Mineral chemistry and petrography of granitic rocks related rare earth elements in Uthai Thani area, central Thailand: Implication for REE potential in Thailand

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Abstract

Granitic rock, one of the rare earth elements (REEs) sources, is exposed in several areas in Thailand, including Uthai Thani province, central Thailand. Biotite-muscovite granite can be found in the Uthai Thani area. The biotite-muscovite granites show porphyritic texture with K-feldspar megacryst and foliated texture in some locations, with mineral compositions of quartz, K-feldspar, plagioclase, biotite, and muscovite with accessory minerals of opaque minerals, apatite, zircon, monazite, and ilmenite. This granite can be classified as Ilmenite series or S-type granite. The primary REE minerals associated with this granite are mainly monazite, xenotime, zircon, apatite, and ilmenite. The mineral chemistry indicates that these REE-bearing minerals can be potential LREE (La, Ce, and Nd) sources and some HREE (Y and Dy) sources.

Keywords: Rare Earth Elements, Mineral Chemistry, Petrography, Granite, Thailand

1. Introduction

Rare earth elements (REE) are in increasing demand today as they are used in industries such as clean energy, medical devices, and military defense systems (Dushyantha et al., 2020; Zhou et al., 2017). The most abundant REEs in the earth's crust are Ce, La, Y, and Nd, most of them being light rare earth elements (LREE), including La, Ce, and Nd (Taylor and McLennan, 1995).

Granitic rocks are one of the REE sources. Moreover, the granitic rocks generally occur together with economic mineralization such as Sn, W, Li, and REE (Wu et al., 2017; Fanka and Tadthai, 2023), most commonly in peraluminous S-type granite (Chappell et al., 2012; Chappell and White, 1992; Wu et al., 2017).

In Thailand, granitic rocks can be classified into three belts (Fig. 1a): Eastern Belt Granite (EBG), Central Belt Granite (CBG), and Western Belt Granite (WBG) (Charusiri, 1989; Charusiri et al., 1993; Cobbing et al., 1986; Nakapadungrat and Putthapiban, 1992). Uthai Thani, located in the CBG (Fig. 1a), comprises both S-type and I-type granites (Nakapadungrat, 1991). In Thailand, several areas with REE deposits have been identified, including Kanchanaburi, Ranong, Uthai Thani, Chumphon, Surat Thani, Chiang Rai, Chiang Mai, and Mae Hong Son provinces. These deposits are mostly associated with granitic rocks (Charusiri, 1989; Charusiri et al., 1991; Charusiri et al., 2006; Charusiri et al., 2009; Chualaowanich, 2013; Imai et al., 2013; Ishihara, 1980; Pongsapich et al., 1983; Sanematsu et al., 2015; Sanematsu et al., 2013).

Therefore, the study aims to examine the petrographic character of granitic rocks related to REEs and the mineral chemistry of REE minerals in Uthai Thani, central Thailand, and to understand the REE potential in Thailand.

