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Article

Enrichment of rare earth elements (REE) in granitic rocks and their weathered crusts in central and southern Laos

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Abstract: This paper reports geochemical characteristics of granitic rocks and enrichment of rare earth elements (REE) in their weathered crusts in central and southern Laos in order to assess a REE resource potential of ion-adsorption type mineralization. The granitic rocks in the studied area consist mainly of biotite ± hornblende granodiorite and biotite granite with low to moderate total REE contents with the range of 36 - 339 ppm. The granitic rocks are enriched in light REE (LREE) with the depletion of heavy REE (HREE) compared with HREE-enriched granites in southern China and southwest Japan. This difference in the enrichment of HREE is probably derived from poor differentiation of magma for granite. Weathered crusts of the granitic rocks are generally well developed and rich in kaolin and illite. The weathered crusts can be divided into the A, B and C horizons from top to bottom and the B horizon is enriched in REE relative to the parent rocks whereas the A and C horizons are generally depleted or less enriched in REE. Weathered crusts with relatively high REE contents are locally identified in the Attapu and Xaisomboun districts. Geochemical data and results of sequential leaching suggest that the enrichment of REE is attributed to the occurrence of ion-exchangeable clay minerals and REE phosphates in the weathered crusts and that HREE are selectively adsorbed on the clay minerals than LREE by weathering.

Keywords: Rare earth elements (REE), granitic rocks, weathered crust, ion-adsorption type mineralization, Laos

1. Introduction

In recent years, a relationship between demand and supply of rare earth elements (REE) resources has been becoming tight in the world market (Roskill, 2007). Especially, prices of heavy rare earth elements (HREE: Gd - Lu) have been dramatically increased compared with those of light rare earth elements (LREE: La - Eu) (Industrial Rare Metals, 2008). This problem results from not only the increase in the demand of HREE but also the limited supply of HREE from ore deposits. In the present day, HREE resources are produced mostly from ion-adsorption type REE deposits in the Longnan district, southern China. The ion-adsorption type deposits are formed by chemical weathering of granitic rocks and subsequent chemical adsorption of REE on kaolinite and halloysite (Yang et al., 1981; Ishihara and Sato, 1982; Huang et al, 1989; Wu et al., 1990; Murakami and Ishihara, 2008). These deposits are characterized by one to five times condensation of REE in weathered crusts relative to the parent rocks and easy recovery of REE from the clayish ores by weak acids (Wu et al., 1990; Ban and Zhao, 2008). Average REE contents of the ion-adsorption ores range from 300 to 2000 ppm approximately and vary depending on the parent rocks (Wu et al., 1996; Bao and Zhao, 2008; Murakami and Ishihara, 2008). Bao and Zhao (2008) showed that the parent rocks of the weathered crusts are I-type and S-type granitic rocks with some A-type granitic rocks, and are classified mainly into ilmenite-series. Most of these granitic rocks are characterized by biotite ± muscovite mineral assemblages with K-feldspar phenocrysts (Huang et al., 1989). In southwest Japan, fractionated ilmenite-series granite is rich in REE, Sn and W, and the enrichment of HREE is remarkable compared with LREE (Ishihara

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and Murakami, 2006). Highly fractionated ilmenite-series granite is generally related to Sn mineralization (e.g., Lehmann and Mahawat, 1989; Cerny et al., 2005). Thus, it is important to investigate the granite exposed in tropical or subtropical regions, where chemical weathering actively occurs, in order to discover promising ion-adsorption type REE mineralization.

In Vientiane, Lao Peoples Democratic Republic (Laos), the annual average temperature is 27 °C and the annual precipitation is about 1834 mm (FAO, 2003). This warm and moist climate accelerates chemical weathering of granitic rocks in Laos. Ilmenite-series granitic rocks associated with Sn deposits are distributed extensively in central and southern Laos (DGM, 1991). This study explores a possibility of ion-adsorption type REE mineralization and the potential of REE resources in central and southern Laos by investigating REE contents of granitic rocks and weathered crusts on them.

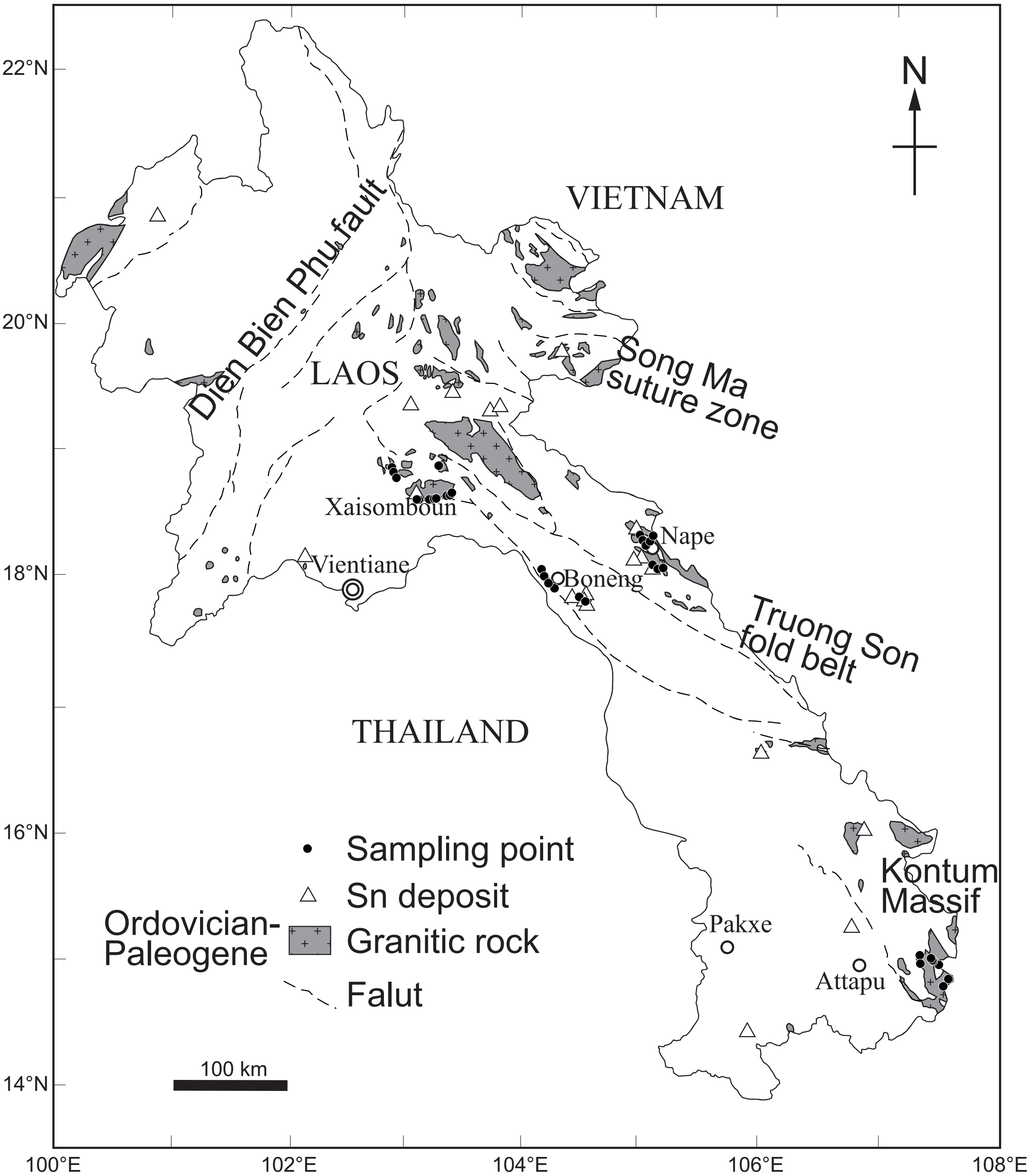

Fig. 1 Simplified geologic map showing the distribution of granitic rocks and sampling points in Laos. Modified from ESCAP (1990), DGM (1991) and Osanai et al. (2008).

2. Geological Settings

The geology of Laos is basically divided into the northwestern Shan Thai block and southeastern Indoshina craton by the NE-SW trending Dien Bien Phu Fault (Fig. 1; ESCAP, 1990; DGM, 2000). The Shan Thai block is believed to have detached from the Indochina craton during 240 - 220Ma (Ferrari et al., 2008). The Indochina craton consists of several zones of basement metamorphic rocks such as the Redriver zone, Song Ma zone, Truong Son belt and Kontum Massif, which are cut by NW-SE trending shear zones (e.g., Hutchison, 1989; ESCAP, 1990; Osanai et al., 2008). Subduction-related volcanic activities are considered to have occurred from Permian to Triassic terranes in northern Laos. The volcanic rocks are composed of andesite and dacite with a small amount of basalt. The intrusive rocks widely distributed in Laos are mostly granodiorite and granite and they are believed to be Devonian to Jurassic in age, although few age data have been reported (ESCAP, 1990; Vilayhack et al., 2008). The ilmenite-series granitic rocks in central and southern Laos are commonly associated with Sn ± W mineralization, which occurs as lateritic placer Sn deposits such as the Boneng and Nam Pathene deposits (DGM, 1991). In the southeasternmost of Laos, there are few Sn deposits within granitic rocks in the Kontum Massif, whereas Cu ± Au mineralization is recognized (Vilayhack et al., 2008). Owada et al. (2007) classified the granitic rocks in the Kontum Massif of Vietnam into garnet-bearing granite and orthopyroxene-bearing granite and argued that they are derived from the partial melting of pelitic gneisses and garnet-bearing mafic granulites, respectively.

2. Sample description

2.1 Description of the granitic rocks

The studied areas in the Truong Son fold belt and Kontum Massif in central and southern Laos are classified into the Attapu, Boneng, Nape and Xaisomboun districts (Fig. 1), and totally 29 least weathered granitic rock samples were collected. Granitic rocks in the east of Attapu are collected from the Xe Xou North and Xe Xou East Plutons (Vilayhack et al., 2008) in the Kontum Massif. The Xe Xou North Granodiorites are foliated and mylonitic in the eastern margin of the pluton, and the Xe Xou East Granites represent locally melanoclatic and heterogeneous facies (Vilayhack et al., 2008). The granitic rocks of the Boneng district were probably collected from Say Phou Ngou Pluton, which is situated in northwest of Thakhek (DGM, 2000). This pluton is classified into the Triassic porphyry accompanied with volcanic rocks and biotite granite with aplitic dykes (DGM, 1991). The granitic rocks of the Nape district is collected from the Nape Pluton (DGM, 2000), located near the border between Laos and Vietnam. They are accompanied with some aplitic and pegmatitic dykes and Au-Sn-W mineralization (DGM, 2000). In the Xaisomboun district, the samples were taken from different plutons in the northeast of Vientiane. Collected granitic rocks are mostly calcalkaline biotite ± hornblende granodiorite, biotite granite and biotite granite porphyry (Table 1; Fig. 2A). They are composed of plagioclase, K-feldspar, quartz, biotite and hornblende with small amounts of accessory minerals. Opaque minerals are mainly ilmenite, hematite and pyrite whereas magnetite-series granitic rocks contain magnetite. Plagioclase and

Table 1 Petrography of representative granitic rock sample.

Sample #	District	Texture	Deformation	Grain size (mm)	Kfs megacryst	Qtz	Plg	Kfs	Bt	Hbl	Ms	Tur	Apt	Zir	Mnz	Xen	Aln	Tit	Alm	Thr
P712	Attapue	Equig.		0.6-4		+	+	+	+				+	+						
P725	Attapue	Equig.		0.8-2.6	+	+	+	+	+	+			+	+				+		
P726	Attapue	Equig.		0.5-3		+	+	+	+				+	+			+	+		+
P793	Attapue	Equig.	Foliated	1-3	+	+	+	+	+	+			+	+			+	+		+
62701	Boneng	Equig.		0.2-2		+	+	+	+				+	+	+	+				
62702	Boneng	Porph.		0.05-0.25	+	+	+	+	+				+	+	+	+	+			
62802	Boneng	Equig.		1-3		+	+	+	+				+	+					+	
62809	Boneng	Porph.		0.1-0.25	+	+	+	+	+				+	+			+		+	+
62814	Boneng	Equig.		0.3-2.5		+	+	+	+			+	+	+	+				+	
62901	Nape	Equig.		1-5		+	+	+	+				+	+	+	+	+			
62903	Nape	Equig.		0.8-5		+	+	+	+				+	+	+					
63001	Nape	Equig.		1-4		+	+	+	+		+?		+	+	+					
63002	Nape	Equig.		1-3		+	+	+	+				+	+	+	+				
63005	Nape	Equig.		1-4		+	+	+	+				+	+	+					
70101	Nape	Equig.		1-4	+	+	+	+	+				+	+	+	+				
70102	Nape	Equig.		1-3	+	+	+	+	+				+	+	+					
70105	Nape	Porph.		0.2-0.5	+	+	+		+				+	+	+		+			
70107	Nape	Equig.		0.5-2	+	+	+	+	+				+	+	+					
70108	Nape	Equig.		1-3		+	+	+	+				+	+	+	+				
70109	Nape	Equig.		1.8-3.5	+	+	+	+	+				+	+	+	+				
70114	Nape	Equig.	Foliated	2-3.5	+	+	+	+	+	+			+	+	+					
70303	Xaisomboun	Equig.		1-3		+	+	+	+	+			+	+						+
70306	Xaisomboun	Equig.		0.6-4.5		+	+	+	+	+			+	+						+
70402	Xaisomboun	Porph.		0.005-0.04	+	+	+	+	+				+							

Equig. = Equigranular, Porph. = Porphyritic
Qtz = Quartz, Plg = Plagioclase, Kfs = K-feldspar, Bt = Biotite, Hbl = Hornblende, Ms = Muscovite, Tur = Tourmaline,
Apt = Apatite, Zir = Zircon, Mnz = Monazite, Xen=Xenotime, Aln = Allanite, Tit = Titanite, Alm = Almandine, Thr=Thorite

biotite are partly illitized and chloritized, respectively by alteration in most samples. Biotite and hornblende commonly contain apatite and zircon within the crystals, exhibiting metamict by radioactivity. Recognized REE minerals and REE-bearing minerals are apatite, zircon, monazite, xenotime, allanite, titanite and almandine (Table 1; Fig. 3).

2.1.1 Attapu district

The granitic rock samples in Attapu are medium-grained biotite granodiorite and hornblende-biotite granodiorite with K-feldspar phenocrysts. These granitic rocks are mostly metaluminous (alumina saturation index < 1.05; samples P725, P726 and P793) I-type series or peraluminous (sample P712) S-type granodiorite. Granodiorite of sample P793 is weakly foliated whereas the others are not deformed. K-feldspar phenocryst is common and is less than 20 mm in size. The occurrence of epidote is commonly recognized due to the saussuritization of plagioclase.

2.1.2 Boneng district

The granitic rocks in Boneng are fine- to medium grained equigranular in texture accompanied with porphyritic biotite granite and tourmaline-bearing biotite granodiorite. All of these granitic rocks are classified into peralminous S-type ilmenite-series. Plagioclase and biotite are commonly illitized and chloritized. Samples 62801, 62802 and 62809 are relatively weathered and contain pinkish to reddish K-feldspar. Sample 62818 is a tourmaline granite consisting of quartz and tourmaline. Sample 62815 is a greizen, which formed by hydrothermal activity associated with granitic magma, and consists of quartz and muscovite. DGM (2000) reported that REE contents of two granite samples from the Say Phou Ngou Pluton and Phou Thuon Pluton, located in the northwest of the Boneng, are 271 and 350 ppm, respectively.

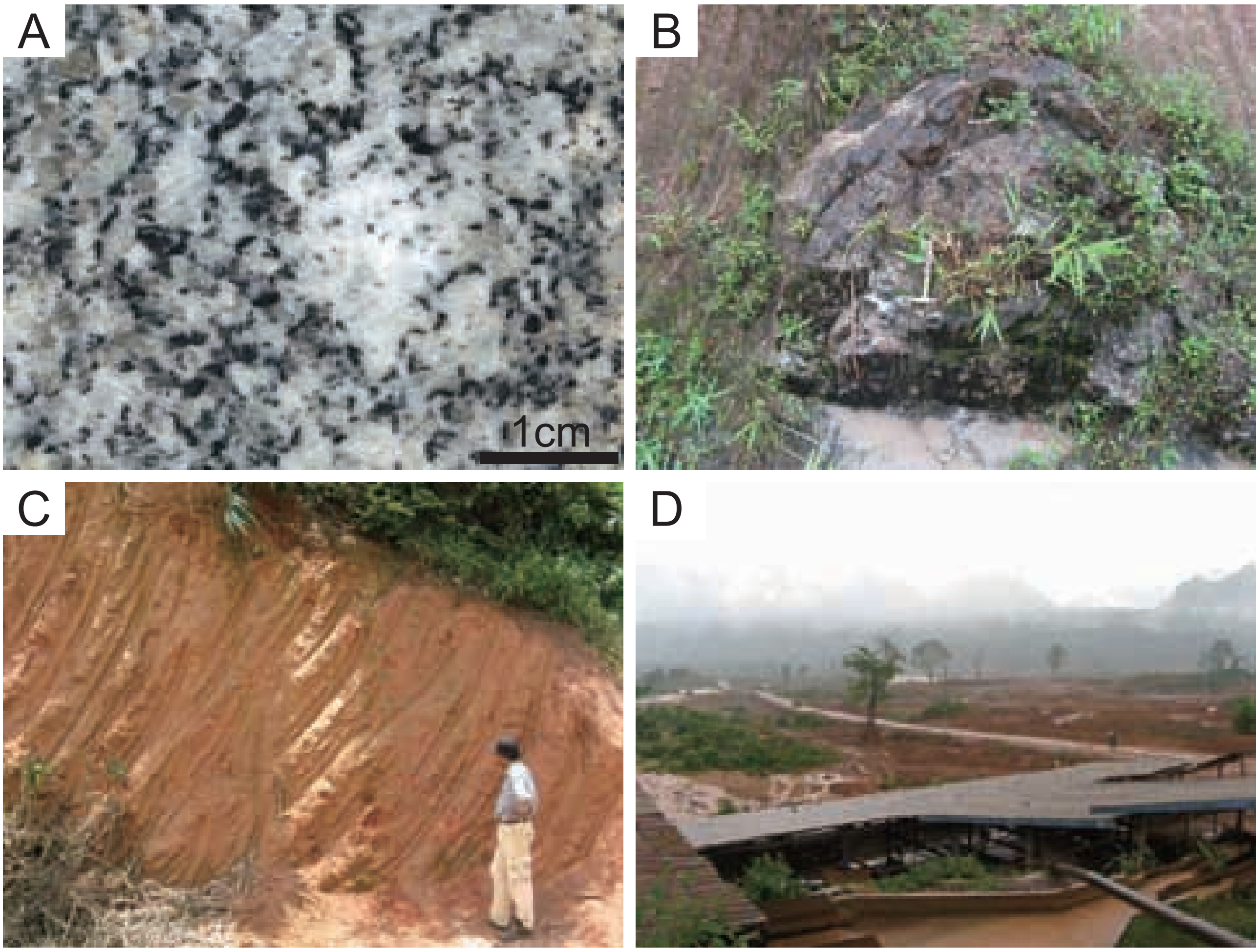

Fig. 2 Photographs of the studied granitic rocks and weathered crusts. (A) Representative medium-grained biotite granodiorite characterized by large feldspar phenocrysts (sample 62814). (B) Granodiorite showing onion structure by weathering within the weathered crust of the C horizon (70101 and 70101C). (C) Weathered crust of a granitic rock which does not crop out on the surface (70307A, B1, B2 and C). (D) Sn bearing sediments derived from granitic rocks and a processing plant in the Boneng Sn mine (P797OR1, P797OR2, P797CN1 and P797CN2).

2.1.3 Nape district

The granitic rocks in the Nape are S-type ilmenite-series medium- to coarse-grained biotite granodiorite and granite, which are characterized by large K-feldspar phenocrysts with the range of 5 - 40 mm in size. Foliation within the granitic rocks is not common except for the sample 70114 which is weakly foliated. The occurrence of secondary muscovite by alteration can be recognized within biotite. Primary muscovite appears to be scarce but only the sample 63002 may be muscovite-biotite granite. Veinlets of illite and muscovite by alteration are also observed (sample 70101). DGM (2000) reported that REE contents of granite samples are 164 and 166 ppm in this district.

2.1.4 Xaisomboun district

Granitic rocks consist of fine- to medium-grained biotite-hornblende granodiorite and granite porphyry in the Xaisomboun district. They are classified into either I-type ilmenite-series (samples 70304-70306) or I-type magnetite-series (samples 70303 and 70402). No foliation is recognized in these samples. K-feldspar is generally microcline and less altered whereas plagioclase, biotite and hornblende are commonly altered. The occurrence of epidote by alteration is recognized within plagioclase and hornblende.

