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Research Article

A Geochemical Evaluation of Metamorphic Rocks from Schirmacher Oasis East Antarctica: Implications of a MORB Source

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ABSTRACT

We analyzed the Rare Earth Elements (REEs) and several trace elements of seven medium to high grade metamorphic rocks, being gneisses, a schist and a quartzite, from Schirmacher Oasis, East Antarctica. The petrographic study shows that the rock forming minerals were altered to secondary minerals. Relative to chondrite, the REEs demonstrate a fractionation with enrichment in light REEs, suggesting a mobilization of heavy REEs during crystallization of the potential protoliths. The presence of negative Eu anomalies of 0.3 to 0.86, support early fractionation of plagioclase. All samples indicate similar elemental patterns relative to chondrite leading to the conclusion that their affiliation was of the same source. However, based on patterns relative to ocean island basalt (OIB), three gneisses may be apparent to OIB. Based on the geochemical discrimination, we obtained a mid ocean ridge basalt (MORB) background as primary tectonic setting, possibly writing an alignment of a continental arc.

Keywords: Gneiss; Schist; Quartzite; Rare earth elements; Enrichment; Anomaly

INTRODUCTION

The metamorphic complex of Schirmacher Oasis is intersected by numerous dykes of lamprophyre, basalt, pegmatite and aplite. The Precambrian crystalline basement of Schirmacher Oasis is part of the East Antarctic shield. It consists of a poly-metamorphic complex represented mainly by various gneisses (Figure 1). The geology of Schirmacher Oasis, East Antarctica mostly consists of gneiss rock and igneous intrusions (Figure 2). Geological Survey of India classified the gneisses rocks to quartzo-feldspathic augen gneiss (± garnet), Quartzo-feldspathic streaky gneiss, augen layers in quartzo-felspathic, garnet rich biotite quartzo-feldspathic gneiss, quarz-garnet sillimanite perthite (± graphite) gneiss. Divided the gneisses from Schirmacher oasis region into three types namely garnet-biotite gneiss, augen gneiss and leucogneiss [1,2]. Petrographic analysis by showed that the typical assemblages of minerals in quartzo-feldspathic gneiss are quartz–K-Feldspar–plagioclase–biotite–hornblend. Whereas, biotite gneiss rocks consist of quartz–K Feldspar–plagioclase–garnet–biotite minerals shows the hand specimen of gneiss rock from study area as indicated by augen textures (Figure 3) and lineations alignment of minerals (Figure 4). Rb/Sr age data of the garnet biotite gneiss and leucogneiss indicate a Late Proterozoic age determined the ages of quarzo-feldspathic gneisses in the range of Early Paleozoik–Late Proterozoic [3]. Several studies have been carried out to understand metamorphic rocks in East Antartica . They present an overview of protoliths of metamorphic rocks in the Napier complex and also report that tonalite–trondhjemite–granodiorite (TTG) is a protolith of rocks within this complex. The study reveals that felsic and garnet rich gneiss in East Antartica are derived from sedimentary rocks while garnet poor gneisses are derived from TTG complex [4,5]. The study on the Massif, Prince Charles Mountains (East Antarctica) reports that several different source materials were involved for magma generation in the study area investigated the geochemistry of igneous and metamorphic rocks of northern Prince Charles Mountains, Antarctica to construct the chronological history of intrusion and metamorphism of the area using U-Pb dating. Our current study aims to investigate the chemical compositions of metamorphic rocks from this area in order to understand the mobility of REEs and several other elements [6].

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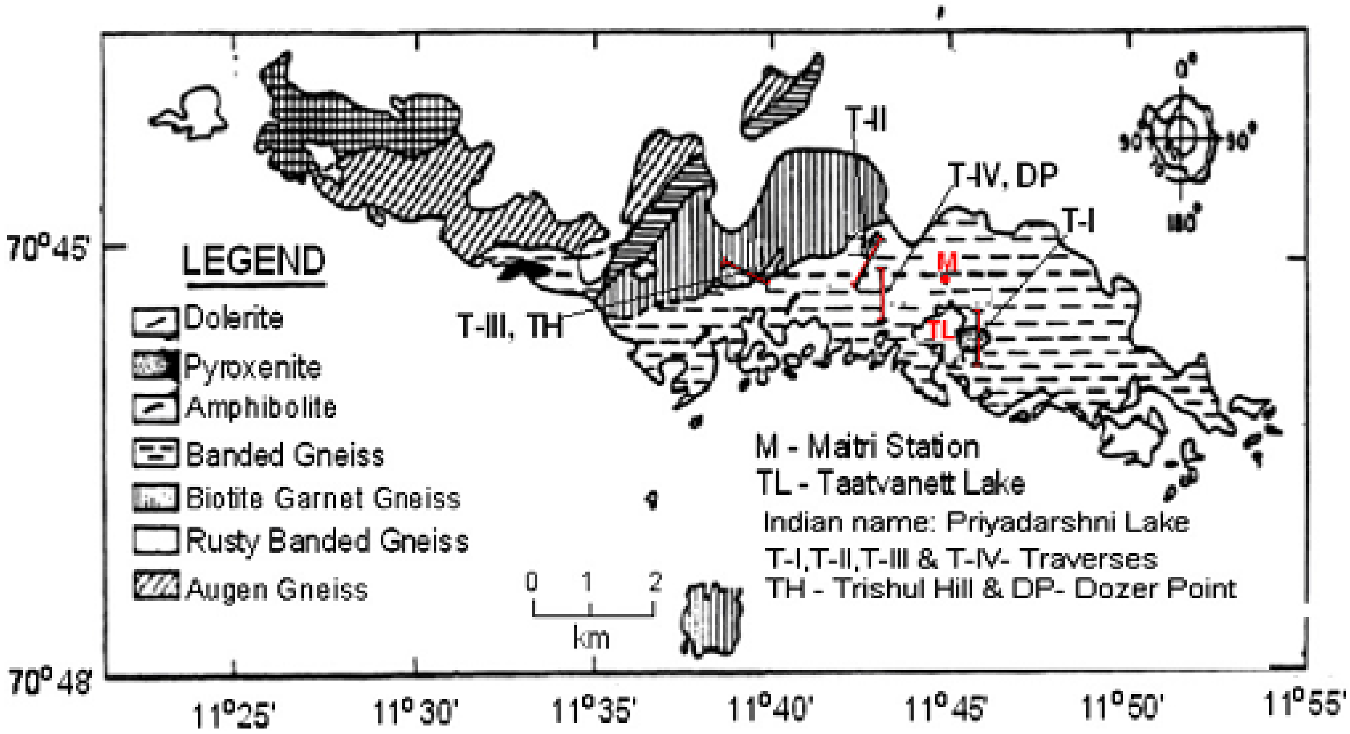

Figure 1: Area of study and sample location, Schirmacher Oasis, east Antarctica.

