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Petrotectonic Framework of the Siwalik Group of Shinghar Range with Special Reference to its Petrography

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ABSTRACT: *Detailed petrological/petrotectonic account from Thatti Nasrati Shava-Shanawah area (Shinghar Range) of the Siwalik Group with reference to its petrotectonic framework has yet been published. It was therefore, important to carry out through petrological/petrotectonic studies in order to understand the nature, origin and condition of deposition of Siwaliks in this area.*

In the past, it was generally considered that the Siwaliks were deposited by the mighty Siwalik River (ancestral Indus). But subsequent studies have indicated that Siwaliks show great lithological as well as petrographic diversity. Siwaliks of the different areas have been derived from different source of regions. Therefore, it was important to trace the sources of Siwalik sediments in this region and to relate them to an evolving petrotectonic framework.

Correlation of Siwaliks on the basis of gross lithological variation (sandstone/ shale ratio) has not proved very satisfactory. Similarly faunal correlation is not always possible, because the distribution of the fossils is not uniform. So it was planned to correlate the Siwaliks of the area on the basis of petrographic studies.

Petrotectonic studies require a thorough understanding of the tectono-stratigraphic evolution of the hinterland as well as the nature of detritus shed by them both in time and space.

In order to understnad the dynamics of the tectono-stratigraphic evolution of the source areas and the changing pattern of composition of the sediments, an integrated scenario have been presented.

INTRODUCTION

The petrographic composition of the sediments, especially the sandstone and conglomerate horizons strongly reflects the nature of the source rocks. Of particular importance, are the lithic clasts in the sandstone as well as in the rudaceous deposits. These clasts directly represent the source area lithologies. However, the relative proportions of the lithic clasts do not represent the quantitative abundances of the parent rocks in the source area. The relative abundances of the clasts depend upon the abundance of the parent types in the source area as well as their ability to survive during transportation. Substantial quantities of soft rocks are not represented in the sandstone and rudaceous rocks, since they are pulverized during transportation. The survival of the rocks susceptible to chemical weathering also depends on the prevailing climatic conditions and relief.

Heavy mineral suites are also useful in interpreting the source area lithologies.

The composition of shales and siltstones as well as the types of clay mineral in them throw light on the source area lithologies.

In the following, petrography of the rocks in the study area will be discussed in detail, leading to their provenance. The petrographic and chemical data will be plotted to haracterize the gross tectonic set-up of the source region.

Petrographic studies of the area comprised thin section studies of sandstones, heavy mineral analysis, studies on palaeochennel clasts and clay mineralogy.

Samples were collected along three geological cross-sections as shown in Fig. 1. The location of these three sections along which samples were collected are as follows:

1. Starting point of NGR of Garung Section 639255 toposheet No. 38-D/4. End point NGR of Garang Section 710186, toposheet No. 38-P/1.

2. Starting point NGR of Zhira-section 584213, toposheet No. 38-P/1. End point NGR or Zhira-section 607120, toposheet No. 38-P/1.

3. Starting point NGR of Shanawah-section 495198, toposheet No. 38-P/1. End point NGR of Shanawah-section 508121, toposheet No. 38-P/1.

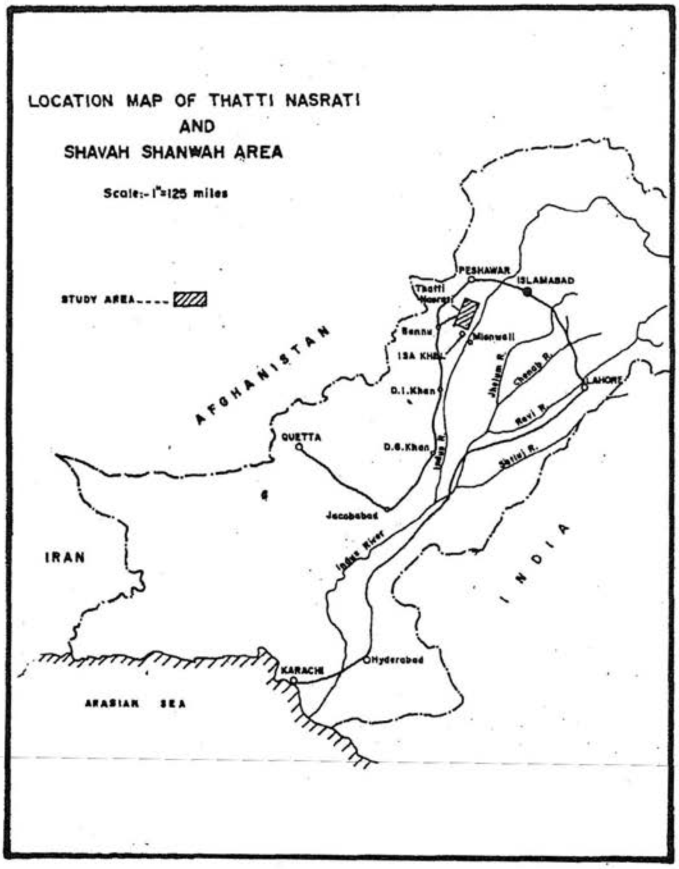

Fig. 1. Location map of Thatti Nasrati and Shavah Shanwah area.

TABLE 1. HEAVY MINERAL PERCENTAGE ANALYSIS

S. #	Sample No.	%age of Horn-blende	%age of Epidote	%age of Garnet	%age of Barite	%age of Apatite	%age of Biotite	%age of limenite	%age of Kyanite	%age of Tourm-aline	%age of Silimanite	%age of Hematite	%age of Zircon	%age of Spinal	Remark
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1	SHN-2	25	>	3	5	4	51								
2	SHN-5	58	13	10	4	9	3		2	1					
3	SHN-6	48	12	25	3	8	0	2	1						
4	SHN-9	47	17	23	2	9	1	0	1						
5	SHN-65	50	19	7	11	9	3		2						
6	SHN-82	49	23	6	6	0	11	1	0	1		0			
7	SHN-96	33	31	10	16	1	1			5		3			
8	SHN-104	54	17	13	4		8			3	2				
9	SHN-109	48	25	8	13		2			4					
10	SHN-120	64	7	11	6		1		6	6					
	CHINJI														
11	CD-3	39	31	24					2			4			
12	CD-7	56	25	16						1		2			
13	CD-13	43	11	37					2	1		7			
14	CD-19	15	2	77				4		1		1			
15	CD-25	23	33	30	3					9		3			
16	CD-35	22	15	47	2			2		6		6			
17	CD-70	66	19	3	9			1	2			1			
	NAGRI														
18	CD-100	50	23	15	7				1	4		1	1		
	DHOK PATHAN														
19	CD-109	17	50	15	8				2	2		4	1		
20	CD-134	64	11	14	2		0	0	1			0	8	0	
21	CD-150	34	27	16	13		2	4	3				1		
22	CD-162	43	26	7	10			4	10				1		

These studies have helped greatly in understanding the sedimentation, diagenetic events and effects, uplift of the Surghar and Shinghar Ranges, history of evolution of the basin, provenance and localization of uranium mineralization in the top portion of the Dhok Pathan Formation.

For above mentioned studies, 149 representative sandstone samples were studied. The samples collected represent all marked lithological variations along the section. Thirty seven samples of shale horizon were also taken. One representative sample from each of the shale horizons within the Dhok Pathan Formation was collected to see if any relation between clay mineralogy and uranium mineralization exist.

The Siwalik Group is very well exposed throughout the study area, affording exact section measurements, collection of systematic samples, observation and measurement of sedimentary and tectonic structures and systematic field study of uranium mineralization.

