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High Heat Producing Volcano-Plutonic Rocks of the Siner Area, Malani Igneous Suite, Western Rajasthan, India

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ABSTRACT

The volcano-plutonic rocks of the Siner area of the Malani Igneous Suite (MIS) are characterized by high content of radioactive elements (U, Th, K) and are classified as high heat producing felsic volcano-plutonic rocks of A-type granitoid. Microgranite shows highly comparable heat production (26.07 HP) and total heat generation value (62.06 HGU in average) as compared to other granite (HP = 12.73; HGU = 26.57), rhyolite (HP = 4.98; HGU = 11.85) and trachyte (HP = 5.00; HGU = 11.91). The volcano-plutonic rocks of the present show higher average value of total HGU than the average value of 3.8 HGU for the continental crust, which suggests a possible linear relationship among the crustal heat generation of the MIS.

Keywords: Radioactivity; Volcano-Plutonic Rocks; Malani Igneous Suite

1. Introduction

The presence of radioactive elements (U, Th, K) in the earth crust and plays a role in continental heat flow. Their content are significant in understanding the nature of the source rocks. The geochemistry of U and Th has been studied in many granitoids from different areas by large number of worker on radioactive heat generation [1-11]. The rocks of the Siner and its adjoining areas are characterized by high concentrations in SiO_2, Na_2O, K_2O, Zr, Nb, Y and REE (except Eu) but low in MgO, Fe_2O_3(t), CaO, Cr, Ni, Sr; showing their A-type affinity [12-16]. This paper describes distribution of the volcano plutonic rocks of the Siner area, Malani Igneous Suite, western Rajasthan and their radioactive heat generation characteristics.

2. Regional Geology and Petrography

The magmatic rocks of the MIS are spread out in an area about 55,000 km^2 in the Indian subcontinent around Tosham in Haryana, Jhunjhunu, Siwana, Jalore, Barmer, Pali, Jaisalmer in Rajasthan and Kirana Hill, Nagar Pakar in Pakistan. The Siner area dominantly consists of felsic volcano-plutonic rocks in the southwestern part of the Siwana Ring Complex occur in the Siner area (**Figure 1**). Volcano-plutonic associations of the MIS belongs to three different phase. First phase is initiated by flow of minor basic volcanic rocks followed by major felsic flows; second phase is represented by intrusive phase. The dyke rock represents the third phase and they have intruded in the earlier phases.

The Siner granites show hypidiomorphic and equigranular textures and mainly comprise of alkali feldspar (perthite, orthoclase), quartz and alkali amphibole and accessory minerals like sphene, rutile, hematite and magnetite (**Figure 2(a)**). Principal minerals vary from a few mm to several mm. orthoclase is subhedral and medium grained and exhibits typical Carlsbad twining (**Figure 2(b)**). Arfvedsonite and riebeckite occur as prismatic, subhedral crystals. Arfvedsonite represents the principal ferromagnesian mineral. Microgranites in the Siner area are fine to medium grained and they have mineralogical constituents with the granites except for being fine grained (**Figure 2(c)**).

Rhyolite shows varied colours, is porphyritic as well as nonporphyritic. The porphyritic rhyolites are showing granophyric and flow textures. Phenocrysts of feldspar are mostly rectangular are embedded in aphanitic groundmass of quartz and ferromagnesians minerals. Spherulitic textures are observed in the nonporphyritic rhyolite in which the groundmass consist aggregates of quartz, alkali feldspar, blue colour amphibole (riebeckite, arfvedsonite), magnetite and hematite (**Figure 2(d)**).

Trachyte shows porphyritic texture comprising alkali feldspar, quartz, plagioclase, alkali amphiboles as essential minerals and magnetite (black) and hematite (brown) as accessory minerals (**Figure 2(f)**). Plagioclase feldspar occurs as euhedral crystals in quartzofeldspathic groundmass of trachytes.

