Geol. Bull. Univ. Peshawar, Vol. 37, pp. 41-57, 2004

Geochemical exploration in the Dir and Swat Kohistan, northern Pakistan

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ABSTRACT: *The Dir and Swat Kohistan cover an area of about 10,000 Sq Km in northern Pakistan. The major portion of the study area is comprised of rocks of the Kohistan Island arc while the rest of the area is composed of the rocks of the Indo-Pakistan plate. Both these terrains are separated by the Indus suture melange zone, which represents the collision suture between the Indo-Pakistan and Eurasian plate.*

Initial identification and delineation of mineral anomalies in the Dir and Swat Kohistan has been carried out by using heavy-mineral panned concentrates and stream sediment sampling from various drainage basins. Mineralogical studies of the heavy-mineral concentrates suggest the presence of gold in the form of piece, speck and color in certain drainage basins, however, no nugget of gold has been found.

The samples of both heavy-mineral concentrates and stream sediments have been analyzed for Cu, Zn, Pb, Cr, Ni, Mo, Sn, W, As, Sb, Bi, Ba, Th, U, Au, Ag and Pt by ICP-MS and AA techniques. These elements were processed by the geostatistical map-analysis technique to: (a) display broad-scale regional distribution of the elements on the basis of single element consideration (b) delineate anomalous areas of most interest for further follow-up. Some of the elements, especially Au, Ag and Pt, show high anomalous values in heavy-mineral panned concentrates which could be related to a specific mineralization either within the Indus suture melange zone or Indo-Pakistan plate. The present study suggests that the areas proximal to the Indus suture have potential for gold, silver, platinum and base metal mineralization. Detail goechemical mapping in these areas is, therefore, recommended for further follow-up.

INTRODUCTION

In recent years the northern part of Pakistan attained greater interest with respect to tourism and geological research due to its highest mountain ranges and longest glaciers of the world. This region is situated at the junction of the Hindu Kush, Karakoram and Himalayan Ranges, which has a complex geotectonic history. For the last two decades, extensive work on the north Pakistan has been carried out to understand the tectonic history of the region. Presently this part of Pakistan is now geologically very well known (Searle & Khan, 1996; Kazmi & Jan, 1997). However, very little work has been done on the exploration of gold and precious metals in this region before 1992. As regional mapping of surficial geochemical data is an important tool in mineral resource evaluation, it was the first time in Pakistan that a regional drainage geochemical exploration has been started on reconnaissance basis in the northern part of Pakistan in 1992 under the Australian Agency for International Development (Sweatman et al., 1995). Since then the two main organizations of Pakistan, the Pakistan Mineral Development Corporation (PMDC) and the Sarhad Development Authority (SDA) are involved in sampling of stream sediments. Recently the drainage samples collected by the PMDC and SDA covering some 100,000 square kilometers in the northern Pakistan have been analyzed and interpreted for multi-elements (31 elements, including Au, Pd and Pt) by Minorco Service BV (Halfpenny & Mazzuchelli, 1999).

On the basis of the studies by Shah (1997), Shah et al. (1998) and Shah and Shervais (1999) the drainage sediments exploration in the Dir and Swat Kohistan has been carried out in collaboration with the Nevada Bureau of Mines and Geology, University of Nevada, Reno, USA in the framework of a Fulbright Fellowship program. As the different sampling media of drainage basins have important chemical differences (Devenport 1990; Bellehumeur et al., 1994), the present study is mainly based on the geochemical investigations of two important sampling media (i.e., heavy-mineral concentrates and -80 mesh stream sediments) of the drainage basins. In order to establish the geochemical anomaly in the drainage sediments, bedrock analyses have also been performed. The main objective of this study is to delineate areas showing significant anomalies of precious metals (especially, Au, Ag, & Pt) and base metals. This will help in further follow-up and delineation of the source rock.

GEOLOGY OF THE AREA

The study area is located in the northern part of Pakistan (Fig.1) and is comprised of three tectonic units: the Kohistan island arc, the Indus suture melange zone and the Indo-Pakistan plate from north to south (Fig. 2). The geology of the northern part of Pakistan is the result of the collision of the Eurasian and Indo-Pakistan plates with the development of Kohistan island arc bounded by two northward dipping major sutures: the Northern Suture Zone (NSZ) in the north and the Main Mantle Thrust (MMT) or Indus suture melange zone in the south (Fig. 1).

It is now well established that the separation of the Indo-Pakistan subcontinent from the Gondwanaland occurred about 130 million years ago. This caused the rapid closure of Neo-Tethys ocean and the development of the two north dipping subduction zones. This intra-oceanic subduction resulted in the formation of the Kohistan-Ladakh arc. This arc, with continued subduction, accreted to the Eurasian plate along the NSZ between 80 and 100 Ma and formed an Andean-type continental margin. Continued subduction of the Neo-Tethys beneath the Kohistan-Ladakh arc and Eurasia resulted in the collision of the Indo-Pakistan plate with Eurasia along the Indus-Tsangpo-Suture Zone in the Eocene (55 Ma). This resulted in the formation of spectacular Himalayas along the Indo-Pakistan margin and also emplacement of ophiolites along the Indus-Tsangpo Suture Zone.

Most part of the study area is covered by the rocks of the Kohistan island arc in the north while the rocks of the Indus suture melange zone and the Indo-Pakistan plate occur in the most southern part of the study area (Fig. 2). The Kohistan island arc, an intra-oceanic arc, is mainly composed of plutonic and sedimentary rocks of Cretaceous to Tertiary age. In the study area the Kohistan island arc is mainly composed of the Kohistan batholith in the north, which comprises extensive intrusions of gabbro, diorite and granodiorite (Fig. 2). The southern part of the arc in the study area is composed of mafic and ultramafic rocks of the Chilas complex and amphibolites, meta-gabbro and orthogneisses of the Kamila amphibolites (Fig. 2). In the central part of the study area, the Kohistan island arc is, however, composed of NE-SW trending elongated belts of Utror volcanics, the Baraul banda slates and the Kalam group (Fig. 2).

The Indus suture melange zone or MMT in the study area demarcates the Kohistan island arc to the north from the Indo-Pakistan plate to the south (Fig. 2). This melange zone is mainly comprised of serpentinite melanges and high pressure blueschists along the hanging wall of the MMT. The Indo-Pakistan plate in the study area is mainly composed of Mesozoic meta-sedimentary rocks with lesser amount of Late Paleozoic greenschist and amphibolite facies meta-sedimentary rocks, Late Paleozoic-Cambrian quartzite and schists, Proterozoic metaclastic and meta-carbonate sedimentary rocks, Archean-Proterozoic granitic gneisses and quaternary sediments. These rocks within the study area are also intruded by the Late Paleozoic Ambela granitic complex, the Late Carboniferous to Permian Malakand granites and the Cambrian-Ordovician megacrystic granites of Swat and Mansehra.

