accurate micro-level ground information about the variations in the piezometric surface of the water levels.

- The site-specific case study of Yelahanka has evidently brought out the impact of withdrawal of groundwater from the nearby BWSSB public water supply bore well over the piezometric water levels of the monitoring well, indicating mutual connectivity of potential fractures between the monitoring well and the public water supply well.
- Though there is not much variation in the quantum of rainfall during the period from April 2011 to July 2012 at the Yelahanka and Hebbal RG stations (966 mm and 957 mm respectively), there has been an appreciable decline in the piezometric level at Hebbal station from October 2011 to July 2012, whereas in the case of Yelahanka, the piezometric level remained almost consistent (except during February 2012), in spite of the impact of withdrawal of groundwater from the public well in the vicinity. This probably indicates the groundwater recharge almost being equivalent to the withdrawal.
- In spite of rainfall of 1098 mm from April 2011 to November 2011, there was a net decline of 41.54 m in the piezometric water level at HSR layout monitoring station, indicating groundwater withdrawal in excess of recharge. Further, from December 2011 (64.50 mbgl) to March 2012 (91.80 mbgl), the piezometric water level reached a maximum depth with a net decline of 79 m, resulting in the piezometer going dry.
- Considering the wide extent of 800 sq. km of Bangalore city and wide variation in the geomorphological, geological and geo-hydrological set-up and heterogeneity of aquifer condition, it is necessary to establish at least one high-frequency water-level monitoring station for each of the 10 sq. km grid area. The data generated from increasing the monitoring stations can be one of the important source materials for specific groundwater modelling to address various geo-hydrological issues.

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Anomalous silver concentration in volcano-plutonic rocks of Siwana Ring Complex, Barmer district, Western Rajasthan

Acid plutonic-volcanic caldera-related environments provide an ideal setting for uranium, thorium and rare metal concentrations. Siwana Ring Complex (SRC) is a well-preserved, ENE–WSW trending elliptical-shaped collapsed caldera structure measuring 30 km × 25 m, comprising basalt–rhyolite–pyroclastic sequence intruded by peralkaline–aegirine–reibeckite-rich granites along the sub-circular fractures. These rock units are traversed by agpaitic, rare earth elements (REE)-rich, felsite, microgranite and aplite dykes of varied dimension all along the periphery of SRC and also within the central caldera sequences. The rocks in SRC are exposed along Ramaniya–Mokalsar–Deora–Kitnod–Indrana–Siner–Kundal area in the Survey of India toposheet numbers 45 C/2, 6, and 10 (Figure 1). The volcano-plutonic complex has been extensively studied for its stratigraphy, geology, structure, petromineralogy, geochemistry and geochronological aspects[1–4].

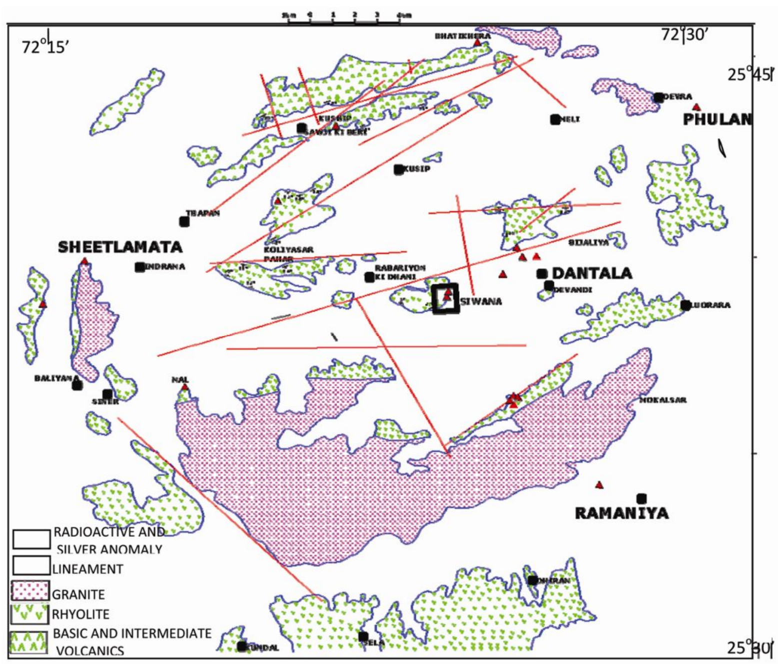

Figure 1. Geological map of Siwana Ring Complex showing radioactivity anomalies and silver occurrences (modified after Bhushan and Mohanty[9]).

