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Geochemical aspects of uranium in the Sumayar valley, northern areas of Pakistan

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ABSTRACT: *The Sumayar valley is located opposite to the Hunza township in the Northern Areas of Pakistan. The area is in the southern extreme of the Karakoram Block and close to the Main Karakoram Thrust (MKT). where medium to high-grade metamorphic rocks are exposed. The Sumayar Pluton, which is a Tertiary tourmaline leucogranite, crops out in the middle part of the valley. The upper part of the valley is filled by the Silkiang Glacier and there is a range of glacial sediments deposited downstream of the glacier.*

As part of a study to establish parameters for further detailed geochemical exploration programs in the region, stream sediments were collected from 12 paired sites representing adjacent high and low energy hydraulic environments. The coarse fraction (125-180 μm), fine fraction (<125 μm) and a pan concentrate (pancon) at each site were analysed. Samples were also collected from adjacent talus fans, glacial deposits, avalanche and lacustrine deposits. This paper focuses on the U data from this sample set.

Uranium contents in the stream sediments range from 1.7 to 35 ppm in the coarse and fine fractions and 1.5 to 184 ppm in the pancons. Elevated U concentrations are spatially associated with the granite in both the stream sediments and talus fans. The presence of slightly elevated U (2 ppm) in one moraine sample indicates U mineralisation possibly extends further towards south under the cover of ice. Uranium contents are typically correlated with Sn, Pb, Zr, Ga, Hf and Lu but negatively correlation with Cr, Cu and Ni. Factor and cluster analysis indicates a strong relationship between U and other elements typically enriched in leucogranites.

The strongest response to the presence of the U-rich Sumayar Pluton is observed in the U contents of the fine stream sediments (<125 μm) and there does not appear to be a strong hydraulic influence on this fraction suggesting the U is either hydromorphically transported or associated with very fine-grained heavy minerals.

INTRODUCTION

Pakistan Mineral Development Corporation (PMDC) carried out a regional stream sediments geochemical survey of the Northern Areas from 1992 to 2001 with the initial assistance by the Australian Agency for International Development (AusAID). The purpose of this survey was to identify target areas for more detailed gold and base metals exploration. The authors carried out a research program on samples from the Sumayar valley as a follow up program at the University of New South Wales (UNSW), Australia to determine parameters for detailed future exploration program. Uranium was analysed as a part of 33 elements to find out its relationship with other elements. This paper focuses on U data from stream sediments in the Sumayar Valley and consideration of: 1) Controls on the concentrations of U in stream sediments, 2) Relationships between U and other elements and source indicators and 3) Geochemical exploration methods for U.

REGIONAL GEOLOGY

Detailed regional geology is summarised by Kazmi et al. (1997) and Bender et al. (1995) along with several other authors referred therein. The structure and plate tectonics are described by Farah et al. (1979), Khan et al. (1989; 1990; 1993), Searle et al. (1986; 1987; 1989; 1993) and Haq et al. (1984) and general geology and petrology by Jan (1979a,b; 1984; 1988), Coward et al. (1987), Chaudhry and Ghazanfar (1992) and Tahirkheli (1979; 1982), Shams (1983) and Le Fort et al. (2002), and geochronology by Baig (1991) and Crawford et al. (1993). Regional geochemistry has been summarised by Halfpenny and Mazzuchelli and Malik (2004).

The Northern Area, in which the Sumayar valley occurs, is composed of the following major tectonic units (from north to south): 1) The Karakoram-Asian Plate commonly known as the Karakoram Block, 2) Main Karakoram Thrust (MKT) Zone (Chalt Volcanic), 3) The northern part of the Kohistan island arc, 4) Main Mantle Thrust and 5) The Indo-Pak Plate (Nanga Parbat-Harmosh Massif).

The Karakoram Block is bounded by the South Pamir Fault in the north (Desio, 1979), Karakoram Fault in the east, Sarobi Fault towards west and the Main Karakoram Thrust (MKT) in the south. It is an east-west trending block with sedimentary to meta-sedimentary rocks towards the north and metamorphic suit towards the south. The Karakoram Batholith is outcropped in between the two. The Karakoram Block is obducted onto the Kohistan Island Arc towards south along MKT that comprises meta-sedimentary volcanics, mélange and pillow lavas with its width ranging from ~500 m to over 4000 m.

The Kohistan Island Arc is a large body consisting of several rock units each with its own geological history. Some of the important units are (from north to south): 1) *Northern Volcanics and Sediments* that are in contact with MKT as a subducted body developed during Cretaceous to Tertiary time that suffered low grade metamorphism, 2) *Kohistan Batholith* that comprise both un-deformed and deformed bimodal trondjhemite and gabbro-dunite suite. Early deformed plutons relate to the collision along MKT, 3) *Jaglot Schist Group* that comprise sedimentary to volcanic rocks with medium to high-grade metamorphism related to intrusion of igneous rocks, 4) *Chilas Complex* consisting of mafic to gabbro - noritic rocks which were emplaced soon after collision between the Karakoram and the Kohistan, 5) *Southern Amphibolites* that are considered to be formed both from tholeiitic and calcalkaline magmas generated in the island arc and oceanic setting. Besides these there are wide range of plutonic rocks and metasediments. The rocks have undergone two phases of deformation and metamorphism. Some of the granitic rocks in the amphibolite and Kohistan Batholith may have been developed due to partial melting of amphibolite and 6) *Jijal Complex* of which the northern half consists of garnet granulite and

including the following rock types: 1) Metaphyllite, 2) Schist (calcareous, chlorite, biotite, garnet-mica, sillimanite, staurolite and graphite schists), 3) Leucogranite and granitic gneiss, 4) Limestone and marble beds and 5) Quartz and calcitic vein material.

