URANIUM DISTRIBUTION IN GRAPHITIC-METAPELITES IN THE PRECAMBRIAN FORMATIONS OF AZAD KASHMIR AND NW PAKISTAN

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ABSTRACT

The graphitic-metapelites of NW Pakistan and Azad Kashmir are exposed in a zone of thrust tectonics, and are scattered in the form of continuous beds and lenses in various nappes. These are highly radioactive at places but the equivalent chemical uranium is found to be lower than its radiometric equivalents. This form of negative disequillibrium is produced due to the presence of daughter products of U, Th and K^{40}. The chemical composition of the graphitic-metapelites indicates that the rocks from Tarbela area are more siliceous and contain more organic carbon compared to the rest of the exposures of the graphitic-metapelites. Due to their fine grain-size, dark colour, and Fe oxidation along fractures, the rock types are classified as black shales. According to the classification of Stribrny et al., 1988, the graphitic-metapelites from Tarbela area are siliceous and those from other areas are dominantly argillaceous-siliceous with high normative quartz.

Uranium associated with other elements is concentrated in the upper part of the graphitic-metapelites and unlike typical black shale deposits do not indicate any corelation with organic carbon. The absence of relationship is primarily caused by the dissolution of some of the elements in groundwater circulating freely in the otherwise impermeable rock made permeable by the structural movements in the region. Compared to metal rich black shale deposits, these rocks are enriched in U, V, Ba and Pb. The enrichment of some of the elements

took place in association with the detrital fraction of the rock while the rest of the enriched elements were concentrated from normal seawater in oxygenated transitional environment close to the continent. The graphitic-metapelites were probably deposited in a basin fed by different source material.

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Chapter-1

INTRODUCTION

1.1 General Statement

The region bounded by MMT (Indus suture zone) in the north and MBT (Main Boundry Thrust) in the south in NW Pakistan and adjacent parts of Azad Kashmir represents the leading edge of the Indian plate. Exposures of graphitic-metapelites are widely scattered in the Precambrian formations of the region in various nappes. These rocks are in the form of continuous beds, lenses and streaks and are associated with evaporite deposits represented by gypsum/anhydrite.

The graphitic-metapelites are fine-grained, dark coloured due to organic carbon and indicate strong iron oxidation particularly along fractures. These are metamorphosed in the green-schist and amphibolite facies conditions. In Reshian area retrograde amphibolite facies rocks are also associated with the graphitic-metapelites. Petrographic study of the rocks reveals a predominance of quartz along with carbonaceous matter and graphite.

The graphitic-metapelites are invariably radioactive and display a higher background radioactivity than their associated rocks. Higher radioactivity has been recorded at Reshian and Tarbela areas while at Kaghan and Thana areas, the radioactivity is comparatively low. The radioactivity is due to the presence of uranium, thorium, their daughter products and K^{40}. The daughter products gave rise to a high order negative disequilibrium. Seasonal variation in radioactivity has also been observed.

The geochemical composition of the graphitic-metapelites indicates that the rocks from Tarbela area are more siliceous and less aluminous compared to the other areas. These are also high in organic carbon while the least organic carbon has been analyzed in the samples from Kaghan Valley. Compared to trace-element composition of the average black shale, the studied graphitic-metapelites are more enriched in Ba, V, and Pb. The U-content of the rocks is in the range of U-rich black shale deposits. Uranium and the other associated elements are enriched in the upper part of the graphitic-metapelites, below the evaporite sequence. The elements in the graphitic-metapelites are regarded as deposited from normal seawater in a transitional environment close to the continent at the time of the deposition of the rocks.

Correlation of the trace elements with organic carbon is poor. U is adsorbed on the surface of the decaying organic matter. Trace elements Vs. Organic carbon and sulpher ratios are high for the graphitic-metapelites as compared with the standard black shale ratios. Higher ratios reflect that sulphidization of Fe by hydrogen sulphide may have played an important part in the deposition and concentration of the elements in the rocks. However, multiple agents must be involved in concentration of the elements including uranium in the upper part of the rocks.

The behaviour of subsurface radioactivity indicates that below the zone of weathering radioactivity corresponds to the equivalent chemical grade of uranium. Supergene uranium concentration is, however, not favoured because large scale mobilization of uranium does not seem probable.

The graphitic-metapelites are classified on a double triangle with corners represented by Q (quartz) P (phyllosilicates) and C (carbonates plus the remaining minerals). The classification adopted in this thesis is modified after Stribrny et al's.,(1988) double triangle classification of sedimentary rocks.

1.2 Previous Work

The Precambrian formations hosting the graphitic-metapelites include Salkhala series in Azad Kashmir and northern Hazara region, the Manki formation of Tarbela in southern Hazara, and the Swat-Buner schistose group (Alpurai schists) in Malakand area These have been mapped and studied by previous workers including Wadia (1957), Martin et al., (1962), Tahirkheli (1971), Calkins et al., (1975), Kazmi et al.,(1984), Greco (1986), Bossart et al.,(1988) and Hylland et al.,(1988).

Salkhala series was originally named by Wadia (1961) after Salkhala village on the Kishinganga river in Kashmir, and he was the first to apply the name syntaxis to the sharply curving mountainous structure known as Hazara-Kashmir syntaxis. Later workers correlated the Salkhala Series with the Jutogh Series of Simla (Butt et at.,1978). Calkins et al., (1975) described Salkhala Series in Hazara and also mapped it at the western bank of Indus river near Tarbela Dam. Later workers subdivided the series into Sharda group north of Batal fault and confined Salkhala to the lower Kaghan Valley (Ghazanfar et al. 1986). Greco (1986) mapped Salkhala Series at Reshian in Jhelum valley and described its deformation and metamorphism. Bossart et al., (1988) carried-out studies on the formation of the Hazara-Kashmir syntaxis and described the lithology of the various formations in and around the syntaxis. Tahirkheli (1979) described many outcrops west of the Indus river in Swat, Dir, Malakand and Mohmand areas and correlated them with Salkhala Series on lithological basis.

Martin et al's.,(1962) Lower Swat-Buner schistose group has been subdivided by Kazmi et al.,(1984) into Saidu and Alpurai schists. They also described Manglaur crystalline schist intruded by Swat granite gneiss as the basement sequence unconformably overlain by the platform sediments of Saidu and Alpurai schists.

In Tarbela area Tahirkheli was the first to map the geology at Gandghar range. Calkins et al., (1975) mapped the precambrian Hazara Formation and Carboniferous to Triassic Kingriali Formation in the sourthern Gandghar range. The name Hazara Formation was later applied only to the rocks exposed in Kherimar Hill succession in southern Hazara while the rock types above Bagh-darra fault were named as Manki formation (Hylland et al., 1988).

Radioactivity has been found associated with the graphitic-metapelites by the geologists of the Atomic Energy Commission (Rehman et al., 1981 ; Butt et al., 1988). It was reported that some areas are highly radioactive compared to others, but the equivalent chemical uranium was always found low.

1.3 Scope of the Present Work

The present work aims at the study of uranium distribution in the graphitic-metapelites of NW Pakistan and the adjoining state of Azad Kashmir. The area hosting uranium anomalies is characterized by recent tectonic activity. Causes of low chemical uranium against high radioactivity are investigated in the light of the study of the rocks associated with the anomalous graphitic-metapelites. Geochemistry is used to classify the graphitic-metapelites in accordance with the classification of the black shales forwarded by Stribrny et al., (1988). Uranium and other metals/elements are plotted to find-out the control of uranium mineralization in the area. The various concentrating agents of uranium and other associated metals/elements are investigated. The graphitic-metapelites were deposited in a transitional environment which was not purely euxinic.

Chapter-2

REGIONAL GEOLOGICAL SETTING

2.1 Introduction

The geology of the northern area of Pakistan is characterized by Cenozoic tectonic activity, Known as Himalayan Orogeny. The Himalayan orogenic evolution has led to the formation of the greatest mountain chains of the world, stretching from Assam through Himalayas, Karakoram and Hindukush to Afghanistan. The mountain chain assumes an arcuate fashion within the Pakistan Himalayan domain. The formation of the mountain chain was first explained by the idea of a southward creep of the Asian crust (Wadia, 1961). Later workers supported the idea of a northward movement of the Indian continent and consequent subduction under the Asian landmass (Dewy and Bird, 1970). They explained the strong seismic activity across Tibet in the light of the plate tectonic Theory. It is considered that Paleo-Tethyan Ocean with its carbonates separated the Indian and the Eurasian plates. As the Indian plate moved northward, a Tethyan geosyncline developed, which subsequently transformed into Himalayas. The suture line where India collided with Asia is termed as northern-Megashear or the Main Karakoram Thrust (MKT). Later workers identified the presence of a former Island Arc (Kohistan Island Arc) and reported another suture, termed as the Main Mantle Thrust (MMT) Tahirkheli, 1979).

The Indian Plate collided with Eurasian Plate in the Early Eocene about 50 ma (Patriat and Achache, 1984) and continued closure at the rate of 5cm/year (Malinconico,1989). Such a tectonic model requires 2000 Km of crustal shortening. In Pakistan only 500-700 Km crustal shortening was calculated to have taken place with balance cross-section method (Coward et al.,1987, Coward & Butler, 1985). In another attempt based on the volume of the crust that remains in the orogen, Malinconico (1989) suggested 550-1100 Km of shortening that has taken place in the Pakistan Himalayas. It appears that less than 2000 Km of shortening has taken place in the Pakistan Himalayas or the balance of closure is accounted for by erosion and/or diffuse deformation (Malinconico, 1989).

Subsequent to the development of the MMT, a great structural loop was formed around the Nanga-Parbat-Haramosh massif. The Hazara-Kashmir syntaxis developed during Oligocene-Miocene. The Main Boundary Thrust (MBT) developed in Pliocene some 13-10 Ma age (Tahirkheli, 1979).

The leading edge of the Indian Plate was extensively deformed during the Himalayan collision. Treloar (1989), while describing the deformation chronology for the internal zones of the northern margin of the Indian Plate, has defined the following three major structures:

a) Structures generated in the footwall of the Main Mantle Thrust (MMT) during southward

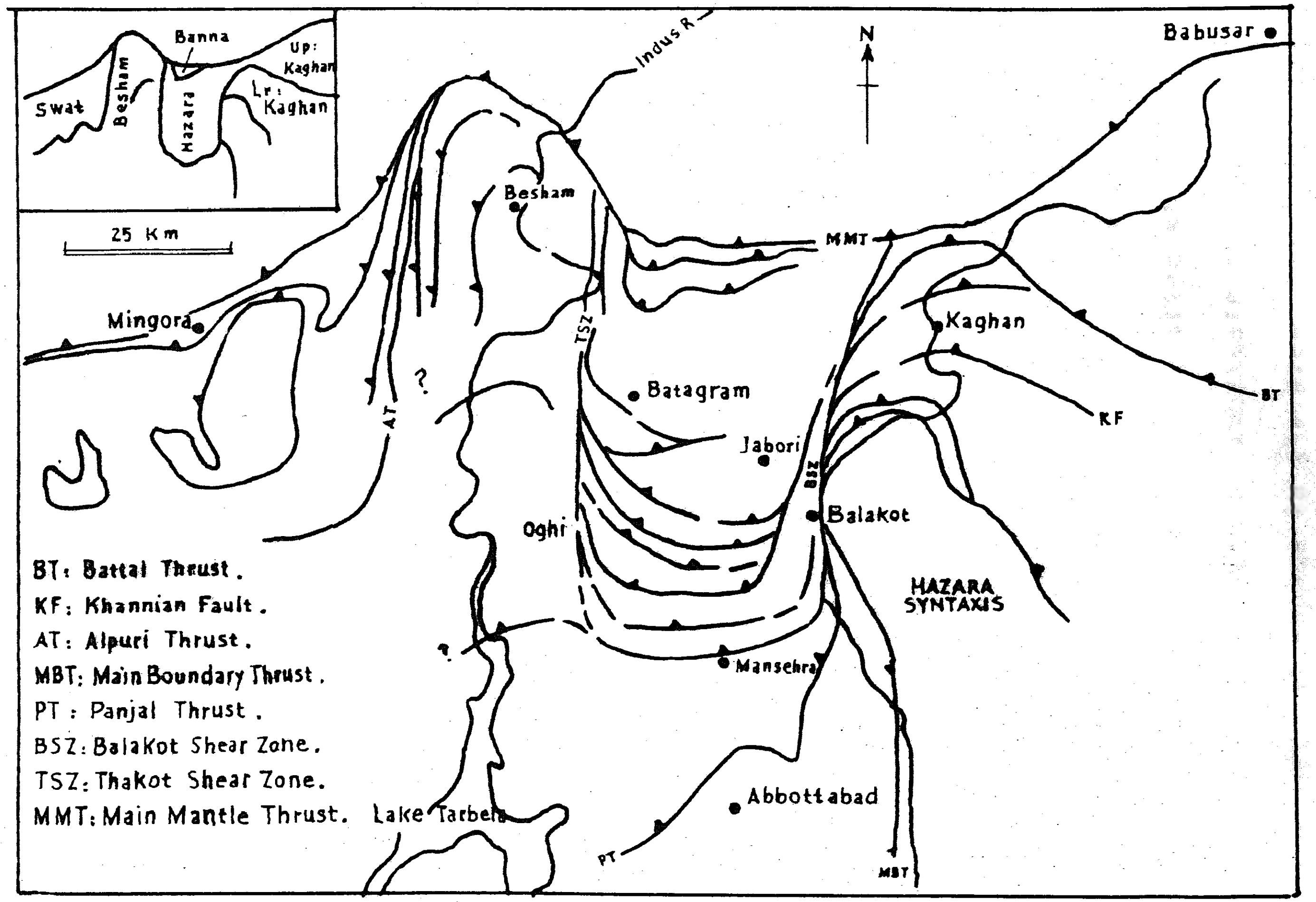


Fig. 1. Tectonic map of NW Pakistan, showing the location of the major crustal nappes (After Treloar, 1989)

obduction of Kohistan. These include small NW verging back thrusts and minor folds, related to the last stages of thickening of the sub-MMT thrust wedge, i.e. Thakot and Balakot shear zones, Oghi shear, Alpurai and Battal thrusts.

b) Structures related to the extensional thinning of the sub-MMT thrust wedge. These include the N-verging extensional normal faulting within the MMT zone, NE to NW verging extensional thrust within the Indian plate, developed at relatively high crustal levels.

c) Late structures related to interfering movement directions at the NW tips of the Main Himalayan thrust, related to the development of the Nanga-Parbat-Haramosh massif and Hazara-Kashmir syntaxis.

During deformation of the leading edge of the Indian Plate as a result of collision, the cover sequences were detached from the basement and both the cover and basement rocks were deformed by internal imbrication at different crustal levels (Treloar, 1989). Such an imbricate faulting led to the formation of several nappes in the area. Six large nappes have been recognized in the region south of the MMT (Treloar, 1989), Fig.1). These nappes include the Besham nappe, Swat nappe, Hazara nappe, upper Kaghan and lower Kaghan nappes and Bana nappe.

2.2 Geology of the Hazara-Kashmir Syntaxis

The Hazara-Kashmir syntaxis comprises Precambrian, Paleozoic, Mesozoic and Tertiary formations. These are overlapping and thrust over each other along the Panjal and Murree Thrusts (MBT). At places older rocks are lying over the younger formation such as observed at Reshian in Jhelum Valley in Azad Kashmir. Inorder to describe the geology of the Hazara-Kashmir syntaxis, the area is divided into the following three tectonic units (Bossart et al., 1988).

a) The tectonic unit above the Panjal Thrust.

This unit consist of Salkhala Series, Hazara Formation and Tanawal Formation. The Precambrian Salkhala Series dominates the lithology in the Kaghan, Neelam and Jhelum Valleys. It consists of ortho-and Para-gneisses, marbles, dolomites, quartzites, amphibolites, garnet-staurolite-mica schists, phyllites and graphitic schists (Bossart et al,1988). High grade metamorphic rocks above Battal thrust have been differentiated from the low grade metamorphic rocks of the Salkhala Series in lower Kaghan Valley and named as Sharda group (Ghazanfar and Chaudhry, 1986).

The Hazara Formation outcrops in the south-western part of the syntaxis and has been assigned lower Proterozoic age (Calkins et al., 1975 and Baig et al., 1987). It consists mainly of slate, phyllite, shale and subordinate limestone and graphite layers. The formation is absent at the appex of the syntaxis and Salkhala Series directly underlies the Tanawal Formation.

The Tanawal Formation within the domain of the Hazara-Kashmir syntaxis consists of quartzose schist, quartzite and at places layers and lenses of quartzose conglomerates (Calkins et al., 1975). In Hazara area the formation (as a part of Hazara group) is considered Pre-cambrian as it underlies the Cambrian/Precambrian Abbottabad Formation (Chaudhry et al., 1991-92) and is intruded by Cambrian Mansehra granite (LeFort et al., 1980). The same rocks in Kashmir are considered mid-Paleozoic in age because of their stratigraphic position and therefore not Tanols (Chaudhry et al., 1991-92).

b) The tectonic unit between Panjal and Murree Thrust.

This unit consists of four different imbricate slices, namely, the basal agglomeratic slates Carboniferous to Permian), the Panjal volcanics (Permian to Triassic), limestone and dolomite (Triassic) and a melange zone. The melange zone consists of limestone of Samana Suk Formation (Middle Jurassic), Hangu Formation (Upper Cretaceous) and Lockhart Formation (Uppermost Paleocene) and

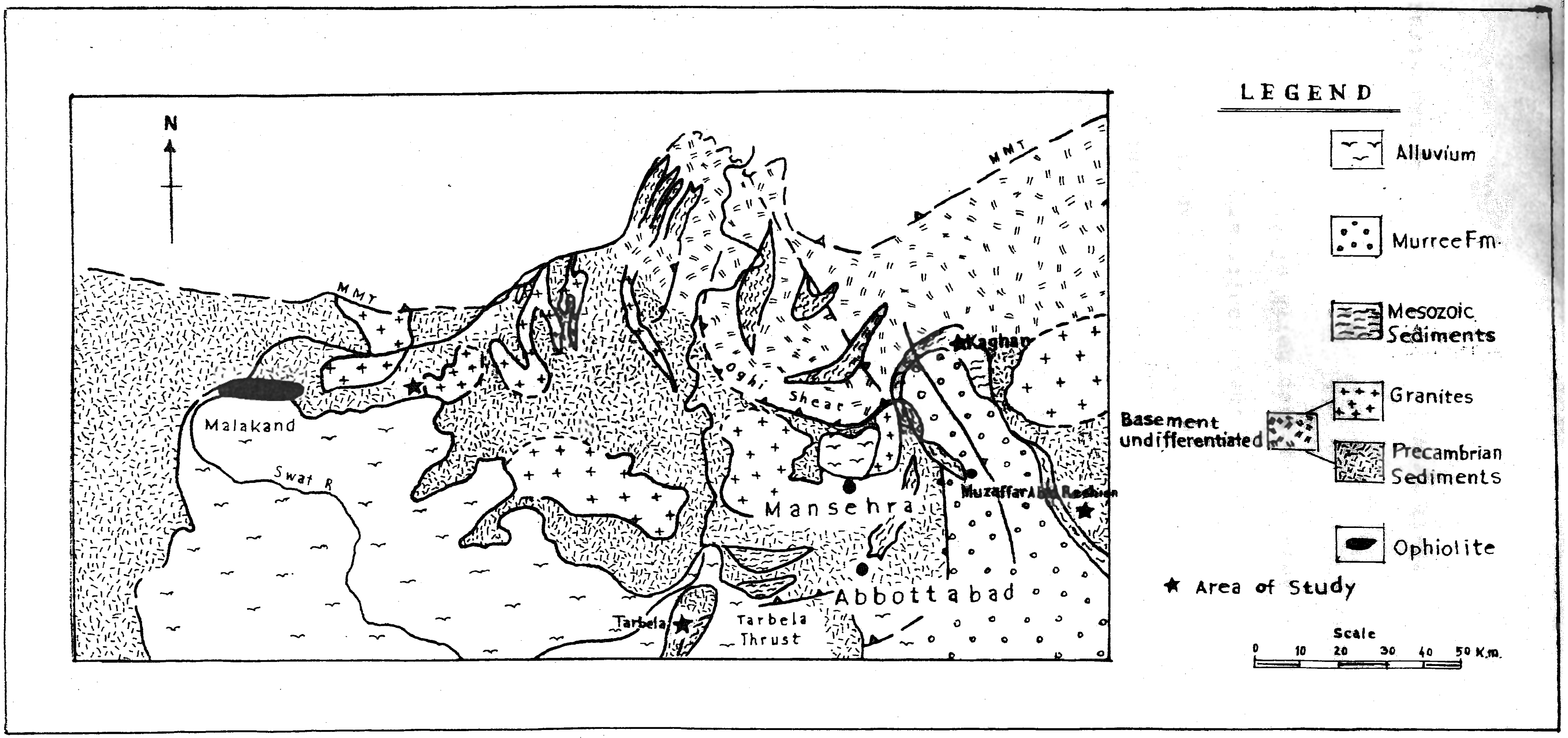


Fig. 2. Geological map of NW Pakistan, showing location of the areas of study (After Cowards and others, 1986)

silts of Murree Formation (Uppermost Paleocene to Early-Middle Eocene). (Bossart et al., 1988 and Ghazanfar et al., 1984).

c) The tectonic unit below the Murree Thrust.

This unit is mainly composed of Tertiary red and green sandstones and forms the core of the syntaxis. The deposits are regarded as continental to shallow marine (tidal flat) developed in an environment of meandering tidal channels in a continuously descending foreland basin (Bossart et al., 1988).

2.2.1 Formation of the Syntaxis

The outer ranges of Himalaya which extend northwestward across northern India continue into Kashmir and the Hazara district of Pakistan and form the eastern limb of the syntaxis. The major faults and most of the geological units turn abruptly westward at Paras to form the apex of the syntaxis and then southeastward to form its western limb (Calkins et at., 1975). The two major faults in the syntaxial zone are considered equivalent to the Wadia's Panjal and Murree faults (Calkins et al., 1975). These faults are generally steeply dipping and merges together north of Balakot, then continues southwards.

In their recent interpretation of the structural data collected within the domain of the Hazara-Kashmir syntaxis the following sequence of development of the syntaxis, has been described (Bossart et al., 1988).

The formation of the syntaxis initiated with the overthrusting of the Precambrian units (Salkhala, Hazara and Tanol) over the Late Paleozoic-Mesozoic units (Panjal imbricate zone). Further compression caused thrusting of the rocks further soutwest over the Murree Formation. Subsequently a progressive change in transport direction took place and became southeast parallel to the Balakot shear zone. The shear zone developed as a result of differential movement of the low level crustal blocks which separates rocks of the prehnite-pumpellyite facies around Balakot from those of the lower amphibolite facies westward.

2.2.2 Geology of Reshian Area

Reshian is located at the eastern limb of the Hazara-Kashmir syntaxis (Fig.2). The geology of the area can be conventiently described with reference to the two regional faults known as Murree and the Panjal thrusts. Rocks of the Precambrian Salkhala Series thrust over the Panjal volcanics associated with Triassic limestone which in turn thrust over the Tertiary clastic rocks of the Murree Formation along the Murree Thrust.

The rock-types comprising Salkhala Series in the

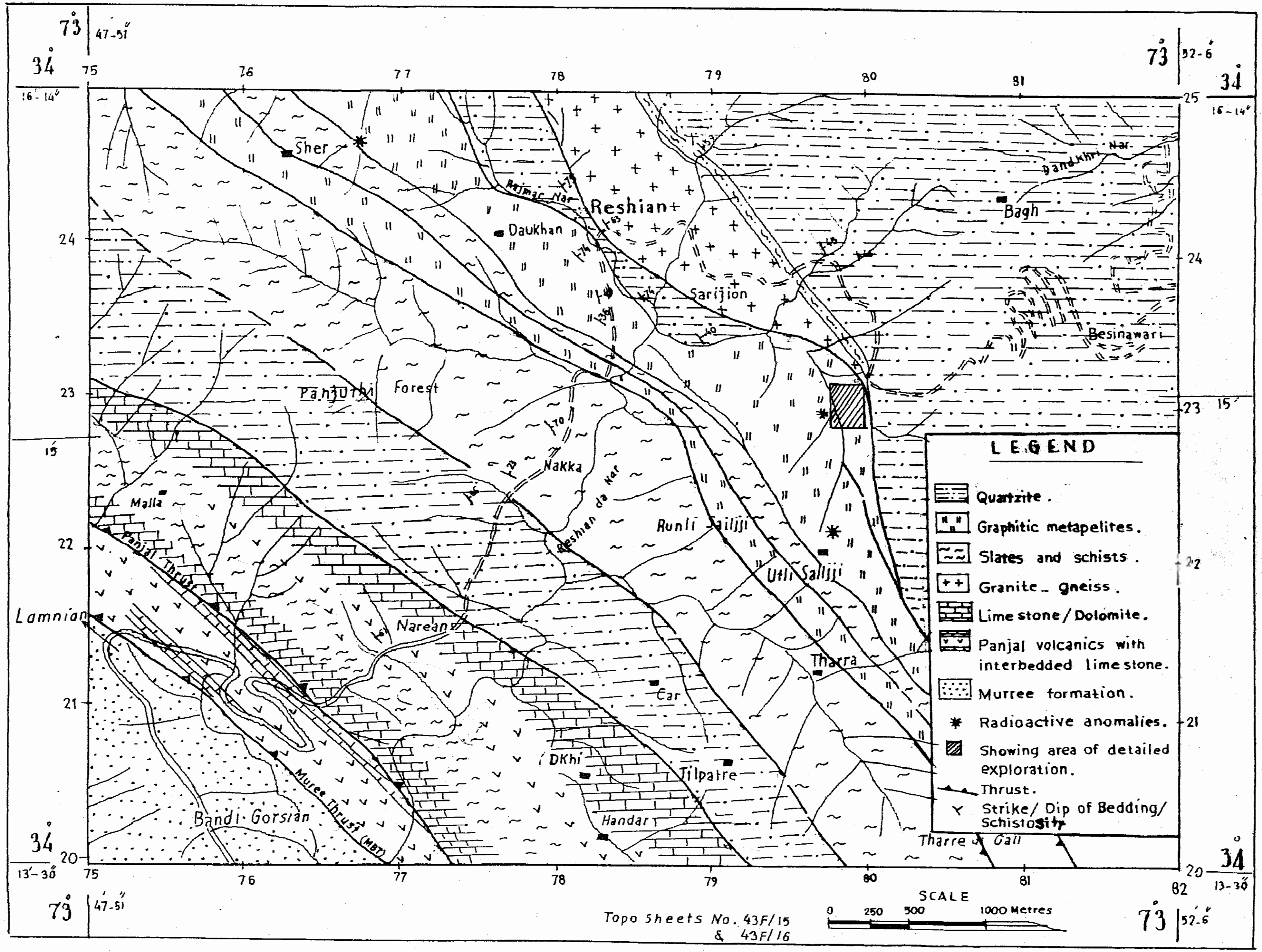


Fig.3. GEOLOGICAL MAP OF RESHIAN AREA - AZAD KASHMIR

area include quartzite, quartz-mica schists, chlorite-mica schists, graphitic-metapelites, gypsum, marble bands and granite gneiss. These are characterized by different grades of metamorphism (Greco, 1986). The lower quartzite and the schistose rocks below the graphitic-metapelites indicate retrogression from amphibolite to green-schist facies and the upper quartzite exposed NE of Reshian apparently show amphibolite grade of metamorphism (Fig.3).

