Acta Mineralogica-Petrographica, Szeged, XXXVII, 75–82, 1996

RARE-EARTH ELEMENTS OF GRANITOID ROCKS OF ST. KATHERINE AREA, SOUTH SINAI, EGYPT

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ABSTRACT

A group of granitic plutons and stocks outcrop in St. Katherine area, South Sinai (Egypt). They belong to the Late Precambrian Pan-African belt.

The granitoid rocks occupying St. Katherine area are composed of a comagmatic plutons and classified into three main phases according to their field relations and compositions: 1- quartz diorite, granodiorite and quartz monzonite (Gr_1), 2- monzogranite and biotite granite (Gr_2), 3- syenogranite, alkali feldspar granite and granophyre (Gr_3).

The distribution of REEs show variations in each phases as well as within one lithological unit which allow the interpretation of complex genesis of the massif.

The phase one (Gr_1) emplaced, as a basic magma in an intermediate magmatic chamber, containing a very low concentrations of REE. This has undergone a fractional crystallization, which resulted in an increase of the amount of ΣREE (average 102.16 ppm) with the moderately fractionated patterns (La/Sm = 6.07) and no significant negative Eu anomalies are found.

Phase two (Gr_2) has higher contents of ΣREE (average 116.86 ppm), and more fractionated LREE (La/Sm = 7.90) with a small negative Eu-anomalies.

Phase three (Gr_3) has a high contents of ΣREE (average 121.97 ppm) and fractionated LREE pattern with a relatively deep negative Eu-anomalies.

METHODS OF ANALYSIS

The REE and some other trace elements were analysed using INNA methods in Technical University, Budapest. The amount of samples used was of about 200 mg.

INTRODUCTION

St. Katherine area is located in the Arabo-Nubian belt of Central South Sinai (Fig. 1). The area covered about 1500 Km^2 of Precambrian crystalline basement complex. It mainly consists of Precambrian intrusive and extrusive rocks.

A detailed petrographic study of the Precambrian granitic rocks of St. Katherine Area was carried out by HASSEN (1987). More than ten varieties of granitoids and two varieties of syenite were recorded.

Granitoid rocks of St. Katherine area can be grouped into two major petrological, genetic and tectonic types (HASSEN and BUDA 1994);

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1. Two feldspar granitoids:
   1a. Qz-diorite, Qz-monzonite, granodiorite and Hb. Bt. granite (Gr_1);
   1b. Coarse-grained monzogranite, pegmatitic Hb. Bt. monzogranite, porphyritic monzogranite and Bt. granite (Gr_2).
2. Alkali granitoids (Gr_3).
   2a. Alkali-feldspar granite.
   2b. Syenogranite.
   2c. Granophyre.

BENTOR (1985): subdivided the crustal history of the Arabo-Nubian Shield (South Sinai) into the following four Phases.

Phase I (>950 M.y.), is characterized by the emplacement of an oceanic mafic and ultramafic magmatic rock assemblage and volcanic equivalents. These ophiolite sequences which were tectonically transported.

Phase II (950-650 M.y.), is an "island arc" stage dominated by andesitic volcanism and intrusive equivalents. Most of these rocks are metamorphosed in the greenschist facies.

Phase III (650-590 M.y.), is characterized by magmas of calc-alkaline silica-rich compositions. Granitic plutons are spread haphazardly over the entire massif. This phase ended with a strong uplift, Arabo-Nubian joins the African craton (Gr_1 and Gr_2).

Phase IV (590-550 M.y.), was the "alkaline batholitic" event producing alkaline to peralkaline high-level granites and their extrusive equivalents. These rocks were emplaced during a non orogenic period where the rigid massif was subjected to tensional stresses, block faulting and differential uplift (Gr_3).

