0.3486	0.3274	0.3558	0.3556
Al	1.5834	1.4136	1.6464	1.6243	1.5706	1.6112	1.576	1.6077
Si	6.039	5.216	6.027	6.018	6.037	6.027	6.025	6.001
K	0.0049	0.0047	0.0051	0.0055	0.006	0.0035	0.006	0.0033
Ca	0.0023	0.0027	0.0019	0.0046	0.0038	0.0026	0.0113	0.0036
Ti	0	0.0005	0.001	0	0	0	0	0
V	0.0042	0.0034	0.0033	0.0019	0.0036	0.005	0.0054	0.003
Cr	0.003	0.002	0.0017	0.002	0.0048	0.0029	0.0043	0.0048
Mn	0	0	0	0.0014	0.0003	0	0.0011	0.0015
Fe	0.0331	0.0279	0.0301	0.0299	0.0366	0.0304	0.323	0.376
Ni	0	0.0008	0.001	0.0008	0.0002	0.0003	0.0014	0.0012
Cs	0	0.0006	0.0003	0	0	0	0.0003	0.0002
Be	3	3	3	3	3	3	3	3
O	18	18	18	18	18	18	18	18

Table 6. Compositions of emerald (grain no. 2) in phlogopite schist of W. Abu Rusheid, SED, Egypt.

Pt#	65	66	67	68	69	70	71	72
Na₂O	1.7068	1.5934	1.8393	1.8558	1.9695	1.8977	1.6651	1.8759
MgO	2.4106	2.2115	2.5337	2.641	2.693	2.7079	2.2178	2.6628
Al₂O₃	14.59	15.15	14.71	14.28	14.21	14.48	15.24	14.72
SiO₂	64.94	64.73	64.78	64.96	63.86	64.13	64.92	65.13
K₂O	0.0337	0.0399	0.0273	0.0453	0.0415	0.0382	0.0252	0.0335
CaO	0.027	0.0267	0.0177	0.0513	0.0461	0.0618	0.0148	0.0209
TiO₂	0	0	0.0027	0	0	0.003	0.0134	0
V₂O₃	0.0609	0.0466	0.0453	0.0321	0.0471	0.0202	0.0409	0.0636
Cr₂O₃	0.0889	0.0856	0.0638	0.1734	0.0509	0.0659	0.0807	0.0547
MnO	0.0151	0	0.0034	0	0.0208	0.0259	0.0415	0
FeO	0.4399	0.4104	0.4855	0.4892	0.4901	0.4981	0.4462	0.5442
NiO	0	0.001	0	0.1132	0.0045	0.0085	0	0
Cs₂O	0.0022	0.0236	0.0224	0.0079	0.0144	0	0.0066	0.0118
BeO	13.45	13.46	13.46	13.46	13.27	13.35	13.51	13.55
Total	**97.77**	**97.78**	**97.99**	**98.11**	**96.72**	**97.29**	**98.22**	**98.67**
No. Cation based on 18 oxygen of anhydrous formula								
Na	0.3073	0.2867	0.3308	0.3337	0.3594	0.3441	0.2984	0.3353
Mg	0.3337	0.3059	0.3503	0.3651	0.3777	0.3775	0.3055	0.3659
Al	1.5964	1.6568	1.6083	1.5607	1.5758	1.5964	1.65	1.5995
Si	6.031	6.007	6.009	6.025	6.01	5.998	6	6.004
K	0.004	0.0047	0.0032	0.0054	0.005	0.0046	0.003	0.0039
Ca	0.0027	0.0027	0.0018	0.0051	0.0047	0.0062	0.0015	0.0021
Ti	0	0	0.0002	0	0	0.0002	0.0009	0
V	0.0045	0.0035	0.0034	0.0024	0.0036	0.0015	0.003	0.0047
Cr	0.0065	0.0063	0.0047	0.0127	0.0038	0.0049	0.0059	0.004
Mn	0.0012	0	0.0003	0	0.0017	0.0021	0.0032	0
Fe	0.0342	0.0318	0.0377	0.0379	0.0386	0.039	0.0345	0.042
Ni	0	0.0001	0	0.0084	0.0003	0.0006	0	0
Cs	0.0001	0.0009	0.0009	0.0003	0.0006	0	0.0003	0.0005
Be	3	3	3	3	3	3	3	3
O	18	18	18	18	18	18	18	18

Table 7. Compositions of emerald (grain no. 3) in phlogopite schist of W. Abu Rusheid, SED, Egypt

Pt#	73	74	75	76	77	78	79	80	81
Na₂O	1.8647	1.9483	1.9552	1.8463	1.85003	1.9504	1.9121	1.8245	1.8904
MgO	2.3614	2.4964	2.4823	2.3342	2.3368	2.6127	2.5449	2.2973	2.4199
Al₂O₃	14.77	14.61	14.58	14.84	14.93	14.63	13.69	15.05	14.79
SiO₂	65	65.48	65.22	65.29	64.94	65.82	65.41	64.72	64.35
K₂O	0.0298	0.0688	0.067	0.0616	0.0584	0.0725	0.0603	0.0681	0.0652
CaO	0.0214	0.0304	0.0209	0.0187	0.0267	0.0476	0.0404	0.0172	0.0219
TiO₂	0.0036	0	0	0	0	0	0.0007	0.006	0
V₂O₃	0.0594	0.0776	0.0842	0.0636	0.0613	0.0336	0.0443	0.0458	0.0827
Cr₂O₃	0.0965	0.1695	0.1827	0.139	0.0685	0.0542	0.0291	0.0251	0.0924
MnO	0.0076	0.0023	0.0129	0.0176	0.0046	0	0	0	0
FeO	0.05649	0.5817	0.6332	0.5476	0.6272	0.5943	0.606	0.5498	0.6291
NiO	0.0074	0.0114	0.0194	0	0	0.0034	0	0.01	0.0096
Cs₂O	0	0.0247	0.0028	0.0056	0.0058	0	0	0.0018	0.0084
BeO	13.5	13.59	13.55	13.56	13.51	13.65	13.43	13.47	13.41
Total	97.78	99.09	98.81	98.72	98.42	99.47	97.77	98.09	97.77
No. Cation based on 18 oxygen of anhydrous formula									
Na	0.3344	0.347	0.3494	0.3297	0.3316	0.3459	0.3447	0.3278	0.3413
Mg	0.3256	0.3418	0.341	0.3204	0.3219	0.3562	0.3527	0.3173	0.3359
Al	1.6101	1.5825	1.5836	1.6113	1.6258	1.5776	1.4999	1.6435	1.6229
Si	6.013	6.015	6.011	6.013	6.002	6.02	6.081	5.998	5.992
K	0.0035	0.0081	0.0079	0.0072	0.0069	0.0085	0.0071	0.0081	0.0077
Ca	0.0021	0.003	0.0021	0.0018	0.0026	0.0047	0.004	0.0017	0.0022
Ti	0.0003	0	0	0	0	0	0.0001	0.0004	0
V	0.0044	0.0057	0.0062	0.0047	0.0045	0.0025	0.0033	0.0034	0.0062
Cr	0.0071	0.0123	0.0133	0.0101	0.005	0.0039	0.0021	0.0018	0.0068
Mn	0.0006	0.0002	0.001	0.0014	0.0004	0	0	0	0
Fe	0.0437	0.0447	0.0488	0.0422	0.0485	0.455	0.0471	0.0426	0.049
Ni	0.0006	0.0008	0.0014	0	0	0.0003	0	0.007	0.0007
Cs	0	0	0	0	0	0	0	0	0
Be	3	3	3	3	3	3	3	3	3
O	18	18	18	18	18	18	18	18	18