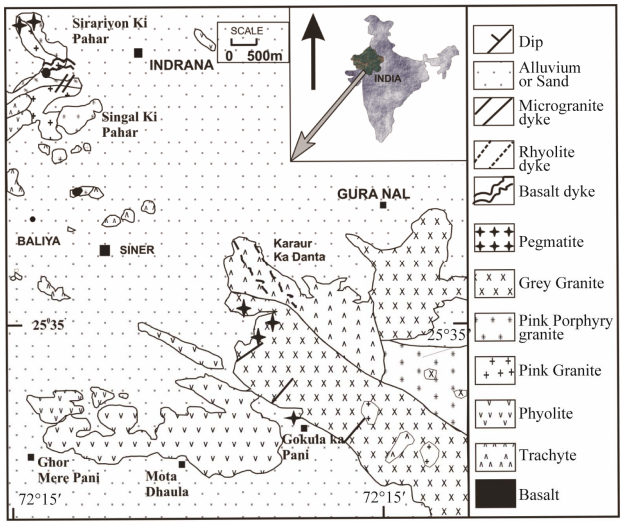

Figure 1. Geological map of the siner and its surrounding of malani igneous suite, western Rajasthan.

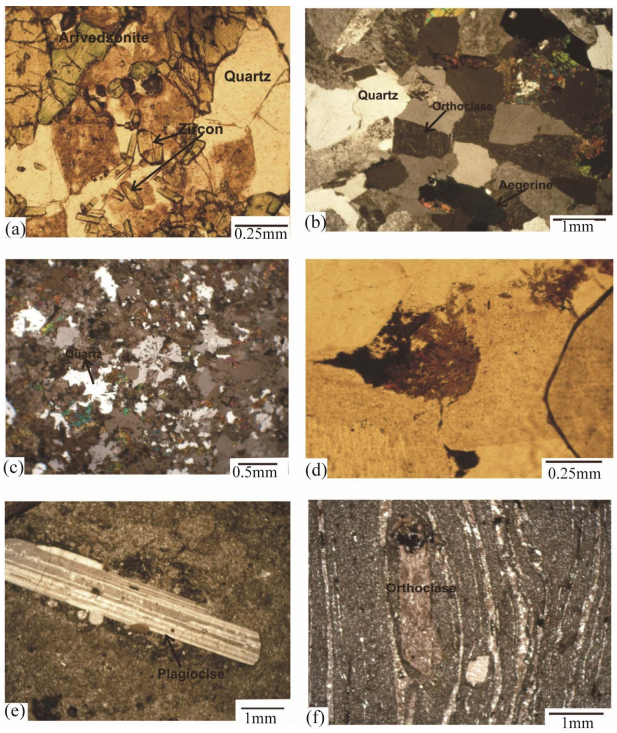

Figure 2. (a) Granite showing hypidiomorphic with crystals of zircon; (b) Equigranular texture of quartz and orthoclase in granite; (c) Hypidiomorphic texture of microgranite; (d) Spherulitic texture shown by rhyolite; (e) Flow structure with porphyry plagioclase in rhyolite; (f) Porphyry orthoclase showing trachytic texture.

3. Geochemistry and Radioactive Heat Generation

The abundances of radioelements viz. U, Th and K in the felsic volcano-plutonic were determined by ICP-MS (Perkin Elmer Sciex ELAN DRC-II) at the National Geophysical Research Institute (NGRI), Hyderabad and X-Ray Fluorescence spectrometer (Bruker S8 TIGER) at the Wadia Institute of Himalayan Geology (WIHG), Dehra Dun (**Table 1**). Sample dissolution procedures and other analytical details as practiced in these laboratories including analytical accuracy and precision are described in earlier publication [17,18].

The felsic volcano-plutonic rocks of the Siwana Igneous Complex including those of Siner area have been shown to be crustal origin [15,16,19]. The rocks in the Siner area are characterized by high SiO_2 (up to 72.65 wt%) and K_2O, and low levels of CaO, MgO, P_2O_5, Fe_2O_3 and Al_2O_3. They show high alkali content and K_2O/Na_2O ratios. Both felsic volcanic and plutonic rocks of the Siner area generally have high abundance of Fe_2O_3, $Na_2O + K_2O$, Rb, Zr, Hf, Th, U, Nb, Ta, Y, REE, high HFSE, high Ga/Al, Rb/Sr, Zr/Rb ratios and negative Eu anomalies.

