CURRENT URANIUM ACTIVITIES IN PAKISTAN

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Abstract

The rocks of Siwaliks group in Pakistan, extending from Kashmir in the east through Potwar Plateau, Bannu Basin and Sulaiman range up to the Arabian Sea in the west have been extensively explored for uranium. The Dhok Pathan Formation, which is younger member of the middle Siwaliks has been aeroradiometrically surveyed and extensively prospected on foot. A large number of anomalies were encountered in Kashmir, Potwar Plateau, Bannu Basin and Sulaiman range. While exploratory work in Sulaiman range and Bannu Basin yielded a few workable deposits, none of the anomalous areas yielded an ore grade concentration in Potwar Plateau. As conventional exploration activities in Potwar Plateau did not yield any ore grade concentration therefore a resource potential evaluation programme through geological modeling was started under the guidance of an IAEA expert. The volcanic material found in the middle Siwaliks is considered to be the main source of uranium and siliceous cement in the sandstones. These findings have considerably increased uranium potential in Siwaliks. The tectonic deformation during and after the deposition of Siwaliks is considered to be the main reason for mobilization of uranium, while permeability barriers and upward movement of oil products may provide trappings for the mobilized uranium. Through this survey south western part of Potwar Plateau being relatively less deformed is considered to provide conducive environments for concentration of uranium. Low grade uranium concentrations have also been discovered in carbonatites in northern part of Pakistan. Preliminary exploration in Sallai Patti carbonatite through drilling supplemented by trenching, pitting and aditing, subsurface continuation of surface concentrations has been confirmed. The ore contains about 200 ppm of uranium and 3 to 4% phosphate in addition to magnetite, rare metals and rare earths. It has been demonstrated on laboratory/pilot scale that the concentrations of uranium and phosphate can be upgraded up to 150 times and 10 times respectively through application of wet magnetic and wet gravity concentrations methods. Considerable potential of uranium exists in this carbonatite.

1. INTRODUCTION

The rocks of Siwalik group in Pakistan have been a target for uranium exploration since the discovery of first radioactive anomaly in these rocks in Dera Ghazi Khan district. These rocks of Miocene to lower Pleistocene age are exposed from Kashmir in the east through Potwar Plateau, Bannu Basin, Sulaiman Range and extend upto the Arabian Sea in the southwest (Fig. 1). The group basically comprises sand - shale interlayering with occasional development of conglomerate of channel lag and terrace deposits.

Siwaliks have been divided into lower, middle and upper Siwaliks on the basis of lithology. The lower Siwaliks are dominantly bright coloured (shades of red, orange) shales with minor sandstones followed by massive sandstone and alternating beds of shale and sandstone in the Middle Siwaliks. These are finally succeeded by coarser facies comprising grit, conglomerate, boulder beds and subordinate shales of upper Siwaliks. The sandstones in the Middle Siwaliks (subdivided into Nagri and Dhok Pathan Formations) are mainly sub-graywackes and lithic arenites. The fine grained facies of Nagri fall into clay/siltstone category whereas those of Dhok Pathan include mudstone, siltstone with rare clay.

The rock exposures of Dhok Pathan Formation, which hosted the first discovery have been aeroradiometrically surveyed and extensively prospected on foot. As a result, a large number of uranium anomalies were encountered in Dhok Pathan Formation in Kashmir, Potwar Plateau, Bannu Basin and Sulaiman Range. Further west, where the character of Siwaliks changes from continental to marginally marine and argillaceous material dominates, no radioactive anomaly was found. Subsequent to exploratory work a few workable deposits of uranium were outlined in Sulaiman Range and Bannu Basin. Potwar Plateau, has however so far not yielded any uranium ore body. Major part of the uranium outlined at various locations in Sulaiman Range (Fig. 2) has been mined out while the ore bodies outlined at Nangar Nai are being tested for mining through in situ leach mining method.

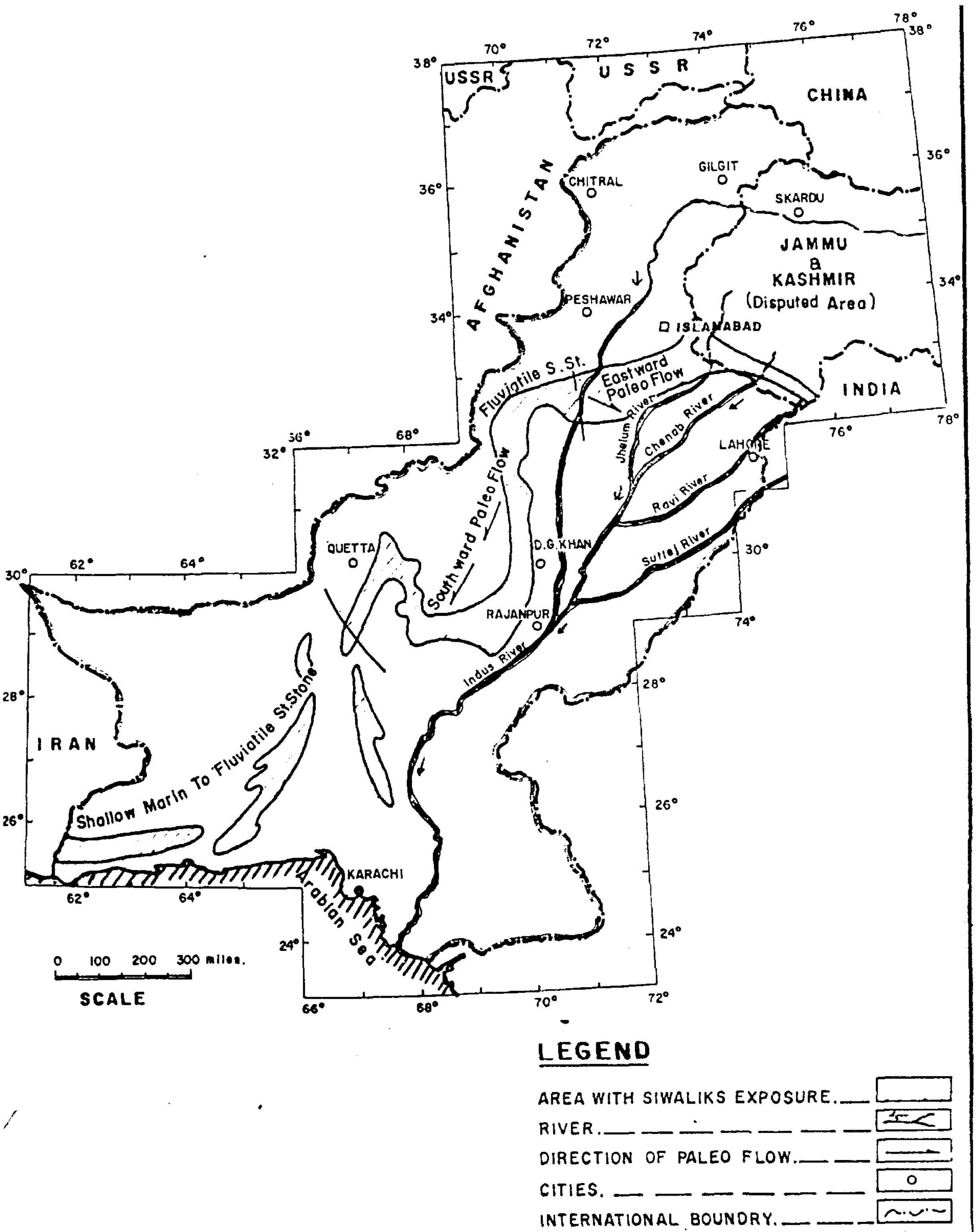

FIG. 1. Map of Pakistan showing Siwaliks exposures.

