Journal of Biosphere, 6: 49-57, 2017 ISSN 2278 – 3342

Geochemical Characteristics of the Mineralized and Barren Igneous bodies of the Tosham Igneous Complex (TIC) Bhiwani District, Haryana, Northwestern India

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Abstract: The Khanak and Tosham are the two main igneous bodies of Tosham Igneous Complex (TIC) of the northwestern India which exhibit ring like structures of the plutonic and volcanic igneous phases. The plutonic and volcanic igneous phases of this complex shows intense post magmatic alteration effect, however the rock types of the Khanak igneous body are devoid from such post-magmatic alteration effect. At Khanak the igneous body is barren, whereas porphyry type Sn-W±Cu mineralization is associated with the Tosham. Geochemically, Tosham igneous body is characterized by higher concentration of SiO_2, total alkali content, K_2O/Na_2O, FeO/MgO and low CaO, FeO^tMgO, and Na_2O, whereas the high Al_2O_3, FeO, MgO, CaO and low SiO_2 and total alkalies are present in the Khanak. Further, higher values of Rb, Ba, Nb, Cs Cu, Th, U and Nb and depletion of Sr, Ga, Ta, HREEs and Y have been observed in Tosham as compared to the Khanak. The geochemistry of the two igneous bodies suggests these granites are A-Type, peraluminous, and potassic rich igneous rocks. The geochemical difference in the rocks of the Tosham and Khanak area indicates that rocks of the Tosham area are more magmatically differentiated than the rocks of the Khanak area. This might be the reason for the presence of mineralization in the Tosham and devoid of any mineralization in the Khanak area.

Keywords: Geochemical; barren igneous bodies; Tosham Igneous Complex; Haryana.

Introduction

Tosham Igneous Complex (TIC) located in the northwestern part of the Indian shield. These rocks have been dated 940±20 ma old by Kochhar (1974), suggesting them to be pre-Malanies but post-Delhi. This igneous suite comprises the acid volcanics and high-level co-magmatic granites. The TIC comprises the overall at least five granite plutons of variable dimensions showing elliptical and/ or circular outcrop pattern of the plutonic and volcanic igneous phases. These granite plutons occur over a 16km from north and south and about 13km in width. Most of these plutons are very small in dimension and only the Khanak and Tosham are larger in size, which have been choose for comparative petrographic and geochemical studies in the present paper.The presence of quartz porphyry ring dykes, association of explosion breccia with the felsite, and plutonic rocks suggest the ring type structure of the TIC. The igneous bodies of the TIC are mostly barren, however, at ToshamSn-W±Cu mineralization is present. Many features of mineralization in the area show the similarity with the porphyry type of Precambrian mineralization. These features are epizonal setting of granites, association of acid volcanics, wall rock alteration pattern, sharp contact between quartz porphyry and felsite and between granite and felsite which does not shows any metamorphic effects and also the association of the mineralization with the explosion breccia. Kochhar (1983, 1985) have

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suggested the porphyry type Cu and Sn mineralization in the area.

In the present paper, two major igneous bodies of the TIC, which forms a part of Malani igneous suite situated at Tosham (mineralized) and Khanak (barren) area studied for their petrographic and geochemical characteristics. The purpose of study is to know whether the mineralized and barren igneous bodies (Tosham and Khanak), which have been considered to be a part of the Tosham Igneous Complex, belongs to the same source of the magma chamber or they belongs to the different source.

Geological Setting

Regional Geology

The present area formed a part of the Aravalli–Delhi metallogenic province in Northwestern India. The geology of the area is summarized in the Table-1.