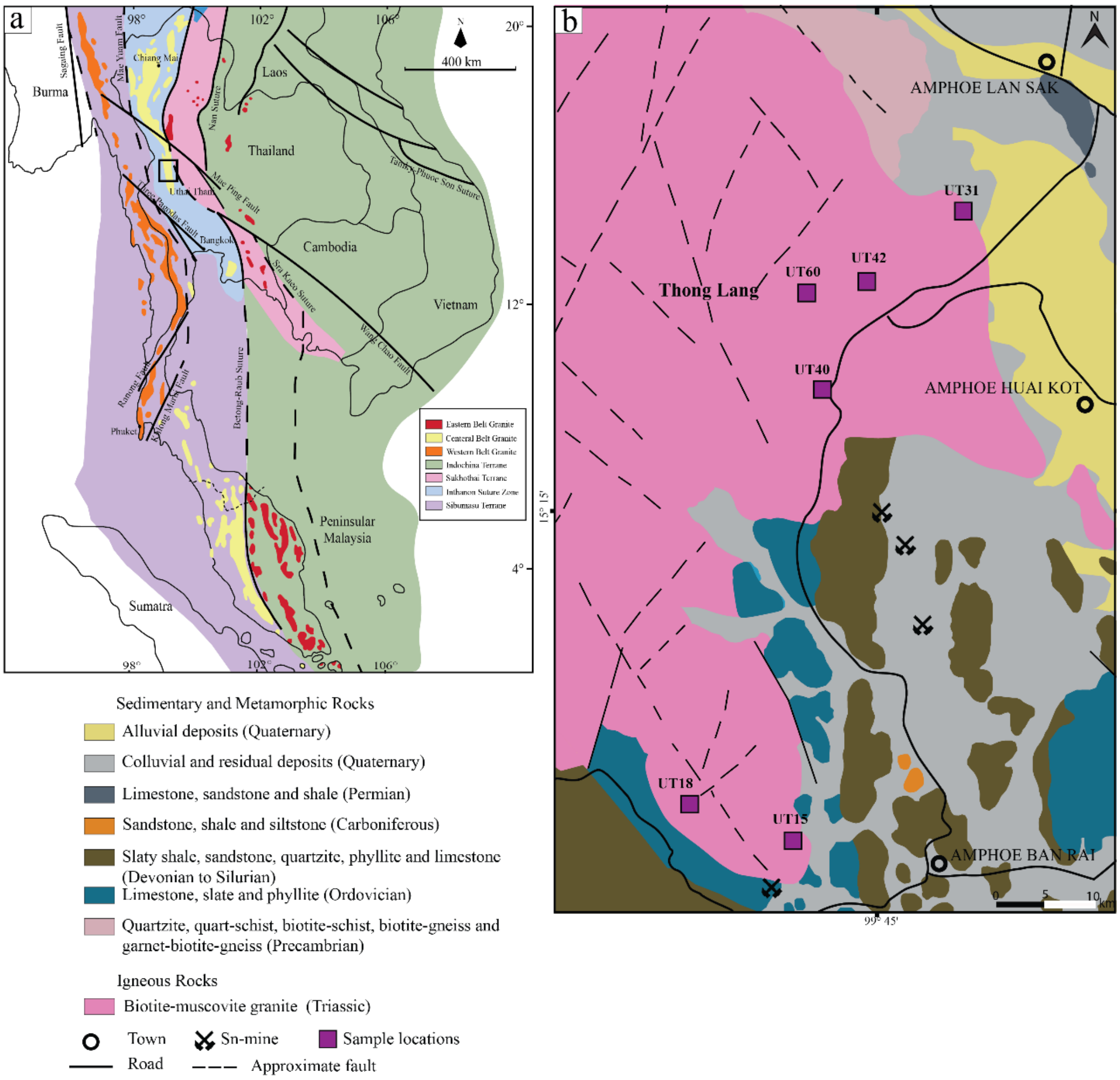


Figure 1. (a) Index map of Thailand shows the distribution of granitic rocks and main granite provinces in Thailand and Southeast Asia (modified after Charusiri et al., 1993; Cobbing, 1992; Hutchison, 2014). (b) The simplified geological map of Uthai Thani, central Thailand (Department of Mineral Resources, 2007) shows the sample location.

2. Geological background

Uthai Thani area, central Thailand (Figure 1a) consists of several rock units, including Precambrian gneiss, Ordovician limestone, Devonian to Silurian low-grade metamorphic rocks, Carboniferous sandstone, Permian limestone, and Triassic granite—overlain by quaternary sediments (Department of Mineral Resources, 2007) (Figure 1b).

The granitic rocks in the study area were defined as the Thong Lang granite that shows massive granitic pluton and exposes in Uthai Thani province characterized by various compositions with the main varieties of biotite–muscovite granite, leucocratic granite, together with aplite and pegmatite veins (Nakapadungrat, 1991). These granitic rocks, located in the Inthanon zone as a part of the CBG of Thailand (Figure 1a), resulted from the collision between the Sibumasu and Indochina terranes during the Triassic (e.g., Charusiri, 2002; Charusiri et al., 1993; Gardiner et al., 2016; Sone and Metcalfe, 2008). In addition, the Sn-W deposits (Figure 1b) (Charusiri et al., 1991; Nakapadungrat, 1992) are associated with these granites. Moreover, these granitic rocks in CBG are mentioned as REE potential sources (Charusiri, 1989; Charusiri et al., 1991; Charusiri et al., 2006; Charusiri et al., 2009; Imai et al., 2013; Ishihara, 1980; Pongsapich et al., 1983; Sanematsu et al., 2015; Sanematsu et al., 2013).

