STUDY OF URANIUM MINERALIZATION IN ROCK SAMPLES FROM MARWAT RANGE, BANNU BASIN BY FISSION TRACK ANALYSIS TECHNIQUE

By
Aziz Ahmed Qureshi
Kafayat Ullah
Nimat Ullah
Mohammad Akram

Nuclear Geology Group

PHYSICS RESEARCH DIVISION
PAKISTAN INSTITUTE OF NUCLEAR SCIENCE & TECHNOLOGY
P. O. Nilore, Islamabad
July 2004

Contents

List of Tables

List of Figures

Abstract

The Geophysics Division, Atomic Energy Minerals Centre (AEMC), Lahore has planned a uranium exploration program in Marwat Range, Bannu Basin. In this connection 30 thin sections of rock samples, collected from four areas; namely, Darra Tang, Simukili, Karkanwal and Sheikhullah from Marwat Range, and one from Salt Range were provided to Nuclear Geology Group of Physics Research Division, PINSTECH for the study of nature and mechanism of uranium mineralization These studies are aimed to help in designing uranium exploration strategy by providing the loci of uranium sources in the Marwat and Salt Ranges. The samples have been studied using fission track analysis technique. A few samples were also studied using auto radiographic technique.

Based on fission track and auto-radiographic analysis techniques, two-types of uranium mineralizations have been noted in the Marawat range. These can be categorized as;

a) Primary uranium mineralization associated with the black ore grains, containing uranium as a minor constituent, capable of enduring distant transport in water from Himalaya and deposited during the diagenesis of Siwaliks in this area. The term of primary mineralization has been used as the black ore grains were deposited during the diagenesis of Siwaliks in this area. This type of mineralization is seen in Simukili area.
b) Secondary uranium mineralization, which consists of mobilized primary mineralization and re-deposited as,
    i) discrete clusters around carbonaceous nuclei
    ii) rims around mineral grains & as veinlets and
    iii) discrete spots/atoms with in the rock matrix.

The secondary mineralization is found in Darra Tang, Karkanwal and Sheikhullah areas, which may have been generated as a result of tectonic movements and solutional activity that leached down the primary mineralization.

c) The phenomenon of uranium mobilization from surface and deposition below water table, similar to Isakhel, may be expected in Darra Tang, Karkanwal and Sheikullah areas.
d) In the sample from Salt Range the uranium is associated with primary black ore grains.

Introduction

The Geophysics Division, Atomic Energy Minerals Center (AEMC), Lahore has initiated uranium exploration program in Marwat Range, Bannu Basin. As a part of initial studies the AEMC has planned to carry out analysis of sandstones from Marwat Range, Bannu Basin by fission track analysis technique. The Marwat Range is the southward continuation of Surghar Range, which contains a uranium deposit that is being mined under a project management named as "Isakhel Uranium Project". The fission track studies are aimed to help in designing exploration strategy in this area by providing the loci of uranium source in the Marwat Range. In this connection 30 thin sections of rock samples, from Darra Tang, Simukili, Karkanwal and Sheikhullah areas, were provided to Nuclear Geology Group of Physics Research Division, PINSTECH for fission track analysis. One thin section sample from Salt Range, where exploration is in progress, was also provided fission track analysis.

The thin sections have been studied using fission track analysis technique. Some of the samples were also studied using auto-radiographic technique. The studies show that there are two-types of uranium mineralization in these areas. This can be categorized as; Primary mineralization associated with the unidentified black ore grains, containing uranium as a minor constituent, capable of enduring distant transport in water from Himalaya and deposited during the diagenesis of Siwaliks in this area. This type of mineralization is seen in Simukuili Area. The other type of uranium mineralization is of secondary nature, which consists of mobilized primary mineralization and re-deposited as i). discrete clusters around carbonaceous nuclei ii). rims around mineral grains and as veinlets and iii). as discrete atoms evenly distributed with in the rock matrix. The secondary mineralization is found in Darra Tang, Karkanwal and Sheikhullah areas, which may have been generated as a result of tectonic movements and solutional activity.

The Technique, Materials and Methods

Rocks are extremely heterogeneous on the micro scale, with the uranium being concentrated in small, accessory or trace mineral phases. The technique of fission track analysis (FTA) can be used not only to measure the average uranium content of a sample, rather it is much more important to measure the spatial distribution of uranium within rock matrix. Using the FTA technique it is easy to measure the uranium distribution and its concentration on a micron scale in rocks and minerals.

