



RADIOACTIVE HIGH HEAT BEARING VOLCANO-PLUTONIC ROCKS AROUND DEORA AREA, SIWANA RING COMPLEX, WESTERN RAJASTHAN

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Abstract: The volcano-plutonic rocks at and around Deora area of the Siwana Ring Complex of Malani Igneous Suite (MIS) are categorized by high concentration of radioactive elements (U, Th, K) and are classified as high heat bearing volcano-plutonic rocks of A-type granitoid. The average distribution of total heat generation in (21.5 HGU), granite (11.10 HGU), microgranite (37.90 HGU) and rhyolite (21.60 HGU) of the area around Deora are much higher than the average value of 3.8 HGU of the continental crust and 8.3 HGU found from Peninsular India and classified as "hot crust". Hence, these are high heat-producing crustal rocks, indicating a possible linear relationship in crustal heat generation within the Malani Igneous Suite (MIS). Geochemical data further suggest that they were formed by a low degree of anatexis of crustal material

Index terms- Deora, Granite, Geochemistry, Heat Generation Unit, Malani Igneous Suite.

I. INTRODUCTION

Radioactive elements are chemical substances whose atoms have unstable nuclei. Due to instability, these atoms freely break down or decay into more stable forms, releasing energy in the form of radiation is termed as radioactivity. The occurrence of radioactive elements such as uranium (U), thorium (Th), and potassium (K) in the Earth's crust significantly contributes to the generation and regulation of continental heat flow. Their composition plays a crucial role in understanding the characteristics and origin of the source rocks. The geochemistry of uranium (U) and thorium (Th) has been extensively investigated in numerous granitoids from various regions by many researchers in relation to radioactive heat generation [1-12]. The volcano-plutonic rocks of the Deora and its adjacent areas are characterized by high concentrations in SiO₂, Na₂O, K₂O, Zr, Nb, Y and REE (except Eu) but low in MgO, CaO, Cr, Ni, Sr; showing their A-type affinity [13-16]. Present attempt refer to the radioactive heat producing characteristics of the volcano plutonic rocks of the Deora area, Siwana Ring Complex, western Rajasthan.

II. REGIONAL GEOLOGY AND PETROGRAPHY

The Siwana Ring Complex (SRC) is a collapsed caldera structure, an anorogenic, rift-related, bimodal volcano-plutonic rock association belonging to the Malani Igneous Suite which spread over 1100 sq. km. area in north-western India (Fig.1). It comprises of felsic and basic volcanic lava flows, rhyolite, peralkaline granite, pyroclastics, tuff and later microgranite, aplite and felsite dykes [17]. Volcano-plutonic associations of the Malani Igneous Suite 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.

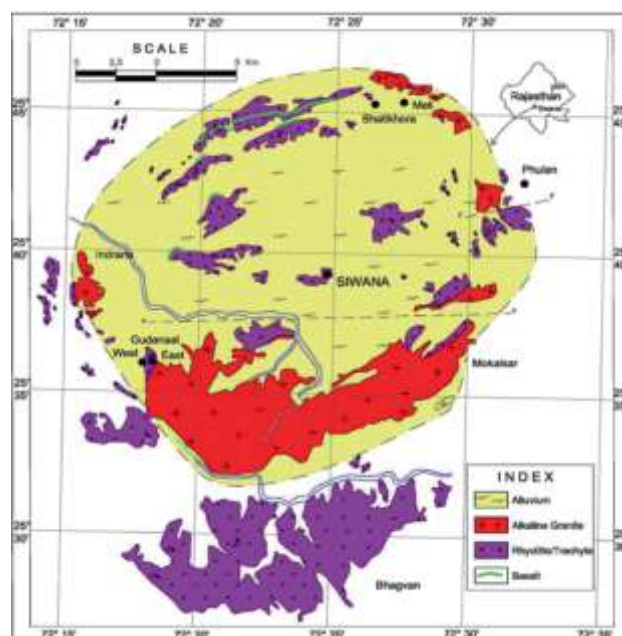


Fig. 1 Geological map of Siwana Ring Complex^[18].