For the petrographic studies, 149 sandstone thin sections have been studied. A total of 117 sandstone samples along Zhira section have been studied out of which 38 are from the Chinji Formation, 31 from the Nagri Formation, 45 from the Dhok Pathan Formation and one from the Soan Formation. A total of ten pebble samples were taken from the Soan Formation, five from CD-175 and another five from CD-176 site (Fig. 1) for study. Along the Shanawah section, fifteen samples were selected for study. Four samples from the Chinji Formation, four samples from the Nagri Formation, four samples from the Dhok Pathan Formation and three samples from the Soan Formation. Ten samples were selected from the Garang section. Four samples from the Chinji Formation, two from the Nagri Formation and four samples from the Dhok Pathan Formation. In addition to these samples, nine samples from the mineralized horizons, which fall mainly in the upper part of the Dhok Pathan Formation, were also selected for uranium mineralization studies.

PREVIOUS WORK

Danilchik and Shah (1976) prepared a fairly detailed report on the stratigraphy and coal resources of the Makarwal area of Trans-Indus Mountains in Mianwali District. Chaudhry and Ashraf (1981) have presented an account of the petrology of Middle Siwalik rocks of Kotli area Azad Kashmir. They concluded that these rocks were derived from the Pir Panjal Range of Kashmir. Wells (1983-84) discussed the depositional environments of the Early Eocence rocks particularly the Kuldana Formation. Abid et al., (1983) gave a preliminary account of the petrography and provenance of the Dhok Pathan Formation from a small part of the Surghar Range along the southern fringes of the Kohat Plateau. Khan (1983) has studied magneto stratigraphy of the Kohat Plateau. McDoughal (1985, 1987, 1989) described associated structures with the Kalabagh lateral ramp in relation to the changes in course of the Paleo Indus River during the last one million year. Khan et al., (1987) have studied the magnetic polarity stratigraphy and tectonics of the Siwalik Group. They have suggested that the Siwalik Group is time trans gressive and that the Siwaliks of Trans-Indus are younger than the Siwalik of Potwar Plateau. Kassi (1987) has presented preliminary sedimentology of the Siwalik Group of Baluchistan area and suggested a source area which lies to the west of Kach and Zarghun region. Ahmad (1989) has recorded sedimentology and structure of the Southern Kohat Trans-Indus Ranges. Wang et al., (1989, 1995), Baig (1990) and Moghal (1992) have studied the sandstone type uranium deposits in the Siwaliks of Pakistan.

PETROGRAPHIC DESCRIPTION OF FORMATIONS

Chinji Formation

The basal portion of the Chinji Formation in the study area is comprised of quartz, detrital carbonate and rock fragments as framework components. Sandstone varies from calcarenite to argillaceous sandstone and litharenite. Detrital carbonate grains range upto 25% are present. They have fractures, some of which are impregnated with the calcite cement. Quartz grains are mainly monocrystalline. Quartz varies from 23% to 50%.

Feldspar percentage varies from 5 to 22%. Rock fragments range from 42 to 72%. Glauconite ranges upto 12%. Lithics concentration vary widely throughout the formation. The metamorphic lithics vary from 29 to 83% whereas sedimentary lithics are from 11 to 68%. The volcanic lithics vary from 3 to 20%.

Heavy mineral studies show that dark green hornblende 50%, epidote 23% and garnet 15% as the predominant constituents whereas barite, ilmenite, kyanite, tourmaline and haematite are the minor constituents table 1, Fig. 2. Within the Chinji Formation hornblende varies from 15 to 66%, Epidote from 2 to 33%, while the concentration of garnet varies from 16 to 77%. Three palaeochannel clasts samples collected from the base, middle and top portion of the Chinji Formation show the following results Fig. 3. Palaeochannel clasts sample from the base of the formation is composed dominantly of the Sakesar Limestone 71%, followed by glauconitic sandstone of the Lumshiwal Formation 20% and chert 5%. The palaeochannel sample collected from the middle portion of the Chinji Formation contains 36% limestone and carbonate concretion followed by quartzite 28% and volcanics 27%. The palaeochannel sample collected from the top portion of the formation has shown some change in the clast percentages. The volcanics increase to 39%, followed by quartzite 33% and glauconite and red sandstone 8%.

Nagri Formation

Sandstone composition varies from litharenite to lithic sub arkose in this formation. Quartz grains are angular to subrounded. Framework constituents are quartz, feldspar and rock fragments. Quartz varies from 18 to 45%, feldspars ranges from 13 to 39%, whereas rock fragments are from 29 to 68%. Considerable quantity of lithics are present. The amount of the metamorphic lithics varies from 23 to 84%, sedimentary lithics range from 8 to 70%, while the volcanic lithics vary from 4 to 19%. Dark green hornblende, epidote and garnet are the main heavy minerals. The minor constituents are barite, kyanite, tourmaline, haematite and zircon.

Palaeochannel clast samples collected from the base of the Nagri Formation contain 41% volcanics, followed by quartzite 25% and granitoids 9%. The sample taken from the middle part of the formation contains 33% volcanics, followed by quartzites 14% and granite clasts 11%. While the sample taken from the top portion of the formation contains 27% volcanics, followed by quartzite 25% and granitoid 10%.

Dhok Pathan Formation

Grain size varies from fine to medium grained within this formation. However within the palaeochannels the grain size is coarse. Grains are generally subangular to subrounded. Both monocrystalline and polycrystalline quartz are present. Some quartz grains show slightly turbid surface, while some other show undulatory extinction due to strain. At few places authigenic overgrowth of silica over quartz have been seen. Some quartz grains contain inclusions of zircon, rutile, epidote and muscovite. In a few grains gaseous inclusions, possibily of volcanic origin have been observed. Shattering of quartz grains is a common feature. Some of the fractures are filled with calcite during diagenesis. Feldspars grains are also angular to subangular. Sericitization of feldspars grains is common within this formation. Inclusions of rutile and zircon have been observed in some grains.

In this formation the composition of the sandstone varies from lithic sub-arkose to litharenite and again to lithic sub-arkose. Framework minerals are quartz, feldspars and rock fragments. Concentration of quartz varies from 31% to 54%, of feldspars from 12% to 29%, while of rock fragments from 23% to 53%. Considerable variation have been observed in the concentration of the lithics present in this formation. Metamorphic lithics varies from 52 to 77%, sedimentary lithics varies from 5 to 40%, while the volcanic lithics varies from 7 to 47%. Heavy mineral analysis have shown that the major heavy minerals within this formation are dark green hornblende, epidote and garnet. The minor heavy minerals are barite, biotite, ilmenite, kyanite, tourmaline, haematite, zircon and spinel Table 1. The dark green hornblende varies from 17 to 64%, epidote varies from <1 to 50%, while garnet varies from 7 to 16%.