3. Methodology

Six fresh rock samples (UT15, UT18, UT31, UT40, UT42, UT60) of the biotite-muscovite granites were collected from the Uthai Thani area, central Thailand (Figure 1). Additionally, representative in situ weathering biotite–muscovite granites were collected from locations near or identical to those of the fresh samples, using the same sample ID as the fresh samples (Figure 1b). The rock samples were prepared as polished thin sections and examined by a NIKON polarizing microscope at the Department of Geology, Faculty of Science, Chulalongkorn University, Thailand, to observe the petrographic characteristics of the granitic rocks.

The six *in-situ* weathering of the biotite-muscovite granites were collected from the C horizon of the soil profile. The samples were labeled by using the same sample number as the rock samples in the same location. They were processed to separate heavy minerals by using specific gravity, utilizing the differential specific gravity of minerals through water and heavy liquid, followed by mounting in epoxy and polishing. All polished mounts were analyzed using a Micro X-ray Fluorescence (Micro-XRF) spectrometer, model Bruker M4 Tornado at the Institute of Earth Sciences, Academia Sinica, Taiwan, and an Electron Probe Micro Analyzer (EPMA), model JEOL JXA-8100, at the Department of Geology, Faculty of Science, Chulalongkorn University, Thailand. Both methods were used to study the mineral chemistry of REE minerals.

4. Results

4.1 Field occurrence and petrography

The six samples of granitic rocks are classified as biotite-muscovite granite, exhibiting a porphyritic texture with K-feldspar megacrysts and occasional foliation (Figure 2b, c). These rocks are typically observed as high hill massive outcrops in the study area (Figure 2a) and are sometimes cut by pegmatite veins (Figure 2c). The representative samples of in situ weathering biotite-muscovite granite were collected from the B-horizon of the soil profile (Figure 2d).

Petrographically, the biotite-muscovite granites are composed of quartz (20%–30%), K-feldspar (30%–40%), plagioclase (15%–30%), biotite (5%–15%) and muscovite (3%–5%), with minor amounts of muscovite, opaque minerals, apatite, zircon, and monazite (Figure 3a, b). The rock from some locations also presents foliated textures (Figure 3c). In terms of the REE minerals, monazite is mainly found in petrographic observation (Figure 3c, d). Based on the modal QAP classification of the rocks in this study, all samples can be classified as granite (Figure 4).

4.2 REE mineralogy and mineral chemistry

The mineralogy of REE minerals was determined by analyzing heavy minerals separated from the *in-situ* weathering of the biotite-muscovite granites. For the micro XRF analysis, the results show that heavy minerals are monazite, xenotime, and ilmenite (Figure 5), the mineral grains exhibiting a green color that contains high Ti concentrations and lower concentrations of Y, Ce, and Nd indicating ilmenite. The mineral grains with high concentrations of Ce and Nd, represented in orange color, indicate the characteristics of monazite. Meanwhile, mineral grains in purple color exhibiting high concentrations of Y are identified as xenotime. UT40 and UT60 samples show highly abundant monazite (63%–69%) compared with xenotime (15%–24%) and ilmenite (7%–22%) (Figure 5a, d, f). UT15 and UT42 samples show comparable amounts of monazite (39%–51%) and ilmenite (40%–54%), which are higher than xenotime (7%–9%) (Fig. 5e). However, UT18 and UT31 samples show the dominant presence of ilmenite (89%–98%) compared with monazite (2%–10%) and xenotime (1%) (Figure 5b, c). The summarized proportion of REE minerals from the samples is reported in Table 1.