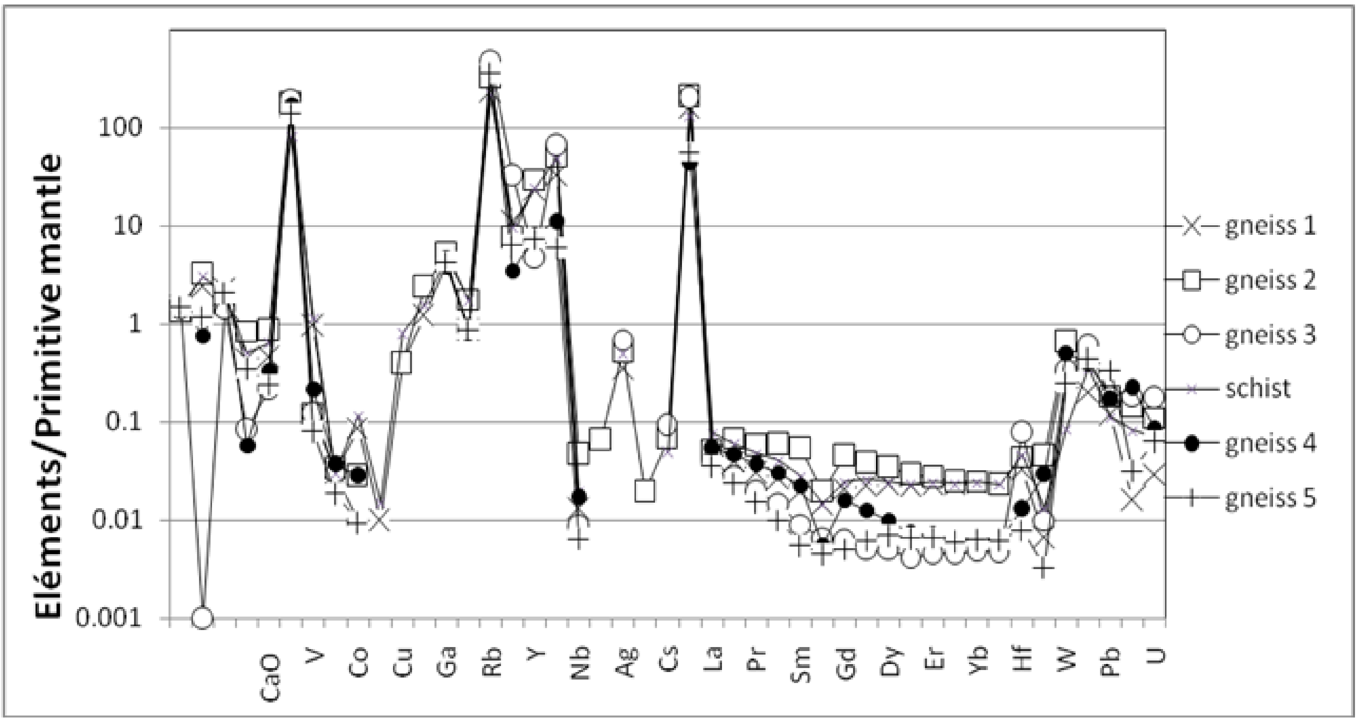

Figure 2: Normalization of concentrations of elements to those in the primitive mantle.