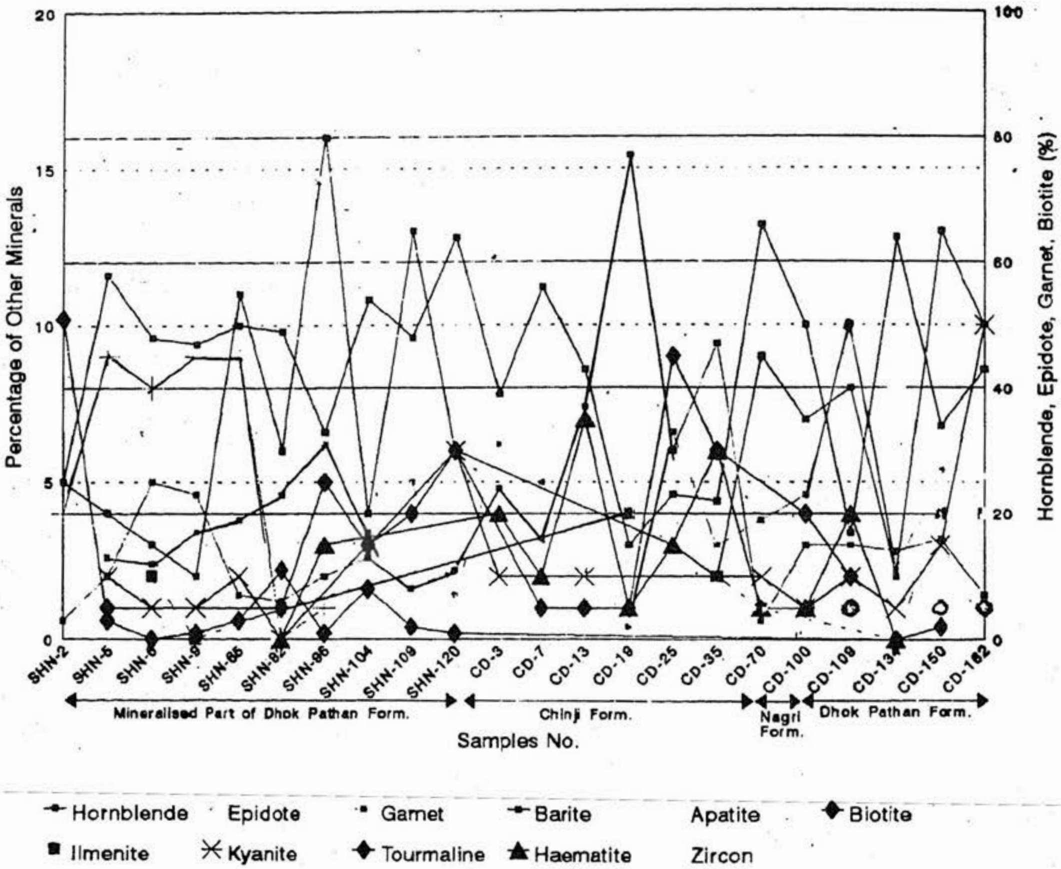

Fig. 2. Graphical presentation of heavy minerals percentages.

TABLE 1a. DIFFERENT PEBBLES FROM PALAEO CHANNEL (MINERALIZED) SHOWING CHEMICAL URANIUM AND THORIUM

S.#	Sample No.		Pebble Lithology	Chem. U308 (ppm)	Radiometric Essay U308	e Thorioum**
1	DPF-1		Concretions (B.V.A.C.)	11	U DTRS Absent	72 + 8 ppm Th DTRS Absent
2	DPF-2		Tonalite	1.5	U DTRS Absent	Th DTRS Absent
3	DPF-3		Amphibolite	2.5	U DTRS Absent(*)	Th DTRS Absent
4	DPF-4		S-Type granitoid	1.5	U DTRS Absent(*)	Th DTRS Absent
5	DPF-5		I-Type granitoid	1.5	U DTRS Absent(*)	21 + 5 ppm
6	DPF-6		Aggiomerate	3.5	U DTRS Absent(*)	45 + 7 ppm
7	DPF-7	Basaitic andesite	Porphyntic volcanic black	4	Slight indication of U DTRS	73 + 8 ppm
8	DPF-8		Vein quartz	1	U DTRS Absent	Th DTRS Absent
9	DPF-9	Andesite	Choclate volcanics	5	Slight indication of U DTRS	20 + 5 ppm
10	DPF-10		Off white chert	1	U DTRS Absent	Th DTRS Absent
11	DPF-11		Red Chert	5.5	U DTRS Absent	30 + 5 ppm
12	DPF-12		Off white quartzite	3	U DTRS Absent	27 + 5 ppm
13	DPF-13		Grey quartizite	1	U DTRS Absent	22 + 5 ppm
14	DPF-14	Andesite	Green volcanics	5.5	Slight indication of U DTRS	36 + 6 ppm
15	DPF-15		Green chert	7.5	Slight indication of U DTRS	81 + 9 ppm
16	DPF-16	Rhyolite	Off white volcanics	3	Slight indication of U DTRS	Th DTRS Absent
17	DPF-17		Slate	4	U DTRS Absent(*)	20 + 4 ppm
18	DPF-18		White Chert	1	U DTRS Absent(*)	20 + 4 ppm

Note: (*) = Slight indication of young uranium and precipitating environments/conditions
(*) = Additional information B.V.A.C. = Bentoritized volcanic ash clasts

TABLE 2. MODEL ANALYSIS DATA OF SAMPLED COLLECTED FROM THE DIAMECTITE BED (DM) PERCENTAGE OF PEBBLES

S. #	Name of Pebbles	Nos.	%age
1	Green Quartzite	203	15
2	Offwhite Quartzite	67	5
3	Green Volcanics (Andesite)	243	18
4	Red Volcanics (Andesite)	9	1
5	Light Colored Volcanics (Rhyolite)	27	2
6	Black Volcanics (Basaltic Andesite)	66	5
7	S-Type Granitoid	35	2
8	I-Type Granitoid	27	2
9	Green Chert	10	1
10	Black Chert	16	1
11	Red Silty Sandstone	9	1
12	Glauconitic Sandstone	6	1
13	Sandstone Datta	7	1
14	Red Chert	42	3
15	Limestone Black	121	9
16	Limestone Offwhite	3	0
17	Samanasuk Limestone	10	1
18	Sakesar Limestone	5	0
19	Micrite	5	0
20	Grayweacke	163	12
21	Slate	197	15
22	Vein Quartz	40	3
23	Diorite/Tonalite	7	1
24	Amphibolite	3	0
25	Serpentine	18	1
26	Total	1339	

Three palaeochannel clast samples were collected from the basal, middle and upper parts of the Dhok Pathan Formation. Limestone is 27%, followed by quartzite 23% and volcanics 21% in the basal part. The palaeochannel sample collected from the middle part of the formation shows that the maximum concentration is of limestones clasts and carbonate concretions 35% followed by quartzites 30% and volcanics 11%. The palaeochannel sample collected from the top of the formation shows a different trend. Quartzite is 22.%, followed by volcanics 12% and graywacke 9%. This palaeochannel sample is from the mineralized horizon. It also contains 6% Bentonitic Volcanic Ash Concretions (B.V.A.Cs). The B.V.A.Cs. still contain (chemically) 11 PPM of U_3O_8. Fig. 4 (Table1a). Another mineralized palaeochannel was selected near the Shanawah area for clast studies. This palaeochannel varies in its clast proportion to some extent from the channel described above. In this channel the quartzite 23% followed by volcanics constitute 17%, and B.V.A.Cs. 9%. These B.V.A.Cs are uraniferous and show upto 11 PPM U_3O_8.

A sample of clasts from the diamectite bed present at the base of the Dhok Pathan Formation was collected. Volcanics are the single largest group and constitute 26%, followed by quartzite 20% and slate 15%. Diamectite bed contain 25 different varieties of pebbles as shown in the Table 2.

Soan Formation
The Soan Formation is not fully preserved in the study area. Weathering and erosion have destroyed it in many places. Its relatively good exposure is present only along the Zhira (CD) section. The samples collected show that sandstone is mainly a lithic arenite. Framework minerals, are quartz, feldspars and rock fragments. Quartz is 35%, feldspar upto 15, and rock fragments are about 50%. The metamorphic lithics constitute upto 68%, sedimentary lithics 19% and volcanics lithics are about 13%.

Two palaeochannel samples were collected for clasts studies, one of pebbles and other of cobbles. In cobbles sample, quartzites are 32%, followed by volcanics 18% and granitoids 12%. While the pebble samples have shown slightly different results. Maximum percentage is of quartzite 24% followed by granites 11% and volcanics, 10%.