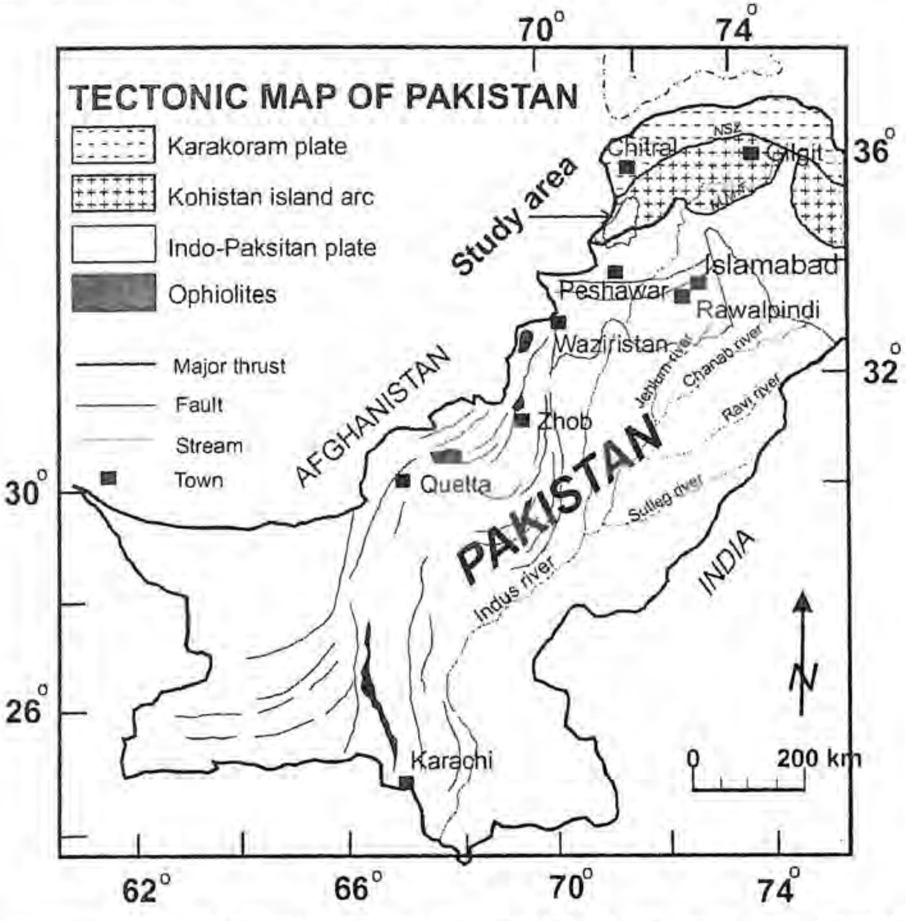


Fig. 1. Tectonic map of Pakistan showing the location of the study area (modified after Asrarullah et al., 1979).

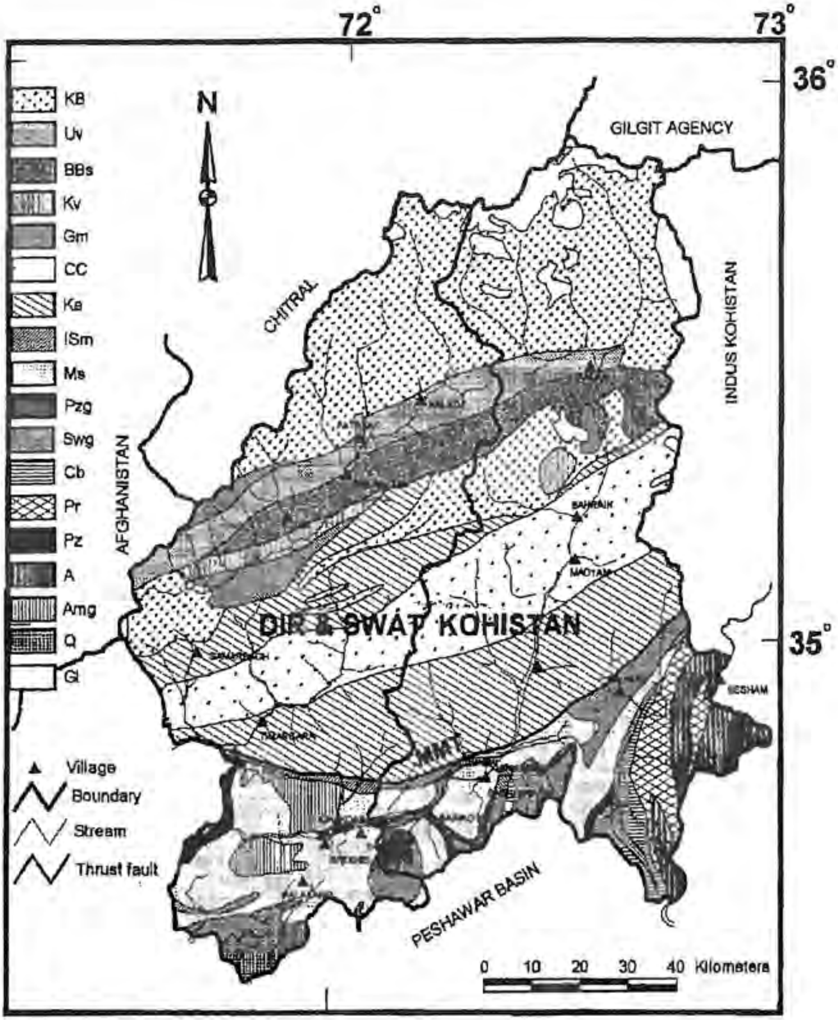


Fig. 2. Geological map of the Dir and Swat Kohistan (simplified after Searle & Khan, 1996). Kohistan island arc: KB = Kohistan batholith, UV= Utror volcanics of Dir Group, BBs = Baraul Banda Slates, Kv = Kalam Group, Gm = Gilgit Complex, CC = Chilas Complex, Ka = Kamila amphibolite complex; Indus Suture melange Zone: Ism = Indus Suture Melange zone; Indo-Pakistan Plate: Ms = Mesozoic metasedimentary rocks, Pzg = Late Paleozoic greenschist and amphibolite facies, Swg = Cambrian-Ordovician megacryst granite, Cb = Late Paleozoic-Cambrian quartzite and schist, Pr = Proterozoic meta-clastic and meta-carbonate sedimentary rocks, Pz = Paleozoic metasedimentary rocks, A = Archean-Proterozoic granite, Amg = Late Paleozoic or younger intrusion, Q = Quaternary alluvium, Gl = Glacier.

METHODOLOGY

Sample collection
Stream sediments and heavy-mineral panned concentrates are commonly the principal sampling media in regional reconnaissance geochemical surveys and are used to characterize the general geochemistry of the catchments and to delineate geochemical anomalies.

140 stream sediments (SS) and 140 heavy-mineral panned concentrates (PC) were collected from active stream channel sites in the study area. The surface area of catchment basins vary considerably, but most of the samples were collected at the outflow of catchment basins ranging from 10 to 70 km^2. Both sample media (i.e., SS & PC) were collected from each site by wet sieving. PCs were collected from the gravel traps. PC trap sites were usually on the side of drainage and were best developed where sediments were poorly sorted and contained a high fraction of compact clay in gravel. About 15 to 20 kg load was sieved to <850 μm (-20 mesh) and the heavy mineral concentrate was prepared by panning in gold pans. The stream sediment samples were obtained by sieving the clay size material to <177 μm (-80 mesh) size from the same site. The stream sediments and heavy-mineral panned concentrates were collected with the help of the prospecting team of the Mineral wing of the Malakand project of the Sarhad Development Authority, NWFP, Pakistan.