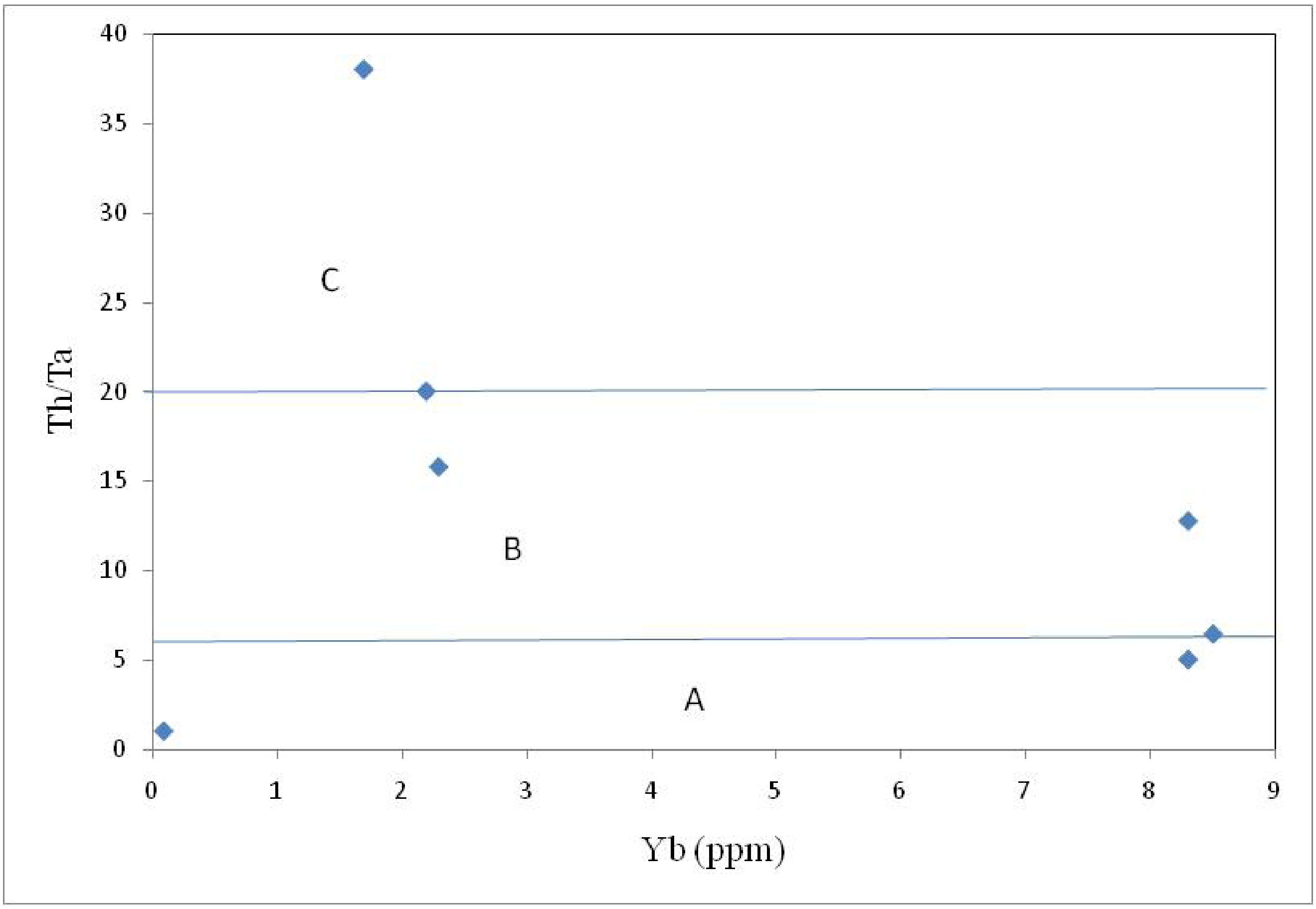

Figure 3: The Th/Ta ratio versus Yb concentrations in the different rocks.

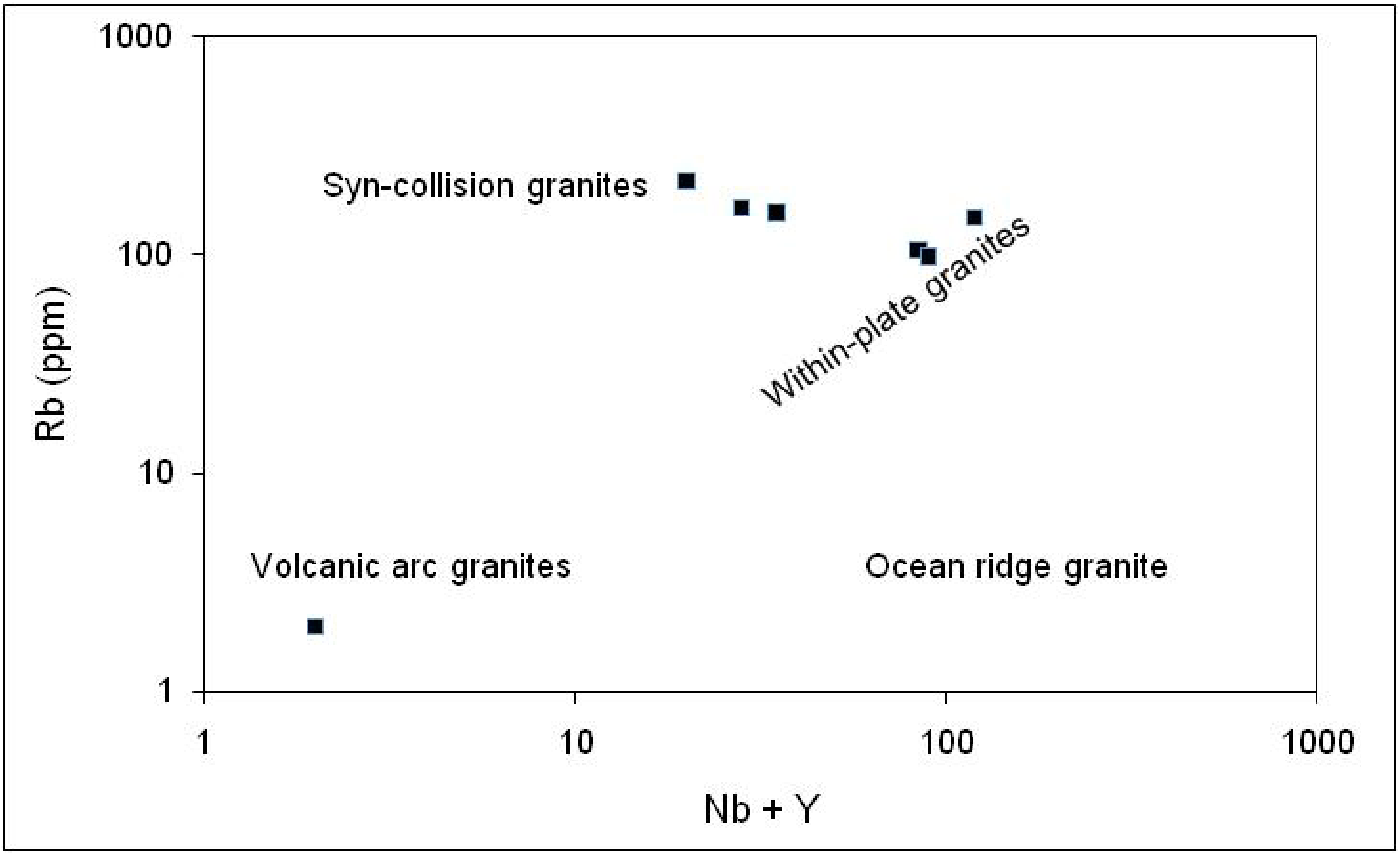

Figure 4: The concentration of Rb versus (Nb+Y).

Geotectonic setting

East Antarctica is an area of a continental shield composed of ancient igneous and metamorphic rocks. The oldest rocks in Antarctica are Precambrian schists and gneisses, spanning the greater proportion of geological time, from at least 3100 to 480 million years. Several previous studies described the lithological composition of Antarctica [7,8]. The rocks of the Schirmacher Range (East Antarctica) have undergone multiple episodes of metamorphism, migmatisation and also deformation. These rock sequences include augen gneiss, biotite gneiss, pyroxene granulites, amphibolites, calc-silicates, dolorites, basalts, vein quartz, and pegmatites [9]. Hereby, the banded gneiss is the dominant rock type, where compositional variations in such rocks reflect the non-uniformity of the present metamorphic sequence, which has suffered superposed folding.

