

Comparison of the Nagar Parkar (Pakistan) and Malani (India) granites with reference to uranium and thorium abundances

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Abstract

U and Th data revealed that the granites of both the suits may be considered as a moderate source for the small scale uranium deposit. Negative disequilibrium in the Nagar Parkar granites and the higher U-content in the wide and extensive zones of kaolin in the low lying inter-plutonic areas suggest mobility of uranium from the system. Higher U and Th concentrations, pronounced hydrothermal activity, relatively higher abundances of trace and REE and presence of UO₂ in zircons in Malani granites enhance the probability of the creation of primary mineralization. U, Hf, and Ta are generally lower as compared to Th, Zr, and Nb in the granites of both the suits. Malani granites show relatively higher abundances of favorable trace and REE, particularly Siwana, which also have higher U/Th ratios (0.11 – 4.5). It has been found that the U and Th concentrations increase as a function of high heat production. Nagar Parkar as well as Malani granites contain certain accessory minerals (especially zircon, sphene, apatite, additionally alanite and epidote in Nagar Parkar granites) favorably accommodate uranium in their structure. The increase in U-content from east to west in Malani, moderate uranium enrichment in Bara Formation and calcretes in Tharparkar are indicative of probable transport, suggesting mobility of uranium from the system. Therefore, lignite-related sandstones of Bara Formation in Thar coal basin, adjacent to both the igneous suits, and calcretes in the desert environment may be the prospective hosts for secondary uranium deposits.

Keywords: Granites; Nagar Parkar; Malani; Uranium; Thorium

1. Introduction

Nagar Parkar marks the extreme southeast corner of Pakistan. To the northeast, east and south it borders the Rann of Kutch and to the west it is in contact with the Sindh platform. Nagar Parkar town is situated at the northern tip of the Rann of Kutch in the south of the Desert Thar (Fig. 1). It lies about 400 km to the southeast of Karachi and is located at 24° 21' 17"N and 70° 45' 15" E.

Wynne (1867) was the pioneer worker in the area and reported the occurrence of red syenite with hornblende diorite dykes. Kazmi and Khan (1973) suggested a Precambrian age for the complex. Pathan and Rais (1975) proposed the probability that the area is the western continuation of the Indian shield region, and suggested the bosses and stocks as connected with a batholithic mass at depth. Butt et al. (1989) proposed that much of the Nagar Parkar igneous complex is underlain by mafic rocks whereas the granite intrusions form thin, sheet-like masses.

Butt et al. (1994) proposed that the Nagar Parkar granite rocks are the product of crustal anatexis in an intraplate (continental) anorogenic environment. Muslim and Akhtar (1995) differentiated two varieties of granite, assimilative pink granite and grey granite. Jan et al. (1997) classified the granite as biotite-hornblende pink granite and riebeckite-aegirine grey granite. More recently, Laghari (2005) concluded that the Nagar Parkar igneous complex is a product of several distinct batches of magma and suggested a bimodal magmatism in the end. They related the Nagar Parkar rocks with the rocks of Malani igneous suit in Rajasthan based on petrographical and geochemical similarities. No significant work regarding uranium has been carried out prior to this work. A total of 178 representative samples were collected from all the granite exposures (Fig. 2). All the samples were analyzed for uranium however, out of these 86 samples were analyzed for eU₃O₈ (equivalent radiometric uranium) and eTh (equivalent thorium). To estimate the active uranium (leachable uranium) from the system, 32

samples were gathered from the vast and extensive kaolinized zone of Phawri village located in north of the Chanida granite exposures. Samples were collected in vertical section from the operative/abandoned mines with an interval of 2-3 m from top to bottom. cU_3O_8 (Chemical uranium oxide) and eU_3O_8 (equivalent uranium oxide) concentrations were measured by fluorimetric and gamma spectrometric analysis respectively.

1.1. Major lithological units of Nagar Parkar Igneous Complex (NIC) Tharparkar area

Laghari (2005) considers that the grey granites of Nagar Parkar can be directly correlated with the Siwana granitic plutons and the pink granites with the Jalor pluton (Bhushan, 1991; Jan et al., 1997; Mukherjee and Roy, 1981; Srivastava et al., 1989). On the basis of lithological and geochemical similarities, both the igneous suits have been compared and correlated for their uranium potential. The magmatism in the Nagar

Parkar complex can be grouped broadly into the following phases: 1) Amphibolites and related dykes as host to, 2) Riebeckite-Aegirine grey granite and biotite-hornblende pink granite (the major intrusive phases), 3) acid dykes, 4) rhyolite plugs, and 5) mafic dykes (Lamprophyric diorite dykes and gabbro/dolerite dykes). Sketches of the geological setting of Malani magmatism in the four major areas of its occurrence is given in terms of the extrusive, intrusive and dyke phases as well as the host rocks (Kochhar, 2000).