The technique for micromapping of uranium in rocks consists of pressing of a track detector, tightly against a flat rock surface or a thin section that is to be studied (Fleischer, 1966). The detector is a thin plastic film, usually lexan, or a clear mica sheet to record fission fragments (Hamilton, 1966). The "rock+detector" assembly is then irradiated in the reactor for a specific time, which induces fission in the uranium present in the rock sample. The fission fragments of uranium create tracks in the attached detector. Separating the detector from the thin section after irradiation and revealing the tracks by etching provides as a guide to the corresponding regions in the sample for uranium micromapping. The transparent thin section and detector can be viewed simultaneously under a microscope where the uraniferous regions in the thin section can be identified by focusing on the track bearing zones in the detector. The rock/thin section + detector assembly to be irradiated in the reactor is shown in the Fig. 1. Autoradiography is done by pressing a CN-85 track detector against the rock

thin sections to record α-tracks emitted by uranium bearing zones present in the rock. For the determination of uranium content in the rock section a reference glass pressed on the detector is also irradiated during studies as a standard.

The utility of the track map depends on the accuracy with which regions on the section being studied can be referenced to the fission map. As shown first by Kleeman and Lovering (1967a & 1969), the simplest method of referencing is to look at the slide through the detector while keeping the rock sample below the detector (Doley et al., 1970, Haines, 1972 Grozaz et al., 1974). The aim of this work is to understand the geochemistry of uranium, its distribution in various rock units/fractions and its microscopic association with geochemically related elements. A figure by Kleeman and Lovering (1976 a) shown as Fig. 2, consisting of a polished rutile grain, on left, and a lexan detector, on right, containing tracks due to the fission of uranium in rutile superimposed over the section demonstrate the usefulness of the technique.

In this study the samples were cut to thin rectangular pieces, fixed on glass slides, ground and polished get thin slides. Lexan detectors were placed in contact with all samples and a Standard Reference Material (SRM-612) of known uranium content. Both the samples and Standard Reference Material were irradiated with thermal neutrons in the Pakistan Research Reactor-1 (PARR-1). After irradiation the lexan detectors were removed from samples and standard and etched in 6.5 M NaOH solution at 50 °C for 45 minutes. The fission tracks registered in the lexan detectors were counted using Zeiss binocular microscope at an overall magnification of 400X. The uranium content in the phosphatic nodules was determined by comparing track density of unknown with standard using the following relation of Fleischer et al., (1975):

$$C_{ux} = \frac{T_x}{T_s}\frac{I_s}{I_x}\frac{R_s}{R_x}C_{us} \qquad (1)$$

Where C_{ux} and C_{us} are the uranium content in the unknown and standard samples, T_x and T_s are the track densities in lexan detectors for the unknown and standard samples, I_x and I_s are the isotopic abundance ratios of U^{235} to U^{238} in the unknown and standard samples and R_x and R_s are the average etchable ranges of fission fragments in the unknown and standard samples, respectively. The ratio R_s/R_x is assumed to be unity, because the average ranges of fission fragments in the SRM-612 and rock material is approximately the same.

General Geology of Area

The Marwat Range falls along the southeast fringes of Bannu Basin, mainly consisting of Nagri, Dhok Pathan and Soan Formations of Siwalik system of rocks as shown in Fig. 3. The lower part of Marwat Range is composed of thick, massive, light colored sandstone while the upper part consists of alternating sequences of light grey sandstone and pale brown to pale yellowish grey siltstone. Presence of sandy and gritty channel deposits with occasional development of flood plains reveal medium to high-energy paleoflow environment.

The known uranium occurrences are mostly confined to the upper part of Dhok Pathan Formation and its transitional zone with overlying Soan Formation. Dhok Pathan Formation is composed of alternating sequence of sandstone and shale.

Sandstone is commonly grey, whitish and dull grey in color, loose, medium to coarse grained, cross bedded and friable. Shale is dull brown to brown and grey in color, with varied amount of volcanic materials. Heavy mineral layers of few centimeter thickness and limited lateral extent are present at places in shale.

