Table 4. Major, minor and REE* in the microgranites of Bhatikhera

Major	BK-2	BK-3	Minor	BK-2	BK-3	REE	BK-2	BK-3
SiO_2	72.81	70.65	Cu	29	16	La	842	942
TiO_2	0.18	0.19	Ni	13	13	Ce	2040	2154
Al_2O_3	7.63	6.01	Zn	846	1338	Pr	224	242
Fe_2O_3	8.28	8.72	Co	22	27	Nd	956	1034
FeO	0.72	0.5	Pb	< 10	232	Sm	238	244
MnO	0.15	0.15	Mo	< 10	< 10	Eu	16	16
MgO	0.13	0.3	V	23	< 10	Gd	232	234
CaO	0.99	2.02	Sr	34	63	Tb	25	25
Na_2O	5.57	3.72	Ba	49	52	Dy	262	268
K_2O	0.95	3.83	Zr	12,383	12,120	Ho	25	19
P_2O_5	< 0.01	< 0.01	Nb	624	649	Er	173	174
H_2O^-	0.12	0.02	Ta	< 50	<50	Tm	23	24
LOI	1.16	1.8	Y	1466	1472	Yb	150	153
			Rb	58	290	Lu	18	19
			Li	112	29	Sc	< 10	< 10
			Be	< 10	90			

*Analysed at Chemical Laboratory, AMD, Jaipur.

peralkaline rocks in the McDermitt and Virgin Valley calderas and are strongly enriched in trace elements associated with epithermal precious-metal deposits like As, Au, Ag, Mo and Sb (ref. 8). Presence of high LREE, Zr, Nb, Th and uranium along with silver in surface samples in the SRC, makes it a potential target for volcanogenic multimetal radioactive mineralization.

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Occurrence of rare earth elements in parts of Nongpoh granite, Ri-Bhoi district, Meghalaya

Rare earth element (REE) minerals occur in a diverse range of igneous, sedimentary and metamorphic rocks in various geological environments such as in beach placers, peralkaline granites, syenites, pegmatites, carbonatites, residual laterites, phosphorites, hematitic granite breccia and ion adsorption clays[1–6]. There are many favourable geological environments in north eastern India where REE mineralization can be searched[7–9]. Different ultramafic–alkaline–carbonatite complexes intruded in the Shillong plateau in North East India, e.g. the Sung Valley (Jaintia Hills), Jasra (Karbi-Anglong), Samchampi and Barpung (Mikir Hills, Assam) are favourable geological provinces for REE mineralization[7,8,10,11]. Apart from alkaline carbonatite complexes, several granitic plutons of alkaline and calc-alkaline nature have intruded in the Shillong plateau. This correspondence reports the significant occurrence of REEs within porphyritic and non-porphyritic varieties of calc-alkaline Nongpoh pluton from Meghalaya and also the possible occurrence of ion-adsorbed-type REE mineralization associated with these granites.

The Neoproterozoic–Cambrian Nongpoh pluton is intrusive into the Precambrian gneissic complex and Umsning schist belt of the Shillong plateau (Figure 1). The Nongpoh pluton comprises dioritic, granodioritic intrusives and two granite variants, viz. porphyritic granite and non-porphyritic granite[10]. The porphyritic granite is exposed in and around Nongpoh, covering an area of about 200 sq. km in the Survey of India (SoI) Toposheet No. 78 O/13. Apophyses of granite within gneisses and caught-up patches/rafts and enclaves of older gneisses of variable dimensions within the granite are the characteristics. The rock is medium grey in colour, hard and compact, medium- to coarse-grained consisting of K-feldspar, plagioclase, quartz, biotite, amphibole and pyrite. The phenocrysts are mainly K-feldspar and show a general E–W alignment along the contact near Shangbangla and Pahamrioh, which imparts a magmatic foliation; but are randomly oriented away from the contact. The longer axis of flesh-red and white-coloured K-feldspar phenocrysts occasionally ranges up to 10 cm. Microscopically, it consists of plagioclase (Pl), microcline (Mc), quartz (Qtz) and orthoclase (Or) as major minerals, whereas biotite (Bt) and hornblende (Hbl) occur as minor minerals and apatite (Ap), sphene (Spn), zircon (Zrn) and opaques occur as accessory minerals (Figure 2 *a*). The rock shows porphyritic texture. Hypidiomorphic granular, myrmekitic and perthitic textures are characteristics.