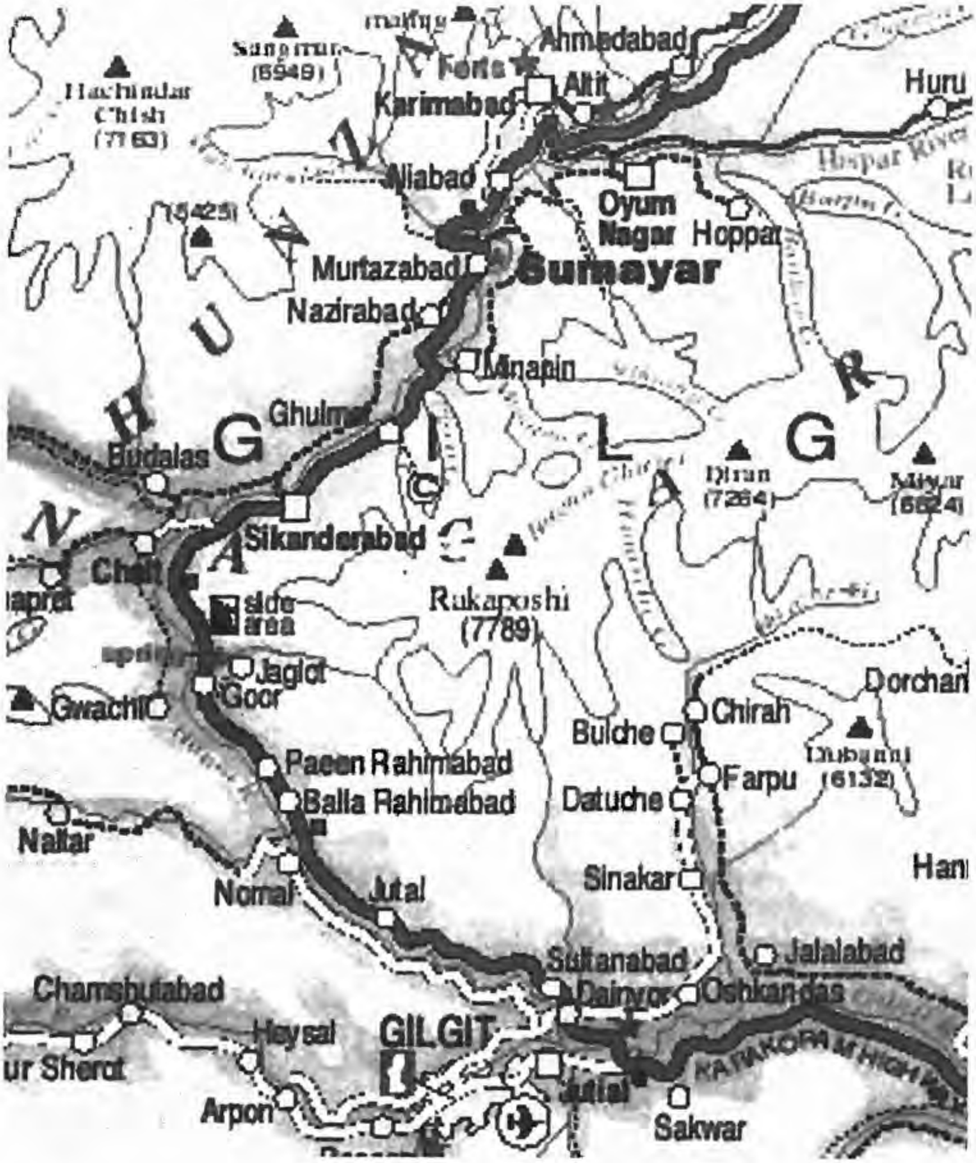


Fig. 1. Location map of the Sumayar valley, Nagar.

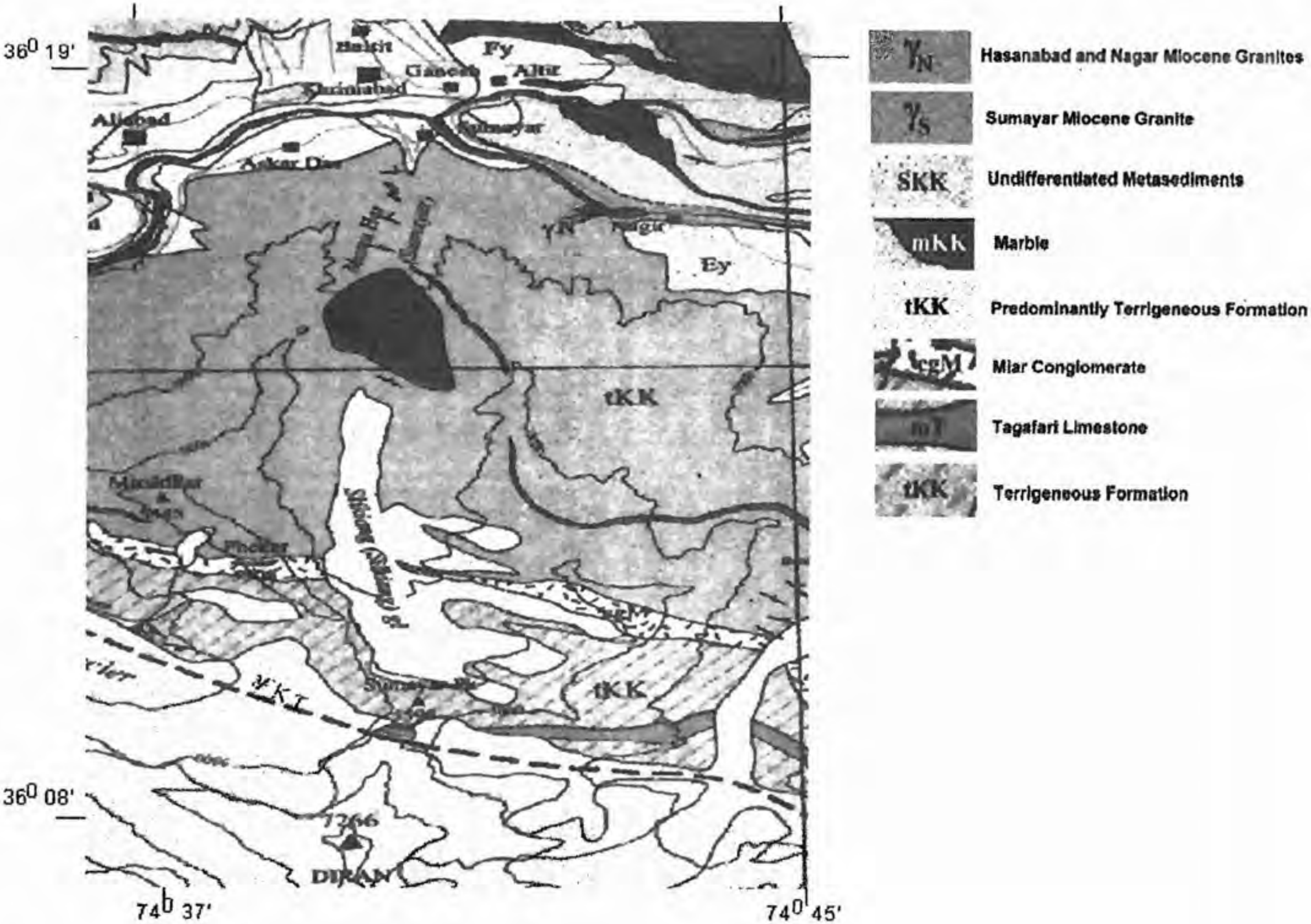


Fig. 2. Geological map of the Sumayuar area (Le Fort et al., 2002)

The Middle Hunza valley, incorporating the Sumayar valley, lies to the north of MKT and the rocks are believed to form the southern margin of Karakoram-Asian Plate prior to collision of the Kohistan Island Arc between 102 and 87 Ma (Treloar et al., 1989). Low-grade metapelites and limestone in the north are separated from sillimanite-grade metamorphic rocks to the south by a large calc-alkaline quartz diorite-granodiorites pluton as a first phase of Hunza plutonic complex within Karakoram Axial Belt (Crawford et al., 1992) that was intruded approximately 95 Ma (Le Fort et al., 1987). The southern part of the pluton and pelitic, calcareous and basic volcanic rocks up to MKT were affected by southward thrusting related to continental collision and continued convergence of Indo-Pakistan and Karakoram-Asian Plate since 50 Ma (Searle et al., 1987). Deformation accompanied metamorphism and thrusting brought deeper level rocks southwards over cooler higher level rocks so that metamorphic grade increases with structural heights. Metamorphic grade increases northward from greenschist-grade to phyllites near MKT through staurolite-grade metapelites to sillimanite grade metamorphic and calc-silicates containing forsterite and diopside at the contact with the Hunza Pluton Complex (HPC). The main changes in metamorphic grade occurred across thrust zone while deformation ceased by 37 Ma (Searle et al. 1989).