Table 1. Geochronology of the Precambrian rocks in the Western Peninsular India

Rocks		Age
Vidhyan system (Jodhpur sandstone)		1400-500Ma
Malani Igneous suite (acid volcanic and granites)		
	Tosham area	750 Ma
	Kirana area	870 Ma
Delhi System		1650 Ma
Raialo series		-
Aravalli System		20000-2500Ma
Bundelkhand granite		2500Ma
Berach granite Banded Gseiss Complex (BGC)		>2500Ma

The Proterozoic felsic magmatism commenced with the intrusion of the Erinpura granite which is represented by widespread and dominantly felsic (locally mafic) volcanism and plutonism collectively termed the Malani Igneous Suite (745 ± 10 Ma: Bhushan, 2000). Because of the contemporaneity of ages, Choudhary *et al.* (1984) suggested a common mechanism for the evolution of this suite. Available geochemical data for some of these granites suggest S- or A-type chemistry (Roy, 1988). Some of these granites plutons host the W±Sn mineralization in this belt (Srivastava and Sinha, 1997), Bhattacharjee *et al.* (1993) has named it Balda–Tosham Tungsten Belt. This 500 km-long linear belt contains several small W-Sn-mineralized plutons, including the Tosham tin- tungsten deposit also Bhattacharjee *et al.*, (1993) Fig.1.

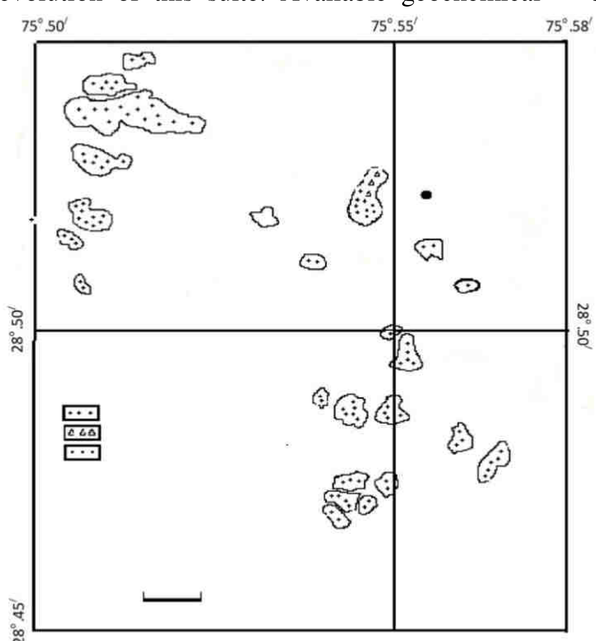

Figure 1. Regional Geological map of the area showing distribution of tungsten deposit in the Balda- Tosham tungsten belt (after Sugden *et al.*, 1990).

Local Geology

Tosham Igneous Complex (TIC) is located on the northwestern part of the Indian Shield about 160km WNW of Delhi. This Igneous Complex comprises the small scattered (more than 5) elliptical granite bodies, which exhibit ring like structures. All these igneous bodies are barren except Tosham Igneous body, which hosts Sn-W-Cu mineralization. The geological map of the Tosham and Khanak Igneous bodies is given in Fig. 2. The outcrop of the Tosham is in form of isolated dome shaped hillock surrounded by aeolian sand and covers small area of 1.56sq.km. A barren igneous body is exposed at Khanak, which is 5 km west to the Tosham hill comprising the hillock in otherwise a flat alluvial terrain. Khanak is the largest igneous body in the TIC. The trend of the Khanak is E-W, whereas the Tosham hillock shows NE-SW. The Tosham and Khanak hillocks are separated by aeolian sand and no connectivity between the two hillocks is seen on the surface. Both Tosham and Khanak hillocks comprises same rock varieties. The area consists of two major lithounits, which comprises the plutonic and volcanic phases and the other is metasediments. The TIC is intruded into the meta- sediments of Delhi Supergroup. The nature of contact between the different phases in the area are well seen which varies considerably. The metasediments are represented by quartzite and quartz -mica -schists, which are exposed on the eastern and northwestern side of the hillock. The Tosham and Khanak pluton is texturally as well as mineralogically heterogeneous and is comprised of biotite granite, medium to coarse-grained granite, K-feldspar porphyry and quartz feldspar porphyry whereas the volcanic phase consists the felsites, explositionbreccias and rhyolite.