Mineralogy
The framework minerals are quartz, feldspar and rock fragments with some mica and heavy minerals as accessories. In order to plot the data on the petrographic discrimination diagrams of Suczek and Ingersol (1979) and Dickenson et.al., (1983), the data have been recalculated in terms of Q,F,L, Qp, Lvm, Lsm, Lm, Ls and Lv. The abbreviations used in these discrimination plots are explained below:

a) Q = Qm+Qp where Q = Total quartzose grains
Qm = Monocrystalline quartz
Qp = Polycrystalline quartz grains

b) F = K+P where F = Total feldspar grains
K = Potash feldspar grains
P = Plagioclase feldspar grains.

c) L = Lv+Lm+Ls where Lv = Volcanic rock fragments
Lm = Metamorphic rock fragments
Ls = Sedimentary rock fragments

d) Lvm + Lsm where Lvm = Volcanic+metavolcanic lithic grains
Lsm = Sedimentary + metasedimentary lithic grains.

Glauconite, is a prominent detrital mineral in the basal portion of the Chinji Formation where it may amount to 12%. Limestone clasts upto 15.0% have also been recorded from the base of the Chinji Formation. Matrix, calcite and detrital carbonate, constitute upto 75% in the lower portion of the Chinji Formation. Whereas in the rest of the Siwalik Group, main frame constituents like quartz, feldspar and rock fragment comprise 60-80% of the rock volume. The balance is composed of pseudo-matrix, calcite, mica and heavy minerals such as epidote garnet and hornblende.

Uranium Mineralization

In the study area, three different radioactive sandstone horizons have been recognized. The uranium mineralization was discovered in the east of Thatti-Nasrati to Shanawah Godi-khel area within a north-south strip of 19 km. Apart from yellow colored mineralized zones a number of radioactive spots with upto 15000 C/S have also been recorded, where no visible mineralization was observed. All of these radioactive spots are almost always associated with the ferruginous, carbonaceous matter in the form of decayed twig remains or large wood logs.

The uranium mineral recognized petrographically and later confirmed by XRD studies is a yellow colored secondary uranium mineral carnotite $K_2(UO_2)_2(VO_4)_2 \cdot 3H_2O$.

Carnotite is named after Marie-Adolphe carnot (1839-1920), a French mining engineer. It is hydrated vanadate of potassium and hexavalent uranium. Carnotite is present as loose microcrystalline aggregates as well as in a powder form. The mineral is present either as disseminations within sandstone or as an adsorbed mineral forms coating on the surface of clay balls and carbonaceous matter present within the palaeochannels. Within these palaeochannels, the carnotite mineralization follows the cross-beds which contain small deformed wood pieces and clay balls (often B.V.A.Cs). Mineralization here also follow the same pattern e.g. along the cross-beds with adsorbed carnotite mineralization along their outer surfaces. Carnotite does not show fluorescence.

A comparison of uranium, vanadium and organic carbon within the sandstone is shown in Table 3. Presence of chemical U3O8 within different clasts of mineralized paleochannels is shown in Table ____.

TABLE 3. A COMPARISON OF URANIUM, VANADIUM AND ORGANIC CARBON WITHIN THE SANDSTONE OF THATTI NASRATI AND SHANAWAH AREA

S.#	Sample No.	Chem. No.	U308	Vanadium ppm	C(organic)%
1	SHN-1	38435	0.16%	1390	0.28
2	SHN-2	38436	0.19%	1220	0.25
3	SHN-5	38437	0.31%	1710	0.74
4	SHN-11	38438	530 PPM	650	0.05
5	SHN-46	38439	90 PPM	340	0.05
6	SHN-62	38440	1.03%	1080	0.17
7	SHN-72	38441	0.10%	1240	0.39
8	STG-96	38442	366 PPM	420	0.23
9	ZRK-101	38443	13 PPM	370	0.19
10	SOD-105	38444	204 PPM	630	0.4
11	SPM-110	38445	357 PPM	370	0.36
12	GRN-116	38446	4 PPM	150	0.15

Carnotite is very widely distributed in the United States in the Colorado Plateau. The deposits have been known since 1898. The mineral occurs chiefly in sandstones of Triassic or Jurassic age, either disseminated or locally as small relatively pure masses, especially around petrified or carbonized tree trunks and other vegetal matter (Bodine, 1954). The carnotite is of secondary origin and has formed by the reaction of meteoric waters with the preexisting relatively unoxidized uranium and vanadium minerals. At radium hill near Olary, South Australia. Carnotite has formed as an alteration of primary ore containing davidite (Crook and Blake, 1910); process has also been observed from the Cowell District, South Australia (Whittle, 1954a). In red sandstone in the Katenga District, Belgian Congo (Schoep and Richot, 1922) with cinnabar and tyuyamunite near San Carlos, Chihuahva, Mexico (George, 1949). It is found as scattered deposits in the alluvial facies of Miocene sandstone over a large area in Siberia, (Osipov, 1941). Carnotite occurs with tyuyamunite and other vanadium and copper minerals. The uranium apparently was carried by sulfatic meteoric waters and was precipitated locally by organic matter (Popov, 1939).

Palaeochannel's Clast Studies

The Siwalik Group in the study area contains a large number of palaeochannels which contain pebbles. These clasts were sampled and studied in order to quantify the pebbles of various rock types moving in the palaeochannels. Such a study, supplemented with sandstone petrography and heavy mineral analysis can give a fairly complete picture of the types of sediments present in the area and their sources.

Fourteen palaeochannel samples were collected. Three samples from the Chinji Formation one from the base, second from the middle part and third from the top portion of the formation were collected. Three samples were also obtained from the Nagri Formation. One from the base, second from the middle and third from the top of the formation. Similarly four samples from the Dhok Pathan Formation were collected, one each from base and middle parts and two from the top of the uranium mineralized palaeochannels. One sample from the diamectite bed which is present at the base of the Dhok Pathan Formation was also taken. Two samples from the Soan Formation were collected, one of pebbles and other of cobbles. The data are given in graphical presentation in Fig. 3.

As shown in the Fig. 3, the palaeochannel at the base of Chinji Formation mainly contains clasts of the underlying Sakesar Limestone and glauconitic sandstones pebbles from the Lumshiwal Formation. It also contains some sandstones clasts of Murree Formation. Silica sand pebbles from the Datta Formation and chert derived possibly from the Sakesar Formation are also recognised. However the palaeochannel in the middle parts of the Chinji Formation shows considerable variation in clast composition from the basal part. Here the carbonate concretions are 29%, while the Sakesar Limestone clasts are 2% considerable quantity of quartzite (black/gray quartzite, 16%, off white quartzite, 12% and pink quartzite <1%). Volcanics (black volcanics, 8%, green volcanics, 15%, light colored volcanics, 3% and red volcanics, 2% are present within the palaeochannels. Apart from the above mentioned clasts, the pebbles, of Samana Suk Limestone, graywacke, glauconitic sandstone, chert of different colors and red sandstone of Murrees are present.

Palaeochannel present at the top of the Chinji Formation contains pebbles of 24 varieties of rock types as compared to the middle part of the formation which has only 16 varieties. Apart from the different varieties of the quartzite and volcanics it also contains pebbles of granitoids of I and S type together with amphibolite, agglomerates and slates.

Three palaeochannel samples collected from the base, middle and top portion of the Nagri Formation show a wide variety of rock types; 24 varieties in the basal part, 25 varieties in the middle part and 26 varieties in the upper part. In the basal part the pebbles of volcanics dominate (green volcanics, 28%, light colored volcanics 5%, black volcanics 8%) followed by quartzites (white quartzite, 20%, black quartzite 5%) and granites (I-type granitoid 4% S-type granitoid 5%). In the middle part the trend remained the same. Volcanics (green volcanics 21%, black volcanics 8% light colored volcanics, 2%, red volcanics <1%) have the maximum share followed by quartzite (black quartzite 6%, white quartzite 8%), followed by granitoids (I-type granitoid 3%, S-type granitoid, 8%). The same trend continued in the palaeochannel at the top of the Nagri Formation. Volcanics (green volcanics, 15%, light colored volcanics 5%, black volcanics 5% and red volcanics 2%) are followed by quartzite, (white quartzite 19%, black/grey quartzite 6%) and granitoids (I-type granitoid 3%, S-type granitoid 7%).