For the mineral chemistry of REE-bearing minerals, the combination methods of Micro XRF analysis for monazite and xenotime and EPMA analysis for ilmenite (Table 2) were used for this study. The high REE concentration minerals include monazite (6–19 wt.% P_2O_5, 4–11 wt.% La_2O_3, 10–24 wt.% Ce_2O_3, 4–8 wt.% Nd_2O_3) and xenotime (13–22 wt.% P_2O_5, 26–35 wt.% Y_2O_3, 2–3 wt.% Dy_2O_3). In addition, some accessory minerals, including ilmenite (Table 2) zircon, also contain REEs with low REE concentration (<1 wt.%).

Figure 2. Representative outcrop exposures of the biotite-muscovite granite (a) common outcrop exposure of biotite-muscovite granite**,** (b) porphyry biotite-muscovite granite with K-feldspar megacrysts in the outcrop, (c) pegmatite dikes in the (d) soil profile of the in-situ weathering biotite-muscovite granite.

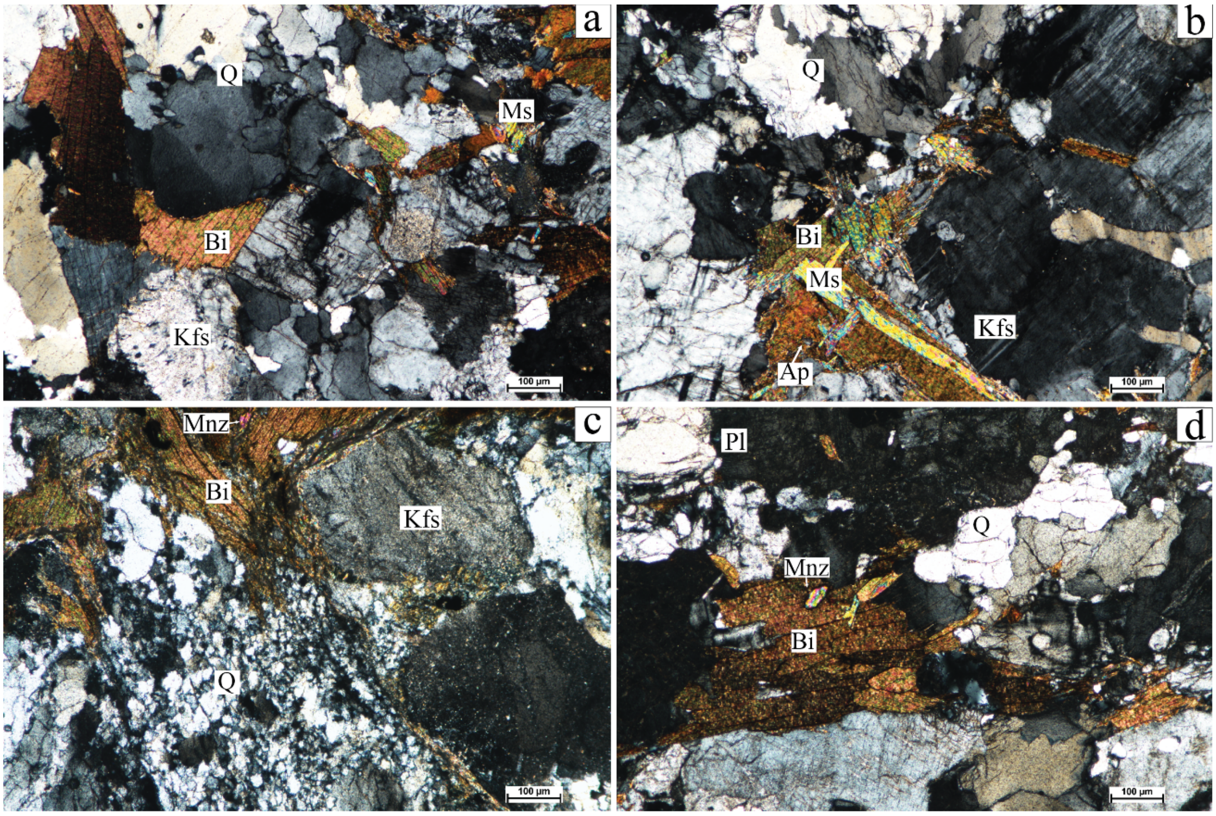


Figure 3 Photomicrograph of biotite-muscovite granite in Uthi Thani, central Thailand, showing (a, b) the typical mineral assemblages and (c, d) primary REE mineral (monazite). Abbreviations: Pl = plagioclase; Kfs = K-feldspar; Q = quartz; Bi = biotite; Ms = muscovite; Ap = apatite; Mnz = monazite.