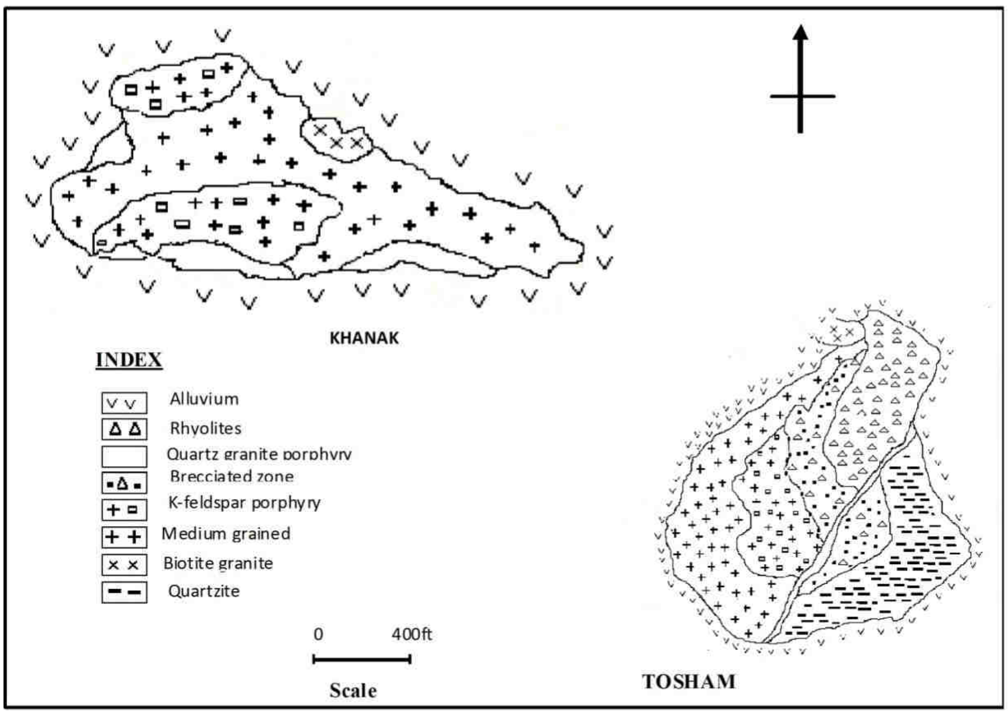

Figure 2. Geological Map of the area (after Gupta and Eisdon, 1994)

Geochemical characteristics

Analytical Techniques

36 representative samples of the different rock varieties from Tosham and Khanak areas are analyzed for their major oxide composition and 22 samples are analyzed for their trace and REEs composition. The samples of the quartz porphyry and k-feldspar porphyry are highly weathered so it is very difficult to collect the fresh samples for the laboratory studies. Care has been taken and attempt has been made to take the few fresh samples for the petrographic and geochemical studies. The rocks varieties of the Khanak igneous body shows less alteration effect as compare to the Tosham Igneous Complex so there is no difficulty in sample collection.

The major oxide analysis is done in the Departmental Geochemical Laboratory where analysis is carried out on UV/Visual Spectro-photometer (ECIL, GS 5701 SS), Systronic Digita Flame Photometer (Model, 125) and Titration method.

The trace elements and REEs are analyzed by using ICP-MS instrument at NGRI Hydrabad. The solution for the analysis of REEs is prepared using HF-$HClO_4$-HNO_4digestion technique. Japanese standard for granite (JG-3) is used for the REEs.

