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An appraisal of uranium source potential of granites, associated felsic rocks, kaolin and calcretes of Nagar Parkar area, Tharparkar Pakistan

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Abstract

In this study geochemistry of Nagar Parkar intrusives has been discussed in detail with particular reference to uranium. The uranium content of southern and eastern plutons is relatively higher as compared to the northern part of the complex. It has been a general tendency that the uranium concentration in pink granites is more pronounced. Negative disequilibrium was observed in some samples of granites and kaolins, indicating labile uranium from the system. Major element data revealed that the alkali and alumina contents are in accordance with the uranium productive granites, while silica concentration is higher than the favorable range. So the chances to host any primary mineralization within the granites are not very high. Trace elements pattern and low aegirine-riebeckite concentrations propose that the pink granites have strong crustal input, and may be more favorable for uranium concerns. The uranium data of kaolins indicates the availability of active (leachable) uranium in the system, and subsequent redistribution by circulating ground water might have created a zone of concentration within the kaolins. Additionally calcretes and lignite related Paleocene sandstones in the Thar coal basin, immediately north of the granitic terrain are the prospective hosts for the labile uranium. Rate of disintegration of the rocks, size and relative age also suggest that the pink granites are more likely the source for any secondary mineralization in a nearby host. The granites may be considered as moderate source for any subsequent small scale uranium deposit.

Keywords: Nagar Parker; Tharparkar; Aegirine-riebeckite; Uranium

1. Introduction

Labile uranium in granites has been proposed as the source for many ore deposits. In the following work, an attempt has been made to gauge the uranium source potential of granites exposed in the extreme southeastern part of Pakistan. Nagar Parkar igneous suit constitutes mainly pink and grey granites covering an accumulative area of 480 km^2. The granite rocks are highly fractured and sheared creating a suitable scenario for weathering, which in turn created vast and extensive zones of kaolinization and lateritization particularly in the low-lying areas surrounded by granite exposures. Paleocene lignite related sandstones and calcretes in the adjacent Thar Desert are likely the hosts for leachable uranium. Vanadium rich laterites probably the altered product of amphibolites has enhanced the possibility of carnotization in calcretes.

The uranium and thorium data revealed that the rocks may be considered as moderate source, because ideal and fertile uranium productive granites have more elevated U-content i.e. 9 ppm (Boyle, 1982), however the U-content is well above the Clarke value. The southern and eastern part of the complex showed relatively higher content of uranium. Disequilibrium studies indicate mobility of uranium from the system to some extent. U- Content in the pink granites is generally higher than in the grey variety. Though radioactivity is generally low within the range of 200-350 cps, however, in Karunjhar pluton at few places it is greater than 500 cps with a maximum value of 1900 cps.

Major element data revealed that the alkali and alumina contents are in accordance with the uranium productive granites (S-type). Silica content is higher than the favorable range for uranium. The "evaluation coefficient" (a function of alkali and silica, well established parameter to assess the rocks for their uranium potential, adopted after the extensive studies in China for uranium deposits associated with granite rocks) both for pink and grey granites showed elevated values, greater than 20, suggesting no ample chances for uranium mineralization within the granites, however uranium still may occur in the disseminated form and subsequent leaching phenomena may form a zone of concentration in a nearby host.

2. Study area

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 Thar Desert towards the northern foothills of Karunjhar (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. The road from Karachi to Nagar Parkar is metalled.

3. Previous work

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, 1976) 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. They also reported two major varieties of granite, riebeckite-aegirine grey granite and biotite-hornblende pink granite. Muslim and Akhtar (1995) differentiated two varieties of granite, assimilative pink granite and 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.

4. Sampling and analytical methods

A total of 178 representative samples were collected from all the granite exposures. All the samples were analyzed for uranium however, out of these 86 samples were analyzed for eU_3O_8 (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) and eU_3O_8 concentrations were measured by fluorimetric and gamma spectrometric analysis respectively. eTh concentrations for 86 samples were estimated by gamma spectrometry technique. To establish the geochemical favorability for uranium, previously reported major and trace element data has been utilized.