1.2. Major lithological units of Malani Igneous Suit (MIS)

The Neoproterozoic Malani Igneous Suit (750Ma) consists mainly of acid volcano- plutonic rocks scattered over in an area of 55,000 km² in the trans-Aravalli block in Rajasthan and Haryana. It comprises peralkaline (Siwana), meta-aluminous to mildly peralkaline (Jalor) and peraluminous (Tusham and Jhunjhunu) granites with cogenetic carapace of acid volcanics (Kochhar, 2000).



Fig. 1. Map showing locations of the names used in text (modified after Google.com)

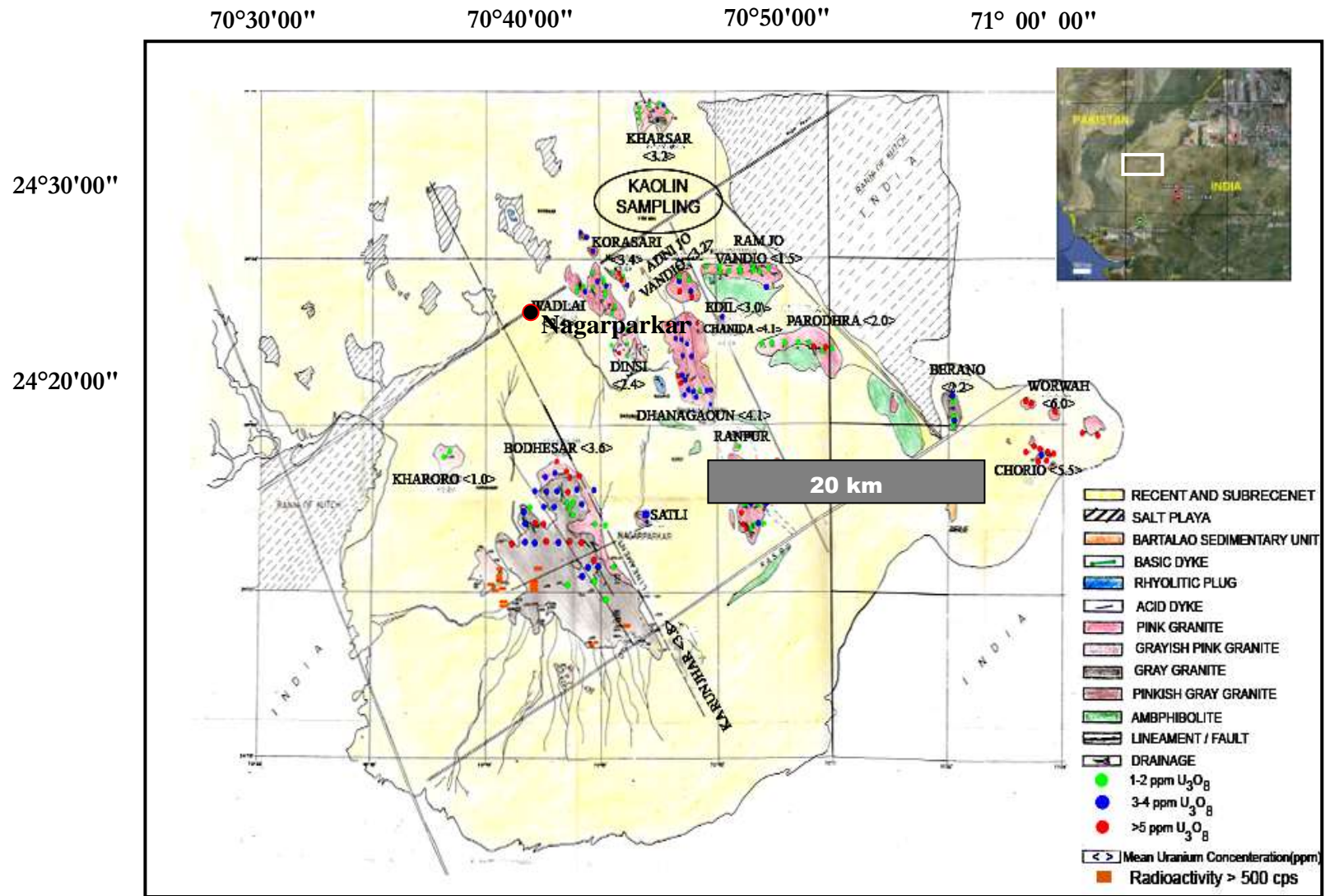


Fig. 2. Geological map showing uranium concentration in the granitic rocks of Nagar Parkar igneous complex (Aqeel et al., 2008, modified after Jan et al., 1997)

1.3. Siwana area (District Barmer, Rajasthan)

It can be grouped broadly into the following phases: 1) basalt, trachyte, rhyolite and minor welded tuff are present as extrusive phase, 2) granites and gabbro with marginal facies variation as intrusive phase, 3) trachyandesite, trachydacite, rhyolite and microgranite as dyke phase.

1.4. Jalor (District Jalor, Rajasthan)

It can be grouped broadly into the following phases: 1) rhyolite, welded tuff, arcuate rhyolite as extrusive phase, 2) olivine gabbro, biotite-hornblende granite, biotite granite and alkali granite as intrusive phase, 3) rhyolite and olivine dolerite as dyke phase.

1.5. Tusham area (District Bhiwani, Haryana)

It can be grouped broadly into the following phases: 1) felsite, welded tuff, explosion breccia as extrusive phase, 2) granite/granite porphyry as intrusive phase, 3) ring dyke of quartz porphyry as dyke phase and, 4) Delhi quartzite, quartz mica schist as country rocks.

1.6. Jhunjhunu area (District Jhunjhunu, Rajasthan)

It can be grouped broadly into the following phases: 1) rhyolite/welded tuff (radial dykes) as extrusive phase, 2) granite/ granite porphyry as intrusive phase.

2. Geochemistry

2.1. Major elements