Crawford and Searle (1993) has suggested that two post-collision magmatic groups are distinguished as Hunza dykes and Sumayar pluton with a possible thermal history ranging from 2.7 to 16.9 Ma (Debon et al., 1996). Accordingly the Sumayar pluton consists of a homogeneous leucogranite emplaced in staurolite-grade zone. It forms a large, homogenous body 4 km across with sharp intrusive contacts and a small contact aureole of slates about 50 m wide. The pluton contains $>2\%$ tourmaline as its primary phase while garnet is common phase except at the margins. The presence of biotite within large muscovite laths is suggestive of higher water contents. The high boron (B) contents, reflected by tourmaline and high Sr/Nd isotopic ratios indicate a mature metapelitic source. The zircon abundance (40.4 ppm) gives a magmatic temperature estimate of about 680 µC that places the magma close to the granite wet melting curve. Crawford and Searle (1993) concludes a vapour-absent melt, due to muscovite breakdown, as a cause for the generation of the Sumayar pluton.

GEOMORPHOLOGY

The area is a part of Trans-Himalayas with an average altitude of about 6000 m. The ranges include northern Hindukush, the Deosai plains, the Laskar Mountains and the Karakoram Range. There are six peaks above 8000 m, including K2, which is the second highest mountain (8611 m) and 35 peaks over 7000 m. The area hosts some of the largest glaciers in the world outside Antarctica. Sumayar village is open throughout the year but the upper valley is permanently covered by snow. The area is largely barren of vegetation. The weather is extreme and flash flooding following high rainfall events are common. There is also a strong diurnal fluctuation in stream flows during summer.

The Sumayar valley rises from 2,000 m at its mouth in the north to over 7,000 m towards the south along a stretch of 15 km distance. The highest peak, Diran (7257 m), is in the southern part of the valley. There are several tributaries to the principal stream. The valley can be divided into three geomorphological units:

i. The Upper part

Upper reaches (southern part) of the valley are extremely rugged, generally covered with ice and a permanent glacier known as

Silkiang. There is almost no vegetation. The valley can be conveniently further divided into two parts - the extreme upper zone that is occupied by a permanent glacier (Silkiang) and till/morainal sediments and the lower part that is of relatively low gradient with meandering of the principal stream. At places it is occupied with avalanche and materials from lateral morains.

ii. The Middle part

The middle to lower Sumayar valley is a deep gorge that is flanked on both sides by high cliffs, probably due to outcropping of the Sumayar granite. Old moraines, with a mix of talus fans and fluvial material, are developed on both side of the stream. The principal stream is extremely narrow in the upper but is slightly wider in its lower part where sediment load is settled as bar-point deposits. Compared to the bar-points developed at the upper reaches these bar-points are larger and less curved. There is also no vegetation in this part of the valley. During winter the area is generally under deep snow.

iii. The Lower part

The Lower part of the valley is wide and open. A mixture of old terraces and moraines flank the stream on both sides. Talus fans are well developed along the valley sides. There is agriculture activity on the terraces but the remaining areas of skeletal soil are devoid of any vegetation. The stream is deeper and flows mostly as a single channel. Before joining the Hunza River in the north, the valley mouth is deeply incised.

Sampling and analysis

In this study, stream sediment sampling was carried out at paired sites representing high and low hydraulic energy environments. Bar point deposits developed along and within the active principal channel were selected for sampling purpose. Talus fans, glacier, moraines, avalanche and lacustrine beds were also sampled to determine their geochemical relationship to exposed rocks as well as the stream sediments.

Stream sediment samples were collected using a plastic pan. Trap sites were selected on point bars with the nose of the point bar designated as a high energy environment trap and the downstream tip of the point bar as a low energy environment. About 25 kg of –7 μm material at each trap-site was collected by wet sieving into a bucket. Out of this material 1.5 - 2 kg of material was further wet sieved to obtain –125 μm material (the fine fraction) and 125-180 μm material (the coarse fraction). These fractions were preserved in cloth bags which were later air dried. Pancon samples were prepared from the remaining material by wet sieving and panning until a heavy concentrate of 70 to 100 g was obtained for each sample. Talus and other media were sampled in similar fashion.

About 11 g of material was milled in a carbide-tungsten steel-grinding mill from 30 to 45 seconds. Very fine fraction material (-63 μm) was not milled. The resulting material was made into aluminium-backed disks using Elvanol binder (a polyvinyl acetate solution). Due to friability, the pancon milled samples were remilled with 50% quartz filler. Total geochemical analysis of the samples was performed on the disks using XRF at UNSW followed by INAA by Actlabs, Canada. Data quality was maintained using in-house reference materials.

RESULTS AND DISCUSSION

Basic data

Basic data of uranium for different fractions under high and low energy conditions of the principal stream sediment and other geomorphic units (talus fans etc.) is produced at Appendix 1a and 1b. The data has been divided into upper, middle and lower part of the valley depending upon the geomorphic conditions of the valley. Ratio of uranium between high and low energy samples is given in Appendix 1c. Thorium uranium ratio data is given in Appendix 1d. The stream sediment and talus fan data has been statistically summarised in Appendix 2a and 2b.

Main data trends

The U content of the three fractions are analysed and presented in Figure 3 and their trend in the principal stream is drawn in Figure 4 and compared with Th/U ratio. The overall U data trend for all stream sediment components is relatively low concentrations in the upper stream reaches, a significant increase over the Sumayar Pluton in the middle reaches of the stream and some further concentration in the lower reaches of the stream. This trend is most prominent in the fine fraction. Although the pancons contain high U contents than the other two fractions, all three media display similar patterns and U concentrations in adjacent high and low energy environments with slightly higher U contents in the fine fraction than the coarse fraction. This suggests U has a significant hydromorphic transport component. The impact of the Sumayar pluton is greatest in the pancon samples, although this fraction displays limited variation between high and low energy environments.

Contrary to the downstream increase in U, especially across the pluton, the Th/U ratio consistently decreases downstream in the coarse and fine fractions with little indication of influence by the Sumayar pluton. The ratio of U between adjacent high and low energy samples display no significant spatial trends in any of the fractions analysed. In the pancons, however, there is a more dramatic decrease in this ratio in the upper section of the stream and a smoother trend in the low energy environment samples.