2.2 Description of the weathered rock samples

Totally 62 samples were collected from weathered crusts of the granitic rocks. The profile of the weathered crusts can be divided into A, B and C horizons from upper part to lower part after the definition by Wu et al. (1990). The A horizon, dark brown to reddish dark brown soil, has the thickness ranging from 5 to 50 cm. It is enriched in organic matter and clay minerals, and rock-forming minerals are not recognized except for quartz due to intense weathering. The B horizon is khaki, brown or reddish brown in color and shows no granitic texture in appearance (Fig. 2C). Plagioclase and biotite are scarcely present but K-feldspar can be

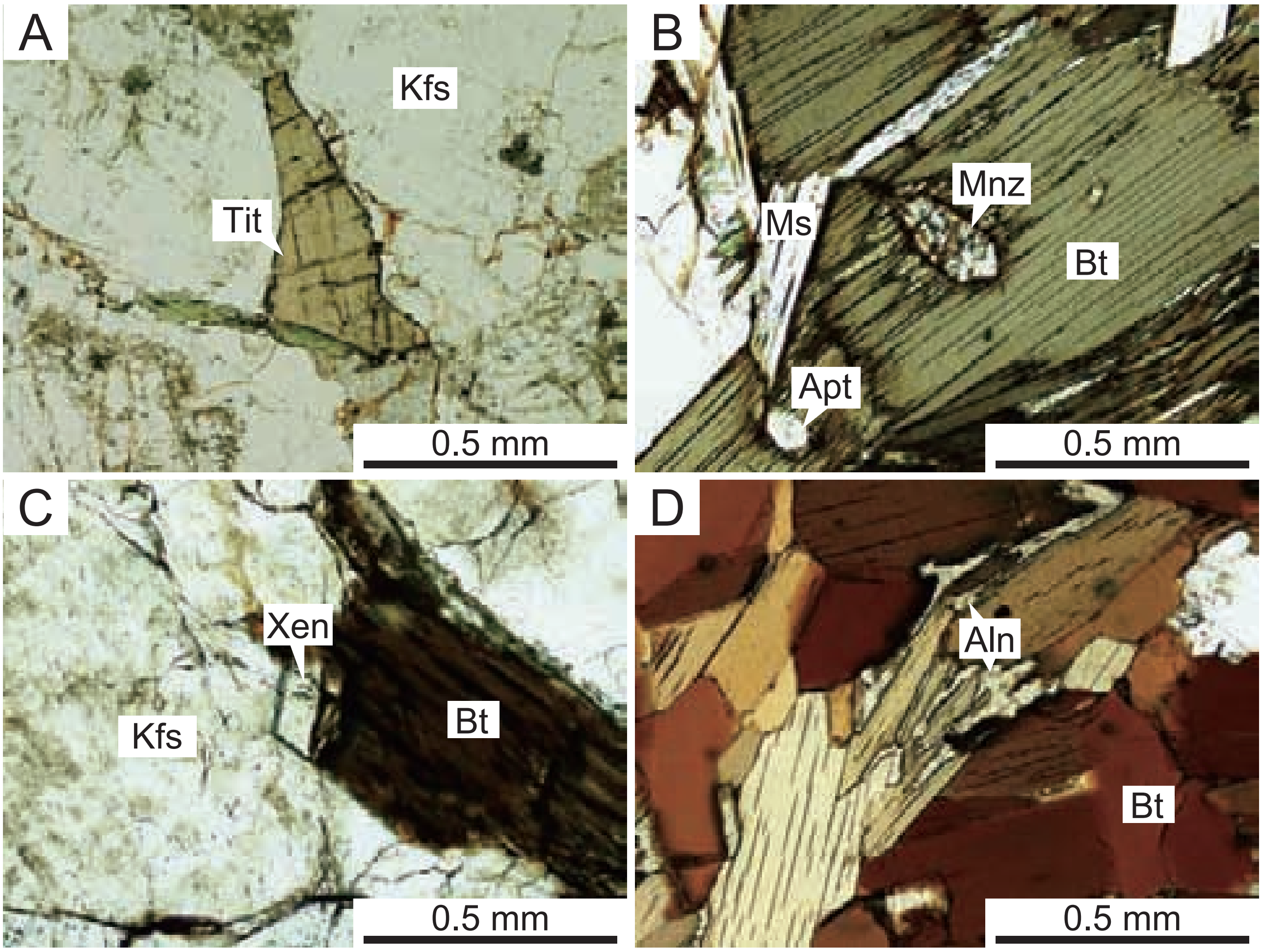

Fig. 3 Photomicrographs showing the occurrence of REE-bearing and REE minerals (open nicol). (A) Titanite in K-feldspar in the sample 62903. (B) Monazite and apatite in biotite (C) and xenotime with biotite in the sample 62901. (D) Anhedral-shaped allanite within biotite in the sample 70105. Abbreviations: Tit = titanite, Mnz = monazite, Apt = apatite, Xen = xenotime, Aln = allanite, Kfs = K-feldspar, Ms = muscovite, Bt = biotite.

identified. This horizon is enriched in clay minerals with less organic matter. In some weathered crusts, the B horizon is divided into B1 and B2 horizons from top to bottom. The C horizon is a slightly fresh but fragile weathered crust exhibiting gray, khaki or brown color. Granitic texture and rock-forming minerals are readily recognized although they are apparently altered. The C horizon gradually changes to the B horizon and the boundary is generally unclear. Although it is hard to identify the fresh parent rocks of weathered crusts, most samples from weathered crusts are derived from biotite granite and granodiorite, and some others (70308B, 70308C, 70310B and 70310C) appears to be derived from hornblende-biotite granodiorite. The thickness of weathered crust consisting of the A, B and C horizons is variable because some weathered crusts were thinned or removed by erosion. It is roughly estimated to be 10 m on average and weathered crust in the Nape district is most developed among the surveyed districts. Weathered crust contains dominantly kaolin (kaolinite ± halloysite), and subordinate illite (mainly -2M) and gibbsite as weathering products. In the Boneng district, gibbsite is more dominant than kaolin and illite. Hematite and goethite are common in reddish colored weathered crusts. Small amounts of smectite and chlorite are recognized in some samples, but no interstratified clay mineral is detected by X-ray diffractometry. The occurrence of vermiculite and zeolite is very rare. Samples 70307B2 and C contain REE phosphates such as monazite and rhabdophane which occur as dirty and anhedral shapes within feldspars (Fig. 4).

Eight kaolin-rich samples were collected in the Attapu and Nape districts. Samples P719CL1, P719CL2, P719CL3 and P788CL are considered to be derived from sedimentary rocks rich in clay minerals. Whitish color of samples P719CL1 and P719CL2 suggest that they underwent hydrothermal alteration and these samples consist of quartz, kaolin, illite and gibbsite. Other two samples (P719CL3 and P788CL) consist of quartz, feldspars, kaolin and illite. Samples 62804CL and 62806CL in the Boneng district are obtained from kaolin-rich veinlets hosted by granitic rocks of the sample 62805 and 62807, respectively. They are composed of quartz, kaolin and gibbsite with a small amount of illite. Samples P798CL and P799CL are massive and hard lateriteic rocks consisting of quartz, illite, kaolin and goethite.

Ten samples were collected from sediments in the Boneng and Nape districts. The sediment samples were derived from sandstone, mica-schist and probably the mixture of sedimentary rocks and reworked granitic

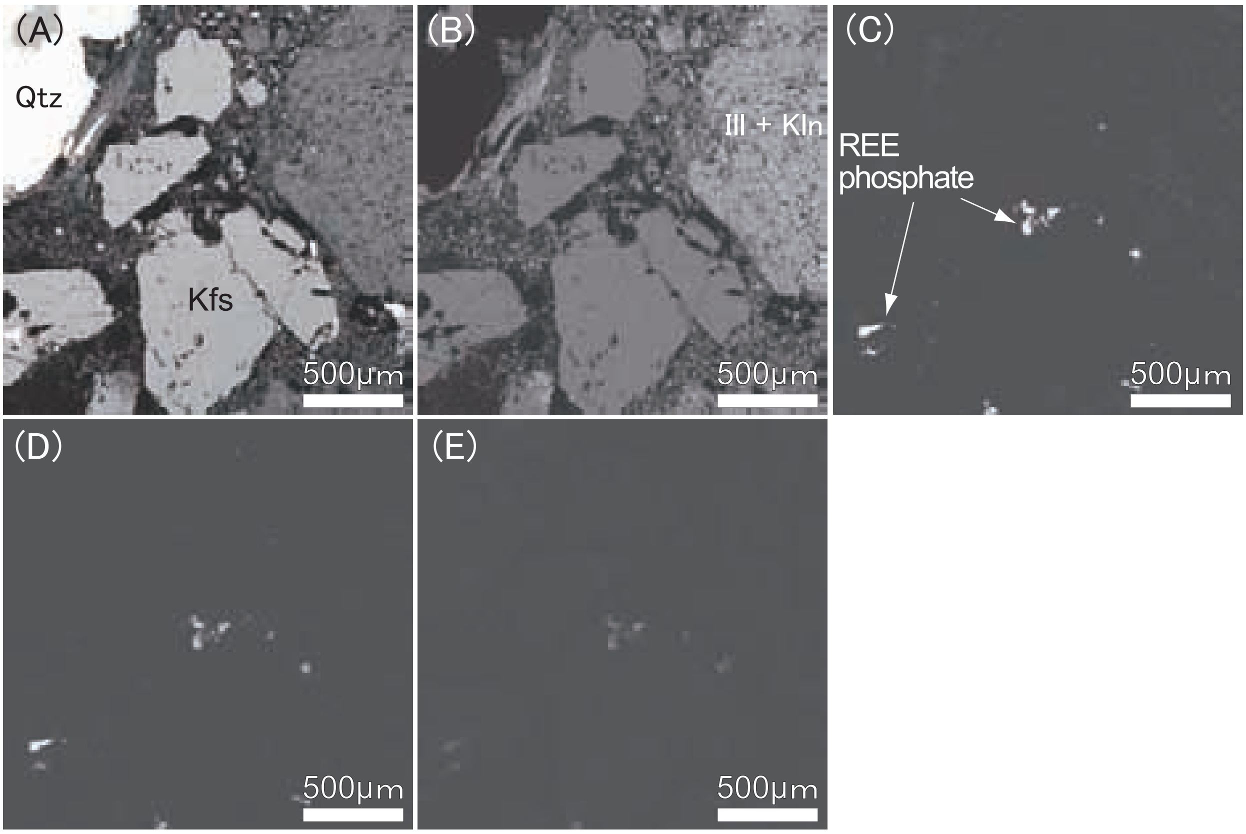

Fig. 4 Elemental mapping images of (A) Si, (B) Al, (C) P, (D) Ce and (E) Y in the sample 70307C determined by electron probe micro analyzer (EPMA). Abbreviations: Qtz = quartz, Kfs = K-feldspar, Ill = illite, Kln = kaolinite.

rocks. They consist of quartz, kaolin, illite and gibbsite but are less abundant in clay minerals compared with the kaolin-rich samples.

Sn-mineralized samples were collected in the Boneng Sn deposit (Fig. 4D). Samples P797OR1 and P797OR2 are Sn ore samples are taken from lateritic sediments which contain quartz, kaolin, illite and cassiterite. The other two samples (P797CN1 and P797CN2) are Sn concentrates after the mineral processing, consisting of quartz, goethite, zircon, cassiterite and xenotime.

3. Analytical method

All the rock samples were dried at room temperature and collected by quartering. The samples were crushed by a jaw crusher or iron mortar and were ground by a mill. Major and trace elements including REE were analyzed with X-ray fluorescence analyzer (XRF) and inductively coupled plasma mass spectrometry (ICP-MS) of a Perkin Elmer SCIEX ELAN 6000 or 6100 at Activation Laboratories Ltd., Canada. Solution of rock samples for ICP-MS analyses was made by acid digestion of fused glass bead using lithium metaborate and tetraborate as flux. The presence of clay minerals was determined by X-ray diffractionmeter (XRD). An experiment of sequential leaching was conducted for the selected weathered rock samples with high REE contents. The sequential leaching was composed of 6 steps: 1) 1 M sodium acetate for 1 hour, 2) 0.1 M sodium pyrophosphate for 1 hour, 3) 1.24 M hydroxylamine at 30 °C for 2 hours, 4) hydroxylamine at 60 °C for 2 hours, 5) aqua regia digestion for 2 hours and 6) four acids digestion by hydrofluoric acid, nitric acid, perchloric acid and hydrochloric acid for 19 hours. Dominantly ion-exchanged or dissolved materials in the weathered rock samples at each step are 1) ion-exchangeable clay minerals, 2) organic materials, 3) amorphous Fe oxides and crystalline Mn oxides, 4) Fe and Mn oxides, 5) clay minerals and phosphates and 6) silicates and some residual materials, respectively.

4. Results

The results of major and trace elements analyses are described in Appendix 1. Chondrite-normalized REE patterns (Sun and McDonough, 1989) of each district are illustrated by determining the average values of the granitic parent rocks, weathered crusts (A, B and C horizons), kaolin-rich rock and sediments (Fig. 5). Figure 6 shows the change in ∑REE (total REE content), ∑LREE, ∑HREE, P, Y, Zr, Th and U of any sample relative to the parent rock following the calculation formula by Nesbit (1979):

$$\text{Change (\%)} = ((C_S / Al_2O_3S) / (C_{PR} / Al_2O_{3PR}) - 1) \times 100$$

Where C and Al_2O_3 are concentrations of any element and Al_2O_3, respectively. Subscripts of S and PR indicate of sample and of parent rock, respectively. We selected Al_2O_3 as an immobile element (oxide) in this paper because the immobility of Al_2O_3 within weathered crust of granitic rocks was assessed by Murakami and Ishihara (2006) and the result of this study (Appendix 1).

4.1 Attapu district

Parent granitic rocks in Attapu are enriched in LREE and depleted in HREE with a very weak negative Eu anomaly (Fig. 5A) compared with the granites in southern China and southwest of Japan (Ban and Zhao, 2008; Ishihara and Murakami, 2006). The REE patterns of the B and C horizons of the weathered crusts have the similar pattern with the granitic rocks whereas the patterns of the A horizon and kaolin-rich rock samples are different. The change in elements by weathering is easily recognized in Figure 6A. The A horizon is highly enriched in LREE and depleted in HREE. In contrast, the kaolin-rich rock is distinctly enriched in HREE although the REE content is not high. The C horizons are depleted in LREE and REE, whereas the B horizons are enriched in both LREE and HREE. With regard to the other elements, Th and U are significantly enriched whereas P is depleted in the A horizon. The average REE contents of the granitic rocks, B horizons, C horizons and kaolin-rich rocks are 166 ± 98 (standard deviation) ppm, 433 ± 238 ppm, 181 ± 60 ppm and 215 ± 139 ppm, respectively.

4.2 Boneng district

All the samples in Boneng show the similar chondrite-normalized REE patterns each other and they are enriched in LREE with negative Eu anomalies. Figure 6B shows HREE are slightly depleted although some HREE (Tm, Yb and Lu) of the A and B horizons appear to be enriched relative to the parent rocks. LREE of the A and B horizons are slightly enriched due to the enrichment of Ce. The kaolin-rich and sediment samples are generally depleted in REE relative to the parent granitic rocks. P is depleted in all the samples and Zr is enriched in the sediment samples. The average REE contents of the granitic rocks, B horizons, kaolin-rich rocks, and sediments are 232 ± 75 ppm, 224 ± 41 ppm, 181 ± 60 ppm and 155 ± 45 ppm, respectively. Sn concentrate samples are rich in HREE and Zr, whereas Sn ore samples are poor in REE (Appendix 1).

4.3 Nape district

All the samples in Nape have the similar REE patterns to each other with the enrichment of LREE and negative Eu anomalies (Fig. 5C), having a similarity with the REE pattern of the Boneng district. The A and B horizons are weakly depleted in total REE and LREE relative to the parent rocks although they are slightly enriched in HREE (Fig. 6C). The C horizons are slightly enriched in REE relative to the parent rock whereas the enrichment of HREE is poor. The sediments are depleted in REE although HREE are enriched relative to LREE. The significant depletion of P in all the samples and the enrichment of Zr in the sediments are recognized. The average REE contents of the granitic rocks, B horizons and C horizons are 179 ± 49 ppm, 165 ± 56 ppm and 205 ± 103 ppm, respectively.

4.4 Xaisomboun district

In Xaisomboun, the granitic rocks have slightly low REE contents with the weak negative Eu anomaly (Fig. 5D) compared with the REE patterns of the Boneng and Nape districts. The REE pattern of the A and B horizons are similar to the parent rocks except for the Eu anomalies. Samples 70307A, B1, B2 and C, which are distinctly enriched in REE, are separately shown

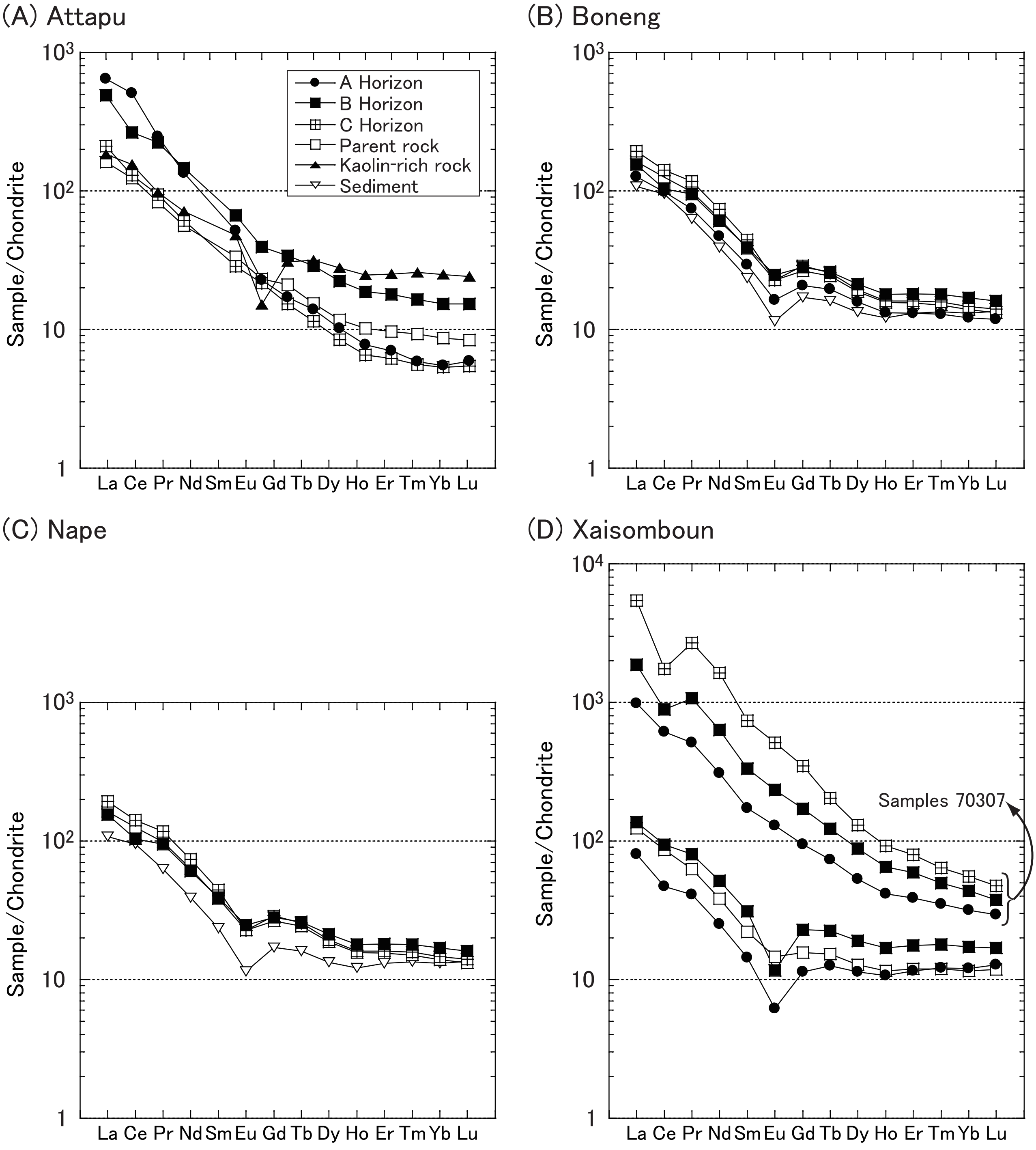

Fig. 5 Chondrite-normalized REE patterns of granitic rocks (parent rocks), their weathered crusts, clay-rich rocks and sediment samples in the (A) Attapu, (B) Boneng, (C) Nape and (D) Xaisomboun districts.

in Figure 5D. They are especially enriched in LREE relative to HREE, showing the negative Ce anomalies and no Eu anomaly. The A horizons are depleted in REE relateive to the parent rocks whereas the B horizons are enriched in REE (Fig. 6D). Both of the A and B horizons are enriched in HREE relative to LREE. Zr, Th and U are enriched whereas P is depleted in both horizons. The change in elements is not illustrated for the samples 70307A - C because their parent rock was not identified. The average REE contents of the granitic rocks, A horizons and B horizons are 123 ± 33 ppm, 159 ± 79 ppm and 205 ± 103 ppm, respectively.