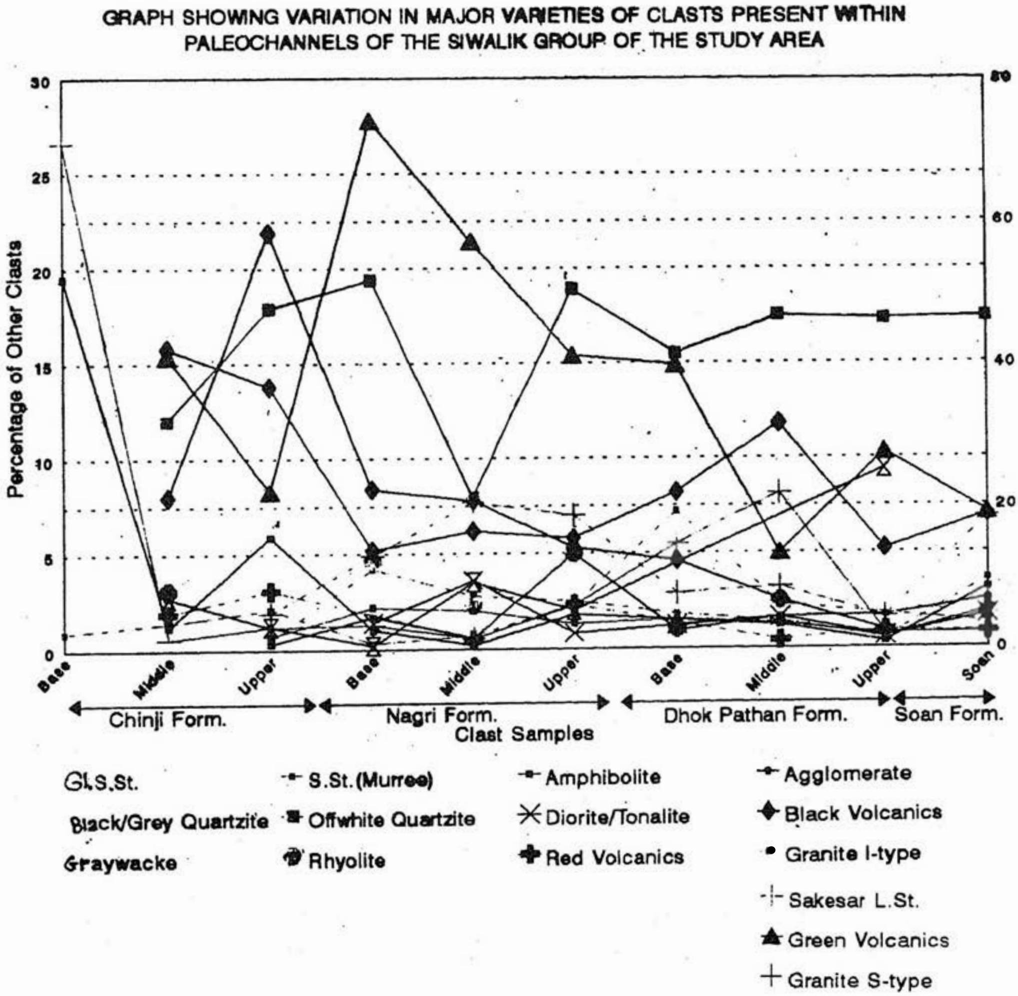

Fig. 3. Graph showing variation in major varieties of clasts present within paleochannels of the Siwalik group of the study area.

Three palaeochannel samples collected from the Dhok Pathan Formation also show considerable varieties of the pebbles. The basal sample has 19 varieties, the middle part 23 varieties and top part sample has 22 varieties. Relative proportions of rock types change to some extent. In the basal palaeochannel sample the maximum percentage is of quartzites (white quartzite, 15%, black quartzite, 8%) followed by volcanics (green volcanics 15%, black volclanics 5%, off white grey volcanics 1%) and Sakesar Limestone (15%). Granite pebbles are in relatively less amount (I-type granitoid 2%, S-type granitoid 3%). The palaeochannel sample collected from the middle part of the Dhok Pathan Formation shows maximum percentage of quartzite (off white quartzite 18%, black quartzite, 12%) followed by Sakesar Limestone 22% and volcanics (black volcanics 3%, white volcanics 3%, red volcanics <1%, green volcanics 5%). Granitoids have relatively lower percentage (I-type granitoid 1%, S-type granitoid 3%). The palaeochannel sample collected from top of the Dhok Pathan Formation from the mineralized palaeochannel contains, maximum percentage of quartzite (white quartzite 17%, ·black quartzite 5%) followed by volcanics (green volcanics 10%, red volcanics 1%, black volcanics 1) and graywacke 9%). Percentage of the granitoid rock are relatively low (I-type granitoid. 1%, S-type granitoid 2%). Another sample collected from the mineralized palaeochannel shows maximum percentage of volcanics (green volcanics, 11%, grey volcanics, 3%, black volcanics, 2%, chocolate colored volcanics, 1%) followed by off white quartzite, 16% and bentonitised volcanic ash concretions, 9%. The percentage of granitoid is relatively low (I-type 2%, S-type granitoid 3%).

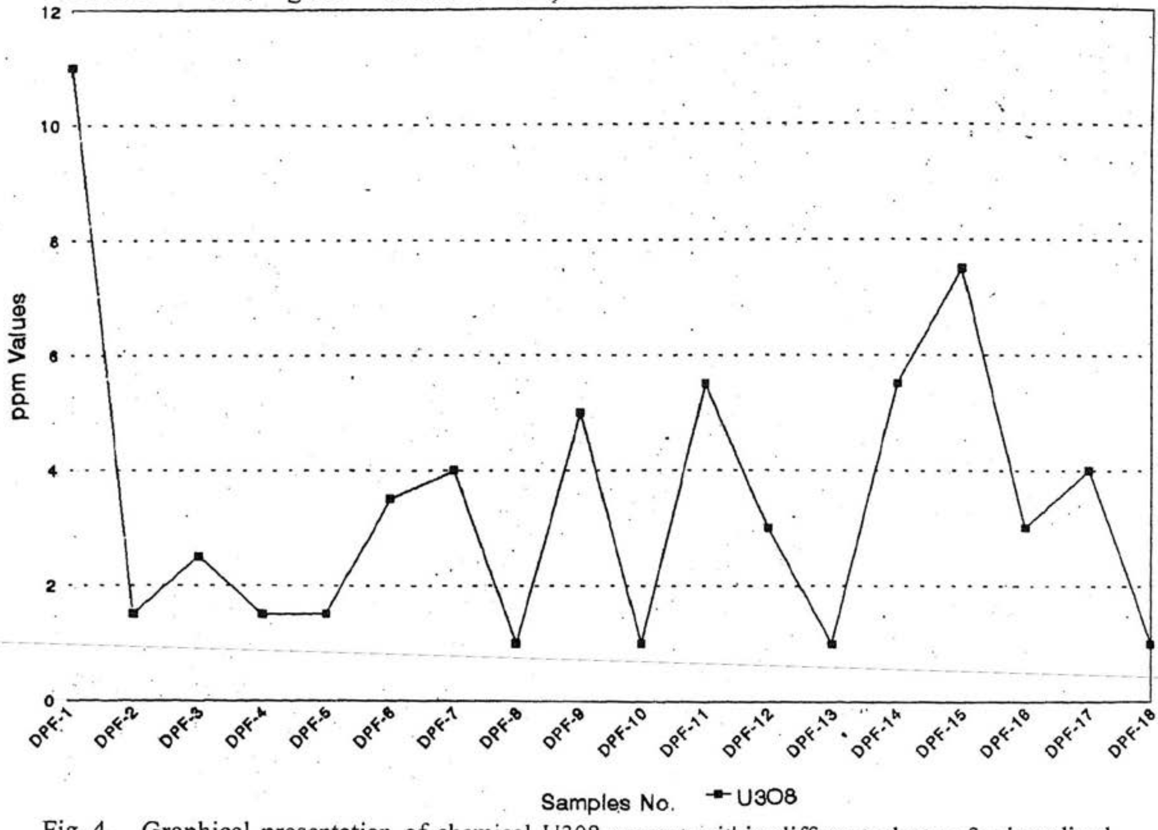

Fig. 4. Graphical presentation of chemical U308 present within different clasts of mineralised Paleo channels.