The Heat Generation Unit (HGU) value and Heat Production (HP) value were computed from the measured abundance of U, Th and K using the relation given by Birch, [1]: A ($\mu \cdot Wm^{-3}$) = 0.01 × ρ (9.69 Cu + 3.58 Ck + 2.65 Cth), where A is heat production and ρ is density in gm/cm^{-3} which is 2.7 gm/cm^{-3} for granites and felsic volcanic rocks [1]. The Cu and Cth are concentration of U and Th in ppm respectively whereas Ck is concentration of K in wt%. The heat production ($\mu \cdot Wm^{-3}$) unit may be converted into heat generation unit (1HGU = 10^{-3} $cal \cdot cm^{-3} \cdot sec^{-1}$) using the value of 1 HGU = 0.42 $\mu \cdot Wm^{-3}$ obtained for the Gansboden granite gneiss at the Guspisbach heat flow site of Central Alps of Switzerland [3]. The radio element concentration (Ur) is calculated as radioelement Ur equivalents: 1 ppm of U in equilibrium (1 ppm eU) = 1 Ur; 1 ppm of Th in equilibrium (1 ppm eTh) = 0.5 Ur; 1 wt% of K = 2Ur[6].

The radioelement data shows that the felsic dyke rocks (microgranite) samples have higher concentration of U (32.29 - 98.71 ppm) and Th (23.26 - 216.8 ppm) than the granite (U = 3.15 - 86.11 ppm; Th = 21.99 - 152.97 ppm), rhyolite (U = 2.91 - 18.10 ppm; Th = 1.54 - 97.66 ppm) and trachyte (U = 5.92 - 12.01 ppm; Th = 21.93 - 62.21 ppm). The felsic dyke rocks (microgranites) have the highest values of Ur vary from 51.06 to 214.11 as compared to granites (24.26 - 68.26), rhyolite (11.64 - 74.15) and trachyte (20.85 - 48.89). The U and Th concentrations in granites are significantly (20 - 8 times) higher than the world average concentration of U (4 ppm) and Th (18 ppm) in granite [2]. The distribution of U and Th for granites, microgranites, rhyolite and trachytes are showing positive correlation in the Th-U diagram. The enrichment of U in granites and felsic volcanic rocks appear to be fractional differentiation which also indicates increase of K. The Th/U ratios of the Siner area volcano-plutonic rocks are comparable and fairly close to

Table 1. Radioelements, heat production and radioactive heat generation data of the Siner area, Malani igneous suite, western Rajasthan.

Sample	U (ppm)	Th (ppm)	K (%)	Th/U	HP ($\mu \cdot Wm^{-3}$)	Ur	Heat generation (in HGU) due to U	Th	K	Total HGU
					Granite					
D8	3.15	25.94	4.07	8.23	3.07	24.26	1.96	4.42	0.94	7.32
S2	24.7	105.44	3.95	4.27	14.39	85.32	15.39	17.96	0.91	34.26
S3	46.71	152.97	4.1	3.27	23.56	131.395	29.10	26.06	0.94	56.10
S8	11.33	41.93	4.1	3.70	6.36	40.495	7.06	7.14	0.94	15.14
S16	19.52	44.44	4.05	2.28	8.68	49.84	12.16	7.57	0.93	20.66
S21	86.11	148.1	4.05	1.72	33.52	168.26	53.64	25.23	0.93	79.80
S24	15.36	60.81	3.85	3.96	8.74	53.465	9.57	10.36	0.89	20.81
GRNL	6.02	21.99	4.3	3.65	3.56	25.615	3.75	3.75	0.99	8.49
					Microgranite dyke					
S7	98.71	216.8	3.5	2.20	41.68	214.11	61.49	36.93	0.81	99.23
S14	32.29	23.26	3.57	0.72	10.46	51.06	20.11	3.96	0.82	24.90
					Rhyolite					
F1	8.13	32.05	4.22	3.94	4.83	32.595	5.06	5.46	0.97	11.50
F2	4.52	31.05	3.76	6.87	3.77	27.565	2.82	5.29	0.87	8.97
F4	18.1	97.66	3.61	5.40	12.07	74.15	11.28	16.64	0.83	28.74
S9	2.91	1.54	3.98	0.53	1.26	11.64	1.81	0.26	0.92	2.99
S30	5.99	28.04	2.49	4.68	3.81	24.99	3.73	4.78	0.57	9.08
S43	4.93	34.71	3.77	7.04	4.14	29.825	3.07	5.91	0.87	9.85
					Trachyte					
S28	5.92	26.43	0.86	4.46	3.52	20.855	3.69	4.50	0.20	8.39
S48	6.21	21.93	4.4	3.53	3.62	25.975	3.87	3.74	1.01	8.62
S37	12.01	62.21	2.89	5.18	7.87	48.895	7.48	10.60	0.67	18.74

