CHAPTER 6

PROVENANCE CHARACTERISTICS

6.1 Introduction

Source area weathering conditions, hydraulic sorting, adsorption, diagenesis, and metamorphism are the factors which affect the overall composition of clastic sedimentary rocks (Wronkiewicz and Condie, 1987; Fedo et al., 1996; Nesbit et al., 1996, 1997). In order to characterize the provenance of terrigeneous sediments, it is necessary to rely on elements that are considered immobile or least mobile during these processes. Weathering and metamorphism are the processes which are commonly involve congruent and incongruent dissolution of rock forming minerals. For example alkaline and alkaline earth metals may be transported as dissolved species and their abundances in sedimentary rocks may not reflect their abundances in source terrain. However, element such as Al_2O_3, Ti, Ni, Cr, Co, Zr and REE are commonly transported in solid detritus, thus are reliable indicator of provenance. Since the Proterozoic clastic sediments of Alwar basin being discussed herein, are metamorphosed up to middle amphibolite facies, our interpretations regarding provenance characteristics rely heavily on immobile and least mobile trace elements and REE (Taylor and McLennan 1985; McLennan and Taylor, 1991). The trace elements such as REE, Th, Sc, Co are especially useful elements for monitoring source area composition because their distribution is not significantly affected by diagenesis and metamorphism and is less affected by heavy mineral fractionation than that for elements such as high field strength elements (Bhatia and Crook, 1986). In addition, this array includes both incompatible and compatible elements, ratios of which are useful in differentiating felsic from mafic source components. However, the HFSE are strongly partitioned into sand size grains and can be decoupled from other element groups because of heavy mineral fraction, owing to their high specific gravity and resistance to weathering (Taylor and McLennan, 1985).

6.2 Source Characteristics

The major element composition of pelites can be used to suggest their detrital mineralogy (Cox et al. 1995). The index of compositional variability [ICV = (Fe_2O_3+K_2O+Na_2O+CaO+MgO+TiO_2)/Al_2O_3] has been effectively used in this regard (Cox et al., 1995). ICV in combination with CIA can also be used to evaluate sediment maturity and weathering intensity (Long et al., 2012). Non-clay minerals have higher ratios of the major cautions to Al_2O_3 than clay minerals, so the non-clay minerals have higher ICV values. For example ICV decreases in the order of pyroxene and amphibole (~10 - 100) - biotite (~8) - alkali feldspar (~0.8 - 1)- plagioclase (~0.6)- muscovite and illite (~0.3)- montmorillionite (~0.15 - 0.3), and kaolinite (~0.03 - 0.05) (Cox et al. 1995). Immature shales with high percentages of non-clay silicate minerals will thus have ICV values greater than one. Such shales are often found in tectonically active settings in first cycle deposits (Van de Kamp and Leake, 1985). In contrast, more mature mud rocks rich in clay minerals ought to have lower ICV values of less than one (Cox et al., 1995). Such shales are derived from stable cratons with quiescent environments (Weaver, 1989). Low ICV values have also been found, however, in some first cycle material that was intensely weathered (Barshad, 1966).

The ICV values of Alwar basin metapelites are less than 1, except samples S22 and S24 which show ICV values of 1.02 and 1.09 respectively. Low ICV values of our samples of metapelites (avg. 0.63), along with high values of weathering indices (PIA = 86; CIW = 83 CIA = 63) suggest that these sediments are generally more mature and were mostly derived from stable cratons as first cycle input. However, presence of samples with ICV >1 suggest periodic inputs of highly immature detritus.

In igneous rocks Al resides in K-feldspar and Ti in mafic minerals such as olivine, pyroxene, hornblende, biotite and ilmenite, as result the values of Al/Ti ratio increase gradually with increasing contents of silica. Therefore the values of Al_2O_3/ TiO_2 shows an increasing trend from (a) 3 to 8 in mafic igneous rocks (SiO_2 = 45 - 52 wt %). (b) 8 - 21 in intermediate igneous rocks (SiO_2 = 53 - 66 wt %) and (c) 21 - 70 in felsic igneous rocks (SiO_2 = 66 - 76 wt %). It has been suggested that the SiO_2 content of normal igneous rocks can be evaluated from their Al_2O_3/ TiO_2 ratio by using the following equation:

$$SiO_2 \text{ wt } \% = 39.34+1.2578\ (Al_2O_3/ TiO_2) - 0.0109\ (Al_2O_3/ TiO_2)^2$$

Since Al and Si are immobile and behave similarly during weathering and transportation the silica content of the source rocks can be inferred from the Al_2O_3/ TiO_2 ratios of the clastic rocks using above equation (Hayashi et al., 1997). When Al_2O_3/ TiO_2 ratios of the silisiclastic rocks of Alwar basin are substituted in the above equation the SiO_2 contents in the theoretically inferred magmatic source rocks of the quartzite ranges from 43 to 75 %; with average of 61 % and metapelites from 52 to 70 % with average of 62 %. These values of SiO_2 contents suggest that siliciclastic rocks of Delhi Supergroup of the Alwar basin possibly derived from a source region comprising predominantly of igneous rocks having intermediate composition or a mixed source consisting felsic and mafic rocks

The Al_2O_3/TiO_2 ratio in felsic igneous rocks is generally >10 and can be up to >100. Mafic volcanic rocks on the other hand tend to have values <20, although they rarely have Al_2O_3/TiO_2 ratios larger than 50 (Byerly, 1999). Al-depleted Mg- rich rocks display the lowest values of around 4 (Sugitani et al., 1996). The Al_2O_3/TiO_2

ratios of Alwar quartzites and pelites are highly variable (2.89-107.22, avg. 28.29; 10.81-34.94, avg. 22.76), suggesting a mixed source consisting felsic and mafic rocks. Hayashi et al., (1997) have suggested that the Al_2O_3/TiO_2 ratio of shale should be similar to their source rocks and therefore this ratio can be used as a significant indicator of the provenance. Ratios exhibiting higher values (>21) indicates the sediments were sourced from a felsic source. The average value of metapelites of Alwar basin is 22.75 (range 10.80 - 34.94) reflecting a source terrain consisting predominantly of felsic rocks.