Table 8. Compositions of emerald (grain no. 4) in phlogopite schist of W. Abu Rusheid, SED, Egypt

Pt#	82	83	84	85	86	87	88	89	90	91	92	93	94
Na₂O	1.319	1.486	1.503	1.482	1.566	1.453	1.461	1.473	1.346	1.610	1.799	1.538	1.510
MgO	1.967	2.247	2.168	2.213	2.167	2.118	1.987	2.119	1.903	2.276	2.568	2.101	2.11
Al₂O₃	15.69	15.4	15.6	15.6	15.33	15.48	15.44	15.29	15.78	14.76	15.01	15.31	15.5
SiO₂	65.77	65.66	66.63	65.55	65.36	65.65	65.47	62.85	64.19	62.56	63.78	62.74	65.17
K₂O	0.057	0.042	0.056	0.033	0.035	0.049	0.052	0.055	0.039	0.056	0.053	0.024	0.036
CaO	0.010	0.002	0.013	0.013	0.008	0.022	0.008	0.011	0.008	0.003	0.025	0.002	0.014
TiO₂	0	0.003	0.001	0	0	0	0	0	0	0.005	0.008	0	0
V₂O₃	0.061	0.071	0.075	0.067	0.079	0.081	0.069	0.078	0.065	0.082	0.015	0.060	0.081
Cr₂O	0.331	0.338	0.341	0.271	0.448	0.407	0.280	0.255	0.235	0.423	0.242	0.380	0.391
MnO	0	0.007	0.013	0.003	0.006	0	0	0	0.002	0	0	0	0.011
FeO	0.292	0.267	0.311	0.323	0.268	0.267	0.273	0.317	0.255	0.382	0.392	0.257	0.302
NiO	0.003	0	0.013	0	0.018	0	0.010	0.001	0.001	0	0.010	0	0.018
Cs₂O	0.006	0.002	0.001	0.022	0	0	0	0	0	0.003	0	0	0.026
BeO	13.68	13.66	13.85	13.66	13.61	13.66	13.6	13.16	13.41	13.08	13.35	13.15	13.59
Total	99.19	99.19	100.5	99.24	98.90	99.19	98.66	95.61	97.24	95.25	97.26	95.57	98.76
No. Cation based on 18 oxygen of anhydrous formula													
Na	0.233	0.263	0.262	0.262	0.278	0.257	0.260	0.271	0.243	0.298	0.326	0.283	0.269
Mg	0.267	0.306	0.291	0.301	0.296	0.288	0.272	0.299	0.264	0.323	0.358	0.297	0.289
Al	1.689	1.659	1.657	1.679	1.657	1.667	1.671	1.710	1.732	1.660	1.655	1.714	1.678
Si	6.006	6.002	6.008	5.991	5.997	6.001	6.013	5.966	5.979	5.972	5.965	5.959	5.989
K	0.006	0.005	0.006	0.003	0.004	0.005	0.006	0.006	0.004	0.006	0.006	0.003	0.004
Ca	0.001	0.000	0.001	0.001	0.000	0.002	0.000	0.001	0.000	0.004	0.002	0.000	0.001
Ti	0	0.000	0.000	0	0	0	0	0	0	0.004	0.000	0	0
V	0.004	0.005	0.005	0.004	0.005	0.006	0.005	0.005	0.004	0.006	0.001	0.004	0.006

Cr	0.024	0.024	0.024	0.019	0.032	0.029	0.020	0.019	0.017	0.032	0.017	0.028	0.028
Mn	0	0.000	0.001	0.000	0.000	0	0	0	0.000	0	0	0	0.000
Fe	0.022	0.020	0.023	0.024	0.020	0.020	0.021	0.025	0.019	0.030	0.030	0.020	0.023
Ni	0.000	0	0.001	0	0.001	0	0.000	0.000	0.000	0	0.000	0	0.001
Cs	0.000	0.000	0.000	0.000	0	0	0	0	0	0.000	0	0	0.001
Be	3	3	3	3	3	3	3	3	3	3	3	3	3
O	18	18	18	18	18	18	18	18	18	18	18	18	18

Table 9. Average of oxides and their cations comparison in two beryl types and emerald at W. Abu Rusheid with those of Wadis Um Kabu and Sikait, SED, Egypt.

Oxides	The present study			Abdallah and Mohamed (1999) (Um Kabu)	Surour (1993) (Sikait)
	Beryl in quartz vein N=3	Beryl in phlogopite schist N=1	Emerald in phlogopite schist N=4		
	Average	Average	Average	Average	Average
Na₂O	1.807	1.69	1.72	1.62	1.81
MgO	2.545	2.32	2.338	2.59	2.62
Al₂O₃	14.647	14.709	14.863	13.4	14.67
SiO₂	64.948	64.58	64.906	64.48	65.87
K₂O	0.039	0.0304	0.0484	0.04	0.05
CaO	0.066	0.024	0.0252	0	0.05
TiO₂	0.001	0.00159	0.0017	0	0.1
V₂O₃	0.042	0.056	0.0591	-	-
Cr₂O₃	0.102	0.073	0.164	0.13	0.07
MnO	0.007	0.0034	0.01	0.01	0.02
FeO	0.506	0.444	0.446	1.2	0.46
NiO	0.006	0.009	0.0085	-	0.02
Cs₂O	0.009	0.0056	0.0061	-	-
BeO	13.49	13.39	13.48	-	-
Cations, 18 oxygen				**32, oxygen**	
Na	0.324	0.306	0.309	0.59	0.76
Mg	0.351	0.323	0.323	0.73	0.85
Al	1.597	1.616	1.623	2.98	3.76
Si	6.01	6.022	6.011	12.181	13.36
K	0.0045	0.0036	0.0057	0.009	0.015
Ca	0.0066	0.00247	0.0025	0	0.006
Ti	0.0001	0.00011	0.0001	0	0.002
V	0.0031	0.0042	0.0044	-	-
Cr	0.0075	0.00544	0.012	0.019	0.01
Mn	0.0005	0.00028	0.0005	0.002	0.004
Fe	0.0392	0.0347	0.0346	0.189	0.083
Ni	0.0004	0.00068	0.0006	-	0.003
Cs	0.0004	0.00023	0.0002	-	-
Be	3	3	3	-	-
O	18	18	18	-	-