HP: Heat production; Ur: Radioelement concentration; HGU: Heat generation unit.

the upper crustal estimate of 3.8 (**Figure 3(a)**) [20].

In K-U-Th diagram (**Figure 3(b)**) of the volcanic and plutonic rocks plot near Th apex, indicating high content of Th (up to 216.80 ppm) in the samples, and hence the heat generation of Th (3.74 - 36.93 HGU) is much higher than U (1.96 - 61.49 HGU) and K (0.20 - 1.01 HGU).

The average total heat generation value of the felsic volcanic (21 HGU) and plutonic rocks (30 HGU) of the study area are much higher than the average value of 3.8 HGU for the continental crust. These volcano-plutonic rocks of the Siner area also also have higher values than the average value of 14.21 HGU obtained from the Kundal volcano-plutonic rocks in the MIS [10] and 8.3 HGU from the Peninsular India [21]. Volcanic and plutonic rocks of the Siner area of MIS shows higher concentration of U and Th as compared to A-type granite and rhyolite of the Northwestern Ontario [22] and A-type rhyolite of the St. Francois Mountains, Missouri [23] (**Figure 3(c)**). The Siner granite samples have the average highest heat productivity value (12.73 $\mu \cdot Wm^{-3}$) closely similar to that of the Jhunjhunu granites of MIS (12.06 $\mu \cdot Wm^{-3}$) [9] and A-type Nigerian younger granites (11.16 $\mu \cdot Wm^{-3}$) [24]. The Ur vs HP diagram (**Figure 3(d)**) show that the Siner volcanic rocks are in a linear pattern with the Mokalsar rhyolite [8] and Jhunjhunu rhyolite of MIS [9]. Granites with inferred heat production value more than 7 HGU are classified as High Heat Producing (HHP) granitoids and "hot crust" category [10]. In this study the granites and other felsic volcanics with heat production values are more than 5 $\mu \cdot Wm^{-3}$, ranging between 2 - 20 $\mu \cdot Wm^{-3}$. This radioactive heat generation data present here also suggest a possible linear relationship between the surface heat flow and crustal heat generation in the MIS.

4. Conclusion

The volcano plutonic rocks of the Siner area are characterized by high content of SiO_2, $Na_2O + K_2O$, Nb, Y, Ta, Zr, Hf, Ga, U, Th, REE and low content of MgO,