Great variation in the trend of the rocks, brecciation and slickensides suggest several intraformational faults. Two of such thrust faults correspond to the two metamorphic zones described by Greco (1986). While going from Panjal fault northeast to Reshian village, one such fault has been placed at the contact of the steeply dipping lower quartzites, with the gently dipping intensely sheared schistose rocks (Fig.3). At the lower contact of the lower quartzite, an intensely sheared zone, dominantly composed of calcareous schists indicates the Panjal imbricate zone. The Panjal fault is reportedly steeply dipping (50^{o}- 70^{o}) towards northeast (Greco, 1986).

The second intraformational fault is marked at the transitional chlorite zone of Greco (1986). Quartz boudins and lineations on the surface of the chlorite schist zone suggest the movement of the overlying strata over the footwall of the chlorite schists (Fig.3).

A third intraformation fault is marked at the upper contact of the graphitic-metapelites along the upper quartzites (Fig.3). Slickensides are clearly observed on the footwall of the fault that steeply dips NE.

These intraformational faults are associated with the regional Panjal and Murree Thrusts (MBT) and are considered as imbricate thrust faults along which rocks of the same formation have been displaced. It is observed that gently dipping strata of the upper quartzite are lying over the graphitic-metapelites in Daukhan area. Gently dipping rocks lying over steeply dipping rocks below are also seen within the upper graphitic-metapelites and the schistose rocks.

2.2.3 Geology of the Kaghan Valley

The Kaghan Valley extends from Babusar in the north to Balakot in the south, over a distance of more than 145 Km and is drained by the Kunhar river. It lies at the apex of the syntaxis.

Geology of the area has been described under the heading of the Hazara-Kashmir syntaxis. The present section is to describe the geology of the anomalous graphitic-metapelites placed within Salkhala series exposed in the area. Several zones of the graphitic-metapelites reportedly occur within Salkhala Series exposed in the valley. Going upstream these horizons are named as Shino-Sharan, Dohar, Seri (Manur), Butan,

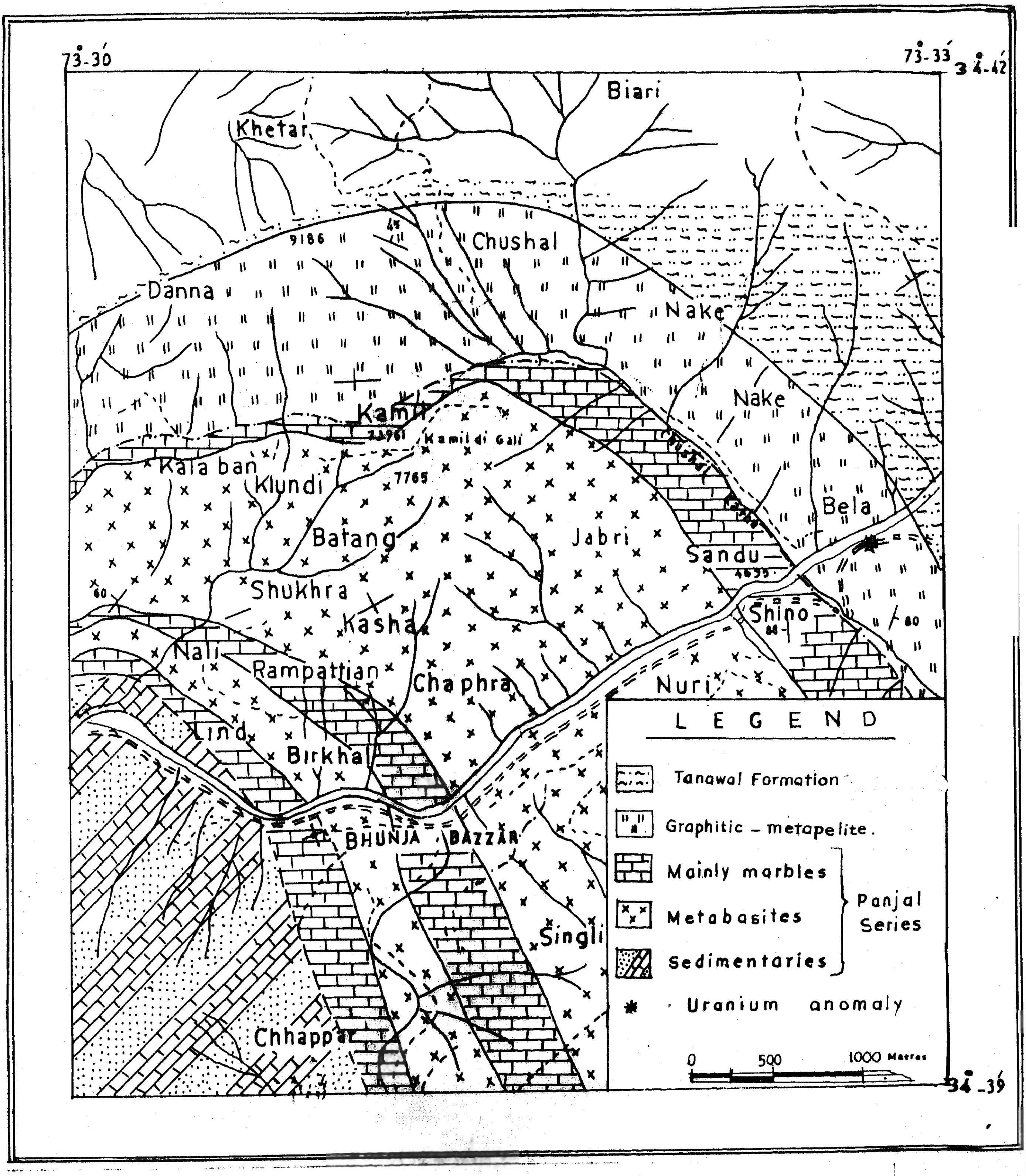


Fig. 4. Geological map of Shino area (Kaghan Valley)
(After Ghazanfar and Chaudhry, 1984)

Chitta Katha-Lambi Patti, Kaghan nalla-Shingri, Rawalkot-Danna and Mahandri graphitic-metapelite patches (Butt et al., 1978). The Shino-Sharan horizon has been studied in some detail in the present work where its geochemical composition has been compared with other such horizons from different areas.

The Shino-Sharan graphitic metapelites are a part of the Salkhala Series (Butt et al., 1978). However these were named as agglomeratic slate series and mapped as underlying the Tanawal Formation in the area (Chazanfar et al., 1984) (Fig.4). The graphitic-metapelites extend for more than 16 Km across the Kunhar river with a variable thickness of about 200m to more than 1.5 Km. Towards north these are in contact with quartz-mica schist, marble and granite gneiss while towards south it makes its contact with limestone and dolomite. The rocks are fine-grained and contain dessiminated quartz grains and laminae. It contains patches of recrystallized limestone and breccia composed of the pebbles of graphitic-metapelites. The rocks are highly folded and fractured and several local faults have been described from the valley which include the Shino, Jutan, Jared, Khanian, Rajwal and Battal faults (Ghazanfar et al., 1986).

2.3 Geology of the Tarbela area (The southern Gandghar range).

The anomalous graphitic-metapelites at Tarbela are associated with slates belonging to Manki formation. The area lies to the south-west of the Hazara-Kashmir syntaxis and tectonically placed in Hazara nappe (Fig.1 and 2).

Tahirkheli (1971) was the first to map the area on the east bank of Indus river in the southern Gandghar range and named the various lithological formations after the locality where exposed (Table 1). He also corelated them with the lithostratigraphic units in the Attock-Cherat range. Calkins et al., 1975, mapped the slates and phyllites (equivalent to Serikot slate of Tahirkheli, 1971) in the Gandghar range and described them as Hazara Formation. The Hazara Formation underlies Tanawal Formation in the northern Gandghar range (Calkins et al., 1975). The Tanawal Formation replaces the local name Tarapaki quartzite (Tahirkheli, 1971) applied to the type rocks exposed near Tarbela Dam (Fig.4). The stratigraphic nomenclature applied in the southern Gandghar range has been modified recently (Hylland et al., 1988) (Table 1). The slates and phyllites have been grouped in Manki Formation instead of Hazara Formation and the later is now considered restricted to the footwall of the Panjal fault (Hylland et al., 1988). The Manki Formation consists of slates, phyllites, subordinate quartz-mica schists, graphitic-metapelites, limestone bands, quartz veins and dolerite dykes and sills. It has a gradational contact with the overlying Shahkot Formation. The base of the Formation is not clear and is marked in the graphitic-metapelites in the hanging wall of the Baghdarra fault (Hylland et al., 1975). Thickness of the Formation is doubled due to isoclinal folding.

TABLE 1. STRATIGRAPHY OF THE TARBELA AREA ACCORDING TO DIFFERENT AUTHORS

Tahirkheli, 1971	Calkins et al., 1975	Hylland et al., 1988
Pirthan Limestone (Upper Permian to Triassic)	Kingriali Formation (? Carboniferous to Triassic)	Shekhai Formation (Proterozoic or Early Cambrian)
Tarapakhi quartzite (Upper Devonian to Late Permian)		Utch Khattak Formation (Proterozoic)
Baghdarra Limestone (Upper Silurian to Late Devonian)		
Sirikot Slate (Middle Silurian)		Shahkot Formation (Proterozoic
Mohat Nawan Limestone (Pre-Cambrian to Silurian)	Hazara Formation (Proterozoic)	Manki Formation (Proterozoic)

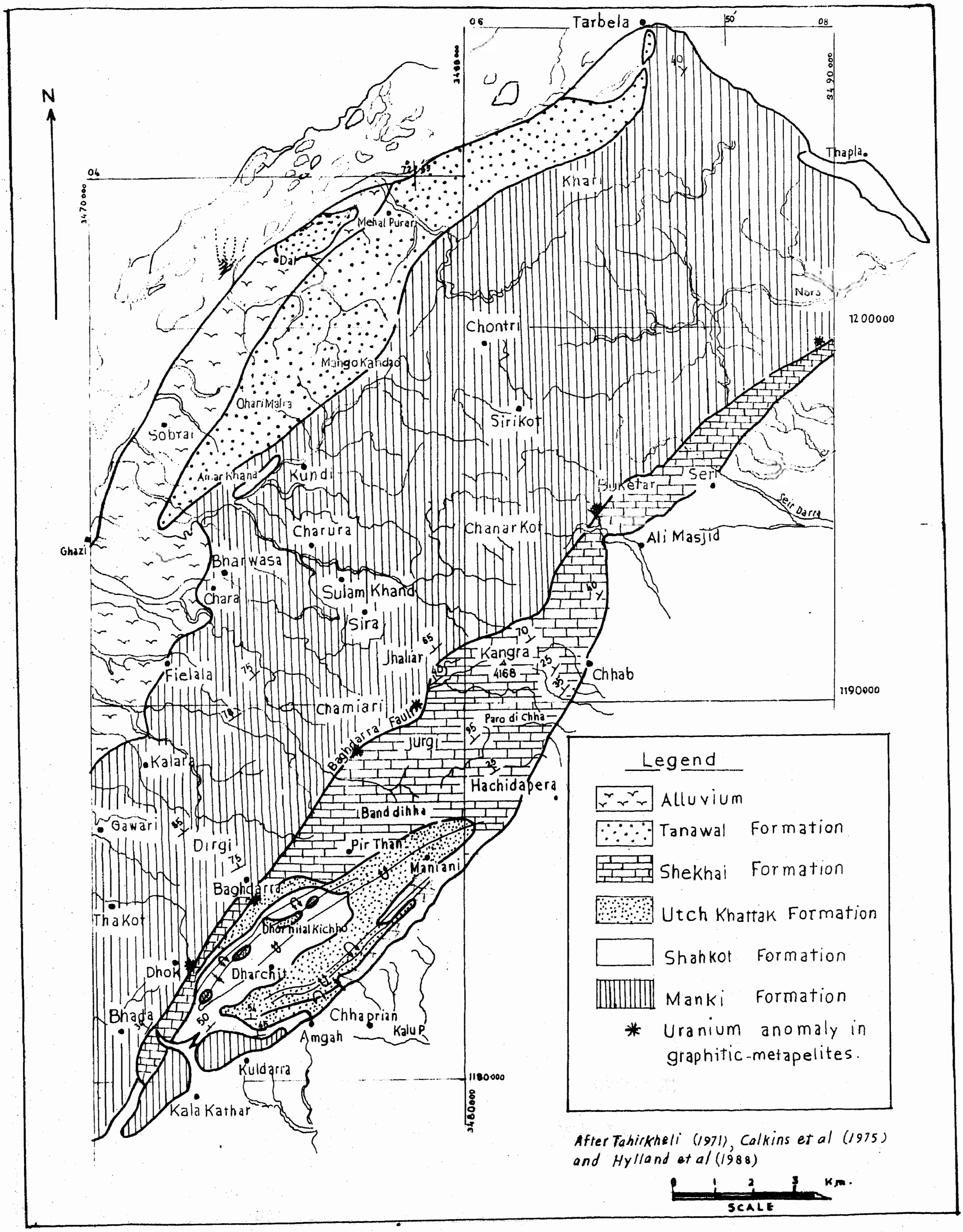


Fig.5. GEOLOGICAL MAP OF GANDGHAR RANGE

The Manki Formation is overlain by limestone and marble belonging to Shahkot Formation, Utch Khattak Formation and Shekhai Formation. The intrusive rocks in the area include dolerite dykes and sills which are generally less than 2m thick. These are considered post-carboniferous and equivalent to Panjal volcanics (Hylland et al., 1988).

The Gandghar range strata thrust over Kherimar Hills along Panjal fault and the range itself is disected into two structural blocks by Baghdarra fault, which is older than the Panjal fault. Two sets of cleavages, one parallel to bedding is the dominant cleavage pattern which represent bedding fissility. The other set is described as the axial plane cleavage in the Manki Formation (Hylland et al., 1988).

2.4 Geology of the Swat area

Swat area is located to the west of river Indus, west of the Hazara nappe (Fig.2). The geology of the area is dominated by three structural units, that is (i) the Kohistan Island arc, (ii) the Indus Suture melange zone and (iii) the Indo-Pakistan subcontinent sequence (Kazmi et al., 1984). For the purpose of the present work, the geology of the Indo-Pakistan subcontinent sequence is described as follows:

The preliminary geological work in the area is that of Martin et al., 1962, who described the following lithological units:

Upper Swat Hornblendic group

Lower Swat-Buner schistose group

Green schist

Phyllitic schist

Marble and clcareous schist

Amphibolite

Siliceous schist

Swat granite gneiss

A major thrust fault brought over the upper Swat Hornblendic group over the Lower Swat-Buner schistose group (Martin et al., 1962). This thrust fault is presently known as MMT (Main Mantle Thrust).

The Indo-Pakistan subcontint sequence includes the lithostratigraphic units ranging from Swat granite gneiss to Lower Swat-Buner schistose group described above. The stratigraphy of the area has been recently interpreted by Kazmi et al., 1984. According to them the Manglaur crystalline schist intruded by the Swat granite gneiss, form the basement unconformably overlain by Alpurai calc-mica-garnet schist. The later is overlain by Saidu schist with a gradational contact.

The Manglaur crystalline schist include mylonitized quartz-mica garnet schist, feldspathized and tourmalinized at places. Quartz-feldspar schist, quartz-mica-kyanite schist and quartz-mica-garnet schist with thin layers of graphitic schist and hornblende schists (para-amphibolite) also belong to the same unit. The Manglaur crystalline schist has experienced atleast two phases of metamorphism separated by a reterograde episode (Kazmi et al., 1984). These crystalline schists were mapped as a part of the Swat granite gneiss or included in the siliceous schists of the Lower Swat-Buner schistose group, however, the Manglaur crystalline schist and the Lower Swat-Buner schistose group are significantly different from each other. The later has been subdivided into Alpurai schist and Saidu schist. The Manglaur schist is intruded by Swat granite gneiss which has been subsequently folded into an antiform. The granite gneiss occurs at the upper and outer part of the antiform while the inner part of the antiform is composed of the Manglaur schist (Kazmi et al., 1984).

The Alpurai schist unconformably overlies the Swat granite gneiss and Manglaur schist. It is equivalent to lower three subdivisions of the Lower Swat-Buner schistose group. It is composed of several hundred meters of siliceous schist and calcareous-quartz-mica schist. It also contain 20 to 50 meters of para-amphibolites in quartzites overlain by marble beds of variable thickness (15-30 meters), interbedded with garnetiferous calcareous schists (Kazmi et al., 1984). The upper part of the unit is more calcareous and less siliceous.

The Saidu schist overlies the Alpurai schist. The contact is apparently gradational, however, an unconformity is suggested between the two on the basis of variation in thickness of the two units and the number of marble horizons in the Alpurai schists (Kazmi et al., 1984). This unit is equivalent to the phyllitic schist of the Lower Swat-Buner schistose group of Martin et al's., (1962) and to a part of the greenschist unit. The greenschist unit is mostly equivalent to the Indus suture melange group. The Saidu schist is calcareous and pelitic. Most of the unit is graphitic but the chlorite schist is locally present. It indicates metamorphism in the upper greenschist to lower amphibolite grade (Kazmi et al., 1984).

Ages of the units described above are uncertain. The Manglaur schist is probably Precambrian. The Alpurai and Saidu schists were previously equated to Salkhala Series (Tahirkheli, 1979), however, presently these are considered as Paleozoic or even Mesozoic (Kazmi et al., 1984).

2.5 Regional Metamorphism

The leading edge of the Indian plate is mostly comprised of Precambrian basement and shelf sediments with only thin younger units. During the Himalayan orogeny, these associated with their intrusives were metamorphosed from chlorite grade in the south to sillimanite grade in the north (Calkins et al., 1975, Tahirkheli, 1979, Ghazanfar et al., 1986 and Baig et al., 1989). The exact location of the metamorphic isograde is uncertain because the estimates are based on studies of mineral assemblages from pelitic rocks which are intruded by large volumes of cambrian granites. The metamorphism is typically of the Barrovian type (Treloar, 1989). $^{40}Ar/^{39}Ar$ dating of the Precambrian rocks of the northern part of the Indian plate shows five pre-Himalayan metamorphic events which occurred at 2000 ± 6Ma, 1950 ± 3Ma, 1865 ± 3 Ma to 1987 ± 5 Ma, 650 ± 2 Ma and 66 ± 2 Ma. The 600-900 Ma events are related to Hazaran orogeny and 550-450 Ma and 466 ± 2 Ma events constitute Cambro-ordovician orogenic event related to the Pan-African orogeny (Baig et al., 1989). The early metamorphism and deformation phases have largely been obliterated by the high grade Himalayan metamorphism and deformation which is generally considered to begin in Late Cretaceous time and continue to the present (Baig et al., 1988).

Peak metamorphic conditions have been calculated on study of rocks from Swat, Hazara and Kaghan nappes (Treloar, 1989). The metamorphic conditions of Alpurai schists from Swat nappe are 600 ± 50°C at 10 ± 2 Kb. In the Karora group cover sediments imbricated with Besham gneisses in Besham nappe, the temperature recorded in the core of the antiform is 400°C and that recorded on its limbs is 600°C. In Hazara nappe staurolite and kyanite-sillimanite grade rocks are believed to have been metamorphosed at 550 ± 50°C at 6-11 Kb and 650-700°C at 7 ± 2 Kb, respectively. In the upper Kaghan nappe the sillimanite grade (associated with extensive partial melting) rocks were metamorphosed at 675 ± 50°C at 11 ± 2 Kb. The pelitic rocks at Thakot (Hazara nappe) are also associated with migmatites, and may have experienced the same metamorphic

Conditions (Butt, personnel communication). The lower Kaghan nappe was metamorphosed upto garnet grade at 6-9 Kb pressure.

In Besham and Hazara nappes an inverse grade of metamorphism is generally observed. Each nappe shows an upward increase in metamorphic grade. In Besham nappe, the lowest grade chlorite-bearing rocks occur in the core while higher granet-grade rocks occur on the limbs of the Besham antiform (Williams, 1989).In Hazara nappe, the Mansehra thrust places garnet-grade rocks over the biotite-grade rocks. The Oghi shear places staurolite-grade rocks over garnet-grade rocks. A shear zone south of Battagram places kyanite and sillimanite-grade rocks over the staurolite-grade rocks (Treloar, 1989). The metamorphic isograds strike east-west in the centre of the Hazara nappe and curve northwards in the west to Thakot shear zone and also curve to Balakot shear zone in the east. A thrust stack model has been forwarded to explain the inverse grade of metamorphism and structure of the region by Treloar (1989).

Recently another model has been forwarded to explain the geological characteristics of the NW Himalayan region by locating MCT (Main Central Thrust) and dividing the region into Tethys, Higher, lesser and Outer Himalayas (Ghazanfar et al., 1986; and Chaudhry et al., 1991-92). According to the authors each belt of the Himalaya is characterized by a unique set of stratigraphic, tectonic and metamorphic (or lack of it) characteristics. The pelite-psammite in Hazara area as a continuation of the same sequence in the east in Neelam Valley, is inverted in the northern part of Hazara with all the metamorphic grades by imbricate faulting.

According to Ghazanfar et al., (1984), the lower Kaghan Valley metasediments show a biotite-grade of regional metamorphism. The Kaghan pelites contain ubiquitous almandine garnet. The Batal, paludaran and Rajwal units in the upper Kaghan Valley are thought to be metamorphosed at staurolite grade. Kyanite-grade metamorphism is reported in the rocks of Naran and Dharir units.

The Salkhala series at Reshian area is metamorphosed in the amphibolite grade. Some of the rocks of the Salkhala series also exhibit retrogression into greenschist facies mineral assemblages (Greco, 1986) while such assemblages are predominant in the Panjal volcanics.

The Gandghar Range is metamorphosed under the greenschist facies conditions, while garnet grade rocks occurs in its north. Garnet occurs locally at the southern Gandghar Range adjacent to Baghdarra fault, probably developed as a result of frictional shear heating (Hylland et al., 1988).

Chapter-3

PETROGRAPHY

3.1 Introduction

Graphitic-metapelites in the northern area of Pakistan and the adjoing state of Azad Kashmir are exposed in the form of several continuous/discontinuous beds, lenses and streaks associated with different Precambrian Formations. The rocks stretch from Jhelum Valley in the east through Neelam and Kaghan vallies to the Indus river at Thakot. West of the river the same rocks are exposed in Swat and Malakand areas (Fig.2). The northern area hosting these rocks, is bounded in the north by MMT. (Indus Suture zone) and MBT in the south.The area is transected by several north-south and east-west trending faults, leading to the formation of several nappes (Fig.1), which control the present distribution of the rocks. The area is intruded, by several granitic complexes of different ages and records multiple deformation phases as a result of Cambrian to the recent Himalayan orogenies. Metamorphic isograde generally correspond to the east-west and north-south trending imbricate thrust faults and shear zones and increases northwards towards MMT (Treloar, 1989).

The rocks at Reshian, Kaghan and Tarbela areas lie in the southern part of the area near MBT and metamorphosed mainly under the lower amphibolite and greenschist facies. Metamorphism in the lower amphibolite facies with a retrograde greenschist facies occur at Reshian while the development of garnets in the generally lower grade rocks at Tarbela has been attributed to the local frictional shear heating developed as a result of movement along Baghdarra fault (Hylland et al., 1988). Graphitic-metapelites in the region close to MMT are medium to high grade and are studied at Thana (Malakand) and Thakot areas. The rocks at Thana area belong to Alpurai schist group and are metamorphosed in the amphibolite grade indicating retrograde greenschist faceis mineral assemblages. The rocks at Thakot reportedly belong to the Sharda group indicating still higher grade metamorphism leading to the development of migmatites (Ghazanfar et al., 1986 and Butt Personnel communication).