The Deora 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. Plagioclase is subhedral, medium grained and tabular to lath-shaped. It shows albite twinning and grey interference colour (Fig. 2 A). Aegirine showing High relief, Moderately to strongly pleochroic: X = deep green; Y = green grass; Z = yellow-brown colour in plane polarized light and near-parallel extinction and strong third order yellow interference colour, showing oscillatory zoning and elongate prisms of idiomorphic in

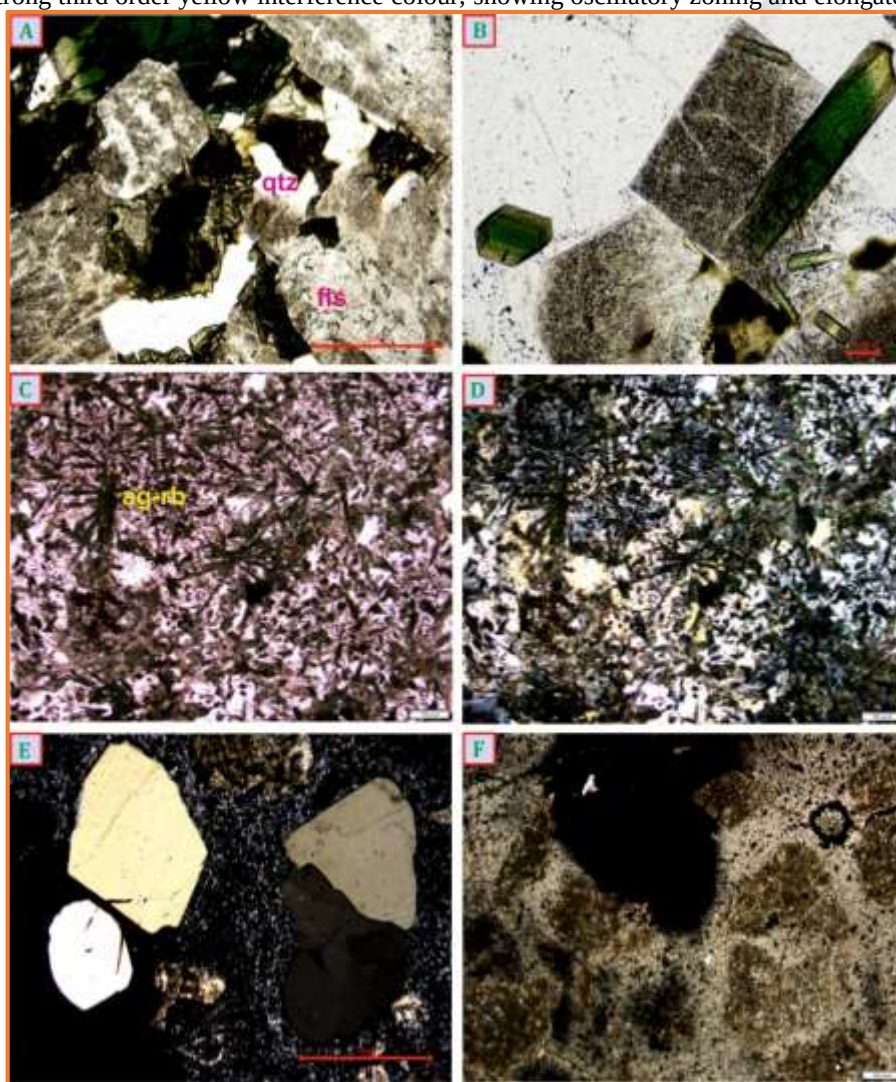


Figure 2. (A) Deora granite showing hypidiomorphic texture (B) Albite twinning in plagioclase with high relief in aegirine in Deora granite (C,D) Fine needles of aegirine are arranged in radial pattern in microgranite. (E) Quartz and feldspar phenocryst embedded in quartzofeldspathic groundmass (F) Spherulitic texture shown by rhyolite.

Microgranite of the study area around Deora are fine to medium grained mainly composed of alkali feldspar and quartz with aegirine and riebeckite. Fine needles of aegirine are arranged in radial pattern (rosette arrangement) showing in plane and cross polarized light. Spherulites containing radiating needles of alkali pyroxene and amphiboles in microgranite (Fig. 2 C,D).

Rhyolite is porphyritic, tuff like and shows variations in colours. The porphyritic rhyolites are showing granophyric and flow textures. Photomicrograph showing quartz and feldspar phenocryst embedded in groundmass of quartzofeldspathic, amphibole (riebeckite, arfvedsonite), magnetite and hematite (Fig. 2 E,F).

III. GEOCHEMISTRY AND RADIOACTIVE HEAT GENERATION

The concentration of radioactive elements viz. uranium (U), thorium (Th), and potassium (K) in volcano-plutonic rocks at and around Deora area was analysed using an inductively coupled plasma mass spectroscopy (ICP-MS) instrument (from Agilent Technologies, Tokyo, Japan) at Department of Earth and Environmental Sciences, IISER Mohali, India (Table 1). Sample dissolution for ICP-MS analysis followed the procedure of International standards of granite (NIM-G) were also analysed along with the samples to check precision and accuracy^[19].