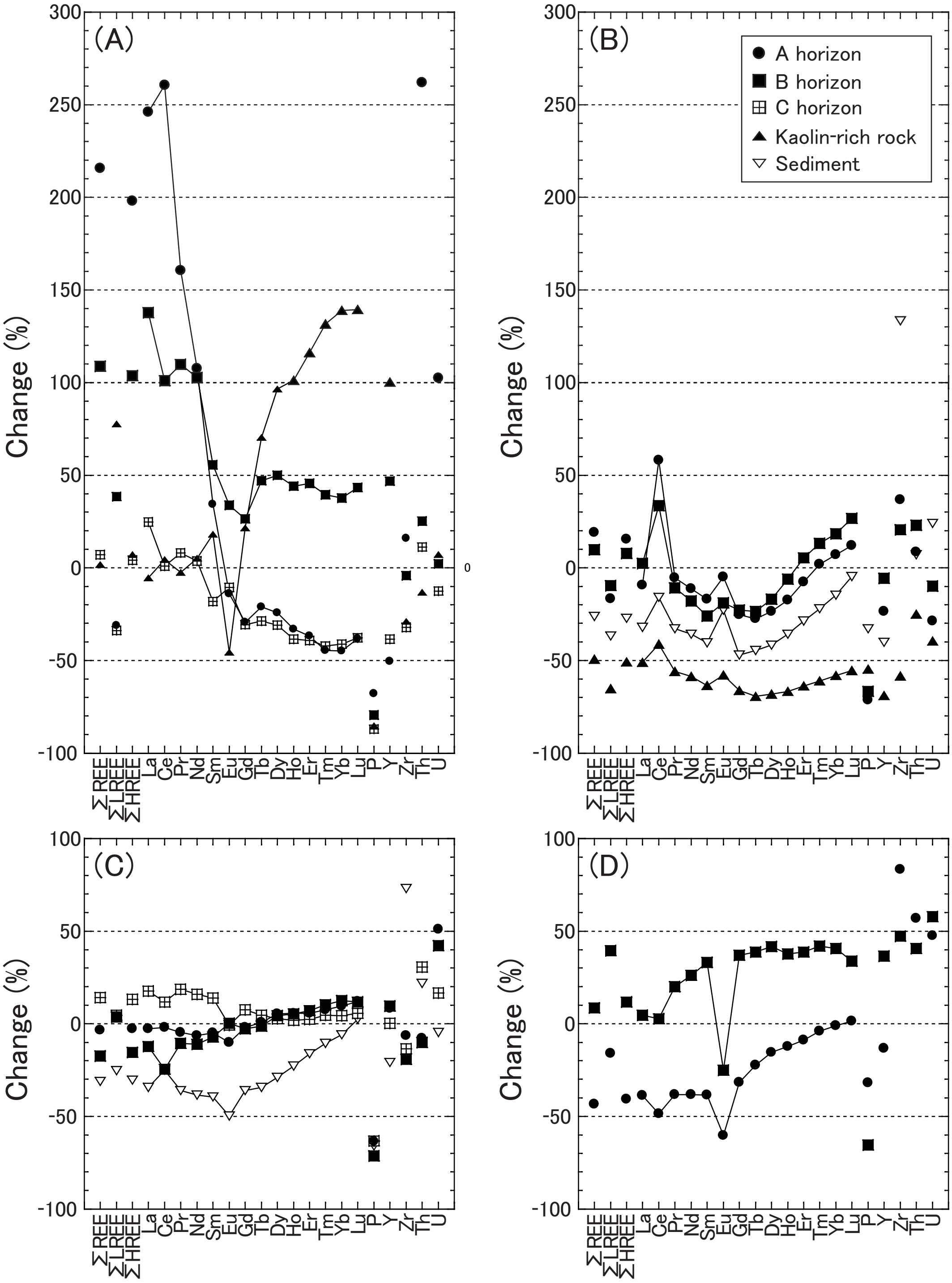

Fig. 6 Diagrams showing the change of elements relative to the parent rocks in the (A) Attapu, (B) Boneng, (C) Nape and (D) Xaisomboun districts. The percentage of the change is given by the following equation: $((C_S / Al_2O_3S) / (CPR / Al_2O_{3PR}) - 1) \times 100$. Contents of any element in a sample (C_S) and parent rock (C_{PR}) are normalized by contents of immobile Al_2O_3 in the sample (Al_2O_{3S}) and parent rock (Al_2O_{3PR}), respectively.

4.5 All the rock samples

All the granitic rocks show REE contents ranging from 35.5 to 338.5 ppm with the average of 181 ± 69 ppm. These values are consistent with the REE contents ranging from 164 to 350 ppm reported by DGM (2000). The tourmaline granite (sample 62818) is excluded in calculating the average value because it is not a representative granitic rock at the studied area in the Boneng district. The tourmaline granite and greizen samples show the REE contents of 31.0 and 51.9 ppm respectively, which are distinctly lower than those of the other granitic rocks. The REE contents of weathered crusts range from 37.9 to 817.4 ppm with the average of 211 ± 144 ppm excluding the samples 70307A, B1, B2 and C. The average REE contents of the horizons A, B and C in all the samples are 210 ± 190 ppm, 217 ± 156 ppm and 196 ± 97 ppm, respectively. Samples of 70307A, B1, B2 and C with the REE contents ranging from 885 to 3664 ppm are distinctly enriched in REE. All the granitic rocks are depleted in HREE and relatively enriched in LREE (average LREE/HREE ratio = 9.40) compared with the parent rocks of ion-adsorption type deposits (Wu et al, 1990; Bao and Zhao, 2008). The weathered crusts of granitic rocks in Laos show the LREE/HREE ratios of 13.1 and they are generally depleted in HREE relative to LREE (Fig. 6A and 6B), whereas some weathered crusts are enriched in HREE relative to LREE (Fig. 6C and 6D). The LREE/HREE ratios of the A, B and C horizons are 16.9, 11.4 and 15.3, respectively. The chondrite-normalized REE patterns exhibit downward-sloping REE patterns, indicating strong enrichment of LREE with weak enrichment of HREE relative to chondrite (Fig. 5). Kaolin-rich rock samples show the REE contents ranging from 111.4 to 418.7 ppm with the average of 220 ± 95 ppm. These samples have the LREE/HREE ratio = 11.5 on average. Sediment samples show REE contents ranging from 93.9 to 224.0 ppm with the average of 149 ± 44 ppm. The REE contents of Sn ore and Sn concentrate samples are 186.3 and 50.8 ppm, and 133.4 and 514.8 ppm, respectively.

4.6 Sequential leaching

The result of the sequential leaching for Y, ∑LREE, ∑HREE and ∑REE is summarized in Table 2 and the result of Mn, Zr, Pb, Th, U, Sc, Y and REE is shown in Appendix 2. The results indicate that Y and REE occur within ion-exchangeable minerals (mostly clay minerals) at the step 1, clay minerals and phosphates at the step 5 and/or residual minerals such as zircon. By contrast, small amounts of Y and REE are present within organic materials, Fe oxides, Mn oxides and silicates. The proportion of the exchangeable ∑REE (step 1) to ∑REE of total fusion analysis ranges widely from 14.2 to 72.7 %. The proportion of ∑HREE is higher than that of ∑LREE at the step 1 for all the samples. The proportions of the exchangeable Y and ∑HREE have a positive correlation to each other (Table 2). The majority of Zr was not dissolved by the sequential leaching from the step 1 to 5 and it is present as residual minerals (Appendix 2). As Th is generally dissolved at the step 5, the host minerals are clay and phosphate minerals (Appendix 2).

5. Discussions

5.1 Enrichment of REE in granitic rocks

Relatively low SiO_2 contents and Rb/Sr ratios of granitic rocks in the surveyed areas suggest that they are mostly classified into granodiorite with some granite and diorite. These granitic rocks are not highly differentiated compared with representative granites of the southwest Japan reported by Ishihara and Murakami (2006) (Fig. 7A). The poor differentiation of magma for granite is also indicated by the small negative anomalies of Eu in the chondrite-normalized REE patterns (Fig. 5). The granitic rocks are more fractionated in the following order: the Xaisomboun, Attapu, Nape and Boneng districts (Fig. 7A). This order is concordant with the result that the average REE contents of the granitic rocks increase in the following order of the Xaisomboun (123 ppm), Attapu (166 ppm), Nape (179 ppm) and Boneng (232 ppm) districts because REE generally concentrate in melt as incompatible elements in the process of crystalization differentiation. A positive correlation between SiO_2 contents and ∑HREE suggests that HREE are enriched by the fractionation of magma (Fig. 7B). Ishihara and Murakami (2006) demonstrated that granitic rocks with high SiO_2 contents (> ~72%) become enriched in HREE in the southwest Japan (Fig. 5B). The HREE-enriched granites of REE deposits in southern China also have higher SiO_2 contents ranging from 70 to 76% (Fig. 7B; Wu et al., 1990). The granitic rocks in southern Laos are slightly depleted in SiO_2 and HREE, compared with those in the southwest Japan and southern China.

No significant correlation is identified between ∑LREE and SiO_2 contents of granitic rocks, but LREE contents are relatively higher in the range of 65 - 75 % SiO_2 (Fig. 7C). As LREE generally occupies the majority of REE in content, the diagrams of ∑LREE (Fig. 7C) and ∑REE (Fig. 7D) versus SiO_2 contents show a similar pattern to each other. The SiO_2-rich sample (62818) composed mainly of quartz and tourmaline, shows 31.0 ppm REE, which is apparently lower than the others. This result suggests that REE minerals crystallized before tourmaline crystallization in highly fractionated magma. The greizen sample (62815) with 51.9 ppm REE, which is lower than the REE contents of the granitic rocks in this area, suggests that greizen-related hydrothermal fluid is depleted in REE relative to the parent rock. The REE content of granitic rocks in Laos ranging from 35 to 339 ppm is roughly equal to that of granites in ion-adsorption type deposits (130 - 350 ppm; Wu et al, 1990; Bao and Zhao, 2008). The REE content in ion-adsorption type deposits is apparently lower than ore grades of 1 - 8 % REE from carbonatite-related REE deposits and prospects in China and North America (Wu et al., 1996; Castor, 2008; Wu, 2008). Although some of the granitic rocks in the ion-adsorption type deposits are distinctly enriched in HREE (LREE/HREE = 0.92 - 2.45) compared with the other REE ores, the others are enriched in LREE (LREE/HREE = 6.7 - 18.7) as reported by Wu et al. (1990) and Bao and Zhao (2008). All of the studied granitic rocks in Laos are depleted in HREE and enriched in LREE, showing intermediate to high LREE/HREE ratios with the range of 6.2 - 15.6 (Appendix 1). From these results, it is concluded that the surveyed granitic rocks in central and southern Laos are not highly fractionated for granite, resulting in the depletion of HREE. Moderate REE contents with the depletion of HREE suggest that the granitic rocks, which are the parent rocks of weathered crusts, have a low potential for HREE resources whereas they may have a potential for LREE mineralization.

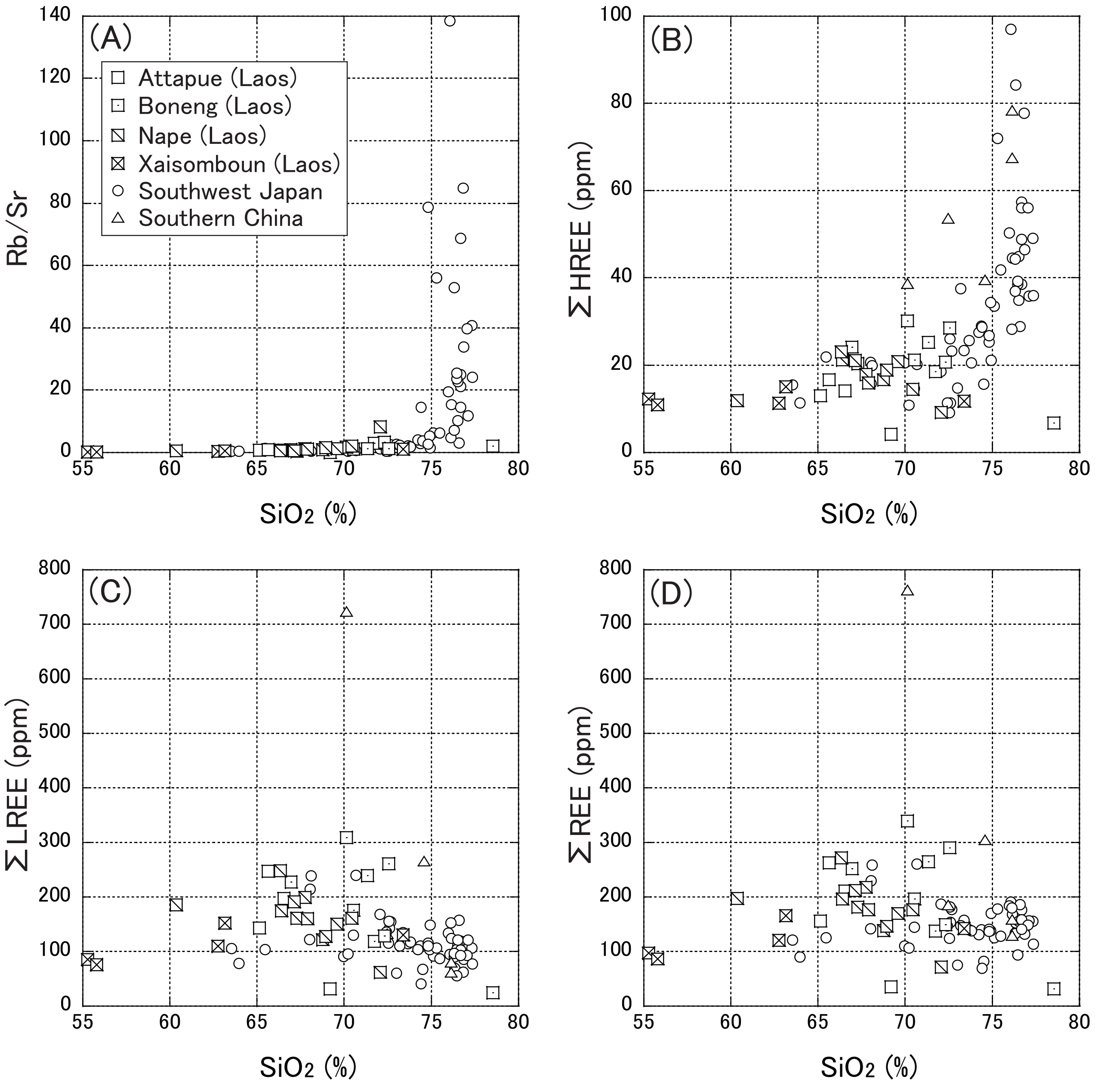

Fig. 7 Diagrams showing (A) Rb/Sr ratio, (B) ∑LREE, (C) ∑HREE and (D) ∑REE versus SiO_2 contents of granitic rocks in the central and southern Laos, Southwest Japan (Ishihara and Murakami, 2006) and southern China (Wu et al., 1990; Bao and Zhao, 2008).

5.2 Enrichment of REE by weathering

Chemical index of alteration (CIA) proposed by Nesbitt and Young (1982) is applied to estimate the degree of weathering of granitic rocks in this study. The CIA value is given by simple calculation of molecular proportions:

$CIA = [Al_2O_3/(Al_2O3+CaO^*+Na_2O+K_2O)] \times 100$ (%)

Where CaO* is the CaO content in silicates. Unaltered feldspars (anorthite, albite and orthoclase) give a CIA value of 50 %. Biotite and muscovite, which are peraluminous rock-forming minerals, generally give CIA values of 65 - 75 and ~75 %, respectively. Illite and kaolinite, which are common clay minerals in weathered crusts, indicate CIA values of 75 - 85 and 100 %, respectively. Thus, CIA values of granitic rocks and weathered crusts in this study range from ~50 to 100 %, suggesting the degree of argillation, from feldspars through illite to kaolinite. Figure 8A indicates that CIA values increase by chemical weathering in the following order: granitic rocks and A, B and C horizons of weathered crusts. The CIA values of the C, B and A horizons represent 55 - 76 %, 69 - 96 % and 73 - 97 %, respectively. The CIA value of the C horizon is intermediate between the least altered granitic rocks and the B horizon, whereas a difference in CIA values between the B and A horizons is relatively unclear because the difference to distinguish these two horizons results mainly from the amount of organic matter. Weathered crusts of ion-adsorption type deposits show CIA values ranging from 66 to 92 % (Wu et al., 1990; Murakami and Ishihara, 2008; Fig. 8A), and this suggests that most of weathered crusts of granitic rocks and kaolin-rich rocks in central and southern Laos are highly weathered and enriched in clay minerals as much as the ion-adsorption type deposits. The presence of clay minerals is also suggested by the diagram of ∑REE versus LOI (loss on ignition) in Figure 8B. The weathered samples in Laos contain kaolinite, halloysite, gibbsite, illite and goethite as weathering products and these hydrous minerals elevate the LOI contents. Most of the weathered rock samples in Laos show LOI contents which are identical to or higher than those of the weathered crusts in southern China (Fig. 8B). The B horizon and kaolin-rich samples in Laos especially have higher LOI contents with the range of 5 - 15 % in most of the samples, suggesting that they are sufficiently weathered and enriched in clay and hydrous minerals, which may have the ion-adsorption type REE mineralization.

5.2.1 Attapu district

In the each studied district of Laos, the most REE-enriched horizon is variable and is dependant on the each weathered profile. Although the most REE-enriched sample in the Attapu district is the A horizon (∑REE = 568 ppm), it was evaluated by the only one sample (P725A). Moreover, the higher REE content results from the high Ce content (311 ppm). This Ce enrichment with the positive Ce anomaly (Ce/Ce* = 1.28) in the A horizon is probably derived from the formation of tetravalent Ce under oxidizing condition near the surface (Henderson, 1984). The elevated REE content may be due to the presence of REE-bearing titanite, which is observed in granodiorite of the sample P725. The occurrence of exchangeable REE is minor and the majority of REE is present in silicates and poorly-soluble minerals (Table 2). The B horizons are generally enriched in REE with the enrichment of LREE relative to HREE (LREE/HREE = 23.2), and kaolin-rich rocks are enriched in HREE (LREE/HREE = 7.8) without significant changes in LREE (Fig. 6A). The B horizons show a moderate REE content on average (433 ppm), whereas the kaolin-rich samples contain less REE (215 ppm). Zr, Th and U of the two samples are not remarkably enriched relative to the parent rocks whereas P is distinctly depleted. These results suggest that host minerals of REE such as monazite, xenotime and allanite are rarely concentrated after weathering, although only the sample P791B2 contains relatively high Th and Zr in the bulk-rock analysis (Fig. 8D and E). For the sample P716B, 73 % of ∑REE is ion-exchangeable (Table 2), indicating the occurrence of ion-adsorption type REE mineralization. The other samples from the B horizon (P791B1 and P791B2) have some amount of exchangeable REE although REE are mainly present in phosphates and poorly-soluble minerals (Table 2). The kaolin-rich sample (P788CL) contains REE in ion-exchangeable clay minerals, phosphate, silicate and poorly-soluble minerals (Table 2). Thus, these results suggest that some of the B horizons in the Attapu district may have a potential of ion-adsorption type REE mineralization with the enrichment of both LREE and HREE.

5.2.2 Boneng district

Some samples (62808A, 62810B and P799CL) show positive Ce anomaly whereas other samples (62803B, 62805B and 62807B) show negative Ce anomaly in Boneng. These positive and negative anomalies suggest the removal of REE except for Ce in oxidizing condition near the surface and deposition of the removed REE in less oxidizing condition, respectively. The enrichment of REE is variable due to the removal and the deposition of REE with minor Ce, but the A and B horizons are slightly enriched in REE (Fig. 6B). The enrichment of HREE relative to LREE is recognized in the A horizons, B horizons and sediment samples; that is due to the presence of residual zircon suggested by the enrichment of Zr (Fig. 6B). The result of sequential leaching also suggests that the majority of REE is present in residual zircon and phosphate minerals with a small amount of exchangeable REE (Table 2). Sn concentrate sample

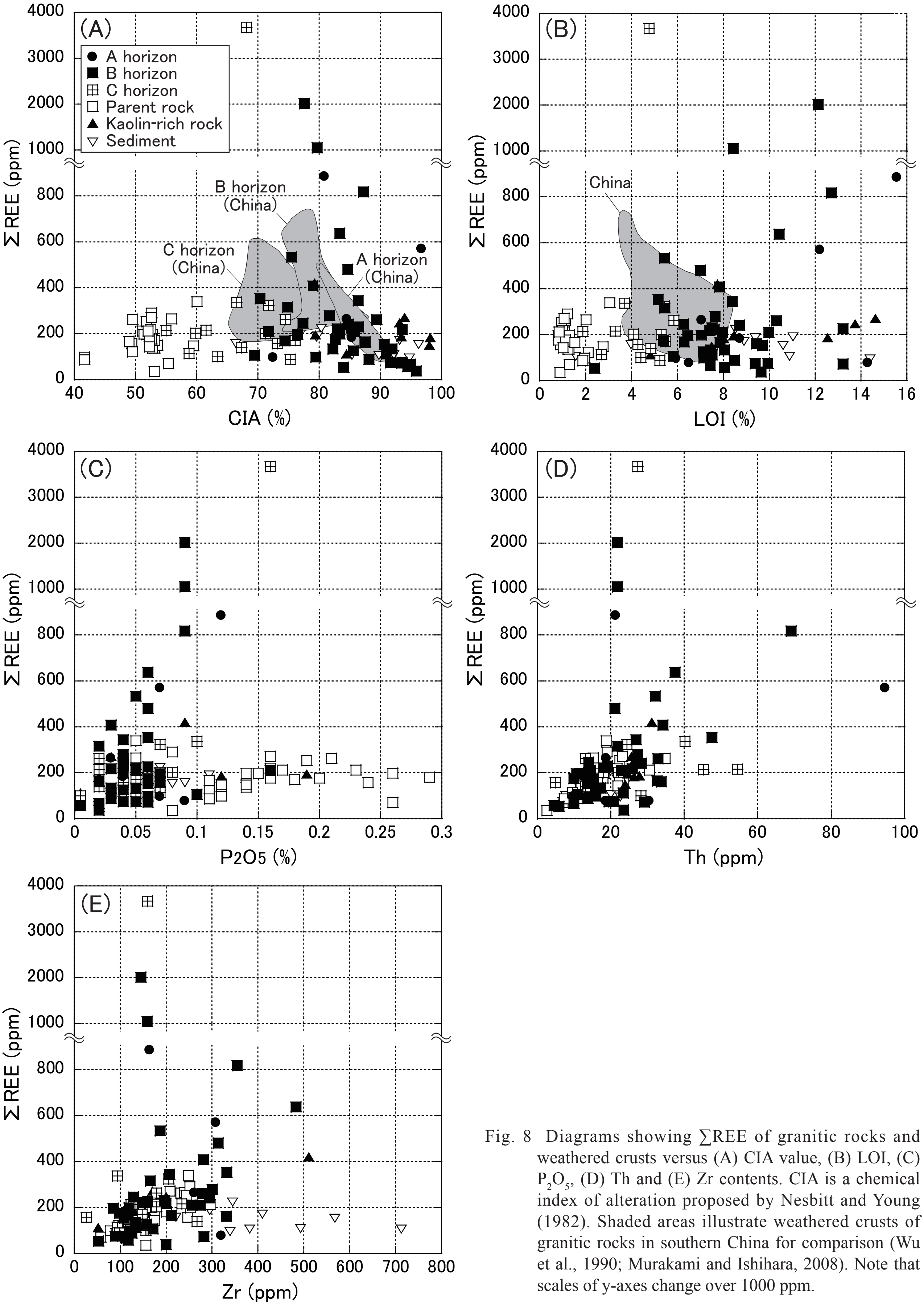

Fig. 8 Diagrams showing ∑REE of granitic rocks and weathered crusts versus (A) CIA value, (B) LOI, (C) P_2O_5, (D) Th and (E) Zr contents. CIA is a chemical index of alteration proposed by Nesbitt and Young (1982). Shaded areas illustrate weathered crusts of granitic rocks in southern China for comparison (Wu et al., 1990; Murakami and Ishihara, 2008). Note that scales of y-axes change over 1000 ppm.