Taylor and McLennan (1985) and McLennan and Taylor (1991) have suggested that the REEs, Th, Sc, Cr and Co and high field strength element (HFSE) are especially useful elements for monitoring source area composition. La and Th are more abundant in felsic rocks than in mafic rocks and opposite is true for Sc, Cr and Co (Lopez et al., 2006). However, the HFSEs are strongly partitioned in sand size grains and can be decoupled from other element groups because of heavy mineral fractionation, owing to their high specific gravity and resistance to weathering (Taylor and McLennan, 1985). Similar situation might have occurred in case of clastics rocks of the Alwar basin and thus use of HFSE is avoided in provenance modeling. Therefore, our discussion on provenance characteristics chiefly relies on immobile elements such as REEs, Th, Sc, Cr and Co contents, their ratios and overall REE patterns which are most useful provenance indicator (Taylor and McLennan, 1985). The relative abundance of Co and Cr (indicative of mafic source), La and Th (indicative of felsic source) and ratios such as Co/Th and La/Sc are generally used to examine the geochemical nature of source rocks (McLennan ad Taylor, 1991; Cullers, 2000; Wang et al., 2012).

A broad hint of felsic plutonic source rock is indicated for Alwar basin siliciclastics, by features such as extreme mineralogical maturity of quartzites and stable heavy mineral population of tourmaline, garnet, rutile and zircon in these rocks. Predominantly reworked sedimentary source is not favored by features such as lithic fragments are sparse, quartz is chiefly monocrystalline and fine quartz grains are texturally immature showing angular to subangular grains. The presence of fresh K-feldspars also indicates a granite source. REE patterns have been used widely in geochemical studies of metasedimentary rocks. The degree of differentiation of LREE from HREE is a measure of the proportion of felsic to mafic components in the source region, whereas Eu anomalies may provide information about the nature of the processes affecting the source area such as whether plagioclase has been removed from the ultimate igneous source areas of the sediments (Taylor and McLennan, 1985). The relatively high LREE enrichment of the analyzed samples of quartzite {$(La/Yb)_n$ = 1.51 - 51.25; avg. 16.17)} and metapelites {$(La/Yb)_n$ = 0.68-35.90; avg. 13.35)} compared to that of PAAS and { $(La/Yb)_n$ = 4.3) }, suggests the dominance of felsic rocks over mafic rocks in the source areas. In addition, the presence of significant negative Eu-anomalies for most of the quarzites and the metapelites suggest the dominance of K-rich granitic rocks in significant proportion (Taylor and McLennan, 1985).

Provenance of both quartzites and metapelites of Delhi Supergroup of the study area can be evaluated using major element discrimination scheme of Roser and Korsch (1988), which classifies sediments into one of four categories i.e. mafic (P1), intermediate (P2), felsic (P3) and quartzose recycled (P4), based on bulk geochemistry. The plots of clastic rocks of Alwar basin in this diagram are shown in

Figure 6.1. It is evident that almost all samples of quartzite are plotted in P4 field (Figure 6.1) and those of metapelites, plot in P3 and P4. Therefore the major element composition of these clastic metasedimentary rocks indicates that they were derived from granitic-gneissic or sedimentary source area similar to passive continental margin, intracratonic sedimentary basins and recycled orogenic provenances.

The felsic rocks dominated source of studied sedimentary rocks is also indicated by TiO_2 versus Zr plot (Hayashi et al., 1997) where all of our samples occupy the, field of felsic igneous rocks (Figure 6.2). TiO_2 versus Al_2O_3 plot are also used extensively to determine source rock characteristics of clastic sedimentary rocks (McLennan et al., 1980; Schieber, 1992). In this plot (Figure 6.3), our samples are confined in granite to granodiorite field indicating a predominantly felsic source for clastic rocks of Alwar basin.

In order to assess the source characteristic of these rocks more effectively the trace elements of petrogenetic significance and their ratios are used and discussed in the following paragraphs. These ratios may exhibit only modest change, even when recycling is important (Wronkeiwicz and Condie, 1990; Gu, 1994). Th/Sc and Cr/Th ratios and the Eu anomalies (expressed as Eu/Eu*) are significantly different in felsic and mafic sources. Therefore, they provide useful information about provenance of the sedimentary rock (McLennan et al., 1993, Cullers, 2000; Armstrong-Altrin et al; 2004). The Th/Sc, Cr/Th and Eu/Eu* ratios of quartzites and metapelites of Alwar basin are similar to those of sedimentary rocks derived from felsic source rocks than those of mafic source rocks (Table 6.1 p).

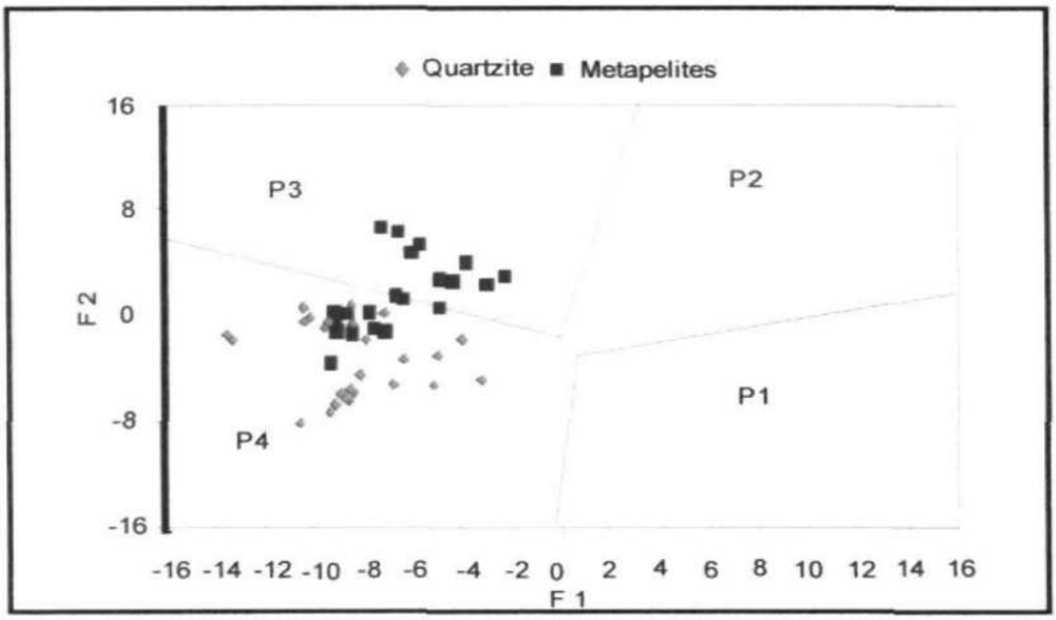

Figure 6.1 Discriminant function diagram (Roser and Korsch, 1988) showing plots of clastic sedimentary rocks Alwar basin. Most of quartzites are lying in the field of P4 and metapelites in P3 and P4 suggesting their derivation from granitic – gneissic or sedimentary source area. F1= $(-1.773TiO_2 + 0.607Al_2O_3 + 0.76(Fe_2O_3)^t - 1.5MgO + 0.616CaO + 0.509Na_2O - 1.224K_2O - 9.09)$ and F2 = $(0.445TiO_2 + 0.07Al_2O_3 - 0.25(Fe_2O_3)^t - 1.142MgO + 0.438CaO + 1.475Na_2O + 1.426K_2O - 6.861)$. P1= Mafic igneous provenance, P1= Intermediate provenance, P3= Felsic igneous provenance, P4= Quartzose sedimentary provenance.