MATERIALS AND METHODS

Seven samples were collected from the study area which five samples have been gneisses, one sample a quartzite and one sample has been schist. Each sample was crushed to fine size powder for subsequent geochemical analysis within a batch system. Each batch contains a method reagent blank, certified reference material and 17% replicates. Samples are mixed with a flux of lithium metaborate and lithium tetraborate and fused in an induction furnace [10]. The molten samples have been immediately poured into a solution of 5% nitric acid containing an internal standard, and mixed continuously until completely dissolved (~30 minutes). Samples fused under code 4B2 are diluted and analyzed by Perkin Elmer Sciex ELAN 6000, 6100 or 9000 ICP/MS. Three blanks and five controls (three before the sample group and two after) have been analyzed per group of samples. Duplicates are fused and analyzed every 15 samples. Instrument was recalibrated for every 40 samples [11].

All samples have been analyzed for major and trace elements including Rare Earth Elements (REEs). The elemental contents were determined on an X-ray fluorescence spectrometry (XRF) equipment (SQU, Oman) for (Mg, Ca, Na, K, Mn and Zn, Fe, Ti and Si) and on an ICP-MS equipment (ICTA lab, Canada) for trace elements (Cu, Ba, Cr, Co, Ni, Rb, Sr, Zr, U and Th) and rare-earth elements (REEs) [12-15].

RESULTS AND DISCUSSION

Mineralogical characterization

The composition of metamorphic rocks acquired during this study was investigated under polarizing microscope (Figure 5). The petrography investigation revealed weathering for some gneiss samples.

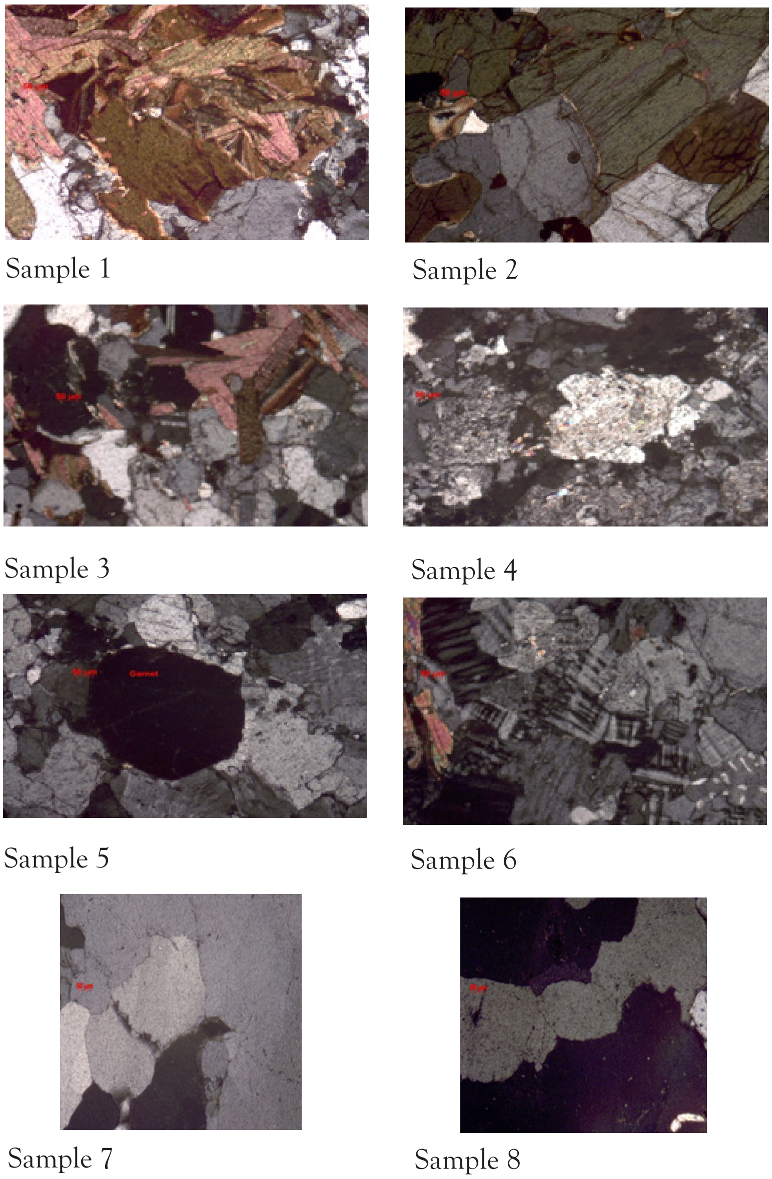

Figure 5: The main minerals identified in samples.

In the first sample of gneiss, the major minerals are orthoclase and plagioclase as both albite and anorthite and quartz and micas mainly biotite and muscovite with about 50% quartz, 30% micas and 10% feldspar. Fine and large particles of quartz appear with inclusions of micas [16]. The minerals such as amphibole and pyroxene and zircon are also observed in this sample with about less than 10% of the total minerals.

In sample 2, there are about 5% of micas, 30% of feldspar and of the rest is mainly quartz. The grains have nearly the same size. Sample 2 shows less foliation than sample 1. Sericite mineral, garnet, zircon and pyroxene have also been identified in this gneiss sample [17].

In sample 3, there is more micas than in sample 1 and 2. The quartz grains have nearly the same size and are smaller than grains in sample 1 and 2. Zircon and amphibole were also identified in this sample [18]. The microphotograph revealed also the presence of garnet. One direction of foliation is observed in this sample.

In sample 4, identified as schist there is about 90% of quartz, 4% of micas and 2% of feldspar. The minerals such as zircon, amphibole and pyroxene were also observed in this sample.

In the sample 5, gneiss with about 5% is garnet mineral, quartz grains exhibit the same diameter with about 80% of large grains and 20% of fine ones. In sample 6 gneiss there is about 50% of quartz, 40% of feldspar and 10% of micas. The size of particles is homogeneous. Some particles of quartz are characterized by inclusions. Sericite mineral has also been identified in this gneiss sample. In sample 7 a quartzite there is about 90% of large grains and 10% of fine particles.