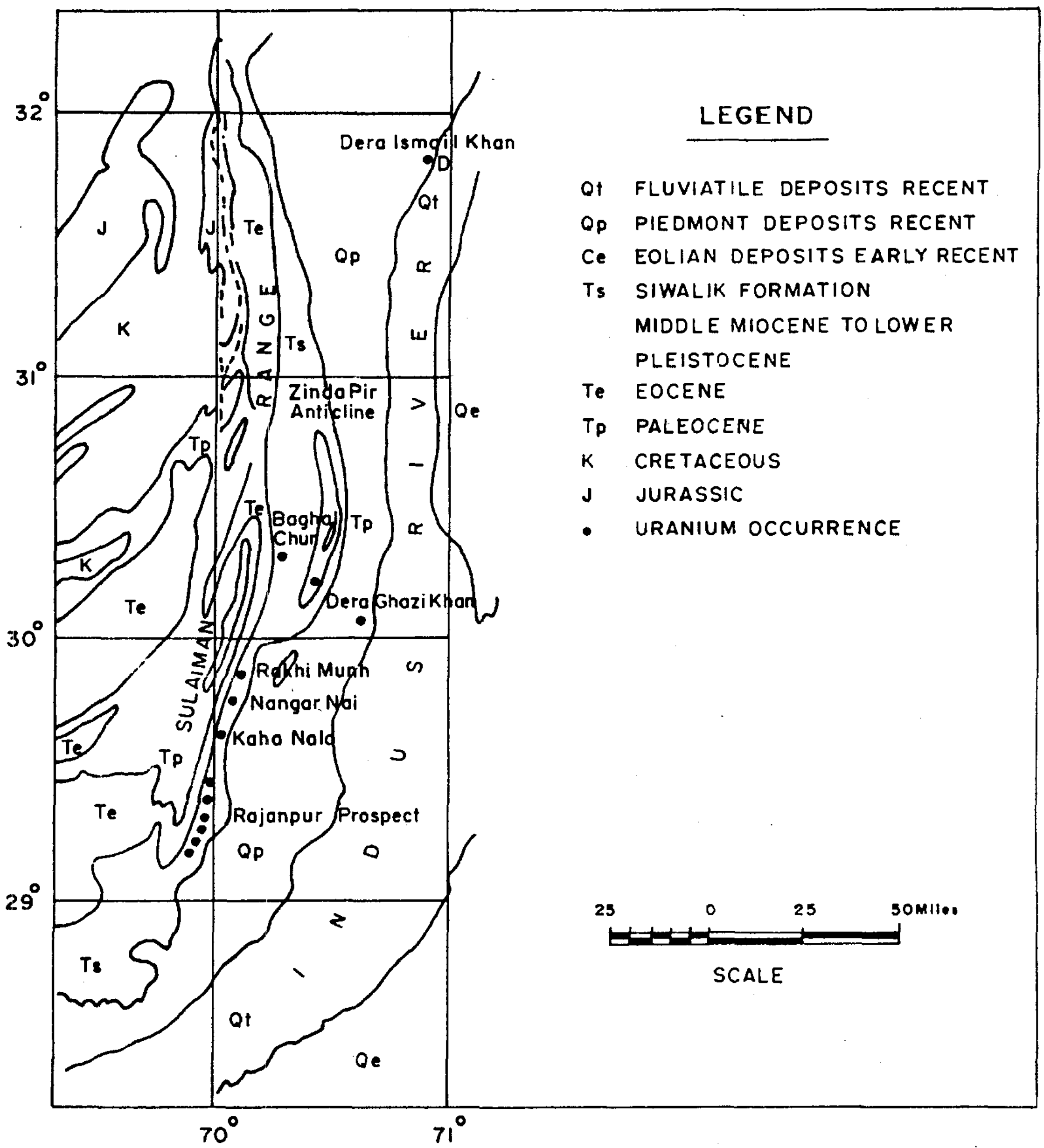

FIG. 2. Geological map Sulaiman range.

2. URANIUM IN BANNU BASIN

The tectonics of the area seems to have played the key role in the genesis of uranium ore bodies in Bannu Basin. The basin has experienced repeated upheavals, accompanied by successive lowering of water table. This has caused the leaching of uranium after each upheaval, which has been reprecipitated below the present water table. The confined geohydrological regime helped the preservation of uranium below the water table. This is evident in Figure 3 in which radioactive halo is shown above the present ore grade concentration.

The ore zones bear very low radioactive signature as compared with the contained chemical uranium. Thus there is a strong disequilibrium in favour of uranium, indicating a very young emplacement age.

The uranium ore bodies outlined in Bannu Basin are hosted by poorly consolidated sandstones. Their exploitation through conventional mining methods was considered impracticable and hazardous due to bad ground conditions and influx of large quantity of water. Alternatively, application of ISL technology was studied which was found to be feasible due to a host of strata characteristics such as high permeability, ore bodies being below water table etc; debarring negative factors such as dips, structural imperfections and for the most part absence of the bottom confining shale. Subsequently, ISL tests were conducted on a number of 5 spot patterns for a period of 4 years and basic ISL parameters were determined to form a basis for start of semi-commercial scale operations in mid 1995. R&D is continued alongside to fine tune the operations with a view to improve recovery and reduce production costs.

The ISL mining technique employs 5 and 7 spot well pattern. Ammonium bi-carbonate and hydrogen peroxide are used as lixiviant and oxidant respectively. These are injected at atmospheric pressure. Production of leach liquor is obtained using submersible pumps. System operates at low pH to forestall mobilization of calcium. The lateral excursion is controlled through maintaining injection and production in balance and is regularly checked through monitor boreholes.

3. EXPLORATION

Till few years back, the exploration in Siwaliks sandstones and other terrains was based on physical activities, comprising various radiometric surveys and follow up of the radioactive/uraniferous exposures through mapping, pitting, trenching, drifting and ultimately drilling to locate the subsurface continuations of the mineralization exposed at the surface. Within last 8 to 10 years the scope of exploration activities has been expanded and the use of non-radiometric geophysical techniques such as Magnetic, Electromagnetic and Resistivity have been introduced. Radon Surveys (SSNTD.ROAC etc.) are also used as a supplementary technique to detect the buried source of radioactive emanations. But again these methods have so far been applied in the areas already known to host uraniferous concentrations.