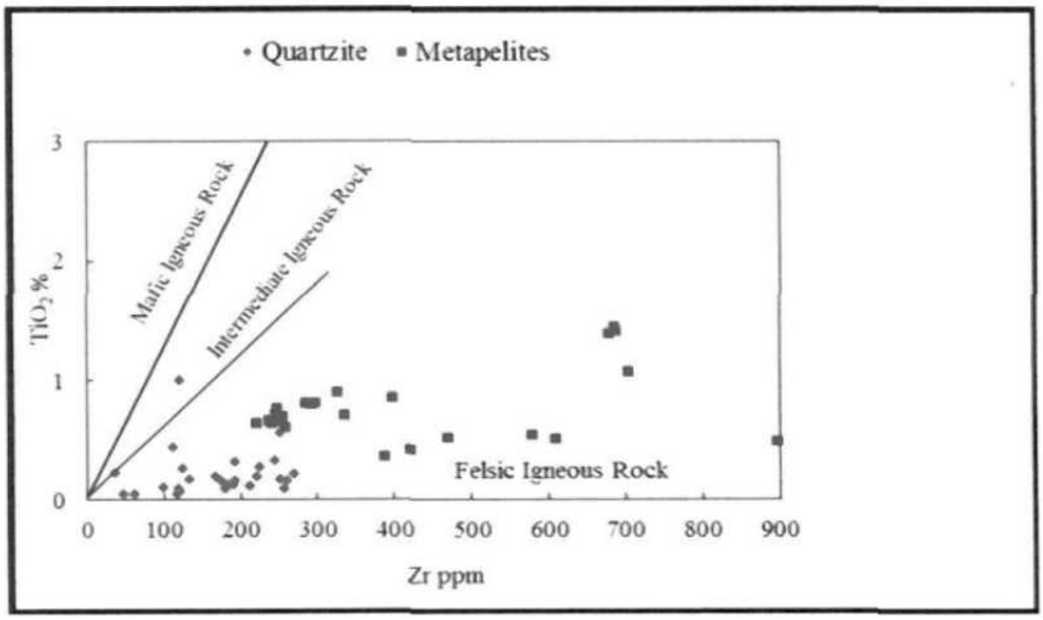

Figure 6.2 TiO_2 - Zr plot of quartzites and metapelites of Alwar basin. Fields of various rock types after Hayashi et al., (1997).

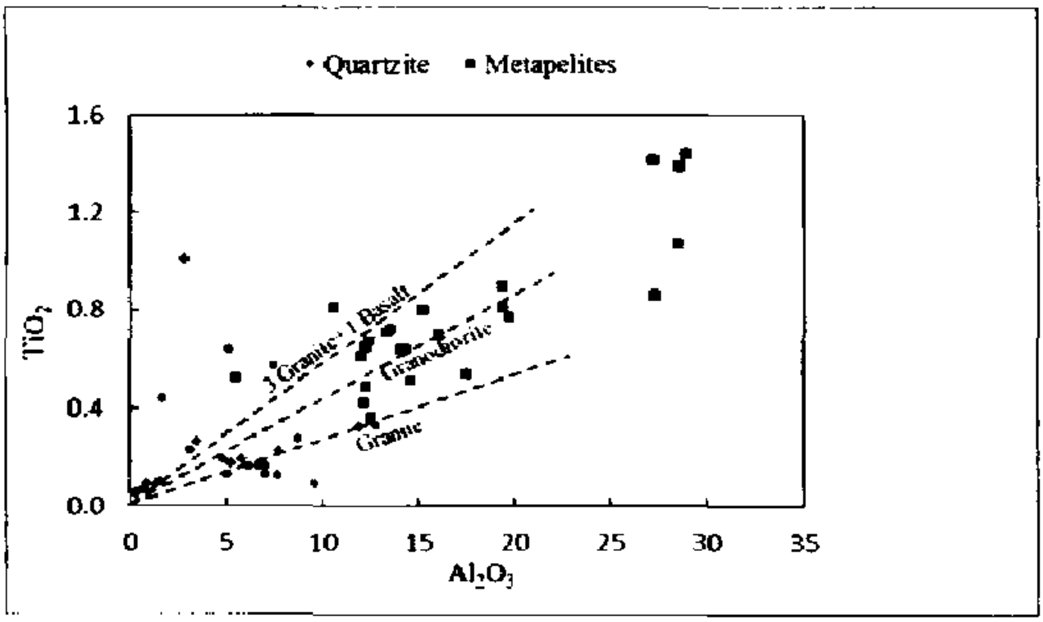

Figure 6.3 TiO_2 versus Al_2O_3 plot for sedimentary rocks of Alwar basin. The 'Granite line', Granadiorite and the '3 Granite +1 basalt line' are from Schieber (1992).

The geochemical provenance signatures discussed above point to derivation of Alwar basin clastic sedimentary rocks from a source dominated by felsic rocks with a lesser mafic, intermediate and sedimentary components. The available paleocurrent data (Singh, 1982a) indicate that the dominant direction of sediment transport was towards N to NW. The sedimentlogical data also indicate transportation of sedimentary debris from south and south-west (Singh, 1982a). The Archaean basement rock of Banded Gneissic Complex (BGC) occurring extensively in southern and central Rajasthan are chiefly composed of Archean TTG (3.2 Ga), Archaean metasedimentary rocks mafic rocks and late Archaean (2.5 Ga) high-K granite (Roy and Jhakar, 2002). As the Alwar basin itself is floored by an Archaean basement similar to BGC, it is reasonable to assume that BGC is the main source component of Alwar sediments.