The talus fans and avalanche deposits display greater U concentrations than the stream sediments upstream of the pluton, but similar concentrations within the pluton zone, suggesting the metasediments are significant contributors to the stream U contents. It also indicates that geological units upstream of the glacier contain low U values and that the morains extending below the glacier are preventing contribution of U to the stream from the adjacent talus fans.

All non-stream sediment materials displayed a consistent but relatively small increase in U concentrations as grain size decreases (sufficient <63 μm material for analysis could not be extracted from the stream sediments). With a ~5 ppm threshold for the stream sediments and with most values below this threshold upstream of the pluton and the lateral morains that protect the stream from influx of sediment from the surrounding valley wall, it is difficult to determine whether there is a significant difference between the effect of the pluton and the surrounding metasediments on the stream sediment U concentrations.

Elevated U values in some avalanche samples and 16 ppm U in a sample of the metamorphic rocks upstream of the pluton indicate that there may be zones of U mineralisation in the metamorphic rocks.

Exploration data analysis (EDA)

The U distributions are presented for each fraction under high and low energy environments using box plots (Appendix 3) and probability plots (Appendix 4a, b & c). There are few samples forming outlier. The spread of values in the fine fraction of low energy environments is substantially greater than the spread for high energy environments.

The range of U values in the pancons is similar for high and low energy environments but less skewed in the low energy environment. With the exception of low energy pancon population (U-6) all the remaining stream sediment fractions and the talus fan materials display lognormal distributions and mixed populations relating to input from background values, a mineralized zone around the granite and outliers.

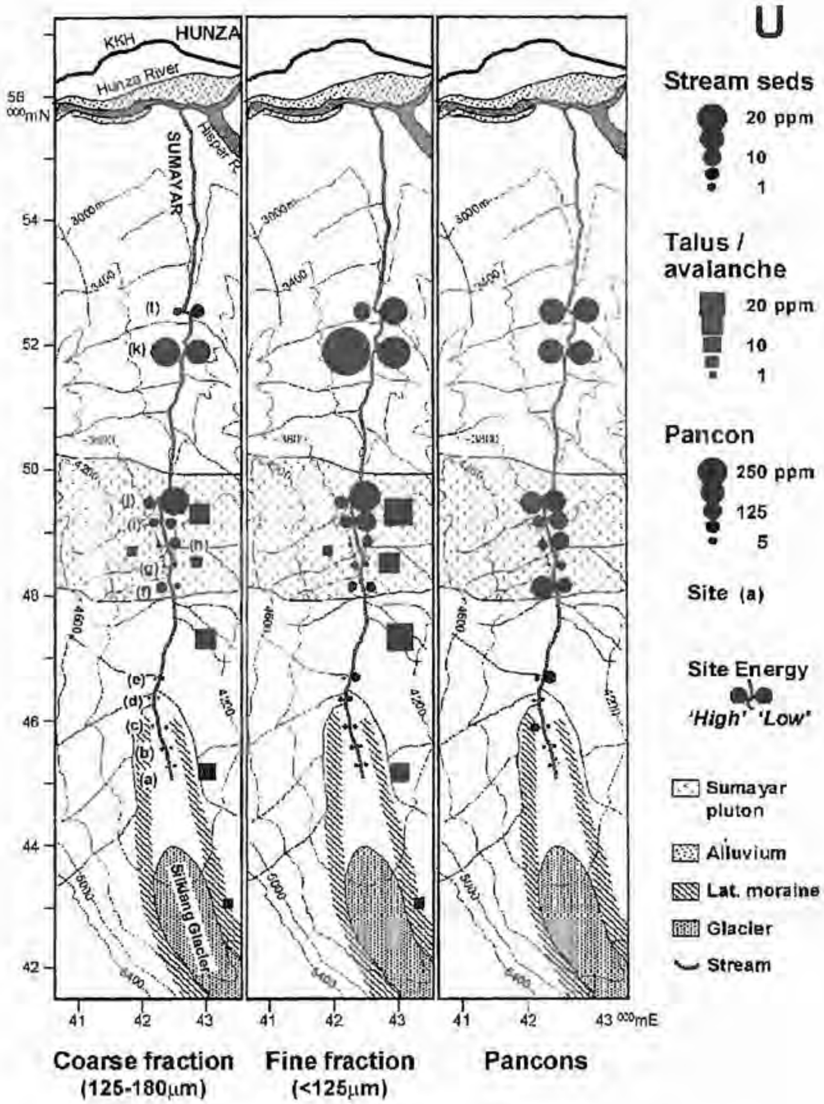


Fig. 3. Uranium content of the coarse (125-180 μm), fine (< 125 μm) and pancon component of active stream channel sediments, Sumayar valley.