4. PLATFORM SURVEY OF POTWAR PLATEAU

Potwar Plateau area, in spite of conventional exploration activities at a number of sites with widespread surface radioactivity, yielded no uranium mineralization and most of the work at various sites remained inconclusive, due to difficulty in properly selecting and testing of prospective area in an active collision zone environment and shallow data handling.

In order to upgrade the technical skill of the local geoscientists and to overcome the deficiencies in exploration methodology, a resource potential evaluation programme through geological modeling generally referred to as Platform Survey was started under the guidance of an IAEA expert.

Potwar plateau was selected for the platform survey because it has excellent molasse outcrops, spreading over 15,000 sq. kilometers, which though hosted a large number of radioactive anomalies (Fig. 4), but did not yield any workable uranium concentration through conventional type of exploration.

Simultaneous with determining the potential of uranium in the area, the project was aimed to build up the expertise of local geoscientists in conclusive evaluation through successive cycles of data collection, synthesis, followed by interpretation and evaluation.

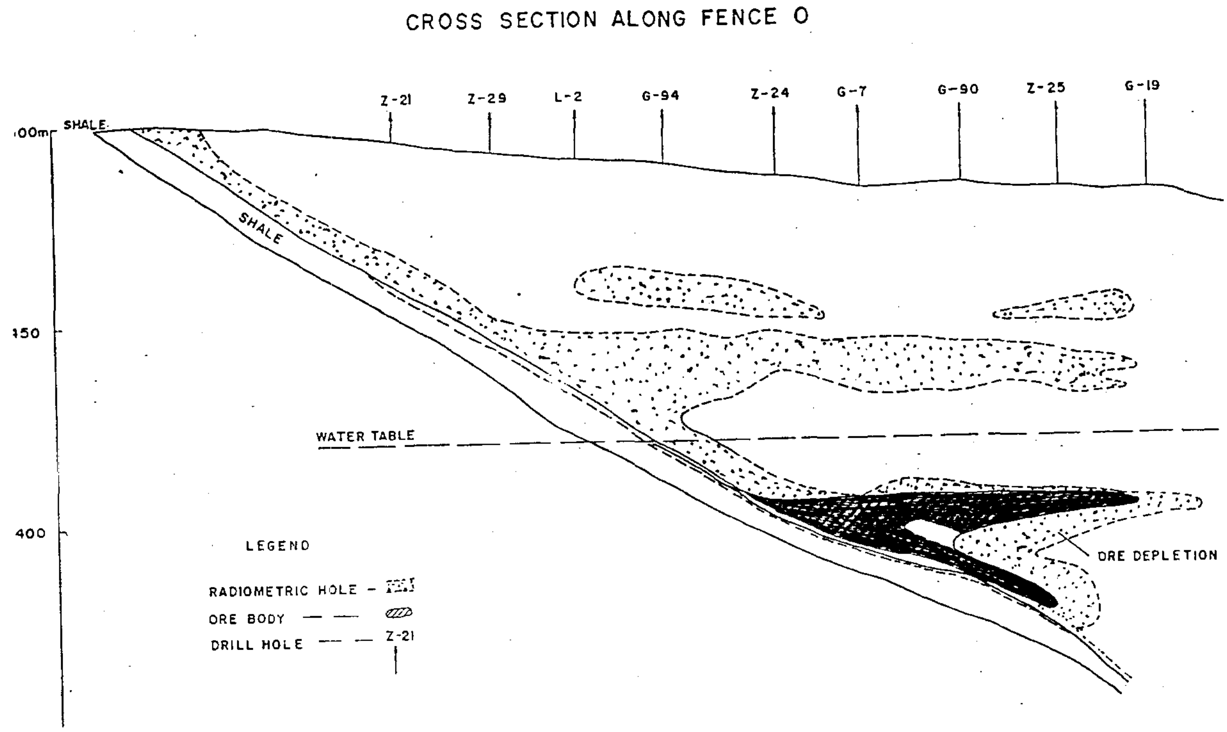

FIG. 3. Cross section along fence O.

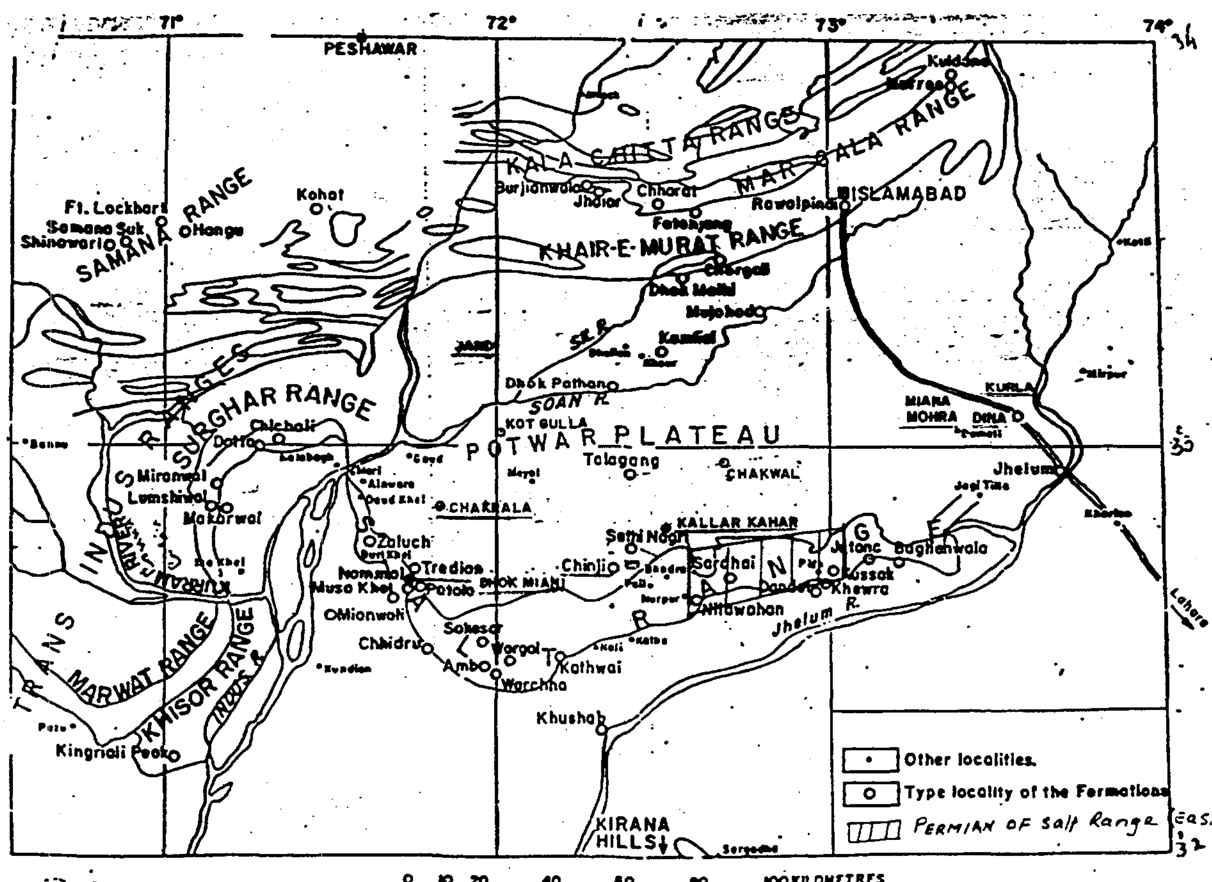

FIG. 4. Distribution of molasse outcrops in Potwar Plateau.