N= number of grains, - :not determined. **Abdallah and Mohamed (1999):** Average of 2 sample of beryl from Um Kabu; **Surour (1993)**: Average of 17 sample of beryl from W. Sikait

The green color of emerald is due to trace amounts of Cr and (or) V replacing Al in the crystal structure. The presence of Cr and V in the beryl structure causes a red fluorescence that enhances the luminosity of the blue-green color, but if Fe^{+3} is present in the emerald crystal, this effect is suppressed [47]. According to the Cr_2O_3 - V_2O_3 - FeO ternary diagram [48], to illustrate the coloration of beryl and emerald in the studied occurrences (Fig. 12).

4.2. Homret Akarem-Homret Mukpid district (HA-HMD):

The compositions of the studied Homret Akarem samples are listed in Tables 10 and 11, and those of Homret Mukpid are listed in Tables 12 and 13. The minimum, maximum, and the average compositions of the studied Homret Akarem and Homret Mukpid samples are listed in Table 14 for comparison. The average values (wt.%) of Na_2O, MgO, Al_2O_3, K_2O, CaO, MnO, NiO, and Cs_2O in Homret Akarem are higher than those of Homret Mukpid. Conversely, the average values (wt.%) of TiO_2,

V_2O_3, Cr_2O_3, and FeO_t of Homret Akarem are lower than those of Homret Mukpid. They are classified as sodic beryl according to the scheme [46].

Table 10. Compositions of beryl in Homret Akarem, SED, Egypt

Pt#	40	41	42	43	44	45	46	47	48	49	50	51	52
Na₂O	0.973	0.386	0.392	0.410	0.822	0.562	1.284	0.465	0.291	0.335	0.331	0.316	0.329
MgO	0.001	0.003	0.000	0	0.007	0.003	0	0.001	0	0.092	0	0.001	0.001
Al₂O₃	18.52	18.57	18.61	18.57	18.55	18.25	18.39	18.02	18.34	22.24	18.14	17.62	18.24
SiO₂	65.22	65.71	64.82	65.48	64.81	64.62	64.15	65.27	65.2	62.96	65.74	64.77	65.52
K₂O	0.012	0.022	0.022	0.023	0.007	0.018	0.016	0.021	0.017	0.008	0.021	0.021	0.015
CaO	0	0.007	0.005	0.006	0.003	0.028	0	0.005	0.006	0.015	0.007	0.047	0
TiO₂	0	0	0.005	0	0	0.001	0	0	0	0	0.003	0	0
V₂O₃	0.022	0.027	0.057	0.023	0.026	0.050	0.024	0.017	0.000	0.062	0.033	0.038	0.019
Cr₂O₃	0	0	0.004	0	0	0	0.000	0	0	0	0.002	0	0
MnO	0.011	0.040	0	0.004	0.002	0.006	0.006	0.025	0.012	0.011	0.005	0.004	0
FeO	0.224	0.271	0.243	0.267	0.266	0.467	0.191	0.772	0.508	0.076	0.241	0.273	0.267
NiO	0.018	0.024	0	0.000	0	0.015	0	0	0.002	0	0.001	0.001	0.016
Cs₂O	0.011	0.046	0.045	0.006	0.004	0.045	0.032	0.030	0.046	0.004	0.023	0.026	0.022
BeO	13.69	13.74	13.59	13.69	13.61	13.54	13.51	13.62	13.62	13.81	13.67	13.43	13.64
Total	98.71	98.85	97.80	98.48	98.11	97.61	97.61	98.25	98.04	99.62	98.22	96.55	98.07
No. Cation based on 18 oxygen of anhydrous formula													
Na	0.172	0.068	0.07	0.072	0.146	0.100	0.230	0.082	0.051	0.058	0.058	0.057	0.058
Mg	0.000	0.000	0.000	0	0.001	0.000	0	0.000	0	0.012	0	0.000	0.000
Al	1.992	1.990	2.015	1.996	2.006	1.984	2.004	1.947	1.982	2.370	1.953	1.931	1.967
Si	5.951	5.974	5.957	5.972	5.946	5.962	5.93	5.986	5.979	5.693	6.007	6.021	5.997
K	0.001	0.002	0.002	0.002	0.000	0.002	0.001	0.002	0.002	0.001	0.002	0.002	0.001
Ca	0	0.000	0.000	0.000	0.000	0.002	0	0.000	0.000	0.001	0.000	0.004	0
Ti	0	0	0.000	0	0	0.000	0	0	0	0	0.000	0	0
V	0.001	0.002	0.004	0.001	0.001	0.003	0.001	0.001	0.000	0.004	0.002	0.002	0.001
Cr	0	0	0.000	0	0	0	0	0	0	0	0.000	0	0
Mn	0.000	0.003	0	0.000	0.000	0.000	0.000	0.001	0.001	0.000	0.000	0.000	0
Fe	0.017	0.020	0.018	0.020	0.020	0.036	0.014	0.059	0.039	0.005	0.018	0.021	0.020
Ni	0.001	0.001	0	0	0	0.001	0	0	0.000	0	0.000	0.000	0.001
Cs	0.000	0.001	0.001	0.000	0.000	0.001	0.001	0.001	0.001	0.000	0.000	0.001	0.000
Be	3	3	3	3	3	3	3	3	3	3	3	3	3
O	18	18	18	18	18	18	18	18	18	18	18	18	18
CatTo	11.13	11.06	11.07	11.06	11.12	11.09	11.18	11.08	11.05	11.14	11.04	11.04	11.04

Table 11. Compositions of beryl in Homret Akarem, SED, Egypt.