Major Oxide Geochemistry

The major oxide composition of the selected samples from Tosham and Khanak areas are given in the Table 2. The analysis suggests that the plutonic as well as the volcanic phase of the Tosham and Khanak areas shows the variations in their major oxide concentration. The acid volcanics contain high potash and low soda. Tosham rocks are characterized by the higher concentration of SiO_2, total alkalies, K_2O/Na_2O, FeO/MgO and low CaO, FeO^t, MgO, and Na_2O, whereas the rock varieties of the Khanak igneous body shows high Al_2O_3, FeO, MgO, CaO and low SiO_2 and total alkalies

Table 2. Major Oxide composition of Tosham and Khanak Igneous bodies of the Tosham Igneous Complex

Rock type	**Medium gained granite**								**Biotite granite**							
Area	**Tosham**					**Khanak**			**Tosham**					**Khanak**		
Sample No	**Ts-50**	**Ts-41**	**Ts-58**	**Ts-32**	**TS-16**	**Kh-06**	**Kh-07**	**Kh-08**	**Kh-12**	**Kh-13**	**TS-65**	**Ts-69**	**Ts-70**	**Kh-20**	**Kh-21**	**Kh-14**
SiO_2	67.5	68.3	67.0	69.3	68.9	66.4	65.5	66.5	66.1	65.2	68.2	69.1	68.4	65.2	65.7	66.2
TiO_2	0.9	0.2	0.7	0.3	0.1	0.5	0.4	0.3	0.3	0.4	0.6	0.6	0.6	0.7	0.7	0.7
Al_2O_3	15.3	14.6	15.9	14.3	14.5	14.2	16.4	14.6	15.3	16.0	13.7	13.7	14.1	13.6	14.6	14.4
Feo^t	7.0	7.0	7.0	6.7	6.8	8.6	8.1	7.9	7.4	8.3	6.6	7.8	8.1	8.9	8.7	8.9
MnO	0.2	0.4	0.4	0.2	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.4	0.3	0.4
MgO	0.5	0.9	0.6	0.7	0.8	1.0	1.0	0.9	0.9	1.1	1.0	0.1	0.1	1.0	1.1	1.1
CaO	0.4	0.3	0.5	0.2	0.2	0.6	0.6	0.5	0.6	0.4	0.3	0.3	0.3	0.4	0.5	0.4
K_2O	6.8	7.3	6.7	7.2	7.4	7.2	7.0	7.4	7.2	6.8	6.7	5.2	5.7	5.9	5.3	6.8
Na_2O	1.2	0.8	1.0	1.1	1.0	1.1	0.8	1.1	1.1	1.2	2.6	3.0	2.4	3.1	2.9	1.0
P_2O_5	0.1	0.1	0.1	0.1	0.0	0.1	0.1	0.1	0.0	0.1	0.0	0.1	0.1	0.1	0.1	0.1
Total	99.6	99.5	99.5	99.8	99.7	99.4	99.8	99.2	99.1	99.6	99.7	100	99.9	99.1	99.9	99.9
Na_2O+K_2O	8.2	7.8	8.4	8.4	8.0	7.9	8.0	7.6	8.2	8.3	9.0	8.2	7.8	9.3	8.2	8.1
Na_2O/K_2O	6.8	9.3	6.8	6.4	5.5	5.9	9.7	6.9	6.8	7.8	1.9	1.8	6.8	2.6	1.7	2.3

In the SiO_2 vs. Al_2O_3/ (CaO+ K_2O + Na_2O) plot samples of both the areas fall in the peraluminous granite (Fig, 3) suggesting the peraluminous nature of the melt. In the (Na_2O+K_2O) - CaO – (FeO+MnO+MgO) ternary diagram (Fig, 4) a demarcation between the samples of the two areas is observed as Tosham rocks are enriched in alkalies and Khanakcontanins more CaO and FeO, MnO and MgO. It indicates that the Sr enrichment is not related with CaO in the mica granite and K-feldspar porphyry of the Tosham and Khanak rocks.

