CONTRIBUTION TO THE RADIOACTIVITY, MINERALOGY AND REE DISTRIBUTION IN THE GRANITOIDS OF GEBEL EL NEKEIBA, SOUTH EASTERN DESERT, EGYPT

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ABSTRACT

Gebel El Nekeiba is composed mainly of quartz-syenite surrounding syenogranite. Syenogranite is characterized by the presence of allanite, zircon and fluorite. Qz-syenite is more radioactive and characterized by the presence of violet and deep violet fluorite, zircon and columbite besides thorium minerals (thorite and orangite). The latter were transformed to thorogummite by hydrolysis. The studied rocks are characterized by low Th/U ratio. Quartz syenite and syenogranite rocks show high concentrations of REEs; the former is characterized by higher concentration of HREEs than LREEs. Distribution of REEs in Gebel El Nekeiba is controlled by the elements concentration in the parent magma, and degree of fractionation in the hosting rocks and minerals.

INTRODUCTION

Gebel El Nekeiba occurs as moderately high mountain (570 m) located at the intersection of lat. 23°52’ and long. 34°22’ (Fig.1) covering more or less a triangular area (about 4.0 km2), (Fig.2).

Khaleal et al. (2007) concluded that the younger granites of G. El Nekeiba are high temperature granitoids formed as a result of high fractionation and emplaced during within-plate regime.

Abdel Gawad (2011) described the central part of the mountain as syenogranite surrounded by qz-syenite covering the eastern, northern and western parts of G. El Nekeiba. It is dissected by many fault sets and bounded by Wadi Road El Sayalla that extends from the western side, passing south the mountain to the eastern side (Fig.3). He attributed the radioactivity of the area mainly to the quartz-syenite and partly to the felsic dykes.

Fig. 1: Location map of G. El Nekeiba
hornblende. Potash feldspars are the main feldspar represented by string perthite, orthoclase perthite and microcline. Allanite, zircon and colorless fluorite are the main accessory minerals. This rock is intensely sheared in the southern part, and characterized by mortar texture and granulation where the fault sets and wadis are common. The minerals show straining, andulose extinction and alteration (sericitization of feldspars and chloritization of biotite) (Fig. 4). Qz-syenite is composed mainly of potash feldspar, quartz, biotite, riebeckite and arfvedsonite (Fig. 5). The rock is characterized by low content of quartz (<20%) but fluorite, zircon and columbite are the common accessory minerals present, besides the radioactive minerals thorite, orangite and thorogummite.

The present work aims to 1- Recognize the minerals responsible for the radioactivity of G. El Nekeiba; 2- Investigate the relation between the distribution of REE and these minerals and 3- Characterize the factors controlling the distribution of REEs in G. El Nekeiba granitoids.

PETROGRAPHY

Gebel El Nekeiba is composed mainly of syenogranite and Qz-syenite. Syenogranite is characterized by an equigranular texture composed mainly of potash feldspar, plagioclase, quartz and biotite with rare crystals of sodic
CONTRIBUTION TO THE RADIOACTIVITY, MINERALOGY AND REE$_3$

RADIOACTIVITY

Both rocks (syenogranite and Qz-syenite) composing G. El Nekeiba are radioactive with different degrees; the former is characterized by lower radioactivity relative to the latter. Uranium and thorium contents are measured chemically by fluorometric method in ten samples (6 samples syenogranite and 4 samples qz-syenite). U ranges from 49 to 86 ppm with an average of 61.7 ppm while Th ranges from 62 to 110 ppm with an average of 83.8 ppm in the syenogranite. Quartz-syenite shows U ranging from 76 to 95 ppm with an average of 86.3 ppm and Th from 110 to 124 ppm with an average of 116.5 ppm (Table 1). Plotting U versus Th of the two rocks on the binary diagram shows a positive relation in the syenogranite. The relationship is disturbed in the qz-syenite showing a slightly negative relation referring to a possible addition of uranium epigenetically (Fig. 6a). Th/U ratio in the syenogranite ranges from 1.27 to 1.58 with an average of 1.37, while in the qz-syenite it ranges from 1.16 to 1.48 with an average of 1.36 (Table 1). The low value of this ratio refers to highly differentiated rocks (Chatterjee and Muecke, 1982) and may be attributed to a post-magmatic enrichment of uranium. The plot of Th versus Th/U ratio shows clearly that the quartz syenite is more differentiated than the syenogranite (Fig.6b).