EYAL and HESKIYAHU (1980) described the Gr_3 of St. Katherine Plutons. It is composed of alkali syenogranite. Three distinctive petrographical zones can be distinguished: Zone A contains 30% quartz, 45% perthitic alkali feldspar, 20% plagioclase and 5% biotite, zone B is 300 to 500 meters thick and contains 30% quartz, 65% perthitic alkali feldspar and 5% biotite, zone C is a transition between A and B. It was concluded that the rocks of zone A represent the original rock type of the intrusion. Zone B is interpreted as a product of the reaction of alkaline solutions with the original rock in the highest part of the pluton.

ABUNDANCES AND VARIATION OF RARE EARTH ELEMENTS

Concentrations of REE in the rocks are greatly variable, reflecting the different degree of differentiation within, as well as between the granitoid types. Further variation can be excepted on account of irregular distribution of REE-bearing apatite, allanite, monazite and zircon.

The result of analyses carried out on the granitoid rocks of St. Katherine area are present in Table 1. REE abundance was normalized to a chondrite (ANDREWS, E. and EBIHARA, M. 1982).

All samples, show the typical granite pattern (CULLERS and GRAFT 1984). They are enriched in light rare earth elements (LREE) relative to heavy ones. Important differences between the three varieties occur in their $\sum$REE contents, their HREE fractionation and the size of their Eu-anomalies.

Table 1

Average of REE and some trace elements data for Katherine granitoid rocks

ppm	Q_z-diorite, Q_z-monzonite and Granodiorite (Gr_1)			Monzogranite and Bt. Granites (Gr_2)			Syenogranite and alkali-feldspar granites (Gr_3)		
	Number of samples: 9			Number of samples: 24			Number of samples: 28		
ppm	mean &	std. dev		mean &	std. dev		mean &	std. dev	
Cr	87. 21 ±	54.19	70.50	49.71 ±	24.63	58.31	9.51 ±	2.87	6.94
Ni	14.22 ±	10.607	13.79	4.96 ±	1.89	4.47	6.88 ±	1.41	3.42
Co	21.70 ±	11.10	14.44	12.76 ±	4.70	11.12	1.99 ±	0.93	2.24
Sc	9.27 ±	5.94	7.72	4.37 ±	2.25	5.32	1.50 ±	0.69	1.78
V	46.78 ±	30.96	40.27	7.92 ±	4.32	10.22	6.29 ±	3.09	7.96
Cu	11.22 ±	12.76	16.61	5.29 ±	4.69	11.09	3.96 ±	2.10	5.41
Pb	10.22 ±	5.13	6.67	10.50 ±	3.86	9.20	19.07 ±	1.77	4.57
Zn	62.22 ±	17.37	22.60	38.04 ±	8.11	19.20	41.18 ±	13.19	34.01
Sb	0.46 ±	0.47	0.62	0.28 ±	0.20	0.39	0.16 ±	0.16	0.39
Rb	81.99 ±	15.59	20.28	102.08 ±	9.89	23.41	136.77 ±	13.08	33.72
Cs	2.55 ±	1.79	2.33	2.88 ±	1.56	3.70	1.00 ±	0.36	0.89
Ba	799.67 ±	148.82	193.61	702.29 ±	117.90	279.17	400.79 ±	93.25	240.47
Sr	628.11 ±	150.47	195.76	166.33 ±	75.32	178.34	128.14 ±	30.61	78.93
Ga	14.78 ±	3.95	5.13	7.58 ±	3.13	7.40	8.04 ±	3.33	8.06
Ta	0.75 ±	0.38	0.50	0.41 ±	0.13	0.25	0.75 ±	0.31	0.81
Nb	2.22 ±	1.38	1.80	3.63 ±	1.33	3.15	17.27 ±	3.45	8.90
Hf	4.59 ±	0.77	1.00	4.31 ±	0.58	1.37	4.44 ±	0.97	2.50
Zr	95.67 ±	53.40	69.47	83.75 ±	29.67	70.25	228.64 ±	65.23	158.02
Y	6.56 ±	3.71	4.83	5.29 ±	2.38	5.65	23.75 ±	4.02	10.38
Th	9.02 ±	3.20	4.17	12.10 ±	1.73	4.10	16.96 ±	2.21	5.69
U	4.52 ±	2.28	2.96	4.09 ±	1.66	3.93	4.40 ±	0.75	1.94
La	23.85 ±	2.36	3.07	30.27 ±	3.92	9.28	28.19 ±	4.25	10.95
Ce	47.62 ±	5.39	7.01	54.20 ±	9.25	21.90	53.00 ±	10.52	27.12
Nd	20.53 ±	4.78	6.22	22.43 ±	3.68	8.70	28.85 ±	4.87	12.55
Sm	3.93 ±	0.47	0.62	3.83 ±	0.62	1.46	4.62 ±	0.97	2.51
Eu	1.11 ±	0.17	0.23	0.84 ±	0.11	0.26	0.45 ±	0.12	0.30
Gd	3.48 ±	0.45	0.581	3.09 ±	0.31	0.74	3.17 ±	0.68	1.76
Tb	0.34 ±	0.09	0.11	0.40 ±	0.07	0.17	0.47 ±	0.15	0.39
Ho	0.26 ±	0.14	0.18	0.20 ±	0.09	0.21	0.48 ±	0.17	0.43
Tm	0.04 ±	0.03	0.04	0.00 ±	0.00	0.00	0.96 ±	0.13	0.33
Yb	0.81 ±	0.40	0.52	1.39 ±	0.24	0.58	1.39 ±	0.52	1.34
Lu	0.19 ±	0.03	0.04	0.21 ±	0.03	0.07	0.39 ±	0.05	0.14
ΣREE	102.16			116.86			121.97		
La/Sm	6.07			7.90			6.10		
La/Yb	29.44			21.77			20.28		
Ce/Yb	58.79			38.99			38.13		
Gd/Yb	1.12			2.22			2.28		