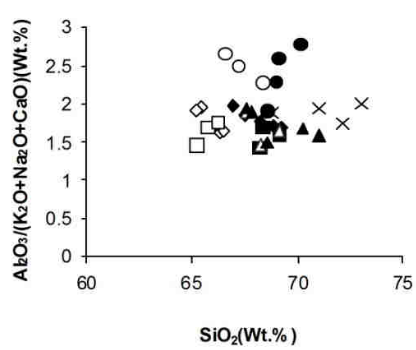

Figure 3. SiO_2 vs. Molar Al_2O_3/ (CaO+Na_2O+K_2O) plot for the Tosham and Khanak igneous bodies (Field after Clarke, 1981)

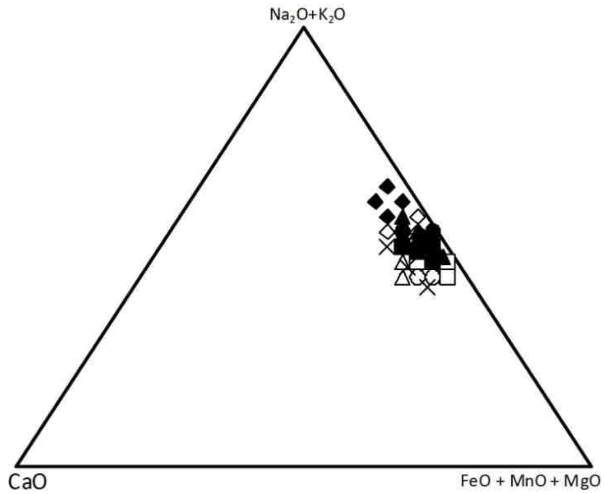

Figure 4. (Na_2O+K_2O)-CaO-(FeO+MnO+MgO) ternary diagram

Trace element and REEs Geochemistry

22 representative samples of the different rock groups from Tosham and Khanak areas are analyzed for their trace and REEs composition and their result is given in Annexure I and II. The trace element variation plot (Fig, 5) suggests higher concentration of Rb, Ba, Nb, Cs Cu, Th, U and Nb and depletion of Sr, Ga, Ta, HREEs, Y for Tosham as compared to the Khanak. The granite porphyry shows high, Ga, La, Ce, Ba, and Cs Zr. When Ga/Al ratios are plotted against its total alkalies, K_2O/Na_2O, FeO/MgO ratios and Zr values the samples from both falls in the A-type granite field (Fig, 6) of Whalen *et al*. (1987). The plot between K/Rb ratio and Rb/Sr ratio (Fig, 7) indicating the negative relationship between the rock varieties of the two areas suggesting the variation trend in the magma with Tosham showing greater magmatic differentiation than Khanak.

This is also supported by the Rb-Ba-Sr ternary field of El-Bousely and El-Sokkery (1975) in which values of Tosham rock varieties falls in the highly differentiated field (Fig, 8), whereas the values of the rock varieties from Khanak falls in the normal granite field which suggest that the Tosham rocks are more differentiated than Khanak rocks.