Table 1. Radioelements, heat production and radioactive heat generation data of Deora area Siwana Ring Complex.

	Sample	U	Th	K	Th/U	HP (μWm^{-3})	Ur	Radioactive heat generation by			HGU
								U	Th	K	
Granite	DR-1	14.7	15.9	6.00	1.08	5.58	34.65	5.32	5.98	1.99	13.29
	DR-2	12.4	13.9	5.49	1.12	5.31	30.34	5.06	5.69	1.90	12.64
	DR-3	8.7	17.6	6.16	2.02	4.52	29.81	4.31	4.85	1.62	10.77
	DR-4	10	18.9	6.00	1.89	3.97	31.45	3.78	4.25	1.42	9.45
	MRD-8	5.3	9.8	5.28	1.85	4.71	20.75	4.48	5.05	1.68	11.21
	MD-11	6.5	30.6	5.63	4.71	5.22	33.05	4.97	5.59	1.86	12.43
	MD-12	3.9	32.4	5.88	8.31	4.22	31.86	4.01	4.52	1.51	10.04
	JM-30	4.2	28.8	4.99	6.86	3.78	28.58	3.60	4.04	1.35	8.99
Microgranite	MOK-24	5.7	24.1	5.13	4.23	4.72	28.02	4.49	5.05	1.68	11.23
	MOK-26	4.3	29.7	6.24	6.91	4.89	31.63	4.65	5.24	1.75	11.63
	BK-17	10.2	34.4	4.16	3.37	5.79	35.71	5.52	6.21	2.07	13.79
	MOK-23	104.8	29.5	3.17	0.28	30.06	125.89	28.63	32.21	10.74	71.57
	MOK-25	112.6	27.6	3.28	0.25	38.23	132.95	36.41	40.96	13.65	91.01
Rhyolite	MGL-14	15.8	91.1	4.63	5.77	11.84	70.60	11.28	12.69	4.23	28.19
	LDR-20	4.5	76.7	5.88	17.04	8.26	54.61	7.86	8.85	2.95	19.66
	BL-27	3.3	69	5.08	20.91	9.15	47.97	8.72	9.81	3.27	21.80
	RK-31	3.7	82.1	5.25	22.19	11.16	55.26	10.62	11.95	3.98	26.56
	FLN-32	4.9	101.6	5.45	20.73	12.26	66.59	11.68	13.14	4.38	29.20
	DT-18	3.7	109.7	5.59	29.65	12.23	69.73	11.65	13.11	4.37	29.13
	DT-19	2.8	112.5	5.25	40.18	1.37	69.56	1.31	1.47	0.49	3.27

The volcano-plutonic rocks at and around Deora area are regarded as by high SiO_2 (up to 72.36 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 $\text{K}_2\text{O}/\text{Na}_2\text{O}$ ratios. They usually have high abundance of Fe_2O_3 , $\text{Na}_2\text{O} + \text{K}_2\text{O}$, Rb, Zr, Hf, Th, U, Nb, Ta, Y, REE, high Rb/Sr, Zr/Rb ratios and negative Eu anomalies.

The Heat Generation Unit (HGU) value and Heat Production (HP) value were calculated from the measured abundance of U, Th and K using the relation given by Birch, 1: $A (\mu\text{Wm}^{-3}) = 0.01 \times \rho (9.69 \text{ Cu} + 3.58 \text{ Ck} + 2.65 \text{ Cth})$, 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 (μWm^{-3}) unit can be converted into heat generation unit ($1 \text{ HGU} = 10^{-3} \text{ cal}\cdot\text{cm}^{-3}\cdot\text{sec}^{-1}$) using the value of $1 \text{ HGU} = 0.42 \mu\text{Wm}^{-3}$ 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 ($1 \text{ ppm eU} = 1 \text{ Ur}$); 1 ppm of Th in equilibrium ($1 \text{ ppm eTh} = 0.5 \text{ Ur}$); 1 wt% of K = 2 Ur .

The radioelement data of the study area shows that the granite samples shows concentration of U upto 3.9- 14.7ppm, microgranite 5.7-112.6 ppm and rhyolite shows 2.8-15.8 ppm whereas Th concentration for granite 9.8-32.4 ppm, microgranite 24.1-34.4 ppm and Rhyolite 69.0-112 ppm respectively. The microgranites have the highest values of Ur vary from 28.02 to 132.95 as compared to granites (20.75-34.65), rhyolite (47.97-70.60). The U and Th concentrations in granites are expressively 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 and rhyolite are display positive relationship in the Th-U diagram. The enrichment of U in granites and rhyolite rocks appear to be fractional differentiation which also designates increase of K (Fig.3 A).