Pt#	53	54	55	56	57	140	141	142	143	144	145	146	147
Na₂O	1.158	0.368	0.284	0.275	0.789	0.317	0.459	0.333	0.224	0.382	0.430	0.324	0.381
MgO	0	0	0	0	0	0	0	0	0	0	0.001	0.003	0
Al₂O₃	18.22	17.93	18.01	18.23	18.53	18.62	18.72	18.24	18.42	18.25	18.26	18.9	18.91
SiO₂	65.74	65.99	65.8	64.71	63.96	66.51	66.36	66.47	65.61	66.42	66.33	67.12	67.47
K₂O	0.008	0.017	0.024	0.016	0.016	0.020	0.014	0.017	0.019	0.022	0.018	0.014	0.011
CaO	0.006	0.001	0.012	0.002	0.005	0.004	0.001	0	0.003	0.002	0.004	0.008	0.006
TiO₂	0.001	0.001	0	0	0.011	0.013	0.004	0	0	0.004	0	0	0
V₂O₃	0.025	0.008	0.011	0.039	0.02	0.015	0.019	0.012	0.022	0.017	0.012	0.017	0.014
Cr₂O₃	0	0	0	0	0.001	0	0	0	0	0.004	0	0	0
MnO	0	0.015	0.026	0.009	0.007	0.045	0.013	0.013	0.019	0.007	0.011	0.007	0.023
FeO	0.200	0.714	0.568	0.407	0.696	0.449	0.282	0.554	0.442	0.594	0.760	0.237	0.537
NiO	0	0.007	0	0.006	0	0.008	0	0	0.017	0.002	0.004	0.017	0.002
Cs₂O	0.010	0.017	0.022	0.031	0	0.017	0.012	0.021	0.034	0.020	0.029	0.011	0.026
BeO	13.74	13.70	13.67	13.51	13.49	13.88	13.86	13.82	13.69	13.82	13.82	14.00	14.08
Total	99.11	98.78	98.44	97.24	97.53	99.90	99.75	99.48	98.50	99.55	99.69	100.6	101.4
No. Cation based on 18 oxygen of anhydrous formula													
Na	0.204	0.065	0.050	0.049	0.141	0.055	0.080	0.058	0.039	0.067	0.075	0.056	0.065
Mg	0	0	0	0	0	0	0	0	0	0	0.000	0.000	0
Al	1.952	1.925	1.938	1.985	2.021	1.973	1.987	1.942	1.979	1.943	1.944	1.985	1.975

Si	5.975	6.011	6.009	5.979	5.919	5.984	5.976	6.006	5.985	6	5.992	5.985	5.98
K	0.001	0.002	0.002	0.001	0.001	0.002	0.001	0.002	0.002	0.002	0.002	0.001	0.001
Ca	0.000	0.000	0.001	0.000	0.000	0.000	0.000	0	0.000	0.000	0.000	0.000	0.000
Ti	0.000	0.000	0	0	0.000	0.000	0.000	0	0	0.000	0	0	0
V	0.001	0.000	0.000	0.002	0.001	0.001	0.001	0.000	0.001	0.001	0.000	0.001	0.001
Cr	0	0	0	0	0.000	0	0	0	0	0.000	0	0	0
Mn	0	0.001	0.002	0.000	0.000	0.003	0.001	0.001	0.001	0.000	0.000	0.000	0.001
Fe	0.015	0.054	0.043	0.031	0.053	0.033	0.021	0.041	0.033	0.044	0.057	0.017	0.039
Ni	0	0.000	0	0.000	0	0.000	0	0	0.001	0.000	0.000	0.001	0
Cs	0.000	0.000	0.000	0.001	0	0.000	0.000	0.000	0.001	0.000	0.001	0.000	0.001
Be	3	3	3	3	3	3	3	3	3	3	3	3	3
O	18	18	18	18	18	18	18	18	18	18	18	18	18
CatTo	11.15	11.06	11.04	11.05	11.14	11.05	11.07	11.05	11.04	11.06	11.07	11.05	11.06

Table 12. Compositions of beryl in Homret Mukpid, SED, Egypt.

Pt#	26	27	28	29	30	31	32	33	34
Na$_2$O	0.4981	0.4439	0.148	0.2842	0.3124	0.2796	0.4354	0.5838	0.3641
MgO	0.0027	0.0027	0.0015	0.0081	0	0	0.0025	0.0045	0.0026
Al$_2$O$_3$	17.32	17.83	18.02	17.22	17.47	17.35	17.59	17.19	17.3
SiO$_2$	65.94	64.52	66.13	65.63	65.64	66.05	65.37	64.41	65.37
K$_2$O	0.0074	0.0112	0.0153	0.0153	0.0076	0.0209	0.0098	0.0122	0.0133
CaO	0.0032	0.0053	0.0036	0	0.011	0.0121	0.0032	0.0007	0.0001
TiO$_2$	0.0024	0	0.0027	0	0	0	0	0	0.0021
V$_2$O$_3$	0.0276	0.0396	0.0362	0.03	0.0361	0.0173	0.0391	0.0247	0.0252
Cr$_2$O$_3$	0	0	0	0	0	0.0032	0	0	0
MnO	0	0.0144	0	0.0177	0	0.0113	0	0.0196	0
FeO	2.2352	1.8647	0.9947	1.7284	1.5583	1.7818	1.6422	1.9404	1.6309
NiO	0	0.001	0	0.0138	0	0.0015	0	0	0
Cs$_2$O	0.011	0.0169	0.0136	0.0217	0.0141	0.0173	0.0241	0.0139	0.0227
BeO	13.73	13.54	13.75	13.61	13.64	13.7	13.63	13.44	13.58
Total	99.78	98.29	99.12	98.58	98.69	99.25	98.75	97.64	98.31
No. Cation based on 18 oxygen of anhydrous formula									
Na	0.0878	0.0794	0.0261	0.0506	0.0555	0.0494	0.0774	0.1052	0.0649
Mg	0.0004	0.0004	0.0002	0.0011	0	0	0.0003	0.0007	0.0004
Al	1.8567	1.9378	1.9289	1.8615	1.8853	1.8632	1.8996	1.8822	1.875
Si	5.998	5.951	6.006	6.021	6.01	6.019	5.99	5.984	6.012
K	0.0009	0.0013	0.0018	0.0018	0.0009	0.0024	0.0011	0.0014	0.0016
Ca	0.0003	0.0005	0.0003	0	0.0011	0.0012	0.0003	0.0001	0
Ti	0.0002	0	0.002	0	0	0	0	0	0.0001
V	0.002	0.0029	0.0026	0.0022	0.0026	0.0013	0.0029	0.0018	0.0019
Cr	0	0	0	0	0	0.0002	0	0	0
Mn	0	0.0011	0	0.0014	0	0.0009	0	0.0015	0
Fe	0.17	0.1438	0.0755	0.1326	0.1193	0.1358	0.1258	0.1508	0.1255
Ni	0	0.0001	0	0.001	0	0.0001	0	0	0
Cs	0.0004	0.0007	0.0005	0.0009	0.0006	0.0007	0.0009	0.0005	0.0009
Be	3	3	3	3	3	3	3	3	3
O	18	18	18	18	18	18	18	18	18
CatTot	11.117	11.119	11.044	11.074	11.075	11.074	11.098	11.128	11.082

Table 13 Compositions of beryl in Homret Mukpid, SED, Egypt.