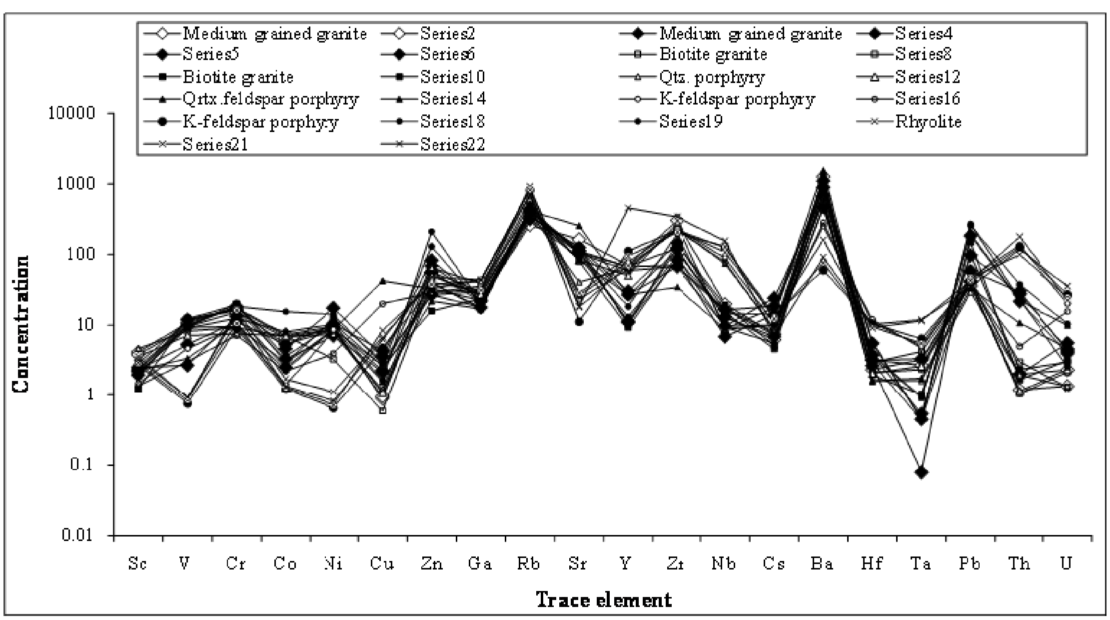

Figure 5. Trace element variation plot for the Tosham and Khanak

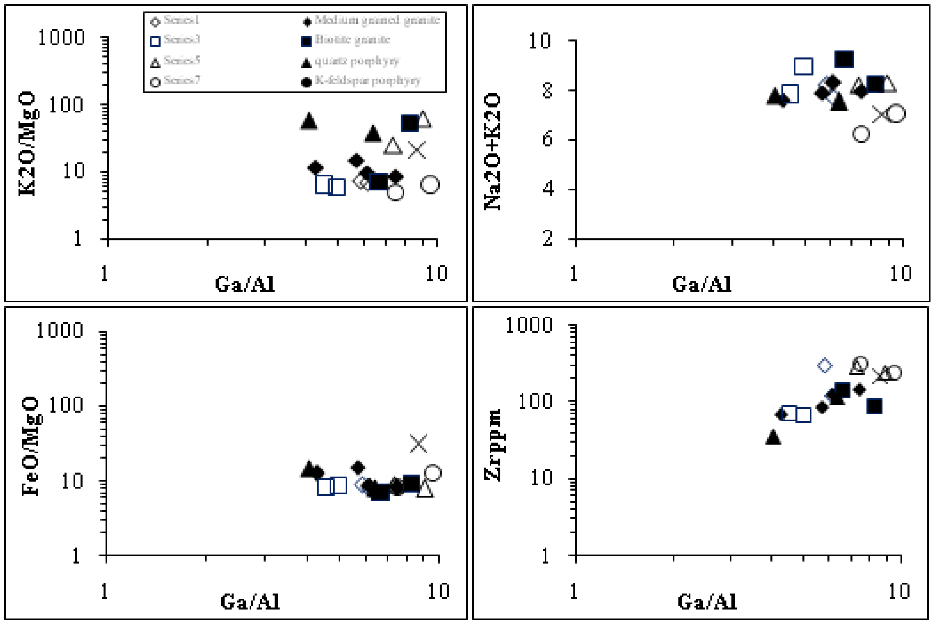

Figure 6. The Ga/Al vs. Na_2O+K_2O, K_2O/MgO, FeO^t/MgO ratio and Zr plot for Tosham and Khanak. The fields are after Whalen *et al.* (1987).