MINERALOGICAL STUDIES

The studied syenogranite and Qz-syenite were ground and sieved. The grains sized between 0.63 mm and 0.5 mm were treated with

Table 1: U, Th and REEs analyses of Syenogranite and Quartz-syenite, G. El Nekeiba

<table>
<thead>
<tr>
<th>Rock Type</th>
<th>Sample</th>
<th>Syenogranite</th>
<th>QZ-Syenite</th>
<th>Cond.</th>
<th>REEs (ppm)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>U</td>
<td>Te</td>
<td>As</td>
<td>N</td>
<td>Nd</td>
</tr>
<tr>
<td></td>
<td>49</td>
<td>66</td>
<td>86.1</td>
<td>0.0122</td>
<td></td>
</tr>
<tr>
<td></td>
<td>62</td>
<td>94</td>
<td>110</td>
<td>69</td>
<td>80</td>
</tr>
<tr>
<td></td>
<td>80</td>
<td>81.8</td>
<td>120</td>
<td>124</td>
<td>110</td>
</tr>
<tr>
<td></td>
<td>116.5</td>
<td>0.0425</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The subscript (N) means that the element is normalized by chondrite (Taylor & McLennan 1985) ; Eu anomaly=(Eu$_3$)/(Sm$_3$) (Gd$_3$), (Henderson, 1984)
bromoform for heavy minerals separation and studied by stereomicroscope and XRD techniques.

The Low-radioactive Rock (Syenogranite)

Gebel El Nekeiba syenogranite contains accessory minerals such as colorless fluorite, allanite, and zircon. Allanite occurs as well-formed crystals with masked interference colors included in biotite (Fig. 7). The biotite itself encloses pleochroic halos that refer to the presence of radionuclides (Hussein, 1978) (Fig. 8). Zircon occurs as zoned crystals exhibiting its characteristic interference colors (Fig. 9). It also occurs as well-formed zoned crystals characterized by intensely metamictized core (isotropic) (Fig. 11). Both of them are identified by XRD techniques showing the characteristic peaks of typical zircon (Fig. 10)
and metamictized zircon (Fig. 12). The radioactive minerals in the syenogranite are nearly absent.

The Highly-radioactive Rock (Qz-syenite)

The quartz-syenite of G. El Nekeiba comprises the following minerals:

The Metallic minerals

The metallic minerals are represented by molybdenite, ilmenite and pyrite. Molybdenite occurs as platy crystals of hexagonal system characterized by grey color with metallic luster (Fig. 13a) while ilmenite occurs as prismatic crystals of trigonal system characterized by black color, metallic luster and moderate magnetism (Fig.13b). Pyrite is present as rare fractured crystals.

The Radioelements-bearing minerals

The radioelements-bearing minerals in the qz-syenite of G. El Nekeiba are mainly fluorite, zircon and columbite. Fluorite displays several colors from colorless, violet (Fig.14a)
to deep violet (Fig. 14b) & it is confirmed by XRD (Fig. 15). The colored varieties are good carrier of U ions (Cunningham et al., 1998). Cunningham et al., 1998 reported that uranium is transported as uranyl trifluoride complex and deposited when fluids react with the wall rock. Zircon is the most common heavy mineral in the studied rock characterized by yellow to yellowish grey colors. It forms short prismatic crystals of the tetragonal system (Fig. 16a) exhibiting its characteristic XRD diffractogram (Fig. 16b). Columbite occurs as well-formed orthorhombic crystals exhibiting its characteristic black color and submetallic luster (Fig. 17a) & it was recognized by XRD (Fig. 17b).

Fig. 14: Stereophotographs of fluorites separated from G. El Nekeiba Qz-syenite showing: a) Anhedral crystals of violet fluorite and b) Anhedral crystals of deep violet fluorite.