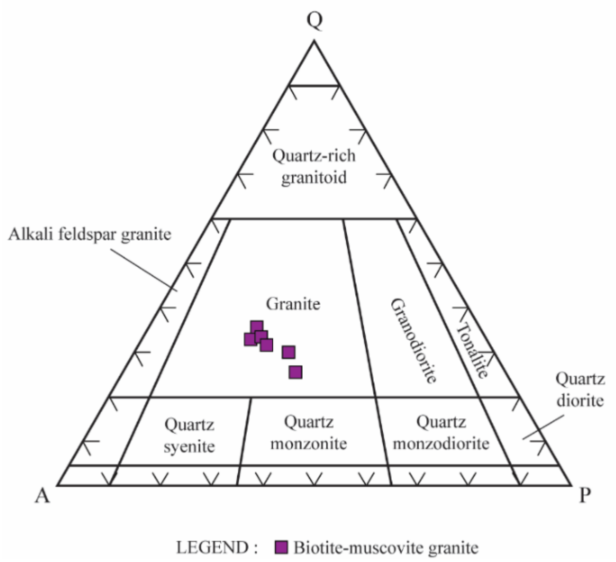


Figure 4. QAP plot showing the relative proportions of quartz (Q), alkali feldspar (A), and plagioclase (P) for the biotite-muscovite granites in Uthai Thani, central Thailand (Streckeisen, 1976)

Table1. Summarized proportion of REE mineral in *situ* weathering granite in Uthai Thani, central Thailand.

Sample	REE minerals		
	Monazite	Xenotime	Ilmenite
UT15	**	*	**
UT18	*	-	***
UT31	**	*	***
UT40	***	**	*
UT42	***	*	***
UT60	***	**	**

*** High abundance
**
* Low abundance

5. Discussion and conclusion

The granitic rock in the Uthai Thani area, central Thailand, characterized by porphyritic texture with K-feldspar megacrysts, is comparable with the typical characteristics of the Central Belt Granites (CBG) in Thailand (Charusiri et al., 1993; Cobbing, 1992; Cobbing et al., 1986). The presence of ilmenite and muscovite in the biotite-muscovite granite probably indicates S-type granites (Chappell, 1974; Cobbing, 1992; Cobbing, 2008; Pitcher, 1983) and Ilmenite Series (Ishihara, 1997) that supported by the numerous research in the CBG (Qian et al., 2017; Tukpho and Fanka, 2021; Wang et al., 2016).

S-type granite typically contains accessory minerals, including phosphate minerals such as apatite, monazite, and xenotime, together with ilmenite. This REE-bearing mineral assemblage is commonly found in S-type granite (Fu et al., 2019; Ishihara, 1997; Zhao et al., 2022; Zhou et al., 2006). In this study area, the dominant REE minerals, including monazite, xenotime, apatite zircon, and ilmenite, indicate the primary REE sources in this area that are constants with the REE province defined by Charusiri et al. (2006, 2009) and supported by total REE concentration in soil reported by Chualaowanich et al. (2018). The monazite compositions containing high Ce, La, and Nd indicate the potential primary LREE sources in the study area. Zircon, apatite, and ilmenite contain lower REE contents. Xenotime, which dominates in Y and Dy concentrations, is less abundant in this study area but could be a primary source of heavy rare earth elements (HREE). The combined proportions and compositions of the REE minerals suggest that the biotite-muscovite granite in the study area can be the LREE potential area (Figure 6), are similar like similar to ion-adsorption deposits of LREE-rich associated with ilmenite-series granites in Southern Thailand (Sanematsu et al., 2013). Additionally, REE survey data in Thailand indicate that the most common productive REE minerals in the country are monazite and xenotime (Charusiri et al., 1991; Chualaowanich, 2013). Additionally, the distribution of tin deposits in the study area can indicate the granitic close relationship between the granitic rocks and Sn-W mineralization that are the typical characteristics of the CBG (Yokart et al., 2003; Jiang et al., 2021) (Figure 1b). The granitic rocks related to Sn-W mineralization could be related to the REE mineralization in the CBG of Thailand, which is consistent with the highly fractionated granite (Charusiri et al., 2006; Li et al., 2019; Mao et al., 2020) and pegmatites (Cerny, 1991a, 1991b).