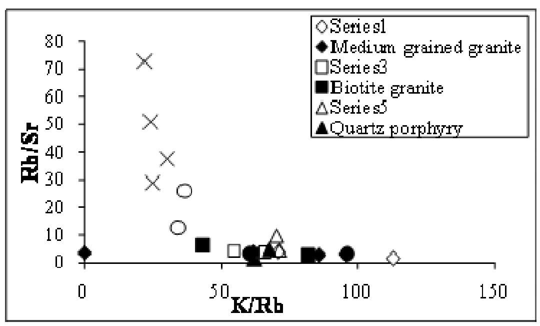

Figure 7. K/Rb vs. Rb/Sr ratio plot for the Tosham and Khanak igneous bodies

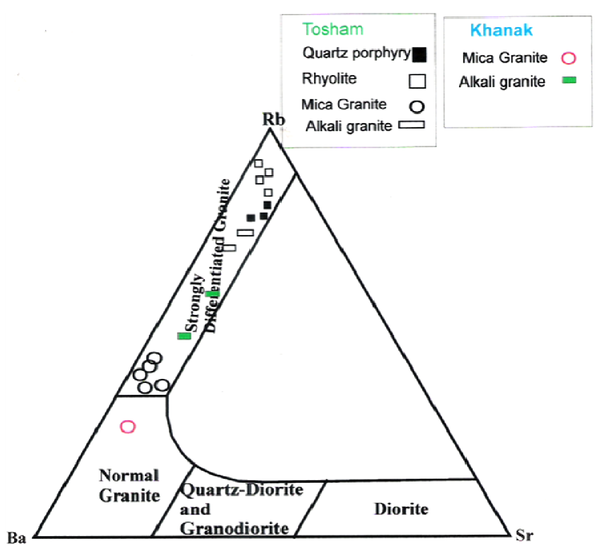

Figure 8. Rb-Ba-Sr ternary plot for the Tosham and Khanak igneous bodies (Field after El-Bousely and El – Sokkery, 1975).

The Chondrite normalized pattern plotted for the different rock groups (Fig, 9) from both areas shows similar pattern suggesting their co-magmatic nature. The Tosham shows high Eu anomaly as compared to Khanak containing LREEs more than HREEs. The samples shows moderate to high negative Eu anomaly with (Eu/Sm)cn ratio ranging between 0.04 to 0.55. The (La/Lu)cn, (La/Yb)cn, and (Ce/Yb)cn, is higher side for the Tosham.

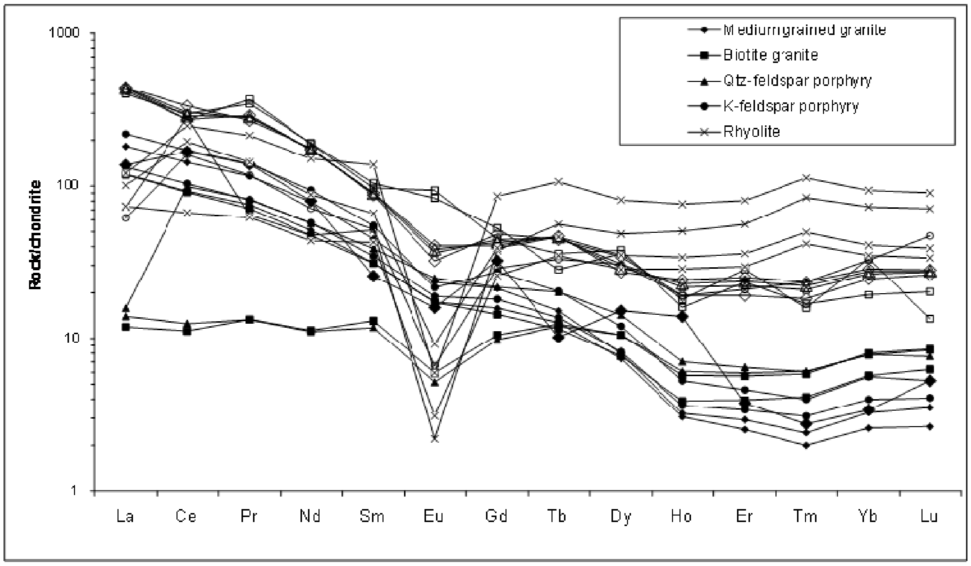

Figure 9. Chondrite normalized REEs pattern for the Tosham and Khanak igneous bodies