The main difference between the uranium mineralized palaeochannels and unmineralized palaeochannels is the presence of bentonitised volcanic ash concretions. Uranium mineralized palaeochannel samples have 6% bentonitised volcanics ash clasts in DP.T sample and 9% in DP.F. sample. Such concretions are not present in the unmineralized palaeochannels. These clasts are the main source of uranium, as shown by the chemical result (Fig. 4). These clay concretions still have 11 PPM U_3O_8. While the green chert has 7.5 PPM U_3O_8. S-type and I-type granites have only 1.5 PPM of U_3O_8.

One pebbles sample was collected from the diamectite bed present near the base of the Dhok Pathan Formation. A total of 1339 pebbles of the sample were counted and their percentages were calculated. Pebbles which have shown the maximum percentage are of volcanics (green volcanics 18%, light colored volcanics 2%, black volcanics 5%, red volcanics 1%) are followed by quartzite (green quartzite 15%, off white quartzite 5%) and slate 15%. The percentage of granitoid is relatively low (I-granitoids 2%, S-granitoid 2%). Two palaeochannel samples were collected from the Soan Formation. One sample is of pebbles and other of cobbles (64-256mm). The pebble sample shows maximum percentage of quartzite (off white quartzite 26%, grey quartzite 10%) is followed by granitoids (I-type granitoid 5%, S-type granitoid 7% and volcanics (green volcanics 7%, white volcanics 2%, red volcanics 1%). Bentonitised volcanic ash concretion are not present. In the cobbles sample the maximum percentage is shown by quartzite (off white quartzite 22%, grey quartzite 13%) is followed by volcanics (green volcanics 11%, light grey volcanics 5%, red volcanics 2%) and granitoids (I-type 6%, S-type 5%).

Diagenesis

Major portion of sandstones of the Siwalik Group are friable. Locally lithified hard sandstone bands, mainly following the bedding, are cemented with calcite. Calcite cement is present upto 25% within these hard sandstone bands. No other type of cement such as silica, collophane, chlorite, barite or gypsum have been observed. The cement is composed of large sparite crystals. Often a single crystal encloses one or more than one clasts completely, exhibiting luster mottling or poikilotopic texture. Compaction has caused squashing and shattering of the less stable grains in shale, slate and phyllite. Rarely strong shattering of quartz grains may be seen. Calcite has invaded the fractures in such grains. The feldspar grains show two types of alteration. The first type of alteration is inherited hydrothermal alteration shown by the presence of tiny epidote, sericite and calcite in the case of plagioclase and sericite and perhaps some kaolinite in the case of K-feldspar. During burial of sediments (upto about 1000m), kaolinite formed diagenetically through the circulation of meteoric waters. Illitisation of rocks (through XRD studies) most probably occurred at deeper levels. Fracturing which occurred during burial, was filled by calcite. Shattering of grains as the textural evidence indicates, was followed by carbonate cementation. At places, feldspar grains have been partially replaced by the calcite cement. An important feature product of the diagenesis is the formation of Pseudo matrix, throughout the rocks of the Siwalik Group. Generally, it is upto 15% and should not be confused with the matrix content of graywackes. Because, graywacke has turbidite depositional environment but the same matrix percentage. This pseudomatrix is the result of compaction and squashing of the mechanically weak and unstable clasts of shale, slate, phyllite and low grade schist. Here, authigenic clay intermixed with some calcite, it may have caused hinderence in the flow of carbonate solutions, resulting in the scanty carbonate cementation in sandstones.

It is well known that cementation is much more abundant in clean sandstones than in poorly sorted and muddy ones. The original Siwalik sand contains very little detrital carbonate. Generally proportion of detrital carbonate varies upto 5% (except in the lower portion of the Chinji Formation). The rather well cemented hard sandstone bands developed along the low pressure zones formed during diagenesis as a result of differential compaction. The carbonate rich solutions therefore were concentrated in these zones thereby cementing them.

Provenance of the Siwalik Group

Synthesis of the petrographic data (studies on sandstones and clasts of the palaeochannels) in relation to the evaluation of the source area, has shown some interesting results as regards to the provenance of the Siwalik Group. Petrographic data have been plotted on the QFL provenance discrimination diagram of Dickenson et. al., (1983) in Fig. 5. Two other diagrams have also been used (Ingersol and Suczek, 1979) to represent the lithics data. One diagram is related with the Lv, Lm, Ls data and another concerns QP, Lvm and Lsm data Fig. 6 and 7. These diagrams helped to understand the provenance of these lithics. Some of the clasts are themselves diagnostic of their formational protoliths, such as Sakesar Limestone, glauconitic sandstone (Lumshiwal Formation)or Murree sandstone. The provenance of other clasts are discussed in the following. The three diagrams show that the lithics and QFL, have their provenance mainly from the suture belt, dissected arc recycled orogen and Afghanistan adjoining Pakistan. These provenance studies are also supplemented with the palaeochannel clast studies.

The petrographic studies of sandstone, show that in the Chinji Formation quartz varies from 23 to 50%, feldspars from 5 to 22% and rock fragments from 42 to 72% along the Zhira section. While along the Shanawah section, the concentration of quartz varies from 38 to 47%, feldspars from 11 to 20% and rock fragments from 33 to 47%. Similarly along the Garang section, the abundance of quartz varies from 42 to 53%, feldspars from 8 to 20% and rock fragments from 31 to 39%. Metamorphic lithics are mainly slate phyllite and quartz mica schist. Sedimentary lithics are composed of shale, silt, detrital carbonates, chert and sandstone. Sandstone and shale are mainly contributed by the basin itself. Garnet, epidote and hornblende are the main heavy minerals. The basement rocks of the Indian Plate exposed along the suture zone are rich in garnet. Palaeochannel clasts studies have shown that the lower part of the Chinji Formation consists of pebbles of glauconitic sandstone, sandstones of Murree type, silica sand, chert and Sakesar Limestone. Glauconitic sandstone is from the Lumshiwal Formation of Cretaceous age. Murree type sandstone is from the Murree Formation of Miocene age, silica sand has been derived from the Datta Formation of Jurassic age and cherts from the Sakesar Limestone of Eocene age. The middle part of the Chinji Formation has fifteen varieties of pebbles. A considerable quantity of quartzites of three different colors, volcanics from basaltic, andesitic to rhyolitic varieties are also present. Other notable clasts are of concretions of the limestone, graywacke, Samana Suk Limestone, glauconitic sandstones, red sandstone, red chert or jasper and green cherts. In the upper part of the Chinji Formation, the variety of clasts further increased from fifteen in the middle part to twenty four, as shown in the Fig. 3. These formations are exposed in the vicinity of the areas towards north.