Fig. 15: XRD diffractogram for violet fluorite, G. El Nekeiba Qz-syenite

Fig. 16: Stereophotographs of Zircon separated from G. El Nekeiba Qz-syenite showing: a) Well-formed crystals of zircon and b) XRD diffractogram for zircon.

Fig. 17: Stereophotographs of columbite separated from G. El Nekeiba Qz-syenite showing: a) Well-formed crystals of columbite and b) XRD diffractogram for columbite.
The Radioactive minerals

The main radioactive mineral in the Qz-syenite of G. El Nekeiba is thorite (ThSiO₄). It is represented by three varieties (thorite, orangite and thorogummite).

Thorite (ThSiO₄)

It is a translucent mineral characterized by brown color and earthy luster, crystallizes in the tetragonal system. The crystals are fractured and occasionally associated with orangite (Th,U)SiO₄ (Fig. 18). It was identified by XRD and its diffractogram shows the characteristic peaks of thorite (Fig.19).

Orangite (Th,U)SiO₄

It is orange-colored thorite (Berry et al., 2000) occasionally present attached to the proper thorite (Fig. 20a&b). This mineral is characterized by the presence of U ions beside Th ions which is proved by transformation to thorogummite (Th,U)[SiO₄, (OH)]. It was identified by XRD giving a diffractogram of thorite mineral (Fig. 21), as there is no a specific ASTM card for orangite.

Thorogummite (Th,U)[SiO₄, (OH)]

Thorogummite occurs as an alteration product of thorite and orangite. It occurs as hydrated mantle enveloping the proper thorite (Fig.22a). Generally, it crystallizes in the tetragonal system as short prismatic crystals (Berry et al., Op. Cit.). It is very soft and
characterized by a yellow color with earthy luster and gum appearance (Fig. 22b). The preliminary examination of this mineral by XRD technique identified it as thorite, while examination, after heating of the mineral, it was found to be thorogummite mixed with fergusonite and zircon (Fig. 23).

RARE EARTH ELEMENTS (REE$_3$) DISTRIBUTION

Ten samples from G. El Nekeiba are prepared and analyzed for REEs by Induced Couple Plasma Spectrometer (ICP) at the Egyptian Nuclear Materials Authority Labs (NMA). The data are normalized to chondrite. (Taylor and McLennan, 1985) and are plotted on the spider diagram (Fig. 24).

On the diagram, Eu exhibits negative anomaly (Fig. 24) this is related to the fact that Eu$^{2+}$ is compatible with plagioclase and the removal of plagioclase from the felsic melt by crystal fractionation give rise to negative Eu anomaly. The ratio $\frac{(\text{Eu})}{\sqrt{(\text{Sm})(\text{Gd})}}$ is proposed by Henderson (1984) (Table 1). When the value is $>1.0$ indicating positive anomaly whilst a value $<1.0$ points to a negative anomaly. As seen from the table the rocks under consideration are characterized by negative Eu anomaly with an average of 0.23 for the syenogranite and 0.18 for the Qz-syenite (Table 1).
ilmenite after Nash and Creecraft, 1985) and for zircon and allanite by Mahood and Hilddreth (1983) (Table 2). In the felsic liquids, the accessory phases such as zircon, allanite and sphene strongly influence REE pattern although they are present in small quantities; zircon is depleted in the HREE (Sm-Lu), allanite is depleted in LREE (La-Nd). (Rol-linson, 1994).

Both rocks of G. El Nekeiba (quartz sy- enite and syenogranite) are rich in the access- ory minerals (zircon, allanite and ilmenite). They are rich in REEs (Table 1) and have high partition coefficients (Table 2). The studied syenogranite is characterized by lower REEs contents (179.7 ppm) than the qz-syenite (see Fig. 24) due to presence of quartz which com- prises about 35% of the rock and has the lowest partition coefficient. Qz-syenite is rich in the total REEs (up to 1265 ppm) with an average of 586.0 ppm and characterized by \( \sum \text{HREE} \) higher than \( \sum \text{LREE} \) (up to three times in sample NS3). Kozlov (2009) concluded that the high content of HREEs is related to a high content of volatiles (this is supported by the presence of different varieties of fluorite in G. El Nekeiba) and considered as good indicator for rare metals potentiality.