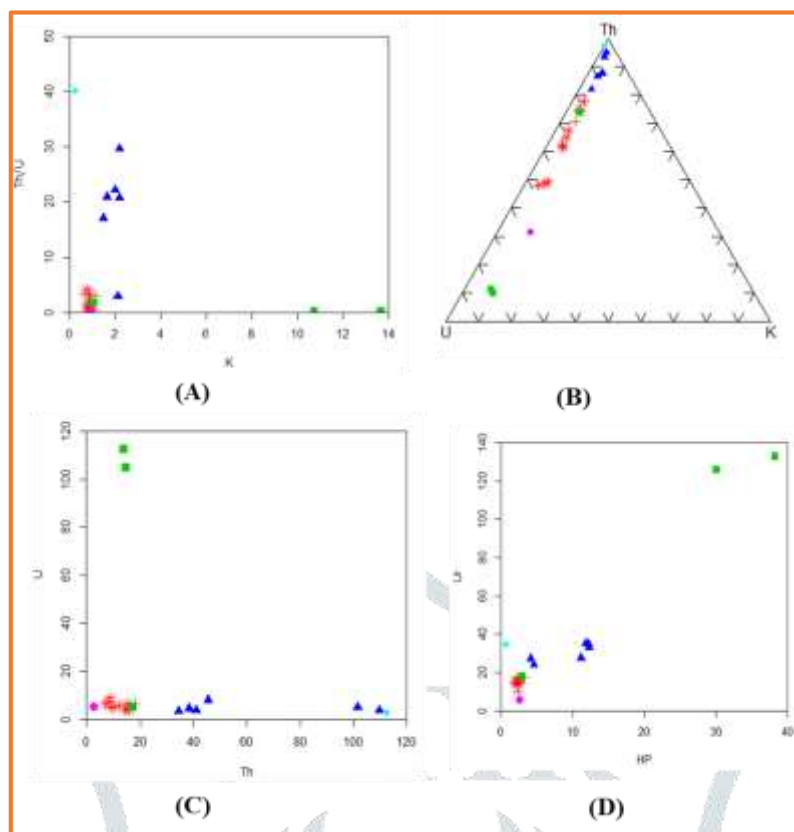


Figure 3. (A) Th/U vs K plot (B) Th-U-K plot (C) U vs Th plot (D) Ur vs HP for the volcano-plutonic rocks of the Deora.

In K-U-Th diagram of the volcanic and plutonic rocks plot near Th apex, indicating high content of Th (up to 112.5 ppm) in the samples, and hence the heat generation of Th (1.47-40.96 HGU) is much higher than U (1.31- 36.41 HGU) and K (0.49 - 13.65 HGU) (**Fig. 3 B**). The average total heat generation value of the plutonic rocks (22.16 HGU) and volcanic rock (22.54) of the study area are much higher than the average value of 3.8 HGU for the continental crust. The Th/U ratios of the Deora area volcano-plutonic rocks are comparable and fairly close to the upper crustal estimate of 3.8. Volcanic and plutonic rocks around Deora area of SRC shows higher concentration of U and Th as compared to A-type granite and rhyolite of the Northwestern Ontario ^[20] and A-type rhyolite of the St. Francois Mountains, Missouri ^[21] ((**Fig. 3 C**). The Ur vs HP diagram show that the Deora volcano-plutonic rocks are in a linear pattern (**Fig. 3 D**). 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, microgranite and rhyolite with average heat production values are $9.03 \mu\text{Wm}^{-3}$, ranging between $1.37 - 38.23 \mu\text{Wm}^{-3}$. The radioactive heat generation data presented here also indicate a possible linear correlation between surface heat flow and crustal heat production in the Siwana Ring Complex of the Malani Igneous Suite, northwestern Rajasthan.

IV. CONCLUSIONS

The volcano-plutonic rocks around Deora areas are characterized by high concentrations in SiO_2 , Na_2O , K_2O , Zr, Nb, Y and REE (except Eu) but low in MgO , CaO , and Al_2O_3 showing their A-type affinity. The average distribution of total heat generation in (21.5 HGU), granite (11.10 HGU), microgranite (37.90 HGU) and rhyolite (21.60 HGU) of the area around Deora are much higher than the average value of 3.8 HGU of the continental crust and 8.3 HGU found from Peninsular India and classified as “hot crust”. Hence, these are high heat-producing crustal rocks, indicating a possible linear relationship in crustal heat generation within the Malani Igneous Suite (MIS). Geochemical data further suggest that they were formed by a low degree of anatexis of crustal material.

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