The major element data for Nagar Parkar and Malani granites (Siwana and Jalor) is based on 49 chemical analysis from Siwana area (Vallinayagam and Kochhar, 1998), 27 analysis from Jalor granites (Kochhar and Dhar, 1993), 54 analysis from pink and 56 from the grey granites of Nagar Parkar area (Laghari, 2005) (Table 1). Uranium potential of granites is generally evaluated on the basis of silica, alkali, alumina, iron and calcium contents (Table 2). It can be summarized that SiO₂ content is higher in Nagar Parkar granites (>75%), while MIS granites have relatively lower and more suitable silica contents (70-71.4 %). On the basis of silica, alkalis and alumina contents the rocks of both the suits may

be referred as to the S-type (Aqeel and Ali, 2007, 2008). Total alkalis for both the suits are quite favorable (i.e. K₂O + Na₂O > 8). Alkalis in the Jalor subsolvus (pink biotite-hornblende and white biotite granites) and hypersolvous (alkali granites) are 6.81-9.40 and 8.13-9.60%, respectively (Kochhar and Dhar, 1993). Likewise in the Siwana granites, alkalis range from 7.54 to 11.35%. (Vallinayagam and Kochhar, 1998). K₂O + Na₂O for Nagar Parkar granites are 7.9- 9.71% for grey and 6.24- 9.61% for pink granites. Both the suits have Al₂O₃/ (K₂O + Na₂O) > 1. On the basis of major element data, Aqeel and Ali (2008) calculated the evaluation coefficient (X), using formula $1/5\text{SiO}_2 + 3/5 \text{Na}_2\text{O} (\text{SiO}_2 + \text{K}_2\text{O})$ widely used by Chinese experts to evaluate the granitic rocks for their uranium favorability (i.e. 27.24 and 26.7 for pink and grey granites respectively for Nagar Parkar), while in the present study the coefficient has been calculated for the Malani granites (i.e. 27.1 and 24.2 for Jalor and Siwana granites respectively). For all these granites coefficient was found > 20 which is not considered favorable for ore formation within the granites, however, uranium still may occur in disseminated form in these rocks and subsequent leaching phenomena may form a zone of concentration in a nearby basin. Nevertheless, the silica content in MIS granites (71-73) can be considered a supporting factor.