Chemical analyses
The magnetite fraction of all the PCs was separated using a magnetic separator. The magnetite free heavy-mineral concentrates were pulverized to <177 μm using a tungsten carbide mortar. Both sample types (i.e., PC & SS) were dissolved and extracted in hot aqua regia and hydrofluoric acid within advanced composite vessels using a microwave oven. The trace elements (i.e., Cu, Zn, Pb, Ni, Mo, Sn, W, As, Sb, Bi, Ba, Tl, Th, U, Ag, Pt and Pd) were analyzed by Inductively Coupled Plasma Spectroscopy (ICP-MS). Gold has been extracted by the organic medium (MIBK) and was determined by graphite furnace atomic absorption (AA). The analytical precision is generally $\pm$ 10% for all the elements analyzed by both ICP and AA techniques. The detection limit of each element is given in Table 1. The analyses were performed in the geochemistry laboratory of the Nevada Bureau of Mines and Geology, University of Nevada, Reno, USA.

Mineralogical studies of heavy-mineral concentrates
Mineralogical studies of heavy-mineral concentrates have been carried out mainly by a binocular microscope. Prior to that magnetic, fluorescent and radioactive minerals have been identified by using a Wike-magnet, ultraviolet light and geiger counter, respectively. Magnetite ($<65\%$) is the dominant fraction of all the heavy-mineral concentrates. The second major portion of heavy-mineral concentrate includes quartz, olivine, pyroxene, amphibole, garnet, feldspar, tourmaline, zircon, sphene, hematite and chromite. Rock fragments occur as minor constituents. In a few stream concentrates sulfides (i.e., pyrite, sphalerite and galena) and radioactive minerals (i.e., uraninite and thorite) have been observed.

Generally, the majority of the heavy-mineral concentrates are devoid of visible gold. However, some of the heavy-mineral concentrates collected, mainly in the south-eastern and south-western part of the study area (Fig. 3), contain visible gold in the form of "color" (<0.3 mm), "speck" (0.3-0.5 mm) and "piece" (>0.5 mm). No nugget of gold has been noticed. The pieces, specks and color are generally angular to subangular, occasionally irregular to rectangular in shape and bright yellow in color.

TABLE 1. SUMMARY STATISTICS FOR THE HEAVY-MINERAL PANNED CONCENTRATES AND STREAM SEDIMENTS FROM DIR AND SWAT KOHISTAN, NORTHERN PAKISTAN

Statistics	Cu ppm	Zn ppm	Pb ppm	Cr ppm	Ni ppm	Mo ppm	Sn ppm	W ppm	As ppm	Sb ppm
Heavy-mineral panned concentrates										
N	140	140	140	140	140	140	140	140	140	140
AVG	48	107	29	456	88	0.92	6	5	0.214	0.39
VAR	2007	8743	2353	89955	25363	1.69	103	1128	0.079	0.48
STD	45	94	48	298	159	1.30	10	34	0.281	0.69
CV	0.92	0.87	1.65	0.65	1.81	1.41	1.61	6.87	1.31	1.76
MAX	349	727	262	1710	1231	8.20	70.44	373.15	1.68	5.95
MIN	6	7	BDL	75.93	BDL	BDL	0.17	BDL	BDL	0.01
T.H.	150	350	125	1100	400	4	30	125	0.65	2
D.L.	5	5	5	5	5	0.05	0.01	0.05	0.05	0.01

Stream sediments

Statistics	Cu ppm	Zn ppm	Pb ppm	Cr ppm	Ni ppm	Mo ppm	Sn ppm	W ppm	As ppm	Sb ppm
N	140	140	140	140	140	140	140	140	140	140
AVG	42	47	7	32	61	0.25	0.22	0.35	5.46	0.09
VAR	315	445	23	1545	15549	0.04	0.437	0.84	29.84	0.006
STD	18	21	5	39	125	0.19	0.661	0.92	5.46	0.079
CV	0.43	0.45	0.66	1.24	2.04	0.77	3	2.60	1	0.87
MAX	110	135	45	317	1272	1	5.27	8.14	38.45	0.525
MIN	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
T.H.	100	130	40	150	450	1	2	3	25	0.35
D.L.	5	5	5	5	5	0.05	0.01	0.05	0.05	0.01

N = Number of samples, AVG = Average, VAR = Variance, STD = Standard deviation, CV = Coefficient of variance, MAX = Maximum, MIN = Minimum, T.H. = Threshold, D.L. = Detection limit, BDL = Below detection limit

(Table 1 continued)

Statistic	Bi ppm	Ba ppm	TI ppm	Th ppm	U ppm	Au ppm	Ag ppm	Pt ppb
Heavy-mineral panned concentrates								
N	140	140	140	140	140	140	140	140
AVG	1.67	75.41	0.43	48.53	14	0.49	1.55	4.51
VAR	13	10123	0.42	19227	2449	3	175	125
STD	3.58	100	0.65	139	48.99	1.68	13.23	11.19
CV	2.14	1.32	1.51	2.92	3.53	3.41	8.52	2.48
MAX	23.80	607	3.43	1371	456	13	144.00	129.09
MIN	0.01	6.07	BDL	0.280	0.122	BDL	BDL	BDL
T.H.	10	250	1.75	300	100	4	40	40
D.L.	0.01	5	0.01	0.01	0.01	0.005	0.05	10

Stream sediments

Statistic	Bi ppm	Ba ppm	TI ppm	Th ppm	U ppm	Au ppm	Ag ppm	Pt ppb
N	140	140	140	140	140	140	140	140
AVG	0.342	42	0.03	7.34	1.46	0.037	2.26	8.52
VAR	1.336	796	0.015	174.3	16.94	0.004	694	64.38
STD	1.156	28	0.121	13.20	4.12	0.062	26.34	8.02
CV	3.38	1	3.64	1.80	2.82	1.66	11.63	0.94
MAX	12.49	244	1.09	96.74	42.56	0.420	11.66	37.72
MIN	BDL	BDL	BDL	0.34	0.07	BDL	BDL	BDL
T.H.	4	150	0.40	50	20	0.20	0.80	30
D.L.	0.01	5	0.01	0.01	0.01	0.005	0.05	10