The REE and Th have been considered as powerful tools to determine the composition of source area of sedimentary rocks (Taylor and McLennan, 1985; McLennan and Taylor, 1991). In La vs. Th diagram (Figure 6.4) the Alwar clastic rocks plot in the field of Archaean and post- Archaean sediments, suggesting that they have been derived from a mixture of Archaean and post- Archaean sources. Inclinations of plots towards PAAS field suggest that the continental crust in Aravalli craton achieved some maturity during Mesoarchaean period.

Table 6.1 Average element ratios of Quartzites and Metapelites of Alwar basin compared to range of ratios in similar fractions derived from Felsic and Basic sources (Cullers, 2000).

Alwar Quartzites

	Avg. Tehla Qtz.	Avg. Rajgarh Qtz.	Avg. Pratapgarh Qtz.	Avg. Kushalgarh Qtz.	Avg. Seriska Qtz.	Avg. Thanagazi Qtz.	Range of Sediments (Sandstones) from felsic sources	Range of sediments (Sandstones) from basic sources
Cr/Th	5.25	9.33	2.18	18.40	2.01	26.63	7.69-0.04	55.55-21.73
Th/Sc	7.36	4.24	2.62	1.36	2.43	3.87	20.5-0.84	0.22-0.05
Eu/Eu*	0.51	0.65	0.68	0.67	0.67	0.54	0.94-0.40	0.95-0.71

Alwar Metapelite

	Avg. Tehla Metpel. (F)	Avg. Kankwarhi Metpel. (F)	Avg. Pratapgarh Metpel. (F)	Avg. Kushalgarh Metpel. (F)	Avg. Seriska Metpel. (F)	Range of sediments (Shales) from felsic sources	Range of sediments (Shales) from basic sources
Cr/Th	3.47	13.71	5.72	10.52	11.45	14.92-0.25	500-22.22
Th/Sc	4.36	0.70	1.36	1.10	0.53	18.1-0.61	4-0.05
Eu/Eu*	1.02	0.57	0.80	0.67	0.96	0.83-0.32	1.02-0.7

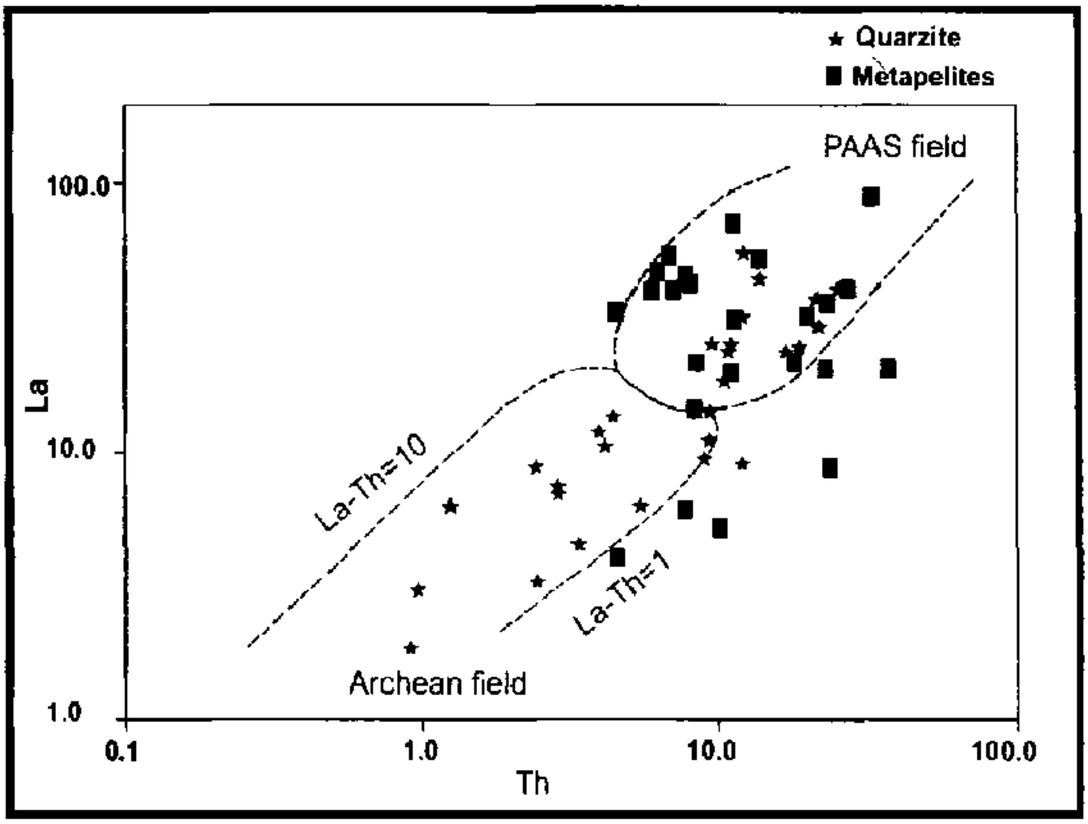

Figure 6.4 La-Th plot of shales and sandstone of Delhi Supergroup of the Alwar basin. Fields of PAAS and Archaean sediments after McLennan et al., (1980).

6.3 Location of Source terrain

The geochemical provenance analysis discussed above identifies several possible end member components that include granite, mafic rocks and TTG. Geochronological work by studies of Choudhary et al., (1984) shows that the ages of granitic plutons in the north Delhi belt lie in the range 1500 – 1700 Ma. Recent geochronological data (Kaur et al., 2006; 2007) suggest the age range of granitoids plutons of NDFB from 1660-1765 Ma. Therefore, these ages indicate that the granitic plutons occurring in the northern part of the Aravalli - Delhi belt were not available to supply debris to the sedimentary basin of NDFB. The other possibility is that the Archaean basement referred to as Banded Gneissic Complex (BGC), or a source terrain of similar composition, may have been exposed for ernsion and thus is likely to be the major source for Alwar and related basin of NDFB. The lithologies, identified as end members in the present study, have striking similarities with those of BGC. The BGC basement of the Aravalli craton occurs extensively to the south of the Alwar basin. This basement complex is composed nf Mesoarchaean, gneisses, TTG, mafic- sedimentary enclaves and late Archaean granitoids. It is well known that the BGC has acted as basement for all the Proterozoic supracrustals sequences of the Aravalli cratonic block. Therefore, the major components of BGC basement viz. Berach Granite (BG), TTG gneisses and mafic enclaves (M) are potential source rocks (Raza et al., 2002; 2012), and thus may be taken as end members for provenance analysis and modeling purpose. The geochemical data of clastic rocks of Alwar basin are plotted on various diagram involving La, Th, Cr, and Sc along with available data for average TTG gneisses (T), Granite (BG) and (M) Mafic rocks which possibly acted as end member components for the Alwar basin clastic sediments.