The evolution of REEs patterns is also best explained with the crystal fractionation. With increasing differentiation the total REE contents and LREE/HREE ratio decrease and the negative anomalies are more pronounced. The fractionation of allanite and apatite, which are present as accessory phases, might have caused the lower total REE contents and lower LREE/HREE in evolved phase (Zhao and Cooper, 1993). Many of the high heat producing granites associated with Sn-W mineralization (Plant *et al.*, 1990; Kochhar, 1989) and many late-, post- and anorogenic granite suites (Rogers and Greenberg, 1990; Raith, 1995) exhibit very similar REE patterns and evolution trends.

Discussion

The association of plutonic and volcanics in the area is characteristic of high level magmatism in anorogenic environment as suggested by Hughes, (1982) elsewhere. In the present areas the field and petrographic features such as association of the plutonic and volcanics, sharp contact between the quartz porphyry with the other rocks in the area, porphyritic, mirmekite and graphic texture of the granite and presence of perthitic nature of the k-feldspar, zoning in feldspars, zircon and tourmaline crystals suggest the fractionated granite of the Tosham and Khanak igneous bodies.

Geochemically Tosham shows low FeO^t, MgO, TiO_2, Sr, and high SiO_2, total alkalies, Rb, Ba, Th, and U, Ga/Al as compared to the Khanak. The major element and trace element geochemistry (relative to other specialized granites types are high SiO_2, Rb, Ba, Th, U, Rb/Sr; low FeO^t, MgO, CaO, TiO_2 and P_2O_5) of the Tosham igneous body reveals that in many respects it is similar to the other tin-tungsten bearing granites of the world (Tishendorf, 1977). The chemistry of the rocks has been modified due to intense alteration and metasomatism. The Tosham granites are characterized by high K/Na ratio, which may be due to the K-metasomatism, which is much pronounced in the granites as well as acid volcanic of the Tosham Igneous Complex. In the potash feldspar porphyry and potash rhyolite soda is less and variation of K_2O is very high which suggest the leaching of the Na and end enrichment of potash through metasomatising fluid. The high K_2O and low soda content of these acids volcanic is due to post emplacement devitrification and hydrothermal alteration (Kochhar, 1973; Pareek, 1986). The Tosham rocks are enriched in the LIL-elements like Rb, K, Th, and U in comparison with average upper crust (Taylor and McLennan, 1985) and also in Y.

The K/Rb, Ba/Rb and Rb/Sr ratio are low in the Tosham rocks as compared to the Khanak. Tauson and Kozolov (1973) have suggested that trace element concentrations and elemental ratios indicate the source of the rock and also the evolution of the parental magma during the crystallization. Kinnarid, (1985)have suggested that the complexes associated with mineralization are characterized by low K/Rb, Ba/Rb and Rb/Sr ratio which holds true for the present areas also where mineralization is present in Tosham in the disseminated form whereas the Khanak igneous body is barren. The rare earth element behavior of these rocks suggests that these are co- magmatic in nature

In the Tosham igneous body mineralization is present in form of quartz-biotite-sulphideveinlets and small networks of quartz-cassiterite veins intruded in the quartz feldspar porphyry and mica granite and associated intense hydrothermal alteration effect indicated the evolution of the hydrothermal fluid in the late stage of the magmatic evolution. The physical association of the Sn-W mineralization with the granite porphyry and rhyolite indicates the evolution of the mineralizing fluids from the granitic magma. This evidence is well supported by the presence of the three types of the fluid inclusions in the quartz of the granites as well as of the mineralized quartz veins and their high homogenizing temperature. The geochemical difference in the rocks of the Tosham and Khanak area indicates that rocks of the Tosham area are more magmatically differentiated than the rocks of the Khanak area. This might be the reason of the presence of the mineralization in the Tosham and devoid of any mineralization in the Khanak area.

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