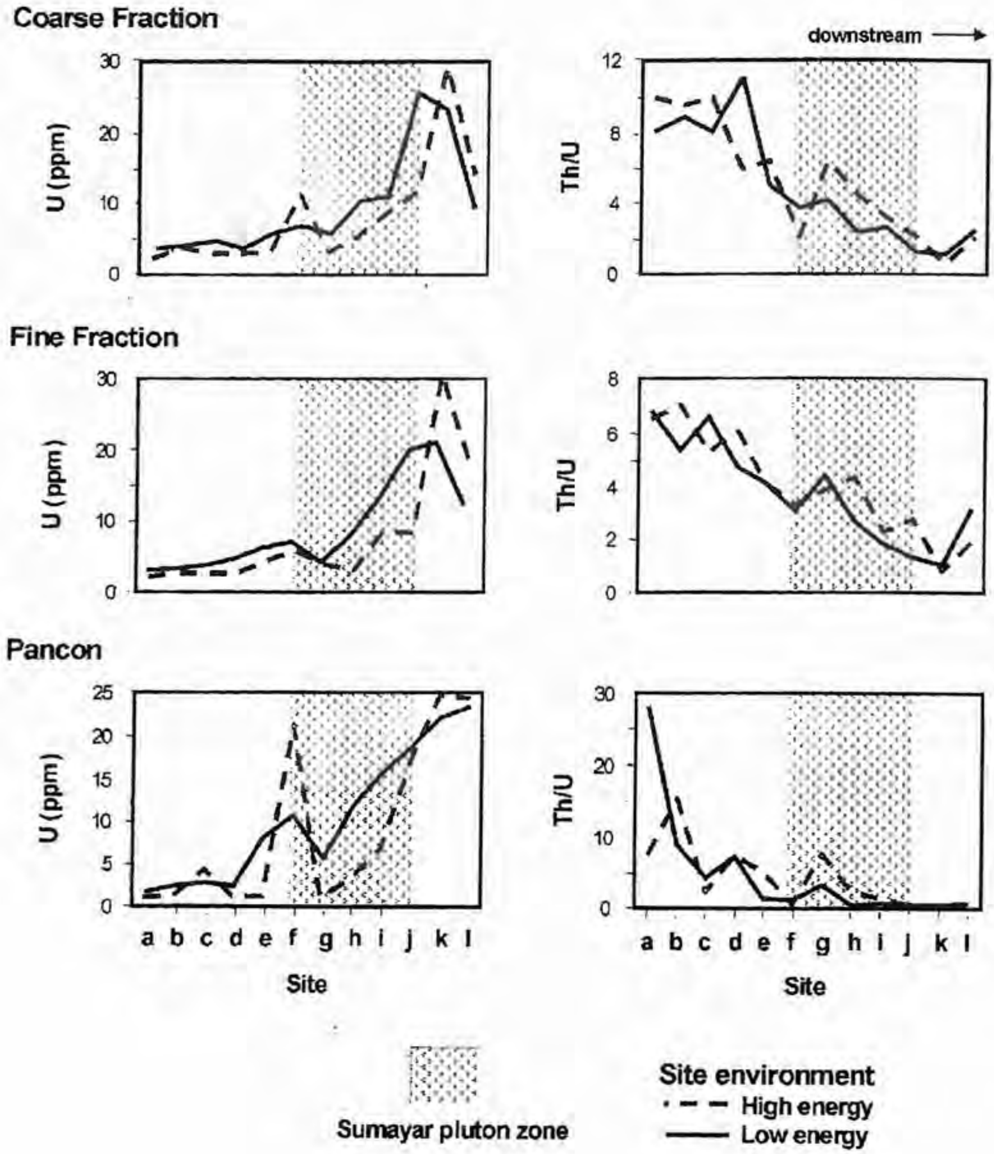


Fig. 4. Downstream section representing U content and Th/U ratio of the coarse (125-180 μm), fine (<125 μm) and pancon component of active stream channel sediments, Sumayar valley.

Results of both F and t-test are indicative that there is no significant variability in the means in between the high and low energy samples (Table 2). This conclusion is equally supported by the ANOVA in which both one-way and two-way models incorporating differences between coarse and fine fractions, and between high and low energy environment do not show any significant sources of additional variance beyond inter-site variation (Table 3). Uranium displays the greatest proportion of total variance related to variation between sites (as opposed to between paired high-low energy environments) of any element in the dataset.

Correlation

All fractions display strong correlation between the U contents of adjacent high and low energy environment samples (Table 4, Fig. 2). The coarse fraction U contents are clustered towards lower values; the fine fraction shows a bimodal distribution whereas the pancon samples appear to show highest U correlation between high and low energy samples.

TABLE 1. PROBABILITY PLOT-BASED POPULATION ARTITIONING OF U DATA (VALUES IN PPM)

	Population 2	Population 2
Coarse fraction	< 3	3 - 10
Fine fraction	< 6	6 - 10
Pancon	< 10	10 - 70

TABLE 2. COMPARISON OF F-TEST AND T-TEST OF U PARAMETERS FROM HIGH AND LOW ENERGY ENVIRONMENTS

	U-1/U-2	U-3/U-4	U-5/U-6
t-Test: Equivalences of means			
P (T< =t) two-tail	0.483	0.834	0.795
F-Test: Equivalence of variances			
P (F< =f) two-tail	0.725	0.916	0.907

TABLE 3. ANOVA FOR U

Fraction	Source	df	SS	MS	%variance	F
125-180 μm	Among sites	11	658	59.8	88.3	7.58
	High vs low	12	95	7.9	11.7	
< 125 μm	Among sites	10	1348	134.8	88.6	7.73
	High vs low	11	192	17.4	11.4	
Pancon	Among sites	11	130493	11863.0	92.8	12.96
	High vs low	12	10987	915.6	7.2	

TABLE 4. CORRELATION BETWEEN U CONTENTS OF FRACTIONS IN BETWEEN HIGH AND LOW ENERGY PAIRED SITES

	Coarse Fraction	Fine Fraction	Pancon
Corr. coef.	0.76	0.78	0.84

In general, U tends to be positively correlated with other heavy or incompatible elements and negatively correlated with the siderophile elements, however correlation patterns are complex (Table 5). Not all fractions display consistent positive or negative correlation with the different uranium fractions (e.g. La and Rb). High energy U in the coarse fraction is positively correlated with Ga, Pb, Rb and Sn but negatively correlated with Cr, Cu, La, and Ni.

The fine fraction (U-3 & U-4 of high and low energy) displays similar patterns to the coarse fraction (U-1 and U-2 fractions of high and low energy) suggesting the little mineralogical difference between these two fractions. The pancon samples (U-5 & U-6 fractions of high and low energy environment) show the closest agreement between high and low energy environments, but this may be a function of an overall higher degree of correlation or anticorrelation between elements. Uranium is strongly correlated with all other heavy elements in the pancons.

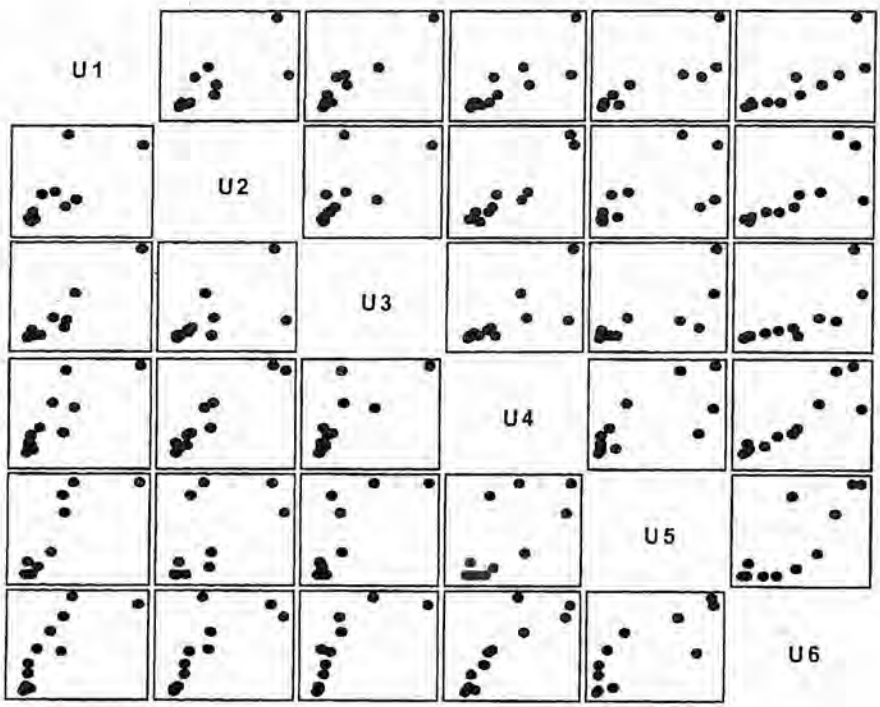


Fig. 5. Scatter plot matrix for U between various stream sediment fractions, Sumayar valley.