In the Nagri Formation the concentration of quartz, feldspars and rock fragments contents are as follows along three different geological cross-sections. Quartz varies from 18% to 44%, feldspars from 13 to 39% and rock fragments from 29 to 68%, along Zhira section. Along the Shanawah section the variation of quartz content is 39 to 45%, feldspars from 18 to 21% and rock fragments from 37 to 40%. Along the Garang section, quartz abundance varies from 41 to 46%, feldspars from 19 to 20% and rock fragments from 35% to 39%. Feldspar content is generally higher within this formation. Major lithics are of metamorphic origin followed by sedimentary and volcanics lithics. This shows further uplift and dissection of the rising Himalayas exposing new rock varieties concomitant with headward drainage extension.

Palaeochannel clasts studies of the Nagri Formation have shown that almost the same varieties of clasts were carried by the ancestral Indus River as have been studied in the top part of the Chinji Formation.

The number of different kinds of clasts varies from twenty four in the basal part, to twenty five in the middle part and twenty six in the top part of the formation as shown in Fig. 3.

Heavy minerals are mainly hornblende, with maximum abundances followed by epidote and garnet.

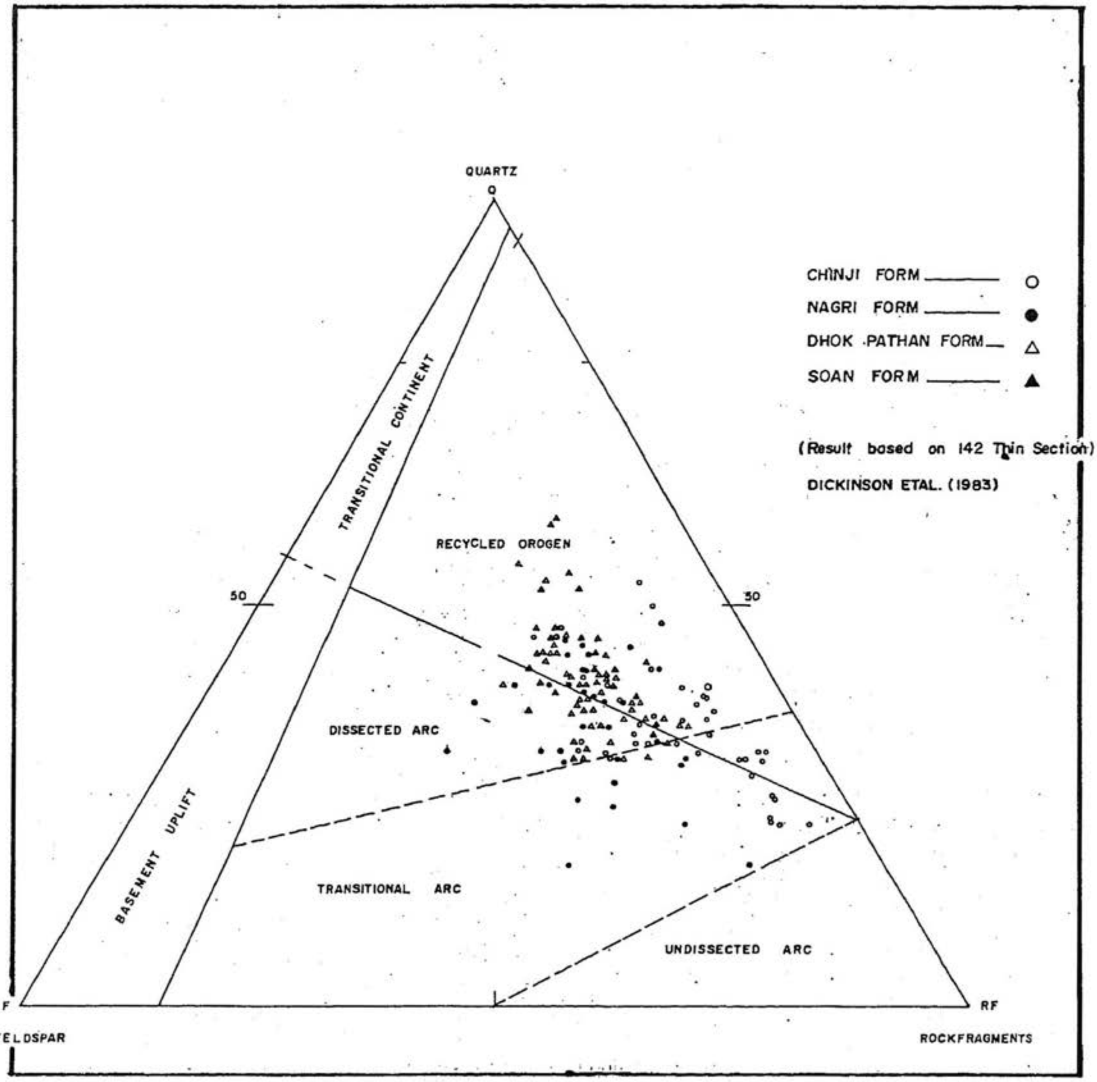

Fig. 5. Different minerals showing their provenance areas.

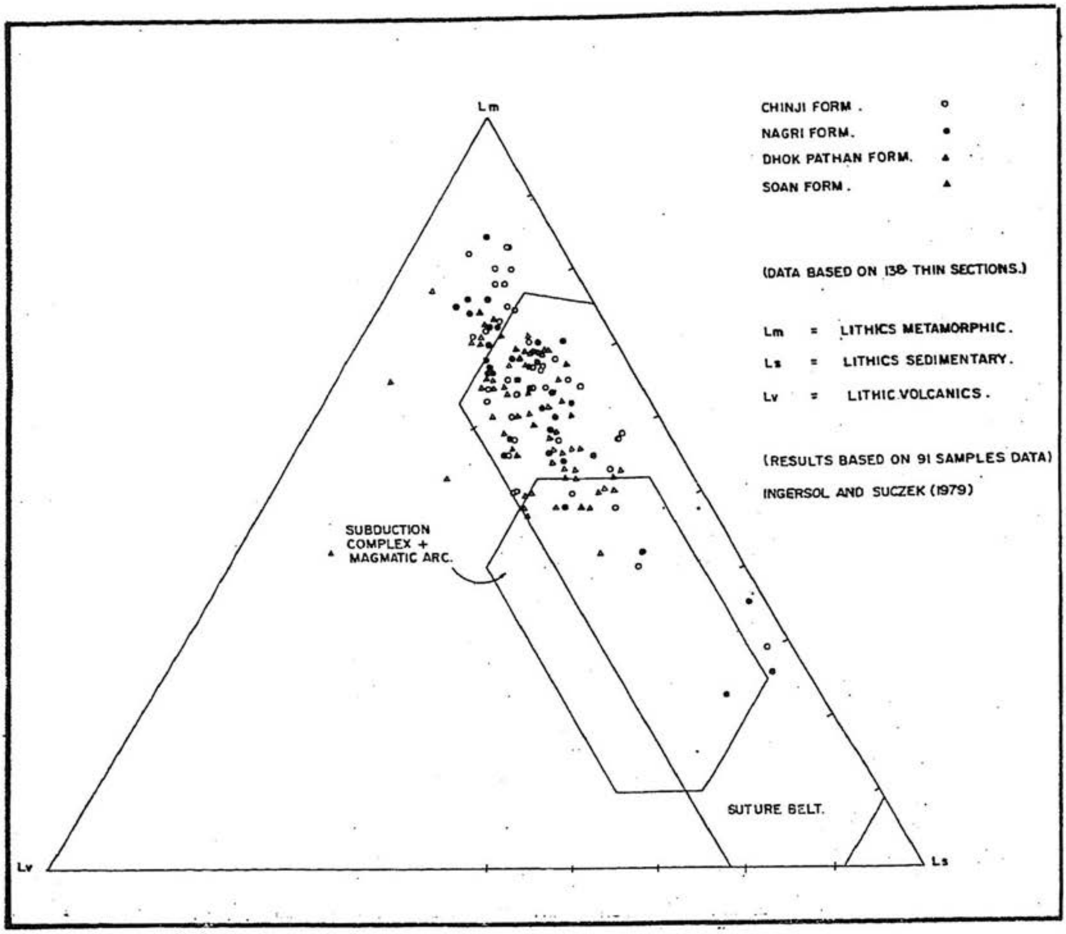

Fig. 6. Different lithics showing their provenance areas.