Pt#	35	36	37	38	39	40	41	42
Na$_2$O	0.375	0.2065	0.6604	0.6103	0.4779	0.4318	0.4319	0.4663
MgO	0.0056	0.0015	0.0246	0.0073	0.0003	0.0052	0.001	0.0031
Al$_2$O$_3$	17.48	17.81	17.74	17.26	17.38	16.92	17.61	17.66
SiO$_2$	65.59	65.58	64.8	64.59	65.56	65.25	66.02	66.03
K$_2$O	0.0071	0.0108	0.0135	0.0046	0.008	0.0002	0.0135	0.0176
CaO	0	0.0041	0.0085	0.0004	0.0048	0	0.0023	0.0026
TiO$_2$	0	0.0065	0.0095	0	0.0029	0.0116	0	0
V$_2$O$_3$	0.0365	0.0271	0.0346	0.0247	0.0527	0.008	0.0132	0.0313
Cr$_2$O$_3$	0	0	0	0.0015	0.0042	0.0023	0.0021	0.0003

MnO	0.011	0.0107	0.0014	0	0	0.0147	0.016	0.0153
FeO	1.6832	1.308	1.2249	1.732	1.9394	2.1627	1.6212	1.7435
NiO	0.0013	0.0147	0.0018	0.0033	0	0	0.014	0
Cs₂O	0	0.0028	0.0161	0.0271	0.0094	0.0173	0.0068	0
BeO	13.65	13.65	13.55	13.47	13.65	13.54	13.74	13.76
Total	**98.84**	**98.63**	**98.09**	**97.73**	**99.09**	**98.36**	**99.49**	**99.73**
No. Cation based on 18 oxygen of anhydrous formula								
Na	0.0665	0.0366	0.118	0.1097	0.0847	0.077	0.0761	0.0821
Mg	0.0008	0.0002	0.0034	0.001	0	0.0007	0.0001	0.0004
Al	1.8854	1.9195	1.9273	1.8864	1.8733	1.8383	1.8871	1.8888
Si	6.002	5.998	5.972	5.988	5.996	6.016	6.001	5.994
K	0.0008	0.0013	0.0016	0.0005	0.0009	0	0.0016	0.002
Ca	0	0.0004	0.0008	0	0.0005	0	0.0002	0.0002
Ti	0	0.0004	0.0007	0	0.0002	0.0008	0	0
V	0.0027	0.002	0.0026	0.0018	0.0039	0.0006	0.001	0.0023
Cr	0	0	0	0.0001	0.0003	0.0002	0.0001	0
Mn	0.0009	0.0008	0.0001	0	0	0.0011	0.0012	0.0012
Fe	0.1288	0.1	0.0944	0.1343	0.1483	0.1668	0.1233	0.1324
Ni	0.0001	0.0011	0.0001	0.0002	0	0	0.001	0
Cs	0	0.0001	0.0006	0.0011	0.0004	0.0007	0.0003	0
Be	3	3	3	3	3	3	3	3
O	18	18	18	18	18	18	18	18
CatTot	**11.088**	**11.060**	**11.122**	**11.123**	**11.109**	**11.102**	**11.093**	**11.103**

Table 14. Minimum, maximum and the average of oxides and their cations comparison in Homret Akarem and Homret Mukpid, SED, Egypt.

Oxides %	Homret Akarem			Homret Mukpid		
	Min.	**Max.**	**Average**	**Min.**	**Max.**	**Average**
Na₂O	0.2248	1.2843	0.486	0.148	0.66	0.412
MgO	0	0.0924	0.0045	0	0.025	0.0043
Al₂O₃	17.62	22.24	18.51	16.92	18.02	17.43
SiO₂	62.96	67.47	65.49	64.41	66.13	65.44
K₂O	0.0079	0.0247	0.0173	0.0002	0.0209	0.0111
CaO	0	0.0475	0.0073	0	0.012	0.0037
TiO₂	0	0.0139	0.0018	0	0.0116	0.0022
V₂O₃	0.0009	0.0624	0.0246	0.008	0.053	0.0296
Cr₂O₃	0	0.0047	0.0005	0	0.0042	0.0008
MnO	0	0.456	0.0127	0	0.0196	0.0078
FeO	0.0763	0.7726	0.405	0.995	2.235	1.694
NiO	0	0.0245	0.0057	0	0.0147	0.003
Cs₂O	0	0.0464	0.0232	0	0.027	0.0138
BeO	13.43	14.09	13.7	13.44	13.76	13.63
Cations						
Na	0.0398	0.2302	0.086	0.0261	0.118	0.07337
Mg	0	0.0125	0.0006	0	0.0034	0.00059
Al	1.925	2.3705	1.988	1.838	1.9378	1.888
Si	5.693	6.021	5.968	5.951	6.021	5.998
K	0.0009	0.0029	0.002	0	0.0024	0.0013
Ca	0	0.0047	0.0007	0	0.0012	0.00035
Ti	0	0.0009	0.00013	0	0.0008	0.00015
V	0.0001	0.0045	0.0018	0.0006	0.0039	0.00218
Cr	0	0.0003	0.000031	0	0.0003	0.00005
Mn	0	0.0035	0.00098	0	0.0015	0.0006
Fe	0.0058	0.0593	0.03082	0.1	0.17	0.13
Ni	0	0.0018	0.00042	0	0.0011	0.00022
Cs	0	0.0018	0.0009	0	0.0011	0.00055
Be	3	3	3	3	3	3
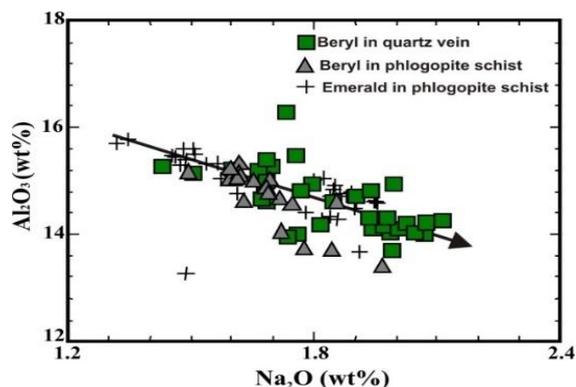
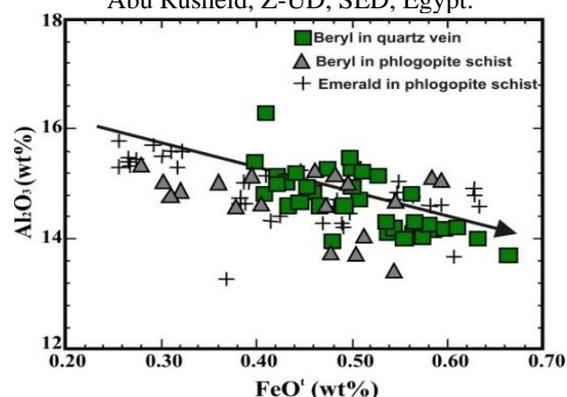Fig. 8. Al2O3 vs. Na2O in beryl and emerald of W. Abu Rusheid, Z-UD, SED, Egypt.