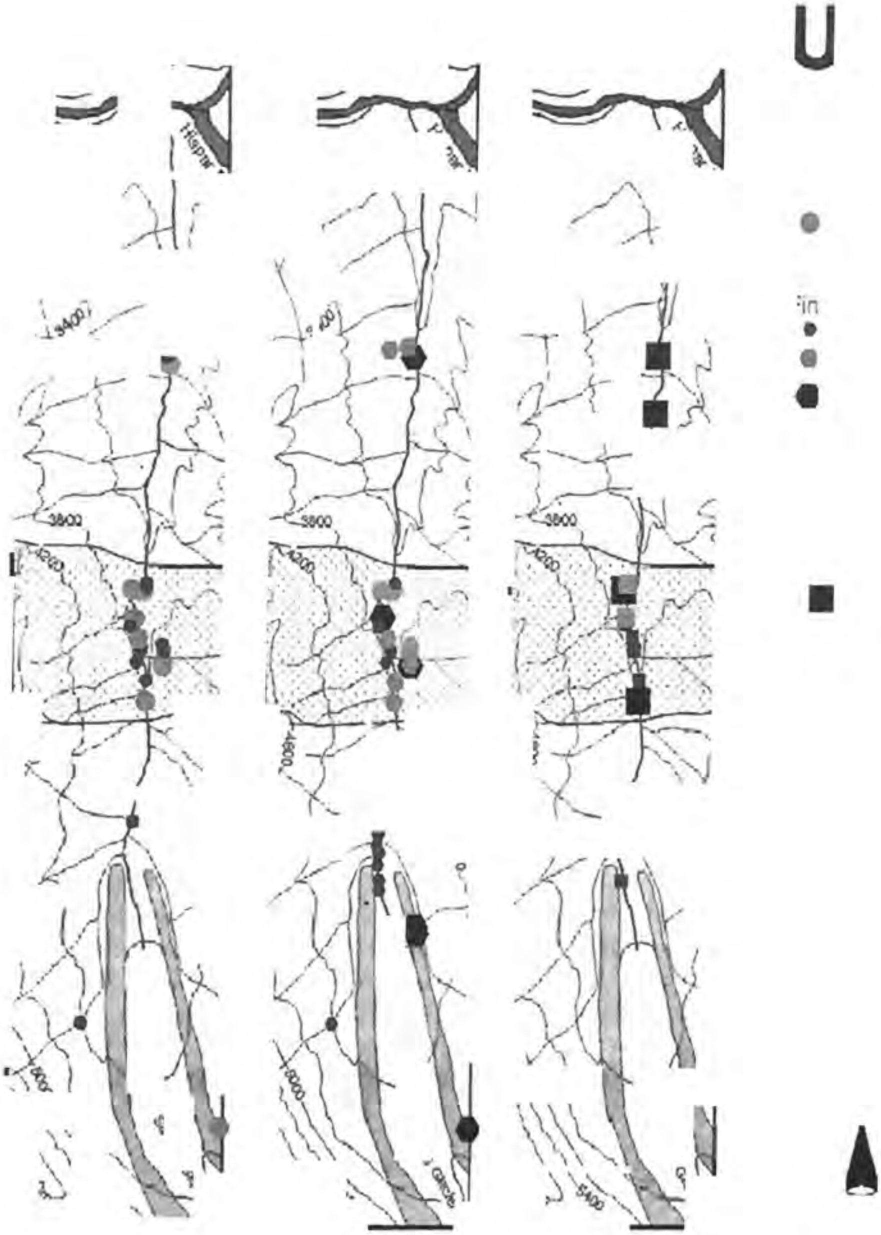
TABLE 5. CORRELATION BETWEEN U AND OTHER ELEMENTS IN VARIOUS STREAM SEDIMENT FRACTIONS, SUMAYAR VALLEY

	Coarse Fraction		Fine Fraction		Pancons	
	High	Low	High	Low	High	Low
	U-1	U-2	U-3	U-4	U-5	U-6
As	*-0.50*	ns	*-0.50*	0.51	ns	ns
Au	ns	ns	ns	0.79	0.65	ns
Ba	ns	0.44	ns	ns	ns	0.64
Ca	*-0.91*	ns	*-0.79*	ns	*-0.41*	*-0.47*
Ce	*-0.46*	ns	ns	0.80	0.85	ns
Cr	*-0.70*	ns	*-0.78*	ns	ns	ns
Cs	0.95	0.44	0.92	0.59	0.51	ns
Cu	*-0.78*	ns	ns	ns	*-0.59*	*-0.61*
Eu	0.76	ns	*-0.50*	0.74	0.88	ns
Fe	*-0.77*	ns	*-0.78*	ns	0.41	ns
Ga	0.93	0.59	0.85	ns	ns	0.48
Hf	ns	0.54	ns	0.92	0.83	0.61
La	*-0.64*	ns	ns	0.81	0.87	0.57
Lu	ns	0.89	ns	0.92	0.98	0.92
Nb	ns	0.71	0.52	0.84	0.85	0.70
Nd	*-0.59*	ns	ns	0.73	0.84	0.50
Ni	*-0.96*	*-0.51*	*-0.96*	*-0.71*	*-0.64*	*-0.54*
Pb	0.94	0.83	0.92	0.76	Ns	ns
Rb	0.91	ns	0.89	ns	*-0.60*	ns
Sc	*-0.85*	ns	*-0.81*	ns	0.68	0.57
Sn	0.59	0.87	0.52	0.82	0.83	ns
Sr	*-0.88*	*-0.70*	*-0.83*	0.54	ns	ns
Ta	0.44	0.86	0.51	0.82	0.90	0.93
Th	ns	0.41	0.76	0.61	0.87	0.73
Ti	*-0.68*	ns	*-0.62*	0.61	ns	*-0.62*
V	*-0.75*	ns	*-0.81*	ns	ns	*-0.54*
Zn	ns	ns	0.78	ns	ns	ns
Zr	ns	0.68	0.78	0.85	0.77	0.50

ns = not significant at 5% (t-values are suggestive that significant values are at 0.58 and above)

Factor analysis

Factor analysis was completed for U and 32 other elements for each of the stream sediment components but without differentiating high and low energy sites (Table 6 & Fig. 6). In most instants, U is strongly associated with factors containing high loadings for heavy and other incompatible elements typically found in fractionated granites. There is no obvious association between U and mafic-associated elements. It is not clear whether the patterns for U are more strongly influenced by lithological source or transportation/ deposition processes, however, U is more closely associated with a granitic suite of elements in the fine and coarse fractions and with the heavy mineral association in the pancons.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APPENDIX 1a. URANIUM CONCENTRATIONS (PPM) IN STREAM SEDIMENT FRACTIONS DERIVED FROM HIGH AND LOW ENERGY SITES, SUMAYAR VALLEY