4.1. Methodology for platform survey

All the related information available in the literature was collected and was illustrated in the form of comprehensive maps and charts depicting sedimentology, paleo-environment, tectonics, radiometry and hydrogeochemistry of the area. For this purpose the Potwar Plateau was divided into four subregions roughly taking NS lineament falling along 72°45'E and NE-SW flowing Soan river as dividing line. While large scale sedimentry features and details of tectonics were identified through study of literature, imagery interpretation and additional field work, scanty data on petrochemistry was supplemented with systematic rock sampling. Systematic rock sampling along 14 sections covering the middle Siwaliks, distributed across Potwar Plateau was carried out to substantiate the data base. The location of these sections is marked on the map in Fig. 5. The samples collected were analysed for mineralogical composition, heavy minerals contents, U_3O_8, U^{+6} U^{+4}, eU, Fe^{+2} and Fe^{+3}, C_{org} and C_{inorg}. The nature of clay minerals was also determined with XRD.

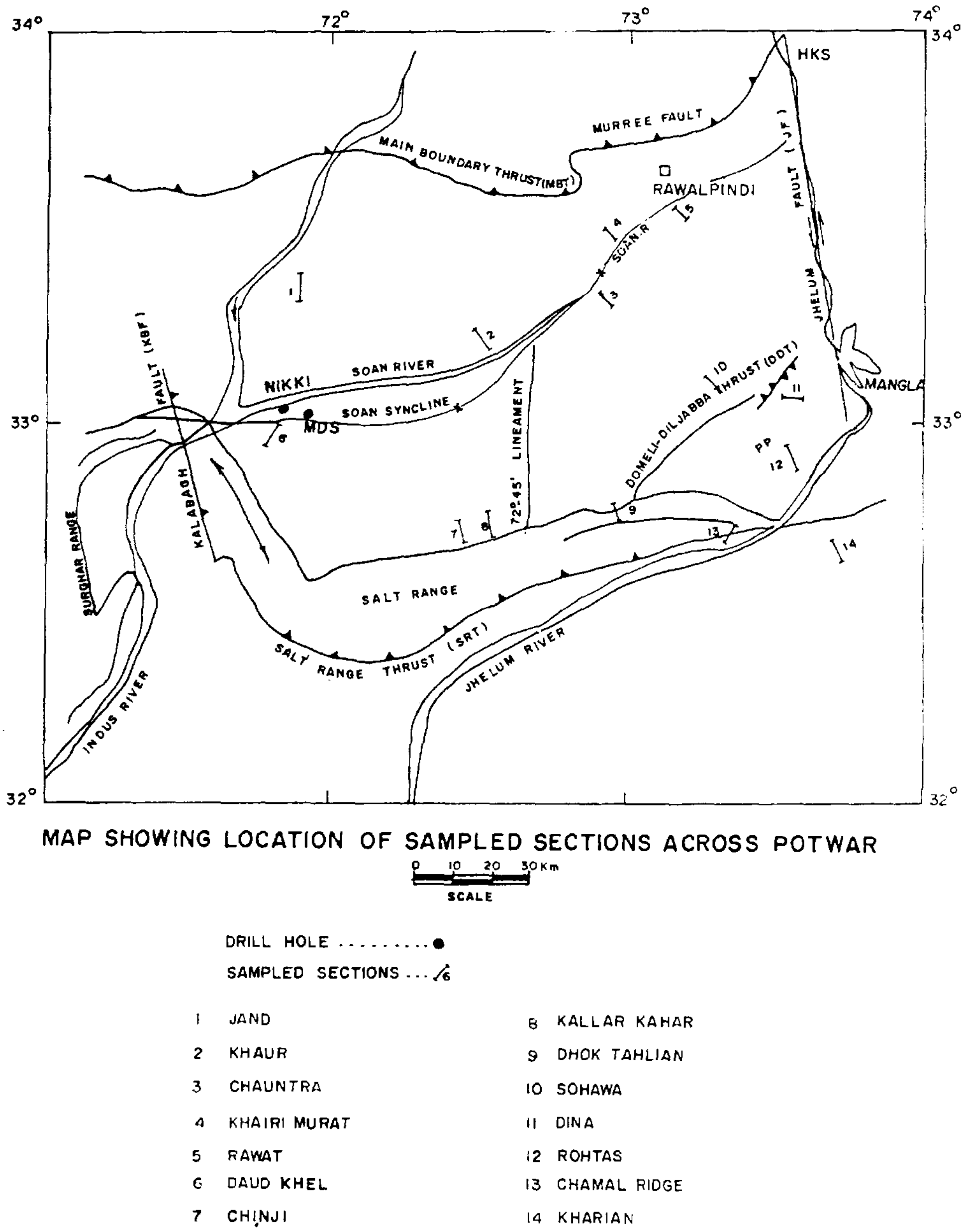

FIG. 5. Map showing location of sampled sections across Potwar.