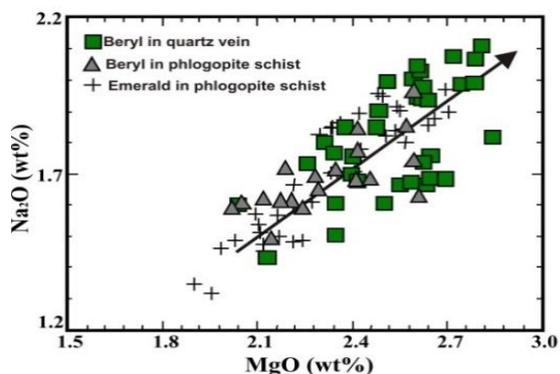Fig. 9. Al2O3 vs. FeOt in beryl and emerald of W. Abu Rusheid, Z-UD, SED, Egypt.

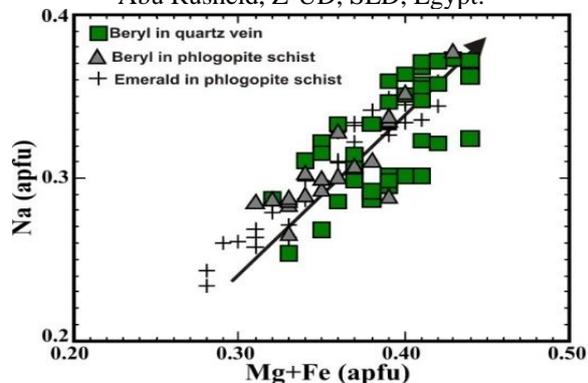Fig. 10. Na2O vs. MgO in beryl and emerald of W. Abu Rusheid, Z-UD, SED, Egypt.

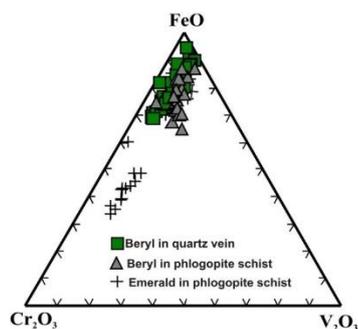Fig. 11. Na vs. Mg+Fe in beryl and emerald of W. Abu Rusheid, Z-UD, SED, Egypt.

Fig. 12. Cr2O3, V2O3, and FeOt triangular diagram to illustrate the colors of beryl and emerald in W. Abu Rusheid, Z-UD, SED, Egypt [48].

The studied beryls in both Homret Mukpid and Homret Akarem show weakly negative correlations between Al_2O_3 and both Na_2O and FeO^t (Figs. 13 A and 13 B, respectively) implying the substitution $AlVI=Mg+(c)+Na$, where (c)=channel position. In Homret Mukpid, there are positive correlations between Na_2O and MgO (Fig. 14 A) and between Na (apfu) and Mg+Fe (apfu) (Fig. 14 B), which indicate partial ionic substitution of octahedral Al by Fe. In Homret Akarem there is positive correlation between Na_2O and MgO (Fig. 14 A), (for values greater than zero) and there is a negative correlation between Na (apfu) and Mg+Fe (apfu) (Fig. 14 B), implying the absence of ionic substitution of octahedral Al by Fe. The pale blue color of Homret Mukpid is attributed to the high contents of Fe, Cr, and V.
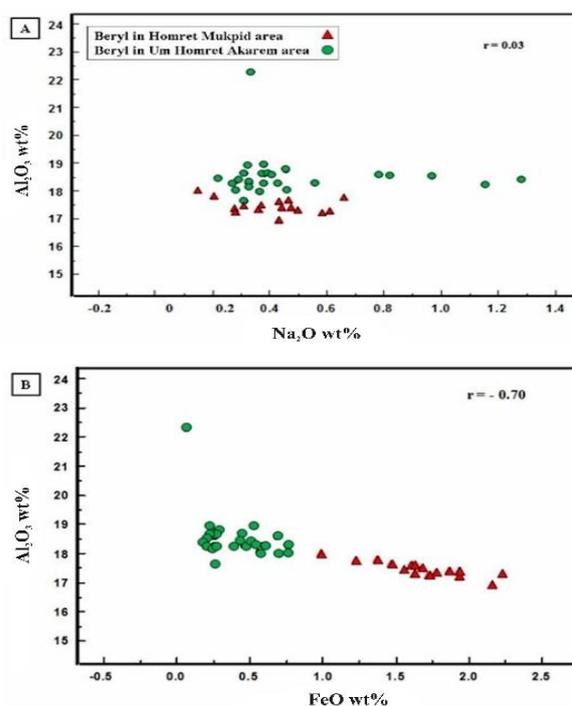
Fig. 13. Binary chemical correlations in beryl between; A: Al2O3 contents vs. Na2O contents and B: Al2O3 vs. FeOt in beryl in HA-HMD; Symbols as in Fig. 13A.
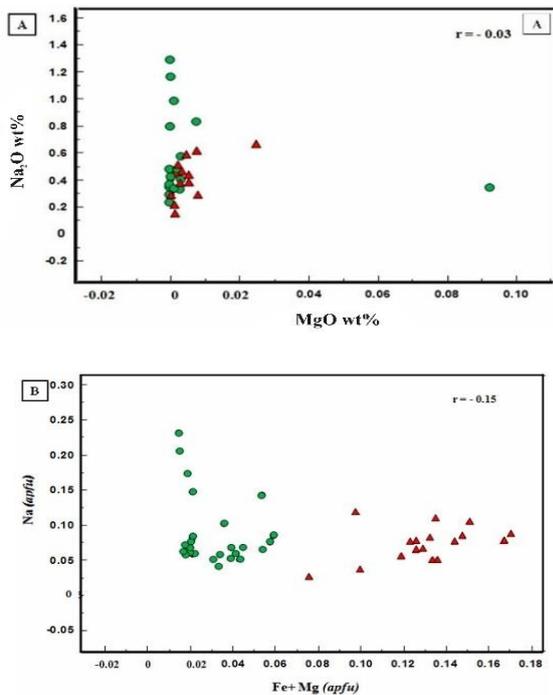
Fig. 14. Binary correlation between; A: Na2O contents vs. MgO contents and B: Na contents vs. (Mg+Fe) contents in beryl HA-HMD. Symbols as in Fig. 13A.