Chemical composition

The chemical composition of different rocks is included in Table 1. The SiO2 content is about 60.8 to 88%. The Al2O3 contents range from 0.16 to 10.13% while the lowest concentration is measured in quartzite. The Fe2O3 content varies from 0.014 to 7.74%, on the other hand the highest concentration is observed in gneiss and the lowest in quartzite [19]. The CaO concentration ranges from 0.26 to 3%, but the concentration of K ranges from 0.045 to 5.5% and the concentration of MnO ranges from 0.01 to 0.084%. Further, the concentration of TiO2 ranges from 0.006 to 0.67%, however, the lowest concentration was observed in quartzite sample.

The content of K, Al and Mn is similar in 2 gneiss samples. The other gneiss samples are distinguished. The schist sample is characterized by lowest concentrations in K but similar concentrations to gneiss samples. The gneiss 3 and 5 samples including garnet are characterized by a depletion of iron (of about 90 and 57% respectively) compared to the other gneiss samples and to gneiss 2 which appears to be a fresh rock. The gneiss samples (sample 5) are also depleted of about 57% in Fe compared to sample 2 of gneiss. A previous study carried on 5 samples of gneiss rocks from the same area (Schirmacher Oasis, Antarctica) showed an enrichment of Fe in 4 samples of gneiss of about 20 to 64% due to weathering and depletion in one gneiss sample. Based on chemical composition, the protolith of all samples of this study may be apparented to a felsic rock.

Relative to the primitive mantle, all rocks were enriched in Zn, Ga, Rb, Sr, Y, Zr, K, Si, Ti and Al but depleted in other elements including REEs. Such distribution may suggest a crustal contamination during magma ascent as it may be due to inputs of elements during a mantle metasomatism [20]. Further, the K/Rb ratio ranges from 198 to 373 with an evidence of more mobility of Rb than K during metamorphism. This ratio is similar to K/Rb ratio of the Tonalite–Trondhjemite–Granodiorite (TTG) and lower than the ratio of the primitive mantle. A similar ratio has also been calculated for augen gneiss investigated by [4]. Compared to gneisses, the schist is characterized by loss of more Rb than K during metamorphism [4].

The observed Th/U ratio during this study varies within 1-9.5 and indicates that there is more mobilization of Th during metamorphism than U for all rocks. Two samples of gneiss in addition to quartzite have lower Th/U ratio than the ratio measured for the upper continental crust ratio of 3.8 one sample has a similar ratio to that of continental crust while for schist and other samples of gneiss, the Th/U ratio is higher than that of the crust. A previous study carried by reported a Th/U ratio about 2.3 to 6 in the augen gneiss [4].

The Plot of chemical data on the discrimination diagram (Figure 6) showed the following results:

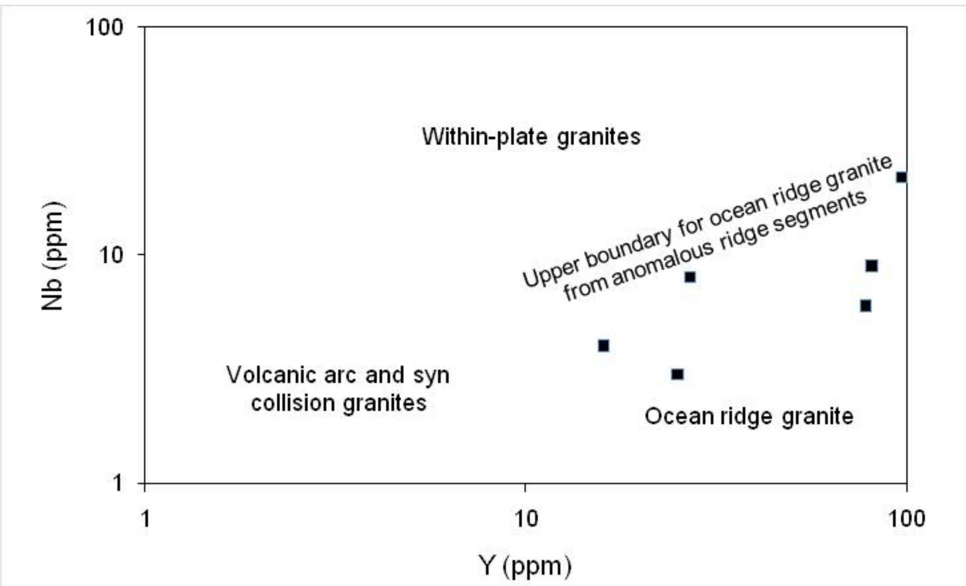

Figure 6: Concentrations of Nb versus the concentration of Y.

Table 1: Chemical composition of rock samples. The concentrations of major elements are expressed in % of oxide, those of trace elements in µg/g.

