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HIGH HEAT PRODUCING GRANITES OF THE MALANI IGNEOUS SUITE, NORTHERN PENINSULAR INDIA

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ABSTRACT

Based on surface abundances of U, Th and K, and selected trace elements, the Siwana, Jalor and Tusham granites of the Malani igneous suite have been identified as the high heat production (HHP) granites. In heat production these granites are similar to the Nigerian Younger granites.

INTRODUCTION

Radioactive heat production is a thermal property of rocks independent of *in situ* temperature and pressure. It contributes a major amount to surface heat flow. On an average, surface heat flow is 63 mWm^{-2} and the heat flow from the mantle in continental areas is around 20 mWm^{-2}; the difference is due to radioactive heat production in crustal rocks (Rybach, 1976).

All natural radioactive isotopes generate heat to some extent, but the significant contribution arises from the decay of ^{238}U, ^{232}Th and ^{40}K. There has been exponential decline in the activity of the long lived isotopes through geological times, and hence markedly high heat has been produced during Archaean-early Proterozoic. The heat production is approximately 9.5 per cent less in Tertiary than during the Cambrian times (Plant *et al*, 1985).

HIGH HEAT PRODUCING GRANITES

The high heat production in the granitic rocks is due to enhanced content of ^{238}U, ^{232}Th and ^{40}K. There is no precise definition of a high heat producing (HHP) granite; a level of 10 ppm U (the dominant heat producing component of the natural radioelements) is accepted as lower limit by Simpson (*in* Parslow, 1985). This is about 2.5 times the mean value of granite (Rogers and Adams, 1969). Taking into consideration the decay of U over geological times, this minimum (10 ppm) has been lowered to about 7.5 ppm 'present day' U for granites over 1.75 Ga in age (*cf.* Parslow, 1985). This value can be further lowered for younger rocks. In view of lack of a precise definition of a HHP granite, Plant *et al* (1985) have suggested the following geochemical characteristics for identifying alkaline and subalkaline HHP granites: (*a*) exceptionally high contents of the radioelements Rb, Th, U, K and Cs, Ta, Nb, Y, Sc and Li together with low Nb/Ta, Th/U, Zr/Sn, V/Nb, K/Rb, Sr/Y and Mg/Li, low to very low contents of Ba, Sr, Ti, Zr and of elements such as Cr, Mg, Co, V and Ni; and (*b*) high total REE contents, pronounced negative Eu anomalies and the heavy REE enrichments at higher silica contents. The HHP granites have been shown to comprise evolved calc-alkaline intrusions emplaced later in orogenic cycles. Alkali and subalkaline post-orogenic granites, commonly enriched in Sn, occur in continental rift zones. These suites show evidence of extended history of crustal fractionation (Plant *et al*, 1985).

Heat production is calculated using surface abundances of U, Th and K according to the following equation (Ashwal *et al*, 1987):

A=Heat generation uWm^{-3}=P(0·966 cU+0·026 cTh+0·036 cK),
where cU and cTh=abundance of U and Th in ppm,
cK=abundance of K in weight per cent, and
P=density gm/cm^3

HEAT PRODUCTION IN MALANI ROCKS

The late Proterozoic, trans-Aravalli Malani igneous suite of rock (55,000 km^2; 750 Ma) comprises peralkaline (Siwana) and peraluminous (Jalor and Tusham) granites with cogenetic carapace of acid volcanics (welded tuffs, rhyolites, trachytes, explosion breccias and perlite) and is characterised by granitic and volcanic ring structures. The Malani granites are of A-type and plot in the "Within Plate Granites" field (i.e. anorogenic magmatism). The emplacement of the Malani magmatism was controlled by NE-SW trending lineaments and owed its origin to hot-spot tectonics (Kochhar, 1984). The radioelement abundances and radioactive heat production in the rocks of Malani suite and the Nigerian Younger Province are given in Table I.