Table 2: Partition coefficients of REEs in some minerals

<table>
<thead>
<tr>
<th>Mineral</th>
<th>Quartz (P.C.)</th>
<th>Ilmenite (P.C.)</th>
<th>Zircon (P.C.)</th>
<th>Allanite (P.C.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>La</td>
<td>0.015</td>
<td>7.1</td>
<td>16.9</td>
<td>2594.5</td>
</tr>
<tr>
<td>Ce</td>
<td>0.014</td>
<td>7.8</td>
<td>16.75</td>
<td>2278.5</td>
</tr>
<tr>
<td>Pr</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>Nd</td>
<td>0.016</td>
<td>7.6</td>
<td>13.3</td>
<td>1620.0</td>
</tr>
<tr>
<td>Sm</td>
<td>0.014</td>
<td>6.9</td>
<td>14.4</td>
<td>866.5</td>
</tr>
<tr>
<td>Eu</td>
<td>0.056</td>
<td>2.5</td>
<td>16.0</td>
<td>111.0</td>
</tr>
<tr>
<td>Gd</td>
<td>---</td>
<td>---</td>
<td>12.0</td>
<td>---</td>
</tr>
<tr>
<td>Tb</td>
<td>0.017</td>
<td>6.5</td>
<td>37.0</td>
<td>273</td>
</tr>
<tr>
<td>Dy</td>
<td>0.015</td>
<td>4.9</td>
<td>101.5</td>
<td>136.5</td>
</tr>
<tr>
<td>Ho</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>Er</td>
<td>---</td>
<td>---</td>
<td>135.0</td>
<td>---</td>
</tr>
<tr>
<td>Tm</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>Yb</td>
<td>0.017</td>
<td>4.1</td>
<td>527.0</td>
<td>30.8</td>
</tr>
<tr>
<td>Lu</td>
<td>0.014</td>
<td>3.6</td>
<td>641.5</td>
<td>33.0</td>
</tr>
</tbody>
</table>

The binary relationship of U versus Ce/U for the two rock types shows a negative corre- lation (Fig. 25) indicating that uranium is not hosted mainly in the accessory minerals. Plotting of Th versus Ce/Th ratio shows negative correlation in syenogranite and positive cor - relation in quartz-syenite (Fig. 26) indicating that Th has two different behaviors in the two rocks of G. El Nekeiba.

The average of LREE/HREE ratios is plotted versus the average of Eu anomaly for the two rock types showing that syenogranite has higher ratio and higher Eu anomaly with less electronegativity than qz-syenite due to presence of plagioclase (Fig. 27).
Degree of Fractionation of REEs

Rollinson (1994) considered the ratio \( \text{La}_N/\text{Yb}_N \) as a measure of the degree of fractionation of REEs. When plotting this ratio on the binary diagram versus Ce, it defines the degree of fractionation with changing REEs contents. Applying this relation for G. El Nekeiba syenogranite and Qz-syenite, it is evident that the REEs are highly fractionated in the former (with an average of 3.92) rather than the latter (with an average of 0.59) (Fig. 28) indicating that the same Ce content fractionates by different degrees in the two melts depending upon the melt composition.

CONCLUSIONS

1- G. El Nekeiba is composed mainly of qz-syenite and syenogranite. The two rocks are moderately radioactive. Radioactivity of syenogranite is attributed to the accessory minerals (allanite and zircon). Qz-syenite has higher uranium and thorium contents than syenogranite and its radioactivity is attributed to the thorium minerals (thorite, orangite and thorogummite) in addition to the other accessory minerals.

2- Accessory minerals play an important role in supporting REEs contents in the two rocks; some of them enhance HREEs (allanite) and others enhance LREEs (zircon). Qz-syenite has higher total REEs due to the low content of quartz that possesses the lowest partition coefficient for REEs. Qz-syenite have \( \Sigma \text{HREEs} \) higher than \( \Sigma \text{LREEs} \) and higher than the corresponding value in syenogranite proved by the presence of rare metals potentiality like molybdenite as well as the high contents of volatiles (fluorite).