%	gneiss 1	gneiss 2	gneiss 3	schist	gneiss 4	gneiss 5	quartzite
Al2O3	10.13	7.6	6.35	9.18	9.77	9.31	0.16
SiO2	67.77	60.8	64.74	68.21	70.75	67.25	88.08
K2O	4.76	5.15	5.45	2.33	4.79	4.03	0.05
CaO	1.64	3.11	0.79	2.3	1.19	0.87	0.26
MnO	0.08	0.08		0.04	0.02	0.02	0.01
Fe2O3	4.06	7.74	0.79	4.72	0.54	3.3	0.02
TiO2	0.5	0.69		0.64	0.16	0.25	0.01
P2O5	0.08	0.68	0.28	0.14	0.13	0.11	
K/Rb	373.1	287.2	208. 7	197.7	254.9	204.4	187.5
µg/g							
V	71	9	9	85	16	6	7
Cr	80	90	80	80	100	50	180
Co	9	3	1	12	3	1	1
Zn	0.65	1.19	0.77	0.29	0.7	0.5	0.2
Ga	18	22	18	20	16	18	1
Ge	1	2	1	2	1	1	1
Rb	106	149	217	98	156	164	2
Sr	172	119	511	153	54	101	2
Y	78	97	16	81	27	25	1
Zr	274	426	555	402	94	50	5
Nb	6	22	4	9	8	3	1
Ag	1.4	2.1	2.7	2	0.5	0.5	0.5
Cs	1.2	1.1	1.5	0.8	0.5	0.5	0.5
µg/g	gneiss 1	gneiss 2	gneiss 3	schist	gneiss 4	gneiss 5	quartzite
Ba	796	1050	1030	661	225	286	3
La	26.3	26.2	20	38.8	27.7	18.3	0.3
Ce	53	91.3	37.8	79.5	63.4	32	0.5
Pr	6.24	11.8	4.08	9.68	7.6	3.12	0.06
Nd	26.5	59.6	14.6	40.4	29.9	10	0.2
Sm	6.4	17.8	2.9	9	7.2	1.8	0.1
Eu	1.79	2.42	0.81	1.81	0.69	0.56	0
Gd	9	19.8	2.7	10.6	6.9	2.2	0.05
Tb	1.8	3.1	0.4	2.1	1	0.5	0.1
Dy	12.7	19	2.7	13.2	5.3	3.8	0.1
Ho	2.7	3.6	0.5	2.8	0.9	0.8	0.1
Er	8	9.6	1.6	8.3	2.5	2.3	0.1
Tm	1.27	1.35	0.25	1.26	0.35	0.33	0.05
Yb	8.3	8.5	1.7	8.3	2.3	2.2	0.1
Hf	7.4	10	17.9	10.4	3	1.8	0.2
Ta	0.2	1.4	0.3	0.4	0.9	0.1	0.1
W	3	8	4	1	6	3	8
Pb	17	26	26	16	25	49	5
Th	1	9	11.4	5.1	14.2	2	0.1
U	0.5	1.9	3.1	1.2	1.5	1.1	0.1

- Th/Ta and Yb: In this diagram, 4 rocks plot in the area of Active continental margins, two samples in the within plate volcanic zones and one sample in the oceanic arcs area.

- Rb versus Nb+Y: In this diagram, all plots of samples between the syn collision area and the within-plate granites area except one sample which plot near volcanic arc granites.

- Nb versus Y diagram: In this diagram, all samples plot between the upper boundary for ocean ridge granite area and ocean ridge granite.

- Th/Nb versus La/Yb. In this diagram, samples plot between the mid ocean ridge basalt (MORB) area and continental arcs.

- Th/Yb versus Ta/Yb In this diagram, samples plot between the MORB and enriched mantle.

Rare earth elements (REEs)

The total content of Rare Earth Elements (REEs) is about 78 to 274 ppm for gneiss rocks and about 226 ppm for schist. The lowest content of REEs was observed in quartzite, about 1.86 ppm. The total REEs observed in gneiss from central Wyoming Province with probably the same age as the gneiss of this study, is about 93.63 ppm. [10] reported a total REEs about 0.103 ppm in gneisses of the East Antarctic shield [21].

The chondrite normalized REE patterns suggest a selectively REE mobility with a mobilization of heavy REEs (HREEs) (Figure 7). The patterns show a negative anomaly in Eu (estimated as Eu/Eu*) about 0.29 to 0.885 except quartzite which shows a positive anomaly in Eu (Eu/Eu*=1.50). This anomaly is in positive correlation with U and may reflect the derivation of gneiss and schist from felsic rocks often characterized by a negative anomaly in Eu obtained 0.57 and 0.66 as Eu/Eu* ratio for gneiss from East Antarctic shield. All rocks either gneiss or schist including the garnet schist are characterized by the same patterns, except quartzite.

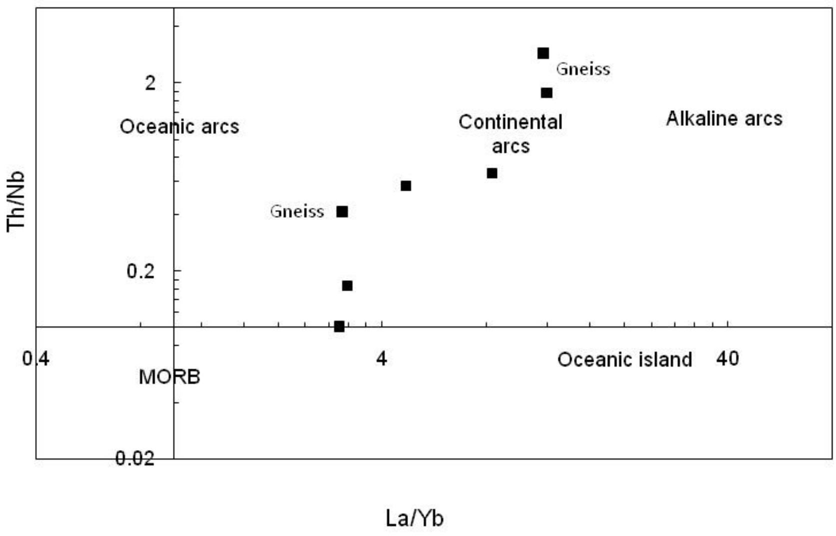

Figure 7: The Th/Nb ratio versus La/Yb ratio in the different rocks.

The enrichment in light REEs (LREEs) was also observed in chondrite normalized gneisses from a previous study. Furthermore, an analogy was observed with the patterns of REEs in mafic gneiss from Antarctica while felsic gneiss are more enriched in LREEs than gneiss of the previous study. The most important enrichment in LREEs is observed for two gneisses with La/Yb ratio about 12 (Table 1). The depletion in HREEs might result from fractionation of amphibole as it was suggested. The negative anomaly in Eu can indicate a fractionation of plagioclase.

The enrichment in LREEs has been reported as an indication of a decrease of the partial melting degree as the increase of Nb/Y and Zr/Y ratios [22]. In the present study, these ratios are about 0.07 to 1 and about 2 to 35 respectively. The highest ratios are observed for samples with highest LREEs/HREEs ratio. However the lack of an increase for Nb, Ta and Zr in parallel to the increase of LREEs excludes such explanation of LREEs enrichment.