Table. 2 Summary of the result of sequential leaching for representative REE-rich weathered rock sample

Sample #	Rock type	Dominant minerals	Leaching step[*1]	Ion-exchanged or dissolved materials	Y Conc. (ppm)	Y Prop.[*2] (%)	Σ LREE Conc. (ppm)	Σ LREE Prop. (%)	Σ HREE Conc. (ppm)	Σ HREE Prop. (%)	Σ REE Conc. (ppm)	Σ REE Prop. (%)
			Step 1	Ion exchangeable minerals	45.8	64.5	428.9	72.7	34.3	72.8	463.2	72.7
		Qtz	Step 2	Organic materials	1.18	1.7	9.68	1.6	0.761	1.6	10.44	1.6
		Kfs	Step 3	Amorphous Fe oxides & Mn oxides	0.40	0.6	3.68	0.6	0.300	0.6	3.98	0.6
P716B	Weathered granitic rock	Kln	Step 4	Fe & Mn oxides	0.053	0.1	1.56	0.3	0.057	0.1	1.62	0.3
		Ill	Step 5	Clay minerals & phosphates	1.0	1.4	30.5	5.2	1.3	2.8	31.8	5.0
			Step 6	Silicates & residue	1.9	2.7	22.5	3.8	2.0	4.2	24.5	3.8
			-	Residue[*3]	20.7	29.1	93.6	15.9	8.4	17.8	102.0	16.0
			Step 1	Ion exchangeable minerals	3.48	36.6	77.2	13.8	3.28	34.8	80.5	14.2
		Qtz	Step 2	Organic materials	0.08	0.8	2.01	0.4	0.079	0.8	2.08	0.4
		Kfs	Step 3	Amorphous Fe oxides & Mn oxides	0.132	1.4	15.65	2.8	0.150	1.6	15.80	2.8
P725A	Weathered granitic rock	Gib	Step 4	Fe & Mn oxides	0.012	0.1	14.59	2.6	0.064	0.7	14.66	2.6
		Kln	Step 5	Clay minerals & phosphates	1.16	12.2	72.2	12.9	1.8	19.1	74.0	13.0
		Ill	Step 6	Silicates & residue	1.9	20.0	116.8	20.9	3.3	35.0	120.1	21.1
			-	Residue	2.7	28.8	259.8	46.5	0.8	8.0	260.6	45.9
			Step 1	Ion exchangeable minerals	15.9	62.6	142.7	27.7	11.81	71.3	154.5	29.0
		Qtz	Step 2	Organic materials	0.46	1.8	3.53	0.7	0.286	1.7	3.82	0.7
		Kfs	Step 3	Amorphous Fe oxides & Mn oxides	0.283	1.1	5.21	1.0	0.228	1.4	5.44	1.0
P791B1	Weathered granitic rock	Ill	Step 4	Fe & Mn oxides	0.038	0.2	5.43	1.1	0.052	0.3	5.48	1.0
		Kln	Step 5	Clay minerals & phosphates	1.67	6.6	228.2	44.2	2.9	17.5	231.1	43.4
			Step 6	Silicates & residue	1.0	3.9	23.5	4.5	1.2	7.2	24.7	4.6
			-	Residue	6.0	23.8	107.3	20.8	0.09	0.5	107.4	20.2
			Step 1	Ion exchangeable minerals	35.4	60.7	310.6	39.8	25.62	67.9	336.2	41.1
		Qtz	Step 2	Organic materials	0.77	1.3	6.28	0.8	0.488	1.3	6.77	0.8
		Kln	Step 3	Amorphous Fe oxides & Mn oxides	0.189	0.3	5.89	0.8	0.154	0.4	6.04	0.7
P791B2	Weathered granitic rock	Ill	Step 4	Fe & Mn oxides	0.040	0.1	18.50	2.4	0.112	0.3	18.6	2.3
		Kfs	Step 5	Clay minerals & phosphates	3.73	6.4	242.7	31.1	5.8	15.4	248.5	30.4
			Step 6	Silicates & residue	2.9	5.0	20.7	2.7	3.4	9.0	24.1	3.0
			-	Residue	15.3	26.2	175.1	22.5	2.14	5.7	177.2	21.7
			Step 1	Ion exchangeable minerals	15.0	48.5	162.1	40.9	12.53	55.7	174.6	41.7
		Qtz	Step 2	Organic materials	0.60	1.9	5.77	1.5	0.419	1.9	6.18	1.5
		Kfs	Step 3	Amorphous Fe oxides & Mn oxides	0.224	0.7	2.61	0.7	0.182	0.8	2.79	0.7
P788CL	Kaolin-rich rock	Kln	Step 4	Fe & Mn oxides	0.020	0.1	1.55	0.4	0.033	0.1	1.58	0.4
		Ill	Step 5	Clay minerals & phosphates	1.78	5.8	99.8	25.2	2.9	12.9	102.7	24.5
			Step 6	Silicates & residue	2.4	7.8	62.1	15.7	2.8	12.4	64.9	15.5
			-	Residue	10.9	35.2	62.3	15.7	3.6	16.2	65.9	15.7
			Step 1	Ion exchangeable minerals	14.8	25.0	108.5	24.3	9.82	28.6	118.3	24.6
		Qtz	Step 2	Organic materials	0.48	0.8	3.42	0.8	0.296	0.9	3.72	0.8
		Kfs	Step 3	Amorphous Fe oxides & Mn oxides	0.842	1.4	6.82	1.5	0.537	1.6	7.36	1.5
62810B	Weathered granitic rock	Gib	Step 4	Fe & Mn oxides	0.922	1.6	29.69	6.7	0.567	1.7	30.3	6.3
		Kln	Step 5	Clay minerals & phosphates	15.3	25.8	79.2	17.8	10.8	31.5	90.0	18.7
		Ill	Step 6	Silicates & residue	6.3	10.6	16.6	3.7	7.7	22.5	24.3	5.1
			-	Residue	20.6	34.7	201.5	45.2	4.55	13.3	206.1	42.9
			Step 1	Ion exchangeable minerals	42.0	53.9	388.8	46.6	32.10	62.8	420.9	47.6
		Qtz	Step 2	Organic materials	2.02	2.6	22.09	2.6	1.477	2.9	23.6	2.7
		Kfs	Step 3	Amorphous Fe oxides & Mn oxides	2.19	2.8	44.56	5.3	1.706	3.4	46.3	5.2
70307A	Weathered granitic rock	Kln	Step 4	Fe & Mn oxides	0.376	0.5	18.53	2.2	0.325	0.6	18.9	2.1
		Ill	Step 5	Clay minerals & phosphates	5.99	7.7	107.7	12.9	6.5	12.7	114.2	12.9
		Gib	Step 6	Silicates & residue	0.5	0.6	4.47	0.5	0.6	1.2	5.07	0.6
			-	Residue	24.8	31.9	247.4	29.7	8.44	16.5	255.9	28.9
			Step 1	Ion exchangeable minerals	85.0	81.0	608.4	61.6	52.93	81.4	661.3	62.9
		Qtz	Step 2	Organic materials	2.92	2.8	19.04	1.9	1.848	2.8	20.9	2.0
		Kfs	Step 3	Amorphous Fe oxides & Mn oxides	1.96	1.9	34.03	3.4	1.553	2.4	35.6	3.4
70307B1	Weathered granitic rock	Kln	Step 4	Fe & Mn oxides	0.463	0.4	28.62	2.9	0.476	0.7	29.1	2.8
		Ill	Step 5	Clay minerals & phosphates	8.54	8.1	146.7	14.9	9.1	14.0	155.8	14.8
		Gib	Step 6	Silicates & residue	2.7	2.6	29.9	3.0	3.0	4.6	32.9	3.1
			-	Residue	3.4	3.3	120.2	12.2	n.v.	n.v.	116.3	11.1
			Step 1	Ion exchangeable minerals	54.4	36.3	873.7	45.9	53.84	51.4	927.5	46.2
		Qtz	Step 2	Organic materials	1.58	1.1	18.79	1.0	1.346	1.3	20.1	1.0
		Kfs	Step 3	Amorphous Fe oxides & Mn oxides	1.80	1.2	42.29	2.2	1.906	1.8	44.2	2.2
70307B2	Weathered granitic rock	Kln	Step 4	Fe & Mn oxides	1.54	1.0	86.33	4.5	1.576	1.5	87.9	4.4
		Ill	Step 5	Clay minerals & phosphates	30.0	20.0	447.8	23.5	26.7	25.5	474.5	23.6
			Step 6	Silicates & residue	5.0	3.3	51.1	2.7	4.3	4.1	55.4	2.8
			-	Residue	55.7	37.1	383.1	20.1	15.2	14.5	398.2	19.8
			Step 1	Ion exchangeable minerals	43.3	26.4	1005.1	28.5	46.24	32.4	1051.3	28.7
		Qtz	Step 2	Organic materials	2.23	1.4	44.15	1.3	2.104	1.5	46.3	1.3
		Kfs	Step 3	Amorphous Fe oxides & Mn oxides	4.84	3.0	96.64	2.7	4.665	3.3	101.3	2.8
70307C	Weathered granitic rock	Kln	Step 4	Fe & Mn oxides	2.10	1.3	59.18	1.7	2.010	1.4	61.2	1.7
		Ill	Step 5	Clay minerals & phosphates	51.4	31.3	1413.6	40.1	53.2	37.3	1466.8	40.0
			Step 6	Silicates & residue	12.6	7.7	324.9	9.2	12.4	8.7	337.3	9.2
			-	Residue	4.75	29.0	578.2	16.4	22.0	15.4	600.2	16.4

*1 See text for the reagent and experimental condition at each step of the leaching.
*2 Proportion of the concentration at each step to the concentration of the whole-rock analysis.
*3 Determined by subtracting the concentration of step 1 - 6 from the concentration of the whole-rock analysis.
Abbreviations: Qtz=quartz, Kfs=K-feldspar, Kln=kaolin, Ill=illite, Gib=gibbsite, n.a.=not analyzed, n.v.=negative value.

(P797CN1), which is enriched in HREE, also contains zircon and xenotime as the host minerals of HREE. The A and B horizons may be slightly enriched in REE, but all the samples in the Boneng district tend to be less enriched or depleted in REE relative to the parent rocks. These results suggest that no potential for ion-adsorption type REE mineralization in this district although the granitic rocks are most enriched in HREE in the studied area of Laos.

5.2.3 Nape district

The A and B horizons of weathered crusts in Nape are not remarkably different from the parent rocks in regard to the REE patterns (Fig. 5C) and the changes in REE (Fig. 6C). The weak enrichment of HREE is recognized in the A and B horizons. In contrast, the C horizon is slightly enriched in REE with 205 ppm on average. The enrichment of REE relative to the parent rocks (∑REE = 179 ppm) is only +14 % and LREE is more enriched than HREE. In the C horizon, the most dominant clay minerals are illite rather than kaolin, suggesting the low potential for ion-adsorption type REE mineralization. The sediment samples are depleted in REE and the enrichment of HREE relative to LREE is probably due to residual zircon (Fig. 6C). Thus, the ion-adsorption type REE mineralization is hardly identified in the Nape district.

5.2.4 Xaisomboun district

In the Xaisomboun district, the A horizons are depleted in REE, and in contrast, the B horizons are enriched in REE relative to the parent rocks (Fig. 6D). The enrichment of HREE relative to LREE in both horizons is probably derived from the occurrence of residual minerals, which is indicated by the enrichment of Zr, Th and U (Fig. 6D). The REE contents range from 37 to 408 ppm with the average value of 145 ppm, which are not sufficient for REE resources. On the contrary, samples 70307A, B1, B2 and C, which show distinctly high REE contents (885 - 3664 ppm) with the enrichment of LREE relative to HREE (LREE/HREE = 18.6), were identified in this district. This weathered crust contains kaolin, illite and gibbsite with small amounts of REE-phosphates, which are detected using an electron probe micro analyzer (Fig. 4). The occurrence of these phosphates is also recognized by high P_2O_5 contents in the result of bulk-rock analysis (Fig. 8C). The REE-phosphate in this weathered crust is poor in Th (Fig. 8D), suggesting the occurrence of secondary form of monazite and/or rhabdophane (Sawka et al., 1986; Mariano, 1989). The result of sequential leaching indicates that the dominant host minerals of REE are ion-exchangeable clay minerals with minor amounts of phosphates and poorly-soluble minerals in the A and B horizons at this weathered crust (Table 2). In the C horizon, more REE occurs in phosphates than ion-exchangeable clay minerals. This difference in the proportion of exchangeable REE is attributed to the degree of weathering as shown by CIA value (Fig. 8A). These results indicate that the dominant host minerals of REE in this REE-rich weathered crust are ion-exchangeable clay minerals (probably kaolin) and REE minerals such as monazite and rhabdophane.

5.2.5 All the rock samples

The B horizon of weathered crust is most commonly enriched in REE in all of the districts although the C horizon enriched in REE is only found in the Nape district (Fig. 6C). This result is concordant with the fact that the enrichment of REE in the B horizon and less enrichment of REE in the A and C horizons occur in ion-adsorption type deposits, southern China (Wu et al., 1990; Bao and Zhao, 2008). Murakami and Ishihara (2008) reported that the most REE-enriched layers are the B horizon of the weathered Dabu Granite and the C horizon in the weathered Dingnan Granite in southern China. These results indicate that enrichment of REE occurs mostly in the B horizon and subordinately in the C horizon. In the studied district of Laos, the enrichment of REE in the B horizon relative to the parent rock is determined to be +52 % with the range from -69 to +391 %. This value is apparently lower than the average value of +164 % with the range from +26 to 380 %, which was determined by REE contents of weathered crusts and parent rocks in ion-adsorption type deposits (Wu et al., 1990; Bao and Zhao, 2008).

The average LREE/HREE ratio in all the B horizons and granitic rocks are 10.9 and 9.39, respectively. Although these ratios show that the B horizon appears to be slightly depleted in HREE compared with the parent rocks, the elevated LREE/HREE ratio of the B horizons results from the LREE-enriched samples in the Attapu district (Appendix 1). If these samples are excluded, the LREE/HREE ratio of the B horizons changes to 8.27, which is slightly smaller than the ratio of the parent rocks. The difference in LREE/HREE ratios in weathered crusts may be attributed to the degree of alteration. Nesbitt (1979) reported that HREE are enriched by the degree of alteration in granodiorite whereas they are depleted in intensively altered zone. An experimental study also indicated that more HREE are selectively adsorbed on kaolinite and smectite at high ionic strength (Coppin et al., 2002). The result of the present study also indicates that HREE are enriched on ion-exchangeable clay minerals in the weathered rock samples (Table 2). This fractionation between HREE and LREE suggests that HREE are more selectively adsorbed on the ion-exchangeable clay minerals than LREE in the process of weathering. The C horizon appears to be enriched in LREE (LREE/HREE = 16.3) due to the highly LREE-enriched samples in the Attapu district (Appendix 1). The average LREE/HREE ratio except for the samples in the Attapu district is 9.89, which is close to the ratio of the parent rocks. Thus, it is concluded that the B horizon is generally enriched in HREE relative to LREE among the weathered rock samples in the studied districts.

Sediment samples commonly show the depletion of REE and the enrichment of HREE relative to LREE. The enrichment of HREE relative to LREE is derived from the concentration of zircon which is suggested by the enrichment of Zr (Figs 6B and 6C; Fig. 8E). Murakami and Ishihara (2008) argued that the enrichment of REE in sediment samples derived from the occurrence of clay minerals such as kaolin for REE, and the presence of both clay minerals and zircon for HREE. In the sediment samples of Laos, such enrichment of REE is not recognized. The depletion of REE in the sediments probably results from dilution of REE by the mixing with sediments and/or reworked weathered granitic rocks.

6. Conclusions

Most granitic rocks distributed in central and southern Laos are granodiorite and granite showing low to moderate REE contents. The enrichment of LREE with the depletion of HREE in the granitic rocks compared with granite in the southwest Japan and southern China is derived from poorly differentiated magma for granite.

Weathered crusts of the granitic rocks are well developed and contain abundant clay minerals such as kaolin and illite, but they are not sufficiently enriched in REE for resources. The B horizon, which is the most prospective horizon, is slightly or moderately enriched in REE and HREE relative to the parent rock whereas the A and C horizons are depleted or less enriched in REE. Kaolin-rich rocks and sediment samples in the granite area mostly show lower REE contents.

Prospective weathered crusts of granitic rocks for REE resources are locally identified in the Attapu and Xaisomboun districts. These weathered crusts have the ion-adsorption type REE mineralization with the occurrence of REE phosphates such as monazite and rhabdophane. The result of sequential leaching suggests that HREE are selectively adsorbed on ion-exchangeable clay minerals than LREE in the process of weathering.

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Appendix 1 Chemical composition of major and trace elements in studied rock samples.

Sequential #	1	2	3	4	5	6	7	8	9	10
Sample #	P712	P725	P726	P793	62701	62702	62703	62801	62802	62809
District	Attapu	Attapu	Attapu	Attapu	Boneng	Boneng	Boneng	Boneng	Boneng	Boneng
Rock type	Bt Grd	Hbl-Bt Grd	Hbl-Bt Grd	Bt Grd	Bt Gr (F)	Bt Gr (F)	Bt Gr (F)	Bt Gr	Bt Gr	Bt Gr Por
Latitude	14°47.027'	14°49.306'	14°49.794'	14°49.576'	17°55.131'	17°55.979'	17°55.979'	17°58.746'	17°58.746'	17°58.876'
Longitude	107°30.168'	107°22.1'	107°21.394'	107°27.649'	104°33.493'	104°32.309'	104°32.309'	104°18.529'	104°18.529'	104°18.467'
SiO_2 (wt%)	69.18	65.15	65.64	66.55	70.53	71.74	72.33	70.15	71.34	72.57
TiO_2	0.31	0.60	0.54	0.51	0.31	0.17	0.16	0.32	0.32	0.34
Al_2O_3	16.4	15.01	15.25	15.43	14.31	13.18	13.65	14.15	13.03	13.37
Fe_2O_3*	2.59	4.74	4.27	3.97	2.57	2.18	2.22	2.69	2.70	3.12
MnO	0.034	0.076	0.073	0.062	0.039	0.050	0.045	0.021	0.018	0.048
MgO	0.94	1.55	1.42	1.21	0.64	0.28	0.29	0.31	0.33	0.49
CaO	2.62	3.01	3.04	2.68	1.55	0.66	0.63	0.27	0.21	0.46
Na_2O	4.68	2.63	2.82	2.72	3.08	3.12	3.21	2.55	3.39	4.16
K_2O	1.86	5.15	4.91	5.03	4.55	4.84	4.99	4.36	4.00	3.99
P_2O_5	0.08	0.24	0.21	0.23	0.14	0.12	0.12	0.05	0.05	0.08
LOI	0.89	0.90	1.12	1.08	1.09	1.28	1.17	3.06	2.03	1.22
Total	99.59	99.07	99.29	99.49	98.79	97.60	98.80	97.91	97.42	99.82
F (wt%)	n.a.	n.a.	n.a.	n.a.	0.11	0.16	0.16	0.04	0.04	0.05
ASI	1.13	0.98	0.99	1.04	1.12	1.14	1.15	1.5	1.27	1.11
CIA (%)	53.1	49.4	49.6	51.1	52.8	53.2	53.6	60.1	55.9	52.7
Rb (ppm)	61	176	196	215	204	244	263	131	115	122
Sr	870	250	222	339	204	83	82	77	92	96
Cs	1.3	5.9	6.0	4.3	10.8	8.6	9.1	2.1	1.5	1.6
Ba	435	1410	1220	1390	777	301	291	1080	1090	875
Sn	2	3	3	3	5	5	6	7	4	4
Zr	156	247	233	296	154	116	117	249	241	252
Hf	4.0	6.2	6.2	7.9	5.1	4.3	4.3	7.4	7.0	7.5
Nb	10	10	12	12	13	14.2	15.1	14.1	13.4	19.1
Ta	0.6	0.8	1.0	0.6	1.44	1.53	1.52	1.45	1.28	1.66
V	24	68	62	61	24	9	8	16	14	15
Co	4	8	8	7	4	79	66	57	65	65
Zn	30	40	50	50	120	60	40	50	50	60
Ga	19	14	15	17	21	20	21	18	16	18
Ge	1	1	1	1	2	2	2	1	1	1
Pb	13	23	35	22	39	29	28	28	24	25
Th	2.6	23.4	34.8	30.6	18.2	14.8	15.6	18.8	15.3	19.0
U	1.7	6.6	5.9	4.1	5.30	4.22	4.23	2.91	2.45	3.10
Y	7	19	22	19	34.1	30.9	34.7	41.6	33.9	51.8
La	8.3	30.5	62.6	52.1	41.1	25.6	26.8	97.3	76.7	75.9
Ce	14.3	69.1	121	97.1	82.0	53.6	57.8	122	87.2	114
Pr	1.42	7.96	12.6	9.55	10.1	6.96	7.55	19.8	16.8	15.5
Nd	5.3	28.4	41.4	30.3	34.3	26.2	28.9	57.1	48.4	45.9
Sm	1.2	5.6	7.7	6.0	6.60	5.69	6.45	10.6	8.82	8.53
Eu	0.86	1.41	1.47	1.62	0.994	0.492	0.509	1.60	1.35	1.17
Gd	1.3	4.8	6.2	5.0	6.54	6.10	6.75	9.78	7.87	8.26
Tb	0.2	0.6	0.8	0.7	1.09	1.05	1.15	1.55	1.20	1.36
Dy	1.0	3.1	4.1	3.7	5.9	5.6	6.3	7.86	6.34	7.39
Ho	0.2	0.6	0.8	0.7	1.10	0.94	1.05	1.45	1.19	1.50
Er	0.6	1.7	2.2	1.9	3.08	2.42	2.74	4.19	3.72	4.50
Tm	0.09	0.26	0.32	0.27	0.450	0.324	0.368	0.637	0.584	0.692
Yb	0.6	1.7	2.0	1.6	2.68	1.82	2.04	4.07	3.83	4.29
Lu	0.10	0.24	0.28	0.23	0.370	0.223	0.257	0.593	0.562	0.647
Σ LREE	31.4	143.0	246.8	196.7	175.1	118.5	128.0	308.4	239.3	261.0
Σ HREE	4.1	13.0	16.7	14.1	21.2	18.5	20.7	30.1	25.3	28.6
Σ REE	35.5	156.0	263.5	210.8	196.3	137.0	148.7	338.5	264.6	289.6
Σ REE+Y	42.5	175.0	285.5	229.8	230.4	167.9	183.4	380.1	298.5	341.4
LREE/HREE	7.7	11.0	14.8	13.9	8.3	6.4	6.2	10.2	9.5	9.1
HREE/REE	0.12	0.08	0.06	0.07	0.11	0.13	0.14	0.09	0.10	0.10
Ce/Ce*	1.02	1.09	1.06	1.07	0.99	0.98	1.00	0.68	0.60	0.81
Eu/Eu*	2.11	0.83	0.65	0.90	0.46	0.26	0.24	0.48	0.50	0.43
La_N/Yb_N	9.9	12.9	22.5	23.4	11.0	10.1	9.4	17.1	14.4	12.7
Rb/Sr	0.07	0.70	0.88	0.63	1.00	2.94	3.21	1.70	1.25	1.27

$Fe_2O_3^*$= Total iron oxides.