In order to facilitate the comparison of ΣREE pattern in different rock units, we plotted on diagram only the relatively homogenous granitoid groups of the Katherine complex (Fig. 1 a,b,c).

Gr_1; they display the lowest ΣREE abundances compared with the other two types. They have relatively low to moderate ΣREE contents and exhibit a limited range in composition (the range of 9 samples ΣREE = 133.24-85.45 ppm and average 102.16 ppm). They are characterized by low fractionated LREE (La/Sm_n ranges from 6.70 to 4.93

with average 6.07) and moderately fractionated HREE patterns (Gd/Yb_n ranges from 19.66 to 2.49 and the average 1.12}, and almost flat REE patterns with more or less absences of any significant negative Eu-anomalies. (Fig. 2a)

Gr_2; they have higher ΣREE content (186.19-53.53 and average 116.86), and have relatively stronger LREE and HREE fractionated patterns (La/Sm_n range from 12.83-6.07 with average 7.90 and Gd/Yb_n range from 6.07-1.25 and average 2.22}.

Samples which represent leuco-monzogranite show lower contents of ΣREE indicating a decrease in the REE content with increasing differentiation. Such a decrease in REE content could be attributed to the removal of some REE-bearing phases which reduce the REE content of the remaning liquid (Frey et al., 1978). This is agreement with the modal mineralogy, since the accessory minerals (apatite, sphene and zircon) are rich in the normal monzogranite, poor in the leuco-monzogranite, suggesting their removal by fractionation. (Fig. 2b)

Gr_3, they seem to be slightly different from the other granitoid types. ΣREE concentrations are greater than in the other types (307.93-67.65 with average 121.97 ppm), they are characterized by larger negative Eu-anomaly, flat HREE patterns (Gd/Yb_n=0.83-20.14 with average 2.28} and moderately fractionated LREE patterns {$(La/Sm)_n$=4.17-26.61 with average 6.10}. Larger negative Eu-anomalies in leucocratic rocks are common feature due to feldspar fractionation or fractionation of REE-rich accessory minerals (CULLERS and GRAF 1984).