Most of the samples are enriched in REEs relative to the primitive mantle except quartzite. Samples from 2 gneisses (sample 3 and 6) show similar patterns to REEs of mid ocean ridge basalt (MORB). Relative to ocean island basalt (OIB) only samples from schist and from two gneisses (sample 1, sample 2) were enriched especially in HREEs (Figures 8 and 9). The patterns of samples from the other gneisses are flat which can suggest their derivation from (OIB).

Calculation of Eu anomaly showed that the significant negative anomaly characterize quartzite and one of the fourth gneisses [23,24]. Although both pyroxene and plagioclase can fractionate Eu, previous studies showed that the influence of plagioclase on fractionation of Eu is more important than that of pyroxene. Reported that the Eu/Eu* ratios range from 19 to 40 in plagioclases and from 3 to 14 in the coexisting clinopyroxenes.

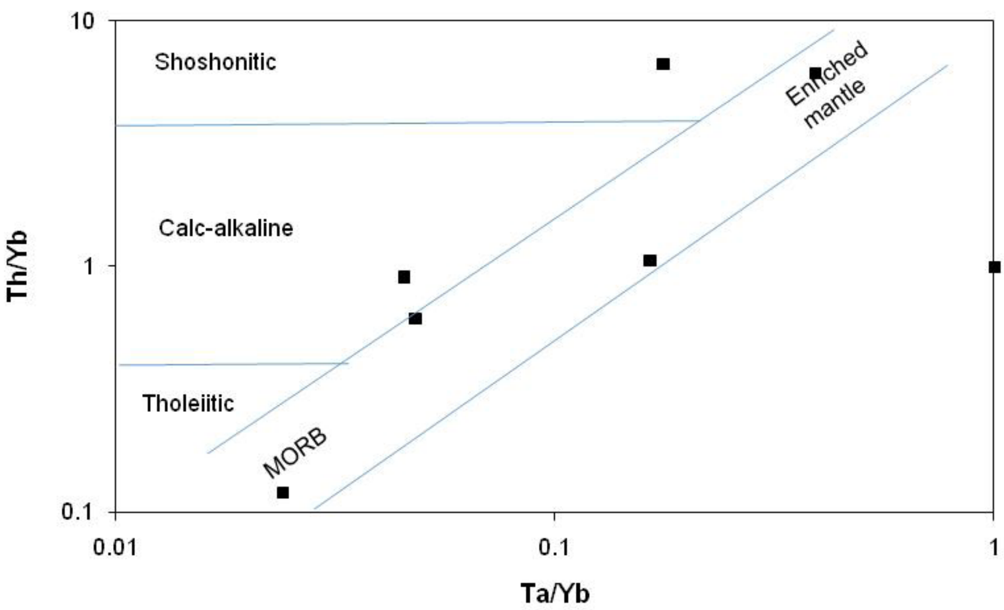

Figure 8: The Th/Yb ratio versus Ta/Yb ratio in the different rocks.

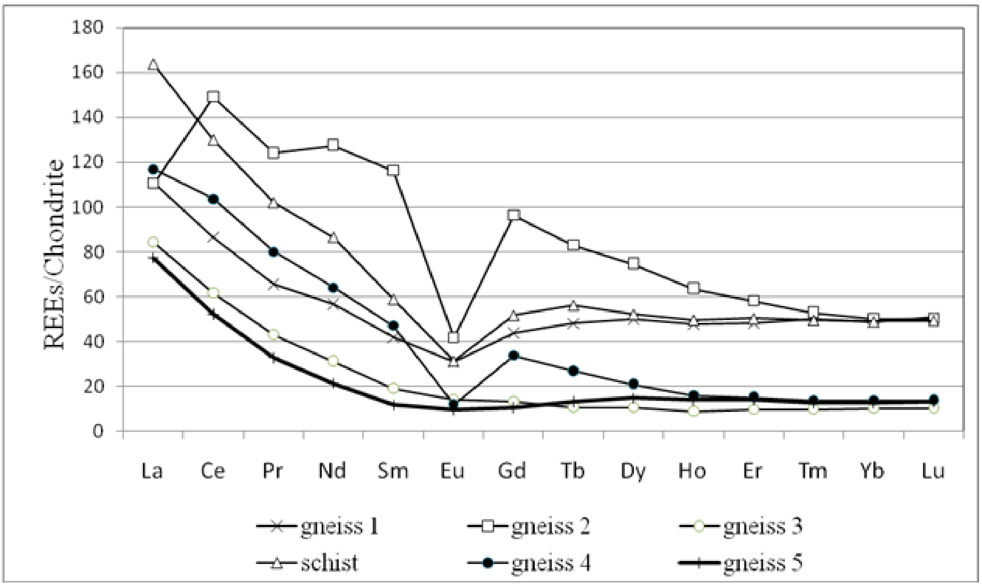

Figure 9: The normalization of concentrations of rare earth elements to those in chondrite.

A significant correlation was observed between the anomaly in Eu and the total of REEs which suggests that the crystallization of most plagioclase inducing a negative anomaly might have an effect of dilution of the total REEs. This effect is removed after crystallization of plagioclase [25]. The positive correlation between Eu/Eu* and Fe (Figure 10) may suggest an effect of oxydation of Fe associated with an oxidation of Eu. Among the analysed elements, U exhibits a good correlation with Eu/Eu* (Figure 11) which suggests that the same conditions caused both a negative anomaly in Eu and the mobilization of U during metamorphism.