ASI = Alumina saturation index determined by molecular proportion of $Al_2O_3/(Na_2O+K_2O+CaO)$.

CIA = Cemical index of alteration determined by molecular proportion of $[Al_2O_3/(Al_2O_3+CaO+Na_2O+K_2O)]$_100, where CaO is not from carbonate.

Ce/Ce* = $Ce_N / (La_N \times Pr_N)^{1/2}$, where N is normalized by chondrite.

Eu/Eu* = $Eu_N / (Sm_N \times Gd_N)^{1/2}$, where N is normalized by chondrite.

Abbreviations: Bt=biotite, Hbl=hornblende, Ms=muscovite, Tur=tourmaline, Gr=granite, Grd=granodiorite, Por=porphyry, (F)=float

W Gr=weathered granitic rock, Kln-rich=Kaolin-rich rock, Conc=concentrate, n.a.=not analyzed

Appendix 1 Continued.

Sequential #	11	12	13	14	15	16	17	18	19	20
Sample #	62814	62815	62818	62901	62903	63001	63002	63005	70101	70102
District	Boneng	Boneng	Boneng	Nape	Nape	Nape	Nape	Nape	Nape	Nape
Rock type	Bt Gr	Greisen (F)	Tur Gr (F)	Bt Grd	Bt Grd	Ms-Bt Gr	Bt Grd	Bt Grd	Bt Grd	Bt Grd
Latitude	18°10.226'	18°10.226'	18°10.239'	18°12.065'	18°12.065'	18°09.492'	18°09.492'	18°17.431'	18°18.552'	18°18.811'
Longitude	104°17.097'	104°17.097'	104°17.118'	105°08.174'	105°08.174'	105°12.102'	105°12.102'	105°04.013'	105°05.671'	105°06.107'
SiO_2 (wt%)	66.96	75.42	78.55	68.77	67.29	72.06	69.60	68.95	66.39	67.74
TiO_2	0.50	0.05	0.09	0.27	0.54	0.13	0.52	0.28	0.41	0.49
Al_2O_3	14.90	14.10	9.75	15.07	14.95	14.37	14.37	14.38	15.34	14.28
Fe_2O_3*	3.98	1.10	4.48	2.52	4.08	1.25	3.57	2.87	3.63	3.84
MnO	0.057	0.028	0.051	0.056	0.055	0.018	0.059	0.070	0.056	0.055
MgO	0.96	0.17	0.39	0.70	1.49	0.27	1.00	0.73	1.10	1.46
CaO	2.24	<0.01	0.06	1.75	3.44	0.46	2.11	0.98	2.50	2.25
Na_2O	3.10	0.27	0.48	2.68	2.69	3.20	2.81	2.41	3.05	2.51
K_2O	4.31	4.22	0.13	5.43	2.75	5.04	3.92	3.73	4.33	4.35
P_2O_5	0.19	0.02	0.01	0.14	0.29	0.26	0.18	0.14	0.15	0.16
LOI	0.97	2.34	1.03	1.24	1.09	1.29	1.20	2.77	0.81	1.01
Total	98.14	97.68	94.99	98.59	98.65	98.32	99.33	97.29	97.74	98.12
F (wt%)	0.11	0.23	0.19	0.04	n.a.	0.10	0.08	0.05	0.08	0.08
ASI	1.08	2.8	9.38	1.12	1.09	1.24	1.13	1.47	1.08	1.1
CIA (%)	51.8	73.7	90.4	52.8	52.3	55.4	53.1	59.5	51.8	52.5
Rb (ppm)	192	442	10	209	128	396	186	211	189	226
Sr	222	6	5	231	358	48	169	131	270	189
Cs	10.2	32.1	0.6	5.3	6.6	21.9	9.3	8.4	7.7	9.0
Ba	901	368	<3	747	985	146	777	356	818	630
Sn	5	35	6	5	4	15	6	6	25	6
Zr	244	32	19	112	201	58	175	111	150	190
Hf	7.3	2.7	1.6	3.7	5.8	2.2	5.4	3.9	4.7	5.7
Nb	15.2	19.6	33.4	8.7	10.3	15.8	11.1	12.8	11.3	13.2
Ta	1.43	6.28	10.5	1.12	0.88	3.04	1.43	1.93	1.11	1.42
V	39	<5	7	30	68	7	42	33	48	52
Co	64	58	126	55	66	73	68	60	57	71
Zn	50	<30	120	40	60	40	80	60	60	70
Ga	22	46	30	17	20	22	20	20	19	20
Ge	2	3	2	2	1	3	2	2	2	2
Pb	24	66	5	34	22	31	32	31	38	33
Th	22.4	7.37	7.90	11.8	12.1	7.07	11.7	11.9	17.0	21.7
U	4.18	9.80	8.26	2.88	2.28	10.4	4.33	4.26	3.60	5.05
Y	36.9	7.4	8.0	27.5	33.0	14.2	31.9	31.6	33.8	26.1
La	54.0	8.2	3.49	28.8	39.1	13.1	35.8	30.0	41.6	47.5
Ce	109	20.6	9.82	58.1	75.4	28.1	70.4	59.6	83.6	96.5
Pr	13.4	2.71	1.51	6.94	9.18	3.46	8.6	7.26	10.0	11.4
Nd	41.6	11.0	7.42	21.7	29.3	13.4	27.5	24.4	31.9	35.5
Sm	8.33	2.32	1.86	4.5	5.81	3.0	5.79	5.08	6.34	6.9
Eu	1.42	0.322	0.256	1.20	1.79	0.413	1.4	0.961	1.49	1.17
Gd	7.89	1.95	1.66	4.38	5.94	3.33	5.81	4.94	5.89	6.13
Tb	1.28	0.36	0.33	0.79	1.03	0.58	1.03	0.91	1.03	0.95
Dy	6.58	1.88	1.80	4.47	5.74	2.74	5.56	5.07	5.74	4.71
Ho	1.19	0.29	0.27	0.87	1.09	0.41	1.08	0.99	1.11	0.87
Er	3.34	0.83	0.83	2.66	3.10	1.02	3.16	3.01	3.34	2.43
Tm	0.482	0.154	0.180	0.420	0.438	0.141	0.488	0.480	0.506	0.358
Yb	2.89	1.14	1.42	2.61	2.60	0.84	3.19	3.10	3.17	2.18
Lu	0.40	0.165	0.196	0.374	0.350	0.107	0.450	0.446	0.447	0.313
Σ LREE	227.8	45.2	24.4	121.2	160.6	61.5	149.5	127.3	174.9	199.0
Σ HREE	24.1	6.8	6.7	16.6	20.3	9.2	20.8	18.9	21.2	17.9
Σ REE	251.8	51.9	31.0	137.8	180.9	70.6	170.3	146.2	196.2	216.9
Σ REE+Y	288.7	59.3	39.0	165.3	213.9	84.8	202.2	177.8	230.0	243.0
LREE/HREE	9.5	6.7	3.6	7.3	7.9	6.7	7.2	6.7	8.2	11.1
HREE/REE	0.10	0.13	0.22	0.12	0.11	0.13	0.12	0.13	0.11	0.08
Ce/Ce*	0.99	1.07	1.05	1.01	0.98	1.02	0.98	0.99	1.00	1.02
Eu/Eu*	0.54	0.46	0.45	0.83	0.93	0.40	0.74	0.59	0.75	0.55
La_N/Yb_N	13.4	5.2	1.8	7.9	10.8	11.2	8.0	6.9	9.4	15.6
Rb/Sr	0.86	73.67	2.00	0.90	0.36	8.25	1.10	1.61	0.70	1.20

Appendix 1 Continued.

Sequential #	21	22	23	24	25	26	27	28	29	30
Sample #	70105	70107	70108	70109	70114	70303	70304	70305	70306	70402
District	Nape	Nape	Nape	Nape	Nape	Xaisom.	Xaisom.	Xaisom.	Xaisom.	Xaisom.
Rock type	Bt Grd (F)	Bt Gr	Bt Grd	Bt Grd	Bt Grd	Bt-Hbl Grd	Bt-Hbl Grd (F)	Bt-Hbl Grd (F)	Bt-Hbl Grd (F)	Bt Gr Por
Latitude	18°19.703'	18°20.932'	18°21.499'	18°22.071'	18°22.049'	18°43.5'	18°43.424'	18°43.424'	18°43.424'	18°58.194'
Longitude	105°06.694'	105°07.790'	105°8.026'	105°8.406'	105°2.012'	103°15.565'	103°18.490'	103°18.490'	103°18.490'	103°18.943'
SiO_2 (wt%)	60.36	70.45	67.92	66.34	67.14	62.75	55.29	55.80	63.16	73.40
TiO_2	0.89	0.36	0.41	0.47	0.44	0.46	0.53	0.57	0.51	0.25
Al_2O_3	16.29	13.73	14.55	15.66	14.80	15.56	13.88	14.01	14.59	13.20
Fe_2O_3*	6.27	2.49	3.28	4.24	4.04	5.89	8.80	8.65	5.44	1.68
MnO	0.070	0.046	0.054	0.059	0.063	0.114	0.143	0.142	0.101	0.040
MgO	2.92	0.71	1.28	1.45	1.27	2.56	6.16	5.80	2.38	0.43
CaO	4.37	1.40	2.28	3.00	2.87	5.18	8.04	7.95	4.46	0.71
Na_2O	2.69	2.50	2.88	2.80	3.00	2.43	1.87	1.88	2.52	3.80
K_2O	2.78	5.23	4.05	3.74	3.19	2.26	1.61	1.85	2.69	4.15
P_2O_5	0.26	0.20	0.16	0.16	0.17	0.11	0.12	0.11	0.11	0.07
LOI	1.30	0.83	1.12	1.07	0.85	2.12	1.97	1.88	1.54	1.03
Total	98.18	97.92	97.99	98.96	97.81	99.41	98.42	98.64	97.49	98.73
F (wt%)	0.09	0.08	0.09	0.09	0.09	0.03	0.04	0.03	0.05	0.01
ASI	1.06	1.11	1.1	1.11	1.09	0.98	0.71	0.72	0.96	1.10
CIA (%)	51.4	52.7	52.3	52.6	52.1	49.5	41.7	41.7	49.0	52.3
Rb (ppm)	150	267	211	163	155	90	69	73	118	159
Sr	326	136	202	333	284	332	383	405	213	160
Cs	5.1	7.2	7.8	7.0	7.1	3.5	4.1	4.5	5.3	2.8
Ba	787	605	667	1210	695	667	569	707	585	721
Sn	2	5	5	5	3	2	3	2	4	3
Zr	253	149	151	209	175	97	80	91	128	175
Hf	6.7	4.7	4.5	6.3	5.4	3.0	2.5	2.7	4.0	5.0
Nb	14.5	12.2	11.4	12.6	12.1	5.7	4.4	4.1	7.0	11.6
Ta	1.	1.7	1.55	1.03	1.19	0.73	0.49	0.42	0.96	1.62
V	106	26	42	60	58	112	226	200	106	13
Co	68	63	75	83	62	48	60	60	74	62
Zn	90	60	60	70	60	70	90	60	70	40
Ga	23	22	19	20	20	16	16	15	16	16
Ge	1	2	2	2	2	2	2	2	2	1
Pb	16	42	33	29	23	15	15	12	27	22
Th	13.3	17.9	16.5	23.2	18.0	14.6	7.86	7.35	22.3	22.0
U	1.54	6.84	6.98	4.10	3.26	1.95	1.72	1.45	3.69	4.07
Y	14.7	21.5	25.3	34.8	33.3	18.9	20.2	17.1	25.1	19.9
La	46.2	37.4	38.8	59.2	45.3	29.5	20.0	17.7	41.4	37.7
Ce	88.8	77.9	77.2	118	91.2	52.8	39.2	35.0	73.9	63.2
Pr	10.4	9.35	9.26	14.6	11.2	5.77	4.85	4.29	8.10	6.89
Nd	32.4	29.3	28.1	45.1	34.6	17.4	16.5	14.4	22.8	18.9
Sm	5.60	6.09	5.76	8.80	7.11	3.15	3.30	2.94	4.19	3.32
Eu	1.69	1.13	1.10	1.89	1.54	0.899	0.861	0.864	1.03	0.595
Gd	4.69	5.04	5.08	7.67	6.36	2.86	3.30	2.99	3.95	3.04
Tb	0.63	0.82	0.83	1.22	1.07	0.49	0.59	0.52	0.71	0.55
Dy	3.03	3.92	4.24	6.11	5.65	2.98	3.25	2.91	3.97	3.05
Ho	0.53	0.67	0.79	1.11	1.07	0.62	0.65	0.58	0.79	0.62
Er	1.43	1.86	2.27	3.28	3.20	1.86	1.98	1.73	2.43	1.92
Tm	0.193	0.276	0.335	0.472	0.468	0.292	0.292	0.263	0.373	0.302
Yb	1.18	1.69	2.06	2.77	2.85	1.88	1.84	1.65	2.38	2.05
Lu	0.172	0.241	0.297	0.401	0.421	0.290	0.289	0.249	0.362	0.317
ΣLREE	185.1	161.2	160.2	247.6	191.0	109.5	84.7	75.2	151.4	130.6
ΣHREE	11.9	14.5	15.9	23.0	21.1	11.3	12.2	10.9	15.0	11.8
ΣREE	196.9	175.7	176.1	270.6	212.0	120.8	96.9	86.1	166.4	142.5
ΣREE+Y	211.6	197.2	201.4	305.4	245.3	139.7	117.1	103.2	191.5	162.4
LREE/HREE	15.6	11.1	10.1	10.7	9.1	9.7	6.9	6.9	10.1	11.0
HREE/REE	0.06	0.08	0.09	0.09	0.10	0.09	0.13	0.13	0.09	0.08
Ce/Ce*	0.99	1.02	1.00	0.98	0.99	0.99	0.98	0.98	0.99	0.96
Eu/Eu*	1.01	0.62	0.62	0.70	0.70	0.92	0.80	0.89	0.77	0.57
La_N/Yb_N	28.1	15.9	13.5	15.3	11.4	11.3	7.8	7.7	12.5	13.2
Rb/Sr	0.46	1.96	1.04	0.49	0.55	0.27	0.18	0.18	0.55	0.99

Appendix 1 Continued.

Sequential #	31	32	33	34	35	36	37	38	39	40
Sample #	P716B	P724C	P725A	P726B	P781C	P782B	P783B	P783C	P785B	P785C
District	Attapu	Attapu	Attapu	Attapu	Attapu	Attapu	Attapu	Attapu	Attapu	Attapu
Rock type	W Gr	W Gr	W Gr	W Gr	W Gr	W Gr	W Gr	W Gr	W Gr	W Gr
Latitude	14°47.937'	14°48.435'	14°49.306'	14°49.794'	14°46.998'	14°47.02'	14°47.075'	14°47.075'	14°47.086'	14°47.086'
Longitude	107°29.399'	107°22.981'	107°22.1'	107°21.394'	107°30.531'	107°30.531'	107°30.476'	107°30.476'	107°30.321'	107°30.321'
SiO_2 (wt%)	49.79	71.84	64.19	66.09	71.76	65.53	69.49	71.34	66.29	68.40
TiO_2	0.66	0.34	0.61	0.58	0.25	0.41	0.30	0.24	0.31	0.22
Al_2O_3	26.67	14.07	17.77	16.99	15.36	20.26	17.06	15.08	17.19	18.57
Fe_2O_3*	6.89	2.60	4.65	3.97	1.95	2.92	2.25	2.11	3.51	1.31
MnO	0.018	0.040	0.012	0.049	0.027	0.021	0.014	0.016	0.032	0.006
MgO	0.56	0.58	0.14	0.64	0.67	0.81	0.53	0.42	0.52	0.28
CaO	0.05	0.76	<0.01	0.09	2.20	0.13	0.29	0.86	1.22	0.16
Na_2O	0.13	1.47	0.02	0.24	3.93	0.25	0.52	1.81	1.94	0.75
K_2O	4.64	4.59	0.50	6.08	1.92	2.05	4.00	3.80	1.25	4.47
P_2O_5	0.06	0.05	0.07	0.06	0.02	0.02	0.02	<0.01	0.05	0.02
LOI	10.43	3.29	12.22	5.16	1.88	7.86	5.45	4.42	7.97	5.85
Total	99.90	99.63	100.18	99.95	99.97	100.26	99.93	100.10	100.28	100.04
F (wt%)	0.04	n.a.	0.02	0.06	0.03	0.03	0.02	0.02	<0.01	0.02
CIA (%)	83.4	61.6	96.8	70.4	55.	87.6	74.9	63.5	71.8	74.5
Rb (ppm)	191	179	53	241	67	79	103	101	64	142
Sr	147	107	22	115	504	71	297	449	250	232
Cs	3.1	5.8	2.4	6.5	1.2	2.3	1.4	1.3	1.9	1.9
Ba	1200	716	148	1550	396	382	1890	1770	324	1120
Sn	3	2	3	3	1	3	<1	8	3	3
Zr	484	235	309	333	124	212	166	156	257	180
Hf	11.5	6.6	8.4	8.8	3.4	5.6	4.2	4.0	6.7	4.7
Nb	19.7	8.0	13.1	11.7	7.0	12.4	8.3	6.0	11.9	7.9
Ta	1.14	0.5	1.04	1.12	0.5	0.85	0.47	0.4	0.85	0.67
V	69	28	77	66	26	34	27	20	38	27
Co	6	5	5	8	3	7	4	3	9	4
Zn	40	<30	<30	40	<30	40	30	<30	40	<30
Ga	35	14	21	19	20	26	21	18	23	23
Ge	2	1	2	2	1	1	1	1	1	2
Pb	33	23	59	42	14	45	50	20	30	34
Th	37.6	54.6	94.7	47.6	45.3	32.7	22.0	28.2	14.5	13.2
U	4.97	9.2	10.6	8.07	2.15	5.31	2.33	3.15	5.10	2.92
Y	71	8.0	9.5	27.6	6.0	6.2	15.3	5.5	16.2	16.0
La	172	57.7	152	88.1	59.7	39.8	94.1	30.8	60.8	76.0
Ce	249	102	311	156	105	90.8	140	41.4	82.8	112
Pr	33.7	10.6	23.5	17.5	9.32	6.68	15.4	4.82	11.0	13.4
Nd	112.0	29.7	62.6	60.2	30.0	20.0	46.9	15.0	36.9	42.8
Sm	19.3	5.10	7.88	8.93	3.74	2.81	6.32	1.98	5.76	6.08
Eu	4.39	1.08	1.32	1.93	0.911	0.836	2.14	1.21	1.38	1.59
Gd	15.7	3.8	3.50	6.88	1.84	1.20	4.04	1.46	4.22	4.30
Tb	2.58	0.4	0.52	0.98	0.25	0.20	0.56	0.20	0.59	0.59
Dy	13.4	2.0	2.58	5.14	1.23	1.18	2.85	0.97	2.94	2.80
Ho	2.42	0.3	0.44	0.95	0.22	0.23	0.53	0.19	0.54	0.50
Er	6.48	0.9	1.16	2.72	0.60	0.67	1.43	0.54	1.51	1.35
Tm	0.844	0.14	0.149	0.391	0.087	0.10	0.206	0.088	0.21	0.178
Yb	4.95	0.9	0.93	2.46	0.58	0.69	1.33	0.64	1.31	1.12
Lu	0.706	0.14	0.150	0.376	0.092	0.113	0.205	0.109	0.204	0.165
Σ LREE	590.4	206.2	558.3	332.7	208.7	160.9	304.9	95.2	198.6	251.9
Σ HREE	47.1	8.6	9.4	19.9	4.9	4.4	11.2	4.2	11.5	11.0
Σ REE	637.5	214.8	567.7	352.6	213.6	165.3	316.0	99.4	210.2	262.9
Σ REE+Y	708.5	222.8	577.2	380.2	219.6	171.5	331.3	104.9	226.4	278.9
LREE/HREE	12.5	24.0	59.2	16.7	42.6	36.7	27.3	22.7	17.2	22.9
HREE/REE	0.07	0.04	0.02	0.06	0.02	0.03	0.04	0.04	0.05	0.04
Ce/Ce*	0.80	1.01	1.28	0.97	1.09	1.37	0.90	0.83	0.78	0.86
Eu/Eu*	0.77	0.75	0.77	0.75	1.06	1.39	1.29	2.18	0.86	0.95
La_N/Yb_N	24.9	46.0	117.2	25.7	73.8	41.4	50.8	34.5	33.3	48.7

Appendix 1 Continued.