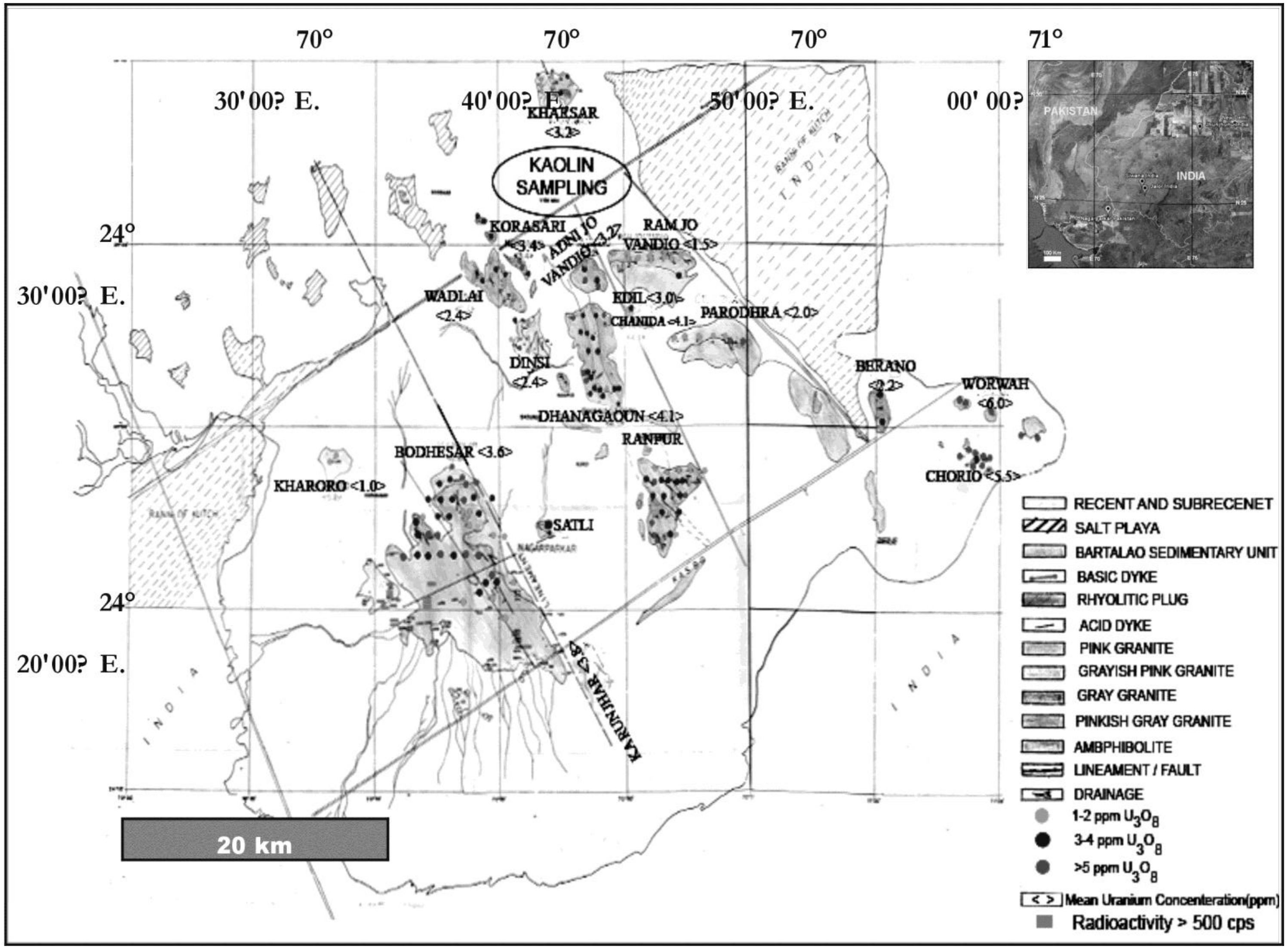

Fig. 1. Geological map showing uranium concentration in the granitic rocks of Nagar Parkar igneous complex (Aqeel el al., 2008, modified after Jan et al., 1997).