3.2 Petrography of the Graphitic-metapelites of Reshian

The graphitic-metapelites are associated with gypsum, quartzites, various schistose rocks and granite-gneiss (Fig.6). These are characterized by dark, grey colour due to the presence of carbonaceous matter/graphite and red limonitic alteration. Garnet-biotite assemblages and the alteration of the later to chlorite in the associated rocks indicate their metamorphism in the lower amphibolite facies with a retrograde phase of greenschist facies. This in conformity with Greco, (1986) who also has described amphibolite facies metamorphism in the rocks above and below the graphitic-metapelites. The approximate

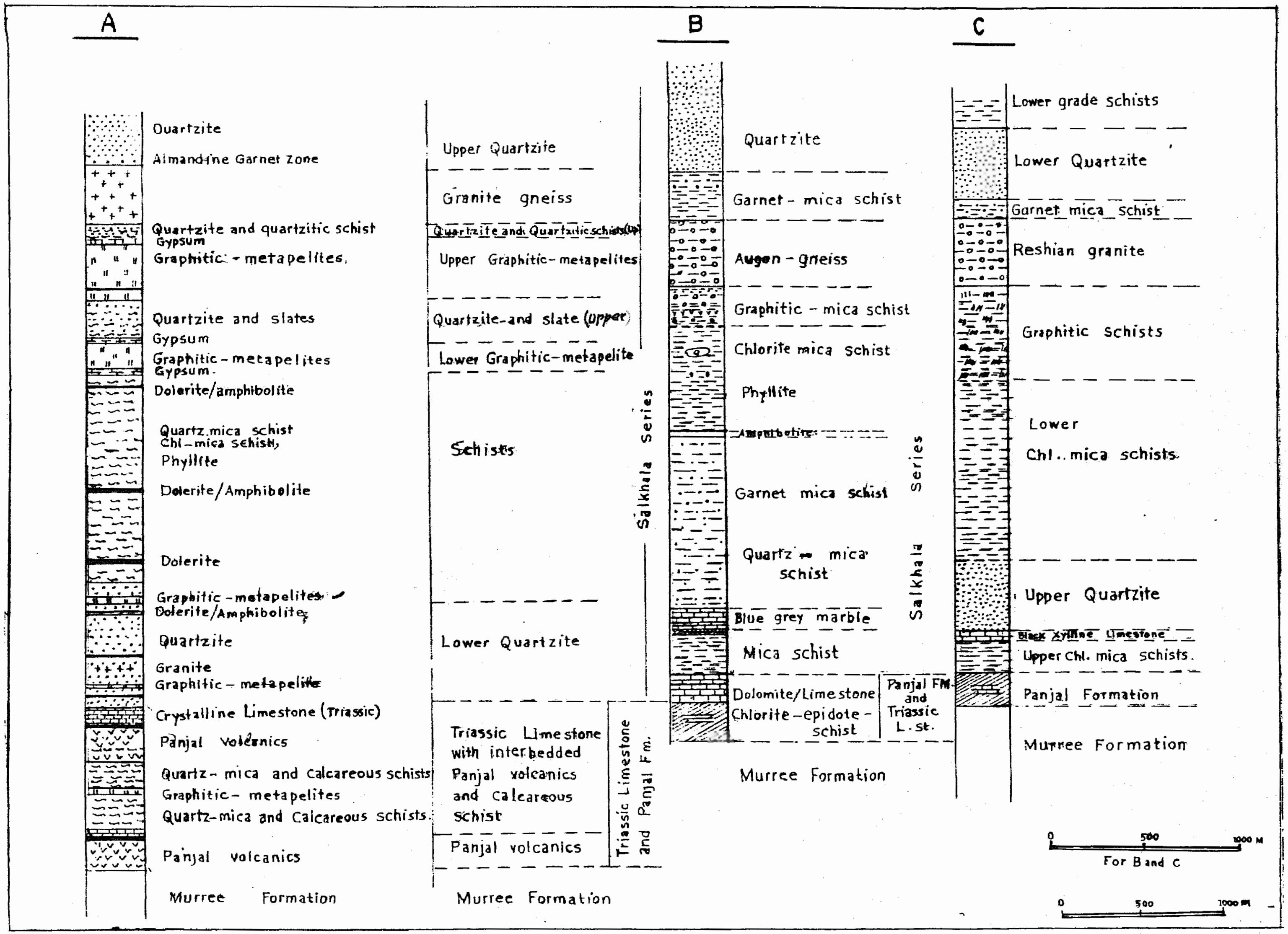


Fig. 6 Columns showing geology along Lamnian Brithwar Gali road, Reshian Area (Column B & C after Greco, 1986)

model composition of the various rock types is given in table 2 and described as follows:

3.2.1 Quartzite

Quartzite is the dominant rock unit mapped in the area. In contrast to the previous studies four different horizons have been mapped (Fig.6). However, the three horizons topographically above the graphitic-metapelites and granite-gneiss shown in Fig.6 are together regarded as upper quartzites while the one below the schistose sequence and in contact with Panjal imbricate zone is the lower quartzite. The lower quartzite horizon is massive, steeply dipping and is characterized by the presence of carbonaceous matter/graphite streaks and red limonitic alteration. It is differentiated from the upper quartzite by the same characters and the absence of slates as described by Greco. (1986). The lower quartzite may correspond to the quartzites of the Tanawal Formation described at the apex of the syntaxis at Kaghan Valley (Calkins et al., 1975; Ghazanfar and Chaudhry, 1986), however these have not been corelated in the present study. The lower quartzite are intruded by several dykes and sills of basic and acidic to intermediate composition and thrust over the crystalline limestone to the south (Fig.3). The upper quartzite horizon is extremely fractured and intruded by granite-gneiss which is a sill-like body. It thrust to the south along its contact with the upper horizon of the graphitic-metapelites and is exposed in the form of three mappable units. The lower two horizons are greatly fractured and low dipping

TABLE 2. MODAL COMPOSITION OF ROCKS FROM RESHIAN AREA - AZAD KASHMIR.

S.No.	Section/ Sample No.	Rock Name	Qtz	Kfs	Pl	Cal/ Dol	Ep	Bt	Ms	Chl	Grt	Hem/ Mag	Gt/ Lim	Py	Remarks
1.	396/397 (R-P(1)/87)	Limonite gossan	6	2	-	-	-	-	8	-	-	1.5	78	Tr	Rock fragments 4%
2.	398/399 (R-P(2)/87)	Quartzite	80	5	-	-	2	-	7	4	-	-	Tr	2	Zrn,Ap,Tur in Tr.
3.	580 (Rn-13)	"	45	2	4	38	-	Tr	-	2	-	2	-	-	Amphibole/pyroxene 7%.
4.	574 (Rn-9)	"	82	4	6	-	-	Tr	Tr	7	-	1	-	Tr	-
5.	541 (Lm-1)	Crystalline Limestone.	-	-	-	99	-	-	Tr	Tr	-	1	-	-	-
6.	564 (C-11)	"	7	-	-	88	-	-	5	-	-	Tr	-	-	-
7.	570 (Rn-3)	"	36	Tr	Tr	62	-	-	Tr	-	-	2	Tr	-	-
8.	564 (C-4)	Panjal Volcanics	14	3	35	3	20	-	3	7	-	10		5	Chloritization and epidotization are observed.
9.	555 (C-3)	"	45	15	3	-	2	-	8	-	-	Tr	-	-	Groundmass (Qtz+Kfs+Pl+Ms+Chl)= 20%, Tur 1%.
10.	532 (R-P(7)/87	Hornblende gneiss.	43	10	12	-	2	1	9	3	-	4	-	-	Hbl 16%,Ap and Spn in Tr.

Table 2. Contd.

S.No.	Section/ Sample No.	Rock Name	Qtz	Kfs	Pl	Cal/ Dol	Ep	Bt	Ms	Chl	Grt	Hem/ Mag	Gt/ Lim	Py	Remarks
11.	552 (C-2)	Augen-gneiss	45	25	10	2	2	1	12	2	-	1	-	-	Tur, Tr.
12.	550 (D-2)	"	45	20	4	-	10	5	16	-	-	Tr	-	-	Ap, Tr.
13.	549 (D-1)	"	48	25	8	Tr	2	8	10	1	Tr	-	-	-	Epidotization and Ap Tr.
14.	562 (C-9)	"	44	15	23	Tr	-	4	14	Tr	Tr	Tr	-	-	Ap Tr.
15.	558 (L-4)	"	45	18	5	-	2	10	19	2	1	Tr	-	-	-
16.	602 (R-6)	Granite-gneiss	36	17	10	-	2	30	1	1	-	3	-	-	Pleochroic haloes present.
17.	598 (R-10)	"	39	20	12	-	1	23	-	Tr	-	5	-	-	-do-
18.	548 (R-12)	Garnet-mica schist.	50	4	2	Tr	-	20	15	-	5	Tr	-	-	Spn 4%. Red Alteration present.
19.	553 (L-5)	"	55	10	-	-	2	8	16	6	2	1	-	-	Ilm and leucoxene Tr.
20.	551 (D-3A)	"	50	4	-	-	1	16	18	Tr	4	6	-	-	Tur 1%.
21.	557 (R-5)	"	50	5	3	-	-	12	24	Tr	5	1	-	-	Chloritization observed.
22.	608 (L-3)	"	52	4	-	-	Tr	25	12	4	1	2	Tr	-	Ap, Tur, Tr. Hematization and chloritization observed.

Table 2. Contd.

S.No.	Section/ Sample No.	Rock Name	Qtz	Kfs	Pl	Cal/ Dol	Ep	Bt	Ms	Chl	Grt	Hem/ Mag	Gt/ Lim	Py	R e m a r k s
23.	603 (R-9)	Garnet-mica schist.	50	2	-	-	Tr	23	15	3	5	Tr	-	-	Ap 2%, Tur in Tr. Pleochroic haloes observed.
24.	592 (R-8)	"	44	2	Tr	-	14	30	5	Tr	5	-	-	Tr	Tur and Ap in Tr. Pleochroic haloes are observed.
25.	600 (Rn-3A)	Silimanite schist.	80	7	Tr	-	Tr	-	4	-	-	Tr	-	-	Sillimanite 8%, Qtz indicate recrystallization.
26.	542 (R-P(4)/87)	Chlorite-mica schist	47	-	-	2	5	Tr	35	10	-	Tr	-	-	Tur 1%.
27.	559 (L-8)	"	45	5	-	-	30	Tr	50	15	-	Tr	-	-	Chloritization observed.
28.	576 (Rn-12)	"	70	5	-	-	-	-	14	6	-	5	-	-	Tur in Tr.
29.	575 (Rn-11)	"	35	-	-	-	12	20	25	6	-	4	-	-	Chloritization observed.
30.	566 (L-2)	"	9	-	-	-	1	-	45	40	-	2	3	-	Apin Tr. Chloritization is observed.
31.	605 (D-3)	'	35	18	Tr	-	-	12	30	4	-	1	-	-	Ap, Tur in Tr. Chloritization is observed.

Table 2. Contd.

S.No.	Section/ Sample No.	Rock Name	Qtz	Kfs	Pl	Cal/ Dol	Ep	Bt	Ms	Chl	Grt	Hem/ Mag	Gt/ Lim	Py	Remarks
32.	382 (Rn-5)	Calc-Chlorite -mica Schist.	40	1	-	25	3	18	3	6	-	Tr	-	4	Ap and Spn in Tr. Chloritization is observed.
33.	590 (C-8)	Qtz-mica schist.	30	10	20	2	5	25	3	2	-	3	-	Tr	Zrn, Ap and Spn Tr. Epidotization is observed.
34.	608 (D-4)	Siliceous-talc schist.	72	Tr	-	-	-	-	10	-	-	Tr	-	-	Tlc 17%.
35.	554 (L-6)	Amphibolite	10	5	Tr	-	18	-	-	4	-	2	-	-	Hbl 60%, Ap and Spn Tr.
36.	571 (Rn-4)	"	9	-	24	-	10	2	-	-	-	3	-	-	Hbl 50%, Ilm and Leucoxene 2%.
37.	601 (K-1)	Graphitic schist.	25	-	-	2	-	-	5	Tr	-	-	8	-	Carbonaceous matter 60%.
38.	585 (Rn-10)	"	20	Tr	-	Tr	-	-	3	Tr	-	2	-	-	Carbonaceous matter and Gr = 75%.
39.	581 (Rn-2)	"	30	Tr	-	-	Tr	3	15	18	-	2	8	Tr	Carbonaceous matter 24%.
40.	1558 (Rn-48)	Graphitic-qtz-mica schist.	30	3	2	-	Tr	-	23	-	-	5	-	2	Carbonaceous matters Gr = 35%.

Mineral symbols after Kretz (1982).

sometimes in reverse to the general trend of the rocks (Fig.3).

The quartzites mostly consist of 80-81% quartz, 7% muscovite, 2-7% chlorite and small amounts of other components (Table 2). Garnet is developed in the garnet mica schist zone in the lower quartzite associated with biotite where chlorite is also noted from traces to as much as 5%. Most of the chlorite is found associated with biotite and is therefore regarded as a retrograde product. The above mentioned mineral assemblages indicate lower amphibolite facies metamorphic conditions with a retrograde greenschist facies as reported by Greco (1986), who also noted the development of garnet prior to the formation of the main schistosity.

Separate garnet (almandine) bearing unit has been mapped at the topographically upper contact of the granite-gneiss (Rehman et al., 1981 and Greco, 1986). The same unit was also observed in the present study, however, because of local and variable extent the unit has not been separately mapped and has been included in the upper quartzite horizon. Microscopically the upper quartzite has the same mineral composition as the lower one, except for the absence of carbonaceous matter. The same is also characterized by the presence of slate and phyllite: Lower amphibolite grade metamorphic conditions are described for the same upper quartzites with obviously no retrograde phase (Greco, 1986).

3.2.2 Schistose Rocks.

These include chlorite-mica schist, phyllite, calcareous schist, garnet-mica schist, talc schist, marble bands, amphibolite and dolerite dykes. The schistose sequence has a thrust contact both with the lower quartzite and the graphitic-metapelites topographically lying above (Fig.3). Its lower contact is clearly marked by the difference in the trend of the rocks and the abundance of basic to intermediate rocks dykes. At its upper contact the presence of quartz boundins and slickensides on the surface of chlorite-mica schist mark the imbricate thrusting associated with Panjal and Murree Thrusts. This sequence of rocks represent a sheared and crushed zone (Greco, 1986), characterized by steeply dipping rocks sometimes trending in the opposite direction. Streaks of graphitic-metapelites are observed at places with several thin and small bands of amphibolites. Younger dolerite intrusions only a few meters across are noted commonly.

The modal composition of the schistose rock sequence is given in table 2. The table indicates that these rocks are generally pelitic in nature though calcareous schists and marble bands are also present at places. The later composition is dominant below the lower quartzite in the Panjal imbricate zone. Sillimanite is noted in one of thin section (Table 2), however, it does not belong to the schistose sequence. The sample was collected from a nalla and difinitely a float sample coming from the faulted contact zone of the granite-gneiss. Biotite, chlorite and actinolite pseudomorphs after hornblende in the amphibolites of this zone have been described by a previous worker who also described other reterograde greenschists facies mineral assemblages (Greco, 1986).

3.2.3 Graphitic-metapelites

Two horizons of these rocks have been mapped in the area apparently separated by thinly bedded low dipping quartzites as observed on a road section near Reshian village (Fig.3). Our mapping is in accordance with a previous work in the area (Rehman et al., 1981). However, there is no difference in the rocks of the two horizons and these are regarded as one and the same unit separated by carbonaceous phyllites and chlorite-mica schists, observed in the deeply cutting Reshian Nor. The thinly bedded quartzites are seen only on the slopes of the Nor and are a part of the upper quartzites thrust over the graphitic-metapelites to the south. The graphitic-metapelites have also been mapped as one unit by the other workers referred in Greco (1986). These rocks thrust over the topographically lower schistose sequence to the south. Gypsum beds are found at the upper contact of the rocks and are also observed at places within the graphitic-metapelites, indicating transitional marine environment of deposition characterized by transgression and regression of the sea. Some extensive gypsum beds at the upper contact are more than 30 meters long.

The graphitic-metapelites are characterized by dark colour due to the presence of carbonaceous matter and graphite. Modal composition of the rocks indicate upto 75% carbonaceous matter and 8% graphite (Table 2). The table shows quartz (20-30%), muscovite and chlorite from traces and 3% to 23 and 18% respectively. Biotite, calcite, epidote and tourmaline are found in traces. The ore minerals include pyrite, limonite, hematite and magnetite. Due to fine grain size and abundant carbonaceous matter recrystallization of the component minerals or retrograde mineral assemblages are not observed in thin sections. However, the presence of graphite itself is considered to indicate lower amphibolite facies metamorphism which affected the area (Winkler, 1974).

Pyrite is abundantly present in the graphitic-metapelites. It occurs as minute crystalline aggregates associated with quartzofeldspathic veins, as dessiminated crystals and as discrete veins about 20 meters long and one meter thick. In vein form it can be observed at the upper contact of the graphitic-metapelites within - the upper quartzites. Limonite gossans which are probably the alteration product of pyrite are also observed here.

Gypsum beds and lenses associated with the graphitic-metapelites are hard and crystalline at places. These contain amphibole, muscovite and biotite. It can be distinguished by its weak birefrengence from anhydrite (Deer et al., 1974). It is considered that the hard and crystalline variety of gypsum may have developed as a result of redeposition by capillary action from groundwater.

Collapse breccia also occur in association with the graphitic-metapelites and is observed on both sides of the

Reshian Nor below the village (G.R 787234, 43-F/15). It is characterized by the pebbles of graphitic-metapelites cemented together and can be distinguished from conglomerates in respect of its monomictic nature.

3.2.4 Granite-gneiss

It is a sheet-like body intruded in the upper quartzite. Contact metamorphic effects are observed at its upper contact while the lower contact is sheared and faulted (Fig.3). The granite-gneiss is characterized by augen structure which are mostly composed of feldspar. Mylonites/cataclasites are the - sheared varieties. Pegmatites and tourmaline bearing quartz veins are observed at the contact zone. Dolerite dykes and sills represent the younger phases of intrusions in the granite.

The granite-gneiss is composed of quartz, feldspar (orthoclase, microcline, perthite/antiperthite and plagioclase), biotite, tourmaline, Chlorite and epidote (Table 2). Feldspar grains are sometimes wrapped with white mica. Chlorite and epidote are developed along fractures. Bands rich in qurtz and feldspar alternate with biotite and muscovite bearing bands. Some tourmaline grains exhibit excellent zoning in thin section.

3.3 Petrography of the Graphitic-metapelites of Tarbela

These rocks are widely exposed in the Precambrian

TABLE 3. MODAL COMPOSITION OF ROCKS FROM TARBELA AREA

S.No.	Section/ Sample No.	Rock Na[illegible]	Qtz	Kfs	Pl	Cal/ Dol	Ep	Bt	Ms	Chl	Hem/ Mag	Lim	Remarks
1.	Min-Ta-19A	Panjal Volcanics	15	7	-	4	16	-	2	26	1	4	Pyroxene 15%, fine grained groundmass 10%. chloritization and epidotization observed.
2.	Min-Ta-7	"	14	5	8	1	25	-	7	35	2	-	Clay 3%, Epidotization and chlorization observed.
3.	T-Pet(5)/90 (1417)	"	23		-	8	44	-	-	19	Tr	Tr	Lencoxene 6%.
4.	T-Pet(4)/90 (1416)	"	18		-	8	45	-	-	23	Tr	Tr	Lencoxene 6%.
5.	T-Pet(3)/90 (1415)	"	21		-	6	46	-	-	24	Tr	Tr	Spn 2%, lencoxene Tr.
6.	Min-Ta-17	Graphitic/ carbonaceous phyllite.	5	-	-	-	Tr	-	2	30	1	-	Carbonaceous matter and Gr=62%.
7.	Min-Ta-15	"	20	5	15	-	Tr	-	2	10	2	1	Carbonaceous matter and Gr=45%.
8.	Min-Ta-6	Calc-qtz-mica phyllite.	37	5	28	15	6	1	6	-	4	-	Sericitization of feldspar observed.
9.	Min-Ta0	Qtz-mica-Chl phyllite.	65	5	-	-	Tr	-	15	10	4	-	Clay 1%.
10.	Gn-3/90 (2015)	Slate	37	11	12	-	-	Tr	2	Tr		10	Clay 26%, carbonaceous matter 2%.

Table 3. Contd.

S.No.	Section/ Sample No.	Rock Name	Qtz	Kfs	Pl	Cal/ Dol	Ep	Bt	Ms	Chl	Hem/ Mag	Lim	Remarks
11.	Min-Ta-14B	Limestone	2	-	-	96	-	-	-	-	1		Clay 1%. coarse grained along veins.
12.	Min-Ta-2	Black Limestone	5	-	-	82	Tr	Tr	7	Tr		3	Carbonaceous matter 3%, coarse along veins.
13.	Gn-6/90 (2020)	Altered pegmatite.	12	7	-	-	Tr	-	2	Tr		2	Fine grained groundmass of Qtz+Kfs = 75%, clay 2%. Alteration observed.
14.	Gn-4/90 (2016)	"	36	12	-	-	-	-	4		2	6	Clay 40%.
15.	Gn-5 (2018)	Soapstone	25	2	-	1	-	-	Tr	Tr	Tr	Tr	Tlc 65%, clay 6%, Carbonaceous matter 1%.

Manki Formation in the area in the southern Gandghar range (Fig.5). On the west bank of the river the same are exposed at various places at Gandaf, Malka Kadai and other areas in the north mapped in the Salkhala Series (Calkins et al., 1975). The graphitic-metapelites are invariably associated with slates/phyllites and are in the form of continuous beds and lenses. In the bedded form it is exposed at the base of the Manki Formation at Chamiari and extends for more than 10 Km with variable thickness both in the north and south of the village. These are bounded in the south by stratigraphically younger limestone deposits of Shahkot, utch Khattak and Shekhai Formation (Hylland et al., 1988) and in the north by the younger Tanawal quartzite (Calkins et al., 1975), indicating transitional environment of deposition of the rocks.

The graphitic-metapelites are grey to black in colour with reddish brown and yellow alteration at places. The alteration has developed after pyrite which is abundantly present. On the surface cubic scars are observed which indicate that pyrite has washed-out. Similar to Reshian area, pyrite is observed in the form of minute crystalline aggregates, discrete cubic crystals and also as layers/veins in the quartzite (Gandaf area). Interbedded limestone of yellow-brown colour are commonly observed in the associated slates/phyllites. The rocks are greatly fractured and sheared where white powdered material (carbonates) can be observed at places within the slates/phyllites on the west bank of river Indus near Tarbela Dam.

Petrographic description of these rocks is based on the study of 32 thin sections of different rock types from the area (Table 3). The graphitic-metapelites are fine grained and contain 45-62% carbonaceous matter with 4-7% crystalline graphite. 8-18% fixed carbon has been reported from Baghdarra, Bandi, Surma Lari near Chamiari and 22-26% in some selected samples from the area (Tahirkheli, 1971). Quartz varies from 5-20%. Rest of the associated minerals include feldspar, chlorite and muscovite. The interbedded limestone contains 96% calcite besides chlorite and quartz. The basic intrusions in these rocks varies from a spot dimention to generally two meters thick, however, large basic sills and dykes also occur within the formation (Calkins et al., 1975). The basic rocks are comprised of 16-46% epidote, 19-35% chlorite, quartz and feldspar (Table 3). These are regarded post-carboniferous and equivalent to Panjal volcanics (Hylland et al., 1988).

These rocks are generally metamorphosed in the green-schist facies and no high grade mineral assemblages have been noted. Garnet has been locally reported from these rocks at Baghdarra, however its development is attributed to the shear heating produced as a result of movement along Baghdarra fault (Hylland et al., 1988).

3.4 Petrography of the Graphitic-metapelites of Kaghan

The shino graphitic-metapelites in Kaghan valley were studied which correspond to the chushal graphitic schist zone

TABLE 4. MODAL COMPOSITION OF ROCKS FROM KAGHAN AREA

S.No.	Section/ Sample No.	Rock Name	Qtz	Kfs	Pl	Cal/ Dcl	Ep	Bt	Ms	Chl	Hem	Gr/ Carbon matter	Py	Remarks
1.	1551 (Kn-1)	Gr-Qtz-mica schist.	48	4	-	-	Tr	10	20	8	4	6	Tr	Zrn, Spn Tr.
2.	1552 (Kn-3)	"	45	12	7	-	Tr	2	-	1	3	30	-	-
3.	1553 (Kn-4)	"	34	5	-	-	Tr	Tr	20	6	1	34	-	-
4.	1554 (Kn-5)	"	51	6	10	6	Tr	-	5	4	10	8	Tr	-
5.	1555 (Kn-7)	"	38	-	-	-	Tr	Tr	10	5	1	45	-	Tur 1%, Qtz in veins.
6.	1556 (Kn-8)	"	15	-	3	-	Tr	-	15	3	Tr	64	-	Zrn and Tur in Tr.
7.	1557 (Kn-9)	"	12	-	-	5	12	-	8	55	Tr	4	Tr	Amphibole 4%.

(Ghazanfar et al., 1986) (Fig.6). In thin sections these rocks consist of quartz (15-51%), calcite (0-6%), carbonaceous/ graphitic material (6-64%), muscovite (0-20%), chlorite (1-8%), perthitic plagioclase (0-10%), biotite (0-10%), ore minerals (including pyrite, hematite Tr-10%) and traces of sericite, Kaolinite, sphene and zircon (Table 4).

The graphitic-metapelites are fine-grained and grey to black in colour. Cubic scars of pyrite indicate that it has washed-out from the surface. Reddish brown and yellow alteration is common on the weathered surface which has been imparted due to pyrite weathering. The mineral assemblages indicate metamorphism in the greenschist facies.

3.5 Petrography of the Graphitic-metapelites of Thana area (Malakand)

Samples were collected from the graphitic-metapelites and associated rock types exposed in the vicinity of Moora granite. The graphitic-metapelites occur as sheets, lenses and streaks in association with siliceous schist, quartz-mica-kyanite schists, quartz-mica-garnet schist and amphibolites. The rocks are folded and crenulated where atleast two phases of deformation have been described (Kazmi et al., 1984). The graphitic-metapelites to the west of the area in Malakand have been described by Chaudhry et al., 1976 and Ashraf et al., 1985.

Modal composition of the rocks is given in Table 5.

TABLE.5. MODAL COMPOSITION OF ROCKS FROM THANA AREA (MALAKAND)

S.No.	Sample/ Section No.	Rock Name	Qtz	Kfs	Pl	Ep	[illegible]s	Bt	Gar	Sil/ Ky	Gr/ Carbon matter	Chl	Hem/ Mag	Remarks
1.	T-1 (1542)	Gr-Qtz-mica schist.	54	-	-	Tr	25	3	-	-	6	8	4	Zrn and Spn in Tr. Alteration observed.
2.	T-2 (1543)	"	60	1	-	-	20	1	-	2	10	3	3	Zrn, Spn, and Clay Tr.
3.	T-3 (1544)	"	52	1	-	-	20	2	-	7	15	-	2	Clay 1% Py, Ap, Zrn Tr.
4.	T-4 (1545)	Qtz-Sillimanite schist	51	5	-	-	12	10	Tr	12	5	-	5	Ap, Zrn Tr.
5.	T-5 (1546)	"	40	2	-	Tr	9	2	-	27	16	-	2	Clay 2% Py, Zrn Tr.
6.	T-6 (1547)	Granite-gneiss.	35	35	20	Tr	7	3	Tr	-	-	-	-	Ap Tr.
7.	T-7 (1548)	Garnet-mica schist.	57	5	-	Tr	20	12	5	-	-	-	1	Clay 1%. Pleochroic holes observed.
8.	T-8 (1549)	Calc-garnet mica schist	30	3	-	7	33	Tr	4	-	-	-	3	Cal/Dol 20%. Alteration observed.
9.	T-9 (1550)	Amphibolite	22	8	-	-	4	2	-	-	-	Tr	Tr	Hbl 64%. Alteration observed.