Results and Discussion

After studying 30 thin section samples from Darra Tang, Simukili, Karkanwal and Sheikhullah areas from Marwat Range, following mechanism of uranium mineralization has been defined.

1. Darra Tang Area

Darra Tang area is located immediately to the south of Isakhel uranium deposit across the Kurram River, where the Surghar Range changes into Marwat Range. At this place there is a change in the trend of NS striking mountain ranges to a sharp SW trend, which ultimately become EW and finally take a NW direction in the Bhitani Range (Fig.3) In Darra Tang area, uranium mineralization is of secondary nature, which consists of mobilized primary mineralization and re-deposited as i). discrete clusters around carbonaceous nuclei and as ii). deposition as discrete atoms uniformly distributed in the whole rock matrix in low values. In general the background and spot count gamma activity is low in this area due to the re-mobilization of uranium to subsurface levels. Only in one sample the uranium was found concentrated as discrete clusters around carbonaceous nuclei at two spots having value of 66 & 18 ppm, but no ore grain was seen to be associated with this uranium concentration.

The black uranium bearing ore mineral seems to have been deposited during diagenesis in this part of the Marwat Range similar to the rocks of Simukilli. The uranium from the black uraniferous mineral/s may have been leached down due to the tectonic movements indicated by the presence of flexuring in the trend of mountain ranges south of Isakhel. Similar mechanisms of uranium ore formation have been noted at the Uranium Districts of SE Utah (USA) and Grants Uranium Regions, New Mexico (Adler & Sharp, 1967 and Santose, 1963). The leached uranium may have been deposited at depth under reducing conditions, as is the case in Isakhel Deposit. Qureshi et al., (1993) also advocated the same idea for the formation of uranium deposit at Isakhel. Results of the study of uranium mineralization in various samples from Darra Tang are given in Table 1.

2. Simukili Area

In Simukili area uranium is mainly associated with the primary black mineral grains, having cubic system of crystallization. These grains contain higher uranium content up to 374, 3146, 1798 & 1166 ppm in sample No. SK-1, SK-5, SK-8 & SK-9 respectively. Spot gamma counts, taken by field parties using a scintillation counter, are also higher due to the presence of primary uraniferous mineral/s in the Simukili. The rocks containing uraniferous mineral grains are usually coarse grained. However, in a few cases these are also associated with medium grained rocks. The association of uranium with the black ore grains is shown in Fig. 4 & 5. In some of the slides the black heavy minerals along with uranium ore minerals form layers, especially in the upper part of the Dhok Pathan. The primary black uranium bearing mineral/s are evenly distributed with in the rock matrix without any tectonics disturbance or movements as compared to Darra Tang area. In one sample SK-3, the uranium occurs

along the rims of a fractured quartz or feldspar grain as secondary mineralization and is shown in Fig. 6. In a few samples secondary uranium mineralization is also found as discrete atoms in the rock matrix (Fig. 7). These rock samples (SK-2, 6, & 7) are fine-grained silty and micaceous in nature. A brief summery of the studies done on the some of the samples from Simukili is given below;

The sample SK-1 is composed of fine to medium grained, grey loose sandstone. Fission tracks induced in the lexan detector are related to seven black grains in this sample. Sample SK-3 is grey micaceous calcified sandstone mainly composed of quartz, feldspar, mica and some rock fragments. In this sample the mobilized uranium forms a rim around a fractured mineral grain shown in Fig. 6. The micaceous nature of the rock may have provided the chance of solutional activity in this sample. Sample SK-5 is light grey, medium to fine grained compact sandstone. In this sample fission tracks, seen at 4 places, indicate the association of uranium with black grains.

Sample SK-8 is grey, medium grained sandstone with layers of heavy minerals. Fission tracks related to black grains containing uranium were seen at 8 places. Sample SK-9 collected from younger part of Dhok Pathan, is fine grained, compact and limonitic having layers of heavy minerals. Fission track clusters were seen at 9 places, apparently with no relation to any primary mineral grain. The limonitic material in the sample must have provided nuclei for the secondary uranium mineralization in the sample. The uranium content calculated in four samples from Simukili is given below:

Sample No	No of grains studied	Range of Uranium concentration (ppm)
SK-1	7	146-374
SK-5	4	284-3146
SK-8	8	391-1798
SK-9	9	410-1164

From the nature of uranium mineralization in Simukili it is concluded that this area has been tectonically stable and the primary nature of mineralization has not been disturbed. However, presence of secondary mineralization around a mineral grain (Fig. 6) and as discrete uranium spots present in the rock matrix only in one sample (Fig. 7) indicate a minor solutional activity that may or may not be related to any tectonic movement. More details on the study of samples from Simukili are given in Table 2.