Table 2. Representative EPMA analyses of REE minerals in the *in-situ* weathering of biotite-muscovite granite in the Uthai Thani, central Thailand.

Analysis No.	UT18-un4	UT31-un8
Mineral name	Ilmenite	Ilmenite
TiO_2	52.21	47.97
ThO_2	0.042	n.d.
MnO	1.49	4.63
FeO_t	46.02	46.37
Y_2O_3	0.04	n.d.
Ce_2O_3	n.d.	0.04
Nd_2O_3	n.d.	0.02
Dy_2O_3	0.26	0.33
Total	100.07	99.38
LREE	0	0.06
HREE	0.30	0.33

n.d.: not detected

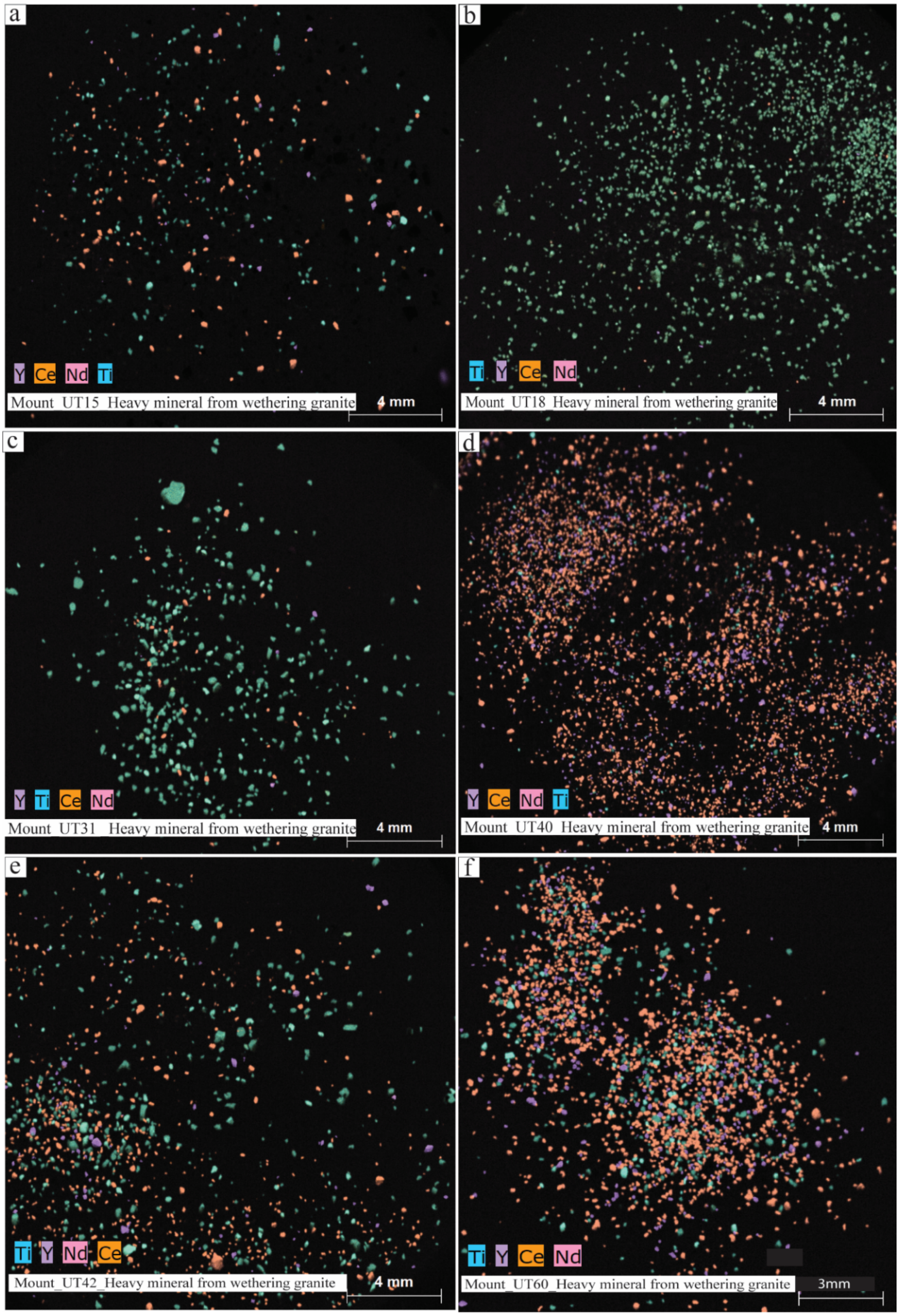