Sequential #	41	42	43	44	45	46	47	48	49	50
Sample #	P786C	P790C	P791B1	P791B2	62803B	62805B	62807B	62808A	62810B	63003A
District	Attapu	Attapu	Attapu	Attapu	Boneng	Boneng	Boneng	Boneng	Boneng	Nape
Rock type	W Gr	W Gr	W Gr	W Gr	W Gr	W Gr	W Gr	W Gr	W Gr	W Gr
Latitude	14°47.111'	14°48.069'	14°49.017'	14°49.017'	17°58.755'	17°58.730'	17°58.730'	17°58.854'	17°58.692'	18°9.492'
Longitude	107°30.247'	102°28.691'	107°28.032'	107°28.032'	104°18.507'	104°18.5'	104°18.5'	104°18.468'	104°18.621'	105°12.102'
SiO_2 (wt%)	66.20	73.42	65.53	53.02	63.10	62.75	65.65	72.40	67.01	77.22
TiO_2	0.47	0.04	0.48	0.96	0.37	0.35	0.37	0.27	0.38	0.24
Al_2O_3	18.20	16.05	18.79	21.81	18.79	19.29	16.29	13.49	15.03	9.28
Fe_2O_3*	3.63	0.65	3.64	7.82	3.44	3.72	3.54	2.42	5.48	1.69
MnO	0.056	0.004	0.045	0.027	0.014	0.009	0.016	0.010	0.028	0.010
MgO	1.12	0.32	0.63	0.77	0.38	0.26	0.31	0.20	0.50	0.27
CaO	1.60	<0.01	0.02	<0.01	0.01	0.02	0.02	0.02	0.01	0.05
Na_2O	2.66	0.13	0.17	0.06	0.04	0.07	0.13	0.14	0.05	0.28
K_2O	1.42	5.23	5.33	2.84	3.04	1.98	3.13	2.02	2.42	2.75
P_2O_5	0.02	0.04	0.05	0.09	0.04	0.04	0.04	0.03	0.06	0.07
LOI	4.86	4.29	5.43	12.72	8.71	10.33	7.66	7.07	7.01	5.94
Total	100.23	100.17	100.12	100.12	97.93	98.80	97.12	98.04	97.95	97.79
F (wt%)	0.06	0.04	0.06	0.09	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
CIA (%)	67.4	73.2	75.5	87.3	84.8	89.4	81.7	84.6	84.7	72.5
Rb (ppm)	90	190	266	236	134	103	122	98	97	191
Sr	306	155	133	48	9	8	17	10	8	23
Cs	1.5	2.8	6.1	6.6	3.6	3.0	2.8	4.0	4.0	30.8
Ba	328	1320	928	505	611	402	717	415	435	219
Sn	3	7	3	7	5	5	5	3	3	8
Zr	268	27	188	355	294	280	301	262	314	129
Hf	6.1	1.0	5.0	8.5	9.0	8.8	9.2	7.8	9.2	4.0
Nb	15.4	1.5	22.2	31.1	19.9	18.	17.8	14.7	16.9	9.2
Ta	0.65	0.97	2.48	2.35	2.08	1.92	1.73	1.39	1.56	1.56
V	37	15	66	169	22	22	20	14	23	23
Co	7	2	16	11	40	54	54	55	45	80
Zn	60	<30	40	60	70	50	60	40	100	<30
Ga	24	16	24	30	25	28	26	18	24	14
Ge	1	2	2	2	2	1	2	1	2	4
Pb	11	18	18	98	59	38	60	33	54	15
Th	13.1	4.94	32.1	69.2	28.4	32.9	27.3	18.8	21.1	9.65
U	6.0	1.66	3.68	12.3	3.59	3.66	4.00	2.63	5.83	4.51
Y	9.2	20.0	25.4	58.3	43.5	38.4	37.8	28.2	59.2	13.6
La	35.1	40.7	152	209	70.7	77.3	85.2	50.3	59.5	20.4
Ce	66.1	51.0	248	388	86.1	89.7	97.7	138	327	41.1
Pr	6.48	8.84	25.6	38.0	13.6	15.5	16.1	11.9	12.6	4.98
Nd	20.4	33.5	78.4	123.0	37.9	44.7	46.0	35.0	37.9	16.2
Sm	3.16	6.20	9.93	18.3	6.39	7.56	7.89	6.39	7.45	3.29
Eu	0.872	1.84	1.95	3.41	0.904	1.05	1.12	1.00	1.32	0.47
Gd	2.01	5.36	5.43	11.4	6.23	7.10	7.26	5.55	8.91	3.18
Tb	0.33	0.80	0.79	1.86	1.04	1.09	1.14	0.88	1.50	0.51
Dy	1.83	4.06	4.25	10.1	6.31	6.15	6.31	4.91	8.68	2.61
Ho	0.33	0.68	0.81	1.93	1.36	1.24	1.26	0.97	1.82	0.45
Er	0.95	1.76	2.35	5.65	4.46	3.99	3.96	3.10	5.77	1.25
Tm	0.133	0.226	0.350	0.829	0.705	0.638	0.622	0.503	0.914	0.186
Yb	0.87	1.34	2.24	5.17	4.51	4.08	3.98	3.23	5.80	1.17
Lu	0.142	0.180	0.342	0.778	0.678	0.625	0.605	0.477	0.869	0.171
ΣLREE	132.1	142.1	515.9	779.7	215.6	235.8	254.0	242.6	445.8	86.4
ΣHREE	6.6	14.4	16.6	37.7	25.3	24.9	25.1	19.6	34.3	9.5
ΣREE	138.7	156.5	532.4	817.4	240.9	260.7	279.1	262.2	480.0	96.0
ΣREE+Y	147.9	176.5	557.8	875.7	284.4	299.1	316.9	290.4	539.2	109.6
LREE/HREE	20.0	9.9	31.1	20.7	8.5	9.5	10.1	12.4	13.0	9.1
HREE/REE	0.05	0.09	0.03	0.05	0.10	0.10	0.09	0.07	0.07	0.10
Ce/Ce*	1.07	0.66	0.97	1.07	0.68	0.64	0.65	1.38	2.93	1.00
Eu/Eu*	1.06	0.98	0.81	0.72	0.44	0.44	0.45	0.51	0.50	0.44
La_N/Yb_N	28.9	21.8	48.7	29.0	11.2	13.6	15.4	11.2	7.4	12.5

Appendix 1 Continued.

Sequential #	51	52	53	54	55	56	57	58	59	60
Sample #	63004B	63005B	63005C	70101B	70101C	70102B	70102C	70103B	70104B1	70104B2
District	Nape	Nape	Nape	Nape	Nape	Nape	Nape	Nape	Nape	Nape
Rock type	W Gr	W Gr	W Gr	W Gr	W Gr	W Gr	W Gr	W Gr	W Gr	W Gr
Latitude	18°9.587'	18°17.439'	18°17.431'	18°18.552'	18°18.552'	18°18.811'	18°18.811'	18°19.219'	18°19.524'	18°19.524'
Longitude	105°11.961'	105°04.021'	105°04.013'	105°05.671'	105°05.671'	105°06.107'	105°06.107'	105°06.435'	105°06.586'	105°06.586'
SiO_2 (wt%)	71.44	72.61	71.04	64.42	68.70	71.32	67.19	66.70	53.90	65.95
TiO_2	0.31	0.21	0.21	0.43	0.41	0.32	0.49	0.30	0.43	0.34
Al_2O_3	13.38	14.67	14.18	18.33	14.76	12.76	14.06	17.49	22.96	17.53
Fe_2O_3*	2.07	2.06	2.14	3.73	3.55	2.54	3.98	2.30	3.67	2.84
MnO	0.018	0.065	0.058	0.039	0.051	0.04	0.05	0.04	0.017	0.03
MgO	0.39	0.22	0.46	0.65	1.05	0.49	1.23	0.29	0.33	0.28
CaO	0.10	0.03	0.69	0.02	0.41	0.04	0.34	0.03	0.04	0.07
Na_2O	0.64	0.14	2.46	0.18	0.76	0.20	3.27	0.13	0.10	0.09
K_2O	4.29	2.58	4.29	3.15	3.65	3.69	3.15	3.92	3.43	3.24
P_2O_5	0.10	0.06	0.07	0.05	0.07	0.06	0.08	0.06	0.06	0.05
LOI	5.83	5.40	2.69	7.61	5.30	6.31	4.11	7.17	13.23	7.45
Total	98.55	98.11	98.27	98.58	98.68	97.76	97.93	98.4	98.14	97.88
F (wt%)	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
CIA (%)	69.5	82.7	58.8	83.	71.3	74.4	59.9	79.5	85.3	82.3
Rb (ppm)	255	171	200	166	187	233	153	254	189	211
Sr	29	36	152	56	93	60	176	49	23	17
Cs	15.5	5.5	6.7	7.0	6.6	8.2	3.6	13.7	6.3	6.5
Ba	278	289	504	650	612	517	832	368	360	330
Sn	9	5	5	12	6	15	6	13	8	6
Zr	172	98	94	148	166	118	180	123	160	134
Hf	5.4	3.6	3.2	4.6	5.4	3.7	5.4	4.3	5.3	4.6
Nb	14.1	9.2	9.0	12.5	11.2	10.1	13.6	15.6	15.4	13.9
Ta	2.3	1.6	1.39	1.71	1.21	1.53	1.62	3.19	2.31	1.97
V	29	23	22	45	45	34	52	31	47	39
Co	86	61	62	63	73	41	65	84	33	52
Zn	40	40	40	50	50	50	50	30	30	<30
Ga	20	19	17	22	18	18	19	22	24	20
Ge	2	2	2	2	2	2	1	2	2	2
Pb	17	31	37	38	30	30	18	35	46	63
Th	11.1	9.98	9.56	18.0	18.1	15.2	22.1	16.0	19.1	16.6
U	5.70	8.76	3.18	7.44	6.31	5.31	6.59	17.7	10.4	9.02
Y	16.5	129	25.6	37.7	33.6	19.6	27.7	22.5	34.9	22.2
La	23.2	27.8	22.5	49.8	42.9	38.1	43.7	18.5	54.6	28.2
Ce	41.7	35.2	46.8	85.8	84.9	74.5	88.8	44.3	79.9	52.2
Pr	5.54	7.98	5.58	12.5	10.3	8.87	10.7	4.35	13.7	7.29
Nd	19.0	30.3	18.4	38.6	32.2	27.3	33.2	13.5	42.8	22.9
Sm	4.03	9.41	3.81	8.01	6.55	5.23	6.54	2.90	8.69	5.05
Eu	0.575	3.70	0.935	1.71	1.11	1.05	1.14	0.829	2.28	1.31
Gd	3.87	14.7	3.8	7.36	5.98	4.69	5.92	3.18	7.93	4.58
Tb	0.61	2.79	0.71	1.18	1.01	0.74	0.96	0.58	1.21	0.77
Dy	3.08	18.0	4.16	6.26	5.61	3.66	4.83	3.44	6.20	3.97
Ho	0.55	3.45	0.81	1.18	1.10	0.65	0.89	0.69	1.09	0.74
Er	1.52	9.81	2.44	3.65	3.45	1.84	2.52	2.18	3.25	2.20
Tm	0.223	1.48	0.399	0.556	0.535	0.266	0.381	0.376	0.492	0.346
Yb	1.40	8.91	2.56	3.50	3.36	1.61	2.27	2.50	3.16	2.30
Lu	0.199	1.16	0.366	0.492	0.492	0.228	0.314	0.365	0.443	0.324
Σ LREE	94.0	114.4	98.0	196.4	178.0	155.1	184.1	84.4	202.0	117.0
Σ HREE	11.5	60.3	15.2	24.2	21.5	13.7	18.1	13.3	23.8	15.2
Σ REE	105.5	174.7	113.3	220.6	199.5	168.7	202.2	97.7	225.7	132.2
Σ REE+Y	122.0	303.7	138.9	258.3	233.1	188.3	229.9	120.2	260.6	154.4
LREE/HREE	8.2	1.9	6.4	8.1	8.3	11.3	10.2	6.3	8.5	7.7
HREE/REE	0.11	0.35	0.13	0.11	0.11	0.08	0.09	0.14	0.11	0.12
Ce/Ce*	0.90	0.58	1.02	0.84	0.99	0.99	1.01	1.21	0.72	0.89
Eu/Eu*	0.45	0.96	0.75	0.68	0.54	0.65	0.56	0.83	0.84	0.83
La_N/Yb_N	11.9	2.2	6.3	10.2	9.2	17.0	13.8	5.3	12.4	8.8

Appendix 1 Continued.

Sequential #	61	62	63	64	65	66	67	68	69	70
Sample #	70106B	70106C	70107B	70107C	70108B	70109C	70111B	70112A	70112B1	70112B2
District	Nape	Nape	Nape	Nape	Nape	Nape	Nape	Nape	Nape	Nape
Rock type	W Gr	W Gr	W Gr	W Gr	W Gr	W Gr	W Gr	W Gr	W Gr	W Gr
Latitude	18°19.845'	18°19.845'	18°20.932'	18°20.932'	18°21.499'	18°22.071'	18°19.027'	18°19.797'	18°19.797'	18°19.797'
Longitude	105°06.848'	105°06.848'	105°07.79'	105°07.79'	105°8.026'	105°08.406'	105°02.474'	105°02.066'	105°02.066'	105°02.066'
SiO_2 (wt%)	56.19	72.30	68.63	67.50	70.07	62.93	74.93	68.85	74.45	65.03
TiO_2	0.96	0.20	0.32	0.61	0.23	0.53	0.27	0.26	0.23	0.31
Al_2O_3	18.17	14.92	16.95	14.34	14.61	15.77	12.37	14.40	11.77	17.28
Fe_2O_3*	6.74	1.63	1.92	4.24	1.98	4.58	2.29	3.21	2.62	3.16
MnO	0.075	0.022	0.013	0.042	0.018	0.063	0.007	0.021	0.014	0.022
MgO	2.56	0.26	0.37	1.52	0.21	1.41	0.10	0.28	0.25	0.37
CaO	0.15	0.03	0.02	0.15	0.02	0.65	0.02	0.04	0.04	0.04
Na_2O	0.09	0.18	0.09	0.49	0.14	0.83	0.03	0.12	0.10	0.22
K_2O	2.38	4.19	2.47	5.65	3.90	3.36	0.52	2.03	1.95	4.25
P_2O_5	0.16	0.05	0.04	0.10	0.07	0.07	0.02	0.04	0.04	0.04
LOI	9.99	5.24	7.15	3.71	6.46	5.43	7.43	8.73	7.04	6.28
Total	97.45	99.02	97.96	98.33	97.69	95.59	97.97	97.96	98.47	96.98
F (wt%)	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
CIA (%)	85.8	75.3	85.6	66.6	76.5	71.8	95.	85.4	83.4	77.4
Rb (ppm)	171	147	179	289	216	213	56	127	105	179
Sr	26	70	26	109	59	155	4	31	31	79
Cs	8.2	8.0	7.1	9.9	8.5	10.1	4.4	4.6	3.6	4.8
Ba	719	587	213	1200	331	1190	44	313	297	743
Sn	2	4	7	1	7	8	6	5	5	6
Zr	275	98	158	94	86	206	114	112	120	130
Hf	7.5	3.3	5.4	2.1	2.8	6.2	3.6	3.7	3.9	4.3
Nb	20.0	7.1	13.4	3.3	7.9	13.8	8.8	9.6	7.8	10.9
Ta	1.75	1.11	1.81	0.72	1.37	1.40	1.24	1.27	1.05	1.46
V	117	27	31	59	30	67	32	37	32	37
Co	87	75	60	68	39	71	87	98	30	57
Zn	140	<30	40	100	<30	80	<30	40	<30	40
Ga	32	19	21	22	17	22	16	19	16	21
Ge	2	2	2	2	2	2	2	2	1	2
Pb	31	41	42	54	74	23	11	34	18	46
Th	23.0	10.8	15.8	40.2	10.7	24.4	10.0	12.7	11.5	14.0
U	4.39	4.21	6.77	4.40	7.19	7.59	3.76	6.66	6.13	8.60
Y	20.7	15.5	19.8	20.7	15.8	35.4	14.2	33.7	37.7	53.1
La	48.0	17.8	28.5	77.3	52.8	79.0	13.6	39.5	45.8	53.4
Ce	93.2	41.3	58.2	153	79.9	132	30.0	79.5	67.0	83.2
Pr	11.2	4.18	5.77	19.0	11.5	18.5	3.14	9.19	12.2	14.5
Nd	35.2	12.9	17.0	56.7	32.9	56.1	9.52	27.8	37.7	46.2
Sm	6.42	2.64	3.15	10.9	5.77	10.7	1.86	5.67	8.09	10.4
Eu	1.13	0.570	0.471	1.54	1.23	2.20	0.279	1.42	1.98	2.76
Gd	5.08	2.34	2.50	8.22	4.60	8.95	1.77	5.33	7.33	9.77
Tb	0.80	0.44	0.50	1.11	0.69	1.39	0.34	0.95	1.20	1.74
Dy	3.94	2.45	3.06	4.61	3.31	6.80	2.06	5.39	6.42	9.60
Ho	0.71	0.49	0.64	0.70	0.54	1.23	0.44	1.04	1.22	1.80
Er	2.00	1.50	1.96	1.83	1.43	3.36	1.44	3.08	3.66	5.44
Tm	0.288	0.235	0.331	0.248	0.206	0.474	0.23	0.470	0.555	0.841
Yb	1.76	1.51	2.19	1.50	1.29	2.70	1.48	2.95	3.47	5.37
Lu	0.258	0.220	0.329	0.219	0.180	0.381	0.236	0.429	0.501	0.749
Σ LREE	195.2	79.4	113.1	318.4	184.1	298.5	58.4	163.1	172.8	210.5
Σ HREE	14.8	9.2	11.5	18.4	12.2	25.3	8.0	19.6	24.4	35.3
Σ REE	210.0	88.6	124.6	336.9	196.3	323.8	66.4	182.7	197.1	245.8
Σ REE+Y	230.7	104.1	144.4	357.6	212.1	359.2	80.6	216.4	234.8	298.9
LREE/HREE	13.2	8.6	9.8	17.3	15.0	11.8	7.3	8.3	7.1	6.0
HREE/REE	0.07	0.10	0.09	0.05	0.06	0.08	0.12	0.11	0.12	0.14
Ce/Ce*	0.99	1.17	1.11	0.98	0.79	0.85	1.13	1.02	0.69	0.73
Eu/Eu*	0.60	0.70	0.51	0.50	0.73	0.69	0.47	0.79	0.79	0.84
La_N/Yb_N	19.6	8.5	9.3	37.0	29.4	21.0	6.6	9.6	9.5	7.1

Appendix 1 Continued.