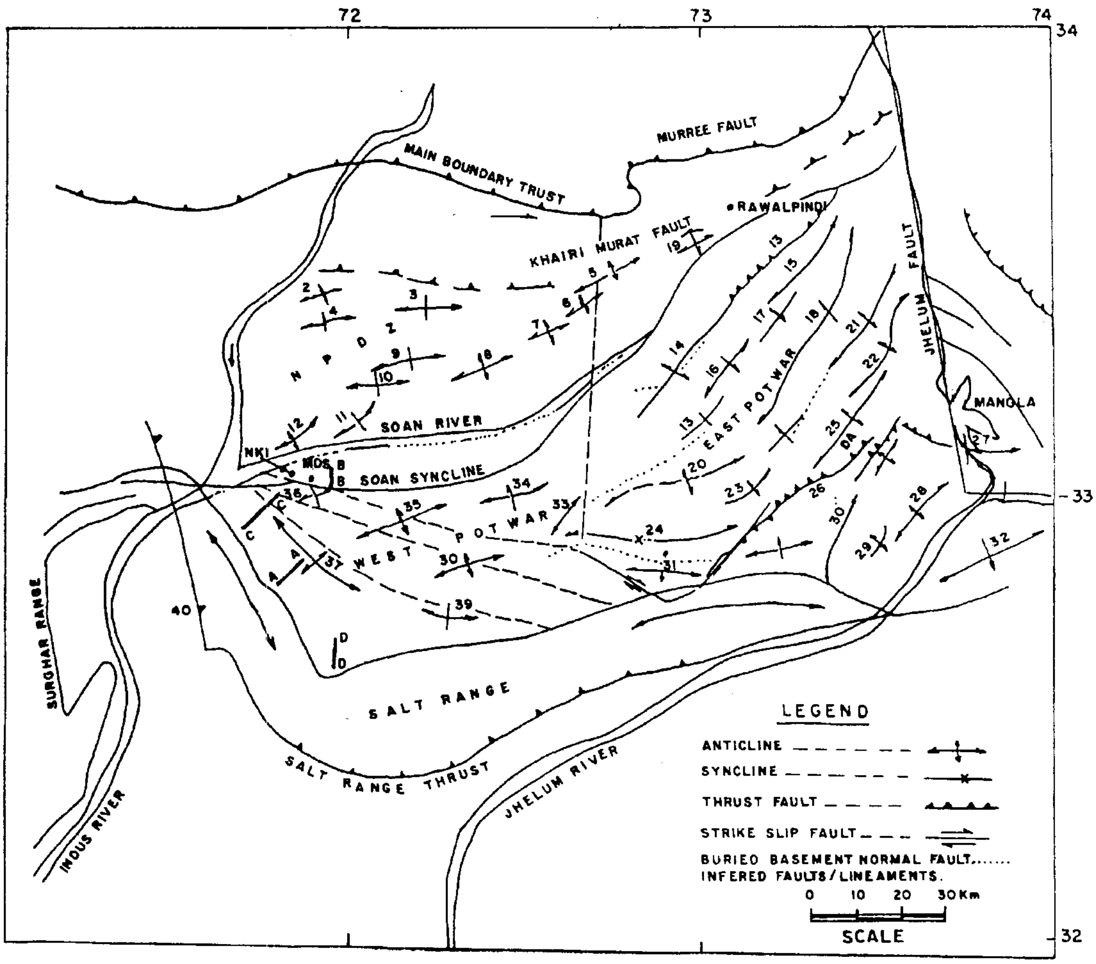

FIG. 6. Structural map of Potwar Plateau (modified after Khan & Pennock).

The petrochemical data was processed to identify variations in nature of provenance, depositional environments, diagenetic changes, evolution of uranium and their time space distribution.

4.2. Tectonics

Structurally the Potwar Plateau consists broadly of a number of faulted anticlines and synclines (Fig. 6) superimposed on the main Soan Syncline trending ENE to WSW roughly co-linear with the Soan River. The LANDSAT imagery interpretation identified the north-south trending long linear features which represent the surface expression of basement related faults. It is observed that the northern and eastern part of Potwar Plateau has attained a higher degree of deformation, as compared to southwestern part of Potwar Plateau. Both in the eastern and northern parts, tight folds generally breached at the anticilinal crest, are common, while in the southwestern part, there is much lesser number of linears/faults and folds are incipient and also much gentler.

4.3. Mineralization

The synthesis of collected data followed by its interpretation/evaluation has provided a better grasp of the overall present geological environment allowing to study the reported anomalies and their time-space distribution and their significance/weightage.

4.3.1. Source of uranium mineralization

Evidence of synsedimentary volcanism has been collected from Potwar Plateau. In the middle Siwaliks, syn-sedimentary volcanism has been a quite frequent feature both in sand and clay facies and its evidence is found in the form of pellets, irregular concretions, bentonitic pockets, ash layers of volcanogenic silt (angular grains in silty matrix) and a siliceous cement in the sandstone.

Pyroclastic layers upto several meters thick have been identified in two drill holes at several levels within the Nagri and Dhok Pathan Formation. These findings have considerably increased the initial uranium stock potential of these members of Siwaliks.

4.3.2. Uranium mobilization/concentration

Syn to post sedimentary tectonic deformation is considered as the main reason for uranium movement whereas the upward migration of oil products is regarded as the main reductant and permeability barriers are two main factors responsible for trapping of uranium mineralization.

The remote sensing imagery and fragmentary field data reveal that the sub region is criss crossed by dense net work of extensive, diverging and discontinuous lineaments marking out the major basement faults with degree of surface expression varying from negligible to flexuring or breaking. The brittle and tensional tectonic style now documented for South West Potwar is likely to provide more channel ways, remobilization medium as well as uranium trapping fronts.

The main parameters considered for evaluation of uranium distribution and potential of Middle Siwaliks of Potwar Plateau subregions are:

i) Uranium source
   Silica cement considered to be released by the devitrification of volcanic glass.
   K-feldspar content of the sediments
   Significant magmatic content
   Volcanic Rock Fragments.
ii) Uranium remobilization
   Alteration as indicated by Fe^{+2}/Fe^{+3} ratio
   Porosity/Permeability
   Uc/eU ratio as indicative of uranium leaching
   U in sandstone/U in shale ratio
iii) Trapping of uranium
   Redox Status inferred by Fe^{+2}/Fe^{+3} ratio
   Reducing Color of sandstone (grey, green etc)
   Uc/e U ratio
   U in S.St/U in shale ratio

The data collected along the sections and two boreholes is graphically represented in Fig. 7.

4.3.3. Results of platform survey

Comparative study of 12 parameters on source, mobilization and trapping selected from the petrochemical data confirms that the southwestern Potwar Plateau is relatively of more interest. Even in this area, three out of six formations are more likely to develop an environment conducive to complete the uranium cycle.

The platform survey thus sets an example in exploration strategy. Through this work an area of 15000 sq. km of Potwar Plateau was narrowed down to 2000 sq. km for detailed prospection in southwestern part. This has been further narrowed down to about 400 sq. km for detailed studies to locate subsurface zones of interest.

5. URANIUM ACTIVITIES IN NORTHERN AREAS

Uranium prospection and exploration activities have also been carried out in ignometamorphic rocks of northern areas of Pakistan which include granites, graphitic metapelites and carbonatites.