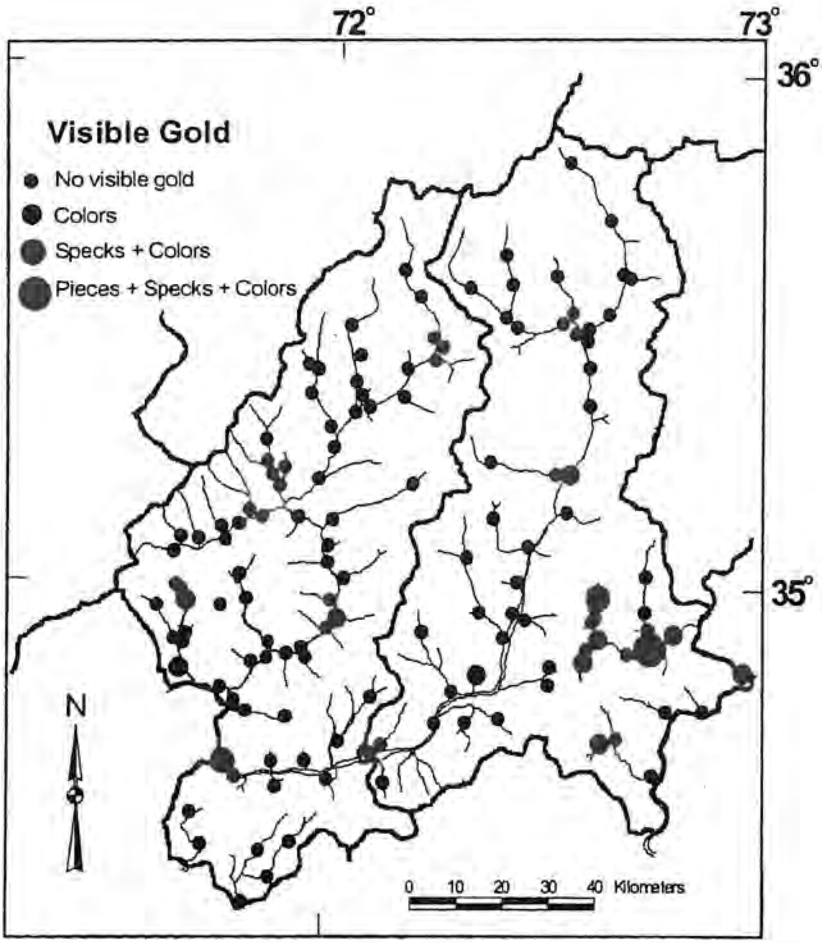


Fig. 3. Distribution map of visible gold in the heavy mineral panned concentrates of the study area.

RESULTS AND DISCUSSION

Reconnaissance stream sediments and heavy-mineral concentrates are usually carried out in the regions where the known mineral occurrences are not reported. It is, therefore, difficult to distinguish between background samples and anomalous samples due to the lack of control data or locations in these areas. Similar is the case with the interpretation of the SS and PC data covering about 10,000 km^2 of the Dir and Swat Kohistan in Pakistan. However, a simplified geological map (Fig. 2) of the area may provide a reasonable geological framework for the geochemical interpretation. This base is used for the interpretation of geochemical distribution of various elements in the following text.

In order to have comparative interpretation, the normalization of heavy-mineral concentrate data is necessary, especially in the case of those elements, which have nugget effect (e.g., gold). Therefore, PC results were first normalized to standard 100 gram sample weight and then treated statistically. The summery statistic of the 18 elements analyzed in both panned concentrates and stream sediments are given in Table 1. Statistical analysis (i.e., histogram, log-probability diagrams and factor analysis) of the geochemical data was applied to define locations of high metal concentration. In this paper we have delineated the places within the study area for which the mineralization is suggested by anomalous geochemical values.

Threshold values used for determination of anomalous concentration for each element of the different sampling media is given in Table 1. These values were determined by examination of statistical methods (mean plus twice the standard deviation), histograms and percentiles and evaluation of cumulative frequency distribution of elements (diagrams not shown here). The elemental populations are partitioned in to background, low and high anomalous populations for all the elements in both the sampling media and the class interval for data plotting were selected according to the procedures out lined by Sinclair (1976). Considering the statistical parameters, the data of all the eighteen elements were plotted on the geochemical maps. However, for the purpose of simplicity, the geochemical maps of 10 selected elements have been presented in this paper (Figs. 4 & 5), which show some meaningful results for mineral exploration in the area.

It is evident from the geochemical maps (Figs. 4 & 5) that almost all the elements have no consistency in their distribution in both PC and SS. Copper (Cu) shows low anomaly in the PC samples in some of the drainage basins (Fig. 4A) within the central part where mainly the kohistan batholith (KB), Utror volcanics (Uv), Kalam group (Kv), Barual Banda slates (BBs) and Gilgit complex (CC) of the Kohistan island arc are exposed (Fig. 2). One drainage basin in the south-western part, where the greenschist and amphibolitic rocks of the Indo-Paksitan plate are exposed near Malakand (Fig. 2), has high anomaly (348 ppm) for copper (Fig. 4A). However, stream sediments show no anomaly for Cu (Fig. 5A).

Zinc (Zn) shows high anomaly (up to 727ppm) in the PC samples of two drainage basins within the south- western portion of the study area (Fig. 4B) where the Mesozoic metasedimentary rocks (Ms) of the Indo-Pakistan plate are exposed (Fig. 2). No zinc anomaly has been observed in the SS (Fig. 5B). Lead (Pb) has similar distribution pattern as that of copper for the PC and SS samples by having low anomaly in the drainage basins within the central parts and high anomaly (262 ppm) in the south-western portion of the study area (Fig. 4C & Fig. 5C).

Geochemical map of Chromium (Cr) for the PC samples (Fig. 4D) displays both low and high anomalies (up to 170 ppm) in the drainage basins within and in proximity to the Indus suture melange zone along MMT. Low anomalies of Cr could be related to the mafic and ultramafic rocks of the Indus suture melange zone and Kamila amphibolites (Fig. 2). However, the high anomaly noticed in one drainage basin in the south-western part (Fig. 4D) could be related to chromite mineralization within the Chilas complex (CC) near Timargara (Fig. 2) as about 5% chromite grains are also noticed in this PC sample. Low anomalies of Cr in the stream sediments (Fig. 5D) of two drainage basins in the western portion of the study area could be related to the Utror volcanics (Fig. 2). Nickle (Ni) has more or less similar distribution pattern in PCs as noticed for chromium by having anomalies related to ultramafic rocks of the Indus suture melange zone in the south-eastern part of the study area (Fig. 4E & Fig. 2).