To determine the relative contribution of felsic to mafic input into the sedimentary basin, the ratio-ratio plots of different compatible to incompatible element pairs have been proved more robust and widely used in provenance analyses of ancient sedimentary sequences (eg. Absar et al., 2010; Raza et al., 2010b). It is observed (Fedo et al., 1997) that Th and Sc may be better provenance indicators than the REE alone. Therefore, the geochemical data of Alwar clastic sediments are plotted in the Cr/Th vs. Th/Sc, La/Sc vs. Sc/Th , and Co/Th vs. La/Sc (Taylor and McLennan, 1985; Condie, 1993; Bhat and Ghosh, 2001) ratio-ratio diagrams along with available data of Berach Granite, TTG and mafic enclaves (Raza et al., 2010b).) of BGC basement of Aravalli Cratonic block.

In Cr/Th vs. Th/Sc ratio-ratio plot (Figure 6.5) the samples of clastic rocks Alwar Group plot on a curve consistent with mixing of a granitic source enriched in incompatible elements (Th) and mafic source enriched in compatible element (Cr, Sc). The diagram suggests that felsic and mafic rocks were both involved in providing detritus for Alwar basin clastic fill. The inclination of plots towards felsic end indicates dominance of granitic components in the source terrain of these clastic rocks.

In La/Sc- Sc/Th diagram (Figure 6.6), majority of our samples plot along a linear trend occupying the space between BG and TTG. However, some samples of metapelites having low La/Sc and high Sc/Th ratios plot more towards the field of mafic composition implying more mafic source of metapelites than quartzites. Some samples of quartzite, having high La/Sc and low Sc/Th ratios plot more towards region of TTG and beyond towards high La/Sc region. These samples are MR1, MR2, MR3, S1, S2, S6, S9, S26, S29, All these samples are characterized by relatively higher values of $(La/Yb)_n$ ratio (26.76, 25.05, 28.50, 24.17, 12.50, 51.25, 17.85, 23.87, 12.37, 12.83 and 22.27 respectively) and $(Gd/Yb)_n$ ratio (3.34,3.08, 3.53, 3.36, 2.37, 2.98, 3.89, 2.30, 2.25, 3.43 and 6.28 respectively) with averages ~23 and ~3.34 respectively. Higher values of these ratios are the characteristic geochemical features of Tonalite-Trondhjemite-Granodiorite (TTG; Jahn et al., 1981) suits, which are important components of shield areas of the world. Thus, it may be visualized that the Alwar clastics had some inputs from a source terrain containing TTG as an important constituent.

In Sc/Th vs. Sc diagram (Figure 6.7), most of our samples of metapelites are plotted near BG and those of metapelites are plotted near T implying more contribution of TTG to quartzites than the associated metapelites. Since Th/Sc and La/Sc ratios are considered to be more sensitive to average source composition (Taylor and McLennan, 1985) they are more distinguished between felsic and mafic components. Th/Sc and La/Sc ratios for quartzites (0.21 - 13.46, avg. 4.29; 0.26, 22.95, avg. 7.79) are high than those of metapelites (0.27 - 6.30, avg. 1.57; 0.24, 9.07, avg. 3.14) implying that the mafic components were incorporated into the sediments mainly in the clay- size fraction.

In these diagrams the plot of Alwar basin clastic sedimentary rocks suggests the dominance of felsic rocks with variable contribution from Berach Granite and TTG in comparison to mafic enclaves. The inclination of the plots toward TTG along with high $(La/Yb)_n$ ratios of these rocks are the features which suggests presence of TTG in their provenance.

The source rock composition of Alwar basin clastic rocks can be further evaluated using La-Th-Sc ternary plot. The diagram is a useful measure to

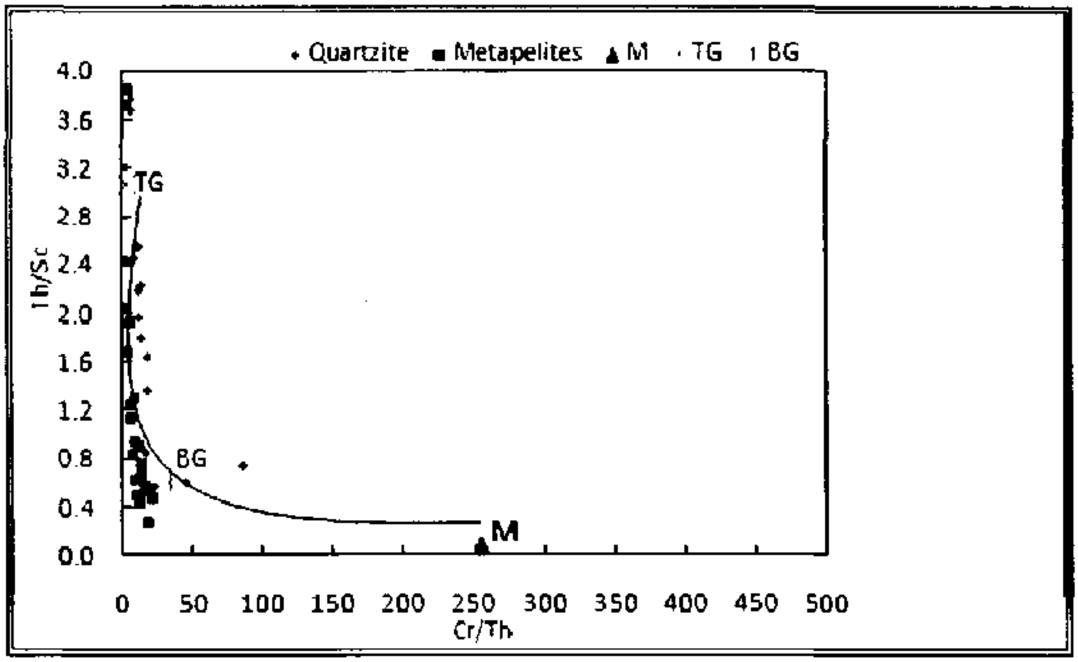

Figure 6.5 Th/Sc versus Cr/Th plot (after Totten et al., 2000) for clastic sedimentary rocks of Alwar basin. Most of the samples fall near granitic component. For reference the data of BGC basement end members are also plotted as BG = Berach Granite, (Raza et al., 2010b) T = TTG gneisses (Martin et al., 2005) and M = Mafic Enclaves (Ahmad and Tarney (1994).