Table 1. High field strength and rare earth elements in various radioactivity anomalies

Area	Rock type	Zr	Nb	Y	La	Ce	Nd	Ag	U	Th
		Chemical data (ppm)#							Radiometric data (%)*	
Bhatikhera (n = 3)	Microgranite/felsite	12,252	649	1469	892	2,097	995	4.9 (n = 18)	0006 (n = 5)	0.019
Phulan (n = 3)	Felsite	10,690	438	5793	5039	12,463	5620	3 (n = 4)	0.037 (n = 7)	0.13
Ramaniya (n = 5)	Granitoid	9,862	302	3659	1138	2,825	1761	2.2 (n = 6)	0.016 (n = 15)	0.052
Mawri (n = 11)	Rhyolite	4,688	304	700	249	646	304	3 (n = 6)	0.025 (n = 11)	<0.01
Nal (n = 12)	QFR	4,250	585	1195	1973	4,564	2012	2.7 (n = 3)	0.019 (n = 18)	0.072
Sheetala mata (n = 4)	Granite	14,276	624	2094	846	1,848	928	5 (n = 4)	0.023 (n = 11)	0.074

*Radiometric assay results (%) from Physics Laboratory, AMD, Jaipur, #Chemical Laboratory, AMD, Jaipur.

Table 2. Silver concentration in different rock types along the margins of SRC

Margin of SRC	Area	Rock type (no. of samples)	Ag (ppm)# Range	Ag (ppm)# Average	Average abundance (ppm)*
Northern margin	Bhatikhera	Microgranite/felsite (n = 18)	1.0–15.0	4.90	0.05
		Basalt (n = 2)	1.0–2.0	1.50	0.1
Southern margin	Nal	Quartzo feldspathic rock (n = 3)	2.0–4.0	2.7	0.037
		Felsite (n = 1)	14.0	–	0.05
		Rhyolite (n = 1)	3.0	–	0.07
		Basalt (n = 1)	2.0	–	0.10
	Ramaniya	Granitoid (n = 6)	1.0–4.0	2.2	0.037
		Rhyolite (n = 1)	3.0	–	0.07
	Mawri–Magreshwar	Rhyolite (n = 6)	2.0–5.0	3.0	0.07
Western margin	Sheetalamata Indrana	Felsite dykes (n = 1)	3.0	–	0.05
		Aegirine granite (n = 4)	4.0–7.0	5.0	0.037
Northeastern margin	Phulan	Felsite (n = 4)	2.0–4.0	3.0	0.05
		Rhyolite (n = 1)	2.0	–	0.07
Central caldera	Siwana, Dantala and Devandi	Tuff (n = 3)	1.0–3.0	2.0	0.07

*After Turekian and Wedepohl[10]. #Silver is analysed by flame AAS in Chemical Laboratory, AMD, Jaipur (values are ± 5%).

Table 3. Rock type-wise silver concentration in SRC

Rock type	Ag (ppm)* Range	Ag (ppm)* Average	Average abundance* (ppm)
Basalt (n = 3)	1–2	1.7	0.1
Rhyolite (n = 9)	2–5	3.2	0.07
Granite (low Ca; n = 4)	4–7	5	0.037
Brecciated granitoid (n = 6)	1–4	2.2	0.05 (normal granite)
Tuff (n = 3)	1–3	2	0.07
Microgranite and felsite (n = 23)	1–15	4.9	0.05
Quartzo feldspathic rock (n = 3)	2–4	3	0.05

*Turekian and Wedepohl[10].