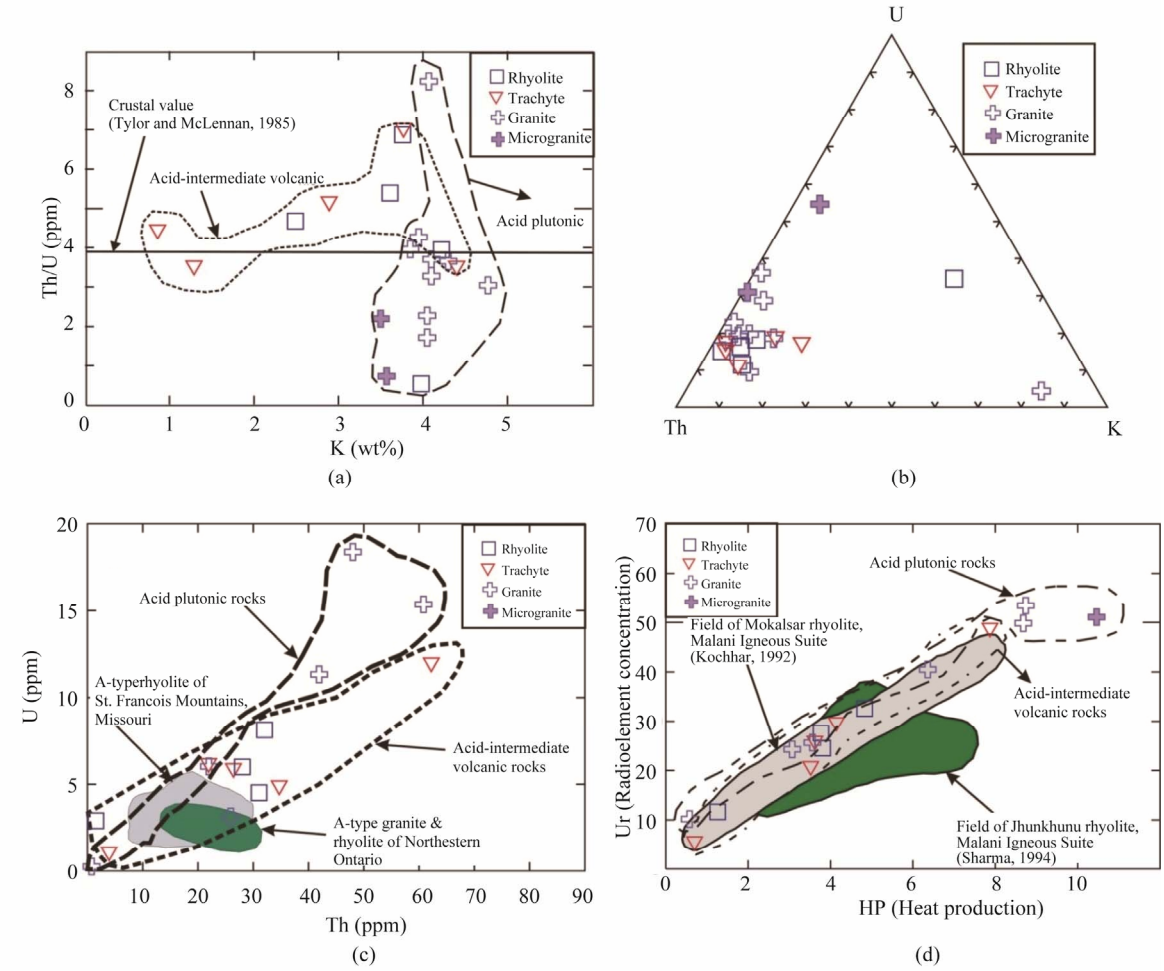

Figure 3. (a) Th/U vs K plot for the volcano-plutonic rocks of the Siner; (b) Th-U-K for the volcano-plutonic rocks of the Siner; (c) U vs Th plot of the Siner volcano-plutonic rocks; (d) Ur vs HP for the volcano-plutonic rocks of the Siner.

CaO and Al_2O_3. The average distribution of total heat generation in (62.06 HGU), granite (HGU = 26.57), rhyolite (HGU = 11.85) and trachyte (HGU = 11.91) of the Siner area are much higher than the average value of 3.8 HGU of the continental crust and 8.3 HGU obtained from Peninsular India and classified as "hot crust". Hence they are high heat producing crustal rocks which suggest a possible linear relationship among the crustal heat generation of MIS and according to the geochemistry data they are formed by low degree anatexis of crustal material.

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