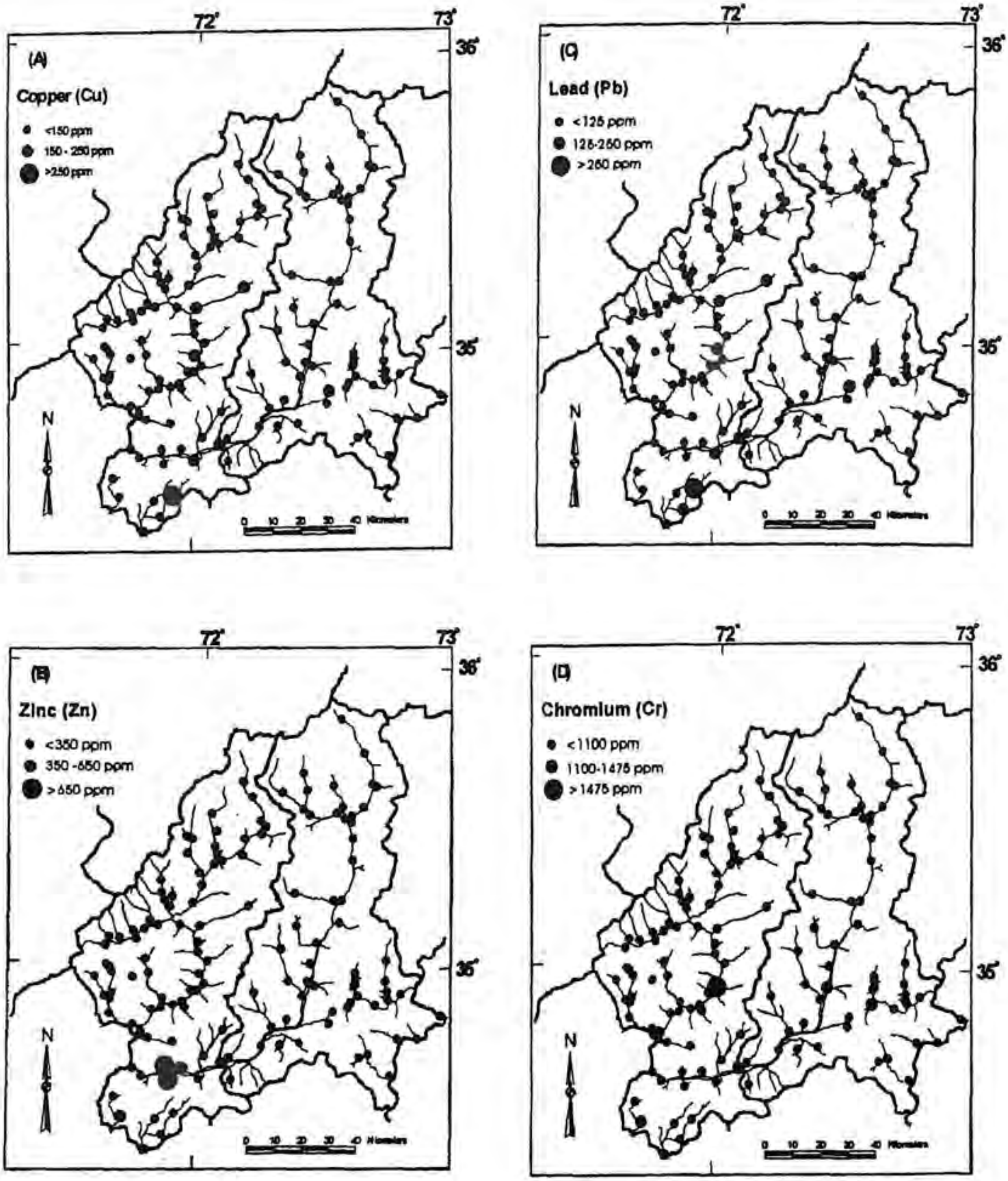
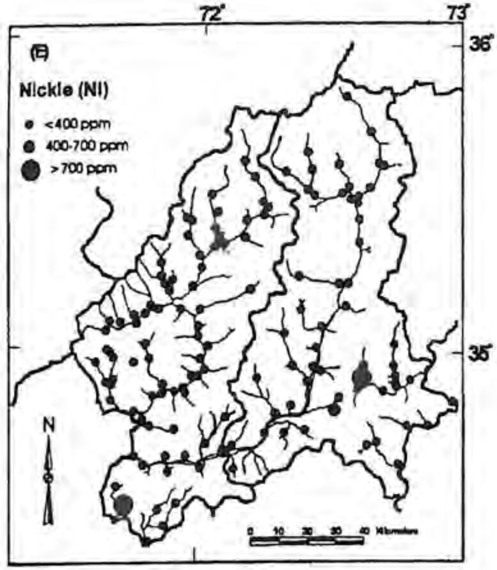
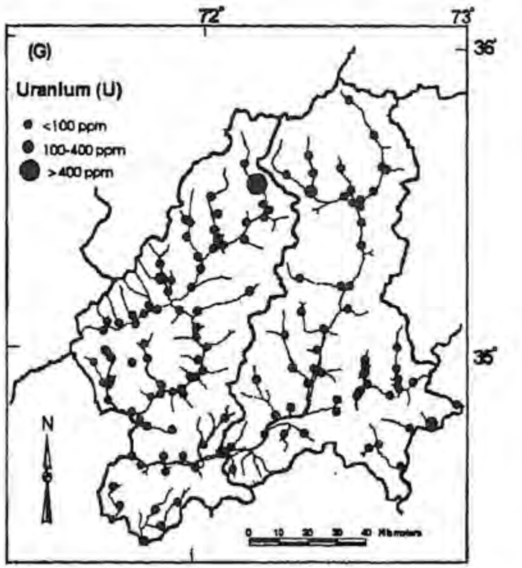


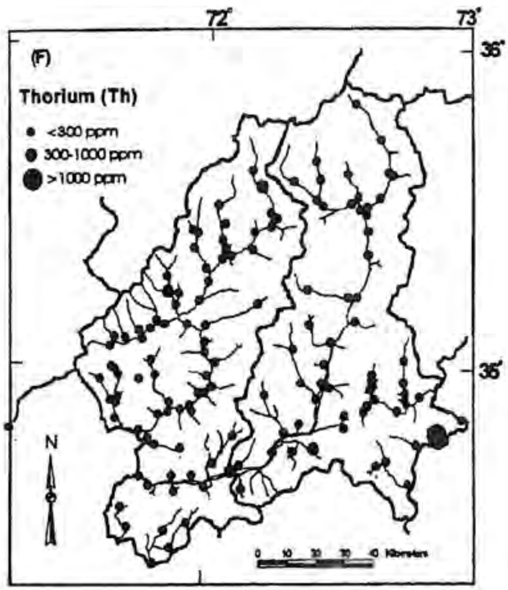
Fig. 4. Distribution map of Cu, Zn, Pb, Cr, Ni, Th, U, Au, Ag and Pt for the heavy mineral panned concentrates of the study area.



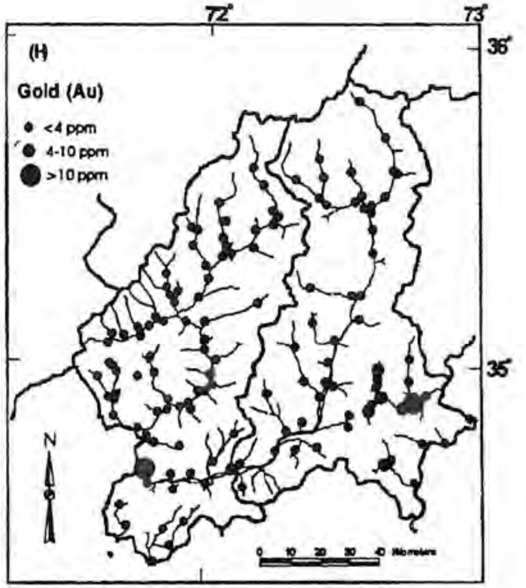
72°
73°
36°
35°
(E)
Nickle (Ni)
<400 ppm
400-700 ppm
>700 ppm
N
0 10 20 30 40 Kilometers



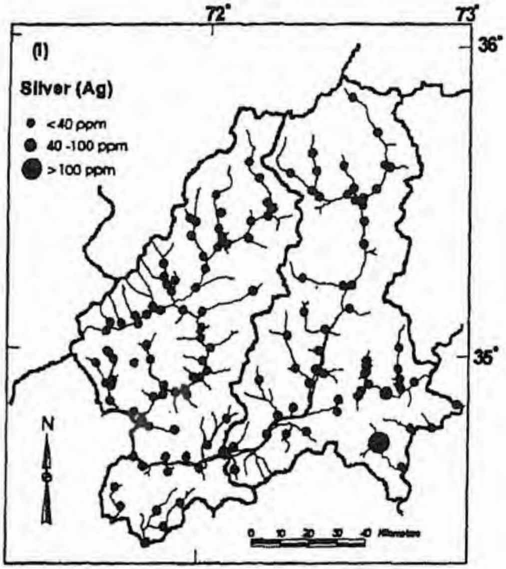
72°
73°
36°
35°
(G)
Uranium (U)
<100 ppm
100-400 ppm
>400 ppm
N
0 10 20 30 40 Kilometers