The table indicates quartz (52-60%), feldspar (0-1%), muscovite (20-25%), biotite (1-3%), sillimanite (0-7%), graphite and carbonaceous matter (6-15%), chlorite (0-8%), ore-minerals (2-4%) and traces of pyrite, clay mineral and sphene in the graphite bearing quartz-mica schists. 12-27% sillimanite is found in quartz-sillimanite schists alongwith other minerals (Table 5), 4-5% garnet is present in garnet-mica and calcareous-garnet-mica schist (Table 5). Chloritization, epidotization and sericitization are the common alteration products after biotite, hornblende and feldspar in the various studied rocks.

Earlier studies in the area indicate 3-17% and 17-21% crystalline graphite in northern area of Malakand (38-N/14, Chaudhry et al., 1976) and Agra-Sillai Patti area falling to the west of the studied rocks (Ashraf et al., 1985). Studied samples from the area point to medium to high grade, amphibolite facies metamorphic conditions that affected the area. Sillimanite is regarded as a high temperature mineral that was found in samples from the contact zone of the Moora granite. The association of chlorite with biotite in thin sections indicate retrograde greenschist facies conditions. This observation is an accordance with Kazmi et al., 1984, who reported amphibolite facies metamorphic conditions with a retrograde greenschist facies rocks from the Alpurai schists.

Chapter-4

RADIOACTIVITY

4.1 Introduction

The graphitic-metapelites of NW Pakistan and Azad Kashmir are characterized by fine grain size, dark colour and wide areal extent (Fig.2). In some areas strong iron oxidation characterizes the rocks like the black shale deposits of the world with which they resumble. They are considered to have been deposited in an oceanic transitional environment. In the following chapter, an attempt has been made to describe and compare the geochemical characteristics of the graphitic-metapelites of Pakistan with those of the standard black shale deposits. The graphitic-metapelites are also classified according to the classification scheme of black shales given by Stribrny et al., (1988).

Like the other black shale deposits, the graphitic-metapelites are also characterized by high radioactivity and low chemical uranium. Samples collected from spot radioactivity of the order of 15000 CPS using SPP-2NF scintillometer gave very low chemical uranium. Seasonal variations in radioactivity and chemical uranium have also been noted. Samples collected from 15000 CPS spot radioactivity at different times yield 16,41,130,9,515 and 177 ppm U_3O_8 on analyses (Table 6).

Radioactivity is mostly found concentrated in shear zones, joints/fractures, Iron oxidation zones (Limonite deposit of Reshian) and brecciated zones. Qualitative-spectrometric analyses indicate U, Th, K^{40}, and their daughter products, causing high radioactivity in the area (Table 8 and 13).

Radioactivity is higher in the graphitic-metapelites of Reshian area (Azad Kashmir) as compared to the other exposures in NW Pakistan. Table 6 presents a record of the radioactivity from Reshian area. The data has been collected from various places both on the surface as well as from the underground excavations. The table indicates that the maximum radioactivity at Reshian area has been15000 CPS (using SPP-2NF scintillometer) against background radioactivity of 250 and 800 CPS. Maximum radioactivity in the range of 5000 CPS against background radioactivity of 150-200 CPS has been noted in Tarbela area (Table 11). In Kaghan area 700 CPS was the maximum radioactivity against 200-250 CPS background radioactivity (Butt et al., 1978). In Thakot area the graphitic-metapelites are reported to host maximum radioactivity upto 2500 CPS at Thakot-Chanjal bands and upto 575 CPS at Jambera area against 200-450 CPS background (Table 9 and 10, AEMC/Geo-36). The average chemical uranium at Reshian and Tarbela areas is about 46 ppm while the same has not been worked out in other areas because of limited number of chemical analyses. Seasonal variation in radioactivity has been particularly noted in Reshian area and is explained by the presence of U, Th, their daughter products and K^{40}. It is considered that during deposition of the rocks some elements got enriched at the upper level below the evaporite deposits. Later orogenic movements caused shearing and mylonitization of these rocks. The resultant crushing of the graphitic-metapelites caused the increased permeability of these rocks, and provided pathways for free groundwater circulation which dissolved and removed the most soluble elements. As a result uranium was leached while its daughter products remained and concentrated. In case of abundant rainfall, probably the daughter products are also carried away resulting in the reduced radioactivity for the time. Unlike most black shale deposits, uranium and other associated elements are not correlated together in the studied rock types. Leventhal (1991) has also described some samples from the northwest part of Swedish alum shale which do not show any correlation among the elements. The absence of positive correlation among elements in the studied rock types has been discussed in the following chapter. The absence of corelation may suggest supergene enrichment of uranium (Bell, 1978). However no evidence is found in favour of remobilization on large scale in the studied rocks of NW Pakistan and Azad Kashmir, which may cause the enrichment.

4.2 Radioactivity in Graphitic-metapelites from Reshian Area.

Radioactivity is widely distributed within the graphitic-metapelites at Reshian (Fig.3) against the background of about 250 CPS or more. Spots with 2-3 times higher background counts per second are commonly observed (Table 6).

TABLE 6. DISTRIBUTION OF RADIOACTIVITY AND CHEMICAL URANIUM AT SAMPLE SITES AT RESHIAN

S.No.	Sample No.	B/G Cps	Maximum Radioactivity Cps	U_3O_8 ppm	S.No.	Sample No.	B/G Cps	Maximum Radioactivity Cps	U_3O_8 ppm
1.	Cm-1/87	200	750	114	27.	R-T(15)/87	800	10000	137
2.	Cm-2/87	200	750	10	28.	R-T(16)/87	800	5000	81
3.	Cm-3/87	200	1500	10	29.	R-T(17)/87	800	1000	43
4.	Cm-4/87	200	2500	22	30.	R-C(14)/87	-	9000	65
5.	Cm-5/87	200	1000	14	31.	S-1	-	1500	15
6.	Cm-6/87	200	1400	14	32.	S-2	-	1000	33
7.	R-C(1)/87	200	2600	102	33.	S-3	-	750	120
8.	R-C(2)/87	200	5000	23	34.	S-4	-	2500	110
9.	R-C(3)/87	250	7500	120	35.	RN-1/88	-	10000	31
10.	R-C(4)/87	250	15000	16	36.	RN-2/88	-	6000	6290
11.	R-C(5)/87	250	15000	41	37.	RN-3/88	-	4000	880
12.	R-C(6)/87	250	7000	47	38.	RN-4/88	-	1500	23
13.	R-T(1)/87	800	7000	153	39.	RN-5/88	-	14000	25
14.	R-T(2)/87	800	3500	100	40.	RN-6/88	-	15000	9
15.	R-T(3)/87	800	10000	310	41.	RN-7/88	-	10000	45
16.	R-T(4)/87	800	7000	170	42.	RN-8/88	-	2500	28
17.	R-T(5)/87	800	2500	67	43.	T-4(1)/88	-	4000	200
18.	R-T(6)/87	800	1100	428	44.	T-4(2)/88	-	4000	75
19.	R-T(7)/87	800	2000	58	45.	T-5(1)/88	-	5000	14
20.	R-T(8)/87	800	8000	400	46.	T-5(2)/88	-	1400	47
21.	R-T(9)/87	800	10000	85	47.	T-5(3)/88	-	1400	55
22.	R-T(10)/87	800	10000	42	48.	T-6(1)/88	-	600	26
23.	R-T(11)/87	800	15000	130	49.	R-1	-	15000	515
24.	R-T(12)/87	800	7000	69	50.	R-2	-	15000	171
25.	R-T(13)/87	800	4000	68	51.	R-3	-	11000	85
26.	R-T(14)/87	800	7500	135	52.	R-4	-	7500	49

The upper horizon is more radioactive than the thin lower one where some hot spots were recorded with 15000 counts per second. A characteristic feature of the radioactivity in the area is that hot spots give very low chemical uranium. γ - spectrometric analyses of the samples from the hot spots indicate that it is the combined effect of U, Th, K^{40} and their daughter products (Table 8).

The following three types of radioactive anomalies are distinguished on the basis of field association in Reshian area :

i) Associated with surficial scree deposits including the limonite deposits of the area. It is considered as a false anomaly resulting from the accumulation of the daughter products of U, Th and K^{40} trapped in limonite (Jones, 1986).

ii) Radioactivity is found associated with shear zones and fractures/joints. The sheared zones are characterized by extreme crushing, as a result the individual laminations and planes of schistosity have lost their identification. Copper staining is found associated with sheared zones. Due to crushing of the rock, some of elements including uranium may have leached and removed by the circulating groundwater (Bell,1978).

TABLE 7. SUBSURFACE DISTRIBUTION OF URANIUM, RESHIAN AREA AZAD KASHMIR

S.No.	Hole No.	Hole Level (m)	Zone No.	Depth (m)	eU_3O_8 ppm	Zone No.	Depth (m)	U_3O_8 ppm
1.	Ly-1	2064	I	80-82	170	A	799-82	101
2.	"		II	85.6-86.4	176	B	86.3-87.5	55
3.	"		III	88-90	170	-	-	-
4.	Ly-2	2034	I	47.2-49.1	230	A	48.5-49.0	63
5.	"		II	62.1-63.8	230			
6.	Ly-4	1977	I	19.5-21.3	500			
7.	"		II	30.2-33.6	200	A	14.6-14.9	56
8.	"		III	36.4-40.3	229	B	49-49.7	51
9.	"		IV	43-47.2	160			
10.	Ly-5	1919.7	I	19.8-25.8	80	A	20.4-21.3	78
11.	"		II	34.8-45.2	70	B	23.8-25.9	57
12.	"		III	47.3-55.4	70	C	49.4-50.6	56
13.	Ly-9	1981	I	3.7-5.7	120			
14.	"		II	15.6-16.4	900	A	16-19.8	62
15.	"		III	20.9-21.7	300	B	62.5-63.1	50
16.	"		IV	22.5-24.7	200	C	70.4-71.6	72
17.	"		V	46.8-48.8	150	D	75.3-77.1	60
18.	"		VI	53.3-58.3	130			

TABLE 8. ESTIMATION OF URANIUM AND THORIUM

S.No.	Sample No.	U_3O_8 (ppm) Chemical	Radiometric Assay
1.	Rn-3	6	Traces of radioactivity mainly due to Th-DTRS plus K^{40}, and U-DTRS*.
2.	Rn-11	7	Traces of radioactivity due to U-DTRS, Th-DTRS and K^{40}.
3.	Rn-18	3	Traces of radioactivity mainly due to Th-DTRS plus K^{40} and U-DTRS.
4.	Rn-21	11	Traces of radioactivity mainly due to U-DTRS, Th-DTRS and K^{40}.
5.	Rn-22	4	Traces of radioactivity mainly due to Th-DTRS, plus K^{40} and U-DTRS.
6.	Rn-37	64	Traces of radioactivity mainly due to U-DTRS, plus K^{40} and Th-DTRS.
7.	Rn-38	91	Traces of radioactivity due to U-DTRS, Th-DTRS and K^{40}.
8.	Rn-39	27	-do-
9.	Rn-42a	75	Traces of radioactivity mainly due to U-DTRS plus K^{40}, Th-DTRS.
10.	Rn-48	0.245%	-do-
11.	Kn-1	448	-do-
12.	Kn-3	52	Traces of radioactivity mainly due to Th-DTRS, plus K^{40}, U-DTRS.
13.	Kn-4	16	Traces of radioactivity due to U-DTRS, Th-DTRS and K^{40}.
14.	Kn-5	85	Traces of radioactivity due to Th-DTRS plus K^{40}, U-DTRS.
15.	Kn-6	12	-do-
16.	Kn-7	45	Traces of radioactivity mainly due to U-DTRS plus K^{40}, Th-DTRS.

Table 8. Contd

S.No.	Sample No.	U_3O_8 (ppm) Chemical	Radiometric Assay
17.	Kn-8	6	Traces of radioactivity mainly due to Th-DTRS plus K^{40}, U-DTRS.
18.	T-1	9	-do-
19.	T-3	24	-do-
20.	T-5	7	-do-
21.	Ly-3(1)	10	-do-
22.	Ly-3(2)	22	-do-
23.	Ly-3(3)	137	-do-
24.	Ly-3(4)	39	-do-
25.	Ly-3(5)	44	Traces of radioactivity due to U-DTRS, Th-DTRS and K^{40}.
26.	Ly-3(6)		-do-
27.	Ly-3(7)	14	-do-
28.	Ly-3(8)	13	-do-
29.	Ly-3(9)	9	Traces of radioactivity mainly due to Th-DTRS plus K^{40}, U-DTRS.
30.	Ly-3(10)	11	-do-
31.	Ly-3(11)	19	-do-
32.	Ly-3(12)	7	-do-
33.	Ly-3(13)	9	-do-
34.	Ly-3(14)	15	-do-
35.	Ly-3(15)	20	-do-
36.	Ly-3(16)	7	-do-
37.	Ly-3(17)	22	-do-
38.	Ly-3(18)	12	-do-

Table 8. Contd.

S.No.	Sample No.	U_3O_8 (ppm) Chemical	Radiometric Assay
39.	Ly-3(19)	8	Traces of radioactivity due to U-DTRS, Th-DTRS and K^{40}.
40.	Ly-3(20)	7	-do-
41.	Ly-3(21)	32	-do-
42.	Ly-3(22)	31	-do-
43.	Ly-3(23)	26	-do-
44.	Ly-3(24)	38	-do-
45.	Ly-3(25)	10	-do-

* DTRS Daughter products.

iii) Radioactivity is found associated with collapse breccia. This form of radioactivity was first recognized in late seventies (Butt, Personnel communication). It is found associated with brecciated rocks of the graphitic-metapelites cemented with limonite. Such rocks are at places associated with gypsum and limestone layers (G.R.786236, 43-F/15).

Subsurface radioactivity was recorded in drill holes with the help of γ-ray 1000-C Mount Sopris Logging Unit. Higher radioactivity is seen confined to the upper level, near the topographic surface (Fig 16), is discussed in the following chapter. High radiometric anomalies in the subsurface correspond to the enriched element level. The figure also shows that high radiometric uranium has always low chemical equivalent. In some cases the analyses at hand indicate high chemical uranium against radiometric uranium of the background level. This is interpreted as the primary uranium which occurs below the zone of weathering and oxidation.

4.3 Radioactivity in Graphitic-metapelites from Kaghan Area.

Several zones of graphitic-metapelites are found in Salkhala series exposed in Kaghan Valley (Table 9). The table shows the background and maximum radioactivity recorded in the different zones (Butt et al., 1978).

TABLE 9. RADIOACTIVITY IN GRAPHITIC-METAPELITES FROM KAGHAN AREA.

Zone No.	Graphitic-metapelites	Background Radioactivity	Maximum Radioactivity
1.	Shino-Sharan Zone.	100-250 CPS	700 CPS
2.	Dohar Zone.	100-250 CPS	1000 CPS
3.	Seri-Manur Zone.	150-300 CPS	800 CPS
4.	Butan Patch.	100-150 CPS	350 CPS
5.	Chitta Katha-Lambi Patti Zone.	100-150 CPS	1000 CPS
6.	Kaghan Nalla-Shingri Zone.	120-150 CPS	500 CPS
7.	Rawalakot-Danna Zone.	300 CPS	1300 CPS
8.	Mahandri Patches.	150 CPS	750 CPS

After Butt et al., 1978

The Shino-Sharan graphitic-metapelites extend for more than 16 Km with a variable thickness of about 180 meters to more than 1.6 Km. Surface radioactivity is low, ranges from 150 to 350 CPS and higher radioactivity has been recorded in shallow trenches made in the area. γ-spectrometric results indicate dominantly thorium and its daughters with minor uranium and its daughters and chemically 448 ppm U_3O_8 at the maximum has been analyzed in the samples from the area (Butt et al., 1978). The subsurface behaviour of radioactivity has also been reported to be similar to that described for Reshian area above.

4.4 Radioactivity in Graphitic-metapelites from Thakot and Thana areas.

At Thakot areas, the Jambera graphitic-metapelites zone (G.R 977967) is about 4-9 meter thick, extending for more than 3.2 Km. Radioactivity is generally low. The background radioactivity from 150 to 225 CPS, with 650 CPS as the maximum radioactivity recorded at some spots. The data on radioactivity and chemical uranium is presented in Table 10 (Baig et al., AEMC/Geo-36). The table indicates 295 ppm U_3O_8 at the maximum.

The Chanjal zone at Thakot contains small patches of graphitic-metapelites. 1200 CPS was the maximum radioactivity recorded in the area and chemically less than 100 ppm uranium has been reported (Baig et al., AEMC/Geo-36, Table 9).

TABLE 10. DISTRIBUTION OF RADIOACTIVITY AND CHEMICAL URANIUM AT SAMPLE SITES AT THAKOT-CHANJAL GRAPHITIC BANDS (After Baig et al., AEMC/GeO-36)

S.No.	Sample No.	B.G. CPS	Spot CPS	U_3O_8 ppm	Host Rocks
1.	TK-CH-44	200	750	10	Graphitic schist with pyrite.
2.	TK-CH-45	250	600	35	Calc-graphitic schist with minor pyrite.
3.	TK-CH-46	250	1200	20	Weathered graphitic schist.
4.	TK-CH-47	200	1100	10	Graphitic schist with limonite and hematite.
5.	TK-CH-48	400	1600	10	Carbonaceous graphitic schist with pyrite.
6.	TK-CH-49	450	1800	100	Carbonaceous schist with limonite.
7.	TK-CH-50	350	2500	250	Carbonaceous schist with pyrite.
8.	TK-CH-51	350	1500	295	Graphitic schist with high alteration.
9.	TK-CH-52	300	400	20	Graphitic schist.
10.	TK-CH-53	250	400	90	Graphitic schist.
11.	TK-CH-54	250	600	30	Graphitic schist with pyrite.
12.	TK-CH-55	150	700	10	Graphitic schist contact zone.

TABLE 11. DISTRIBUTION OF RADIOACTIVITY AND CHEMICAL URANIUM AT SAMPLE SITES AT JAMBERA AREA THAKOT (After Baig et al., AEMC/Geo.38)

S.No.	Sample No.	B.G. CPS	Spot CPS	U_3O_8 ppm	Host rocks
1.	TK-JA-37	200	420	100	Graphitic schist interbedded.
2.	TK-JA-38	200	470	100	Graphitic schist with limonite.
3.	TK-JA-39	185	470	100	Graphitic schist with quartz and mica.
4.	TK-JA-40	225	575	100	Graphitic schist with quartz and mica.
5.	TK-JA-41	225	450	100	Graphitic schist with limonite.
6.	TK-JA-42	240	450	100	Graphitic schist with minor quartz and limonite.
7.	TK-JA-43	220	480	100	Graphitic schist with quartz and mica.

In Thana area (Malakand) patches of graphitic-metapelites have been studied near Moora granite which give low - radioactivity and low chemical uranium (Table 18).

4.5 Radioactivity in Graphitic-metapelites from Tarbela Area.

The graphitic-metapelites associated with Manki Formation at Tarbela extend for more than 10 Km. These rocks indicate variable but generally high radioactivity. Here the maximum radioactivity has been found near Chamiari Village after which the anomaly has been named. The data on radioactivity and chemical uranium content of these rocks is given in Table 12. The table indicates 5000 CPS as the maximum radioactivity while the maximum chemical uranium in surface samples in Chamiari is 269 ppm. In another horizon at Tarbela 283 ppm U_3O_8 has been analyzed from the surface samples (Table 12). The radioactivity in Tarbela area is similar to Reshian, in a respect that radioactive hot spots give low chemical uranium. Like Reshian radioactivity is due to the combined affect of U, Th and their daughter products(Table 14). The rocks from Tarbela area are metamorphosed in the lower greenschist facies condition. The role of metamorphism in uranium mobilization has not been important particularly in low grade rocks (Dostal et al., 1978). Therefore in the studied rock types metamorphism is not considered to play a part in redistribution of uranium. On the other hand groundwater circulation seems to be the prime factor causing the present distribution of radioactivity and chemical uranium. As

TABLE 12. DISTRIBUTION OF RADIOACTIVITY AND CHEMICAL URANIUM AT SAMPLE SITES AT TARBELA.

S.No.	Sample No.	Maximum Radioactivity (cps)	U_3O_8 ppm	S.No.	Sample No.	Maximum Radioactivity (cps)	U_3O_8 ppm
1.	T-C(1)/88	1200	66	24.	DK-1	5000	12
2.	T-C(2)/88	2200	73	25.	DK-2	4000	31
3.	T-C(3)/88	2500	84	26.	DK-3	3000	32
4.	T-C(4)/88	2500	22	27.	DK-4	1000	2
5.	T-C(5)/88	2500	25	28.	DK-5	3000	51
6.	T-C(6)/88	5000	170	29.	TC 2-1	3000	33
7.	T-C(7)/88	3000	40	30.	TC 2-2	2000	92
8.	T-C(8)/88	2000	40	31.	TC 2-3	750	42
9.	T-C(9)/88	3000	51	32.	TC 2-4	800	134
10.	T-C(10)/88	2000	40	33.	TTI-1	1800	56
11.	T-C(11)/88	3000	47	34.	TTI-2	1200	127
12.	T-C(12)/88	1000	22	35.	TTI-3	1000	84
13.	T-C(13)/88	2500	22	36.	TTI-4	350	22
14.	T-C(14)/88	1000	19	37.	TTI-5	800	112
15.	T-C(15)/88	2000	33	38.	TTI-6	1000	38
16.	T-C(16)/88	3000	25	39.	TTI-7	400	10
17.	T-C(17)/88	2000	12	40.	TTI-8	350	16
18.	TG-1/88	700	8	41.	TTI-9	750	19
19.	TG-2/88	500	3	42.	TTI-10	430	28
20.	TG-3/88	600	4	43.	TTI-11	320	6
21.	TC-18/88	1000	45	44.	TTI-12	3500	247
22.	TC-19/88	600	39	45.	TTI-13	900	127
23.	TC-20/88	200	19	46.	TTI-14	360	22

Contd...

Table 12. Contd.

S.No.	Sample No.	Maximum Radioactivity (cps)	U_3O_8 ppm
47.	TTI-15	270	14
48.	TT 3-16	1100	59
49.	TT 3-17	300	12
50.	TT 3-18	300	10
51.	TT 3-19	750	8
52.	TT 3-20	1100	77
53.	TT 3-21	300	12
54.	TT 3-22	220	11
55.	TT 3-23	900	17
56.	TT 3-24	300	13
57.	TT 3-25	850	10
58.	TT 2-26	1000	35
59.	TT 2-27	1000	31
60.	TT 2-28	200	21
61.	TT 2-29	200	14
62.	TT 2-30	750	17
63.	TT 2-31	200	12
64.	TT 2-32	1000	9
65.	TT 2-33	800	36
66.	TT 2-34	750	16
67.	TT 2-35	200	8
68.	TT 2-36	150	12
69.	TT 4-37	140	22
70.	TT 4-38	150	15
71.	TT 4-39	750	28
72.	TT 4-40	800	28
73.	TT 4-41	150	15
74	TT 4-42	750	28
75.	TT 4-43	150	14
76,	TT 4-44	800	24
77.	TT 4-45	750	269
78.	TT 4-46	200	56
79.	TT 5-47	500	269
80.	TT 5-48	300	38
81.	TT 5-49	300	34
82.	TT 5-50	400	12
83.	TT 5-51	230	18
84,	TT 5-52	600	17
85.	TT 5-53	280	14
86.	TT 5-54	350	35
87,	TT 5-55	750	224
88.	TT 5-56	250	35
89.	TT 5-57	280	14
90.	TT 6-58	880	113
91.	TT 6-59	250	23
92.	TT 6-60	250	27
93.	TT 6-61	500	136
94.	TT 6-62	270	37

Contd....

Table 12. Contd.

S.No.	Sample No.	Maximum Radioactivity (cps)	U_3O_8 ppm
95.	TT 6-63	220	23
96.	TT 6-64	450	45
97.	TT 6-65	200	43
98.	TT 6-66	180	29
99.	TT 6-67	350	15
100.	TT 6-68	200	22
101.	TT 6-69	220	15
102.	TT 7-70	750	16
103.	TT 7-71	350	28
104.	TT 7-72	260	20
105.	TT 7-73	500	18
106.	TT 7-74	330	16
107.	TT 7-75	270	10
108.	TT 7-76	600	21
109.	TT 7-77	300	13
110.	TT 7-78	320	10
111.	TT 7-79	500	26
112.	TT 7-80	280	21
113.	TT 7-81	300	28
114.	TT 7-82	750	61
115.	TT 7-83	300	38
116.	TT 7-84	320	10
117.	TT 7-85	800	49
118.	TT 7-86	280	10
119.	TT 7-87	260	11
120.	TT 8-88	500	40
121.	TT 8-89	200	13
122.	TT 8-90	200	13
123.	TT 8-91	500	23
124.	TT 8-92	220	19
125.	TT 8-93	230	23
126.	Gn-1/90	500	1
127.	Gn-2/90	-	27
128.	Gn-3/90	400	63
129.	Gn-4/90	500	5
130.	Gn-5/90	-	190
131.	Gn-6/90	-	94
132.	Gn-7/90	-	44
133.	B-1	-	31
134.	B-2	-	253
135.	B-3	-	214
136.	M-1	-	283
137.	M-2	-	66
138.	M-3	-	63

TABLE 13. SUBSURFACE URANIUM DISTRIBUTION IN CHAMIARI AREA TARBELA

S.No.	Hole No.	Hole Level(m)	Zone No.	Depth (m)	eU_3O_8 ppm	Zone No.	Depth (m)	U_3O_8 ppm
1.	W-3	882.7	I	7.8-5.5	165	A	13.7-16.1	120
2.	"	"	II	7.1-8.1	282	B	24.4-28.3	192
3.	"	"	III	18.1-21.2	114			
4.	W-4	884	I	3.96-4.87	388	A	12.2-14	163
5.	"	"	II	8.8-9.7	118	B	15.5-17	192
6.	"	"	III	10.67-12.8	143			
7.	W-5	884	I	2.1-6	240	A	15.8-31.1	142
8.	"	"	II	9.9-13.0	230			
9.	"	"	III	10.1-11.1	320			
10.	"	"	IV	17.3-18.3	200			
11.	"	"	V	28.7-29.8	168	A	17.37-17.98	160
12.	W-8	884	I	3.1-4	100			
13.	"	"	II	5.5-7	90			
14.	"	"	III	9.8-14	100			
15.	"	"	IV	15.4-16.7	155			
16.	W-19	842	I	1.6-2.4	230			
17.	"	"	II	5.2-6	160	A	15.24-16.76	142
18.	"	"	III	6.2-7.3	150	B	20.4-21.3	159
19.	"	"	IV	9.7-12.1	150			

Table 13. Contd.