3. Karkanwal Area

In general the uranium content in this area is low with low spot counts as compared to Simukili area. The secondary uranium mineralization occurs in the form of discrete spots and as well as in the general matrix of the rock as discrete atoms. The spots where uranium occurs do not show association with any ore grain. Such spots are found in sample No. KW-2 (U 141 ppm), KW-3 (U 99, 139 & 153ppm) KW-5 (U 11 & 22 ppm) & KW-7 (U 15 ppm). In sample No. KW-1, 4 & 6, the uranium occurs as discrete atoms in the whole rock matrix with low uranium content of 152, 88 & 19

ppm respectively. Originally the uranium may have been associated with the black ore grains as in case in Simukili area and this appears to have leached out and deposited in the form of discrete spots with in the rock and as uniformly distributed discrete atoms with in the rock matrix. The leaching and deposition of uranium are shown in Fig. 8. More detail of the studies carried out on samples from Karkanwal is given in the Table. 3.

4. Sheikhullah Area

Seven samples from Sheikhullah area were studied using the fission track analysis technique. In this area secondary uranium mineralization is present in the form of uraniferous spots and as uniformly distributed discrete atoms in the rock matrix. In one sample (SU-4/02840) there are four spots where uranium is associated with blackish material/grains. However, it could not be confirmed whether this is primary mineralization or otherwise. Two such spots are shown in Fig. 9 & 10. In another sample (SU-3) the uranium is distributed along the margins of a quartz/feldspar grain. The occurrence of uranium along the grain margins is shown in Fig. 11. From the study of samples from Sheikhullah it has been concluded that this area also contains secondary mineralization. The four black spots seen in the sample No. (SU-4/02840) are of doubtful origin. More details about the study of samples from Sheikhulla is given in Table 4.

5. Sample from Salt Range

The Geophysics Division, Atomic Energy Minerals Center, Lahore also provided a sample bearing No. 2863 (Khajji-2) from Salt Range to carry out analysis for its uranium content by fission track technique. These studies are also aimed to develop uranium exploration strategy in this area by providing the loci of uranium source.

Feldspar, quartz, mica and some opaque minerals were identified in this sample by means of petrographic studies. In this sample 10 points containing sufficiently high uranium content were noted, as shown in Table 5. These points were observed resulting from the primary black ore grains. The uranium content of the ten points is as follow;

Grain No	Uranium content ppm	Grain No	Uranium content ppm
1	2969	6	1872
2	2696	7	1734
3	2162	8	1639
4	2093	9	1343
5	1992	10	1128

Conclusions

Two-types of uranium mineralization has been noted in the samples studied from Marwat range. These can be categorized as;

A). Primary uranium mineralization associated with the unidentified black ore grains, containing uranium as a minor constituent, capable of enduring distant transport in water from Himalaya and deposited during the diagenesis of Siwaliks in this area. This type of mineralization is seen in Simukuili area.

B). Secondary uranium mineralization, which consists of mobilized primary mineralization and re-deposited as;

i). discrete clusters around carbonaceous nuclei

ii). rims around mineral grains & as veinlets and

ii). discrete spots with in the rock matrix. The secondary mineralization is found in Darra Tang, Karanwal and Sheikhullah areas. The secondary mineralization may have been generated as a result of tectonic movements and solutional activity that leached down the primary mineralization.

C). The phenomenon of uranium mobilization from surface and deposition below water table, similar to Isakhel, may be expected in Darra Tang, Karkanwal and Sheikhulla areas.

D). The sample from Salt Range also contains high uranium content associated with primary black ore grains.

References

A. A. Qureshi, G. Hussain, K. M. Ghazali, M. A. Samad Baig and H. A. Khan (1993), Use of Alpha Sensitive Plastic Film (ASPF) Technique to locate the re-mobilized uranium ore bodies in sandstones. Nucl. Tracks Radiat. Meas. 22, 1-4, 431-433.