A perusal of the Table 1 shows that the Tusham granites have uniformly high HPU values followed by Mokalsar and Kolar (Jalor) granites. The sample B-14 has the highest value recorded. The low value of TG (Tusham) is due to potash depletion. The lower values of some rhyolites and trachytes are also due to potash depletion accompaning hydrothermal alterations and devitrification (Kochhar, 1984). In heat productivities the Malani granites are quite similar to the Nigerian Younger granites. The high radioactive heat production in the Malani rocks appear to be the cause of the observed high heat flow in the Khetri copper belt (Gupta *et al*, 1967) and in Tusham area (A. Sunder, *person. commun.*).

TRACE ELEMENT BEHAVIOUR OF MALANI ROCKS

In order to understand variations among the Malani and Nigerian granites, the abundance of selected trace elements (Table 2) have been normalised to the primordial (undepleted) mantle and are shown in the Figs. 1-2. The primordial mantle (bulk Earth minus the core) is useful in this context as it gives the fractionations that have been involved in generating the present mantle since the accretion of the Earth (Wood, 1979). The figures show that the Mokalsar (Siwana) granites have higher contents of U, Th, La, Ce, Zr, Hf and Sm as compared to the Nigerian Younger granites but are very low in Ba and Ta. K and Ti are similar to those of the Nigerian granites.

The Kolar (Jalor) granites have lower abundance of U, Th, La, Ce, Zr, Hf and Sm but higher Ba than the Siwana granites. The Tusham rocks are very much depleted in Ta and Ti as compared to the Jalor rocks; however Ba, Th, U, K, Zr, Hf and Sm abundances are also quite low. The Mokalsar granites are characterised by high total REE abundance and relatively flat chondrite normalised patterns (La/Yb : 2.3). The Tusham samples fall in a very restricted range of REE abundance and LREE are significantly enriched with respect to HREE (La/Yb : 17). The Mokalsar granites have much more pronounced Eu anomalies (Eu/Eu* : 0·44). The chondrite normalised La/Yb ratio for Jalor granites (La/Yb: 5) are intermediate between the Siwana and Tusham granites. The Jalor granites have the lowest total REE abundances and the Eu/Eu* is 1.24-0.56 (Eby and Kochhar, in press).

TABLE 1

RADIOELEMENT ABUNDANCE AND HEAT PRODUCTIVITIES FOR ALKALI GRANITE, RHYOLITE, TRACHYTE OF MALANI IGNEOUS SUITE AND NIGERIAN YOUNGER GRANITE PROVINCE