S.No.	Hole No.	Hole Level (m)	Zone No.	Depth (m)	eU_3O_8 ppm	Zone No.	Depth (m)	U_3O_8 ppm
20.	W-20	820	I	1-1.9	100	A	10.4-13.1	113
21.	"	"	II	2.8-4.6	100	B	17-17.9	101
22.	"	"	III	6.7-10.7	180			
23.	W-13	882	I	3.8-4.6	200	A	6.4-9.75	139
24.	"	"	II	6.9-7.8	200	B	15.5-16.76	110
25.	"	"	III	12-12.7	240			
26.	"	"	IV	15.5-16.6	260			
27.	W-25	823	I	1.9-2.75	140	A	7.6-8.2	104
28.	"	"	II	11.3-13.5	140			

TABLE 14. ESTIMATION OF URANIUM AND THORIUM IN CORE SAMPLES FROM TARBELA AREA.

S.No.	Sample No.	U_3O_8 (ppm)	Radiometric Assay
1.	Ly-2(4)/90	12	Almost barren
2.	Ly-2(9)/90	13	Slight radioactivity due to Pb^{214}, Bi^{214}.
3.	Ly-2(13)/90	19	Almost barren.
4.	Ly-2(17)/90	25	Slight radioactivity due to Pb^{214}, Bi^{214}.
5.	Ly-2(22)/90	36	"
6.	Ly-2(26)/90	45	"
7.	Ly-2(30)/90	16	"
8.	Ly-2(34)/90	14	"
9.	Ly-2(38)/90	16	Almost barren.
10.	Ly-2(42)/90	26	"
11.	Ly-2(47)/90	21	Slight radioactivity due to Pb^{214} and Bi^{214}.
12.	Ly-2(51)/90	28	Almost barren.
13.	Ly-2(55)/90	28	Slight radioactivity due to Pb^{214} and Bi^{214}.
14.	Ly-2(60)/90	26	"

alreay stated such consideration would favour supergene uranium enrichment somewhere at favourable places. However, the same has not be found at depth probably because of the absence of large scale uranium remobilization.

Chapter-5

GEOCHEMISTRY

5.1 Introduction

Fifty six samples were chemically analyzed for the major, minor and trace elements in the graphitic-metapelites exposed in NW Pakistan and the adjacent area of Azad Kashmir. These include both the surface and core samples from Reshian and Tarbela areas and only surface samples from Kaghan and Thana (Malakand).

The various exposures of graphitic-metapelites represent metamorphism under different conditions and lie in structurally different blocks (Fig.1). Those at Reshian area indicate amphibolite grade metamorphism with a retrograde to greenschist facies. At Kaghan and Tarbela areas, the studied rock types indicate metamorphism under the greenschist facies conditions and at Swat, the same rocks were placed in Alpurai schist unit which indicate metamorphism in the amphibolite facies with a retrograde greenschist facies (Kazmi et al., 1984).

Structurally the rock types studied at Reshian area are exposed on the eastern side of the Hazara-Kashmir syntaxis and thrust over the younger sequence along the Panjal and Murree thrusts. In Kaghan Valley the Shino graphitic-metapelites lie at the apex of the syntaxis and fall in the lower Kaghan nappe. The studied rocks in Tarbela area lie in the southern part of Hazara nappe away from the syntaxis. Those exposed at Thana belong to the Swat nappe to the west of the Indus river.

The major, minor and trace elements composition of the studied rock types is given in tables 15,16,17 and 18. In order to compare the chemical composition of the various exposures, some basis of comparison has to be established. Following Ferry (1987), a constant Al reference framework was adopted which is justified by the low solubility of Al in aqueous fluids. Consequently the ratios of concentration of the various elements to that of Al were calculated for all the analyzed samples. Table 19 presents the average Si, Ti, Fe, Mg, Ca, Na and K values relative to Al for all the analyzed samples. The relative abundance of the various components is shown in Fig. 7. The graphitic-metapelites from Tarbela and Thana (Malakand) areas have higher average Si, Followed by those from Reshian area which in turn has higher Si than that of the Kaghan area. This is also in conformity with the double triangle classification of the graphitic-metapelites from NW Pakistan and Azad Kashmir (Fig. 18A and B) discussed in the following pages.

According to the classification, the graphitic-metapelites from Tarbela and Thana areas plot above the 60% quartz line (siliceous black shale) and the others plot below and close to the above mentioned line (Argillaceous-siliceous black shale, Fig. 18A and B). The siliceous black shales are deposited within a shelf of marginal seas and in epicontinental

TABLE.15. CHEMICAL ANALYSES OF SURFACE SAMPLES FROM RESHIAN AREA

Element (%)	Rn-3	Rn-1	Rn-18	Rn-21	Rn-22	Rn-37	Rn-38	Rn-39	Rn-42a	Rn-48
SiO_2	62.03	68.84	70.71	70.0	76.08	72.97	65.73	63.72	58.39	61.42
TiO_2	0.83	0.81	0.89	0.89	0.31	0.69	0.71	0.42	0.58	0.73
Al_2O_3	13.5	20.58	16.47	18.65	11.33	15.59	15.27	9.50	13.19	13.2
Fe_2O_3	0.4	0.1	0.17	0.82	1.00	0.29	1.62	0.93	1.44	4.59
FeO	0.38	1.20	2.74	0.32	0.88	0.78	1.12	0.88	0.70	0.76
MnO	0.01	0.01	0.04	0.01	0.01	0.01	0.01	0.01	0.01	0.02
CaO	0.05	0.05	0.05	0.05	0.05	0.49	0.71	0.05	0.05	0.05
MgO	0.16	0.13	0.19	0.05	0.06	0.18	0.18	0.19	0.09	0.31
Na_2O	1.75	1.01	1.12	6.73	2.92	1.98	2.05	0.94	0.75	1.04
K_2O	2.54	7.02	3.45	0.10	0.36	3.63	6.00	5.13	4.91	4.01
P_2O_5	0.04	0.04	0.09	0.09	0.05	0.04	0.31	0.23	0.13	0.14
H_2O (t)	3.55	0.85	1.29	0.92	1.04	1.43	2.41	0.10	4.13	5.42
CO_2	0.03	0.21	0.62	0.03	0.03	0.03	1.66	0.83	1.86	4.34
Corg*	14.2	3.80	2.80	0.10	6.60	2.30	1.10	16.60	14.02	3.60
S	0.23	0.40	0.09	0.28	0.68	0.45	0.29	0.25	0.43	0.20
	Trace elements (ppm)									
Zn	16	49	63	32	12	16	35	16	16	33
Ba	805	100	128	50	39	660	618	172	139	67
Cu	28	47	23	57	21	314	1885	220	1951	15
V	415	140	100	100	100	130	145	790	530	160
Mo	50	87	66	50	74	50	52	70	52	83
Co	9	26	18	23	51	18	79	32	29	80
Rb	121	38	171	5	5	159	144	130	124	82
Pb	50	34	32	23	24	26	24	500	254	500
Cr	111	178	117	61	78	133	172	133	122	133
Ni	50	57	50	50	50	-	113	52	-	166
U_3O_8	6	7	3	11	4	64	91	27	75	2450

*Organic carbon

TABLE 16. CHEMICAL ANALYSES OF CORE SAMPLES FROM RESHIAN AREA

Element (%)	LY-3 (1)	LY-3 (2)	LY-3 (3)	LY-3 (4)	LY-3 (5)	LY-3 (6)	LY-3 (7)	LY-3 (8)	LY-3 (9)	LY-3 (10)
SiO_2	55.22	64.78	53.30	47.62	55.19	52.40	75.88	63.30	56.56	46.98
TiO_2	0.58	0.79	0.92	0.67	0.67	0.81	2.00	0.94	0.89	2.85
Al_2O_3	15.59	13.65	15.87	12.17	12.94	16.77	8.94	16.96	19.33	21.25
Fe_2O_3	2.20	0.10	4.89	6.16	5.28	1.13	3.32	2.80	5.75	5.83
FeO	1.88	0.86	1.00	2.18	1.04	0.54	1.46	1.08	3.12	1.64
MnO	0.02	0.03	0.01	0.02	0.03	0.01	0.02	0.01	0.01	0.02
CaO	0.60	0.29	0.48	0.43	0.05	0.41	1.12	0.55	1.21	2.50
MgO	0.23	0.52	0.42	0.53	0.30	0.39	0.32	0.32	0.38	0.12
Na_2O	1.16	1.68	1.86	1.83	1.33	2.16	1.36	2.17	3.99	2.82
K_2O	5.49	3.98	5.78	4.63	6.02	5.19	0.17	3.13	0.22	3.17
P_2O_5	0.04	0.13	0.10	0.09	0.05	0.09	0.08	0.09	0.10	0.31
H_2O(t)	1.40	1.05	1.60	1.30	2.10	1.02	2.01	0.82	2.30	2.04
CO_2	1.03	2.07	1.03	0.83	0.21	1.03	1.03	2.27	1.24	2.69
Corg *	12.3	19.1	12.6	16.5	11.0	16.1	0.4	1.2	0.6	0.2
S	0.91	0.25	0.34	4.94	4.74	2.33	2.05	3.52	3.21	5.51
	Trace elements (ppm)									
Zn	55	27	19	14	9	11	5	8	38	84
Ba	960	1315	999	411	777	938	299	793	222	233
Cu	101	55	216	332	214	66	277	201	182	182
V	1305	1017	420	395	445	440	225	305	235	310
Mo	79	79	105	50	83	65	50	88	50	50
Co	30	15	200	84	82	15	100	200	94	83
Rb	81	175	123	110	142	102	15	185	5	42
Pb	43	29	43	49	29	31	24	24	30	27
Cr	233	183	250	228	222	144	250	239	150	133
Ni	52	50	244	144	233	76	139	106	94	174
U_3O_8	10	22	137	39	44	29	14	13	9	11

*Organic carbon

Table-16. Contd.

Element (%)	LY-3 (11)	LY-3 (12)	LY-3 (13)	LY-3 (14)	LY-3 (15)	LY-3 (16)	LY-3 (17)	LY-3 (18)	LY-3 (19)	LY-3 (20
SiO_2	53.5	60.93	56.2	53.29	48.31	49.73	49.5	62.51	67.2	69.08
TiO_2	3.31	0.98	1.06	1.10	0.98	4.06	3.91	0.89	0.73	1.04
Al_2O_3	21.93	14.83	29.41	23.02	16.96	16.49	21.10	16.29	14.54	13.60
Fe_2O_3	0.01	5.89	1.54	2.40	3.29	7.00	5.08	2.60	0.92	5.08
FeO	1.44	1.00	1.12	1.06	0.10	0.10	0.10	1.12	0.72	0.10
MnO	0.02	0.01	0.03	0.01	0.01	0.06	0.05	0.01	0.01	0.01
CaO	3.75	0.72	0.65	1.83	1.17	4.70	3.02	1.20	0.24	0.05
MgO	0.17	0.19	0.40	0.35	0.28	0.10	0.05	0.44	0.32	0.32
Na_2O	4.81	4.43	5.19	3.96	3.98	4.27	2.44	2.32	1.63	0.94
K_2O	3.99	0.11	1.35	4.45	3.04	2.81	5.66	2.82	2.81	3.02
P_2O_5	0.14	0.08	0.13	0.10	0.09	0.52	0.55	0.12	0.10	0.08
H_2O (t)	1.11	1.40	0.96	1.31	1.01	1.02	1.14	0.80	0.90	1.15
CO_2	1.44	1.24	1.03	1.24	3.30	4.13	2.13	1.86	1.03	2.48
Corg*	0.90	0.60	0.40	3.6	9.7	0.90	0.40	2.20	9.10	3.79
S	1.59	7.10	1.25	2.78	8.26	4.13	4.97	4.72	2.51	0.13
	Trace elements (ppm)									
Zn	55	20	39	12	17	86	124	36	16	10
Ba	672	299	139	1326	660	483	1060	999	1221	905
Cu	130	150	195	143	278	124	184	84	96	88
V	285	100	240	170	125	285	340	-	-	-
Mo	50	50	50	97	74	50	50	50	50	97
Co	64	80	56	37	31	22	75	27	19	38
Rb	85	5	5	92	39	71	142	129	141	151
Pb	22	30	21	30	35	32	31	35	31	27
Cr	128	133	211	233	250	67	78	317	272	328
Ni	123	107	102	112	134	50	170	92	93	101
U_3O_8	19	7	9	15	20	7	22	12	8	7

*Organic carbon

Table 16. Contd.

Element (%)	LY-3 (21)	LY-3 (22)	LY-3 (23)	LY-3 (24)	LY-3 (25)
SiO_2	61.14	66.72	63.10	64.69	61.32
TiO_2	0.67	0.50	0.83	0.69	0.83
Al_2O_3	16.78	15.85	15.69	16.37	19.12
Fe_2O_3	6.26	1.13	5.18	1.56	1.64
FeO	0.28	0.68	1.32	0.12	0.10
MnO	0.01	0.01	0.03	0.01	0.01
CaO	0.05	0.05	0.05	0.05	0.05
MgO	0.15	0.17	0.17	0.16	0.27
Na_2O	0.97	0.57	1.71	0.89	0.77
K_2O	6.18	5.71	5.40	5.55	7.11
P_2O_5	0.13	0.08	0.03	0.11	0.10
H_2O (t)	1.16	1.21	1.43	1.44	1.22
CO_2	1.24	1.03	0.41	0.83	2.27
Corg*	4.38	6.13	4.01	6.61	4.22
S	0.39	0.19	0.38	0.17	0.12
	Trace elements (ppm)				
Zn	5	5	7	5	6
Ba	910	533	672	716	877
Cu	99	121	141	58	103
V	-	-	-	-	-
Mo	56	69	93	83	125
Co	21	39	64	69	23
Rb	139	130	115	136	178
Pb	37	37	20	99	20
Cr	233	261	289	250	344
Ni	95	107	153	96	114
U_3O_8	32	31	26	38	10

*Organic carbon

TABLE 17. CHEMICAL ANALYSES OF CORE SAMPLES FROM TARBELA AREA

Element (%)	LY-2 (4)	LY-2 (9)	LY-2 (13)	LY-2 (17)	LY-2 (22)	LY-2 (26)	LY-2 (30)	LY-2 (34)	LY-2 (38)	LY-2 (42)
SiO_2	71.68	66.64	63.53	54.23	51.93	53.77	58.45	61.03	59.26	55.79
TiO_2	0.71	0.45	0.71	0.45	0.71	0.10	0.80	0.80	0.80	0.71
Al_2O_3	8.03	8.22	8.21	5.76	8.41	8.12	9.54	10.01	14.40	8.97
Fe_2O_3	0.63	2.57	3.43	3.50	4.72	4.65	4.29	5.18	2.06	1.43
FeO	0.24	0.14	0.30	0.18	0.24	0.16	0.22	0.12	0.28	0.48
MnO	0.01	0.03	0.04	0.11	0.06	0.10	0.05	0.02	0.04	0.11
CaO	1.10	2.44	2.86	7.22	5.63	5.59	1.73	1.94	2.36	4.11
MgO	0.51	1.00	1.06	0.51	0.71	0.78	0.74	0.70	0.71	0.78
Na_2O	0.37	0.30	0.35	0.64	0.59	0.65	0.60	0.58	0.45	0.64
K_2O	2.05	1.97	1.90	1.57	1.55	1.48	1.87	2.46	2.40	1.57
P_2O_5	0.04	0.11	0.04	0.09	0.05	0.09	0.32	0.04	0.07	0.04
$H_2O(t)$	2.14	1.93	2.00	1.54	1.90	2.64	2.74	4.70	2.43	2.94
CO_2	0.50	1.09	1.09	5.72	2.85	4.21	0.50	0.50	0.50	1.32
Corg *	11.55	9.91	11.01	13.54	15.92	13.05	16.2	11.80	13.70	13.15
	Trace elements (ppm)									
Rb	96	100	96	62	82	76	107	110	151	98
V	1370	925	955	1105	1470	1330	370	245	235	680
Ho	50	50	50	50	50	50	50	50	50	50
Zn	200	200	200	200	200	200	200	200	200	200
Ba	899	77	1171	477	688	372	50	865	722	860
Pb	50	31	37	32	49	45	45	28	39	66
Cu	64	61	81	62	77	65	98	81	114	95
Ni	173	296	275	105	124	108	121	118	129	137
Co	10	10	10	10	19	17	33	28	38	31
Cr	172	172	166	144	161	156	94	172	128	178
U_3O_8	12	13	19	25	36	45	16	14	16	26

* Organic carbon

Table 17. Contd.

Element (5)	LY-2 (47)	LY-2 (51)	LY-2 (55)	LY-2 (60)
SiO_2	59.10	58.10	61.76	51.40
TiO_2	0.63	0.53	0.53	0.63
Al_2O_3	8.97	11.52	9.95	8.03
Fe_2O_3	5.32	1.86	2.29	6.09
FeO	0.16	0.24	0.18	0.14
MnO	0.07	0.07	0.07	0.06
CaO	4.06	3.80	4.48	4.55
MgO	0.65	0.78	0.72	0.79
Ma_2O	0.53	0.59	0.48	0.45
K_2O	1.91	1.90	1.63	1.57
P_2O_5	0.04	0.11	0.04	0.25
H_2O(t)	2.85	2.83	3.16	4.91
CO_2	0.65	2.44	3.10	3.99
Corg *	13.32	11.33	10.15	15.35
	Trace elements (ppm)			
Rb	106	108	91	80
V	645	645	790	825
Mo	50	50	50	50
Zn	200	200	200	200
Ba	799	194	1032	816
Pb	43	39	53	44
Cu	81	82	84	67
Ni	123	121	117	115
Co	26	24	21	17
Cr	66	128	106	94
U_3O_8	21	28	28	26

* Organic carbon

TABLE 18. CHEMICAL ANALYSES OF SURFACE SAMPLES FROM KAGHAN & THANA

Element (%)	Kn-1	Kn-3	Kn-4	Kn-5	Kn-6	Kn-7	Kn-8	T-1	T-3	T-5
SiO_2	62.56	53.69	66.99	59.63	67.57	67.77	79.09	73.08	69.72	69.88
TiO_2	1.00	0.94	1.00	1.00	0.81	0.96	0.57	0.46	1.00	0.81
Al_2O_3	20.78	18.34	20.78	21.41	15.59	15.59	12.16	10.68	16.82	15.92
Fe_2O_3	3.12	7.39	2.56	5.55	0.93	0.82	1.43	1.82	0.59	1.23
FeO	1.50	1.46	0.40	1.64	3.80	0.64	0.64	1.52	0.96	0.70
MnO	0.09	0.02	0.03	0.11	0.05	0.01	0.07	0.01	0.01	0.01
CaO	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
MgO	0.16	0.32	0.15	0.44	0.51	0.11	0.09	0.24	0.05	0.11
Na_2O	0.92	0.98	1.08	0.61	1.35	1.31	1.36	0.86	0.96	1.11
K_2O	4.66	4.70	4.18	1.57	5.28	5.84	3.07	4.17	2.82	2.63
P_2O_5	0.11	0.10	0.01	0.33	0.16	0.09	0.12	0.43	0.12	0.06
$H_2O(t)$	3.11	2.20	1.35	2.81	1.86	2.13	1.56	1.90	2.31	2.66
CO_2	0.03	2.48	0.03	1.66	1.44	0.03	0.03	1.44	0.62	0.41
Corg *	1.50	4.80	0.90	0.90	0.30	4.20	0.30	2.10	4.6	3.9
S	0.04	2.17	0.02	0.02	0.12	0.11	0.09	0.10	0.17	0.46
	<u>Trace elements (ppm)</u>									
Zn	116	65	83	142	126	55	62	160	24	25
Ba	366	161	771	255	477	588	222	588	1060	1116
Cu	2895	342	175	675	83	279	106	109	228	94
V	190	205	170	180	160	165	105	160	50	105
Mo	50	50	50	50	50	50	50	50	-	57
Co	20	29	03	33	21	19	27	25	08	19
Rb	44	106	74	09	110	146	54	91	110	147
Pb	130	49	62	55	44	144	-	49	63	54
Cr	178	128	89	100	78	100	89	144	133	128
Ni	63	50	50	63	50	50	50	59	50	50
U_3O_8	448	52	16	85	12	45	6	9	24	7

* Organic carbon

TABLE 19. AVERAGE MAJOR ELEMENT COMPOSITION OF THE GRAPHITIC METAPELITE, RELATIVE TO Al.

Element	Reshian area	Tarbela area	Kaghan area	Thana (Malakand area
Si/Al	3.54	5.7	3.23	4.33
Ti/Al	0.05	0.08	0.06	0.06
Fe/Al	0.58	0.53	0.35	0.22
Mg/Al	0.02	0.09	0.01	0.01
Ca/Al	0.06	0.55	-	-
Na/Al	0.17	0.08	0.08	0.09
K/Al	0.43	0.32	0.37	0.35

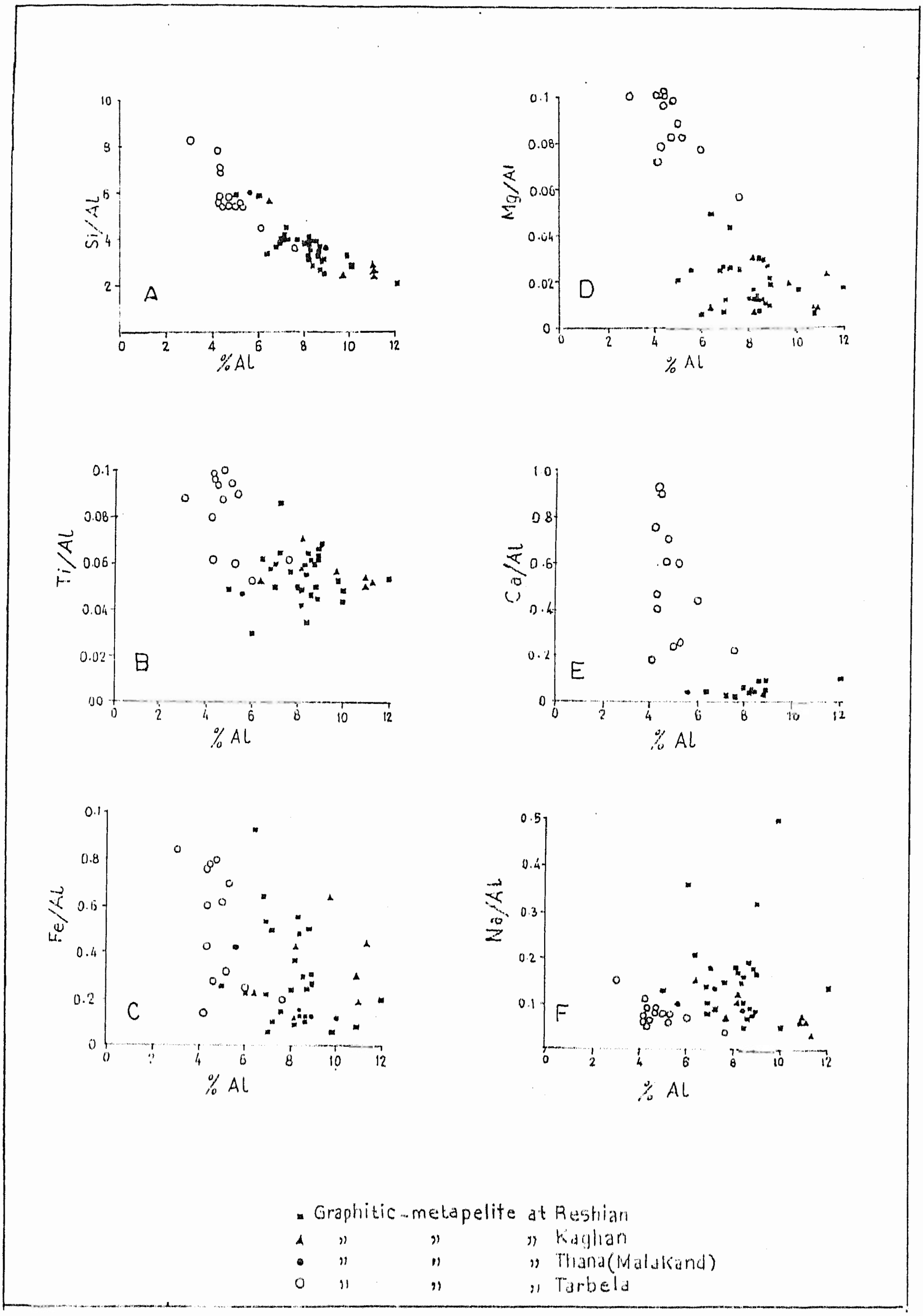


Fig. 7. Plot of Si, Ti, Fe, Mg, Ca, Na, and K vs. Al for the graphitic metapelites.

basins open to the ocean, in a relatively less stable zone compared to other types of black shale deposits.

Fig.7B, D and E indicate that relative to Al, the average Ti, Mg, and Ca are also higher in samples from the Tarbela area. The average Ti in samples from Kaghan and Thana (Malakand) areas is about the same, and a little lower in samples from Reshian area. Ti is believed to be concentrated in ilmenite which is a detrital mineral. The analyzed Mg and Ca values are attributed to calcite and dolomite. Compared to average black shale, the Ca content of the graphitic-metapelites is lower except for Tarbela area, while Mg is lower in all the studied samples (Table 20). Higher average Ca in samples from Tarbela area may be due to biogenic separation from seawater characterized by higher organic activity than the other areas.

Fig.7C and Table 19 show that i) average total Fe relative to Al is about the same at Reshian and Tarbela areas, ii) it is higher in these two than in the Kaghan and Thana (Malakand) areas, and iii) that the samples from Thana area has the lowest total Fe. Average Fe_2O_3/FeO ratios are in the following order: Tarbela area has the highest (19.34), followed by Reshian (4.29), Thana (3.56) and Kaghan 2.95). These ratios are used to infer that the graphitic-metapelites at Tarbela are probably more oxidized compared to others.