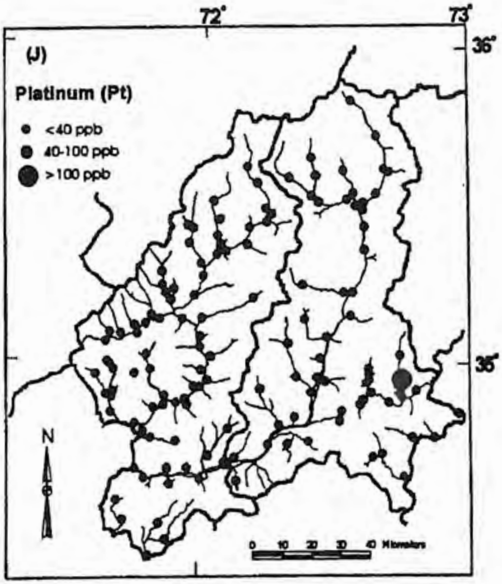


72°
73°
36°
35°
(F)
Thorium (Th)
<300 ppm
300-1000 ppm
>1000 ppm
N
0 10 20 30 40 Kilometers



72°
73°
36°
35°
(H)
Gold (Au)
<4 ppm
4-10 ppm
>10 ppm
N
0 10 20 30 40 Kilometers


72°
73°
36°
35°
(I)
Silver (Ag)
<40 ppm
40 -100 ppm
>100 ppm
N
0 10 20 30 40


72°
73°
36°
35°
(J)
Platinum (Pt)
<40 ppb
40-100 ppb
>100 ppb
N
0 10 20 30 40

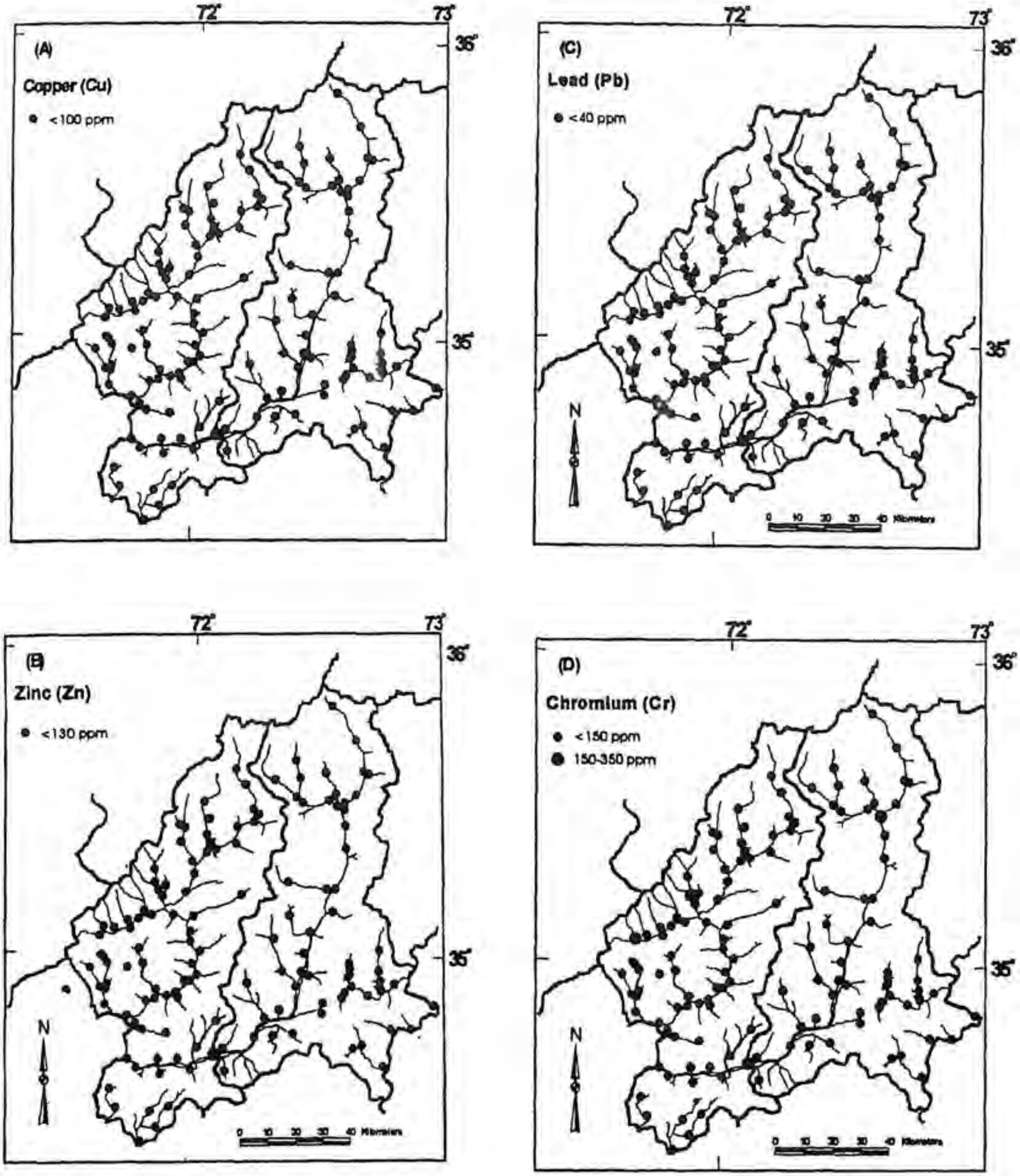
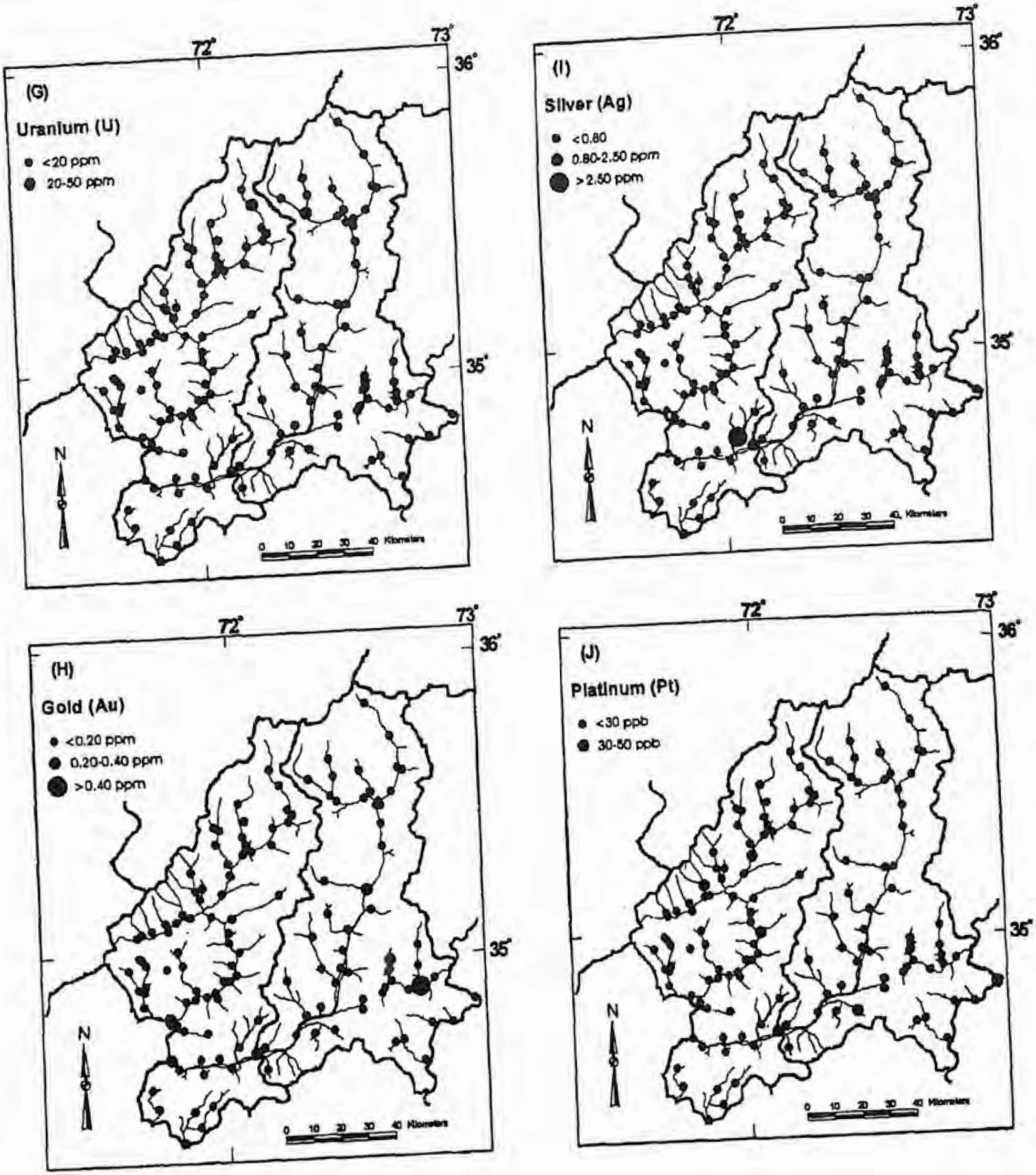
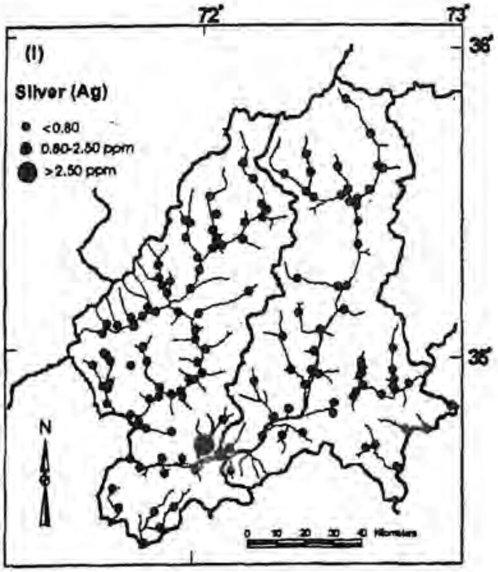
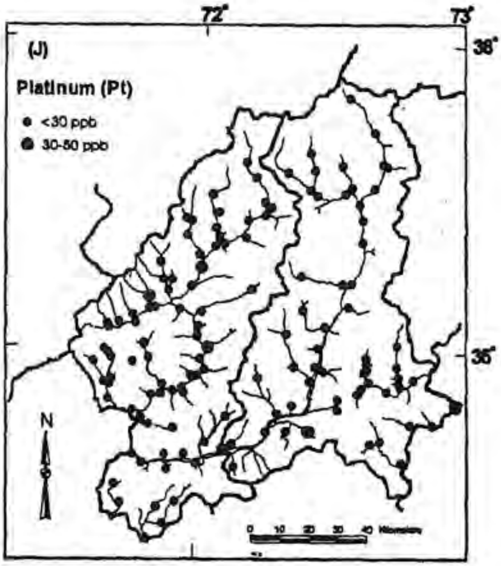