The characteristic chondrite-normalized pattern of the Gr_3 (Fig.2c) shows a marked negative Eu anomaly, whereas that of the other types exhibit a significant flat Eu (Gr_1) or small negative anomaly (Gr_2).

The more or less flat HREE trend of the syenogranite is an important feature. This indicates that hornblende fractionation is less significant in the evolution of these granitoids; or that they are derived by partial melting of a source without residual amphibole and/or garnet.

DISCUSSION

The older granitoids (Gr_1) display moderately fractionated normalized REE patterns The $(La\backslash Sm)_n$ ratios of the older Sinai granitoids average 6.07. The younger granitoids are more evolved and have higher REE contents than the older granitoids. They display moderately to strong fractionated normalized REE patterns $(La/Sm)n$ = 6.10 to 7.9) with moderate to strong negative Eu anomalies.

The three variety of granitoids are enriched in REE (Table 1). They exhibit LREE enrichment over HREE. The moderately fractionationated patterns of the LREE in older granite and a smaller one in the younger granite (Fig.1), are the only differences in the two units. Early fractionation of the feldspars may have caused depletion of Eu in the syenogranite. The patterns exhibited the older granite and the monzogranite are typical of those of calc-alkaline to subcalc-alkaline granites in the Arabo-Nubian Shield (MARZOUKI et al. 1982).

In case of Old granitoid (Fig 2a), there is no Eu anomaly. This can be regarded as a result of the fractional crystallization of the basic magma dominated by the plagioclase feldspar accumulation.