Fig.7F indicates that average Na relative to Al is the highest at Reshian while it is about the same in the rest of the exposures. Average K relative to Al is also higher in the graphitic-metapelites from Reshian area than that of Kaghan which in turn has higher K than Thana (Malakand) and Tarbela areas. The Na and K concentration may indicate redistribution of the elements due to later processes (Beus, 1976). However, higher Na and K in the graphitic-metapelites from Reshian area compared to average black shale (Table 20) probably indicate that these rocks were originally enriched in these elements and do not indicate any remobilization due to later processes.

5.2 Composition of Graphitic-metapelites compared to Average Black shale.

The major, minor and trace element composition of the graphitic-metapelites from NW Pakistan and Azad Kashmir is compared with that of the average black shale composition of the same elements described by Vine and Tourtelot (1970), reproduced in Table 20, and shown in Fig.8. It includes comparison with the trace element composition of the average shales, black shales, black sea muds, alum shales and Outokumpu black schists reproduced in Table 21 (Bell, 1978). The data has also been compared with the metal rich black shale in Table 21, shown in Fig.8.

Major element chemistry shows that Al in samples from Tarbela area is lower than the average black shale, and is

TABLE 20. AVERAGE MAJOR AND MINOR ELEMENTS (IN PERCENT) IN AVERAGE BLACK SHALE AND GRAPHITIC METAPELITES OF PAKISTAN AND AZAD KASHMIR.

Elements	Average* Black Shale	Reshian area	Tarbela area	Kaghan area	Thana (Malakand) area
Al	7	8.22	4.84	9.42	7.66
Fe	2	4.75	2.57	3.30	1.67
Mg	0.7	0.16	0.45	0.15	0.10
Ca	1.5	0.50	2.68	0.05	0.05
Na	0.7	1.38	0.38	0.80	0.73
K	2.0	3.58	1.53	3.47	2.66
Organic C	3.2	7.4	12.85	1.84	3.53
Ti	0.2	0.45	0.39	0.53	0.45
Mn	0.015	0.012	0.05	0.045	0.008
Ba	0.03	0.065	0.069	0.04	0.09
Co	0.001	0.0054	0.0023	0.002	0.0017
Cr	0.01	0.019	0.0138	0.011	0.013
Cu	0.007	0.025	0.0080	0.065	0.014
Mo	0.001	0.008	0.005	0.005	0.0057
Ni	0.005	0.012	0.0147	0.0063	0.0059
Pb	0.002	0.0068	0.0043	0.0081	0.0055
V	0.015	0.0387	0.0828	0.0168	0.0138
Zn	0.03	0.0031	0.020	0.009	0.007

* After Vine and Tourtelot, 1970.

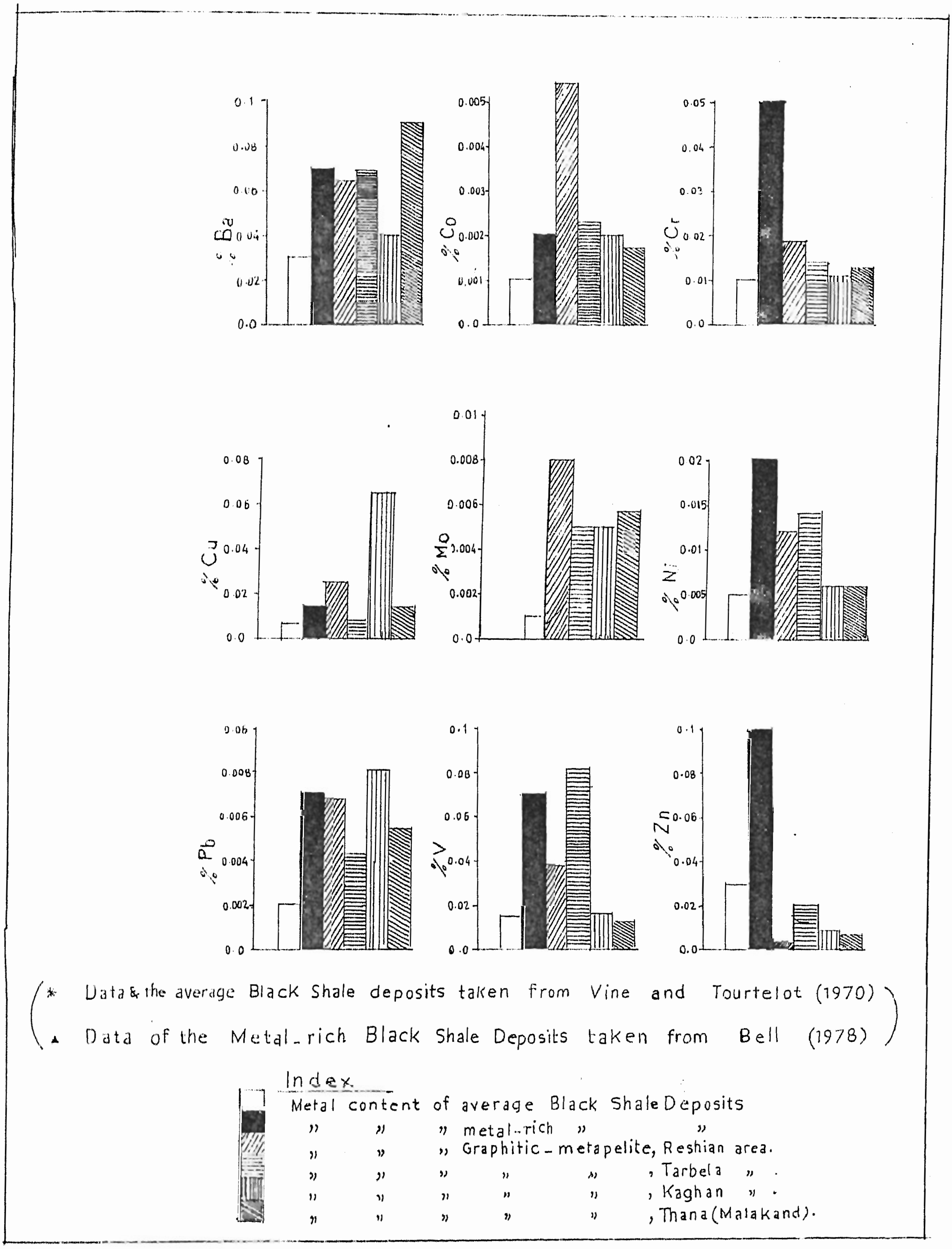


Fig. 8. Major and Minor Elements in Average and Metal-rich Black Shale Deposits and graphitic-metapelites.

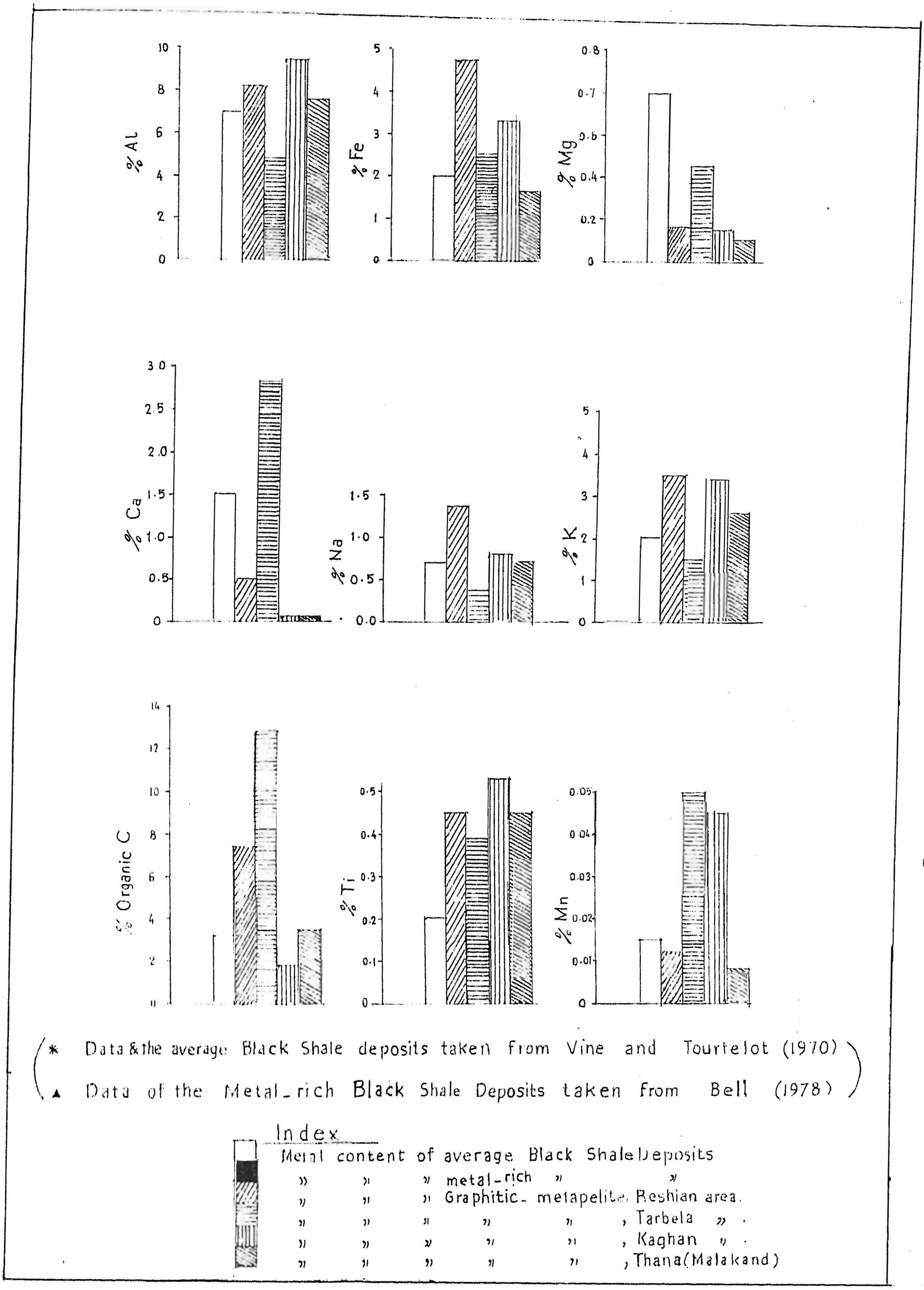


Fig.8. Major and Minor Elements in Average and Metal-rich Black Shale Deposits and graphitic-metapelites.

higher in samples from Reshian and Kaghan areas. It is about the same in Thana area as that of the average black shale deposits. Total Fe in the samples from Reshian and Kaghan areas is higher than the average black shale and is the same in samples from Tarbela and Thana areas. Average Mg is low in the graphitic-metapelites from NW Pakistan and Azad Kashmir. Ca in the samples from Tarbela area is higher than the average black shale deposits and is lower in other areas. Fig.8 shows higher average Na and K in the samples from Reshian area than the black shale average of the same elements. Na in samples from Thana (Malakand) area is about the same as that of the average black shale, while the K values are slightly higher. Graphitic-metapelites from Tarbela area indicate lower Na and K than the average black shale composition of the same elements.

The minor and trace element data (Table 20 and Fig.8) indicate that the various exposures of the graphitic-metapelites have higher average Ti, Ba, Co, Cr, Cu, Mo, Ni and Pb than the average black shale deposits. Mn is lower than the average black shale deposits and V is lower in the graphitic-metapelites from Thana area, and is higher in other areas (Table 20, Fig.8). Lower Zn values were obtained in samples from all the four areas.

The above comparison of the elements indicates that the studied rock types on the average contain slightly higher detrital component. Correlation of Al and Ti is considered as the characteristic of a detrital mineral fraction (Vine

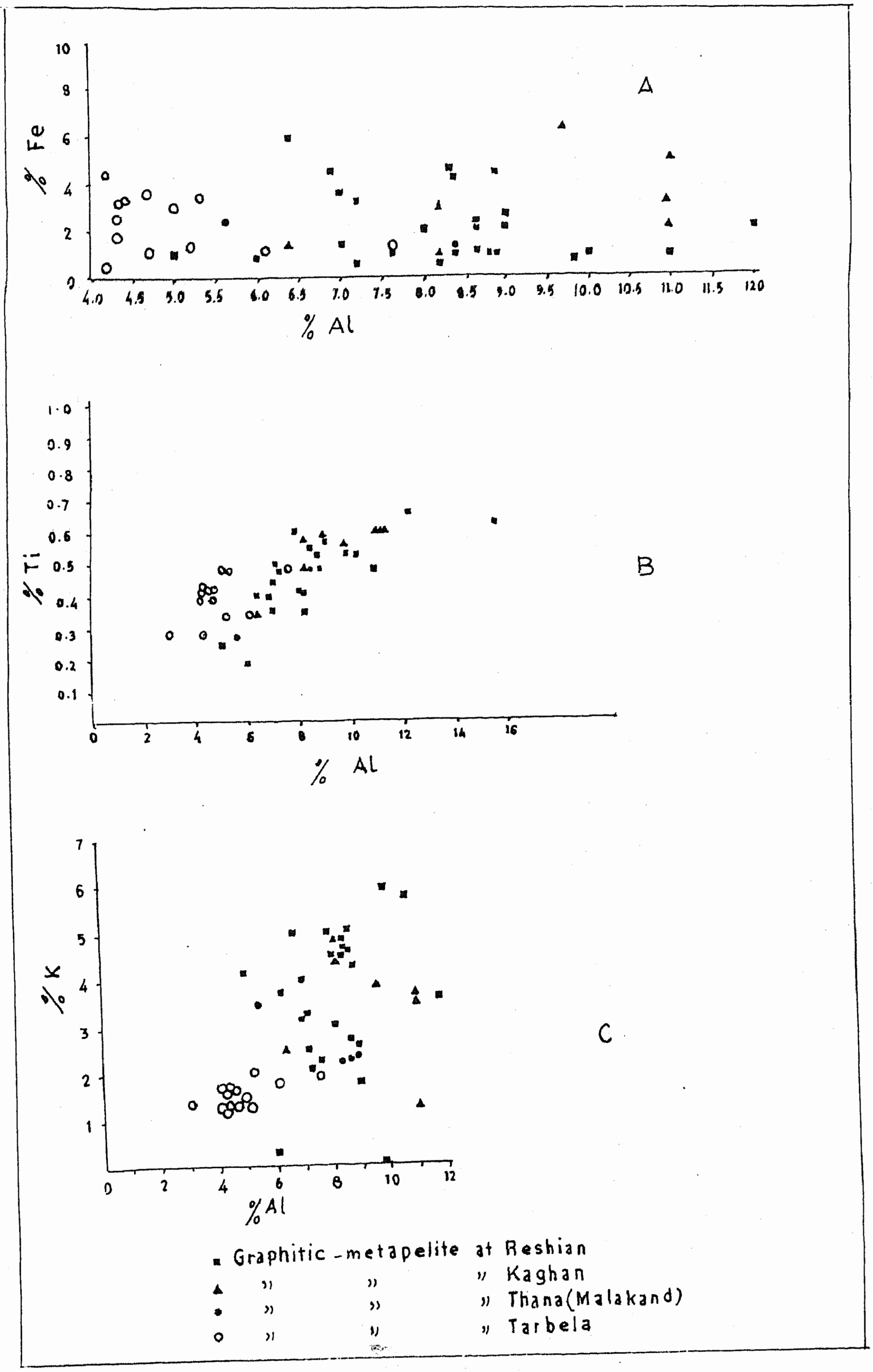


Fig. 9. Plot of Fe, Ti, and K vs. Al

and Tourtelot, 1970). Positive correlation among the two elements indicated in our samples shown in Fig.9B, suggests that these element are associated with the detrital mineral fraction of the rocks. The non-detrital fraction of the rocks is represented by Ca which is characteristically low in the graphitic-metapelites except for Tarbela area. Higher Ca in the samples from Tarbela area may be due to the biogenic separation of the same element from seawater.

Plots of the minor and trace elements in Figs.10 and 11, do not indicate any corelation of the elements with Organic Carbon and Sulphur which is in contrast to typical black shale deposits. In this respect, the graphitic-metapelites of Pakistan and Azad Kashmir are similar to the Paradox member of the Hermosa Formation, the Paleozoic Shales of Arkansas and Oklahoma and the Western Assemblages of the Cordilleran Geosyncline in U.S.A., described by Vine and Tourtelot (1970). The black shales of the Paradox Member of the Hermosa Formation were deposited in a hypersaline marine basin with beds of halite, anhydrite and dolomite. The lack of enrichment of most minor minor elements in the deposits has been attributed to the increase in solubility of metals in saline waters. The paleozoic shales of Arkansas and Oklahoma contain minor elements associated with the detrital mineral fraction of the rocks, whereas only a few elements show significant association with organic Carbon. Some portions of the black shales of the Western Assemblages also indicate association of the minor elements with the detrital mineral fraction of the rock

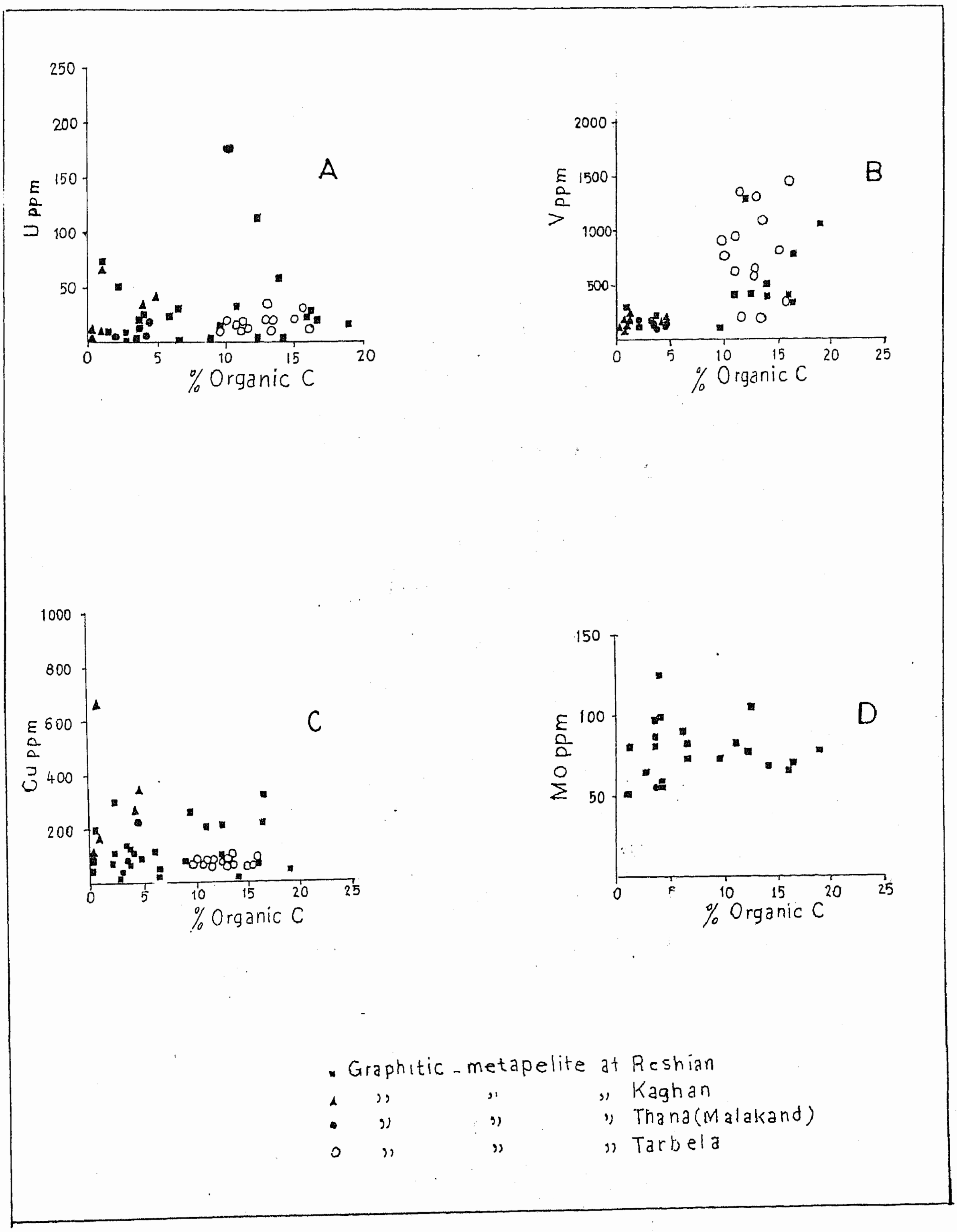


Fig.10. Plot of U, V, Cu and Mo Vs. Organic C

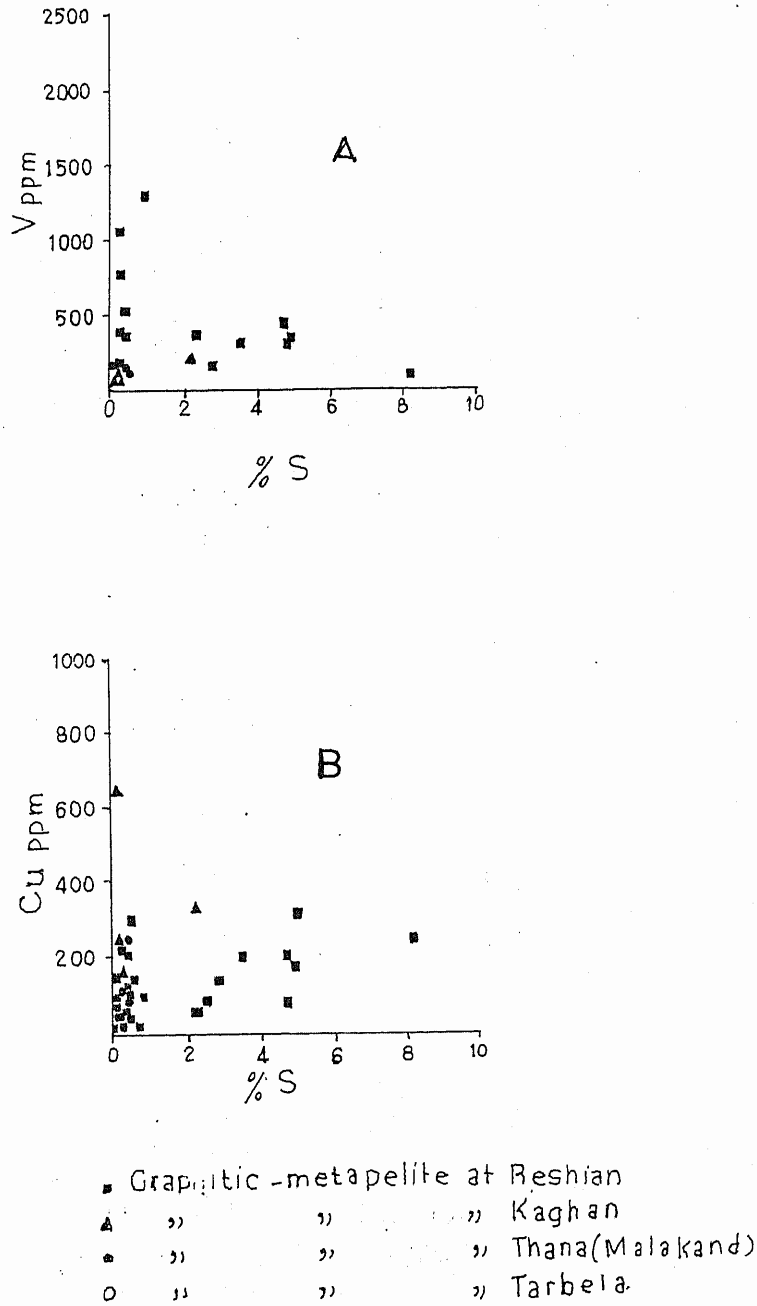


Fig. 11. Plot of V and Cu Vs.S

(Vine and Tourtelot, 1970). The lack of correlation of the elements with organic carbon and sulphur in parts of Swedish alum shale has been described by Leventhal (1991). According to him the elements were deposited from hydrothermal solutions (Leventhal 1991). Lack of correlation smong the elements in the studied graphitic-metapelites may be due to the association of the trace elements (other than uranium) with the detrital mineral fraction of the rock. Uranium is probably associated with organo-metallic compounds and also in adsorbed form on organic matter. The adsorbed uranium was probably dissolved in groundwater and redeposited in microfractures. Fission track study of a few samples provide an evidence to the above statement. As a result the corelation of uranium with organic Carbon was disturbed.

5.2.1 The Metal-rich Black Shales and the Graphitic-metapelites of NW Pakistan and Azad Kashmir.

Table 21 and Fig.8 indicate that compared to the metal rich black shales defined by Bell (1978), the graphitic-metapelites from Tarbela area contain higher V, and therefore, are classified as V-rich. Ba is also in the range of Ba-rich black shales in samples from the Tarbela area while samples from Thana (Malakand) area indicate even higher Ba than the Ba-rich black shales. The graphitic-metapelites at Reshian, Kaghan and Tarbela areas are classified as Co-rich, where Co is two times higher than the Co-rich black shales (Table 21, Fig.8). The rocks at Thana (Malakand) area are in the range of Cu-rich black shales, while samples from Reshian area indicate

TABLE 21. TRACE ELEMENTS IN BLACK SHALES (IN PPM) (AFTER BELL, 1978)

Element	Average Shale	Black Shales		Black Sea Muds		Alum Shale			Outomumpu Black schists
		Median	Metal rich	(Volkov 1973	(Wedep-ohl, 1964)	Sweden (Wedepohl, 1964)	Sweden (Carlsson, 1977)	Norway (Björlykke 1974)	(Petola, 1960)
V	130	150	700	177	98	1070	650	587	620
Cr	90	100	500	68	84	50	-	141	550
Co	19	10	20	30	12	27	-	-	200
Ni	68	50	200	92	67	140	200	125	400
Cu	45	70	150	106	30	100	-	107	600
Zn	70	300	1000	-	-	15	-	86	400
Mo	2.6	10	-	77	-	150	300	-	160
Ba	580	300	700	-	-	-	-	1701	-
Pb	20	20	70	-	-	36	-	-	50
U	3.7	-	20	12	-	85	270	150	51
Th	12	-	-	-	2.5	-	-	13	-

higher Cu. The analyzed samples from Kaghan area are much higher in Cu than the Cu-rich black shales and also contain higher Pb. The rocks from Reshian area are in the range of Pb-rich black shales. Average uranium content of the rocks is higher than the average U-rich black shales of Bell (1978).