Sample No.		Rock type	U (ppm)	Th (ppm)	K (%)	Th/U	HPU (uWm^{-3})
Malani Igneous Suite							
M1	(Siwana)	Mokalsar alkali granite	10.5	58.1	3.76	5.53	7.09
L6		,, ,, ,,	6.8	29.8	3.59	4.38	4.16
100		,, ,, ,,	6.4	43.0	3.99	6.72	5.01
B14		,, ,, ,,	17.1	95.0	3.5	5.56	11.31
R8		,, ,, ,,	11.2	33.3	3.67	2.97	5.53
190		,, ,, ,,	11.0	60.8	3.65	5.53	7.39
P1		,, ,, ,,	15.3	50.6	3.59	3.31	7.78
144		,, ,, ,,	5.93	26.3	2.15	4.44	3.55
157		,, ,, ,,	10.84	38.8	3.74	3.58	5.83
184		,, ,, ,,	9.87	52.0	3.32	5.27	6.45
85		Mokalsar alkali rhyolite	14.0	59.9	3.90	4.28	8.33
M12		,, ,, ,,	5.38	29.5	3.32	5.48	3.84
132		,, ,, ,,	4.61	30.5	4.23	6.62	3.80
R1		,, ,, ,,	1.21	5.29	3.67	4.37	1.06
M11		Mokalsar alkali trachyte	3.72	12.10	2.29	3.25	2.08
101		,, ,, ,,	1.4	9.23	2.91	6.59	1.32
R9		,, ,, ,,	1.14	8.14	3.84	7.74	1.26
K01	(Jalor)	Kolar biotite granite	5.8	29.3	4.19	5.05	3.92
K02		,, ,, ,,	6.9	31.0	3.67	4.49	4.27
K05		,, ,, ,,	2.6	13.3	3.16	5.12	1.89
K06		,, ,, ,,	3.8	17.8	3.41	4.68	2.54
K08		,, ,, ,,	2.0	8.4	3.01	4.20	1.38
B3	(Tusham)	Tusham microcline oligoclase granite	9.3	94.0	4.32	10.05	9.32
C4		,, ,, ,,	11.3	74.0	3.74	0.51	8.39
D3		,, ,, ,,	7.9	57.7	3.74	7.30	6.39
M5		,, ,, ,,	11.0	88.4	4.57	8.04	9.39
KH1		Tusham granite porphyry	10.5	96.5	4.57	9.19	9.83
TG2		Tusham muscovite-biotite granite	4.1	21.6	2.49	5.27	2.79
Nigerian Younger Granite Province (Kinnarid *et al*, 1985)							
SH5		Shira peralkaline granite	3.9	12.0	3.30	3.10	2.15
SH90		,, ,, ,,	7.0	5.5	2.76	0.79	2.44
D23		Dutse peralkaline granite	4.6	1.4	3.24	3.04	1.59
N83		Ririwal peralkaline granite	14.0	51.0	3.43	3.64	7.46
N80		,, ,, ,,	10.0	120.0	3.57	12.0	11.24
N82		,, ,, ,,	17.0	124.0	3.06	7.29	13.26
N25		Amo biotite granite	5.2	2.1	3.39	4.04	1.80
N28		,, ,, ,,	3.9	32.0	3.30	4.78	3.54
N151		Jos biotite granite	5.4	22.0	3.84	4.07	3.28
JB149		,, ,, ,,	2.0	35.0	3.17	7.50	3.25
DW7		Dutsen biotite granite	7.5	23.7	2.98	3.16	3.85

Average Sp. gr.: Mokalsar granite—2.77; Trachyte—2.76; Mokalsar rhyolite—2.74; Jalor granite—2.71; Tusham granite—2.65.

SIGNIFICANCE OF HHP GRANITES

The identification of HHP granites is important not only in locating magmatic mineral deposits, but also in locating epigenetic ore fluids in carbonate and other sedimentary cover

TABLE 2

TRACE ELEMENT DATA FOR MALANI ROCKS (in ppm)

	Mokalsar (Siwana)													
	Alkali Granite										Alkali Rhyolite			
	M1	L6	100	B14	R8	190	P1	144	157	184	85	M12	132	R1
CS	5.30	3.80	4.50	4.60	3.40	1.50	3.80	2.80	3.60	1.40	1.11	0.88	1.87	0.88
Rb	380.00	321.00	210.00	421.00	377.00	388.00	318.00	162.00	326.00	177.00	274.00	129.00	207.00	60.00
Ba	111.00	nd	168.00	nd	60.00	113.00	nd	nd	nd	nd	nd	71.00	nd	770.00
Th	58.10	29.80	17.30	38.10	36.70	29.60	50.60	26.30	30.80	52.00	59.00	29.50	30.50	5.29
U	10.50	6.80	6.40	17.10	11.20	11.00	15.30	5.93	10.84	9.87	14.00	5.38	4.61-	1.21
K	37608.06	35864.64	39849.60	34951.42	36694.84	36528.80	35864.64	31547.60	37359.00	33208.00	39019.60	33208.00	42340.20	36694.80
Ta	15.90	11.10	11.90	24.670	12.40	18.40	16.00	9.36	15.00	13.40	16.80	9.55	9.00	2.92
La	320.00	216.00	227.00	401.00	173.00	425.00	208.00	161.00	161.00	202.00	275.00	153.00	200.00	58.00
Ce	757.00	514.00	576.00	841.00	423.00	799.00	570.00	398.00	527.00	714.00	—	379.00	506.00	140.00
Nd	426.00	275.00	320.00	421.00	212.00	439.00	291.00	218.00	260.00	312.00	405.00	191.00	250.00	83.00
Hf	80.00	79.20	52.00	114.00	110.00	88.90	128.00	73.70	132.00	78.00	107.00	63.10	57.40	19.65
Zr	3470.00	3190.00	2330.00	4410.00	3970.00	3390.00	4870.00	2730.00	46500.00	3170.00	3980.00	2490.00	2180.00	780.00
Sm	94.10	60.60	74.30	91.90	49.00	81.50	70.40	45.00	60.00	70.00	88.80	40.40	46.60	18.60
Ti	1858.45	1558.70	3956.70	2158.20	1318.90	2697.75	1498.75	2997.50	1438.80	3057.45	2098.25	2038.30	4256.45	1258.95
Tb	16.80	11.00	12.70	17.40	10.20	14.60	14.60	8.44	12.20	—	16.90	7.36	8.10	3.02