5.1. Geology

Northern Pakistan can be subdivided into three broad geological domains from south to north (Fig. 8). These are:

1. The Indo Pakistan Plate
2. Island Arc Assemblage
3. Eurasian Plate.

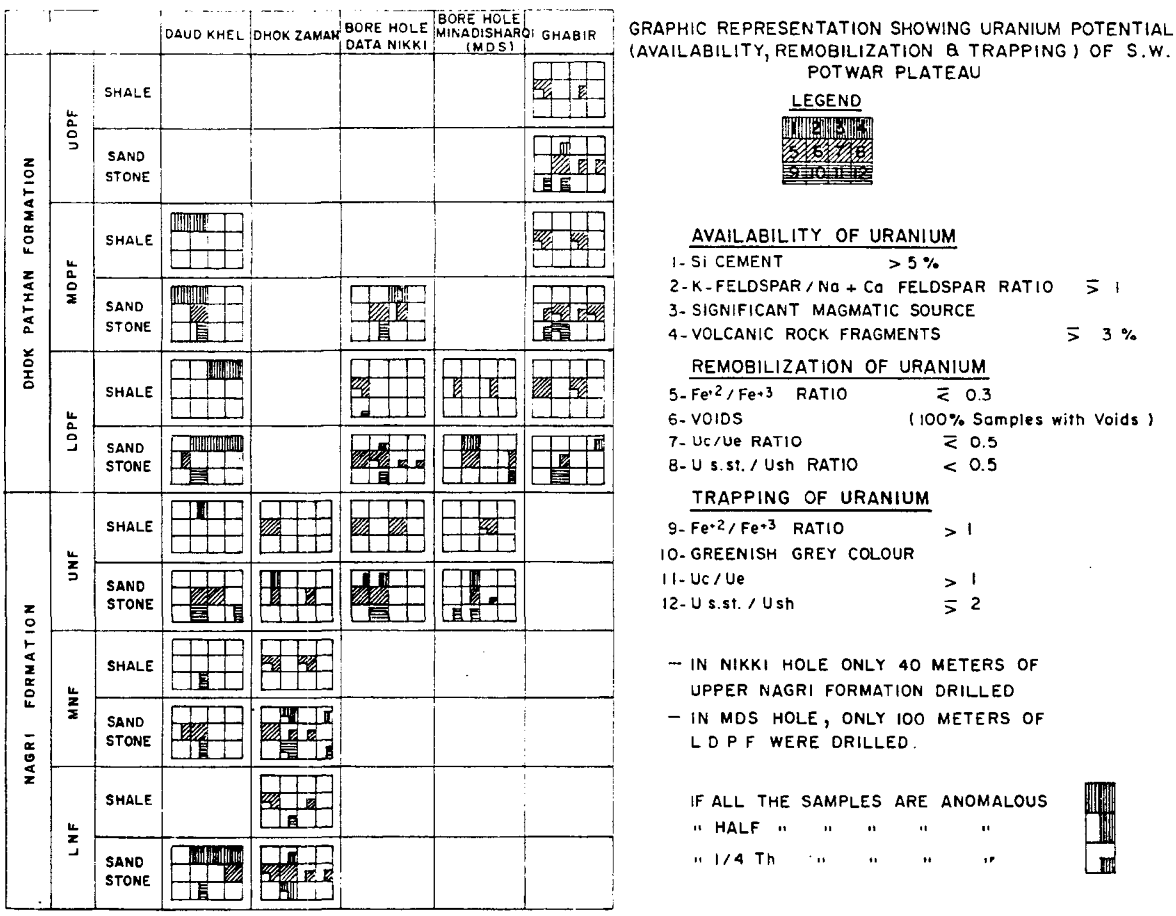

FIG. 7. Graphic representation showing uranium potential (availability, remobilization 8, trapping) of S.W. Potwar plateau.

A PRELIMINARY GEOLOGICAL MAP OF KOHISTAN AND THE ADJOINING AREAS, N. PAKISTAN

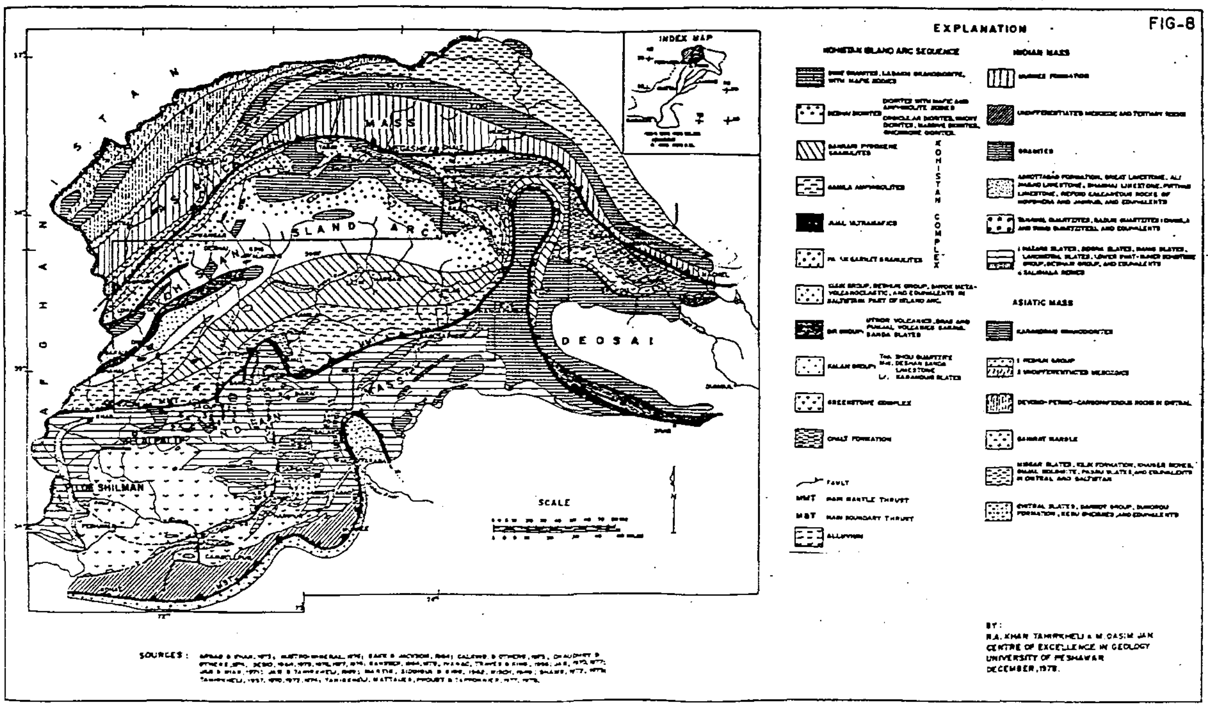

FIG. 8. A preliminary geological map of Kohistan and the adjoining areas, N. Pakistan.

These three units are separated by two major regional structural elements known as Main Mantle Thrust (MMT) and Main Karakarum Thrust (MKT).

The present tectonic picture of Northern Pakistan shows that the Indo Pakistan Plate to the south subduct along MMT under the Island Arc Assemblage which in turn subduct under the Eurasian Plate to the north along the other suture zone i.e. MKT.

The lithological assemblage belonging to Eurasian Plate include metasediments comprising pelitic and calcareous rocks and Karakorum Granodiorite Group consisting of granodiorite, granite pegmatite and aplites.

The lithological assemblage between the two suture zones comprises of 30-40 km. thick zone of metasediments, calc alkaline intrusive and volcanic and ultra mafic rocks. The sequence has been regarded as a complete cross section of a fossil island arc abducted on to the Indo Pak Plate.