Some of the elements were associated with the detrital mineral fraction of the graphitic-metapelite while the rest would require enormous enrichment of the seawater. Inorder to explain the elements enrichment in seawater it was suggested that "trace elements are concentrated by living plankton in aerated surface waters and the dead bodies are carried by subsurface counter-currents to accumulate in great masses. Their decay causes high oxygen consumption, production of hydrogen sulphide and precipitation of the enriched trace elements in bitumenous sediments" (Vine and Tourtelot, 1970). Constant wind direction produces counter-currents and upwelling adjacent to land. Such conditions may produce an increase in salinity, so that metal rich bitumenous shales occur below an evaporite sequence. The elements enriched horizon in the graphitic-metapelites (Fig.14) is also found below gypsum (Fig.3) at Reshian area. Therefore, the above mentioned hypothesis is favoured to explain the concentration of some of the trace elements by living plankton during deposition of the graphitic-metapelites. Acomplete explaination of the source of elements, their enrichment and deposition in the studied rock types is beyond the scope of the present work.

5.3 Corelation of the elements in Graphitic-metapelites

The major, minor and trace elements of the various graphitic-metapelites are plotted and compared with the plots of the same elements for the Cambrian Alum Shale of Sweden and Chattanooga Shales of the United States of America described by Leventhal (1991). The Alum Shale of Sweden is an organic-rich marine sequence of Middle Cambrian to Early Ordovician age. The shales are represented by black laminated, dark brown organically banded and grey mudstones referred to as "alum shales" because of their K, Al and S content. The Middle to Upper Devonian (and locally Lower Mississipian) shales of the Appalachian basin, are known by various names, such as Chattanooga shale in Tennessee, New Albamy shale in Kentucky, Ohio shale in Ohio and various names in New York and Pennsylvania (Marcellus, Genesse, West Falls, and Java Formations) (Leventhal, 1991). The Chattanooga shale is characterized by high organic matter and very fine grain size and is deposited in Chattanooga Sea bounded on three sides by land. Uranium in Chattanooga shale was deposited syngenetically with the shale. No uranium minerals are known from the unweathered shale (Jones, 1978).

Fig.12 shows organic carbon and sulphur relationship for the Alum Shale and the graphitic-metapelites from Pakistan and Azad Kashmir. Fig.12A indicates that most of the samples from Alum Shale plot above the normal marine line. Fig.12B shows that only a few samples from Reshian area plot

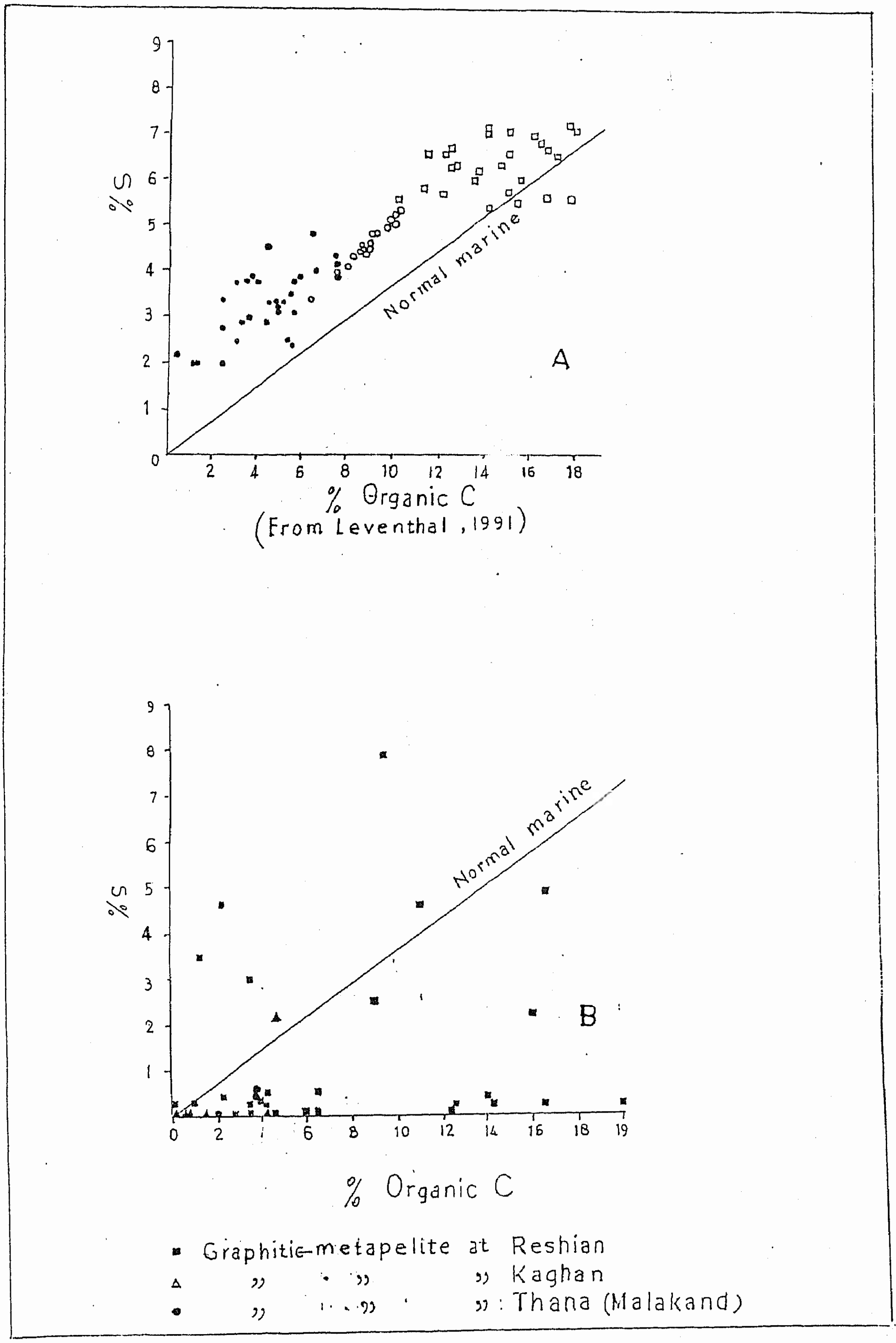
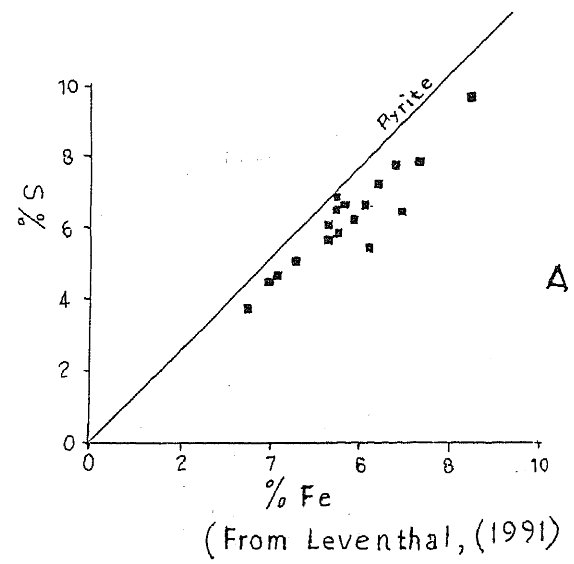


Fig.12. Plot of sulphur Vs. Organic Carbon.

above the normal marine line. The rest of the samples from Reshian and other areas plot below the line. This relationship indicates that the graphitic-metapelites from Pakistan and Azad Kashmir are not normal marine in nature but were probably deposited in a transitional environment close to the land. This interpretation is consistent with the interpretation put forth earlier on the basis of comparison of elements of the graphitic-metapelites with the average black shale deposits.

Sulphur Vs. Fe are plotted in Fig.13 to clearly demonstrate the C/S relationship in Fig.12. Fig.13A shows S/Fe relationship in the Alum Shale (Leventhal, 1991). The figure indicates that all the samples plot below and close to the pyrite line. This trend indicates that all the reactive Fe in the Alum Shale was sulphidized. The sulphidization results from the high organic carbon providing substrate organic matter with which the sulphate reducing bacteria produce excess hydrogen sulphide that reacts with Fe or is escapted and oxidized (Leventhal, 1991). Fig.13B shows S/Fe relationship for the studied graphitic-metapelites. Compared to Fig.13A, Fig.13B indicates that some samples from Reshian area plot close to and below the pyrite line, some plot above the line and the rest of the samples plot away from the pyrite line. Samples from Kaghan and Thana (Malakand) areas also plot below and away from the pyrite line. The S/Fe plot in Fig.13B compared to Fig.13A suggests that sulphidization of



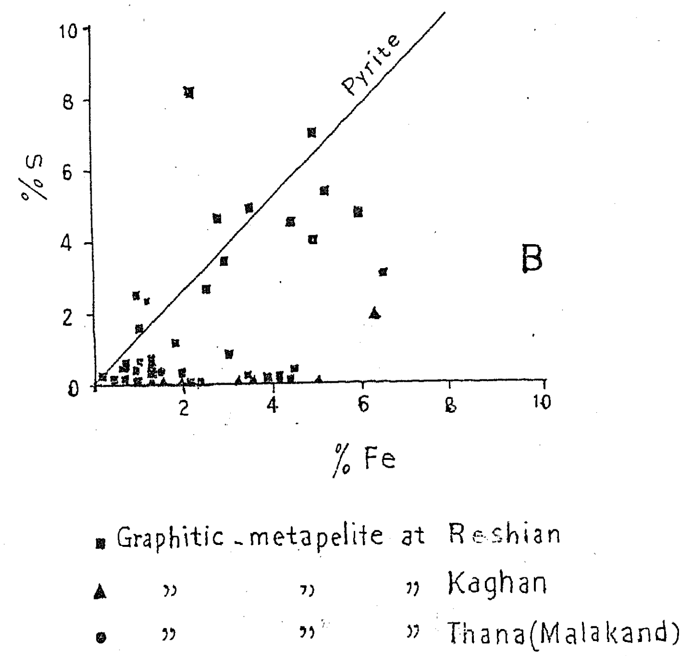


Fig.13. Plot of Sulphur Vs. Iron

Fe at Reshian area has taken place, some sulphides have escaped and oxidized and the rest of the samples indicate that sulphidization of Fe had been incomplete in the graphitic-metapelites. In Reshian area pyrite is the most common sulphide mineral, pyrite is ubiquitous in graphitic-metapelites in other areas also and is found as discrete cubic crystals scattered in the rocks. Pure pyrite veins 0.5-1.0m thick are found associated with graphitic-metapelites at Tarbela and Reshian. It is regarded syngenetic and as the product of reaction of hydrogen sulphide with Fe during deposition of the rock.

Fig.9A shows Fe/Al relationship for the graphitic-metapelites of NW Pakistan and Azad Kashmir. Nagative relationship is indicated similar to Alum shale. Fig.9B shows positive Ti/Al relationship for the graphitic-metapelites. This relationship is indicative of fine grained clay/refractory minerals in the graphitic-metapelites. The relationship is considered as characteristic of shales (Leventhal, 1991). Fig.9C shows a fair corelation between Al and K similar to the Alum Shales, which indicates that some fraction of the elements Kand Al are together, probably as feldspars or illite (Leventhal, 1991).

Trace elements Vs.Organic carbon and sulphur plots are given in Fig.10 and 11. The plots shows no positive relationship which is in contrast to many black shales that are enriched in these elements and show positive corelation with organic carbon or sulphur (Leventhal, 1991). This lack of corelation among elements in the graphitic-metapelites has been explained in the previous section. Accordingly it has been attributed to the elements association with the detrital mineral fraction of the rock and the degrading organic matters while some of the uranium was leached with groundwater resulting in the lack of relationship among the elements.

5.3.1 Trace elements Vs. Organic Carbon and Sulphur ratios.

Trace elements Vs. organic Carbon and Sulphur ratios were computed for the graphitic-metapelites from NW Pakistan and Azad Kashmir and were compared with that of the typical black shale ratios described by Leventhal et al., (1982). The data is presented in Table 22 and 23. The ratios are considered to normalize the metals to their concentrating agents.

Table 22 shows that the average U/organic C ratio for Kaghan area graphitic-metapelites is higher than for typical black shale deposits . The same ratio for the rocks from Reshian area is comparable to the one computed for the Overto Co. Tenn. The ratios for the rocks from Thana (Malakand) and Tarbela areas are lower than the typical black shales (Table 22).

Other elements Vs. organic Carbon ratios, such as Co/organic C, Ni/organic C and Cu/organic C, are also much

TABLE 22. TRACE ELEMENT/ORGANIC C AND TRACE ELEMENT/S RATIOS COMPARISSON IN DEVONIAN SHALE* SAMPLES FROM FIVE CORES AND THAT OF THE GRAPHITIC-METAPELITES FROM PAKISTAN.

Element	Washington Co., Ohio		Carroll Co., Ohio		Wise Co, Va.		Martin Co., Ky.		Overton Co. Tenn.		G.Meta-pelites Reshian area.		G.meta-pelites Kaghan area.		G.meta-pelites Thana (Malakand)		G.meta-pelites Tarbela area.	
	Ratio of element to		Ratio of element to		Ratio of element to		Ratio of element to		Ratio of element to		Ratio of element to		Ratio of element to		Ratio of element to		Ratio of element to	
	Organic C	S	Organic C	S	Organic C	S	Organic C	S	Organic C	S	Organic C	S	Organic C	S	Organic C	S	Organic C	S
Co	20	12	9.2	10.5	6.8	8.3	7.5	10	7.6	14.5	6.8	34.4	11.8	58.7	4.9	72.2	1.8	-
Mo	10	6	12.1	13.8	9.3	11.3	13.6	14.3	11	21	10.7	54.3	-	-	-	-	-	-
Ni	24	39	22	49	21	47	17	41	22	55	15.6	79.1	34.2	170.3	-	-	11.5	-
Zn	40	49	21	48	-	-	-	-	43	94	3.1	15.6	50.4	250.6	19.7	290.3	15.6	-
Cu	38	23	28	32	19	23	-	-	16	31	35.6	179.8	353.6	1758.7	40.7	598.6	6.2	-
U•	5.5	3.3	4.4	5.0	4.8	5.8	4.9	5.1	6.1	11.5	6.3	31.7	51.5	256.4	3.8	55.5	3.7	-

* After Leventhal and Hosterman (1982).

• Based on 46.56 ppm average U_3O_8 at Reshian and 48 ppm average U_3O_8 at Tarbela.

higher for the Kag han area graphitic-metapelites (Table 22). Co/organic C ratio for Reshian area is equivalent to Wise Co. Va., but is much lower for the rocks from Thana (Malakand) and Tarbela areas compared to the typical black shales (Table 22). Mo/organic C ratio for the samples from Reshian area is about the same as that for the Washington Co., Ohio, and is lower than the other typical black shales ratio. Ni/organic C and Zn/organic C ratios are lower for the rocks from Reshian, Thana and Tarbela areas compared to the typical black shales (Leventhal et al., 1982; Table 22). Cu/organic C ratios for the rocks from Reshian and Thana (Malakand) areas are comparable to that for Washington Co. Ohio, but are lower for Tarbela area (Table 22).

U/sulphur ratio for the graphitic-metapelites from NW Pakistan and Azad Kashmir is very high compared to the same ratio for the typical black shale deposits (Leventhal et al., 1982; Table 22). U/S ratio for the rocks from Kaghan area is much higher compared to typical black shales. Mo/S ratio is also very high for the rocks from Reshian area as compared to the same ratio for the typical black shales (Table 22). Ni/S and Cu/S ratios for the rocks are also higher compared to the typical black shale ratios (Leventhal et al., 1982). Zn/S ratio for the rocks from Reshian area is lower compared to the typical black shales, however, the same is higher for the rocks from other areas (Table 22).

The data in Table 22 described above indicate that generally the trace elements Vs. organic carbon and sulphur ratios computed for the graphitic-metapelites from NW Pakistan and Azad Kashmir are higher compared to the typical black shales. According to Leventhal et al., 1982 (Table 22) higher ratios reflect complete sulphidization of Fe to pyrite and concentration of other elements as sulphides by the action of the excess sulphides after all the available Fe had been reacted. In the studied rocks the higher ratios especially for the rocks from Kaghan area are considered as due to the low organic carbon content of the rocks and that other sulphides are not known axcept for minor chalcopyrite and pyrhotite.

There remains controversy about the source of elements/metals in black shales. Normal seawater is regarded as a source of elements (including Re, Mo, Cd, Se, V, Br, Sb, Ag, Ni, Cu, Cr, Zn and Pb) concentrated in Suzak (Eocene) shale of Central Asia. All these elements have highly insoluble sulphides and/or strongly complexed to organic matter (Leventhal et al., 1982). Wedepohls (1964) calculations indicated that the seawater, from which the Kupferschiefer black shale was deposited, contained enhanced amounts of elements. Brongersma-Sanders (1965) proposed that the metals of the Kupferschiefer were supplied by normal seawater (Leventhal et al., 1982). Normal seawater is considered as a source of elements in the studied graphitic-metapelites where concentration of the elements took place by multiple concentrating agents. However, further work is required to solve the problem.

5.4 Down-hole plots of the Elements

Results of chemical analyses of core samples from Reshian area of Azad Kashmir and Tarbela area of NW Pakistan are plotted to demonstrate that certain elements are relatively enriched in some parts of the graphitic-metapelites. The enriched elements levels are found at the top part of the graphitic-metapelites shown in the down-hole plots which occur immediately below the evaporite sequence (represented by gypsum/anhydrite deposits in the area) as a result of deposition in a transitional environment.

5.4.1 Down-hole plots of the Elements for Reshian Area

Fig.14 shows that the elements including U, Mo, Ni, Cu, Co, V, Zn, Cr, Pb and organic carbon are relatively enriched at two levels but generally vary greatly with depth. Below a depth of about 77m, the amount of sulphur is greatly minimized and shows its concentration at the background level. Fig.14 also shows that with the depletion of sulphur with increasing depth of the hole, other elements also decrease in amount, suggesting their association with sulphur. Iron generally shows a closer affinity to sulphur than to organic carbon (Fig.14). Mn-content is usually considered related to CaO, but the relationship is not clear in these plots because of the low MnO content of the samples from the graphitic-metapelites.

The trace elements do not show relationship with organic carbon and sulphur and are enriched at a certain level below the topographic surface. Some of the elements, including uranium, may have concentrated by organic matter, other by co-precipitation with Fe-sulphides, and some elements are related to the detrital mineral fraction of the rock. Organic matter might accumulate the trace elements during passage from a terrestrial erosional environment to a marine depositional environment. Deep marine environment may have limited organic matter compared to the shallow marine environment (Convey et al., 1989).

Generally, euxinic conditions are considered necessary for the formation of the black shale deposits, where the presence of H_2S layer might preserve the organic matter from aerobic destructive processes. In the absence of H_2S layer, and if water above the sediment surface is oxygenated, a reducing environment will be present within the sediment where anerobic organisms can convert sulphate into sulphide. The sulphide may react with the trace elements that are liberated when the organic matter is degraded by microorganisms or by inorganic processes during early diagenesis (Leventhal et al., 1982). Trace elements in the graphitic-metapelites of Pakistan and Azad Kashmir were concentrated during sedimentation in a near-shore transitional environment. The conditions were reducing within the sediments where some the trace elements were probably liberated from the degrading organic matter during early diagenesis.

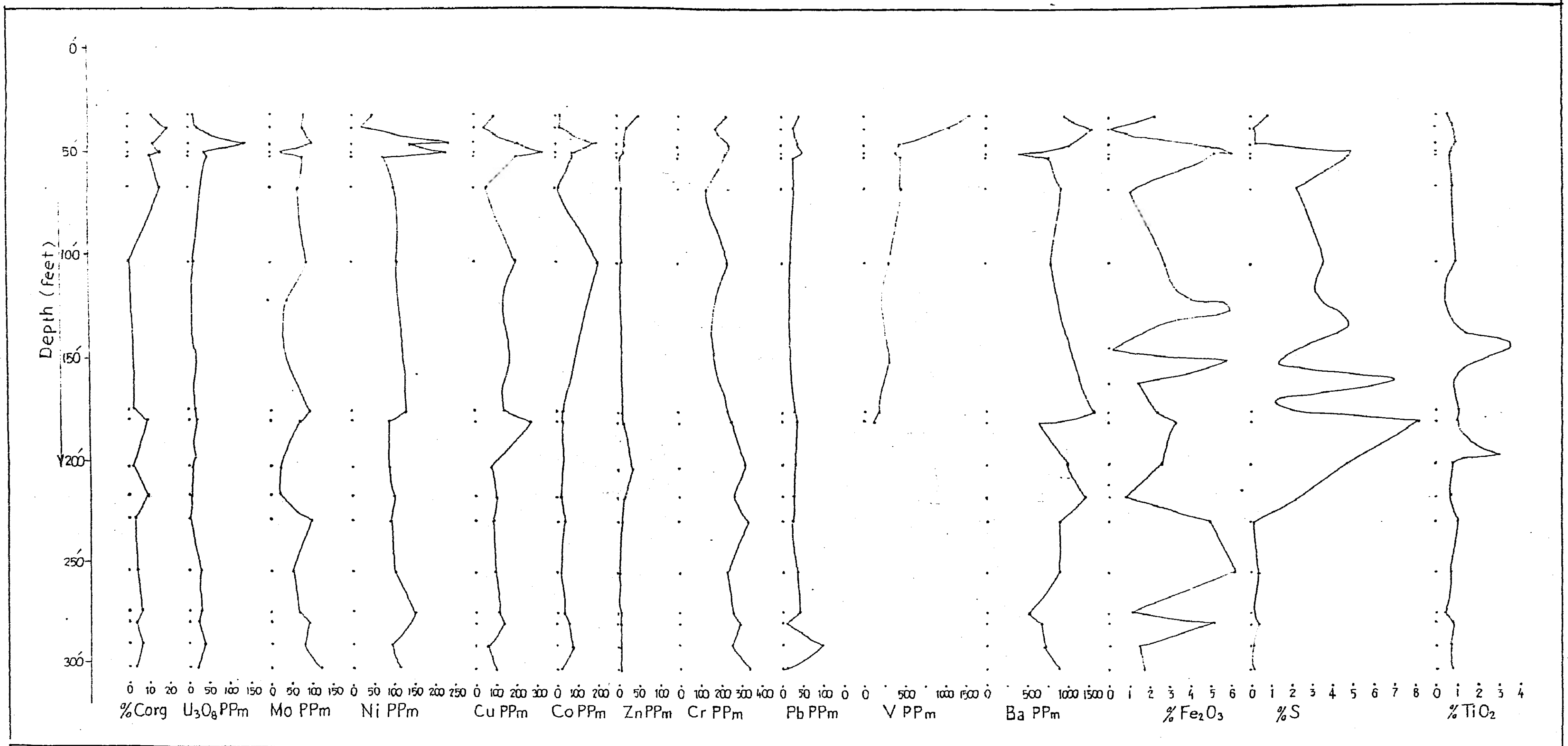


Fig.14. Down hole plot showing variation in the amounts of elements and oxides in Graphitic-metapelites, Reshian area - Azad Kashmir.

5.4.2 Down-hole plots of the Elements for Tarbela Area

Plots of organic carbon, U, Ni, Cu, Co, V, Cr, Pb, Mo, Ca, Fe (total) and Mg for core samples from chamiari area Tarbela, graphitic-metapelites are shown in Fig.15.

The figure indicates that the elements are enriched in the upper 30 meters of the rock. Sulphur analyses for the samples from the area are not available. No clear association of the elements with organic carbon is observed. It is considered that Fe might have closer affinity to sulphur, as observed for the graphitic-metapelites from Reshian area. The same concentrating agents and processes are also considered responsible for the elements enrichment and concentration in the rocks from Tarbela area as those proposed for Reshian area. More analyses of the core samples from deeper drill-holes will be of help to out-line clearly the distribution of elements in both of the above mentioned areas.

5.4.3 Subsurface Uranium Distribution at Reshian Area

Fig.16 presents the distribution of radiometric and equivalent chemical uranium in the anomalous zones defined through γ-ray logging of the various drill-holes at Reshian area of Azad Kashmir (Table.7). The holes are drilled roughly along the strike of the rocks in about 1 Km long area. The location of the drill-holes follows Reshian-Brithwari Nalla running roughly along the upper contact of the upper graphitic-

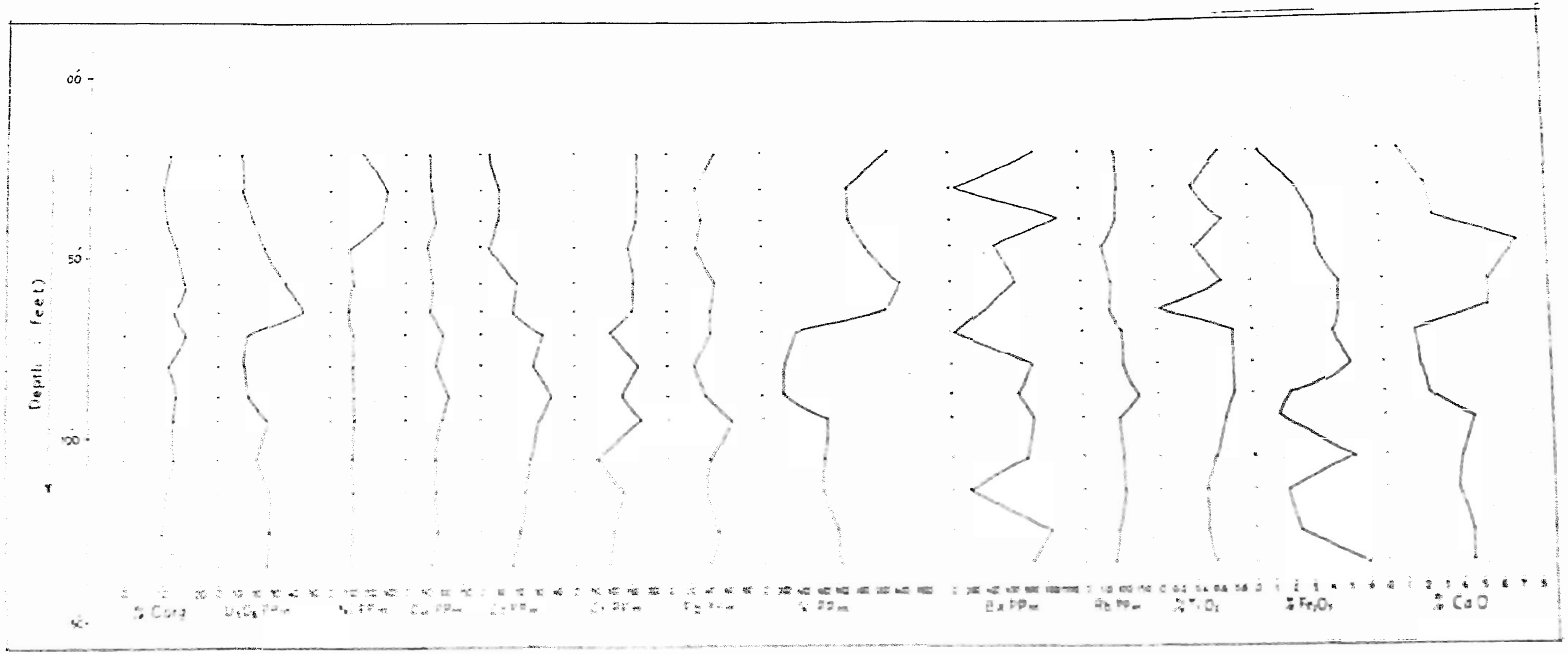


Fig.15. Down hole plot showing variation in the amounts of elements and oxides in Graphitic-metapelites, Tarbela area - NW Pakistan.