5. Genesis of beryl mineralization

The well-known schist-hosted emerald deposits of the Habachtal (Austria) and of Leydsdorp (Transvaal, South Africa) have been generally attributed to the interaction between invading granitic to pegmatitic magma and (or) its derived fluid phase with preexisting mafic to ultramafic rocks [1,49].

[50] recognized two main types of emerald deposit: Those related to granitic intrusions (type I) and those where mineralization is mainly controlled by tectonic structures, such as a fault or a shear zone (type II). Most emerald deposits fall into the first category and are subdivided based on the presence or absence of biotite schist at the contact. Type II deposits are subdivided into schist without pegmatite and black shale with veins and breccia.

[51] suggested that the emerald and beryl occurrences resulted from regional metamorphism; but this has been challenged by subsequent studies [2,36];

[9] classified the emerald occurrences into two main types:

1. Type I: with tectonic magmatic-related with sub-types hosted in: (IA) Mafic-ultramafic rocks (Brazil, Zambia, Russia, and others); (IB) Sedimentary rocks (China, Canada, Norway, Kazakhstan, Australia); and (IC) Granitic rocks (Nigeria).

2. Type II with tectonic metamorphic-related with sub-types hosted in: (IIA) M-UMR (Brazil, Austria); (IIB) Sedimentary rocks-black shale (Colombia, Canada, USA); (IIC) Metamorphic rocks (China, Afghanistan, USA); and (IID) Metamorphosed type I deposits or hidden-granitic intrusion-related (Austria, Egypt, Australia, Pakistan), and some unclassified deposits.

In the Zabara-Um Addebaa district (Z-UD), beryl mineralization occurs disseminated in biotite schist (phlogopite), in quartz veins, and associated with pegmatite. These three rocks host beryl mineralization that occurs coincident with the major Nugrus thrust and related shear zone. Ancient mine workings are located along this zone. In all localities along the Z-UD, beryl occurs in the same setting, which implies the same genesis. Beryl and emerald are thought to be formed by metasomatic interaction between felsic magma (muscovite leucogranite and cogenetic pegmatites) with the mafic-ultramafic rocks (ophiolitic mélange). This felsic magma was enriched in Be, F, Al, Ba, Na, and K. Metasomatic reactions responsible for growing phlogopite at the expense of actinolite led to the release of Cr, which is the principal chromophore for the green coloration of gem quality emerald. In this study we agree with the petrogenetic model proposed by [52] for the pegmatite-granite (glimmerite) type that involves the intrusion of granitic pegmatites within Cr-V-bearing basic-ultrabasic rocks. In these deposits emerald formed through metasomatic processes, occurring in phlogopitic schists/phlogopitite (glimmerite) contained within serpentinites and talc-schists or in plagioclasites formed from the pegmatite. The metasomatic process involves the addition of elements characteristic of an evolved granitic assemblage (Be, F, B, P, alkalis) to a typical ultrabasic assemblage that becomes reactive with Mg, Ti, Cr, Ni, and Cu (Fig. 15). The origin of the beryl mineralization of HA-HMD is most likely ascribed to metasomatism by fluids related to a deep-seated felsic magma source.
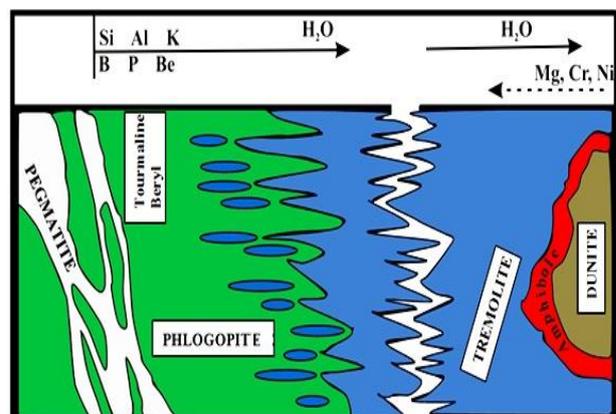

Fig. 15. Magmatic-hydrothermal petrogenetic model of beryl in the Z-UD belt is similar to with the model proposed by [52].

6. Discussion

In the Zabara-Um Addebaa district (Z-UD), beryl mineralization occurs disseminated in the biotite schists (phlogopite), in the quartz veins and to a lesser degree in pegmatites. These three rocks host beryl mineralization that occurs in coincidence with the major Nugrus thrust and its linked ductile shear zones. In all localities along the Z-UD district, beryl occurs in the same geologic setting, which implies the same origin. [14] noted that in Zabara-Um Addebaa belt the beryl mineralization is confined to the contact between the gneiss rocks and the overthrusted schists and if gneisses are not observed this means that they are hidden. In fact, along all the contact between the gneiss rocks and the overthrusted schists not all localities have beryl mineralization and also along all the contacts between the biotite schists and the intruding felsic magma (muscovite leucogranite and cogenetic pegmatites). In the Abu Rusheid area, the gneissic rocks have the highest radioactive anomaly in the south Eastern Desert of Egypt [53]. In this area, beryl mineralization occurs at or near the contact between these radioactive gneisses and the overthrusted schists. Beryllium is a very small cation (Be^{+2}) that does not enter the structure of the common rock-forming minerals during fractional crystallization of magmas (incompatible). Be^{+2} is therefore concentrated in the residual magma together with other small cations, such as boron and lithium, which can also act as fluxes and lower the liquidi and solidi of these melts; the same applies to large anions (fluorine, hydroxyl (OH-groups), and chlorine. Very large cations (e.g. tin, tantalum, uranium, and thorium) are also generally incompatible within these fractionating magmas [54]. Late-stage magmatic fluids are exsolved during ascent, emplacement, and advanced crystallization. These exsolved volatiles can be highly enriched in incompatible cations and halogens and subsequently crystallize relatively rare minerals that contain small (or large) cations. The mineral beryl therefore occurs in late stage granitic rocks, commonly in very coarse-grained rocks called pegmatites. Beryl is typically associated with quartz, potash-feldspars, Li-mica, tourmaline (a boron mineral), and other "exotic" minerals [55].