Sequential #	71	72	73	74	75	76	77	78	79	80
Sample #	70112C	70113B1	70113B2	70114B	70301B	70301B	70302A	70302B1	70302B2	70307A
District	Nape	Nape	Nape	Nape	Xaisom.	Xaisom.	Xaisom.	Xaisom.	Xaisom.	Xaisom.
Rock type	W Gr	W Gr	W Gr	W Gr	W Gr	W Gr	W Gr	W Gr	W Gr	W Gr
Latitude	18°19.797'	18°21169'	18°21169'	18°22.049'	18°40.438'	18°40.438'	18°40.774'	18°40.774'	18°40.774'	18°43.309'
Longitude	105°02.066'	105°02.232'	105°02.232'	105°02.012'	103°07.166'	103°07.166'	103°08.376'	103°08.376'	103°08.376'	103°19.850'
SiO_2 (wt%)	66.96	63.81	68.17	65.44	69.67	63.91	74.11	68.62	70.75	52.87
TiO_2	0.34	0.34	0.35	0.44	0.22	0.16	0.22	0.27	0.25	0.89
Al_2O_3	16.67	17.67	15.27	16.40	14.38	17.27	10.92	17.54	15.36	18.42
Fe_2O_3*	3.16	4.71	4.27	4.03	2.78	2.67	5.06	2.62	1.84	6.14
MnO	0.021	0.037	0.012	0.036	0.013	0.011	0.018	0.007	0.007	0.099
MgO	0.43	0.15	0.22	0.73	0.18	0.25	0.21	0.37	0.26	0.51
CaO	0.04	0.01	0.02	0.02	0.01	0.01	0.02	0.01	0.01	0.26
Na_2O	0.20	0.09	0.08	0.10	0.05	0.07	0.04	0.04	0.03	0.18
K_2O	4.46	1.52	1.73	2.17	0.81	1.33	0.77	1.52	1.18	3.31
P_2O_5	0.05	0.06	0.03	0.04	0.04	0.05	0.06	0.03	0.03	0.12
LOI	5.47	9.72	8.49	7.51	9.40	9.94	6.51	7.52	8.06	15.57
Total	97.76	98.09	98.63	96.90	97.53	95.65	97.92	98.54	97.75	98.36
F (wt%)	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
CIA (%)	76.1	90.7	88.2	86.5	93.6	91.7	92.1	91.	91.9	80.9
Rb (ppm)	242	92	127	119	88	153	68	143	116	219
Sr	58	19	16	37	6	6	6	6	4	178
Cs	7.6	4.5	6.0	6.9	8.1	11.1	4.8	7.6	5.9	5.0
Ba	684	150	190	543	43	40	57	77	46	961
Sn	6	10	11	3	20	20	10	38	14	4
Zr	148	109	126	196	105	90	122	135	134	165
Hf	4.6	3.7	4.0	6.1	4.3	3.9	4.2	4.9	4.5	5.1
Nb	12.2	12.0	10.6	12.1	8.7	11.6	7.1	11.3	10.2	12.4
Ta	1.56	1.61	1.76	1.16	1.99	2.75	1.41	2.6	1.99	1.64
V	41	44	46	50	28	44	39	27	18	92
Co	58	75	48	80	74	58	73	42	38	21
Zn	40	40	<30	50	<30	<30	<30	<30	150	70
Ga	20	23	19	21	21	27	16	24	20	23
Ge	2	2	2	2	2	3	1	2	2	2
Pb	44	32	17	30	19	22	15	26	26	106
Th	15.0	13.6	13.8	19.2	20.8	19.5	18.7	23.5	17.3	21.4
U	5.82	4.95	3.57	4.63	5.14	3.86	3.11	2.69	2.6	6.65
Y	34.9	24.4	14.4	37.4	34.6	45.1	25.5	36.5	29.8	77.9
La	37.3	34.4	21.7	49.8	12.4	9.99	14.8	21.5	28.7	232
Ce	61.3	59.9	32.2	95.2	26.1	22.7	29.4	43.7	56.4	375
Pr	9.66	8.37	5.07	12.5	3.21	2.77	3.64	5.25	6.43	48.7
Nd	31.6	27.4	15.3	39.3	11.3	12.1	12.2	18.1	21.2	144.0
Sm	6.41	5.35	2.91	7.96	2.54	2.75	2.47	3.46	3.60	26.4
Eu	1.72	1.27	0.686	1.62	0.186	0.160	0.298	0.371	0.361	7.50
Gd	6.17	4.78	2.55	7.29	3.29	4.12	2.88	3.95	3.45	19.3
Tb	1.09	0.83	0.42	1.20	0.83	1.06	0.63	0.85	0.69	2.73
Dy	6.01	4.46	2.31	6.38	5.46	7.12	3.93	5.56	4.45	13.4
Ho	1.13	0.81	0.45	1.21	1.11	1.45	0.81	1.14	0.90	2.34
Er	3.47	2.39	1.40	3.54	3.54	4.59	2.48	3.51	2.74	6.39
Tm	0.547	0.372	0.221	0.530	0.603	0.752	0.386	0.543	0.425	0.888
Yb	3.47	2.35	1.47	3.25	3.90	4.81	2.43	3.45	2.67	5.35
Lu	0.510	0.339	0.224	0.476	0.565	0.673	0.353	0.497	0.369	0.741
Σ LREE	148.0	136.7	77.9	206.4	55.7	50.5	62.8	92.4	116.7	833.6
Σ HREE	22.4	16.3	9.0	23.9	19.3	24.6	13.9	19.5	15.7	51.1
Σ REE	170.4	153.0	86.9	230.3	75.0	75.0	76.7	111.9	132.4	884.7
Σ REE+Y	205.3	177.4	101.3	267.7	109.6	120.1	102.2	148.4	162.2	962.6
LREE/HREE	6.6	8.4	8.6	8.6	2.9	2.1	4.5	4.7	7.4	16.3
HREE/REE	0.13	0.11	0.10	0.10	0.26	0.33	0.18	0.17	0.12	0.06
Ce/Ce*	0.79	0.87	0.75	0.94	1.01	1.06	0.98	1.01	1.02	0.86
Eu/Eu*	0.84	0.77	0.77	0.65	0.20	0.15	0.34	0.31	0.31	1.02
La_N/Yb_N	7.7	10.5	10.6	11.0	2.3	1.5	4.4	4.5	7.7	31.1

Appendix 1 Continued.

Sequential #	81	82	83	84	85	86	87	88	89	90
Sample #	70307B1	70307B2	70307C	70308B1	70308B2	70310B1	70310B2	70401A	70401B1	70401B2
District	Xaisom.	Xaisom.	Xaisom.	Xaisom.	Xaisom.	Xaisom.	Xaisom.	Xaisom.	Xaisom.	Xaisom.
Rock type	W Gr	W Gr	W Gr	W Gr	W Gr	W Gr	W Gr	W Gr	W Gr	W Gr
Latitude	18°43.309'	18°43.309'	18°43.309'	18°43.585'	18°43.585'	18°44.018'	18°44.018'	18°57.926'	18°57.926'	18°57.926'
Longitude	103°19.850'	103°19.850'	103°19.850'	103°24.419'	103°24.419'	103°25.311'	103°25.311'	103°18.082'	103°18.082'	103°18.082'
SiO_2 (wt%)	63.44	59.87	64.03	70.38	63.65	73.23	60.99	56.93	55.36	71.38
TiO_2	0.72	0.42	0.43	0.35	0.50	0.37	0.61	0.81	0.85	0.41
Al_2O_3	15.49	16.63	16.65	12.32	17.58	12.07	20.74	19.22	21.19	12.62
Fe_2O_3*	5.22	3.61	3.34	3.27	3.63	2.99	4.07	5.32	5.51	2.95
MnO	0.109	0.089	0.040	0.049	0.012	0.010	0.013	0.015	0.013	0.011
MgO	0.44	0.20	0.49	0.20	0.23	0.10	0.25	0.26	0.30	0.12
CaO	0.23	0.04	0.06	0.04	0.03	0.01	0.01	0.02	0.01	0.01
Na_2O	0.15	0.09	0.24	0.08	0.17	0.04	0.06	0.08	0.09	0.03
K_2O	3.04	4.22	6.71	1.61	4.02	0.69	2.63	1.07	1.21	0.44
P_2O_5	0.09	0.09	0.16	0.04	0.03	0.03	0.07	0.09	0.06	0.02
LOI	8.44	12.14	4.77	8.40	7.85	7.41	9.46	14.31	13.23	9.65
Total	97.35	97.38	96.92	96.72	97.68	96.91	98.88	98.10	97.81	97.63
F (wt%)	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
CIA (%)	79.7	77.6	68.2	86.4	79.	93.6	87.5	93.5	93.5	95.9
Rb (ppm)	184	136	291	90	141	73	223	74	67	31
Sr	154	88	142	20	34	5	8	21	20	7
Cs	4.2	2.3	4.9	3.0	2.4	3.7	6.2	5.9	5.8	2.6
Ba	876	598	966	289	775	95	392	157	155	59
Sn	4	3	3	6	9	5	8	5	5	3
Zr	159	145	160	208	282	200	332	321	283	200
Hf	4.9	4.6	5.2	6.6	8.5	6.3	9.9	9.4	8.3	5.6
Nb	10.3	8.0	8.5	10.2	15.2	8.9	15.8	21.9	21.7	13.8
Ta	1.31	1.2	1.45	1.22	1.84	1.08	1.65	2.55	2.51	1.8
V	76	53	59	37	40	36	54	83	92	38
Co	51	17	52	62	71	106	53	34	64	40
Zn	60	50	40	50	<30	<30	<30	<30	40	<30
Ga	19	22	25	17	22	16	27	25	29	19
Ge	2	2	3	2	2	2	1	1	2	1
Pb	95	47	23	37	54	27	50	17	13	16
Th	21.9	21.8	27.3	26.9	34.2	25.9	33.7	30.5	29.2	23.6
U	6.18	3.85	7.33	4.67	5.48	5.33	11.5	4.93	4.68	2.99
Y	105	150	164	59.8	70.4	17.4	17.2	11.6	11.1	5.8
La	325	558	1290	75	121	33.4	34.2	23.1	21.2	11.6
Ce	357	728	1070	141	110	136	74.2	28.1	25.8	13.5
Pr	66.9	137.0	255.0	18.2	28.2	7.74	8.41	4.16	3.80	1.91
Nd	195.0	394.0	764.0	58.8	84.3	22.5	24.2	11.3	11.5	5.05
Sm	33.6	68.3	113.0	12.0	16.7	4.29	4.64	1.93	2.07	0.85
Eu	9.39	17.7	29.7	2.01	2.67	0.599	0.571	0.416	0.395	0.149
Gd	26.1	43.9	71.3	11.5	15.9	3.33	3.60	1.78	1.89	0.81
Tb	3.43	5.73	7.64	1.93	2.25	0.58	0.65	0.31	0.29	0.14
Dy	16.8	27.9	33.0	9.79	11.4	3.14	3.45	1.84	1.82	0.84
Ho	2.87	4.45	5.20	1.82	2.10	0.61	0.66	0.40	0.39	0.19
Er	7.88	11.6	13.2	5.27	6.09	1.91	2.15	1.34	1.36	0.66
Tm	1.05	1.48	1.63	0.769	0.890	0.314	0.365	0.233	0.226	0.120
Yb	6.08	8.70	9.42	4.66	5.40	2.01	2.50	1.68	1.68	0.91
Lu	0.818	1.09	1.21	0.678	0.761	0.306	0.379	0.294	0.293	0.163
ΣLREE	986.9	1903.0	3521.7	307.0	362.9	204.5	146.2	69.0	64.8	33.1
ΣHREE	65.0	104.9	142.6	36.4	44.8	12.2	13.8	7.9	7.9	3.8
ΣREE	1051.9	2007.9	3664.3	343.4	407.7	216.7	160.0	76.9	72.7	36.9
ΣREE+Y	1156.9	2157.9	3828.3	403.2	478.1	234.1	177.2	88.5	83.8	42.7
LREE/HREE	15.2	18.1	24.7	8.4	8.1	16.8	10.6	8.8	8.1	8.6
HREE/REE	0.06	0.05	0.04	0.11	0.11	0.06	0.09	0.10	0.11	0.10
Ce/Ce*	0.59	0.65	0.46	0.94	0.46	2.07	1.07	0.70	0.70	0.70
Eu/Eu*	0.97	0.99	1.01	0.52	0.50	0.48	0.43	0.69	0.61	0.55
La_N/Yb_N	38.3	46.0	98.2	11.5	16.1	11.9	9.8	9.9	9.1	9.1

Appendix 1 Continued.

Sequential #	91	92	93	94	95	96	97	98	99	100
Sample #	70403B	70404B	P719CL1	P719CL2	P719CL3	P788CL	P798CL	P799CL	62804CL	62806CL
District	Xaisom.	Xaisom.	Attapu	Attapu	Attapu	Attapu	Boneng	Boneng	Boneng	Boneng
Rock type	W Gr	W Gr	Kln-rich	Kln-rich	Kln-rich	Kln-rich	Kln-rich	Kln-rich	Kln-rich	Kln-rich
Latitude	18°58.480'	18°52.091'	14°42.297'	14°42.297'	14°42.297'	14°47.868'	17°53.049'	17°53.059'	17°58.730'	17°58.730'
Longitude	103°19.385'	102°54.454'	107°32.964'	107°32.964'	107°32.964'	107°29.359'	104°36.243'	104°36.254'	104°18.5'	104°18.5'
SiO_2 (wt%)	73.54	87.78	74.97	72.20	72.30	57.47	34.92	38.31	51.93	55.25
TiO_2	0.21	0.08	0.04	0.26	0.24	0.68	0.94	0.83	0.23	0.27
Al_2O_3	14.17	5.99	16.71	17.97	17.20	22.96	26.27	31.25	25.80	24.93
Fe_2O_3*	1.92	0.85	0.43	1.89	1.73	5.22	22.94	12.99	3.09	3.35
MnO	0.012	0.004	0.038	0.002	0.006	0.011	0.040	0.087	0.011	0.007
MgO	0.20	0.17	0.37	0.17	0.29	0.61	0.62	0.88	0.26	0.27
CaO	0.01	0.01	<0.01	0.03	0.01	0.03	0.04	0.07	0.02	0.04
Na_2O	0.08	0.04	0.05	0.07	0.03	0.16	0.04	0.08	0.03	0.05
K_2O	0.62	0.97	2.74	0.18	0.23	5.24	1.56	7.26	1.44	1.53
P_2O_5	<0.01	0.02	<0.01	0.02	0.02	0.09	0.12	0.19	0.03	0.04
LOI	8.06	2.40	4.83	7.49	8.03	7.76	12.55	8.47	14.63	13.75
Total	98.80	98.29	100.18	100.30	100.09	100.23	100.04	100.41	97.44	99.47
F (wt%)	n.a.	n.a.	0.08	n.a.	0.02	0.04	0.04	0.03	n.a.	n.a.
CIA (%)	94.5	84.1	84.5	98	98.2	79.3	93.5	79.4	94	93.2
Rb (ppm)	47	56	386	32	36	192	92	360	105	105
Sr	3	5	<2	<2	<2	159	48	494	6	7
Cs	2.8	2.8	20	3.4	3.8	2.1	6.6	16.7	4.3	4.2
Ba	78	76	11	<3	4	1430	72	390	239	268
Sn	6	3	14	5	7	4	846	20	4	4
Zr	118	53	52	104	131	511	155	114	171	200
Hf	2.1	1.9	3.0	3.9	4.2	11.6	4.2	3.3	5.4	6.2
Nb	10.8	2.2	31.3	18.0	23.6	19.2	15.8	15.5	11.8	13.3
Ta	0.49	0.42	9.07	4.1	4.67	0.90	1.64	1.62	1.25	1.28
V	15	22	<5	16	22	40	205	153	22	23
Co	71	90	<1	1	2	4	7	4	51	49
Zn	30	<30	<30	<30	<30	40	230	160	70	60
Ga	17	7	26	15	20	28	37	31	27	28
Ge	2	1	2	<1	1	1	4	2	2	2
Pb	5	12	73	18	19	27	378	127	54	50
Th	4.61	5.98	14.0	23.9	26.4	31.2	27.9	24.6	25.6	26.3
U	1.05	1.74	5.19	7.2	7.88	3.35	5.43	6.24	3.12	3.13
Y	7.4	16.5	52.8	34	44.1	30.9	11.8	8.5	35.4	36.3
La	10.7	9.87	14.5	24.1	29.2	107	51.2	12.2	79.8	74.6
Ce	20.6	19.0	40.4	65.1	83.8	190	87.9	161	89.1	73.6
Pr	2.87	2.61	4.08	5.83	7.15	20.0	8.02	2.19	17.6	16.7
Nd	10.4	9.45	17.9	23.8	26.0	65.7	24.7	7.31	50.9	48.1
Sm	2.09	2.18	5.25	6.1	6.76	11.1	3.85	1.56	8.7	8.36
Eu	0.329	0.316	0.263	0.41	0.497	2.35	0.864	0.445	1.15	1.11
Gd	2.15	2.31	6.07	5.1	6.62	7.54	2.27	2.40	7.89	7.66
Tb	0.41	0.42	1.27	1.0	1.22	1.23	0.43	0.29	1.14	1.11
Dy	2.60	2.58	8.14	6.3	7.48	6.28	2.61	1.82	6.04	5.97
Ho	0.52	0.54	1.61	1.4	1.45	1.12	0.49	0.38	1.15	1.13
Er	1.58	1.62	4.97	4.1	4.60	3.01	1.43	1.29	3.52	3.53
Tm	0.24	0.243	0.815	0.62	0.777	0.412	0.228	0.24	0.544	0.536
Yb	1.57	1.53	5.32	4.10	5.03	2.55	1.55	1.80	3.42	3.36
Lu	0.223	0.219	0.797	0.58	0.707	0.368	0.235	0.284	0.499	0.506
Σ LREE	47.0	43.4	82.4	125.3	153.4	396.2	176.5	184.7	247.3	222.5
Σ HREE	9.3	9.5	29.0	23.2	27.9	22.5	9.2	8.5	24.2	23.8
Σ REE	56.3	52.9	111.4	148.5	181.3	418.7	185.8	193.2	271.5	246.3
Σ REE+Y	63.7	69.4	164.2	182.5	225.4	449.6	197.6	201.7	306.9	282.6
LREE/HREE	5.1	4.6	2.8	5.4	5.5	17.6	19.1	21.7	10.2	9.3
HREE/REE	0.17	0.18	0.26	0.16	0.15	0.05	0.05	0.04	0.09	0.10
Ce/Ce*	0.91	0.92	1.29	1.35	1.42	1.01	1.06	7.64	0.58	0.51
Eu/Eu*	0.47	0.43	0.14	0.22	0.23	0.79	0.89	0.70	0.42	0.42
La_N/Yb_N	4.9	4.6	2.0	4.2	4.2	30.1	23.7	4.9	16.7	15.9

Appendix 1 Continued.

Sequential #	101	102	103	104	105	106	107	108	109	110
Sample #	62811S	62812S	62813S	62813S	62813S	62816S	62817S	62819S	62902S	70110S
District	Boneng	Boneng	Boneng	Boneng	Boneng	Boneng	Boneng	Boneng	Nape	Nape
Rock type	Sediment	Sediment	Sediment	Sediment	Sediment	Sediment	Sediment	Sediment	Sediment	Sediment
Latitude	18°0.057'	17°59.808'	17°58.994'	17°58.994'	17°58.994'	18°10.191'	18°10.239'	18°9	18°09.560'	18°17.302'
Longitude	104°17.972'	104°17.884'	104°18.808'	104°18.808'	104°18.808'	104°17.101'	104°17.118'	104°17'	105°10.150'	105°2.844'
SiO_2 (wt%)	74.09	66.73	63.58	67.83	33.27	67.42	70.05	87.04	73.92	57.48
TiO_2	0.52	1.11	0.86	0.79	0.61	0.69	0.51	1.43	0.34	0.86
Al_2O_3	12.71	15.62	15.12	12.78	15.52	12.62	12.60	4.55	11.77	18.06
Fe_2O_3*	2.34	3.41	5.92	4.49	34.85	4.82	3.38	2.14	2.72	6.43
MnO	0.021	0.042	0.006	0.005	0.011	0.025	0.021	0.067	0.039	0.023
MgO	0.22	0.11	0.57	0.46	0.53	0.28	0.18	0.36	0.65	0.23
CaO	0.02	0.02	0.02	0.01	0.01	0.02	0.02	0.09	0.24	0.01
Na_2O	0.06	0.03	0.11	0.15	0.15	0.11	0.07	0.19	0.64	0.06
K_2O	0.87	0.47	3.20	2.79	3.39	1.12	0.71	0.28	4.13	0.80
P_2O_5	0.04	0.08	0.07	0.07	0.11	0.07	0.06	0.03	0.09	0.04
LOI	7.22	10.61	8.54	9.39	11.04	10.88	8.91	1.57	3.98	14.40
Total	98.09	98.20	97.98	98.75	99.49	98.05	96.50	97.73	98.50	98.39
F (wt%)	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
CIA (%)	92.2	96.3	80.4	79.6	79.8	89.8	93.2	85.4	66.4	94.8
Rb (ppm)	61	40	196	162	174	84	67	24	228	38
Sr	9	12	55	49	48	15	21	13	68	15
Cs	4.3	2.0	12.4	10.1	8.7	8.2	9.2	2.0	12.6	8.2
Ba	98	104	279	284	350	225	115	49	568	213
Sn	4	6	5	5	5	19	8	8	10	6
Zr	493	568	345	295	160	383	410	713	222	339
Hf	13.4	15.6	10.1	8.7	4.9	11.1	12.3	20.3	6.5	9.8
Nb	14.1	21.6	17.3	13.9	11.8	13.9	14.0	21.8	11.4	16.5
Ta	1.40	1.93	1.67	1.49	1.16	1.63	1.74	2.2	2.05	1.6
V	48	53	107	81	104	77	41	33	36	119
Co	42	42	29	39	24	64	80	156	90	46
Zn	50	80	40	30	140	40	40	70	60	70
Ga	21	20	23	19	22	21	21	11	16	25
Ge	1	1	2	2	2	2	1	1	2	2
Pb	26	32	31	28	47	33	25	164	32	17
Th	13.7	16.8	20.9	17.2	18.8	20.0	21.8	10.6	14.6	22.6
U	3.50	3.98	4.18	3.74	5.10	5.17	6.24	2.51	4.32	4.56
Y	13.1	15.3	32.6	29.6	24.5	18.1	19.6	13.3	24.1	19.4
La	22.7	36.3	50.2	41.1	42.9	25.5	40.0	24.2	33.9	17.1
Ce	51.8	71.1	98.3	81.6	84.3	43.4	75.1	47.9	68.7	47.7
Pr	4.92	7.49	11.7	9.59	10.0	5.53	8.85	5.52	8.22	3.74
Nd	14.8	21.3	35.5	29.2	30.8	16.3	26.0	16.6	25.4	11.1
Sm	2.75	3.79	6.40	5.44	5.50	3.03	4.76	2.78	4.94	2.25
Eu	0.544	0.765	1.21	1.12	1.07	0.506	0.578	0.316	0.836	0.494
Gd	2.13	3.17	5.51	4.88	4.45	2.80	4.14	2.43	4.45	2.55
Tb	0.38	0.52	0.97	0.87	0.75	0.51	0.68	0.37	0.73	0.47
Dy	2.17	2.81	5.43	4.90	4.17	3.03	3.61	2.06	3.90	2.89
Ho	0.46	0.56	1.08	1.00	0.84	0.62	0.67	0.45	0.74	0.63
Er	1.57	1.86	3.36	3.08	2.55	1.99	2.08	1.51	2.27	2.05
Tm	0.271	0.314	0.516	0.469	0.392	0.335	0.334	0.269	0.351	0.335
Yb	1.98	2.26	3.27	3.00	2.49	2.25	2.22	1.89	2.22	2.24
Lu	0.340	0.384	0.505	0.442	0.360	0.352	0.346	0.326	0.324	0.367
ΣLREE	97.5	140.7	203.3	168.1	174.6	94.3	155.3	97.3	142.0	82.4
ΣHREE	9.3	11.9	20.6	18.6	16.0	11.9	14.1	9.3	15.0	11.5
ΣREE	106.8	152.6	224.0	186.7	190.6	106.2	169.4	106.6	157.0	93.9
ΣREE+Y	119.9	167.9	256.6	216.3	215.1	124.3	189.0	119.9	181.1	113.3
LREE/HREE	10.5	11.8	9.8	9.0	10.9	7.9	11.0	10.5	9.5	7.1
HREE/REE	0.09	0.08	0.09	0.10	0.08	0.11	0.08	0.09	0.10	0.12
Ce/Ce*	1.20	1.06	0.99	1.01	1.00	0.90	0.98	1.02	1.01	1.46
Eu/Eu*	0.69	0.67	0.62	0.66	0.66	0.53	0.40	0.37	0.55	0.63
La_N/Yb_N	8.2	11.5	11.0	9.8	12.4	8.1	12.9	9.2	11.0	5.5

Appendix 1 Continued.