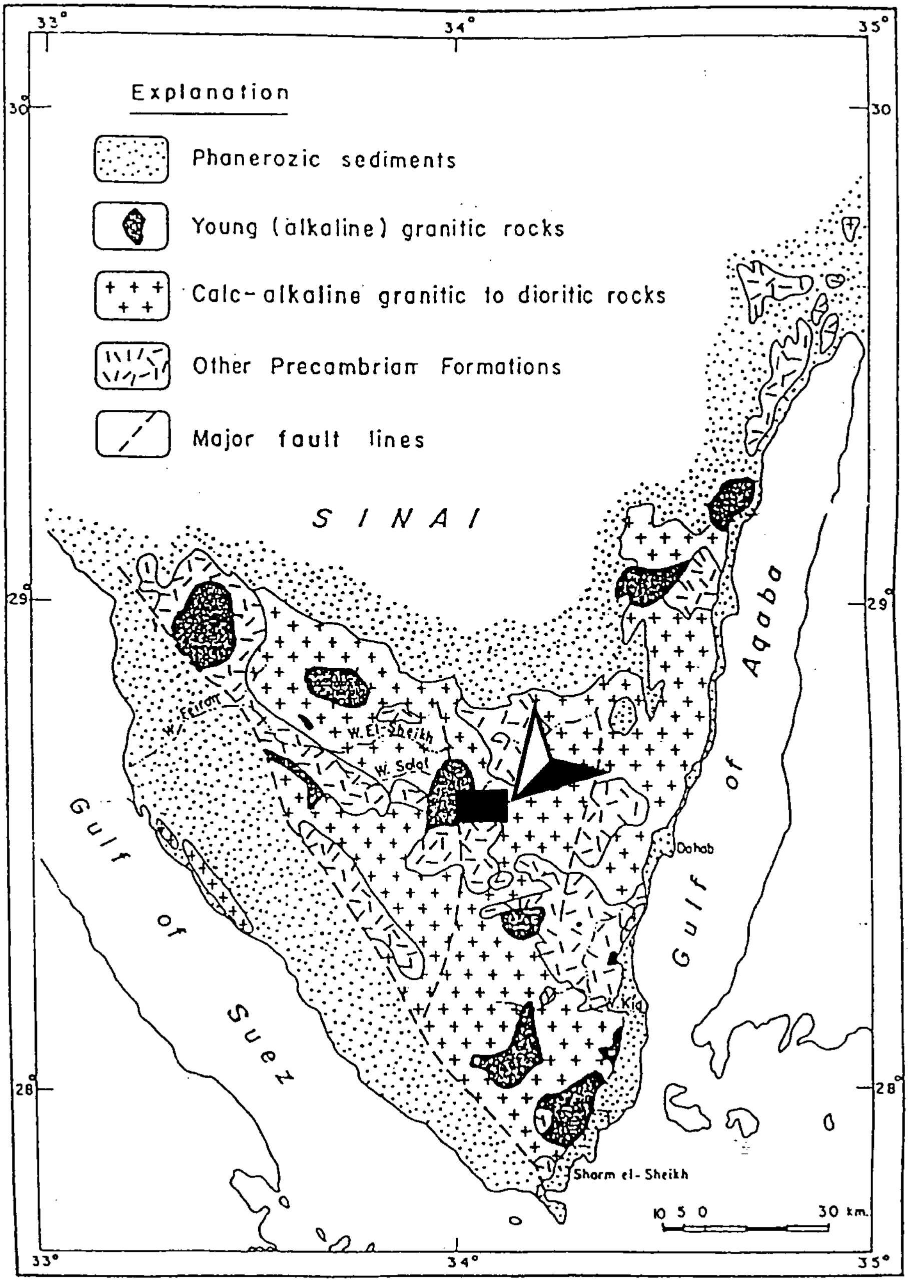

Fig. 1. Generalized geological map of the Precambrian of Sinai Peninsula after SHIMRON (1980).
➢ Studied area