3- The normalized-Ce content of the quartz syenite and syenogranite corresponds to two degrees of fractionation (3.92 and 0.59) indicating that the degrees of fractionation depend upon the rock composition (mineralogical and chemical).

4- Finally, the factors that control the distribution of the rare earth elements in the granitoides of G. El Nekeiba are: a) The concentrations of REEs in the parent magma. b) The degree of fractionation of REEs in the hosting rock.

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REFERENCES


Kozlov, V. D., 2009. Rare-earth elements as indicators of ore sources and degree of differentiation and ore potential of rare metal granite intrusions, Eastern Transbaikalia. Russian Geol. Geophy., No. 50, 29-42.


يشير جبل النكبة في جنوب الصحراء الشرقية عند نقطة تقاطع خطي العرض ۲۳ ٫۵۵ مع خط الطول ۲۲° ۳۴ تشاغلا مساحة متشابهة للشكل تقطع حياتنا والصناديق. يتكون الجبل من صخور جرانيتية (سليانوجرات و كوارتز سلاتينت). تحتوي صخور جبل النكبة على العديد من المعادن الثقيلة المصنفة كمعادن فلزية (مثل الألمانيت والموليبدينيت بالكوارتز سلاتينت)، ومعادن لافتة للإشعاع (مثل الألمانيت والزركون). وتتكون أساسا من المعادن المشعة (معادن الثوريوم بالكوارتز سلاتينت). قامت الدراسة بتقييم المستوى التشغيلي لكل من الصخرين كيميائياً، وأظهرت أن صخر السليانوجرات هو الأقل إشعاعية بمتوسط ۲۲ جزء في المليون للثوريوم و ۷۸ ٪ جزء في المليون للثوريوم بينما يصل متوسط الابرازوم إلى ۱۱۶ جزء في المليون في الكوارتز سلاتينت. وأنتجت إشعاعية الأول إلى وجود المعادن الحاسمة للمعادن المشعة (الألوانتات والزركون) بينما ترجع إشعاعية الكوارتز سلاتينت إلى وجود معادن الثوريوم ممثلة بنوع ثوريوم و الأورانجيات والثوروجريت التي يمكن التعرف عليها ميكروسكوبياً بواسطة أشعة إكس الحيوية. أظهرت الدراسة إلى إنخفاض نسبة الثوريوم / الابرازوم عن معدلها الطبيعي (بمتوسط ۱.۳۷ في السليانوجرات و ۱.۳۶ في الكوارتز سلاتينت) مشيرة إلى إنخفاض معادن الثوريوم ارتفاع الابرازوم مما يدل على أن أورانجيات الثوريوم (أورانجيات) لمواجهة هذا النقص وتتحول هذه المعادن لأشكال الأورانجيات السليانوجرات (SiO₂) ك))[كيندلي نجزي (OH) من خلال عملية التبيث التي تسهم في بناء سليانوجرات (LREE) من المعادن الرخية (مثل الزركون) و الأخر بدعم مجموعة المعادن الرخية لذات الألوان (LREE) بالإضافة إلى وجود معادن ذات مادة توزيع من المعادن الرخية يتميز بجرح الألوان والموليبدينات. أظهرت الدراسة إلى دور المعادن المثلية في البناء، حيث أن بعضها يدعم مجموعة المعادن الرخية. كما أظهرت الدراسة على توقيع المعادن الرخية ودرجة التباين HREEs والثوريوم. وفقاً دفعاً درجة التفاضل الإشعاعي المثالي (۲۳ ٫۹۶ في السليانوجرات و ۱.۵۹ في الكوارتز سلاتينت). أنتجت الدراسة إلى التعرف على معادن الأورانيتية الثوروجريت كواضحة إلى المعادن المشعة. فأظهرت أن التوزيع الجيولوجي. وأظهرت إلى تحديد المعادن المؤثرة على توزيع المعادن الرخية. فأظهرت أن توفر المعادن الرخية على مستوى المعادن جميعاً توزيعها في الصخرين المتنوعة والتي تتوفر على توقيع المعادن ذاتية.