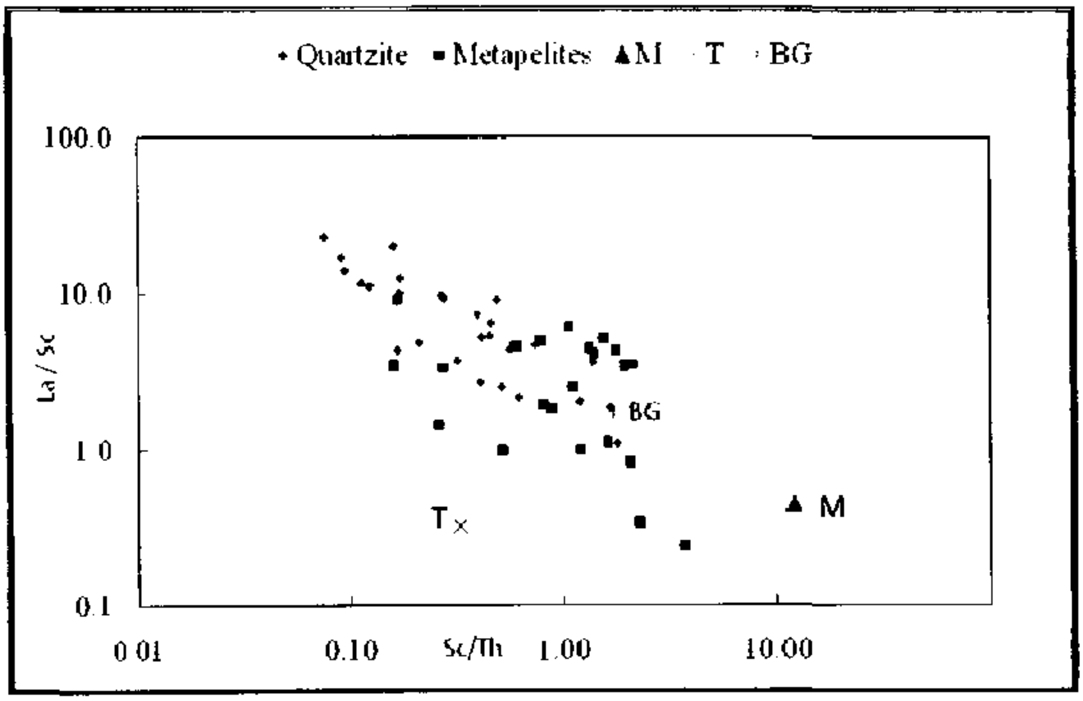

Figure 6.6 La/Sc vs. Sc/Th plot for quarzites and metapelites of Delhi Supergroup of Alwar basin. For reference the data of BGC end members are also plotted. TTG (T), Berach Granite (BG) and Mafic rocks (M) (Data source as in Figure 6.5).

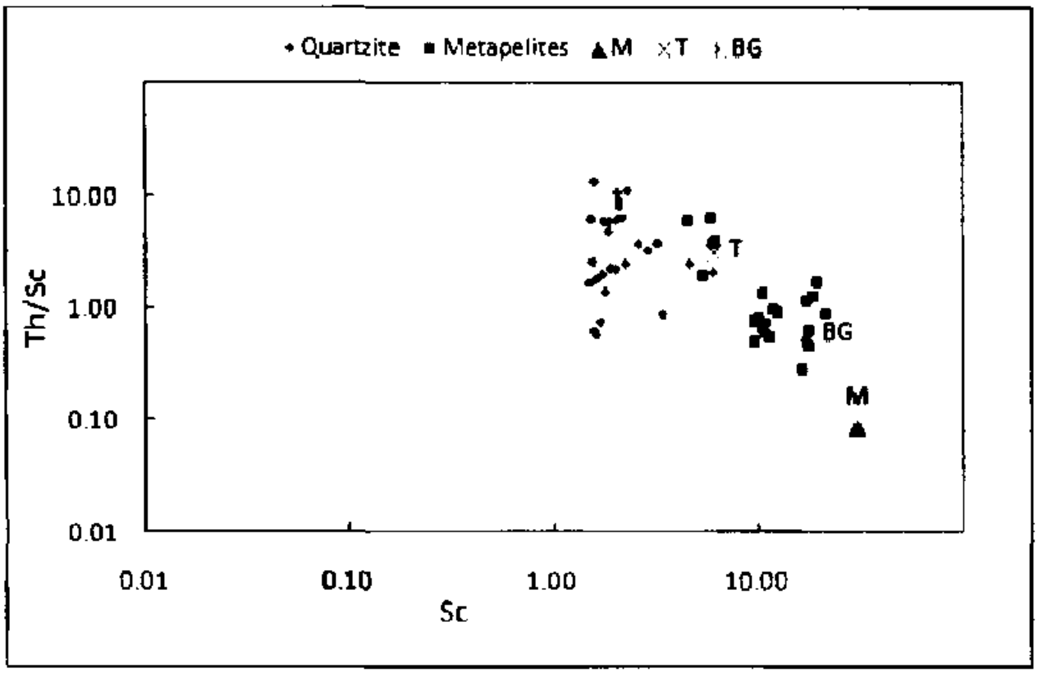

Figure 6.7 Th/Sc vs. Sc plot of quartzites and metapelites of Delhi Supergroup of Alwar basin. For reference the data of BGC end members are also plotted. TTG (T), Berach Granite (BG) and Mafic rocks (M) (Data source as in Figure 6.5).