5. Geological setting

Jan et al. (1997) have broadly grouped the magmatism in the complex into six older to younger phases; 1) Amphibolites and related dykes 2) Riebeckite-aegirine grey granites, 3) Biotite hornblende Pink granite, 4) Acid Dykes, 5) Rhyolite Plugs, 6) Basic Dykes. A general and brief description of these igneous rocks is as under,

5.1. Amphibolites

The amphibolites, forming the basement for subsequent acid and basic magmatism, are medium to fine grained rocks commonly metamorphosed in epidote amphibolite facies or green schist facies. Largely exposed at Dhed Vero (Jan et al., 1997).

5.2. Riebeckite-aegirine grey granite

The granite is generally grey to grayish white, essentially composed of perthitic feldspar, quartz and small amount of plagioclase and sodic minerals such as riebeckite and aegirine. Zircon occurs as the main accessory mineral. Tourmaline, fluorite and rutile occur occasionally. Allanite, sphene and leucoxene occur as minor accessories along with local epidote (Jan et al., 1997). Riebeckite-aegirine grey granites cover an area of 130 km^2 exposures at Karunjhar, Khimpora, Adhigam and Berano.

5.3. Biotite hornblende pink granite

The granite is generally coarse and medium but locally fine grained, essentially made up of perthitic feldspar and quartz with local microcline, and minor plagioclase. Biotite and hornblende are main accessory minerals. Fayalitic olivine, zircon, sphene, apatite, tourmaline, fluorite, allanite and cassitterite occur as sporadic accessory minerals. The pink granites constitute a total area of 150 km^2 exposed at Karunjhar, Ranpur, Dinsi, Chanida-Dhanagaon, Kharsar, Vorwah and Churio (Laghari, 2005).

5.4. Acidic dykes

Butt et al. (1994) reported rhyolites to quartz trachyte, which are later named as orthophyres in Nagar Parkar and Dhed Vero areas (Muslim and Akhtar, 1995). Many small dykes of acidic composition cut the older lithologies. They range from aplite to porphyritic microgranite, and rhyolite to quartz trachyte in composition (Jan et al., 1997).

Generally the dykes are smaller in size, only few dykes having thickness more than 3 m, however some of the dykes have extension of more than 500 m, at Ghantiari two dykes each about 4 m wide and more than 600 m long run sub-parallel in N30W direction, also at Banbhan-ji-dungri, pink granite is intruded by 10 X 300 m aplite dyke trending at N30W.

5.5. Rhyolite plugs

Dark and glassy-looking rhyolites occur in two small, domal outcrops exposed at Sadurous and Boodher of size1.0 X 0.3 and 1.0 X 0.5 km, respectively.

Dark grey Sadurous rhyolite is homogeneous and apparently banded, porphyritic to subporphyritic and fine grained mainly composed of K-feldspar (mainly perthite) and quartz with small amount of plagioclase. Other minerals include Fe-oxide, sphene, biotite, epidote, muscovite and secondary carbonate. Zircon and apatite occur as accessory minerals.

Boodher rhyolite trending at N20˚W is exposed east of Boodher village, generally homogenous dark grey to black with grayish-white bands, fine grained porphyritic to subporphyritic containing phenocrysts of K-feldspar, quartz and minor plagioclase. Accessory minerals include amphibole, aegirine, sphene, rutile, zircon and apatite (Jan et al., 1997).

5.6. Basic dykes

The basic dykes can be divided into two groups; Lamprophyric diorite dykes and gabbro/dolerite dykes (Jan et al., 1997).