2.2. Uranium and thorium

Detailed field studies and systematic sampling for uranium and thorium has been carried out and a total of 234 samples have been collected from granites (pink and grey), rhyolite and acidic dykes from Nagar Parkar area (Aqeel and Ali, 2008) (Fig. 2). The mean values for uranium and thorium in 178 samples collected from the granitic exposures of the area (Table 3) is 3.4 and 15.4 ppm respectively, however, the southern and eastern parts of the complex are more fertile and show elevated content of uranium, i.e., 4.1 ppm in contrast to the northern plutons where it is 2.6 ppm. Also the Th/U ratio in the southeast and eastern exposures is 4.1; lower than in the north where it is ≥ 5.5 (Aqeel and Ali, 2008).

Kaolin, the alteration product of the pink granites, is generally found in the low lying inter-plutonic areas, which overlies the granitic basement. Chemical analyses show that the mean U-content in

kaolin is > 5 ppm with a maximum value of 45 ppm. That is an enriched amount of leachable uranium. Therefore, it can be assumed that there has been a sufficient amount of leachable uranium in the system (Aqeel and Ali, 2008).

The uranium and thorium data from the Siwana granites (Table 4) is on the basis of 30 chemical analyses (Kochhar, 2000; Vallinayagam and Kochhar, 1998), 18 analyses from Jalor granites (Kochhar, 2000; Kochhar and Dhar, 1993), six

analyses from Tusham granites and 06 from the Jhunjhunu granitic body (Kochhar, 2000).

The alkali granites of Siwana and Jhunjhunu contain an average uranium content of 10.15 and 18 ppm, respectively while the alkali granites of Jalor have 4.8 ppm of uranium. Vallinayagam and Kochhar (1998) noted that the mean Th/U for Siwana granites is 3.74 which is close to the bulk earth value of 3.

Table 1. Major element analysis of Nagar Parkar granite and Malani igneous suit

Elements	Nagar Parkar		Malani	
	Grey granite	Pink granite	Siwana granite	Jalor granite
FeO	-	-	1.6	2.2
Fe ₂ O ₃	2.3	1.9	5.4	1.9
MnO	0.1	0.1	0.2	0.1
MgO	0.1	0.3	0.3	1.0
Al ₂ O ₃	11.4	12.0	10.3	15.5
SiO ₂	76.3	75.6	70.7	71.4
K ₂ O	4.5	4.6	4.7	4.9
Na ₂ O	4.3	4.0	4.5	3.6
TiO ₂	0.3	0.4
CaO	0.4	0.8	1	0.8

Table 2. Major element favorability for uranium

Standard values (%)	Pink granite	Grey granite	Jalor granite	Siwana granite
SiO ₂ : 69-76	75.57	76.34	71.41	70.74
K ₂ O (5%)	4.55	4.50	4.9	4.7
Na ₂ O (3%)	3.96	4.26	3.57	3.57
K ₂ O+Na ₂ O ≥ 8	> 8	> 8	> 8	> 8
Al ₂ O ₃ =12.83 ~ 14.23	12	11.4	15.5	10.3
Al > K +Na+ 2Ca,	Al(12)>K+Na +2Ca(10.03)	Al(11.4)>K+Na + 2Ca(9.52)	Al(15.5)>K+Na +2Ca(11.6)	Al(10.3) <K+Na +2Ca(13.5)
Al ₂ O ₃ / K ₂ O+Na ₂ O > 1	1.41	1.19	1.8	1.2
CaO : 1.18 ~ 1.507	0.76	0.38	0.8	1
Fe ₂ O ₃ : 0.14 ~0.96	1.9	2.26	1.9	5.4
TiO ₂ : 0.11 ~ 0.37	0.35	0.32
MgO: 0.45 ~ 1.36	0.3	0.1	1	0.3

Table 3. U and Th concentration in Nagar Parkar granites

Pluton	No. of Samples	cU ₃ O ₈ (ppm)			eTh (ppm)	Th/U
		Mean	Mode	Median		
Korasari	5	3.4	3	2.5	18.6	5.5
Wadlai	17	2.5	2	2	14.2	5.7
Kharsar	10	3.2	4	3.5	15.7	5.5
Dinsi	7	2.7	2	2	10.9	4
Adni-Jo-Vandio	6	3.3	3,5	2.5	-	-
Eidal granite	1	3	-	-	-	-
Khororo	2	1.5	-	-	-	-
Ram-Jo- Vandio	11	1.7	2	2	-	-
Parodhara	9	2.2	1	1	-	-
Nagar Parkar Complex North	68	2.6	2	2	15	5.5
Chanida	9	4.1	4	4	16	3.9
Dhanagaon	14	4.1	4	4	14	3.4
Ranpur	25	3.7	3	3	18.4	5.1
Satli	1	4	-	-	-	-
Berano	5	2.2	3	2.5	-	-
Chorio	10	5.5	6	6	-	-
Vorwah	3	6	6	6	-	-
Bhodesar	21	3.6	4	4	-	-
Karunjhar	22	4	5	4	-	-
Nagar Parkar Complex South	110	4.1	4	4	16.1	4.1
Over All	178	3.4	2	3	15.5	4.5