Beryl mineralization of Egypt occurs in two geologic environments. In the first environment, beryl occurs in micaceous rocks and other schistose rocks close to contacts with psammitic gneiss in W. El Gemal – Zabara belt [11, 14]. In this study, we stated that in Z-UD district, the beryl mineralization occurs at the contact between the ophiolitic mélange rocks and the intruding felsic magma (muscovite leucogranite and linked pegmatites) whether or not gneiss rocks were observed.

In the second geologic environment, beryl occurs in pegmatite veins, pegmatoidal lenses and veins in disseminated form in orthoclase – rich pink granites in Homret Akarem and Homret Mukpid areas [14]. The beryl mineralization is inferred to be as a result of metasomatic fluids from a hidden felsic magma source.

[34] noted there are two favorable environments for the localization of beryl mineralization in the Precambrian rocks of Egypt namely; 1) emerald- schist and 2) beryl specialized granitoid associations. Emerald occurs within the mica-schists and is typically confined to the Nugrus major shear zone. The beryl associated with granitoids occurs in pegmatite veins, greissen bodies and cassiterite quartz veins. The authors (op. cit) concluded that the emerald is formed as the result of epitactic nucleation of Be, Al and alkali-rich solutions on the mica of the schist country rocks. [56] suggested that the Egyptian beryl Deposits resulted from regional metamorphism, but this has been challenged by subsequent studies [2, 36] that introduced K-Ar phlogopite ages of 520 to 580 Ma [36].

[57] W. Sikait is not a Type II emerald deposit, where Be-bearing hydrothermal fluids permeated Cr- or V-bearing rocks along thrust faults or shear zones. Both W. Sikait and Regal Ridge classify as Type I emerald deposits, where Be-bearing quartz or pegmatite veins from a granitic pluton intruded Cr- or V bearing mafic or ultramafic rocks [26]. There are two categories for emerald and beryl deposits in the world:

1. Schist – hosted deposits due to the interaction between granitic pegmatites or fluid emanations from granitic magma with ultramafic rocks or their derivatives [1].

2. Beryl associated with black wall zones resulted from metasomatic reactions at the contact between ultramafic rocks and Be – bearing mica – rich quartzo-feldspathic rocks during regional metamorphism [58]. The absence of Be in the schist [32] excludes the formation of beryl by metasomatic alteration during regional metamorphism as described by [58]. The Be content in the gneissose granite in the studied area is 2.18-4.1ppm [35] while the Be content in the muscovite leucogranite is 6ppm [59] indicating that the muscovite leucogranite is the source of beryllium. The Pan-African age of phlogopite bearing beryl mineralization [36] and very low content of Be in gneisses (1.9-2.2) [35] exclude any genetic relation of studied beryl mineralization to the gneisses (of Pre-Pan African age).

The beryl mineralization in Z-UD district was formed by metasomatic interaction between felsic magma (muscovite leucogranite and linked pegmatites) with the mafic-ultramafic rocks (ophiolitic mélange rocks). This felsic magma was enriched in Be, F, Al, Ba, Na and K. Metasomatic reactions responsible for growing phlogopite on the expense of actinolite leading to the release of Cr, which is the chief player in green coloration of gem quality emerald. The origin of the beryl

mineralization of HA-HMD is most likely ascribed to metasomatism by emanation related to a deep seated highly evolved felsic magma source.

7. Conclusions

1. Beryl-bearing rocks in Zabara-Um Addebaa district (Z-UD) comprise quartz veins, pegmatites and phlogopite schist. All are confined to the major Nugrus thrust zone and linked ductile shear zones. Many old mining workings (forming dumps) were observed along that thrust zone. The gem quality beryl (emerald) is found in phlogopite schist.

2. The average contents of Al_2O_3, K_2O, CaO, TiO_2, V_2O_3, and BeO in emerald of Abu Rusheid phlogopite schist are higher than that found in W. Abu Rusheid beryls and emerald of both W. Sikait and W. Um Kabu. The average contents of Na_2O and Cs_2O of beryl in quartz vein are more than those found in all studied phlogopite schist of Wadis Sikait and Um Kabu. The average contents of MgO, FeO, and NiO of beryl in quartz veins are higher than that of emerald and beryl of phlogopite schist. The studied emeralds are sodic (Na_2O = 1.74 - 1.96 wt.%).

3. The studied beryl hosted in quartz vein, beryl hosted in phlogopite, and emerald hosted in phlogopite show negative correlations between Al_2O_3 and both Na_2O and FeO^t implying the substitution Al^{VI}=Mg+(c)+Na, where (c)=channel position. In both these types, the positive correlations between Na_2O versus MgO and Na (apfu) against Mg+Fe (apfu) indicate partial ionic substitutions of octahedral Al by Fe. There are some inclusions of Fe, Mn, Al, Ba, W, and Sn in beryl.

4. In Zabara-Um Addebaa district (ZUD), beryl that occurs in phlogopite schist is of a deeper green color than that which occurs in quartz veins and pegmatites and sometimes becomes grass green color of gem quality (emerald).

5. For future exploration of beryl in Z-UD, phlogopite schists close to the felsic magmatic rocks (muscovite leucogranite and its associated pegmatites) should be a priority.

6. In Z-UD district, beryl mineralization is thought to be formed as a result of the intrusion of felsic magma (muscovite leucogranite and cogenetic pegmatites) within Cr-V-bearing mafic-ultramafic rocks (ophiolitic mélange rocks). In these deposits emerald, formed through metasomatic processes, occurs in phlogopite schists/phlogopitite contained within serpentinites and talc-schists or in plagioclasites formed from the pegmatite. The metasomatic process involved the addition of elements characteristic of an acid granitic assemblage (Be, F, B, P, alkalis) to a typical ultramafic assemblage, that became depleted in Mg, Ti, Cr, Ni, and Cu.

7. Beryl of Homret Akarem area is a whitish and pale green color (due to the low contents of Cr and V) and the beryl of Homret Mukpid is a blue color (due to the high contents of Fe, Cr, and V), both occurring in pegmatite (lenses, bodies, and dykes) and quartz veins cutting the albitized and greisenized zone of alkali feldspar granites or as disseminations in the granite itself.

8. The origin of the beryl mineralization of HA-HM district is most likely ascribed to metasomatism by volatiles exsolved from a deep seated highly evolved felsic magma source.

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Conflict of interest

The authors declare that there is no conflict of interest.

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