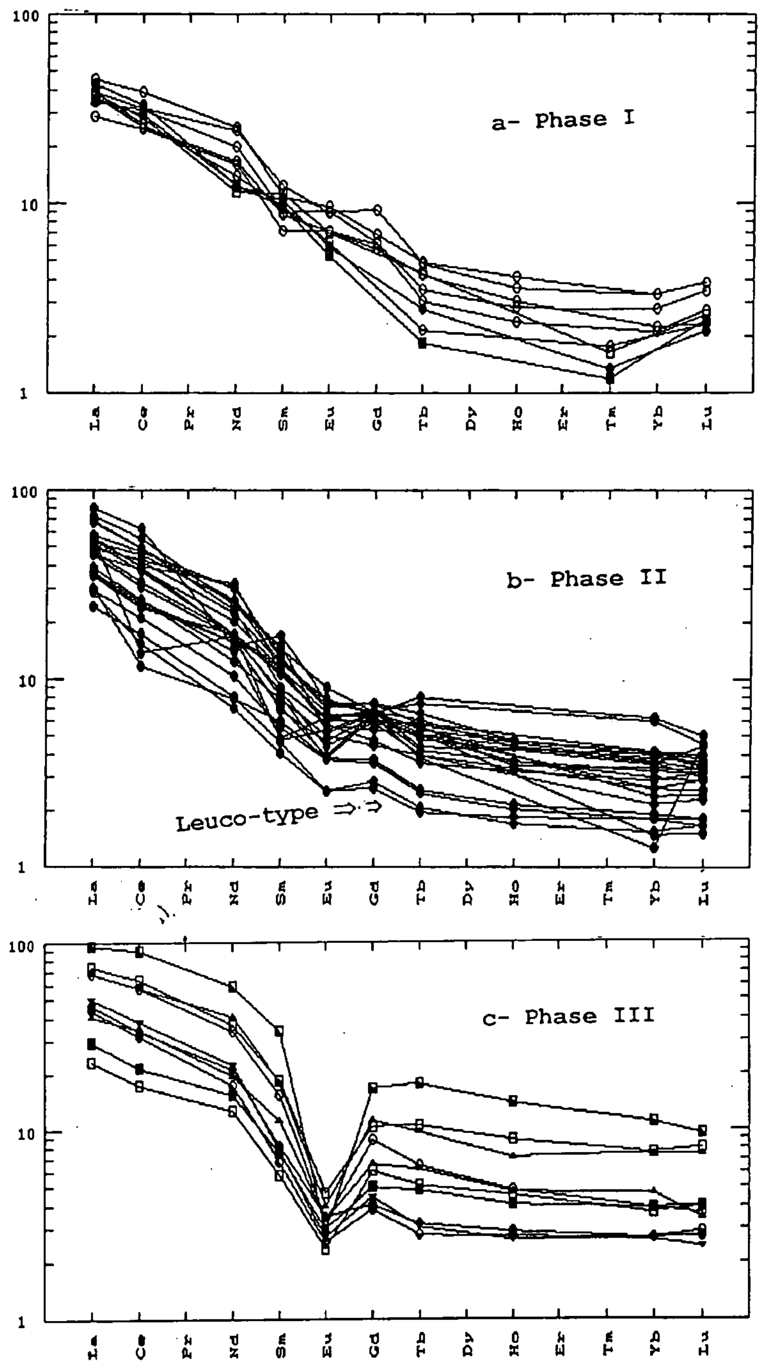

Fig. 2. Chondrite normalized REE distribution patterns of the three main phases of granitoids occurring in St. Katherine area.

Although there are certain discontinuities, the geochemical variations seem to show differentiation tendencies at least at the level of the old granite (Gr_1) and monzogranites (Gr_2) in one side and syenogranite in the another side.

The REE, distribution also indicates that the massif was generated by successive magma pluses and variations in each lithological unit as well as from one unit to another allow the interpretation of a complex genesis of the massif.

The first moment includes a basic magma (low values of REE) whose fractional crystallization in an intermediary magmatic chamber led to the appearance of Old granites.

A new magma plus, very likely richer in acidic materials, took over some of the previous crystals (resulting from the fractionation of the above mentioned rocks), and formed an intimate mixture, being emplaced at the actual level where a new magmatic differentiation took place.

Monzogranite of Gr_2, has typical subcalc-alkaline characters (HASSEN, 1987), behave less differentially from the Old granite. Therefore it is possible that the products of this phase might belong to modified old granitoids magma.

Potassic granites (Gr_3) probable generated in an ensialic tensional environment (HASSEN, 1987) having the high abundances of Y and Nb which, are typical of "within-plate" granites. Further, they have rather high contents of e.g. $\sum$REE, Zr, Th and U. Another important features is the flat HREE trend. This indicates that hornblende fractionation is less significant in the evolution of such granitoid; or that they are derived by partial melting of a source without residual amphibole and/or garnet.

Although the granites (Gr_3) may have been generated in a tensional setting, it is likely that a true continental rift was developed. Acid volcanics of the same age can be found where the Gr_3 are known in the investigated area (Katherine volcanics). In continental tensional environments, where degassing of the mantle occurs (BAILEY 1977). Continued heating by the gas flux may lead to melting of the upper mantle and lower crust. When the lower crust melted, the trace element characteristics were obtained by the mixing of the mantle volatiles, (rich in CO_2, alkalies and the trace elements characterstic of "within-plate" granites) with the crustal fusion products.

CONCLUSION

Three type of REE distribution can be distinguished:

Type 1: Quartz diorite and granodiorite (Gr_1) display moderately fractionated REE patterns, less fractionated HREE patterns and no significant Eu-anomalies.

Type 2: Monzogranite and normal (Gr_2) granite differ from the previous type in being more LREE fractionated and by the presence of small negative Eu-anomalies.

Type 3: The syenogranites and alkali feldspar granites (Gr_3) have fractionated LREE patterns and flat HREE patterns. With the exception of two samples, all the samples have relatively deep Eu-anomalies and high contents of REE compared to the other varieties.

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Manuscript received 5 Aug. 1996.