E. S. SANTOS (1963), "Relation of ore deposits to the stratigraphy of host rocks in the Ambrosia Lake area", Geology and Technology of the Grants Uranium Region, New Mexico State Bur. Mines Mineral Res. Mem. 15 53-59.

E. L. Haines, A. J. Gancarz, A. L. Albee, and G. J. Wasserburg (1972), "The Uranium Distribution in Lunar Soils and Rocks 12013 and 14310," Lunar Science-III, C. Watkins (ed.), 350-352, Lunar Sci. Inst., Houston.

E. I. Hamilton (1966), "Distribution of Uranium in Some Natural Minerals," Science 151, 570-572.

G. C. Crozaz, D. Burnett, and R.M. Walker (1974), "Uranium and Thorium Distributions in Meteorites," Meteorities.

H. H. Adler and B. J. Sharp (1967), Uranium Ore rolls – occurrence, genesis and physical and chemical characteristics, Uranium Districts of Southereastern Utah, (HINTZE, L.F., et al., Ends), Utah Geol. Soc., Guidebook to the Geology of Utah No. 21 53-77.

J. D. Kleeman and J. F. Lovering (1967a), "Uranium Distribution in Rocks by Fission Track Registration in Lexan Plastic," Science 156, 512-513.

J. D. Kleeman and J.F. Lovering (1969), " Lexan Plastic Prints: How are they formed? Proc. Intl. Topical Conf. On Nuclear Track Registration in Insulating Solids and Applications, Clermont-Ferrand, 2, Section VI, 41-52

J. R. Dooley, Jr., R. B. Taylor, and F. J. Jurceka (1970), "Dual Microscope Comparator for Fission Track Studies," Rev, Sci. Instr. 41, 887-888.

R. L. Fleischer (1966), "Uranium Micromaps: Technique for In Situ Mapping of Distributions of Fissionable Impurities," Rev. Sci. Instr. 37, 1738-1739.

Table 1. Results of uranium mineralization studies in samples collected from Darra Tang Area, Bannu Basin

Sample No.	Radioactivity (B.G/Spot) cps	Sample Description	Fission Track Study	Autoradiographic Study
DT-1	105/150	NA	NA	NA
DT-1 (G)	NA	NA	Fission tracks clusters were observed with no relationship with any mineral is sample. Uranium content determined in two grains is: 1. 66 ppm 2. 18 ppm	NA
DT-2	105/150	NA	Fission tracks revealed low uniform uranium distribution in the sample	NA
DT-3	105/200	NA	Pattern of fission tracks showed low uniform uranium distribution in the sample	NA
DT-4	105/250	Medium to fine grained light grey sandstone with calcified hard bands	Uniform distribution of fission tracks indicates equal uranium distribution in the sample. Average uranium content is 146 ppm	Negligible tracks were observed even after exposure of 960 hours.
DT-5	105/150	A Channel in the rock having coarse sand, grey colored, clay ball of various sizes.	Fission tracks seen in whole of the sample but there are two zones having marked difference in track densities. A) Zone with high track density having 181 ppm of U B)) Zone with high track density having 40 ppm of U; Average uranium is 83 ppm	Negligible tracks were observed even after exposure of 40 days.
DT-6	105/100	NA	Uranium content is negligible in the sample	NA
DT-6 (G)	NA	NA	Negligible uranium content in the sample.	NA
DT-7	105/140	NA	NA	Sample affected during etching. No results observed

Table 2. Results of uranium mineralization studies in samples collected from Simukili Area, Bannu Basin