The importance of SRC for its potential for uranium, thorium, rare metals and REE was realized by AMD in the late 1950s and the southern margin of the ring complex and the Siwana fort hill were the prime initial targets. Importance of the agpaitic dykes intruding peralkaline granites near Mokalsar–Ramaniya was recognized due to anomalous concentration of high field strength (HFS) elements, including REE. Fersmite ($CaNb_2O_6$) was identified in the Microgranite dykes[5]. Besides, the moat sediments (~30 m thickness) occurring between tuff and the youngest flow of columnar rhyolite at Siwana Fort Hill, Siwana, Barmer district (45 C/6) drew attention for analysing uranium up to 220 ppm.

AMD's current exploration programme targets the periphery of SRC, especially the contact between the bimodal basalt–rhyolite volcanic rocks and granite, which are intruded by younger intrusives of felsite, microgranites and aplites. Reconnaitory surveys have indicated the presence of Th–U–REE-rich mineralization of varied dimension at a number of places in the southern, northern, northeastern and western margins of SRC, associated with granites (Sheetalamata, western margin); brecciated granitoid (Ramaniya, southern margin);

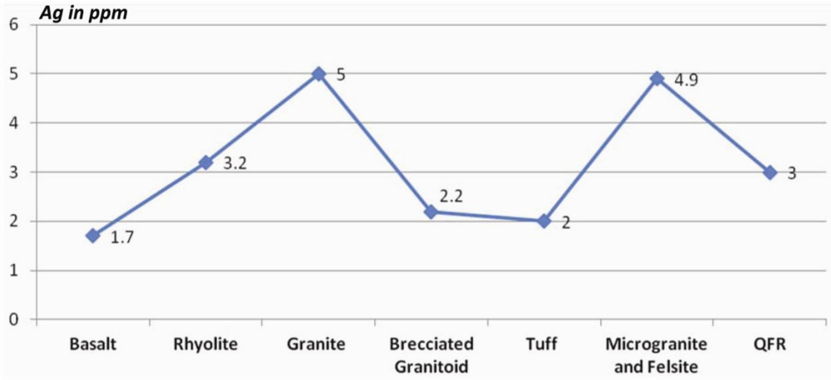

Figure 2. Silver values in various rock types. Showing progressive enrichment from basalt to granite.

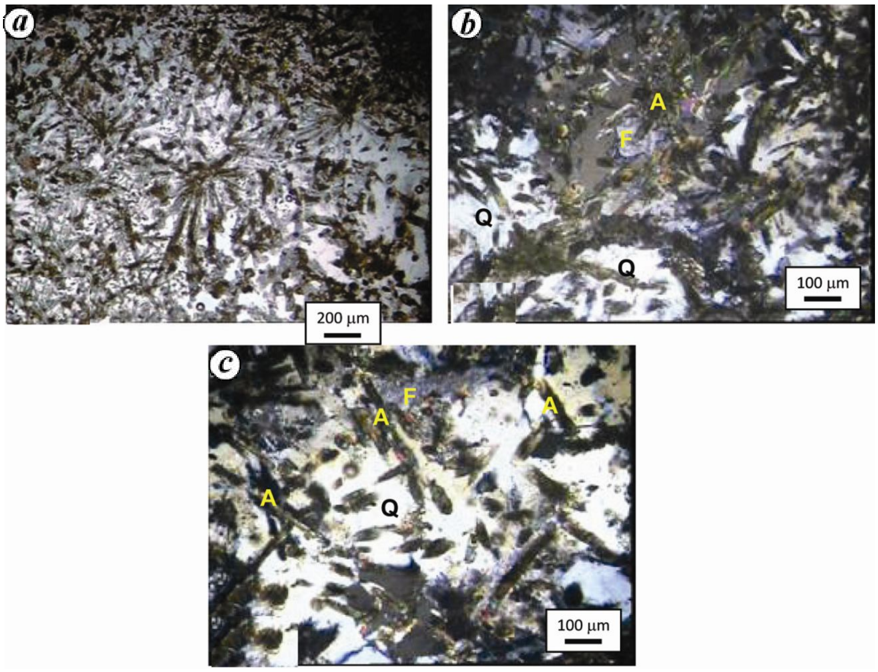

Figure 3 ***a–c***. Photomicrographs of microgranite from Bhatikhera. ***a***, Rosette-shaped and fine needles of aegirine in microgranite. TL – transmitted light, 1 Nicols (plane polarized light) in air. ***b***, Intergrowth of coarse quartz (Q), fine feldspar (F) and needle-shaped aegirine (A). TL – transmitted light, 2 Nicols (cross Nicols) in air. ***c***, Intergrowth of coarse quartz (Q), fine feldspar (F) and needle-shaped aegirine (A). TL – transmitted light, 2 Nicols (cross Nicols) in air.