6. Discussion

The mean uranium and thorium content is 3.4 and 15.5 ppm, respectively. It has been observed that the uranium content increases towards southern and eastern part of the complex (Table 1). Mean Th/U ratio for all samples is 4.5. Data for eU_3O_8 and cU_3O_8 for 86 samples is summarized (Table 2). A total of 64 samples showed less than 10 ppm radiometric uranium, while the average chemical uranium in these samples is 3.5 ppm. However, for 22 samples the radiometric uranium is considerably higher than chemical uranium.

Table 1. U & Th concentration in Nagar Parkar granites.

Pluton	No. of Samples	cU_3O_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 2. Radiometric and chemical uranium in Nagar Parkar granites.

Location	No. of Samples	eU_3O_8 (ppm)	cU_3O_8 (ppm)
Northern granites	22	<10	3
	14	25	2.6
Southern granites	42	<10	3.9
	8	26.1	4.8

Radiometric uranium was found 25 ppm against 2.6 ppm chemical uranium in north, while in south 26.5 ppm mean radiometric uranium was found against 4.8 ppm chemical uranium. Almost 65 % of the total samples show uranium content above the Clark value of 2.5 ppm. The samples with uranium concentration ≥ 4 ppm constitute 47 % of the total samples. Mean U-content in kaolins was found >5ppm with a maximum value of 45 ppm. Radiometric uranium in some selected samples of kaolins was found upto 27, 69 and 66 ppm against chemical uranium values of 10, 30 and 45 ppm respectively (Table 3).

Table 3. Uranium concentration in kaolin near Pawari village, Nagar Parkar area.

Sr. No.	Sample No.	cU_3O_8 (ppm)	eU_3O_8 (ppm)
1	K -2	5	-
2	K -7	10	27
3	K -8	5	-
4	K -10	5	-
5	K -11	5	-
6	K -19	7	-
7	K -20	30	69
8	K -21	5	-
9	K -24	5	-
10	K-27	45	66
11	K-29	7	-
12	K-30	7	-

Major element data for 54 and 56 samples from pink and grey granites was utilized to ascertain the suitability of these 36ntrusive for uranium. Mean values of oxides are given in Table 4. Trace element analyses for 06 and 04 samples both for pink and grey granites (Laghari, 2005) have also been incorporated to examine their relationship with uranium (Table 5).

6.1. Radioactivity

Radioactivity is generally low and was found 150-250 cps in most of the area; however, in contrast to the general tendency it is considerably higher in Karunjhar pluton. Both pink and grey granites of Karunjhar area exhibit relatively higher values i.e. >500 cps with a maximum of 1900 cps. The radioactivity is mainly associated with fractures and joints. (Fig. 1)

Table 4. Major element distribution in Nagar Parkar granites (after Laghari, 2005).

Elements	Grey granite (%)	Pink granite (%)
FeO	-	-
Fe_2O_3	2.3	0.87
MnO	0.06	0.05
MgO	0.1	0.3
Al_2O_3	11.4	12
SiO_2	76.3	75.6
K_2O	4.5	4.6
Na_2O	4.3	4
TiO_2	0.3	0.4
CaO	0.4	0.8

Table 5. Mean concentration of trace elements in Nagar Parkar granites (after Laghari, 2005).

Trace Elements	Pink granite (ppm)	Gray granite (ppm)
Sr	50.17	10
Ba	407.6	124.25
Zr	78.5	324
Cr	5	5
Ni	5	5
Rb	38.6	57.15
Ta	0.85	0.6
Nb	8.55	13.73
Hf	4.08	11.4
Y	55.46	53.83

6.1.1. Uranium and Thorium

The average uranium and thorium abundances in acidic intrusive/extrusive rocks (granites, rhyolites etc) are 4.5 and 15 ppm, respectively, average Th/U ratio is 3.3 (Boyle, 1982). The mean concentrations of both elements in Nagar Parkar intrusive were found to be 3.4 and 15.5 ppm respectively. From the data, it can be observed that the uranium content is even not in accordance with the average abundance, moreover, the Th/U ratio is still higher to be favorable. Th/U ratio in south and eastern exposures is 4.1, lower than the north where it is ≥ 5.5. Th/U ratios in relation to uranium concentration are relatively better in south as compared to north (Fig. 2a). However, Th/U ~4 could be favorable if average uranium concentration would have been 6-7 ppm.