Table 4. Average Th and U content in different type of rocks in MIS

No. of Samples	Locality	Rock unit	U (ppm)	Th (ppm)	Th/U (ppm)
30	Siwana	Alkali granite	10.15	42.75	4.2
9	Jalor	Biotite granite	4.7	20.23	4.3
5		Biotite-hornblende granite	3.6	19.6	5.44
4		Alkali granite	4.8	14.5	3.05
4	Tusham	Microcline granite	9.9	78.5	7.9
1		Granite porphyry	10.5	96.5	9.1
1		Muscovite- biotite granite	4.1	21.6	5.26

2.3. Heat productivity and its impact on the U and Th availability

The Malani granites are high heat production (HHP) type. Their average heat productivities are as follows (Kochhar, 1989)

Jhunjhunu : 12.06 uWm⁻³
 Tusham : 7.68 uWm⁻³
 Siwana : 5.90 uWm⁻³
 Jalor : 2.80 uWm⁻³

It is obvious that the granites having HPU > 9 (Table 5) have higher concentrations of uranium (9-28 ppm, mean = 16.7 ppm) and thorium (69.8-135.1 ppm: mean = 97.3). There is a definite and direct relationship between the heat productivity and the concentration of U and Th. The thorium and uranium content in the Malani granites increases as a function of heat productivity. Likewise, the samples having lower HPU (<5) contain very low uranium (Table 6) (2-6.8 ppm: mean = 4.9 ppm) and thorium (8-43 ppm: mean = 24.5) concentrations.

Table 5. U and Th content in samples with HPU > 9

Locality	HPU	Th	U
Siwana	11.3	95.1	17.1
Tusham	9.3	94.0	9.3
	9.4	88.4	11
	9.8	96.5	10.5
Jhunjhunu	16.8	126.1	28.4
	15.4	135.1	20.9
	9.6	75.7	14.8
	14.5	112.6	23.4
	9.3	79.5	12.7
	10.2	69.8	18.7
Average	11.6	97.3	16.7

Table 6. U and Th content in samples with HPU ≤ 5

Locality	HPU	Th	U
Siwana	4.2	29.8	6.8
	5.0	43	6.4
	3.6	26.3	5.9
Jalor	3.9	29.3	5.8
	4.3	31	6.9
	1.9	13.3	2.6
	2.5	17.8	3.8
	1.4	8.4	2
Tusham	2.8	21.6	4.1
Average	3.3	24.5	4.9

2.4. Trace elements

The following discussion is on the basis of trace elements data, that is, 31 chemical analysis from Siwana Granites and 13 sample analysis from Jalor granites (Vallinayagam and Kochhar 1998; Kochhar and Dhar, 1993). Trace element data was also available for few samples from Nagar Parkar granites (Laghari, 2005) (Table 7). It also revealed that the MIS granites are richer in trace elements Zr, Cr, Th, Ta, Nb, Hf, Y and Ce in contrast to the Nagar Parkar granites. Siwana granites show higher abundances of these trace elements in contrast to Jalor and Nagar Parkar granites. Th/U, Zr/Hf and Nb/Ta are useful guides in the geochemical prospecting. The granites of both the suits have higher abundances of Th, Zr and Nb as compared to U, Hf and Ta. The higher of these ratios not considered favorable for uranium.

The higher abundances of Th, Nb, Ta, Zr, and REE in Siwana granites are also encouraging for uranium separation from magma due to isomorphism, such as found in zircon. Uranium may be separated out through some other processes like, 1) hydration of uranium halides to UO₂, and 2) capturing of uranium in the crystal lattice defects in the rock forming minerals or due to entrance of uranium into magmatic hydrothermal solution. Trace element studies along with morphological observations indicate that the Tusham zircons belong to hydrothermal and late magmatic stages. The high content of UO₂ in the Tusham zircons is a reflection of high abundance of UO₂ in the host rock. Jalor zircons are magmatic (Kochhar et al., 1991).