Fig. 5. Dirstribution map of Cu, Zn, Pb, Cr, Ni, Th, U, Au, Ag and Pt for the stream sediments (-80 mesh) of the study area.


(G)
Uranium (U)
<20 ppm
20-50 ppm
72°
73°
36°
35°
N
0 10 20 30 40 Kilometers
(I)
Silver (Ag)
<0.80
0.80-2.50 ppm
>2.50 ppm
72°
73°
36°
35°
N
0 10 20 30 40 Kilometers
(H)
Gold (Au)
<0.20 ppm
0.20-0.40 ppm
>0.40 ppm
72°
73°
36°
35°
N
0 10 20 30 40 Kilometers
(J)
Platinum (Pt)
<30 ppb
30-50 ppb
72°
73°
36°
35°
N
0 10 20 30 40 Kilometers





High anomaly of Ni observed in the drainage basin in the south-western portion (Fig 4E) is, however, related to the Dargai ultramafics of the Indus suture melange zone near Malakand (Fig. 2). No significant Ni anomaly has been observed in SS and rock samples (Fig. 5E & 6E).

Thorium (Th) and uranium (U) though have same radioactive character but show different distribution pattern in both the sampling media within the study area (Fig. 4F & G; Fig. 5F & G). High anomaly (up to 1371) of thorium has been observed in both PC and SS samples of one drainage basin in the south-eastern portion of the study area near Besham (Fig. 4F & 5F), where the Archean-Proterozoic granites of the Indo-Pakistan plate are exposed (Fig. 2). High anomaly (455 ppm) of uranium has been noticed in the PC sample of one drainage basin (Fig. 4G) within the Kohistan batholith of Kohistan island arc in the northern most portion of the study area (Fig. 2). However, no significant anomaly for U has been noticed in the SS (Fig. 5G). In general Uranium and thorium concentrate in the fine-fraction of the stream sediments (Wenrich-Verbeek, 1976) but in the study area both uranium and thorium show high values in the heavy-mineral concentrates relative to SS (-80 mesh). This indicates that both uranium and thorium occur as uranium and thorium-bearing accessories such as uraninite, thorite and zircon in the heavy-mineral concentrates (Wenrich-Verbeek, 1977). This is also consistent with the mineralogical studies of the heavy-mineral concentrates.

Gold (Au) distribution pattern is more or less similar in both heavy-mineral concentrates and stream sediments. Gold anomalies in both PC and SS samples are observed in two drainage basins; one in the south-eastern and another in the south-western portion of the study area (Fig. 4H & 5H). These anomalies are associated with the mafic and ultramafic rocks of the Indus suture melange zone and the metasedimentary rocks of the Indo-Pakistan plate near Besham (Fig. 2). Silver (Ag) displays high anomaly (up to 144 ppm) in one PC sample (Fig. 4I) and one SS sample (Fig. 5I) in different drainage basin in the south-eastern and south-western part of the area respectively within the Indo-Pakistan plate (Fig. 2). Platinum (Pt) displays high anomaly (129 ppb) in one PC sample of the drainage basin in the south-eastern part of the study area (Fig. 4J) where from the high anomalies are also observed for gold. This suggests the same source (i.e., mafic and ultramafic rocks) for Au and Pt.