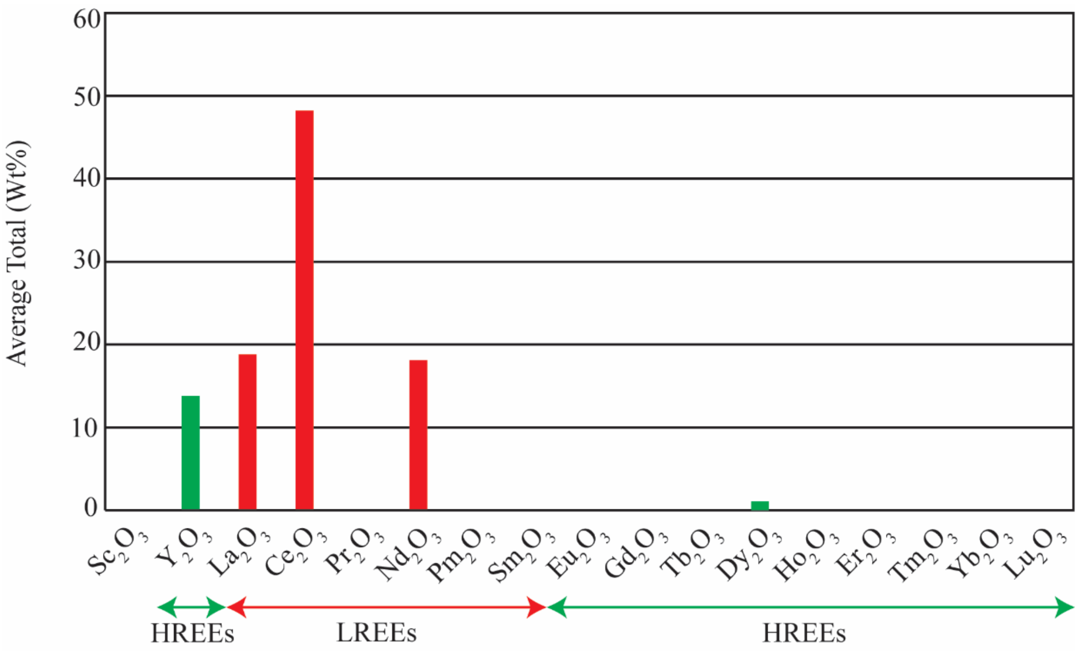


Figure 5. Micro XRF results of heavy minerals from the *in-situ* weathering granitic rocks in Uthai Thani, central Thailand. (a) Sample UT15, (b) Sample UT18, (c) Sample UT31, (d) Sample UT40, (e) Sample UT42, and (f) Sample UT60.



Figures 6. Average REE concentration in in-situ weathering granite in Uthai Thani, central Thailand.

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