The lithological assemblage belonging to Indo Pak Plate consist of metasedimentary, sedimentary, igneous and metaigneous rocks. The metasediments are composed of metapelites and psammites showing progressive increase in metamorphism towards MMT from chlorite to sillimanite schist and gneiss.

The igneous rocks mostly comprise granite and granite gneiss, along with alkaline rocks, which include alkaline granites, syenites, nepheline syenites and carbonatites.

Extensive prospection has been done scanning the terrains of metapelites as well as granites. Although a large number of radioactive anomalies have been discovered in these rocks but there has not been much success in locating any significant uranium concentrations.

5.2. Uranium in carbonatites

During routine prospection activities some of the carbonatites have been found to be radioactive. The main source of radioactivity is pyrochlore mineral. In mid seventies, a carbonatite body in Loe Shilman area was explored through drilling and large samples were obtained through trenching and aditing in the area for pilot scale processing. The anomalous zones within the carbonatite were however too scattered and of small dimensions, therefore exploratory work was discontinued.

Another carbonatite body occurs near Sallai Patti Village in Malakand Agency (Fig. 8) which in parts is radioactive. Preliminary analysis indicated the presence of uranium in the rock samples, which also contained rare metals, rare earths, phosphate and to a lesser degree magnetite, Geological investigations were therefore undertaken to determine the trend and size of the radioactive zones in the carbonatite body and to evaluate it's potential for exploration as a multimineral prospect.

5.2.1. Geological setting of Sallai Patti Carbonatite

The geological setting of Sallai Patti carbonatite is shown in Fig. 9. It is a sheet like body and has intruded along the fault running in N.W. direction between granite and schist. The dip of the carbonatite body is low to moderate in the western part and moderate to vertical in the eastern part. The carbonatite body varies from 2 to 30 m in width and on the surface extends for about 12 km. West ward extensions have not been checked so far.

There is another parallel and elongate body, partly covered under the alluvium towards east of main carbonatite body. This body is 2 to 7 m thick and is intruded within the schists. This body joins the main carbonatite body in the eastern and western parts of the area. This body of carbonatite has almost vertical dips.

5.2.2. Exploration in Salli Patti Carbonatite

Surface radiometric maps of two selected blocks of the carbonatite body were prepared to understand relationship of uranium mineralization to lithology and structure. The maps indicated that roughly 25% of the carbonatite body is radioactive and has potential for further subsurface exploration.

Subsurface exploration on these two blocks was subsequently undertaken and diamond core drilling was initiated in a bid to correlate surface radiometric data with the subsurface data. Fifty holes up to a depth of 90 meters were drilled. The data obtained from the drill holes established the subsurface continuation of radioactivity which showed a systematic pattern of distribution along well defined zones.

Uranium mineralization in the area has been found to have a definite structural control which can be traced both along the strike as well as dip of the carbonatite body.

A reconnaissance diamond core drilling programme of relatively deeper boreholes was thereafter carried out along the entire length of the carbonatite body to see the behaviour of uranium mineralization with depth. Six boreholes were as such drilled, depth of which ranged from 140 to 350 meters. All the boreholes were logged radiometerically. Core samples were analysed for determination of chemical uranium values. Results show that uranium mineralization continues with depth, thus considerably enhancing the workable volume of the carbonatite body.

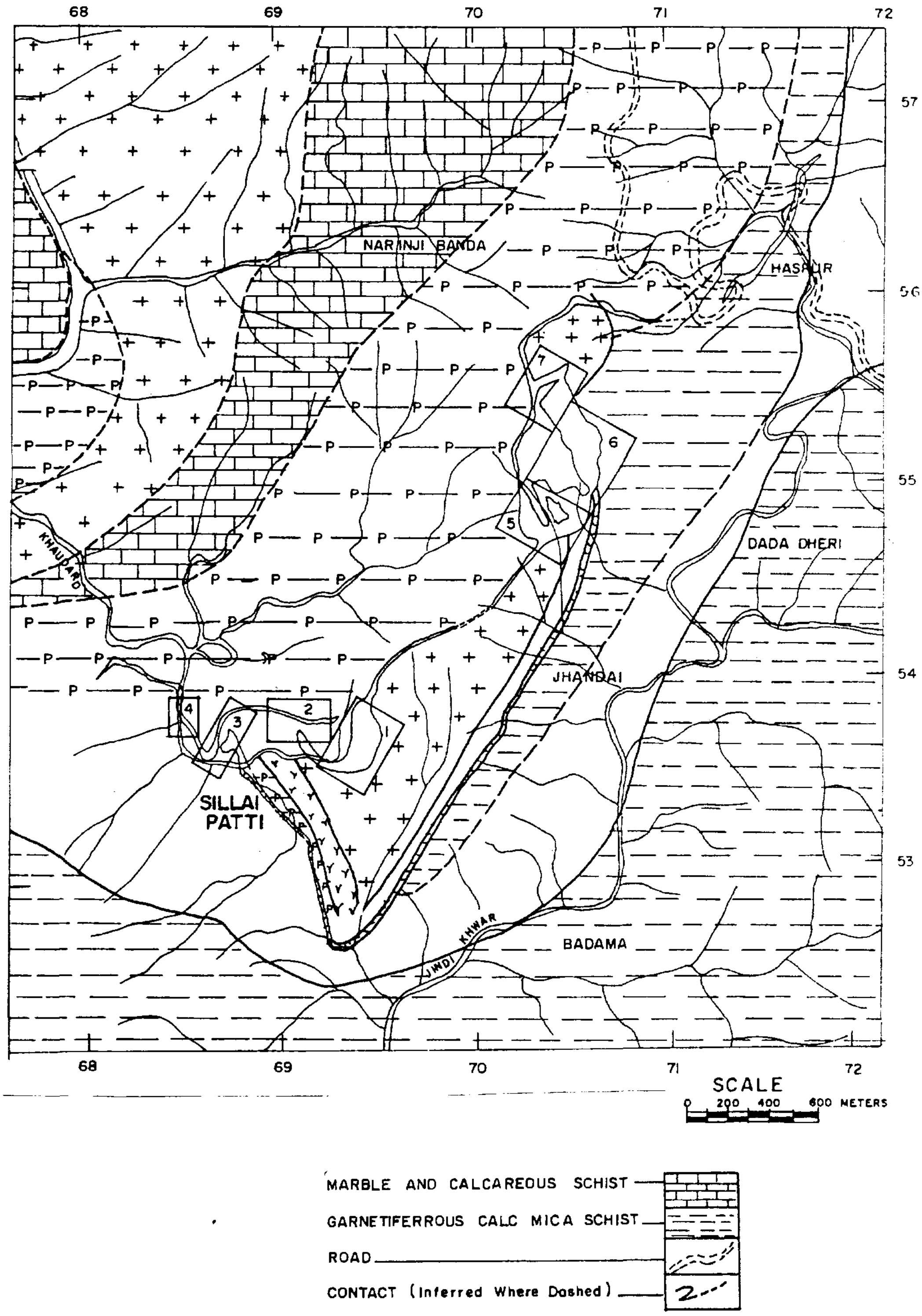

FIG. 9. Geological map of Sillai Patti area.