Contd.

TABLE 2 (*Contd.*)

	Mokalsar (Siwana)			Kolar (Jalor)					Tusham						Average low Ca-granites (Turekian and Wedepohl, 1961)
	Alkali trachyte			Granites					Granites						
	M11	101	R9	K01	K02	K05	K06	K08	B3	C4	D3	M5	KH1	TG2	
Cs	2.61	2.70	1.85	7.10	4.80	8.30	7.50	33.80	7.70	11.30	13.20	7.70	9.30	10.30	—
Rb	69.00	66.00	166.00	213.00	186.00	89.00	138.00	159.00	331.00	360.00	370.00	314.00	357.00	233.00	170.00
Ba	86.00	116.00	nd	680.00	790.00	930.00	670.00	930.00	1000.00	1170.00	960.00	1430.00	890.00	550.00	840.00
Th	12.10	9.23	8.14	29.30	31.00	13.30	17.80	8.40	94.00	74.00	96.40	57.70	88.40	21.60	17.00
U	3.72	1.40	1.14	5.80	6.90	2.60	3.80	2.00	9.30	11.30	10.50	7.90	11.10	4.10	3.00
K	22913.52	29057.00	38438.26	41925.10	36694.84	31630.62	34121.22	30053.24	43170.40	37359.00	45661.00	37359.00	45661.00	24906.00	—
Ta	5.82	4.55	3.80	1.80	1.70	1.10	1.40	0.70	2.10	2.00	2.30	1.90	2.20	1.50	3.50
La	107.00	103.00	103.00	57.30	74.30	41.60	51.40	30.10	194.00	176.00	184.00	139.00	203.00	49.20	—
Ce	272.00	253.00	256.00	126.00	156.00	96.30	114.00	63.80	366.00	339.00	347.00	266.00	381.00	98.00	—
Nd	162.00	156.00	168.00	57.00	72.10	46.70	55.10	30.60	126.00	130.00	132.00	103.00	140.00	41.90	—
Hf	35.80	29.60	29.20	11.40	30.60	12.20	13.30	9.50	8.40	11.80	7.60	10.50	7.90	6.10	5.00
Zr	1430.00	1080.00	1040.00	360.00	1110.00	450.00	490.00	350.00	270.00	380.00	230.00	350.00	250.00	220.00	175.00
Sm	36.50	34.90	36.90	12.30	15.30	9.60	11.60	6.80	20.40	20.20	21.10	16.50	21.70	8.10	—
Ti	1258.95	7074.10	3716.90	2278.10	2158.20	3716.90	3537.05	3297.25	119.90	59.95	1139.05	1558.70	1139.05	239.80	—
Tb	7.39	5.68	5.97	1.83	2.27	1.49	1.69	1.09	2.34	2.34	2.48	1.95	2.45	1.17	—