6.1.2. Disequilibrium status

A total of 64 samples out of 86 showed eU_3O_8 less than 10 ppm, an indicative of less labile uranium, nevertheless, enhanced radiometric uranium (> 10 ppm) for 22 samples both from pink and grey granites is a reflection of leachability (Figs. 2 b&c). Plot of ratio eU_3O_8/cU_3O_8 for these 22 samples showed negative disequilibrium. It is note worthy that the chemical uranium is considerably lower as compared to the radiometric uranium particularly in north.

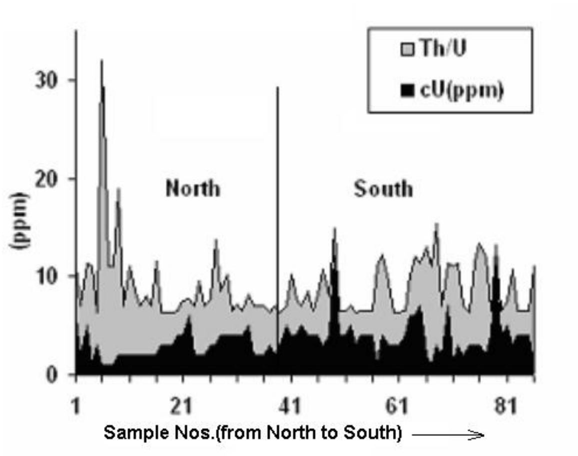

Fig. 2a. Relationship between Uranium and Thorium.

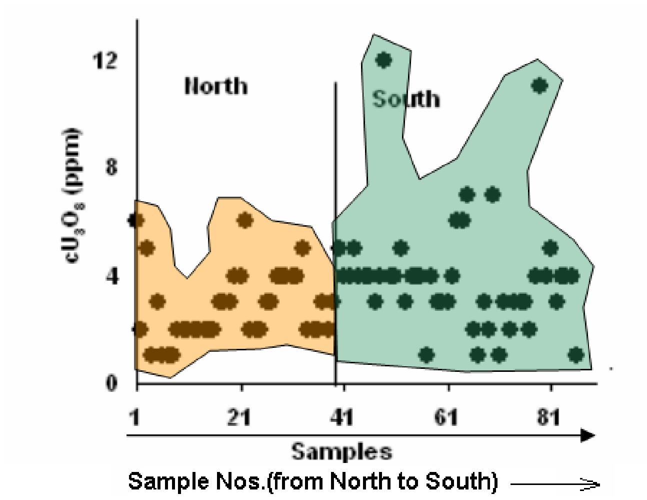

Fig. 2b. cU_3O_8 concentration in granitic samples.