3. Significant accessory minerals

In uranium productive granites, uranium is mostly present as accessory mineral. The granites with uranium locked in the lattice structure of minerals do not hold many chances for producing any considerable uranium deposits. Uranium is generally found in accessory minerals, Zircon (100-6000 ppm), apatite (5-150 ppm), sphene (10-70 ppm), alantite (30-1000 ppm), epidote (20-200 ppm), monazite (500-3000 ppm), xenotime (300- 35000 ppm), garnet (6-30 ppm), ilmenite (1-50 ppm) and magnetite (1-30 ppm) (Clark, 1966). The grey granites of Nagar Parkar contain minute, well-developed zircon in almost all the studied samples. Apatite occurs only in a few samples. Sphene is minor accessory along with local epidote. Zircon, alantite and sphene occur as sporadic accessory minerals in the pink granites of Nagar Parkar complex while epidote formed due to alteration of the feldspars. The mottled pink granite in the northeast of Mokrio village contain sphene, zircon, alantite as main accessory, with epidote as alteration product. In Wadlai adamellite sphere, zircon and apatite are present along with altered product epidote (Laghari, 2005). Mineralogical studies for Siwana granites showed that the accessory minerals apatite, sphene, hematite and zircon are present. The Tusham, Jhunjhunu and the subsolvus component of the Jalor granite contain zircon, sphene and apatite as accessory minerals (Kochhar, 2000).

Table 7. Trace element data from Nagar Parkar and Malani

Trace Elements	Nagar Parkar		Malani Igneous Suit	
	Pink Granite	Grey Granite	Jalor Granite	Siwana Granite
Sr	50.2	10	139	27.4
Ba	407.6	124.3	127.2	940.3
Zr	78.5	324	586.2	2642.3
Cr	5	5	12.7	-
Ni	5	5	-	-
Rb	38.6	57.2	-	240.4
Th	11.9	11.3	18.6	42.8
Ta	0.9	0.6	1.0	14
Nb	8.6	13.7	-	382.6
Hf	4.0	11.4	2.8	89.1
Y	55.5	53.8	67.4	399.5
Ce	74.8	87.7	-	459.3

4. Discussion and conclusion

1. Chemical analysis for major and trace elements in addition to uranium and thorium have been utilized to evaluate the U-favorability of the Nagar Parkar granites in comparison to the adjacent Malani intrusives of Rajasthan (India).
2. The mean uranium and thorium contents in the Nagar Parkar complex are 3.4 and 15.4 ppm respectively; however the southern and eastern parts of the complex are more fertile and showed elevated U-content (i.e. 4.1) ppm in contrast to the northern plutons where it is 2.6 ppm. Also the Th/U ratio in the southern and eastern exposures is 4.1, which is lower than in the north where it is ≥ 5.5 (Aqeel and Ali, 2008).
3. The uranium content in Malani granites is relatively higher (i.e. 10.2, 4.05, 8.2 and 18.4 for Siwana, Jalor, Tusham and Jhunjhunu granites, respectively) (Aqeel and Ali, 2007, 2008). The granites of Jhunjhunu, Tusham and Siwana are thorium dominant while the Jalor granites have relatively less thorium.
4. The Th/U ratio for Siwana and Jalor granites is 4.2, while for Tusham and Jhunjhunu it is 8 and 6. U/Th ratios show considerable spread and vary from 0.07 to 1.23 in Miniari and 0.11 to 4.5 around Siwana. On the basis of bivariant plots between U and trace elements, they suggested that the uranium is not wholly contained in minerals such as zircon, monazite etc. They interpreted the mobility of uranium from the system and have suggested the strata bound and vein-type uranium mineralization related to MIS.
5. Evaluation coefficients for the granites of the suits showed elevated values, i.e. > 20 which is not considered favorable for ore formation within the granites. However, uranium may still occur in disseminated form in these rocks and subsequent leaching may have form a zone of concentration in a nearby basin. However, higher evaluation coefficient reflects that there are not many chances to host primary mineralization within the granites. Higher uranium and thorium concentrations and pronounced hydrothermal activity, reported by some workers in the Malani granites may be a favorable factor to host primary mineralization. Kochhar (2000) suggested that the Malani granites have the potential of rare metals mineralization. Bidwai and Krishnamurthy (1996) found a general increase in U, Th and K abundances from East (Miniari) to west (Siwana).
6. The lower U-content in Nagar Parkar complex may be due to its over acidity ($\text{SiO}_2 > 75$) which does not favor the ore formation. On the other hand, the higher fertility of Malani intrusives may be attributed to their adequate SiO_2 (70-71.4 %).
7. Granites of both the suits are persistent in containing certain favorable accessory mineral especially zircon, sphene, apatite and also alanite and epidote in Nagar Parkar. Both the suits have higher abundances of Th, Zr and Nb as compared to U, Hf and Ta, indicating that the granites have originated