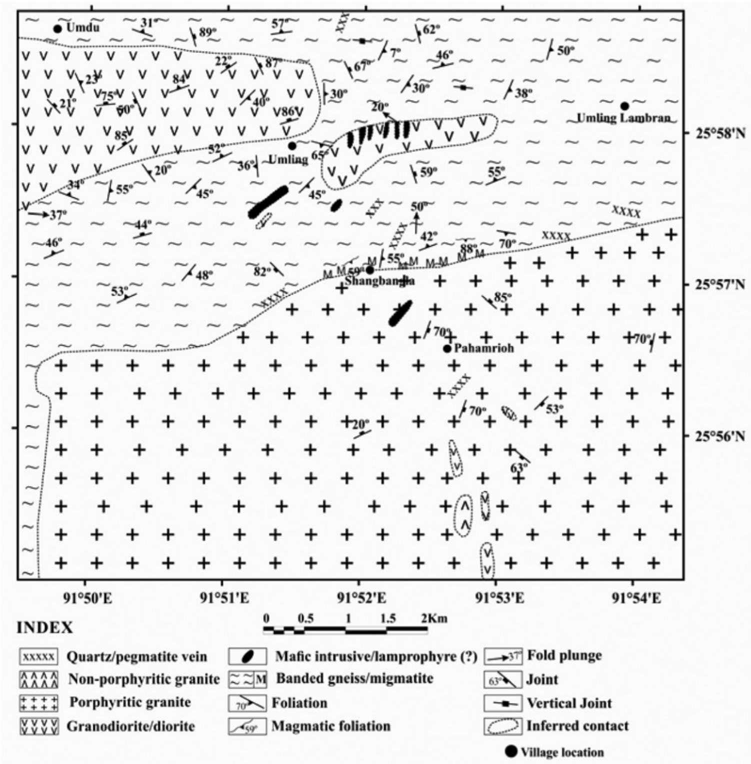

Figure 1. Large-scale geological map in parts of 78 O/13, Ri-Bhoi district, Meghalaya.

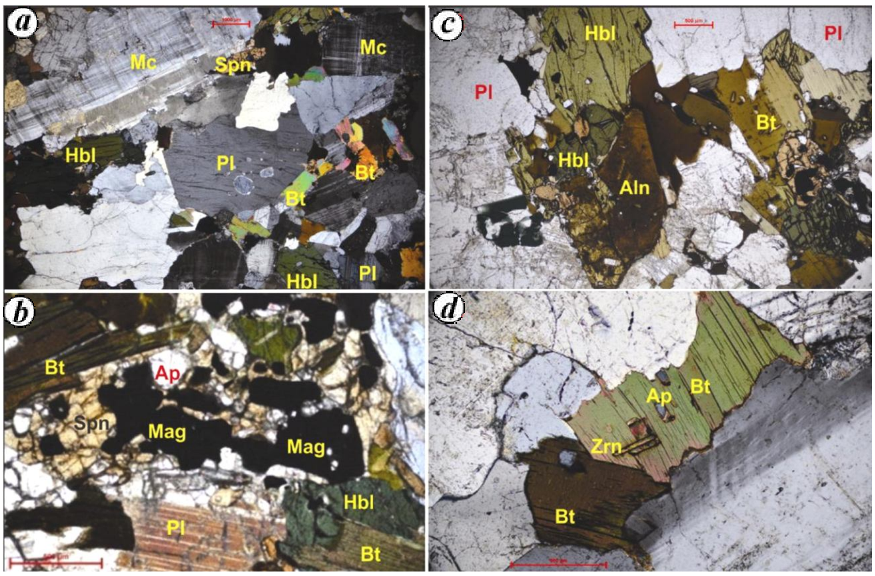

Figure 2. Photomicrographs of porphyritic granite. ***a***, Hypidiomorphic texture. ***b***, Development of secondary sphene around magnetite and associated with apatite. ***c***, ***d***, REE-bearing phases, viz. allanite, sphene, apatite and zircon.

Medium-grained, light to dark grey-coloured non-porphyritic granite is exposed around Nongpoh and Pahamrioh covering an area of about 46 sq. km in SoI Toposheet No. 78 O/13 and petrographically consists of plagioclase, quartz, microcline, orthoclase, hornblende and biotite. It is characteristically a biotite granite and is younger than the porphyritic granite[12].

The soil cover developed over granites ranges from a few metres to more than 40 m in a few places. Besides, bedrock samples, soil sample was also collected from the thick soil profile developed over the granites to locate ionic or ion-adsorption-type REE mineralization developed in association with the weathered granites.

Bedrock and soil samples were collected from the porphyritic granite and analysed in the Central Chemical Laboratory, Geological Survey of India, Kolkata using ICP-MS for its REE content (Table 1). The four bedrock samples of the porphyritic granite contain $\sum$REE + Y + Sc in the range between 697.62 and 985.59 ppm with an average value of 853.38 ppm (LREE ranges between 585.62 and 855.55 ppm and HREE ranges between 44.95 and 58.15 ppm). These REE values may be due to minor and accessory mineral phases in granite such as sphene, apatite, allanite, monazite, zircon (Figure 2 *b*–*d*). One sample from the soil

Table 1. REE analysis (in ppm) of bedrock sample (BRS) and soil sample (SS)