Geomorphic section		Site	Samples	High Energy Samples			Low Energy Samples		
				Coarse Fraction (125-180μm)	Fine Fraction (<125 μm)	Pancon	Coarse Fraction (<125-180μm)	Fine Fraction (<125 μm)	Pancon
				U-1	U-3	U-5	U-2	U-4	U-6
	Upper valley	a	6, 7	1.7	2.8	5.0	2.0	2.5	1.5
		b	8, 9	2.8	3.3	6.5	2.3	2.9	6.7
		c	10, 11	2.2	3.5	30.0	2.8	3.4	8.2
		d	13, 14	2.2	3.3	6.4	1.9	4.5	6.6
		e	15, 16	2.4	5.2	6.2	3.8	6.3	46.0
	Middle valley	f	18, 19	8.1	6.8	158.0	4.6	7.2	64.0
		g	1, 2	2.3	4.8	6.0	3.8	3.9	29.0
		h	3, 4	3.9	3.9	22.0	7.6	8.1	70.0
		i	20, 21	6.3	9.6	48.0	8.1	14.0	98.0
		j	22, 23	8.4	9.2	128.0	20.0	22.0	120.0
	Lower valley	k	67, 68	21.0	35.0	184.0	18.0	23.0	142.0
		l	65, 66	10.0	19.0	182.0	6.6	13.0	152.0

APPENDIX 1b. URANIUM CONCENTRATIONS (PPM) IN OTHER GEOMORPHIC UNITS, SUMAYAR VALLEY

Material	Samples	< 63 μm	63-125 μm	125-180 μm
Ablation till	41	2.4	2.3	1.8
	42	3.4	1.9	2.5
Avalanche	36	9.3	5.9	3.5
	37	7.2	4.8	2.7
	26	5.8	5.0	5.2
	27	6.2	5.4	4.7
Lateral moraine	60	4.2	4.4	4.2
	69	-	6.6	7.2
Lacustrine sediments	59	2.8	2.7	-
	70	-	10	6.0
Talus fans	51	25	18	14
	52	24	15	17
	53	23	15	15
	54	7	4.1	5.3
	47	30	20	18
	48	28	21	17
	49	23	19	17
	30	11	7	6.4
	31	34	11	7.8
	32	17	10	7.9
	33	12	7.5	6.1
	34	20	7.7	5.7
	55	25	8.6	7.1
	56	21	7.3	5.0
	57	8.7	4.2	3.8

APPENDIX 1c. RATIO OF U IN HIGH AND LOW ENERGY ENVIRONMENTS, SUMAYAR VALLEY

		Site	High to Low energy environment U ratio Coarse Fraction U1/U2	Fine Fraction U3/U4	Pancon U5/U6
Geomorphic section	Upper	6, 7	0.9	0.7	1.1
		8, 9	1.2	0.7	1.1
		10, 11	0.8	0.8	1
		13, 14	1.2	0.6	0.7
		15, 16	0.6	0.7	0.8
	Middle	18, 19	1.8	0.7	0.9
		1, 2	0.6	0.8	1.2
		3, 4	0.5	1.9	0.5
		20, 21	0.8	0.8	0.7
		22, 23	0.4	2.2	0.4
	Lower	67, 68	1.2	0.5	1.5
		65, 66	1.5	0.3	1.5

APPENDIX 1d. TH/U RATIO OF THE STREAM SEDIMENT SAMPLES, SUMAYAR VALLEY

	Th-1/U-1	Th-2/U-2	Th-3/U-3	Th-4/U-4	Th-5/U-5	Th-6/U-6
Upper valley	10.06	8.10	6.50	6.84	7.44	28.20
	9.64	8.91	7.03	5.34	15.34	8.90
	10.00	8.11	5.31	6.62	2.21	4.34
	5.95	11.16	6.03	4.76	7.53	7.33
	6.46	4.97	4.15	4.13	5.26	1.48
Middle valley	2.10	3.74	3.32	3.11	0.67	1.15
	6.39	4.16	3.92	4.41	7.70	3.34
	4.49	2.42	4.36	2.74	2.56	0.71
	3.14	2.64	2.36	1.90	1.47	0.93
	2.15	1.22	2.78	1.40	0.72	0.68
Lower valley	0.51	1.08	0.86	1.08	0.66	0.58
	2.11	2.58	1.96	3.15	0.81	0.74

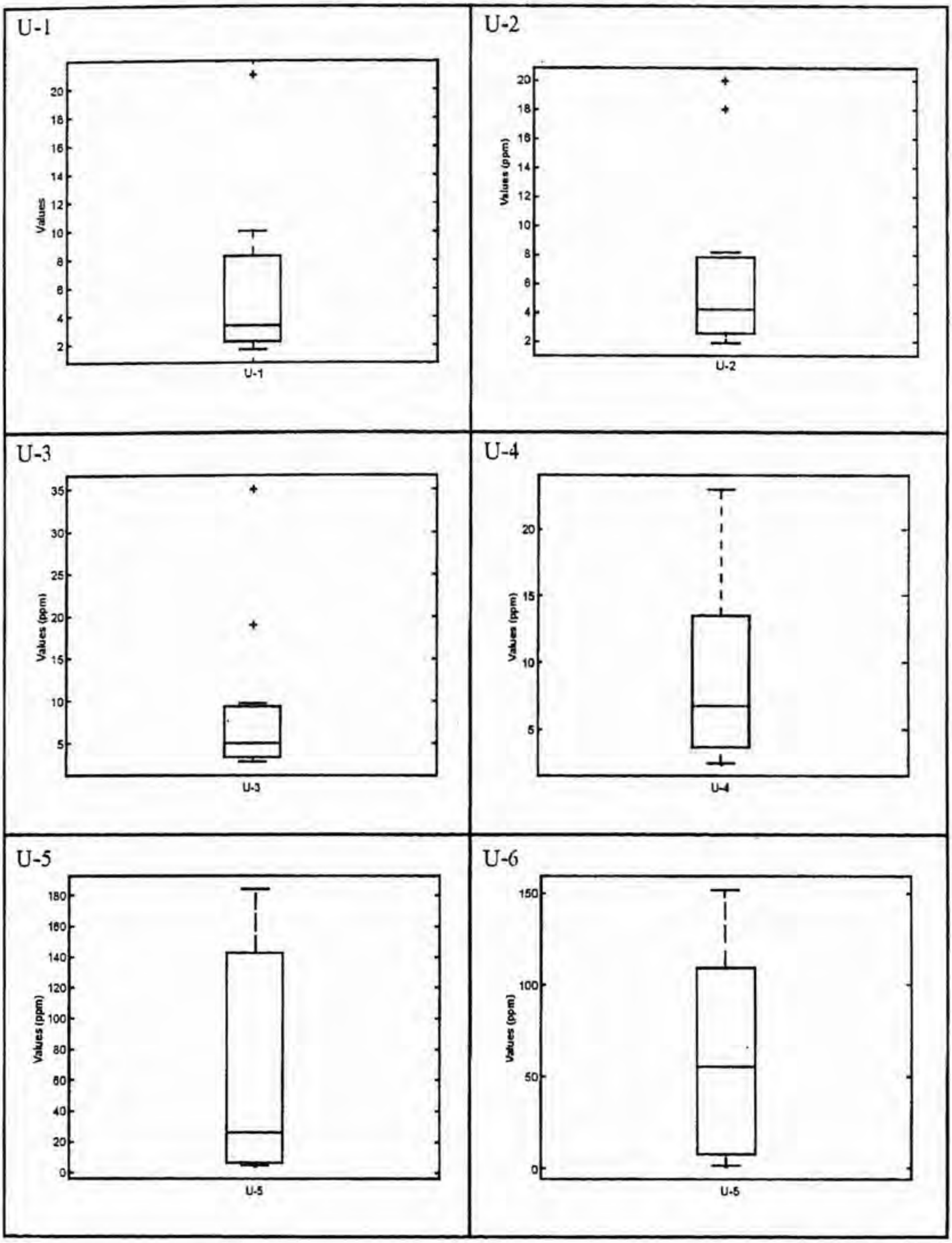
APPENDIX 2a BASIC STATISTICAL SUMMARY OF U IN STREAM SEDIMENTS (IN PPM)