from the alkaline magmas. However, higher abundances of Th, Nb, Ta, Zr, and REE in Siwana granites are encouraging for uranium separation from magma due to isomorphism. The Malani granites appear more favorable to host primary uranium mineralization due to its low SiO₂ content and relatively higher abundances of favorable trace elements.

8. On the other hand higher active U- content in the wide and extensive zones of kaolin (upto 45ppm) in Nagar Parkar and the higher degree of weathering enhance the probability of finding any secondary uranium deposit. Chemical analysis of wide and extensive zones of kaolin showed an enrichment of uranium. There is a direct relationship between the heat productivity and concentration of uranium and thorium content in the Malani granites.
9. The relatively higher and persistent radioactivity (up to 1900c/s) found at and near the contact of pink and grey granites of Karunjhar pluton is interesting, also 90% of the collected samples show negative disequilibrium (equivalent U₃O₈ is greater than chemical U₃O₈), indicating mobility of uranium from the system.
10. From the present comparative study it can be established that both the complexes have the potential to act as a fair source for any subsequent secondary uranium deposit.
11. Increased U and Th concentrations in Malani granites as compared to the Nagar Parkar granites may be attributed to its higher heat productivity. This is supported by the fact that the Jalor granites, having lowest heat productivity among the Malani granites also contain lower uranium and thorium concentrations, much closer to the Nagar Parkar granites. Likewise it may be inferred that the granites of the Nagar Parkar are not high heat production type, however, similar type of studies should be carried out in Nagar Parkar to confirm the hypothesis
12. Bara Formation (Paleocene) and calcretes to the immediate north of the Nagar Parkar complex and in west of the MIS are the potential rocks for uranium. (Abdullah et al, 1997) suggested that the detritus for the Bara Formation was supplied by the igneous/metamorphic provenance, most probably the granitic complex exposed in the Nagar Parkar area. They also proposed that the Bara sediments may also be derived by the weathering of sedimentary or meta- sedimentary rocks, probably situated to the east.
13. Regional gradient studies at top and below the coal bearing Bara Formation in the Thar Desert also support that the adjacent volcano-magmatic suit (MIS) is the probable source for the Bara sediments in addition to Nagar Parkar igneous complex (Zaigham, 2006).
14. A perusal of gamma logging data for Bara formation from 276 holes revealed that 140 holes are radiometrically anomalous. Chemical data showed up to 111 ppm uranium (Aqeel and Ali, 2008).
15. The surface/near surface gradients originating from the northeast and east towards west and south also support the possible transport of U, V, and K through shallow ground waters to the distal parts of the Thar Desert.
16. The potential non-pedogenic calcretes in the desert may host uranium mineralization (Aqeel and Ali, 2009). Preliminary studies for calcretes showed that a number of calcretes showed some anomalous U content i.e. >50 ppm (Aqeel and Ali, 2009), however detailed hydro-geochemical and geophysical studies are required to ascertain the prospective mineralized zone. These moderate U-concentrations may be attributed to either source.
17. On the basis of major element data, the granites of both the suites may be termed as S-type (Aqeel and Ali, 2007, 2008), (Kochhar and Dhar, 1993). The rocks of the complexes may be considered as moderate source for uranium.
18. Therefore it is recommended that further detailed studies should be carried out with particular emphasis on lignite related sandstones and the calcretes in the area.