The comparison of the geochemical maps of various elements with the geological map in above discussion defines certain areas within the Indus suture melange zone and the Indo-Pakistan plate that may have mineral occurrences, especially for Au, Ag and Pt. These could be associated with mafic and ultramafic rocks of the Indus suture melange zone and or the metasedimentary rocks of the Indo-Pakistan plate. Platinum-group elements and gold anomalies in the adjacent areas have also been reported by previous workers (Miller et al., 1991; Arif & Moon, 1996; Suzuki & Khan, 1992). These areas, therefore, have the potential for precious metals and need further follow-up studies.

The geochemical distribution of elements and statistical parameters further suggest that the values for almost all the elements are relatively higher in the panned concentrate samples than those of stream sediments. This indicates that the PCs are enriched in both heavy-mineral and sulfides such as pyroxene (Fe, Cr), olivine (Ni, Cr) amphibole (Ti, Mn, Fe), magnetite (Fe, Ti, V), chromite (Cr, Fe), chalcopyrite (Cu, Fe), galena (Pb), sphalarite (Zn), uraninite (U) and gold in the form of pieces, specks, and colors as also noticed in the mineralogical studies. Generally base metals occur in the silicate and sulfide phases of bedrock of which silicates are more stable than sulfides in the stream environment. Therefore, the surficial processes are usually responsible for the concentration of these metals in the fine-fraction (-80 mesh) of stream sediments, which are derived from the less resistant minerals such as sulfides. The lower amount of even Cu, Zn and Pb, in the studied stream sediments is, therefore, unlikely. This unlikely behavior of the base metals could be attributed to the high energy environment due to rapid uplift encountered in the mountainous terrain of the region, where mechanical weathering processes are much more important than chemical weathering. This favor the concentration of heavy minerals along with sulfides in the PC samples rather than in the fine-fraction of SS samples in the study area. This study, therefore, emphasize that heavy-mineral panned concentrates could be the right medium to delineate areas of interest, especially for precious metals, during follow-up studies in the area.

CONCLUSIONS

Following conclusions are made during this study:

1. No consistent suite of geochemical distribution is noticed in the heavy-mineral concentrates and stream sediments in the drainage basins of the Dir and Swat Kohistan.
2. The heavy-mineral concentrates were determined to be the most effective medium in the differentiation of most favorable areas, especially for Au, Ag, and Pt mineralization in the study area.
3. Discrete areas of interest are identified within the Indus suture melange zone and adjacent Indo-Pakistan plate on the basis of their geologic distributes and geochemical data of heavy-mineral concentrates and stream sediments for further follow-up.

Acknowledgements: We would like to thank the Sarhad Development Authority (SDA), Peshawar, Pakistan for providing assistance during field work and also for providing most of the heavy-mineral concentrates and stream sediments samples from its collections. The geologists, especially Nawaz Khan, Noroz Khan and Ali Sarwar, of SDA are also thanked for their help in collection of stream sediment samples during field. The NCE in Geology, University of Peshawar and the University Grants Commission, Islamabad, Pakistan are highly acknowledged for financial support during field work. We are thankful to the Nevada Bureau of Mines and Geology, University of Nevada, Reno, USA for providing the geochemical and computer facilities. The first author was supported by Fulbright Fellowship Program for his nine months stay at Reno, USA to carry out this research which is highly acknowledged.

REFERENCES

Arif, M. & Moon, C.J., 1996. The platinum-group element geochemistry of chromitites and silicate rocks from Swat, north-western Pakistan. Geol. Bull.Univ. Peshawar, 29, 1-8.

Asrarullah, Ahmad, Z. & Abbas, S.G., 1979. Ophiolites in Pakistan: An introduction. In: Geodynamics of Pakistan (A. Farah and K.A. DeJong, eds). Geol. Surv. Pak. Quetta, 181-192.

Bellehumeur, C., Marcotte, D. & Jebrak, M., 1994. Multi-element relationship and spatial structures of regional geochemical data from stream sediments, south-western Quebec, Canada. J. Geochem. Explor., 51, 11-35.

Davenport, P.H., 1990. A comparison of regional geochemical data from lakes and streams in northen Abrador: implication for mixed-media geochemical mapping. J. Geochem. Explor., 39, 117-151.

Halfpenny, R. & Mazzucchelli, R.H., 1999. Regional multi-element drainage geochemistry in the Himalayan mountains, northern Pakistan. J. Geochem. Explor., 67, 223-233.

Kazmi, A.H. & Jan, M.Q., 1997. Geology and tectonics of Pakistan. Graphic publishers, 554p.

Miller, D.J., Loucks, R.R. & Ashraf, M., 1991. Platinum-group element mineralization in the Jijal layered ultramafic-mafic complex, Pakistani Himalayas. Econ. Geol., 86, 1093-1102.

Searle, M.P. & Khan, M.A., 1996. Geological map of N. Pakistan and adjacent areas of northern Ladakh and western Tibet. AMOCO. Shell, BHP Sponsored Publication.

Shah, M.T., 1997. Mineralogy, texture and geochemistry of the volcanic hosted hydrothermal copper mineralization in Dir area, Kohistan arc terrain, northern Pakistan. In: Geology in South Asia-II (N. P. Wijayananda, P. G. Coory & P. Mosley, eds.). Geol. Surv. Min. Burea. Sri Lanka, Prof. Pap., 7, 263-289.

Shah, M.T. & Lechler, P.J., 2002. Gold anomalies in the Dir and Swat Kohistan, northern Pakistan. J. Sci. Tech. Univ. Peshawar, 26(1&2): 1-6.

Shah, M.T., Sarwar, A., Ahmad, W. & Siddiqui, S.A., 1998. Litho and stream sediments geochemical studies for gold and base metals in areas around Timargara and Samarbagh, district Dir, northern Pakistan. Acta Mineralogica Pakistanica 9, 37-54.

Shah, M.T. & Shervais, J.W., 1999. The Dir-Utror metavolcanic sequence, Kohistan arc terraine, northern Pakistan. J. Asian Earth Sci., 17, 459-475.

Sinclair, A.J., 1976. Application of probability graphs in mineral exploration. Assoc. Explor. Geochem. Spec. vol., 4, 95p.

Suzuki, M. & Khan, S.R., 1992. Geochemical exploration in Jijal area. Proceedings of Geosciences Colloquium, Geoscience Laboratory. Geol. Surv. Pakistan, 2, 79-109.

Sweatman, T.R., Clavarino, J.G. & Dawney,

R.L., 1995. Drainage geochemical exploration and mineral potential of Northern Pakistan. Unpub. report Assoc. Austr. Agen. Intern. Develop.
Wenrich-Verbeek, K.J., 1976. Water and stream sediment sampling techniques for use in uranium exploration. U.S. Geol. Surv. Open File Report, 76-77, 30p.
Wenrich-Verbeek, K.J., 1977. Uranium and coexisting element behavior in surface waters and associated sediments with varied sampling techniques used for uranium exploration. J. Geochem. Explor., 8, 337-355.