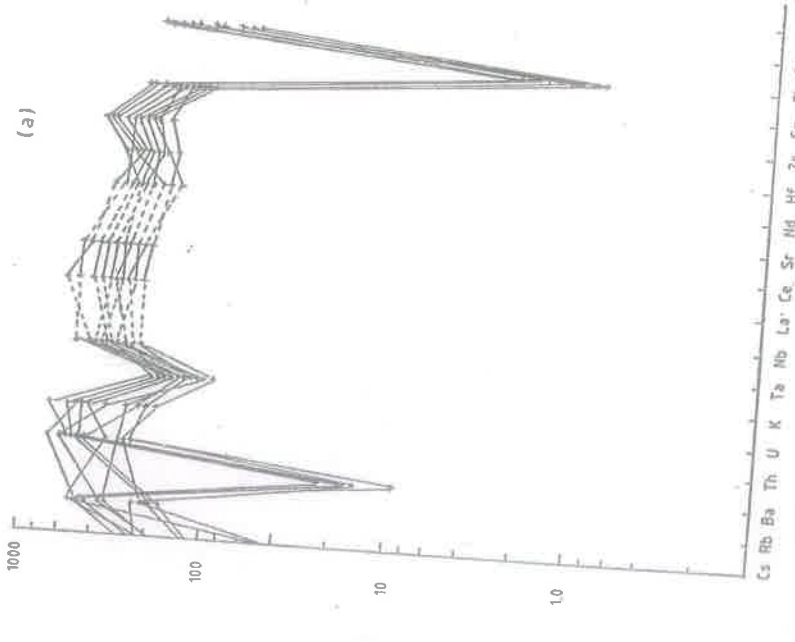

Fig. 1*a*. Primordial mantle normalised trace element diagram for Siwana granites. Absent data indicated by dotted line.

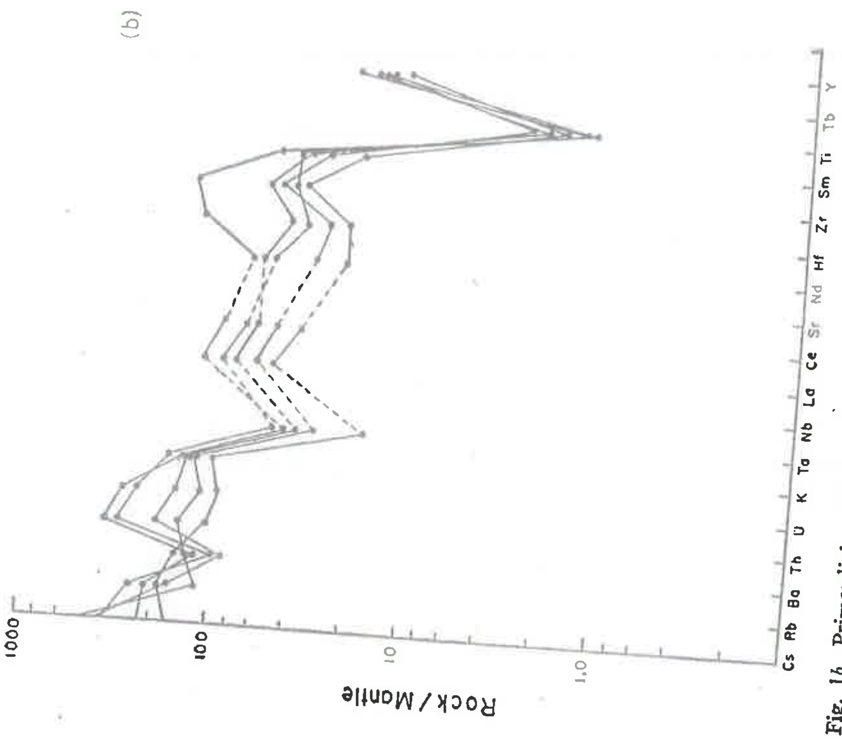

Fig. 1*b*. Primordial mantle normalised trace element diagram for Jalor granites. Absent data indicated by dotted line.