felsite dykes (Phulan, northeastern margin); massive rhyolites at the contact of basalt and granites (Mawri–Asadra–Magreshwar in the southern margin); massive rhyolite at the contact between basalt and upper flow of porphyritic rhyolite (Kusip), microgranite/felsite dyke at Bhatikhera in the northern margin, and with quartzo feldspathic rock overlying trachyte, as in Nal area (southwestern margin). The surface samples were analysed for minor and trace elements, including silver. Anomalous silver values (analysed by flame AAS method in Chemical Laboratory, Western Region, AMD, Jaipur) have been obtained in different rock types from various margins of SRC. Area-wise trace and minor elemental distribution associated with volcanogenic radioactive mineralization elements is given in Tables 1 and 2.

It is observed that in rhyolites, tuffs and basalts the HFS and REE (LREE) concentrations are lower along with the silver concentration compared to the granites, microgranites and felsites in SRC. Silver occurs as nuggets and increases progressively in bimodal volcanics, basalt, rhyolites and also in granites – 1.5, 3.2 and 5 ppm respectively (Figure 2). Last phase intrusives (microgranite and felsite) which intruded basalt–rhyolite suite of rocks, have analysed silver (up to 15 ppm and average of 4.9 ppm; Table 3). Silver in this geo-environment might appear in post-petrogenetic ore fluids.

At Bhatikhera in the northern margin of SRC (Figure 1), microgranite/felsite occurs as 700 m × 10–30 m dyke intruded into basalt. These are greyish to greenish-white, fine-grained rocks, comprising quartz, feldspar, aegirine and minor epidote. Aegirine is predominant and shows rosette structure (Figure 3 *a*). Intergrowth of quartz and aegirine (Figure 3 *b*), and feldspar and aegirine (Figure 3 *c*) is common. The microgranite dyke occurring as low ridges intruding basalt–rhyolite sequence has gained significance due to high silver values of 1 to 15 ppm. Basalt at the contact with microgranites/felsites have analysed 1–2 ppm silver, av. 1.7 ppm (Table 3).

Whole-rock analysis of microgranites from Bhatikhera suggests that samples are high in SiO_2, Fe_2O_3, Na_2O, low to moderate in Al_2O_3 and low in FeO. They also contain HFS elements like Nb, Y and Zr and also zinc. LREEs, especially La, Ce, Nd and Sm are high. Alkali–alumina ratio, high zircon content, and also the presence of aegirine and reibeckite indicate that the rock is peralkaline (Table 4).

Tuffaceous rocks of Siwana, Dantala and Devandi in the central caldera contain 2.0, 3.0 and 1.0 ppm Ag respectively ($n = 2$ each). At SRC, bimodal volcanism is prevalent with basalt forming the basal flow. The associated mafic rocks at the contact of acid volcanic and plutonic rocks in the periphery of the SRC could be the possible source for silver, with an average value of 1.7 ppm. Data generated till now suggest that silver occurs as nuggets in the rocks of SRC.

Radioactive occurrences in peralkaline rocks have associated enrichments of REE, thorium and zirconium. Felsic volcanic rocks proximal to uranium deposits typically contain uranium concentrations in excess of 10 ppm. Enriched uranium contents are characteristic of rocks with aluminous and alkaline affinities[6]. A few Hercynian volcanogenic deposits in Europe and Asia are polymetallic as a result of complex, multistage hydrothermal history and are noted for enrichment in copper, lead, silver and zinc[7]. Caldera-related occurrences are hosted by

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