Sequential #	111	112	113	114
Sample #	P797OR1	P797OR2	P797CN1	P797CN2
District	Boneng	Boneng	Boneng	Boneng
Rock type	Sn ore	Sn ore	Sn Conc	Sn Conc
Latitude	17°53.027'	17°53.027'	17°53.027'	17°53.027'
Longitude	104°36.432'	104°36.432'	104°36.432'	104°36.432'
SiO_2 (wt%)	75.29	86.83	9.74	16.71
TiO_2	0.67	0.34	1.73	0.40
Al_2O_3	10.89	5.52	2.85	4.38
Fe_2O_3*	4.80	3.94	36.28	60.15
MnO	0.009	0.006	0.542	0.671
MgO	0.41	0.19	0.16	0.21
CaO	0.04	0.04	0.10	0.06
Na_2O	0.07	0.03	0.09	0.20
K_2O	1.51	0.55	0.21	0.42
P_2O_5	0.08	0.04	0.25	0.62
LOI	6.32	2.88	7.78	10.35
Total	100.09	100.37	59.73	94.17
F (wt%)	0.03	0.03	0.01	0.02
CIA (%)	85.7	88.5	83.6	83.1
Rb (ppm)	102	33	12	16
Sr	19	5	20	20
Cs	13.8	2.9	1.5	1.9
Ba	196	59	205	284
Sn	130	164	>1000	>1000
Zr	383	223	>10000	1020
Hf	10.0	5.7	706	28.0
Nb	11.6	5.4	50.1	7.5
Ta	1.22	0.67	4.42	0.75
V	75	33	224	179
Co	<1	<1	35	36
Zn	70	80	1080	1210
Ga	15	6	14	12
Ge	1	1	1	1
Pb	75	40	1030	1020
Th	16.8	8.9	51.2	11.6
U	2.81	1.64	45.1	5.88
Y	14.1	5.5	244	42.9
La	44.4	13.1	96.5	25.5
Ce	85.9	22.8	177	46.8
Pr	8.69	2.16	19.1	5.76
Nd	29.8	7.19	68.8	22.3
Sm	4.93	1.17	13.8	5.08
Eu	1.04	0.25	2.77	1.31
Gd	3.58	0.88	17.7	5.55
Tb	0.56	0.16	4.17	1.12
Dy	2.95	1.03	29.8	7.14
Ho	0.53	0.22	7.09	1.49
Er	1.57	0.68	26.6	4.65
Tm	0.243	0.122	5.03	0.752
Yb	1.75	0.89	38.9	5.13
Lu	0.315	0.156	7.50	0.812
Σ LREE	174.8	46.7	378.0	106.8
Σ HREE	11.5	4.1	136.8	26.6
Σ REE	186.3	50.8	514.8	133.4
Σ REE+Y	200.4	56.3	758.8	176.3
LREE/HREE	15.2	11.3	2.8	4.0
HREE/REE	0.06	0.08	0.27	0.20
Ce/Ce*	1.07	1.05	1.01	0.95
Eu/Eu*	0.76	0.75	0.54	0.75
La_N/Yb_N	18.2	10.6	1.8	3.6

Appendix 2 Result of sequential leaching of representative REE-rich weathered rock samples.

Sample #	Leaching step[*1]	Mn (ppm)	Zr (ppm)	Pb (ppm)	Th (ppm)	U (ppm)	Sc (ppm)	Y (ppm)	La (ppm)	Ce (ppm)	Pr (ppm)	Nd (ppm)	Sm (ppm)	Eu (ppm)	Gd (ppm)	Tb (ppm)	Dy (ppm)	Ho (ppm)	Er (ppm)	Tm (ppm)	Yb (ppm)	Lu (ppm)
P716B	Step 1	11.6	<0.08	5.07	0.987	1.27	0.5	45.8	138	164	24.8	84.3	14.8	3.02	12.9	1.83	9.21	1.65	4.53	0.542	3.18	0.445
	Step 2	0.4	<0.1	<1	1.0	<0.2	0.3	1.18	3.21	3.84	0.567	1.74	0.27	0.053	0.225	0.034	0.194	0.036	0.114	0.018	0.123	0.017
	Step 3	1.86	<0.4	0.37	0.045	0.036	0.3	0.40	1.0	1.66	0.204	0.672	0.115	0.025	0.096	0.017	0.089	0.016	0.044	0.005	0.028	0.005
	Step 4	3.01	<0.4	0.31	0.027	0.049	<0.2	0.053	0.131	1.29	0.032	0.087	0.016	0.004	0.017	0.005	0.013	0.003	0.007	0.002	0.007	0.003
	Step 5	27	0.3	4.67	17.0	0.7	0.7	1.0	7.6	15.7	1.4	4.98	0.7	0.1	0.6	0.1	0.3	0.1	0.1	<0.1	0.1	<0.1
	Step 6	23	13	13.2	3.4	0.9	n.a.	1.9	5.0	11.0	1.2	4.3	0.8	0.19	0.7	0.1	0.6	0.1	0.3	<0.1	0.2	<0.1
	Residue[*2]	73	470	9.4	15.1	2.0	n.a.	20.7	17.1	51.5	5.5	15.9	2.6	1.0	1.2	0.49	3.0	0.52	1.4	0.28	1.3	0.24
P725A	Step 1	3.7	0.11	7.06	1.79	2.92	1.2	3.48	18.9	39.4	3.86	12.8	1.94	0.348	1.51	0.172	0.746	0.132	0.366	0.043	0.274	0.039
	Step 2	<0.3	0.1	<1	1.2	<0.2	0.4	0.08	0.440	1.17	0.088	0.27	0.03	0.007	0.027	0.003	0.017	0.003	0.009	0.002	0.016	0.002
	Step 3	1.42	<0.4	1.09	0.101	0.079	0.4	0.132	0.582	14.5	0.122	0.382	0.055	0.013	0.069	0.009	0.031	0.006	0.014	0.003	0.014	0.004
	Step 4	2.28	<0.4	0.58	0.09	0.097	0.3	0.012	0.119	14.4	0.022	0.043	0.007	0.001	0.047	0.004	0.003	0.001	0.003	0.001	0.003	0.002
	Step 5	35	1.1	19.1	54.9	2.4	4.8	1.16	17.4	41.7	3.0	8.6	1.3	0.2	0.9	0.1	0.4	0.1	0.2	<0.1	0.1	<0.1
	Step 6	30	19	26.3	21.4	3.8	n.a.	1.9	47.0	36.9	7.9	21.6	2.9	0.46	1.7	0.2	0.8	0.1	0.3	<0.1	0.2	<0.1
	Residue	21	289	4.9	15.2	1.3	n.a.	2.7	67.6	162.9	8.5	18.9	1.6	0.29	n.v.	0.03	0.58	0.10	0.27	0.1	0.32	0.10
P788CL	Step 1	2.1	<0.08	3.61	0.642	0.762	0.4	15.0	41.0	76.3	8.79	29.6	5.26	1.12	4.74	0.672	3.41	0.592	1.59	0.195	1.17	0.162
	Step 2	<0.3	<0.1	<1	0.7	<0.2	<0.3	0.60	1.69	2.6	0.314	0.97	0.16	0.031	0.131	0.019	0.111	0.020	0.059	0.010	0.061	0.008
	Step 3	0.91	<0.4	0.56	0.087	0.043	0.4	0.224	0.558	1.44	0.123	0.405	0.07	0.016	0.058	0.012	0.049	0.011	0.025	0.004	0.018	0.005
	Step 4	1.93	<0.4	0.26	0.026	0.032	<0.2	0.02	0.16	1.27	0.034	0.072	0.012	0.002	0.011	0.004	0.006	0.002	0.004	0.001	0.003	0.002
	Step 5	16	0.1	3.61	21.5	0.9	0.2	1.78	26.9	50	4.9	15.6	2.1	0.3	1.5	0.2	0.7	0.1	0.2	<0.1	0.2	<0.1
	Step 6	16	7	15.6	2.5	0.4	n.a.	2.4	15.9	29.9	3.1	11.0	1.8	0.37	1.3	0.2	0.7	0.1	0.3	<0.1	0.2	<0.1
	Residue	48	504	3.4	5.7	1.2	n.a.	10.9	20.8	28.5	2.7	8.1	1.7	0.51	n.v.	0.12	1.3	0.30	0.83	0.2	0.90	0.19
P791B1	Step 1	30.7	<0.08	0.37	0.49	1.22	0.4	15.9	72.2	13.6	11.7	38.5	5.69	1.01	4.68	0.580	2.84	0.511	1.53	0.2	1.28	0.187
	Step 2	2.7	<0.1	<1	0.4	<0.2	<0.3	0.46	1.70	0.52	0.293	0.89	0.11	0.02	0.09	0.013	0.065	0.013	0.041	0.007	0.049	0.008
	Step 3	150	<0.4	1.13	0.279	0.068	0.4	0.283	0.999	3.32	0.191	0.591	0.092	0.019	0.079	0.014	0.054	0.013	0.03	0.005	0.027	0.006
	Step 4	7.08	<0.4	0.15	0.076	0.036	<0.2	0.038	0.196	5.09	0.038	0.089	0.013	0.002	0.023	0.004	0.007	0.002	0.006	0.001	0.007	0.002
	Step 5	14	0.4	0.95	25.3	0.9	0.4	1.67	62.4	121	10.8	30.6	3.0	0.4	1.8	0.1	0.5	0.1	0.2	<0.1	0.2	<0.1
	Step 6	28	20	10.5	1.8	0.6	n.a.	1.0	5.8	11.9	1.2	3.8	0.6	0.16	0.4	<0.1	0.3	0.1	0.2	<0.1	0.2	<0.1
	Residue	116	168	4.9	3.8	0.9	n.a.	6.0	8.7	92.6	1.4	3.9	0.43	0.34	n.v.	0.08	0.48	0.07	0.34	0.14	0.48	0.14
P791B2	Step 1	13.6	<0.08	12.7	0.527	6.84	0.4	35.4	159	23.1	26.9	86.9	12.4	2.25	10.1	1.28	6.14	1.12	3.32	0.438	2.81	0.414
	Step 2	0.8	<0.1	<1	0.4	<0.2	<0.3	0.77	3.19	0.62	0.558	1.68	0.2	0.035	0.164	0.02	0.107	0.023	0.068	0.012	0.082	0.012
	Step 3	69.6	<0.4	5.92	0.077	0.074	0.2	0.189	0.803	4.42	0.143	0.443	0.064	0.015	0.061	0.009	0.036	0.007	0.019	0.003	0.016	0.003
	Step 4	8.2	<0.4	1.08	0.08	0.067	<0.2	0.04	0.179	18.1	0.052	0.135	0.028	0.004	0.07	0.007	0.012	0.003	0.007	0.002	0.008	0.003
	Step 5	28	0.4	23.6	56.6	2.6	2.5	3.73	47.0	154	9.0	28.2	4.0	0.5	2.8	0.3	1.1	0.2	0.6	0.1	0.6	0.1
	Step 6	18	43	28.1	2.5	1.6	n.a.	2.9	4.7	10.2	1.0	3.9	0.8	0.14	0.8	0.1	0.9	0.2	0.6	0.1	0.6	0.1
	Residue	71	312	26.6	9.0	1.1	n.a.	15.3	n.v.	177.6	0.35	1.7	0.81	0.47	n.v.	0.1	1.8	0.38	1.0	0.17	1.1	0.15

*1 See text for the reagent and experimental method of the leaching at each step.
*2 Determined by subtracting the concentration of step1 - 6 from the concentration of the total fusion analysis.
n.a. = Not analyzed, n.v. = Negative value

Appendix 2 Continued.

Sample #	Leaching step	Mn (ppm)	Zr (ppm)	Pb (ppm)	Th (ppm)	U (ppm)	Sc (ppm)	Y (ppm)	La (ppm)	Ce (ppm)	Pr (ppm)	Nd (ppm)	Sm (ppm)	Eu (ppm)	Gd (ppm)	Tb (ppm)	Dy (ppm)	Ho (ppm)	Er (ppm)	Tm (ppm)	Yb (ppm)	Lu (ppm)
	Step 1	39.8	<0.08	10.5	0.387	0.641	0.4	14.8	27.2	51.1	5.68	20.4	3.51	0.578	3.33	0.483	2.62	0.499	1.44	0.18	1.11	0.153
	Step 2	2.6	<0.1	<1	0.3	<0.2	<0.3	0.48	0.76	1.87	0.157	0.54	0.08	0.015	0.077	0.012	0.07	0.015	0.046	0.008	0.059	0.009
	Step 3	26.9	<0.4	3.74	0.061	0.065	0.4	0.842	0.964	4.67	0.214	0.787	0.155	0.029	0.154	0.03	0.142	0.03	0.083	0.013	0.071	0.014
62810B	Step 4	12.4	<0.4	1.43	0.031	0.076	<0.2	0.922	0.801	28.0	0.172	0.574	0.122	0.023	0.212	0.032	0.135	0.03	0.076	0.013	0.055	0.014
	Step 5	57	0.3	13.6	14.7	2.8	2.5	15.3	14.1	49.4	2.8	10.2	2.3	0.4	2.8	0.4	2.8	0.6	1.9	0.3	1.7	0.3
	Step 6	16	26	10.1	1.8	1.2	n.a.	6.3	5.8	6.0	1.0	3.1	0.6	0.14	0.7	0.2	3.8	0.3	1.1	0.2	1.2	0.2
	Residue	62	288	14.6	3.8	1.0	n.a.	20.6	9.9	186.0	2.6	2.3	0.68	0.14	1.6	0.34	n.v.	0.35	1.1	0.2	1.6	0.18
	Step 1	93.7	<0.08	15.2	0.844	0.863	1.9	42.0	165	62.3	29.8	108	19.0	4.74	13.9	1.73	8.	1.36	3.72	0.431	2.6	0.354
	Step 2	7.4	0.4	<1	0.9	<0.2	1.5	2.02	5.67	10.1	1.26	4.19	0.7	0.166	0.473	0.063	0.326	0.061	0.208	0.035	0.273	0.038
	Step 3	337	<0.4	8.97	0.037	0.053	0.5	2.19	6.92	29.9	1.45	5.17	0.896	0.222	0.645	0.093	0.449	0.078	0.216	0.03	0.171	0.024
70307A	Step 4	33.1	<0.4	2.48	0.013	0.058	<0.2	0.376	0.837	16.7	0.205	0.622	0.132	0.036	0.135	0.022	0.07	0.014	0.035	0.007	0.033	0.009
	Step 5	87	1.0	32.1	14.2	3.1	5.5	5.99	27.4	54.6	4.9	16.9	3.1	0.8	2.4	0.3	1.7	0.3	0.8	0.1	0.8	0.1
	Step 6	36	19	20.8	0.3	1.3	n.a.	0.5	1.3	1.6	0.3	1.0	0.2	0.07	0.2	<0.1	0.2	<0.1	0.1	<0.1	0.1	<0.1
	Residue	173	145	26.5	5.1	1.3	n.a.	24.8	24.9	199.8	10.8	8.1	2.4	1.5	1.5	0.52	2.7	0.53	1.3	0.29	1.37	0.22
	Step 1	51.3	<0.08	11.5	0.428	0.667	1.5	85	302	27.2	56.5	184	31.1	7.6	23.1	2.84	13.3	2.27	6.14	0.713	4.01	0.56
	Step 2	5.7	0.3	<1	0.5	<0.2	1.4	2.92	8.39	2.72	1.62	5.22	0.88	0.208	0.587	0.083	0.422	0.078	0.259	0.045	0.329	0.045
	Step 3	453	<0.4	9.87	0.03	0.05	0.3	1.96	6.49	21.0	1.32	4.3	0.734	0.19	0.581	0.088	0.405	0.073	0.201	0.029	0.154	0.022
70307B1	Step 4	43.3	<0.4	2.85	0.02	0.079	<0.2	0.463	1.13	26.1	0.292	0.853	0.19	0.05	0.209	0.026	0.099	0.02	0.054	0.01	0.048	0.01
	Step 5	80	1.4	28.7	18.5	3.1	5.2	8.54	41.1	66.8	7.6	25.2	4.8	1.2	3.5	0.5	2.4	0.4	1.1	0.2	0.9	0.1
	Step 6	40	23	18.2	1.6	1.5	n.a.	2.7	9.8	11.1	1.7	5.8	1.2	0.32	1.0	0.1	0.8	0.2	0.4	0.1	0.4	<0.1
	Residue	171	134	23.9	0.8	0.8	n.a.	3.4	n.v.	202.1	n.v.	n.v.	n.v.	n.v.	n.v.	n.v.	n.v.	n.v.	n.v.	n.v.	0.24	0.08
	Step 1	73.9	<0.08	1.95	0.253	0.339	0.8	54.4	421	16.8	87.5	296	42.8	9.58	26.3	3.03	12.8	1.96	5.31	0.572	3.44	0.429
	Step 2	4.7	<0.1	<1	0.2	<0.2	<0.3	1.58	9.0	0.76	1.97	5.93	0.93	0.199	0.556	0.067	0.313	0.05	0.152	0.023	0.165	0.02
	Step 3	414	<0.4	6.74	0.06	0.054	0.3	1.8	8.42	23.1	2.2	7.03	1.24	0.297	0.761	0.112	0.502	0.081	0.216	0.03	0.178	0.026
70307B2	Step 4	29.5	<0.4	1.45	0.038	0.084	<0.2	1.54	4.86	75.8	1.25	3.44	0.779	0.199	0.704	0.09	0.393	0.062	0.164	0.022	0.122	0.019
	Step 5	24	0.4	4.91	16.6	1.4	3.7	30.0	138	176	25.9	86.6	17.2	4.1	11.4	1.5	7.3	1.1	2.7	0.4	2.1	0.2
	Step 6	13	11	5.9	1.6	0.8	n.a.	5.0	12.3	23.1	2.8	10.2	2.1	0.55	1.6	0.2	1.1	0.2	0.6	0.1	0.4	0.1
	Residue	130	134	26.1	3.0	1.2	n.a.	55.7	n.v.	412.4	15.4	n.v.	3.3	2.8	2.6	0.73	5.5	1.0	2.5	0.33	2.3	0.30
	Step 1	52.4	<0.08	1.59	0.163	0.279	0.7	43.3	525	19.3	89.3	324	39.0	8.46	24.7	2.47	9.41	1.52	4.49	0.474	2.79	0.385
	Step 2	5.2	<0.1	<1	<0.1	<0.2	<0.3	2.23	22.6	1.49	3.98	14.0	1.72	0.356	1.04	0.108	0.423	0.071	0.216	0.03	0.191	0.025
	Step 3	110	<0.4	3.73	0.053	0.087	0.5	4.84	38.5	22.3	7.2	24.5	3.34	0.801	2.19	0.262	1.12	0.181	0.482	0.06	0.322	0.048
70307C	Step 4	16.3	<0.4	0.86	0.021	0.09	<0.2	2.1	12.4	35.6	2.44	7.14	1.27	0.329	0.967	0.12	0.477	0.077	0.194	0.024	0.132	0.019
	Step 5	34	0.7	6.12	19.3	3.5	5.2	51.4	459	541	83.1	277	43.2	10.3	28.9	2.9	12.1	1.8	4.1	0.5	2.6	0.3
	Step 6	26	12	15.1	4.2	1.9	n.a.	12.6	97.1	140	17.1	58.7	9.7	2.3	6.0	0.6	2.9	0.5	1.2	0.2	0.9	0.1
	Residue	66	147	n.v.	3.6	1.5	n.a.	47.5	135.4	310.3	51.9	58.7	14.77	7.2	7.5	1.2	6.6	1.1	2.5	0.34	2.5	0.33

ラオス中南部における花崗岩類とその風化殻中の希土類元素の濃集

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要　旨

イオン吸着型希土類鉱化作用の資源ポテンシャルを評価することを目的として、ラオス中南部における花崗岩類とその風化殻の地球化学的特徴を本稿において報告する。調査地域の花崗岩類は主に黒雲母±普通角閃石花崗閃緑岩および花崗岩であり、総希土類含有量は低ないし中程度 (36-339 ppm) である。これらの花崗岩類は中国南部や西南日本の重希土類に富む花崗岩に比べると軽希土類に富み重希土類に乏しい。この重希土類の濃集における違いは花崗岩としてマグマの分化が十分でなかったことに起因すると考えられる。花崗岩類の風化殻は全体的に発達しており、カオリンやイライトに富む。風化殻は上部から下部に向かって A、B、C 層に分類され、B 層は原岩に比べて希土類に富むが、A 層と C 層は一般に希土類含有量が減少するかわずかに増加する程度である。比較的高い希土類含有量を示す風化殻はアタプー地区とサイソンブーン地区において確認される。地球化学データと段階溶出実験結果は、これらの風化殻において希土類の濃集がイオン交換性粘土鉱物や希土類リン酸塩に起因すること、風化によって軽希土類に比べ重希土類が選択的に粘土鉱物に吸着されていることを示唆する。

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