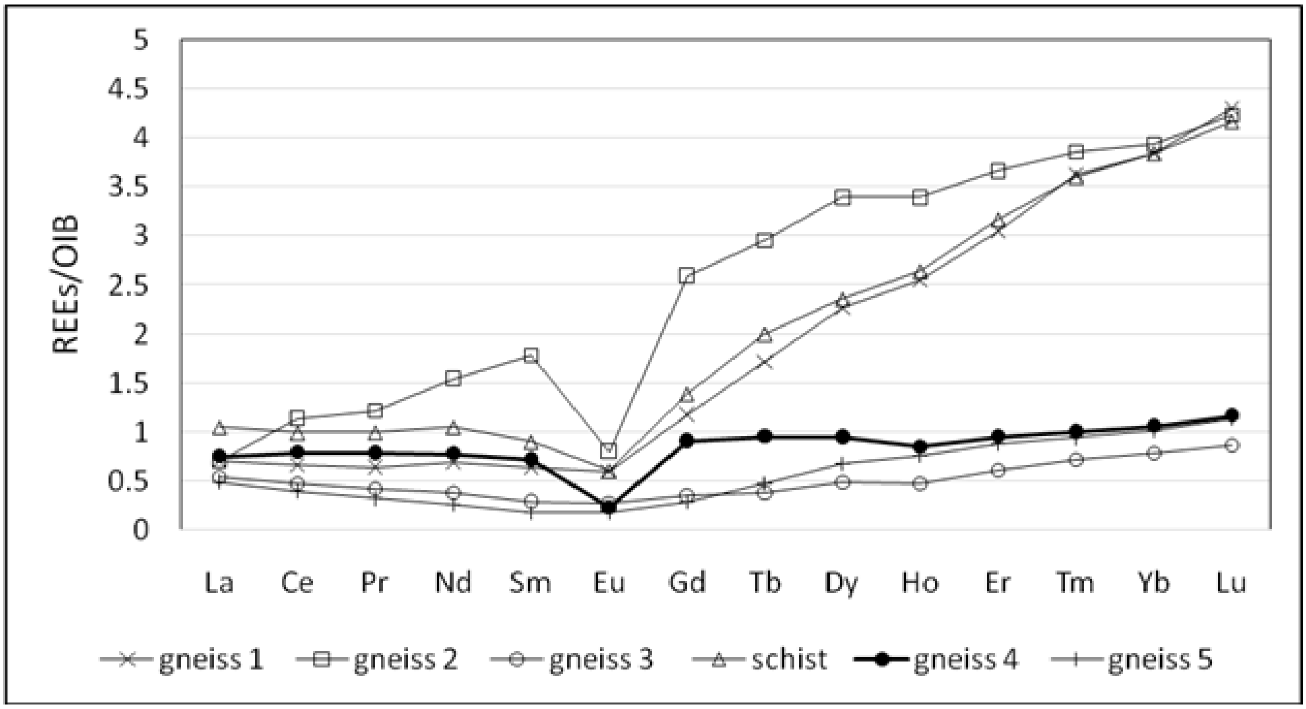

Figure 10: The normalization of concentrations of rare earth elements to those in OIB (Ocean Island Basalt).

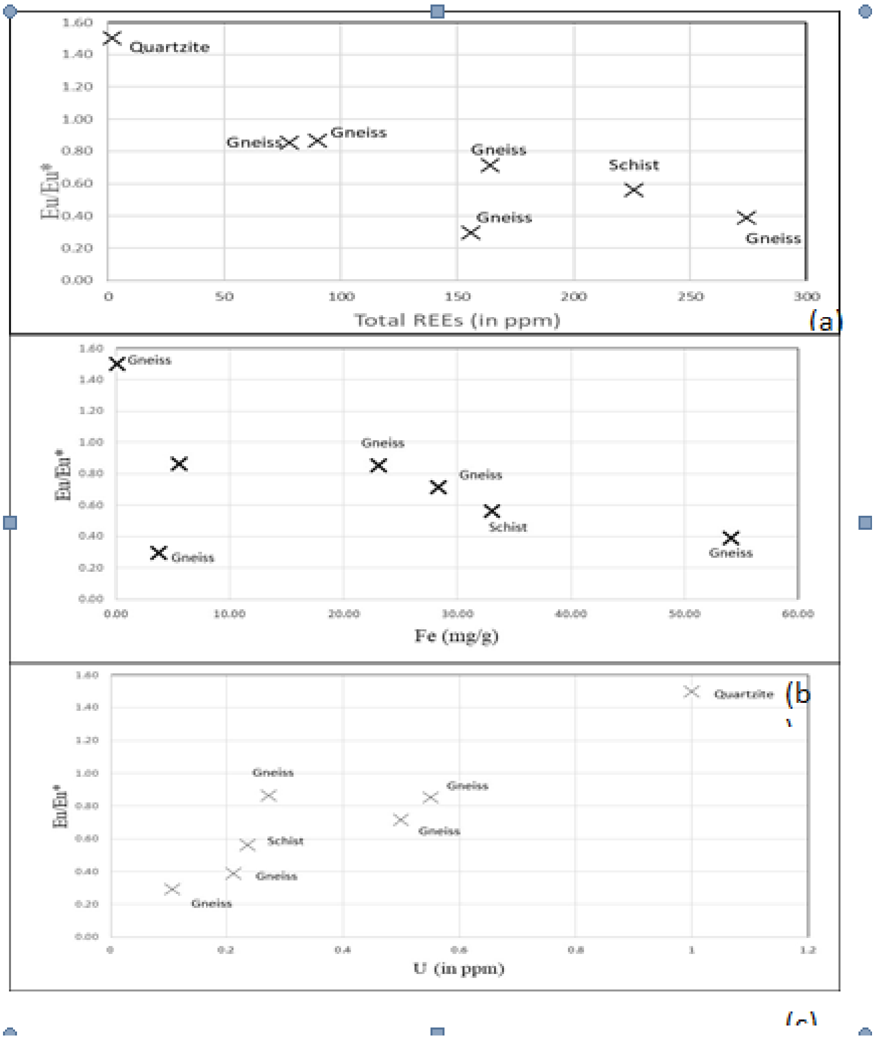

Figure 11: The Eu/Eu* versus a) the total of REEs; b) Fe concentration and c) U concentration.

CONCLUSION

In this study, we examined the abundance of REEs and the ratios among trace elements in metamorphic rocks from Schirmacher Oasis of Antarctica

The petrographic characterization of samples shows that some samples are found to be fresh and other samples show weathering of minerals to sericite.

The major and trace element patterns of the majority of the massive rocks indicate that they might have been derived from different sources.

On the basis of REEs and major elements, the different samples of gneiss and schist are apparented to felsic type.

Based on concentrations and ratios of trace elements Ta, Th and Yb as geochemical tectonic discriminants, three tectonic settings are defined: as

- Ocean ridge granite
- Continental Arcs and
- MORB.

Both samples from schist and gneiss derived from the same source.

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