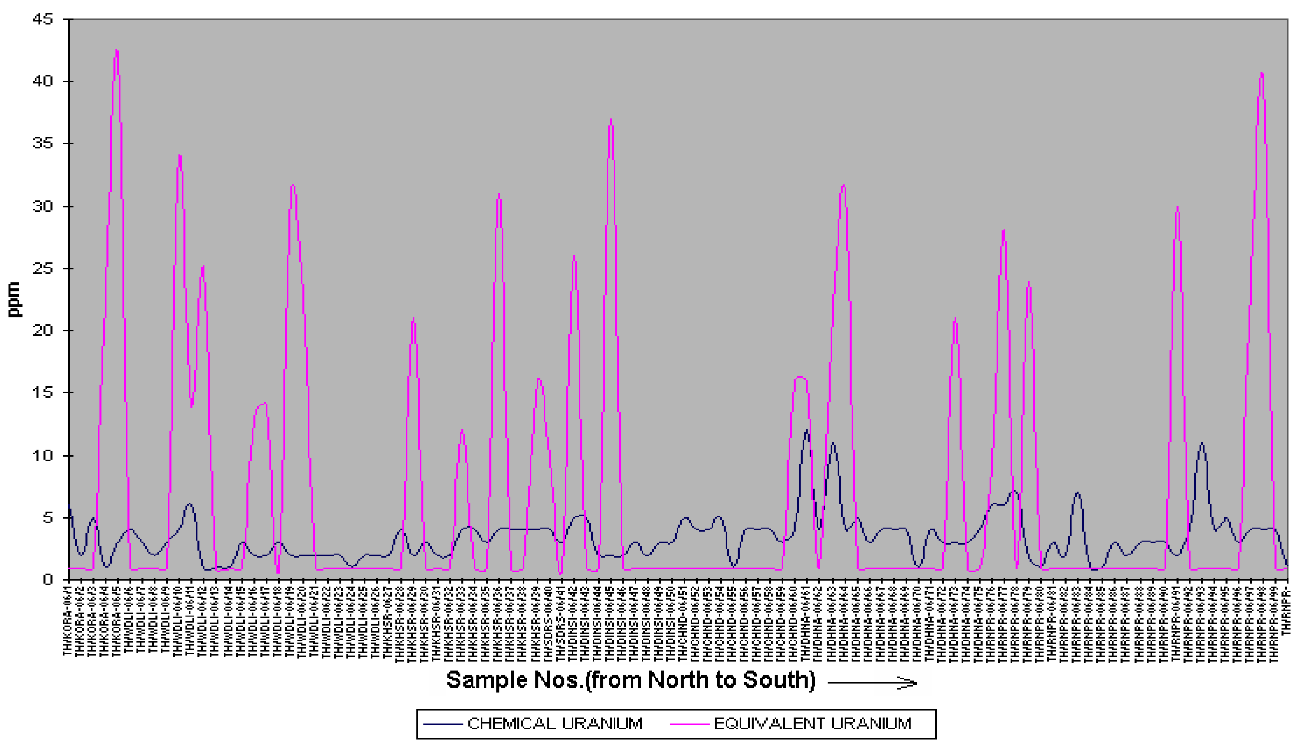

Fig. 2c. Correlation between cU_3O_8 and e U_3O_8 in samples collected from Nagar Parkar igneous complex.

6.1.3.Uranium response in kaolins

The extensive kaolin zone with higher chemical uranium (upto 45 ppm) with negative disequilibrium also lies in the northern half of the suit surrounded by low lying weathered pink granites.

The relatively increased U-concentration indicates the availability of active uranium in the system. The enhanced concentrations like 45 and 30 ppm may be the result of redistribution of the leached uranium by circulating and meteoritic waters.

6.2. Major elements

Silica content in both granites is little higher i.e., >75.5%. In China, usually the rocks having silica content of 71-73% host the uranium concentrations. Higher silica concentration (>73%) is not considered favorable. It has been observed that uranium does not crystallize out of the magma in an over acidic environment, rather it tends to disperse in the whole rock as accessory minerals. Total sum of alkalis is greater than 8 % but the relative K_2O value is less than 5 %. On the other hand, Na_2O has increased value i.e. more than 3 %. Alumina concentration is greater than the total alkali, which is a favorable factor, it also falls in the favorable range for both the granites.

On the basis of silica and alkali contents "Evaluation coefficient" ($X=1/5\ SiO_2+3/5Na_2O$ ($SiO_2\ +K_2O$)), has been calculated which was found 27.24 and 26.7 for pink and gray granites respectively. These values are too high. Commonly the granites with evaluation coefficient < 20 are considered to be the potential rocks to host ore grade concentration. Nevertheless, uranium may exist in disseminated form in the system.