	Coarse Fraction 125-180 μm		Fine Fraction 63-125 μm		Pancon	
	High Energy	Low Energy	High Energy	Low Energy	High Energy	Low Energy
	U-1	U-2	U-3	U-4	U-5	U-6
N	12	12	12	12	12	12
Mean	5.9	6.8	8.9	9.2	65.2	62.0
Geo. Mean	4.3	5.0	6.3	7.0	27.2	31.1
Median	3.4	4.2	5.0	6.8	26.0	55.0
Std. Dev.	5.6	6.1	9.4	7.2	74.6	55.0
Kurtosis	4.7	1.5	5.7	0.0	-1.3	-1.3
Skewness	2.0	1.6	2.4	1.1	0.8	0.5
Minimum	1.7	1.9	2.8	2.5	5.0	1.5
Maximum	21.0	20.0	35.0	23.0	184.0	152.0
Q-1	2.3	2.7	3.5	3.8	6.4	7.8
Q-3	8.2	7.7	9.3	13.3	135.5	103.5

APPENDIX 2b. BASIC STATISTICAL SUMMARY FOR U IN TALUS FANS (IN PPM)

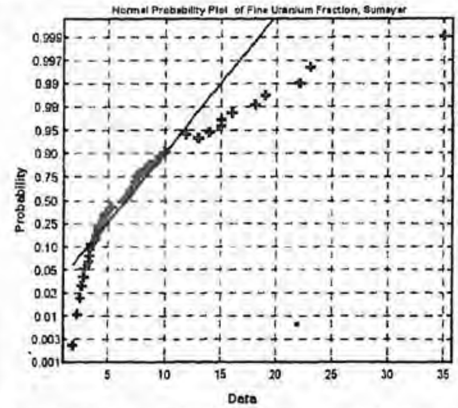
	Coarse Fraction	Fine Fraction	Very Fine Fraction
	125-180 μm	63-125 μm	<63 μm
N	12	12	12
Mean	19.0	9.6	8.4
Geo. Mean	17.2	8.7	7.6
Median	21.0	8.0	7.0
St. Dev	8.0	4.4	4.4
Kurtosis	-0.5	-0.4	-0.1
Skewness	0.1	0.7	1.1
Minimum	7.0	4.1	3.8
Maximum	34.0	18.0	17.0
Q-1	11.8	7.2	5.6
Q-3	20.5	8.2	6.8

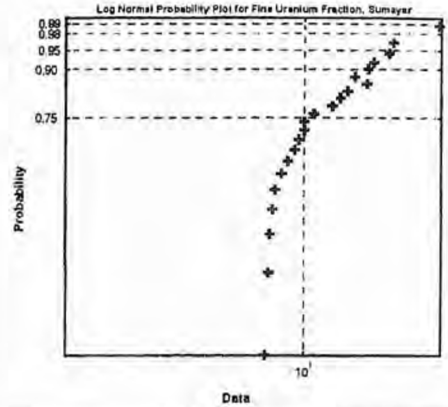
APPENDIX 3. BOX PLOT DIAGRAMS FOR STREAM SEDIMENTS URANIUM FRACTIONS



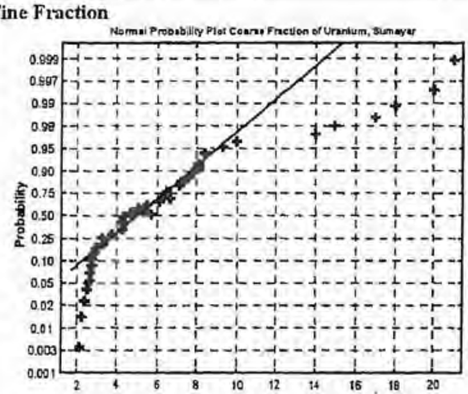
APPENDIX 4. NORMAL AND LOG NORMAL DISTRIBUTION OF U IN THE SUMAYAR VALLEY

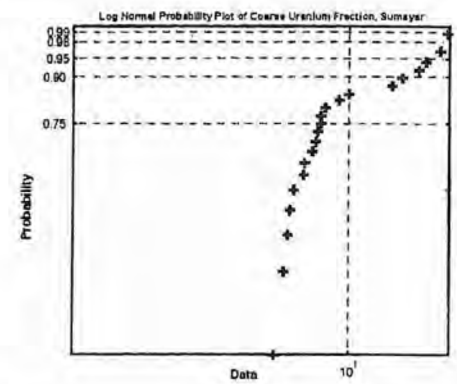
Coarse Fraction



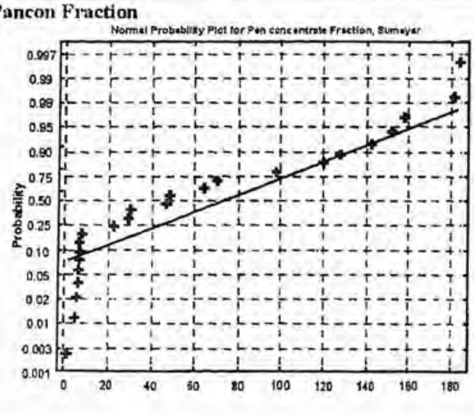


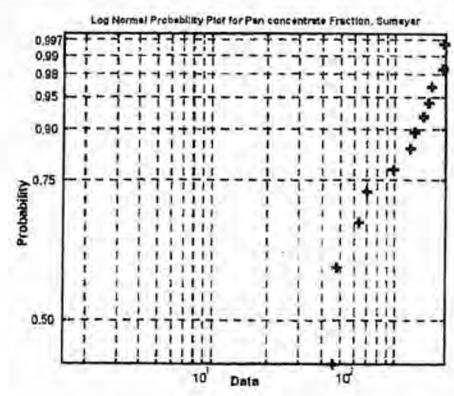
Fine Fraction





Pancon Fraction





APPENDIX 5. BOX PLOTS FOR COARSE, FINE AND PANCON SEDIMENTS, SUMAYAR