Element/ sample no	Porphyritic granite				Non-porphyritic granite		Soil cover
	BRS-1	BRS-26	BRS-27	BRS-28	BRS-30	BRS-31	SS-32
Sc	15.00	20.00	23.00	16.00	24.00	14.00	28.00
Y	43.00	55.00	61.00	51.00	59.00	67.00	56.00
La	196.09	225.96	174.88	153.26	161.05	159.15	259.10
Ce	359.11	386.41	317.36	261.65	299.02	295.74	478.49
Pr	42.60	50.41	44.53	34.83	40.91	41.10	59.18
Nd	145.23	164.74	153.67	115.54	139.44	140.10	196.74
Sm	23.36	28.03	28.39	20.34	25.36	26.72	32.95
Eu	4.22	4.90	4.43	3.23	2.86	2.98	5.62
Gd	17.61	18.38	18.25	13.70	17.49	17.93	21.46
Tb	2.02	2.64	2.87	2.13	2.77	2.99	3.01
Dy	9.37	12.02	13.65	10.20	13.57	14.84	13.78
Ho	1.63	2.41	2.74	2.15	2.72	3.00	2.65
Er	4.46	6.02	6.70	5.48	6.69	7.14	6.60
Tm	0.67	1.04	1.12	0.99	1.10	1.25	1.17
Yb	4.31	6.63	7.28	6.18	6.77	7.38	7.27
Lu	0.66	1.00	1.11	0.94	1.01	1.05	1.16
LREE	766.39	855.55	718.83	585.62	665.78	662.81	1026.46
HREE	44.95	55.04	58.15	45.00	54.98	58.56	62.72
HREE + Y	87.95	110.04	119.15	96.00	113.98	125.56	118.72
∑REE + Y + Sc	869.34	985.59	860.98	697.62	803.76	802.37	1173.18

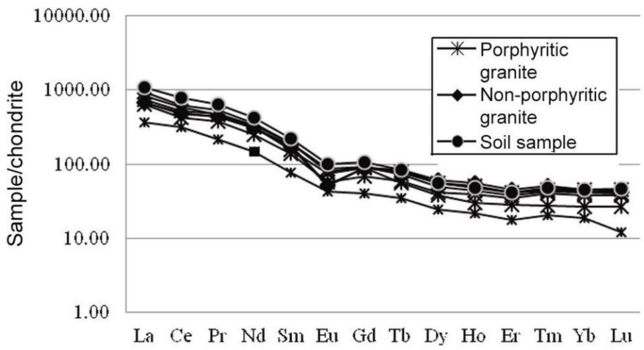

Figure 3. Chondrite-normalized REE diagram[13] showing LREE enrichment and negative Eu anomaly.

developed over the porphyritic granite contains ∑REE 1173.18 ppm (LREE 1026.46 ppm and HREE 62.72 ppm). The soil cover developed over granite shows a higher concentration of total REE, which is a possible indication of secondary/ion-adsorption-type REE enrichment. Ion-adsorption ores are known from China (Long Nan, Yianxi, Southern China)[6]. The two bedrock samples of the non-porphyritic granite contain almost identical values of ∑REE is 803.76 and 802.37 ppm with an average value of 803.07 ppm (LREE ranges between 662.81 and 665.78 ppm and HREE ranges between 54.98 and 58.56 ppm).

Chondrite-normalized REE diagram[13] of Nongpoh granites (porphyritic granite, non-porphyritic granite and soil sample) shows fractionated REE trend with negative Eu anomaly (Figure 3). The REE pattern of soil developed over the porphyritic granite faithfully represents the source rock as it shows similar REE pattern like the porphyritic granite. Eu^{2+} cations are similar in size and carry the same charge as Ca^{2+} in plagioclase and other minerals. While Eu is an incompatible element in its trivalent form (Eu^{3+}), in an oxidizing magma, it is preferentially incorporated into plagioclase in its divalent form (Eu^{2+}) in a reducing magma where it substitutes for calcium (Ca^{2+}) (ref. 14).

Enrichment or depletion of Eu is generally attributed to its tendency to be incorporated into plagioclase preferentially over other minerals. A positive Eu anomaly occurs if a magma crystallizes plagioclase and most of the Eu is incorporated into this mineral causing a higher-than-expected concentration of Eu in the mineral versus other rare earths in that mineral. If the Eu-depleted magma is then separated from its plagioclase crystals and subsequently solidifies, its chemical composition will display a negative Eu anomaly as in the present case. LREE enrichment in the samples is due to the presence of LREE-rich accessory and minor mineral phases present in the granites discussed above.

The Nongpoh pluton covers a large area. This finding opens a scope for search of REE mineralization and further evaluation of the REE potential in different varieties of granite of the Nongpoh pluton and residual clays developed in association with the granites. Since the Shillong plateau is intruded by several batholithic granitoids (Kyrdem, Mylliem, South Khasi, Rongjeng, Sindhuli granitoids and isolated granitic pluton around Samingiri–Dilsekgiri in West Garo Hills[15]), the present outcome may indicate that these granitoids of the Shillong plateau are possibly worth examining for their REE abundance.

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