References

- Abdullah, R.M., Baig, M.A., Abro, A.R., Saghir, A., Pathan, M. A., Ahmed, M. R., 1997. Mineral composition and the provenance of the sediments of the Thar coal basin. Geological Bulletin University of Peshawar, 30, 97-106
- Aqeel, A.S., Ali, M., 2007. Tharparkar, a review and data synthesis with special emphasis on

- Uranium prospects of igneous complex, Bara Formation and calcretes. Internal documents, Regional Exploration Office Karachi (REOK) Pakistan Atomic Energy Commission.
- Aqeel, A.S., Ali, M., 2008. Evaluation of uranium source potential of Nagar Parkar granites and associated felsic rocks. Internal documents, REOK Pakistan Atomic Energy Commission.
- Aqeel, A.S., Ali, M., 2009. Discovery of uraniferous calcretes in Tharparkar area. Internal documents, Regional Exploration Office Karachi (REOK) Pakistan Atomic Energy Commission.
- Butt, K. A., Nazirullah, R., Syed, S.A., 1989. Geology and gravity interpretation of Nagar Parkar area and its potential for surficial uranium deposits. *Kashmir Journal of Geology*, 6-7.
- Butt, K.A., Jan, M.Q., Karim, A., 1994. Late Proterozoic rocks of Nagar Parkar, Southeastern Pakistan: A preliminary petrologic account. In: Ahmed, R., Sheikh, A. M. (Eds.), *Geology in South Asia-1*. Hydrocarbon Development Institute of Pakistan, Islamabad, 106-109.
- Bhushan, S.K., 1991. Granitoids of the Malani igneous suite, Western Rajasthan, India. *Indian Journal of Earth Sciences*, 19, 184-194.
- Bidwai, R., Krshnamurthy, P., 1996. Radioelement abundance in some acid rocks of Neoproterozoic Malani igneous suite in parts of western Rajasthan and its implications. *Journal of Atomic Mineral Sciences*, 4, 21-27.
- Clark, S.P. Jr. (Ed.), 1966. *Handbook of Physical Constants*. Geological Society of America Memoir, New York.
- Jan, M.Q., Laghari, A., Khan, M.A., 1997. Petrography of the Nagar Parkar igneous complex, Tharparkar, Southeastern Sindh. *Geological Bulletin University of Peshawar*, 30, 227-249.
- Kazmi, A.H., Khan, R.A., 1973. The report on the geology, mineral and mineral resources of Nagarparkar, Pakistan, Geological Survey of Pakistan, Information Release, 64.
- Kochhar, N., 1989. High heat producing granites of the Malani igneous suite, northern peninsular India. *Indian Minerals*, 43, 339-346.
- Kochhar, N., Dhar, S., 1993. The association of hypersolvus-subsolvus granites: A study of Malani igneous suite, India. *Journal of Geological Society of India*, 42, 449-467.
- Kochhar, N., Vallinayagam, G., Gupta, L.N., 1991. Zircons from the granitic rocks of the Malani igneous suite: morphological and chemical studies. *Journal of Geological Society, India*, 38, 561-576.
- Kochhar, N., 2000. Attributes and significance of the A-type Malani Magmatism, northwestern peninsular India; Crustal evaluation and metallogeny in the northwestern peninsular India, Narosa, New Delhi.
- Laghari, A., 2005. Petrology of Nagar Parkar granites and associated basic rocks. Tharparkar, Sindh, Pakistan. Unpublished Ph.D. thesis, University of Peshawar, Pakistan.
- Mukherjee, A.B., Roy, A., 1981. Cooling conditions of the high level Precambrian granites of Siwana, western Rajasthan. *Journal of Geological Society of India*, 20, 158-161.
- Muslim, M., Akhtar, T., 1995. Geology of Nagarparkar massif, Sindh. *Geological Survey of Pakistan, Information Release*, 605, 1-17.
- Pathan, M.T., Rais, A., 1975. Preliminary report of the investigation of Nagarparkar igneous complex. *Sindh University Journal of Science*, 1, 93-97.
- Srivastava, K.R., Maheshwari, A., Upadhyaya, R., 1989. Geochemistry of felsic volcanics from Gurapratap Sindh and Dir, Pali district, Rajasthan, India. *Journal of Geological Society of India*, 35, 617-631.
- Vallinayagam, G., Kochhar, N., 1998. Geochemical characterization of A-type granites and the associated volcanics of Siwana ring complex, north peninsular India. In: Paliwal, B.S. (Ed.), *The Indian Precambrian*, Scientific Publisher, Jodhpur.
- Zaigham, N.A., 2006. Strategic sustainable development of groundwater in Thar Desert of Pakistan, Department of Geology, University of Karachi, <http://www.sciencevision.org.pk>.