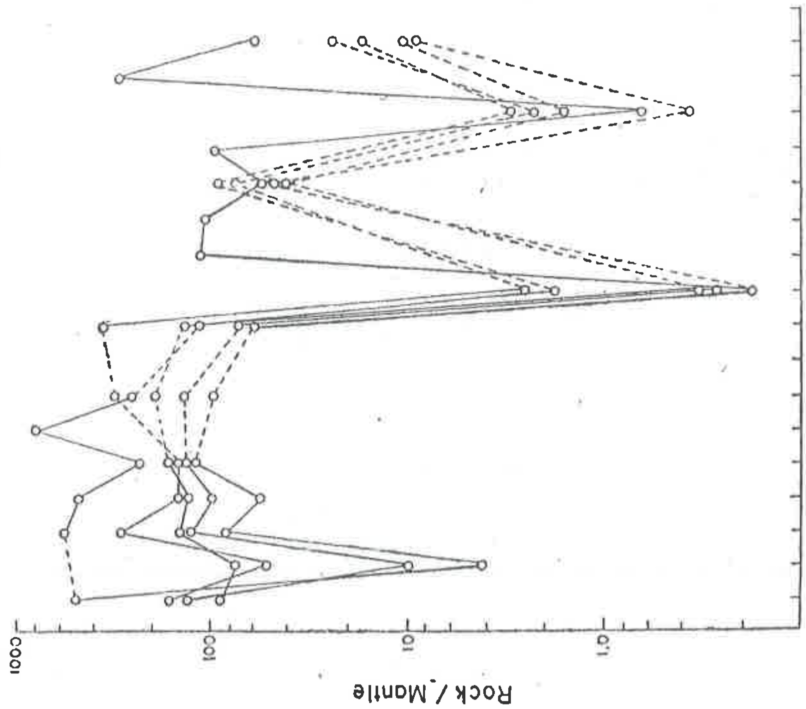

Fig. 2b. Primordial mantle normalised trace element diagram for Nigerian Younger granites. Absent data indicated by dotted line.

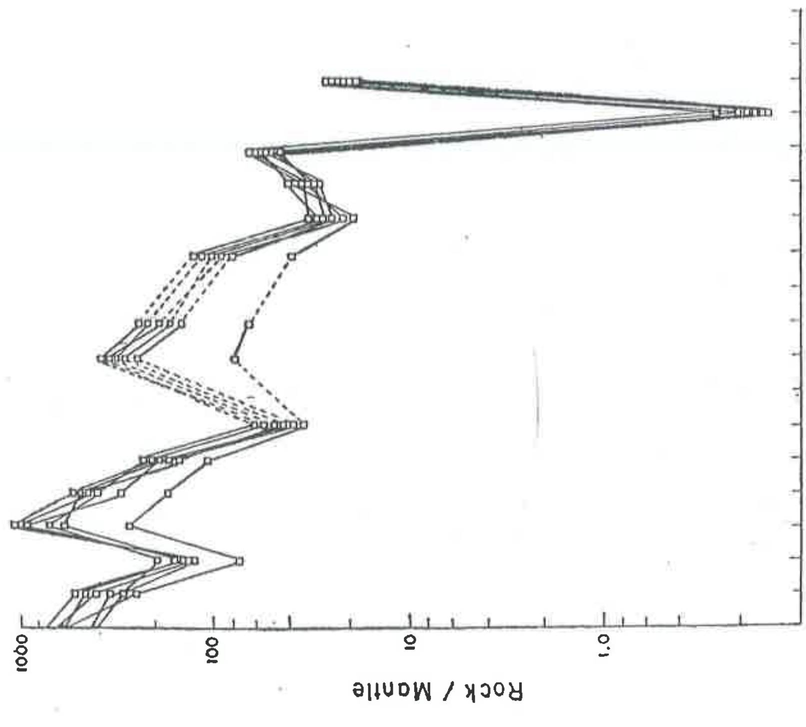

Fig. 2a. Primordial mantle normalised trace element diagram for Tusham granites. Absent data indicated by dotted line.

sequences over such HHP granites in the basement. The HHP granites act as 'heat engines' which prolong the circulation of ore-bearing hydrothermal fluids. Nb, Sn, W and Zn deposits are associated with the Nigerian Younger granites (Kinnarid *et al*, 1985) and Nb, Zr, REE, U and Th mineralisations are associated with Saudi Arabian granites (Jackson *et al*, 1985). Tin mineralisation in the Tusham ring complex (Kochhar, 1985) is also associated with the HHP granites of the Malani representatives of the Tusham area.

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