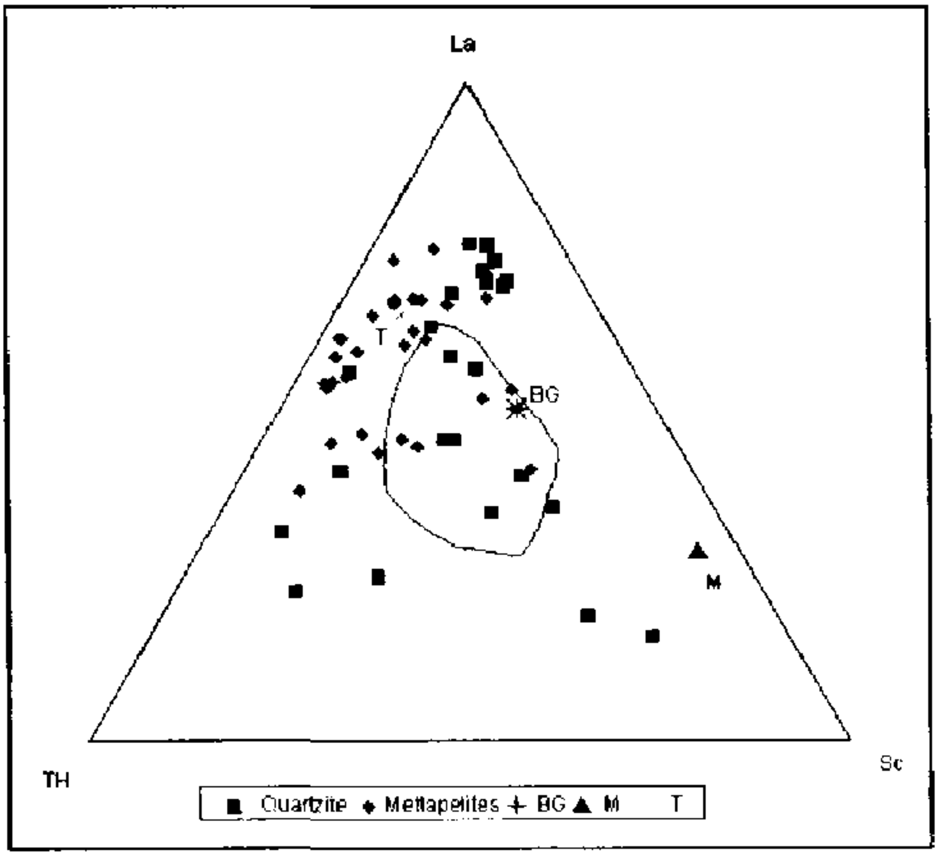

Figure 6.8 La-Th-Sc ternary plot for clastic sedimentary rocks of Alwar basin. For reference the TTG (T), Granite (G) and mafic (M) end members of BGC are plotted. (Data source as in Figure 6.5).

determine relative contribution of felsic and mafic input into the sedimentary basin. In this diagram (Figure 6.8), the data of Alwar basin sedimentary rocks are plotted again along with available data of TTG, Berach Granite, mafic enclaves (Raza et al., 2010b). This diagram (Figure 6.8) also exhibits similar situation where most of quartzites and metapelites of Alwar basin plot nearer to Berach Granite (BG) and TTG (T) and away from mafic enclaves (M) indicating their derivation from a source consisting predominantly of granite and TTG with subordinate amount of mafic rocks. Here also few samples of metapelites extend more towards mafic end member.

6.4 Provenance Modeling

Therefore, with the identification of several likely source components it is possible to quantitatively model the relative contribution of granite, TTG and mafic source types to generate average clastic rocks of Delhi Supergroup of the Alwar basin. In this regard mass balance has to be taken into consideration before attempting such calculation. The consideration of only pelites and quartzites component may give rise erroneous result; while pelites contains more abundances of REE and other trace element than source rock, the quartzites are relatively depleted. It is well established that fine grained terrigeneous sediments (shale and siltstones) comprise 70 % of sedimentary mass, while coarse grained sediments (sandstone) contribute 30 % to the sedimentary mass (Garrels and Mackenzie, 1971; Taylor and McLennan, 1985). It is reasonable to consider that 70:30 ratio of shale and sandstone is representative of source composition, Hence, mixture of 70 % metapelites and 30 % quartzite of Alwar Group and same for Ajabgarh Group of the Delhi Supergroup is taken as model composition of Alwar basin siliciclastic rocks. The paleocurrent data, as discussed above, indicates derivation of Alwar basin clastics from south of the basin where

BGC is exposed. The BGC terrain is composed predominantly of Mesoarchaean TTG gneisses with mafic enclaves and late Archaean (2.5 Ga) high K-granites. The REE data of TTG gneisses, mafic enclaves and Berach Granite (Raza et al. 2010b) are taken as end members for modeling purpose. To determine the contribution of these components of BGC to the overall composition of Alwar clastic sediments the mixing calculations are performed. Parameters and results of mixing calculations are shown in Table 6.2 and Figure 6.9. The purpose is to search a best-fit composition which would most closely reproduce the observed REE patterns (Figure 6.9). A reasonable fit is obtained for a mixture of sediments derived from a provenance consisting of 50 % Berach granite (BG), 30 % TTG (T) and 20 % mafic rocks (M). The total individual REE abundances and ratios like $(La/Sm)_n$, $(La/Yb)_n$ and $(Gd/Yb)_n$ are also in excellent agreement with model values (Table 6.2).

To further confirm these results we have used multielement patterns to quantify the relative contribution of different end members to overall composition of sedimentary fill of the Alwar Basin. Multielement patterns are shown in Figure 6.10, where they display excellent agreement with model values.

Table 6.2: Chondrite – normalized Rare Earth Element data of average Alwar basin clastic sedimentary rocks, basement end members (T=TTG; BG= Berach Granite; M= Mafic enclaves of BGC) and mixing results

REE (N)	clastic sedimentary rocks of Delhi Supergroup, Alwar basin				Mixing results		BGC end Members			Mixing Results
	Avg. Alwar Quartzite A	Avg. Alwar Metapel B	Avg. Ajabgarh Quartzite C	Avg. Ajabgarh Metapel D	Avg. clastics Alwar Group 70B:30A	Avg. clastics Ajabgarh Group 70D:30C	T	BG	M	50BG:30T:20M
La	98.33	166.91	61.14	114.94	146.34	98.8	45.78	29.64	13.49	131.85
Ce	76.15	125.91	43.3	89.67	110.98	75.76	86.72	59.01	31.29	100.94
Pr	66.27	87.15	32.14	61.3	80.88	52.56	9.87	6.89	3.91	75.66
Nd	51.33	67.48	24.02	51.68	62.63	43.38	35.35	26.58	17.8	58.78
Sm	29.11	40.24	13.78	37.28	36.9	30.23	6.54	5.66	4.78	37.57
Eu	13.9	22.3	7.64	22.77	19.78	18.23	0.94	1.13	1.32	19.16
Gd	18.87	24.53	10.48	24.53	22.83	20.31	5.3	5.09	4.88	24.87
Tb	16.69	18.6	10.59	18.84	18.03	16.36	0.79	0.85	0.91	22.57
Dy	11.65	14.64	8.3	14.65	13.74	12.75	3.85	4.92	5.98	18.93
Ho	8.83	14.5	7.22	14.76	12.8	12.5	0.72	1.01	1.29	17.25
Er	8.36	13.23	7.11	13.21	11.77	11.38	1.95	2.94	3.92	17.14
Tm	8.88	15.9	7.8	16.12	13.79	13.63	0.29	0.46	0.62	17.2
Yb	8.58	13.94	7.59	14.22	12.33	12.23	1.68	2.77	3.86	15.65
Lu	9.64	15.69	9.46	16.28	13.88	14.23	0.26	0.42	0.58	15.91
(La/Sm					3.97	3.27				3.51
La/Yb					11.87	8.08				8.42
Gd/Yb					1.85	1.66				1.59