Sample No.	Radioactivity (B.G/Spot) cps	Sample Description	Fission Track Study	Autoradiographic Study
SK-1	105/145	Fine to medium grained, grey colored loose sandstone	Fission track related to black grains containing uranium were seen at places. The track density and U content is given below; Grain Track ρ U ppm 1. $4.9x10^5$ 374 2. $2.9x10^5$ 222 3. $2.9x10^5$ 222 4. $2.7x10^5$ 209 5. $2.0x10^5$ 159 6 $1.9x10^5$ 146	No tracks seen after an exposure of 15 days, perhaps due to short exposure time.
SK-2	105/140	Fine to medium grained, grey loose sandstone	Sample could not be studied due to some technical problem.	No tracks seen after an exposure of 15 days.
SK-3	105/650	Grey micaceous calcified sandstone. Mainly quartz some feldspars, mica & rock fragments	Tracks clustered around grain boundaries. The area containing tracks was 45 % of the rock. Based on the track density ($8.4x10^5$) the U content was calculated as 635 ppm.	Exposure time 40 days. Tracks along fractures & some grain boundaries, possibly due to a solution activity in the rock.
SK-4	105/105	Grey micaceous, medium grained calcified sandstone	Due to some etching problem tracks could not counted.	Exposure time 40 days. Track Clusters at a few places but no match with any mineral grain
SK-5	105/100	Light grey, medium to fine grained compact sandstone	Fission track related to black grains containing uranium were seen at 4 places. The track density and U content is given below; Grain Track ρ U ppm 1. $8.8x10^5$ 3146 2. $2.2x10^5$ 838 3. $1.2x10^5$ 473 4. $0.7x10^5$ 284	Exposure time 40 days. Track Clusters at a few places seen associated with some black mineral grains

SK-6	105/200	Fine grained, grey colored micaceous loose sandstone	Only a few tracks were seen indicating a very low U content.	Exposure time 40 days.Very few tracks with no association with any grain or rock structure
SK-7	105/2000	Earthy grey colored silt with fine grained limonitic material	Tracks indicate uniform U distribution in the rock. Average track density is $2.9x10^5$; uranium content calculated is 1103 ppm.	Exposure time 40 days. Uniform tracks throughout the detector
SK-8	105/350	Grey, medium grained sandstone with layers of heavies	Fission track related to black grains containing uranium were seen at 8 places. The track density and U content is given below; Grain Track ρ U ppm 1. $4.5x10^5$ 1798 2. $3.7x10^5$ 1412 3. $2.9x10^5$ 1097 4. $2.3x10^5$ 889 5. $2.1x10^5$ 801 6 $2.0x10^5$ 756 7 $1.3x10^5$ 498 8. $1.0x10^5$ 391	Exposure time 40 days. Track Clusters at a few places associated with black mineral grains
SK-9	105/300	From younger part of Dhok Pathan, fine grained compact and limonitic having layers of heavies. Mainly feldspar, quartz, mica and abundant ore	Fission track clusters at 9 places, apparently relation to any mineral grain was not seen. The track density and U content was is given below; Grain Track ρ U ppm 1. $3.1x10^5$ 1166 2. $2.9x10^5$ 1103 3. $2.9x10^5$ 1103 4. $2.2x10^5$ 851 5. $2.1x10^5$ 788 6 $2.1x10^5$ 788 7 $1.6x10^5$ 599 8. $1.2x10^5$ 473 9. $1.1x10^5$ 410	Exposure time 960 hours. Track Clusters at more than 10 places associated with ore minerals. This means that the upper part of Dhok Pathan be checked for uranium mineralization in this area. This part contains some uraniferous mineral.

Table 3. Results of uranium mineralization studies in samples collected from Karkanwal Area, Bannu Basin

Sample No.	Radioactivity (B.G/Spot) cps	Sample Description	Fission Track Study	Autoradiographic Study
KW-1	105/150	Sample collected from zero point of geological cross-section, loose, medium grained grey sandstone.	Fission tracks are almost equally distributed in the detector. It means that uranium is uniformly distributed in the sample. Average uranium content is 52 ppm.	NA
KW-2	105/100	Light grey sandstone, calcified, fine to medium grained.	Fission tracks clusters were observed with no obvious relationship with grains in sample. Uranium content of a single grain is 141 ppm.	NA
KW-3	105/145	Grey colored sandstone, medium grained. Sample has a layer of dark colored heavies.	Fission tracks clusters were observed with no obvious relationship on matching outline of these clusters with grain in sample. Uranium content determined for three grains is given: i). 153 ppm, ii). 139 ppm & iii). 99 ppm	NA
KW-4	105/400	Calcified sandstone, fine to medium grained, light grey.	Fission tracks pattern show that uranium is deposited throughout in the sample. Some relatively coarse grains printed no tracks on the detector. Average uranium content is 88 ppm.	NA
KW-5	105/105	Grey color , loose sandstone, medium grained, micaceous	Negligible tracks restricted to selected region. Some small clusters were also observed with low uranium content. Uranium content determined for two grains is given: i). 22 ppm & ii). 11 ppm	NA
KW-6	NA	Siltstone, fine grained, grey colored, light weight.	The sample is fine grained and uranium is throughout distributed in the sample as fission tracks are evenly distributed in the sample. Average uranium content is 19 ppm.	NA