6.3 Trace element distribution and tectonic setting

Zr is also present in the system with a mean value of 78.5 and 324 ppm in pink and grey granites respectively, indicating the possibility for isomorphism with these elements. Ce and Y having similar ionization potential and electronegativity are often closely associated in an acidic environment. Boyle (1982) suggested that Y and Ce and other rare earths, V, P, As, Cu, Zn, Se, and Mo are commonly in enriched amounts in uraniferous terrains. The possibility of isomorphism amongst these elements is greater.

Laghari (2005), suggested that the trace element pattern and the resemblance with the crust dominated, A-type granites indicate that the granites of Nagar Parkar igneous complex were formed in an extensional setting that failed to mature into rifting. He also attributed the elevated concentration of aegirine-riebeckite concentration in grey granites to relatively stronger extension. Conversely, pink granites having generally low aegirine-riebeckite suggests that the extensional environment was not so strong or, more likely, the emplacement of grey granites induced melting within the overlying crust.

Generally, anorogenic A-type granites are not considered favorable for uranium, but the more differentiated and anatectic granites are thought to be favorable for uranium. Butt el al. (1994) also suggested that the Nagar Parkar granite rocks are the product of crustal anatexis in an intraplate (continental) anorogenic environment.

6.4. Weathering and alteration

During the extensive field work, it has been observed that there is no pronounced hydrothermal activity and alteration. The rocks are highly fractured and faulted due to different tectonic phases, facilitating the weathering processes. Pink granites are more susceptible to weathering in contrast to the refractory grey granites, so the detritus can more easily be contributed by pink granites to the immediate hosts.

6.5. Relative age

In differentiated series of granite rocks, there has been a general tendency for uranium to increase with the youthfulness of the pluton (Boyle, 1982). In China and Russia, the granites of younger ages contain high uranium concentrations. Similarly, the younger magmatic phases within the same complex have high average abundance of uranium. In our case pink granites, intruded at later stage may be regarded as more favorable for uranium than the grey granites.

6.6 Uranium concentrations in calcretes and ground water

The authors have also evaluated the uranium potential of calcretes in the Thar Desert, north of the igneous complex. Preliminary sampling showed some spotty but anomalous concentrations of uranium (70-158 ppm) in few calcrete bodies. Hydro-geochemical investigations for ground waters also suggested 15 anomalous areas in the Thar Desert (Hindal, 1980). The ground water and calcretes anomalies are indicative of the probable transport of uranium from Nagar Parkar granites. The granite terrain, MIS (Malani Igneous Suit), further east of the desert may also be the source for these anomalous concentrations.

7. Conclusions

1. Uranium concentration in the granites are not well pronounced, also the Th/U ratio is higher than 2.5, however, the rocks may be considered as the moderate source for small scale deposits.
2. Disequilibrium studies proposed uranium leaching from the system particularly in north. However, U-Th-Pb isotopic systematics can be used to obtain quantitative or semi-quantitative data on the timing and extent of uranium mobilization.
3. The total alkalis and alumina contents are in close agreement to the U-productive granites (S-type); however, silica content is relatively higher than the desired range. No pronounced hydrothermal alterations have been observed. The data also suggests that there are lesser chances to host primary mineralization within the granites.
4. Though Nagar Parkar granites are not typical S-type, strong crustal input, youthfulness and susceptibility to weathering are the factors to designate the biotite pink granites favorable for uranium.
5. Detailed studies of kaolins are required to investigate the uranium distribution and alteration pattern followed by inter-montane basin analysis.
6. Sandstones of Bara Formation and calcretes in the adjacent Thar coal basin are the potential hosts for leachable uranium. Detailed and systematic studies are required to evaluate the host capabilities of these rocks.

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