In the Dhok Pathan Formation, the concentration of quartz varies from 31 to 63%, feldspars ranges from 12 to 29% and rock fragments vary from 23 to 52% along the Zhira section. Along the Shanawah section quartz varies from 33 to 41%, feldspars 15 to 20% and rock fragments from 41 to 52%. Along the Garang section quartz varies from 42 to 46% feldspars from 20 to 25% and rock fragments from 32 to 34%. Within the uranium mineralized horizon, the quartz content varies from 36 to 60%, feldspars from 14 to 22% and rock fragments from 25 to 50%. Metamorphic lithics are present in a major quantity followed by sedimentary and volcanic lithics. Palaeochannel clasts studies within the Dhok Pathan Formation have shown that almost same kind of clasts were carried by the streams as that of the Nagri Formation. Basal part of the formation contains ninteen different varieties, middle part palaeochannels have twenty three varieties. In the top portion the number of clast types varies from twenty to twenty five between the two uranium bearing palaeochannels as shown in Fig. 3. The main difference of these uranium bearing palaeochannel with the rest of the Siwalik Group palaeochannels of the study area, as discussed previously, is that they contain bentonitized volcanic ash concretions which still retain 11 PPM of uranium.

Main heavy minerals are hornblende, epidote and garnet. Epidote has the maximum concentration followed by hornblende and garnet.

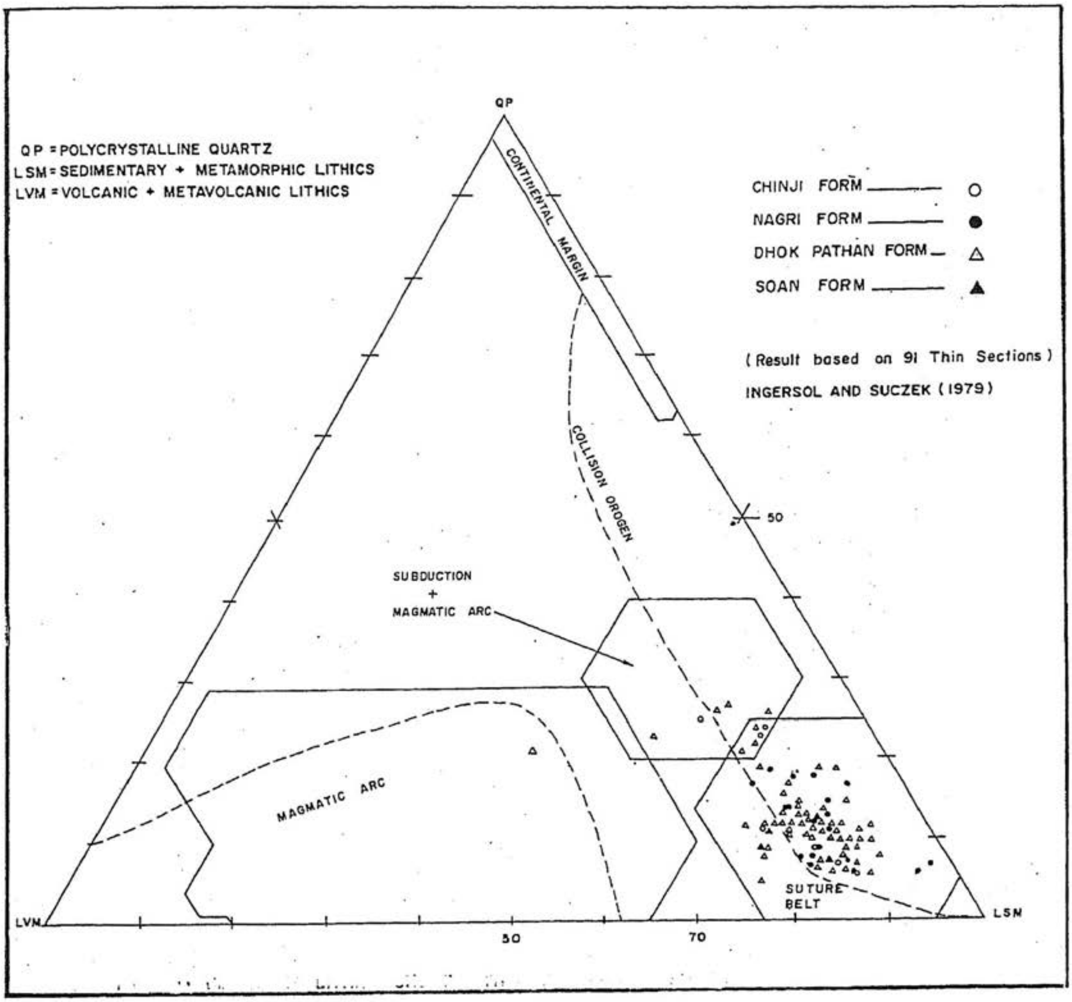

Fig. 7. Different lithics showing their provenance areas.

CONCLUSIONS

1. The collision of Kohistan Island Arc with Eurasia occurred at about 90-100m.a. resulting in an Andean type of margin. At 40 to 65 m.a. the Indian Plate collided with the Eurasian Plate sandwiching the Island Arc.

2. The Himalaya represents the most extensive active collision zone in the World, extending westwards from Burma through India, Nepal and southern Tibet into Northern Pakistan. Active foreland thrusting is occurring on continental scale as the Indian Shield is being overridden by its own northern margin in a series of south-verging thrusts. Southward migrating thrust sheets from the Himalaya shed their erosion products into the active foredeep (Ganga Basin in India: Jhelum Plain in Pakistan) which is itself migrating

southward. The study area is part of Himalayan foreland fold and thrust belt.

3. The Molasse of the study area contains a fair amount of red and green cherts, which are uncommon in sutures and volcanic arc of Pakistan but are more common in southeastern Afghanistan. Agglomerates appear to have been derived from both Pakistan and adjoining Afghanistan. Schist slate and phyllite fragments could not have been derived from far of sources of Himalayas and Karakoram, so they have mainly been derived from the nearby source rocks of Afghanistan. In addition to material derived from Kohistan Island Arc and Western Karakoram, substantial amounts of material have been derived from the adjoining Afghanistan and Parachinar. Blue green hornblende derived from Kohistan is minor. Green hornblende derived from Afghanistan is more abundant. Ampibolite and diorite are minor, therefore contribution from Kohistan proper is subordinate. Diamectite bed contains substantial amounts of red cherts and slates. In fact the diamectite granule and pebble clasts are fairly similar to clasts in the Dhok Formation. This diamectite is known to have come from Afghanistan as a Lahar, therefore a large part of the Siwalik Molasse is likely to have been derived from Afghanistan too. Local derivation of Lumshiwal sandstone, Murrees, Datta and Eocene limestone is minor. Mostly shale horizons of the Dhok Pathan Formation contain saponite clay (smectite group) as high as 15%. This variety of clay is derived from the volcanic ashes, which contain uranium. Leaching of this clay has also provided the uranium to the system. So the whole Trans-Indus molassic sediments have now assumed greater importance from uranium exploration point of view.

4. The study area possesses a potential for a sandstone type uranium deposit. This may be similar to those of Baghalchur, Nangar Nai and Qubul-Khel in characters. As a large number of surface samples, have more than 0.05% chemical U_3O_8. Further integration of data and exploration work particularly core-drilling may add to uranium tonnage of the country.

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