KW-7	NA	Sandstone, yellow colored (limonitic), fine grained, with siltstone.	The sample is fine grained and uranium is throughout distributed in the sample as fission tracks are evenly distributed in the sample. Average uranium content is 15 ppm.	NA
KW-8	NA	Siltstone, calcified, fine grained. Sample seems to have some tuffacious material.	Fission tracks clusters were observed and are matching with selective ore grains in sample. Uranium content determined for two grains is given: i). 47 ppm & ii). 45 ppm	NA

Table 4. Results of uranium mineralization studies in samples collected from Sheikhullah Area, Bannu Basin

Sample No.	Radioactivity (B.G/Spot) cps	Sample Description	Fission Track Study	Autoradiographic Study
SU-1	100/140	Sample collected from zero point of geological crossection, semi compacted sandstone, light grey, medium grained.	Fission tracks clusters were observed with no obvious relationship on matching outline of these clusters with grain in sample. Uranium content determined for two grains is given: 1. 109 ppm 2. 81 ppm	NA
SU-1 (GM)	NA	NA	Negligible tracks were Negligible uranium content in the sample.	NA
SU-2	100/135	Loose sandstone, light grey, medium grained.	Fission tracks clusters were observed with no obvious relationship on matching outline of these clusters with grain in sample. Uranium content determined for two grains is given: 1. 109 ppm 2. 81 ppm	NA
SU-3	100/300	Light grey, calcified sandstone, medium grained, biotitic	Fission tracks are along the grain margins in the form of clusters indicating the presence of uranium in the matrix of the sample. Average uranium content is 95 ppm	NA
SU-4	100/300	Sandstone, fine grained having layers of mica. Part of the sample contain limonitic sandstone, loose, medium grained.	Fission tracks are in a continuous band in one part of the sample. This portion of sample obviously show solution activity and some grains are oxidized. Grains here in this part have preferred alignment relative to the rest of the sample. Average uranium content along the uraniferous band is 82 ppm	NA
SU-4 (G)	NA	NA	Negligible tracks were observed at conditions applied for fission. Negligible uranium content in the sample.	NA

SU-4/02840	NA	NA	Fission tracks are distributed throughout resulted from uranium possibly distributed by solution activity. Ore grains at places are oxidized. Clusters of fission tracks resulted from selective ore grains. Average uranium content is 133 ppm	NA
SU-5	100/300	Sandstone, calcified, light grey colored, medium to fine grained.	Fission tracks are distributed throughout resulted from uranium possibly distributed by solution activity. Average uranium content is 16 ppm	NA
SU-6	100/100	Loose sandstone, light grey colored, medium to fine grained	Negligible tracks were observed at conditions applied for fission. Negligible uranium content in the sample.	NA
SU-6 (2)	NA	NA	Negligible tracks were observed at conditions applied for fission. Negligible uranium content in the sample.	NA
SU-7	100/200	Sample collected from the upper part of middle Siwaliks (Dhok Pathan Formation), semi compacted sandstone, light grey colored, medium to fine grained	Fission tracks clusters were observed with no obvious relationship on matching outline of these clusters with grain in sample. Negligible uranium content in the sample.	NA

Table 5. Results of uranium mineralization studies in samples collected from Khajji Area, Salt Range

Study/Sample No.	Radioactivity (B.G/Spot) cps	Sample Description	Fission Track Study	Autoradiographic Study
2863 (KHAJJI-2)	NA	Mainly feldspar, quartz, opaque minerals and mica.	Clusters of fission tracks were observed obviously resulting from 10 grains: 1. 2969 ppm 2. 2696 ppm 3. 2162 ppm 4. 2093 ppm 5. 1992 ppm 6. 1872 ppm 7. 1734 ppm 8. 1639 ppm 9. 1343 ppm 10. 1128 ppm	Exposure time was 960 hours Alpha tracks were observed in the form of clusters at different places from region containing ore mineral grains