5.3. Uranium resource evaluation

The surface behaviour of the radioactive zone has been found to continue in the subsurface. Therefore in order to determine the uranium potential, the carbonatite body was divided into seven arbitrary blocks, and in each block channels were cut across the mineralized zones at a regular interval of about 50 meters. Samples collected from each channel and all the channel samples from one block were then mixed and further sampled to represent the whole block. Then all the samples from all the seven blocks were mixed to represent the entire carbonatite body. Results of these analyses are presented in Table I. The resource potential of this carbonatite body could be a thousand tons uranium at an average grade of 0.02% U.

5.4. Beneficiation studies

The chemical and mineralogical analyses of the Sallai Patti carbonatite is as follows:

PYROCHLORE	0.4%
Uranium	200 ppm
Rare metal	600-800 ppm
APPATITE	7.1%
Phosphate	3% P_2O_5
REE	0.2%
MAGNETITE	5.0%
Fe	3.0%
CALCITE	70%
$CaCO_3$	68%

As is evident from the analyses of ore that the uranium content in the carbonatite is rather low. Beneficiation studies for upgrading of uranium were therefore, conducted on laboratory scale as well as on pilot scale, which has indicated that the ore is amenable to upgrading by physical concentration methods like wet magnetic separation, wet gravity separation and froth floatation. The preliminary results indicate the recovery percentage of different fractions, and attainable upgrading ratio as below:

Mineral Concentration	Assay	UGR	Recovery
Pyrochlore	3% U	150.0	78.75%
Apatite	30% P_2O_5	10.0	70.00%
Magnetite	71% Fe	19.7	95.00%
Calcite	95% $CaCo_3$	1.4	83.00%

Thus the uranium content can be upgraded up to 150 times before subjecting it to chemical processing. Pyrochlore concentrate containing upto 3% U can be processed for recovery of uranium. Similarly using froth flotation techniques, phosphate (P_2O_5) can also be upgraded from 3% to 30% which is the acceptable grade for use in the manufacture of fertilizer.

TABLE I: CHEMICAL ANALYSES OF CHANNEL SAMPLE IN SALLAI PATTI CARBONATITE

Sr. No.	Sample No.	U_3O_8 (ppm)	P_2O_5%	Fe%
1.	SPB-1/1	113	3.35	2.54
2.	SPB-1/2A	146	4.06	4.63
3.	SPB-1/2B	21	3.88	2.65
4.	SPB-1/3	133	3.88	1.90
5.	SPB-1/4A	396	4.93	2.48
6.	SPB-1/4B	127	4.58	3.35
7.	SPB-1/5	125	3.35	2.93
8.	B-1	183	3.97	2.40
9.	SPB-2/1A	159	3.79	3.91
10.	SPB-2/1B	114	3.53	4.63
11.	SPB-2/2A	55	3.79	3.13
12.	SPB-2/2B	159	4.58	4.94
13.	SPB-2/3A	82	4.41	2.97
14.	SPB-2/3B	368	3.52	3.91
15.	SPB-2/3C	1633	4.23	4.47
16.	SPB-2/4A	204	5.29	4.47
17.	SPB-2/4B	204	3.88	4.84
18.	SPB-2/5A	84	2.99	4.56
19.	SPB-2/5B	95	3.52	4.34
20.	SPB-2/6A	408	3.47	3.13
21.	SPB-2/6B	245	3.35	5.19
22.	SPB-2/7	52	2.73	1.89
23.	SPB-2/8	91	2.99	1.91
24.	SPB-2/9	163	2.64	2.14
25.	B-2	327	4.06	4.97
26.	SPB-3/1	585	8.53	12.75
27.	SPB-3/2A	340	3.62	11.47
28.	SPB-3/2B	281	3.11	10.25
29.	SPB-3/3A	64	4.38	10.56
30.	SPB-3/3B	359	4.38	5.69
31.	B-3	281	4.47	11.63
32.	SPB-4/1A	604	3.79	4.56
33.	SPB-4/1B	91	1.89	4.50
34.	SPB-4/2A	359	3.79	3.83
35.	SPB-4/2B	264	4.29	5.50
36.	SPB-4/3A	91	4.80	6.31
37.	SPB-4/3B	32	4.60	3.45
38.	SPB-4/4A	48	2.61	4.85
39.	SPB-4/4B	59	4.52	19.31
40.	SPB-5/1	427	3.73	4.13
41.	SPB-5/2	233	3.41	2.93
42.	SPB-5/3A	194	2.76	2.80
43.	SPB-5/3B	119	3.16	3.85
44.	SPB-5/4	60	0.73	10.05
45.	B-5	155	2.59	3.88
46.	SPB-6/1A	272	3.97	3.53
47.	SPB-6/1B	233	4.54	2.13
48.	SPB-6/1C	143	0.73	5.31
49.	SPB-6/2	194	0.92	5.28
50.	SPB-6/3	893	10.13	3.56
51.	SPB-6/4	505	4.06	2.51
52.	B-6	388	4.05	2.58
53.	SPB-7/1	544	5.07	9.98
54.	SPB-X	271	3.32	3.88

6. DISCUSSION

Pakistan has undertaken conventional exploration in sedimentary and ignometamorphic rocks. Initially, workable concentrations of uranium were discovered, which were mined-out to meet the internal requirement for power generation. Realizing the shortcomings of the conventional exploration techniques, we have undertaken re-evaluation of all the geological formations considered to be favourable for occurrence of uranium, through platform surveys in order to establish the availability of source of uranium, its mobilization and location of trappings.

This approach initiated under the guidance of IAEA expert has proved very useful. It has helped in upgrading the technical capabilities of local geoscientists to undertake formation evaluation studies in other area of the country with more confidence. Previously in spite of several known uranium anomalies in the Potwar Plateau, no significant break through was achieved. The platform survey of the area has indicated that South Western Potwar is relatively more favourable for uranium resource. Semi detailed investigations in the south west Potwar has yielded some significant surfacial information to supplement the findings of Platform survey. Moreover, the economic significance of the Nagri Formation has also been established for the first time in addition to the previously known Dhok Pathan Formation. Nagri Formation will now be checked all across the country for its uranium potential.

Besides Siwaliks, there are other favourable formations present in Pakistan, amongst which metapelites exposed in Kashmir and northern areas are important. Work has already been started to understand the significance of the widely spread radioactive anomalies with chemical uranium at a number of places. Thus Pakistan has a very large volume of rocks which could host uranium deposits, but their discovery is difficult due to constant uplifting which activate the destructive processes of leaching of the precipitated uranium concentrations.

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