Data source: Berach Granite (BG) after Raza et al. (2010 b) and mafic enclaves after Ahmad and Tarney (1994); TTG after Martin et al (2005).

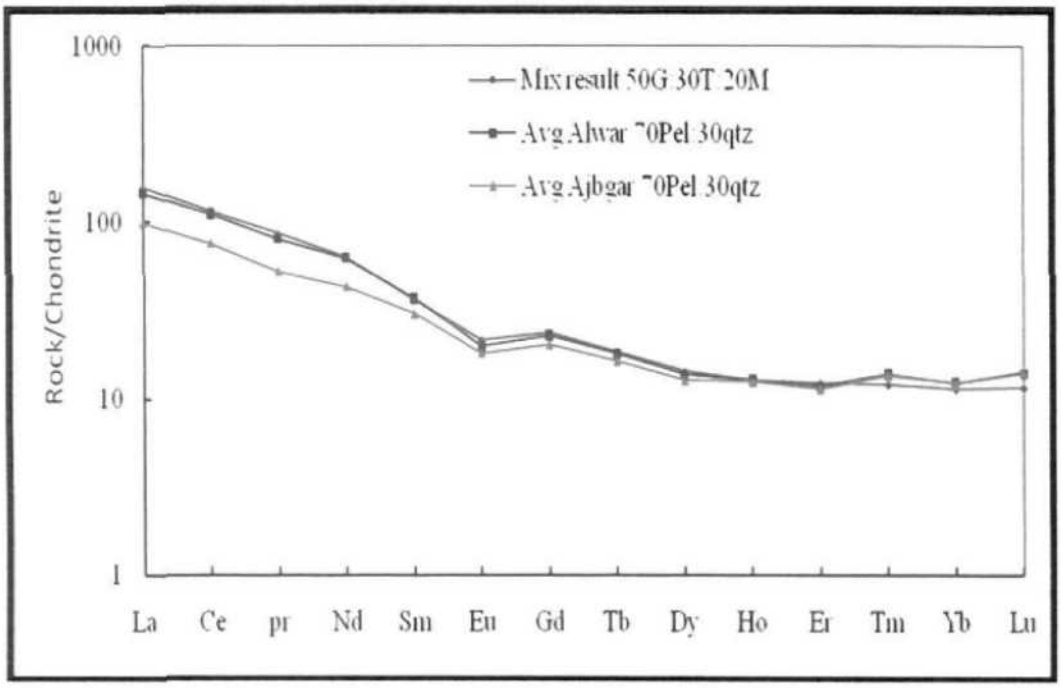

Figure 6.9 REE patterns of average Alwar basin clastics (Mixture of 70 % pelites and 30 % quartzite) and estimated provenance after mixing the end members in the proportion of 50BG:30T:20M. Source: BG- Raza et al., (2010b); TTG- Martin et al., (2005) M- Ahmad and Tarney (1994).

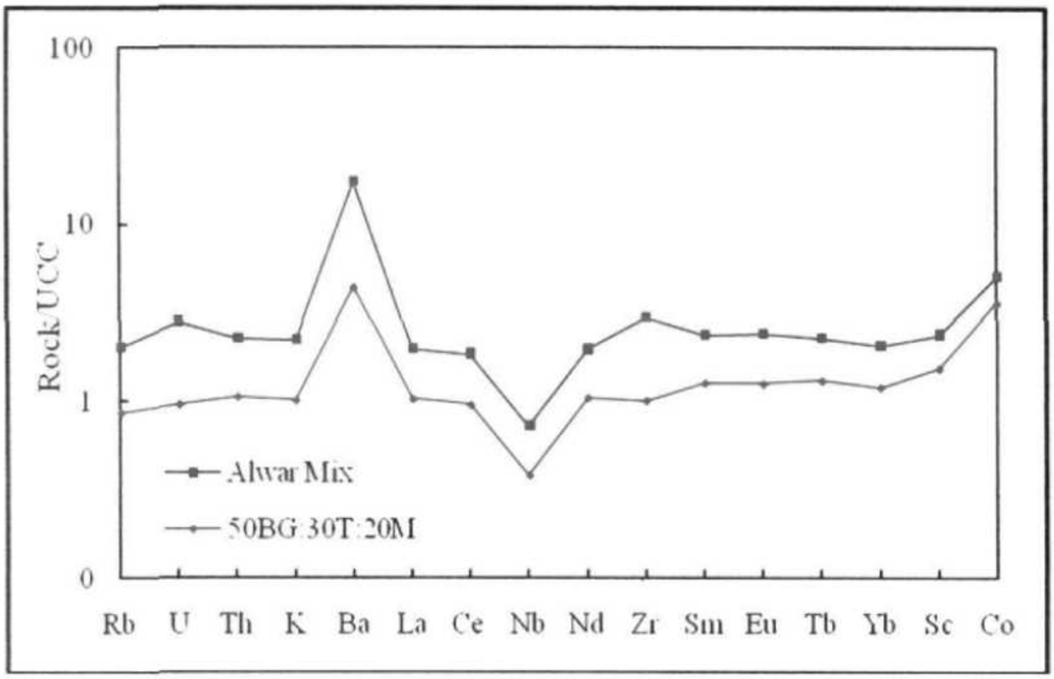

Figure 6.10 Multi-element spidergram patterns of average Alwar basin clastics (Mixture of 70 % pelites and 30 % quartzite) and modeled provenance after mixing the end members in the proportion 50 % Berach Granite (BG), 30 % Tonalite-Trondhjemite-Granodiorite (TTG), and 20 % mafic enclaves (M). (Data source same as in Figure 6.9).