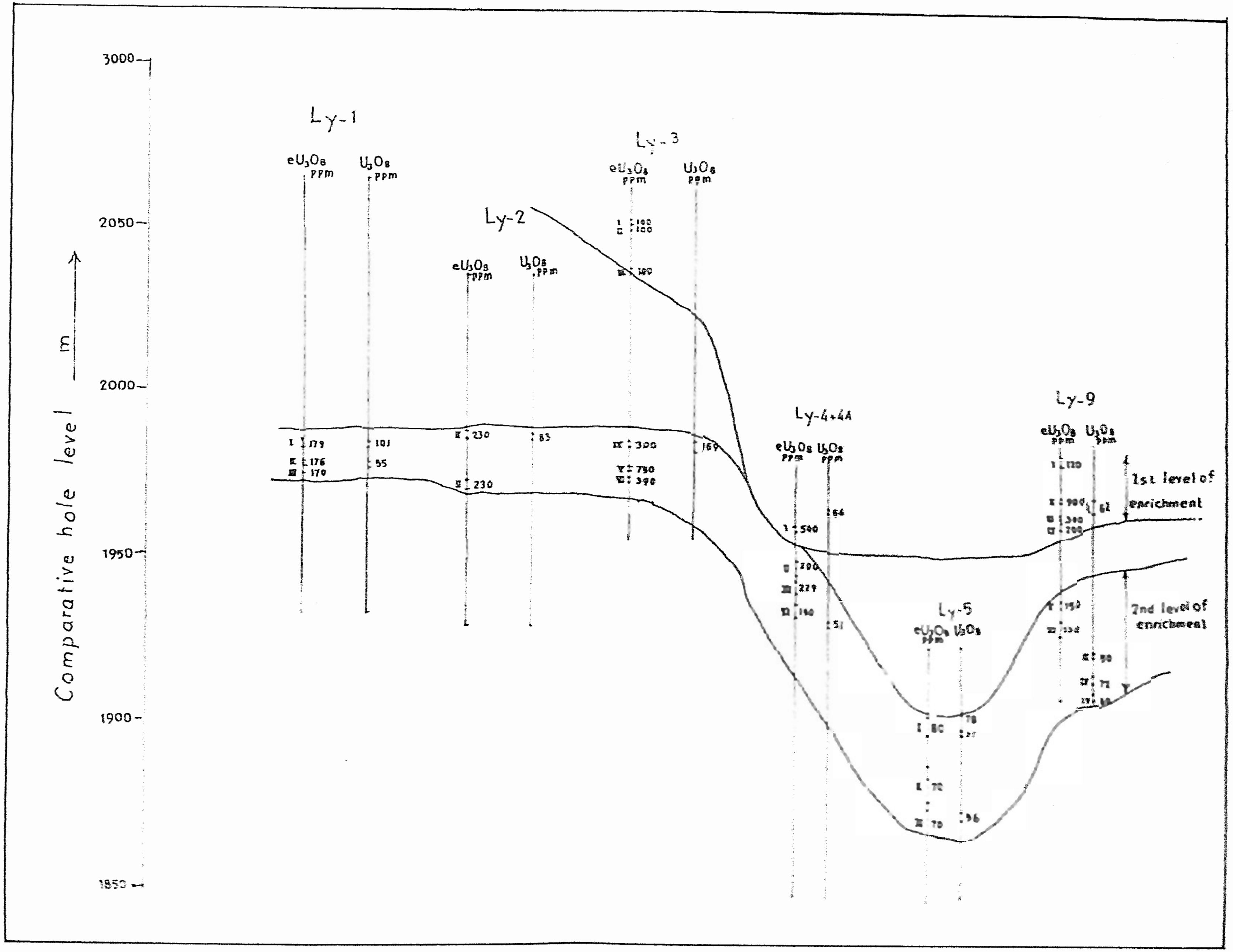


Fig.16. Subsurace uranium distribution at Reshian area - Azad Kashmir.

metapelites (Fig.3).

Fig.16 shows that chemical uranium in the samples from the anomalous zones of the drill-holes, is always less than its radiometric equivalent, indicating negative disequilibrium. The figure further points-out that high radiometric grade of uranium is always found at the top levels of the various holes, while chemical uranium is sometimes found high at the depth below the zone of wathering.

The problem of high radioactivity and low chemical uranium has been pointed out in many black shale deposits (Bell, 1978), As elsewhere, no satisfactory explaination can be put forward for the same problem in the studied rock types. However, it is suggested that due to shear deformation these otherwise impermeable rocks were made permeable. Uranium was dissolved in the circulating groundwater and carried away, leaving behind its daughter products (Table 8). The presence of the daughter products of U associated with Th and K^{40} are responsible for the high radioactivity in the area.

It is considered that the anomalous zones indicating high radiometric uranium at the top levels of the drill-holes correspond to the enriched elements level, discussed earlier in the present chapter (Fig.14 and 15). Uranium was leached easily from the enriched level by the action of the groundwater leaving behind insoluble elements. Such consideration make allowance for the insoluble elements in the enriched parts of the graphitic-metapelites. It is not fayoured that the top level of enriched elements in Fig.14 may be present in every hole (Fig.15). The idea is based on comparing the toporgraphic levels of drill-holes. The location of hole No.Ly-7 is about 150m topographically below the hole No.Ly-1. The anomalous zones recorded in hole No.Ly-7 do not coincide with the anomalous zones found at the top level in hole No.Ly-1, but must belong to some other level of concentration. It is also observed that below the zone of weathering where leaching effects are not found, chemical uranium corresponds to its radiometric equivalent (Fig.14 and 15).

5.4.4. Subsurface Uranium Distribution in Tarbela Area

Fig.17 presents the distribution of radiometric and chemical uranium in the anomalous zones encountered in γ--ray logging of the holes (Table 12). Drill-holes are mostly drilled across the strike of the graphitic-metapelites at Chamiari area within Tarbela graphitic-metapelites.

The figure indicates the same problem of high negative disequilibrium, i.e. the chemical uranium is lower than its radiometric equivalent. The anomalies are found at the top levels of the holes similar to Reshian area and in some holes high chemical uranium is shown below the high radiometric zones at depth.

Like Reshian area, high radioactivity and low

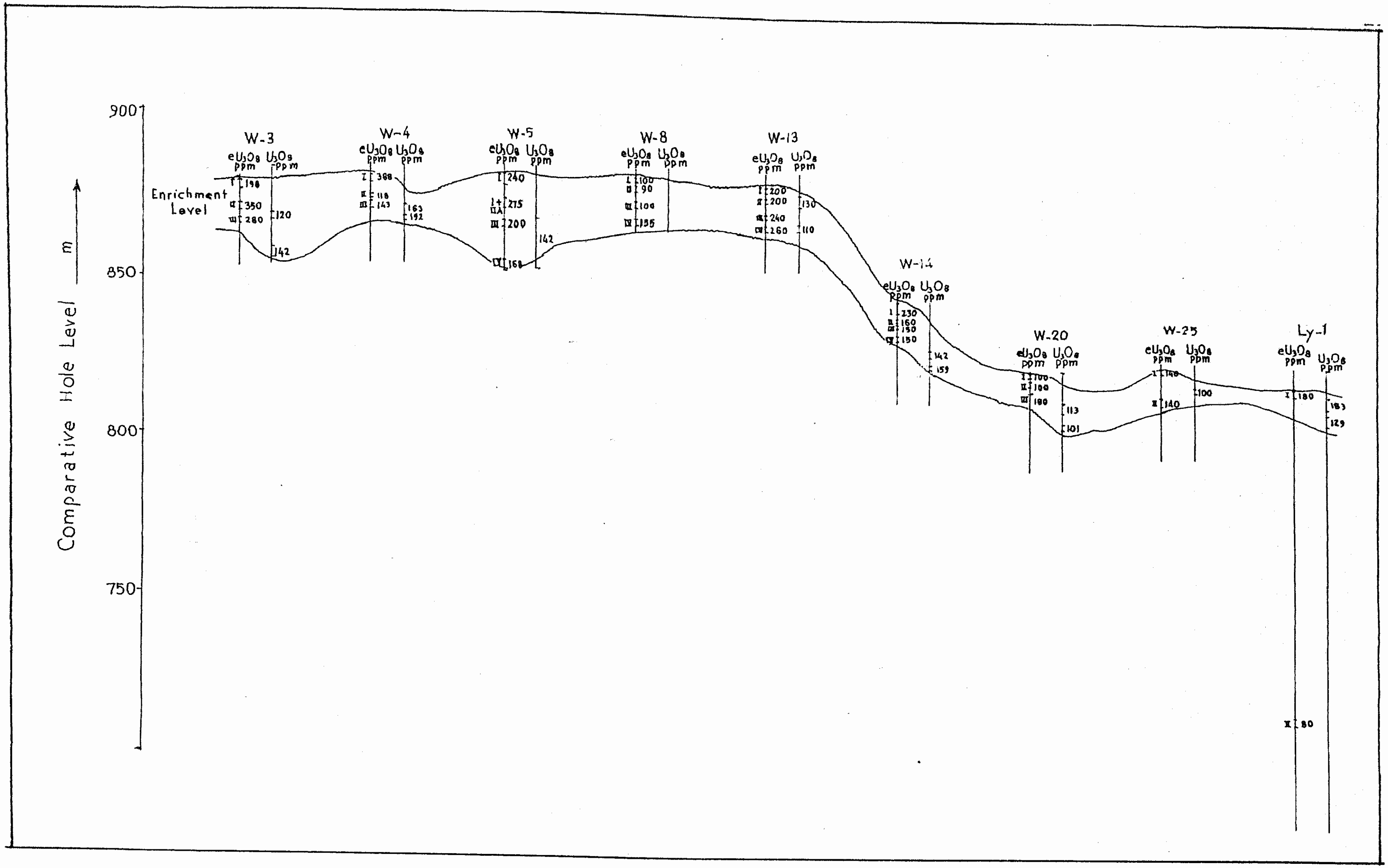


Fig.17. Subsurface uranium distribution at Chamiari area - Tarbela (NW Pakistan)

Chemical uranium is explained by the presence of U, Th their daughter products and K^{40} (Table 13). High radiometric U and the other associated elements are found at the upper levels of all the drill-holes. It is explained by the deposition of the elements below the evaporite sequence. The evaporite sequence is found associated with Manki Formation at places like the gypsum exposed on Sirikot road near the Tarbela Settlement Colony. It is also considered that shear deformation induced permeability in otherwise impermeable graphitic-metapelites, providing channelways for circulating groundwater. The groundwater leached and transported uranium elsewhere. High chemical uranium in some samples from the depth of the hole is regarded as the unleached uranium below the zone of weathering.

5.5 Classification of the Graphitic-metapelites from NW Pakistan and Azad Kashmir.

The graphitic-metapelites are characterized by fine grain size, dark colour and limonitic alteration. The dark colour is due to the presence of organic matter. The rocks show the characteristics of black shale deposits of the world probably deposited in a transitional marine environment. In the present section attempt has been made to classify the graphitic-metapelites according to the double triangle classification scheme given by Stribrny et al., (1988). According to the classification, rocks containing more than 1% organic carbon are the normal shale. An organic carbon content of

2 to 10% is considered as a common range in black shales (Tourtelot, 1979).

Following Stribrny et al., (1988), petrographic, X-ray diffraction and chemical data is used to define the major mineral phases in the graphitic-metapelites. Based these data the normative minerals in the analyzed samples were calculated. The mineral calculation scheme of Stribrny et al., (1988) has, however, been modified in these cases where minerals like sillimanite/kyanite and biotite appear in rocks, indicative of high temperature-pressure metamorphic conditions. (Norm of the said minerals have not been calculated by the above-mentioned authors). In the present work, some K_2O was attributed to biotite and the balance Al_2O_3 (after allocation to albite, chlorite, muscovite and biotite) was assigned to sillimanite/kyanite. K_2O has not been calculated for arthoclase because of the lowe concentration of the K_2O in the graphitic-metapelites of NW Pakistan, and also because of the occurrence of orthoclase in trace amounts. The procedure for the normative minerals calculation in the studied rocks is given in Appendix.

The normative minerals in the graphitic-metapelites were plotted in the double triangle with corners Q, P and C for quartz, phyllosilicates, and carbonates plus the remaining minerals respectively. The normative mineral compositions ($Q + P + C = 100$) of the rocks with a content of organic carbon greater than 1% are plotted in the upper part of the double-triangle. The lower part of the diagram is used for rocks with less than 1% organic carbon. Fig.18A shows the plots of the samples from the Reshian area in Azad Kashmir. It indicates that most of the samples plot below 60% quartz line in the upper triangle in the black shale and argillaceous-siliceous black shale fields. A few samples plot in the carbonatic-siliceous black shale and four samples plot in siliceous black shale field.

Fig.18B shows the normative minerals plots for the samples of the graphitic-metapelites from Tarbela, Kaghan and Thana (Malakand) areas. The figure indicates that most of the samples from Tarbela area plot in the siliceous black shale field (containing 60% quartz), and although four samples from the area plot below 60% quartz line, these contain more than 50% quartz. Two out of the four samples plot in the orgillaceous-siliceous black shale and siliceous black shale boundary. Samples from Kaghan area plot in the argillaceous siliceous black shale field. Some samples from the Kaghan area also indicate less than 1% organic carbon and plot in the lower triangle in the field of argillaceous-siliceous shale. Samples from Thana (Malakand) graphitic-metapelites plot in the argillaceous-siliceous black shale and close to the 60% quartz line.

Figs.18A and B indicate that the graphitic-metapelites of Reshian, Tarbela, Kaghan and Thana (Malakand) areas are generally characterized by high normative quartz. Samples from Reshian area show 35-65% quartz and those from Tarbela 50-70% quartz (with the exception of one sample with 75% normative quartz).

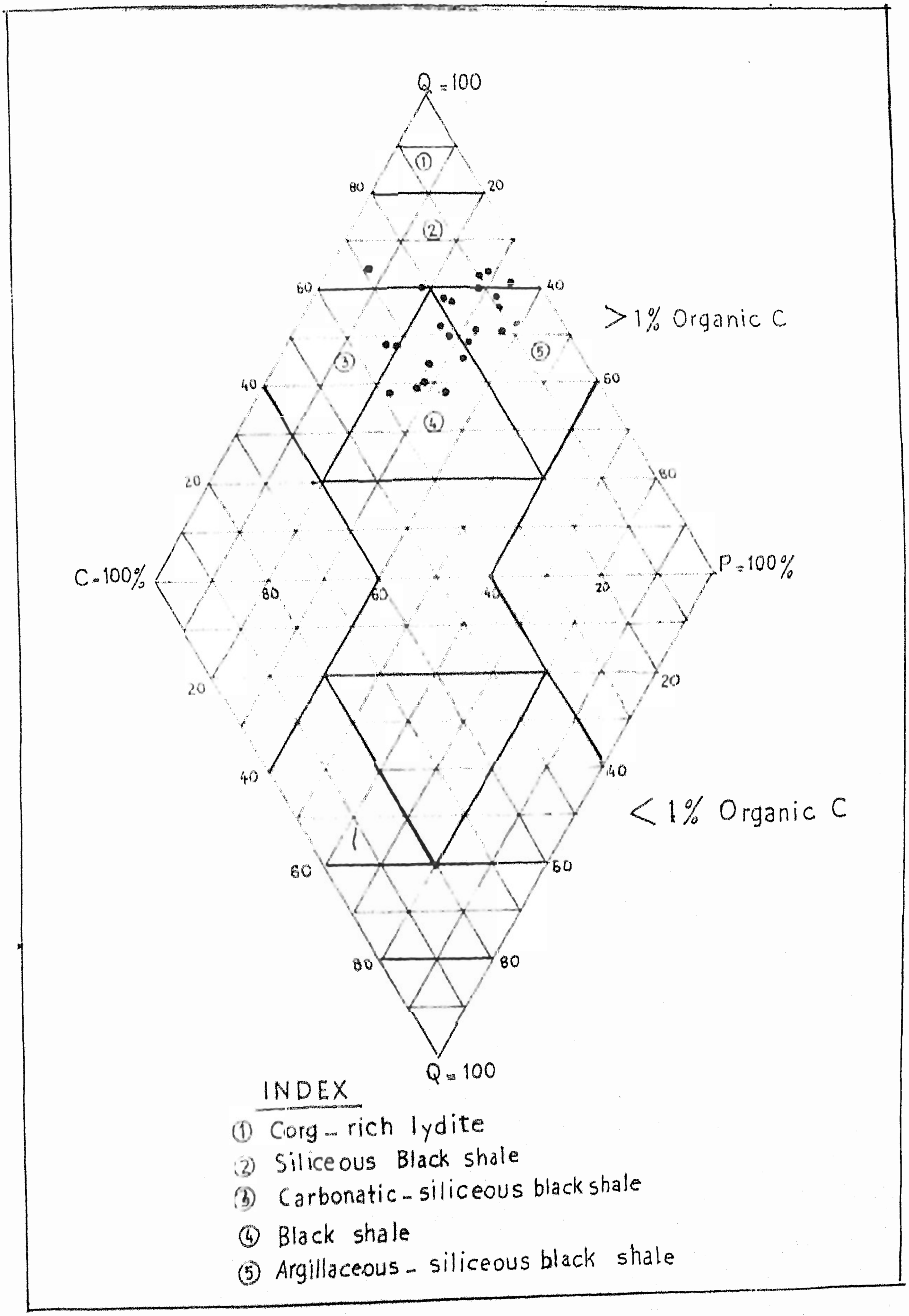


Fig. 18A. Classification of Graphitic-metapelites, Reshian area (Azad Kashmir).

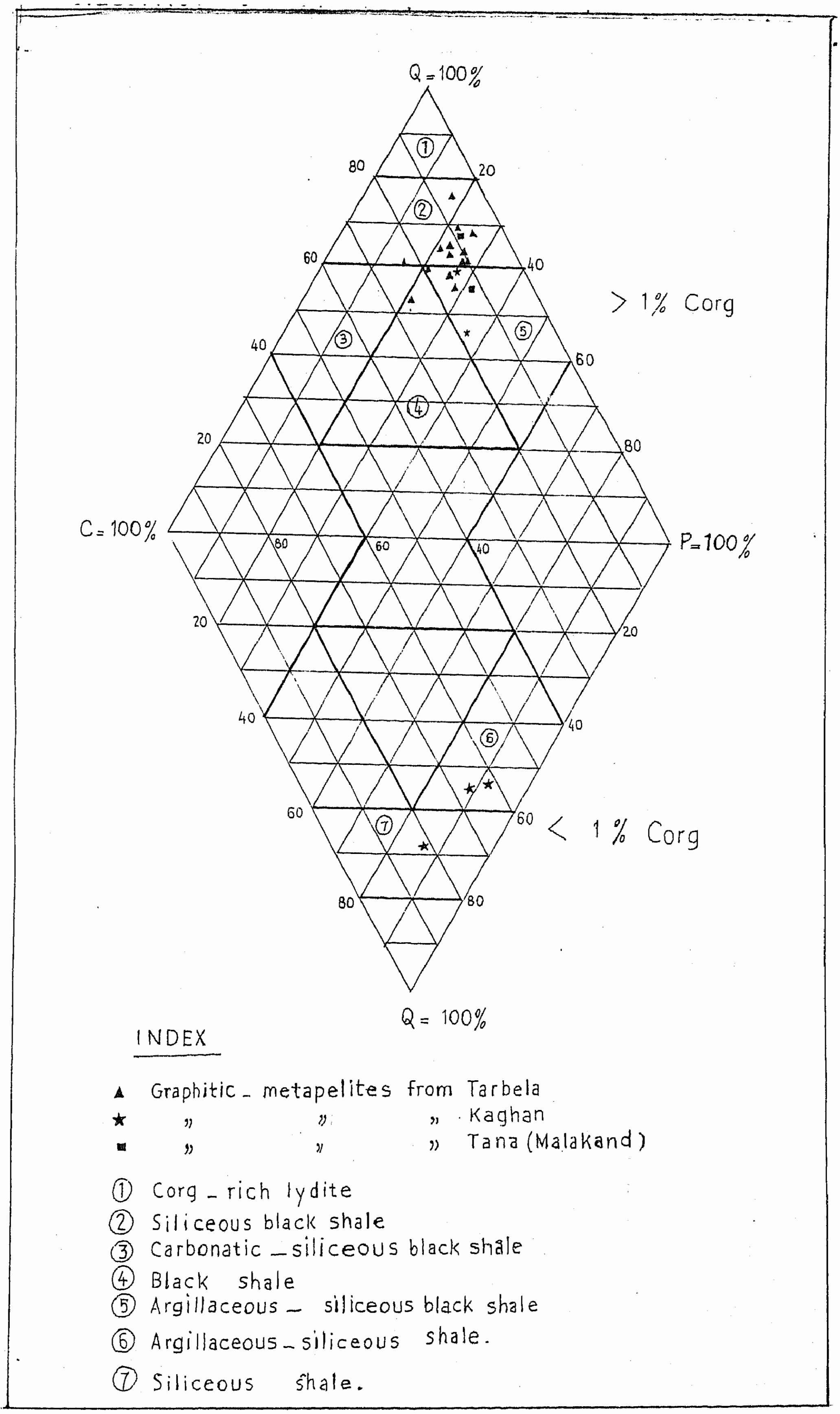


Fig. 18B. Classification of Graphitic-metapelites Thana (Malakand), Kaghan & Tarbela areas, NW Pakistan.

Samples from Kaghan area show 45-60% and 50-70% quartz that plot in the upper and lower triangles respectively. Samples from Thana (Malakand) area have 55-70% quartz.

The average organic carbon content of the graphitic-metapelites from Pakistan and Azad Kashmir is given in Table 20, shown in Fig. 8. The table indicates that samples from the Tarbela area contain 12.85% organic carbon on the average. The organic carbon content of the rocks dereases from Reshian (7.4%) to Thana (3.53%)and is the lowest in Kaghan area (1.84%).

Average high normative quartz in the graphitic-metapelites indicates the derivation of the material from acid magmatic rocks close to the continent. The graphitic-metapelites from Tarbela area were probably deposited more close to the shore-line as compared to those from the other areas. The higher organic carbon in rocks from the Tarbela area also indicates deposition under shallow water conditions. Black shales deposited under deep-marine conditions contain lower organic carbon content (Jones, 1978). The graphitic-metapelites from the other areas contain less organic carbon as compared to Tarbela, however, the depositional environment may have been the same. Slight differences in the studied rocks are attributed to the difference in source material and different basins of deposition.

5.6 Depositional Environment of the Graphitic-metapelites from NW Pakistan and Azad Kashmir.

Exposures of the graphitic-metapelites are found in Precambrian Formations. East of the Indus river these belong to the Salkhala Series and are exposed as several continuous/discontinuous bands for tens of Killometers from the border area of the Indian occupied Kashmir in Jhelum Valley through Neelam Valley. Exposed at the apex of the Hazara-Kashmir syntaxis at Kaghan Valley, the graphitic-metapelites cross Kunhar river into northern Hazara and are exposed in Allai Chor area. The same rocks extend upto the Indus river at Thakot. West of the river, the graphitic-metapelites are exposed in the Alpurai schist(Swat-Buner schistose group) including those of the Thana (Malakand) area. The Precambrian age of the Swat-Buner schistose group is controvercial (Martin et al., 1962, Kazmi et al., 1984). According to Dr.Butt (Personnel communication) this group of rocks may be Proterozoic in age. East of the Indus river in southern-Hazara and also at the West bank along the river at Tarbela, the graphitic-metapelites of the Gandghar range belong to Manki Formation and Salkhala Series. The Manki Formation is quite extensive and is exposed in the Attock-Cherat ranges, subsequently pushed to the south during the development of the Peshawar Valley.

In his earlier attempts, Tahirkheli (1969) correlated the Salkhala series of Hazara and Kashmir with the Swat-Buner schistose group (Alpurai schists). He also correlated the rock-types in the southern Gandghar range to the Attock-Cherat ranges.

In the light of the structural framework of the region to the south of MMT and north of MBT, the graphitic-metapelites were probably deposited in a single or many small basins. The present distribution of the rocks is controlled by later structures leading to the formation of several nappes in the region.

These rocks show similar chemical characteristics. These are fairly siliceous and generally plot close to the 60% quartz line in the upper part of the double triangle. The graphitic-metapelites contain more than 1% organic carbon and plot in the black shale field. Compared to each other the rocks from Tarbela and Thana areas are more siliceous than those of Reshian and Kaghan areas, whereas the rocks from Tarbela area contain higher organic carbon than the rest of the areas. Chemical and field characteristics of these rocks indicate their deposition in transitional environment close to the land. The basin of deposition was shallow, however, rducing conditions prevailed in the sediments being deposited.

Elements were concentrated in the graphitic-metapelites from normal seawater. Some of the trace elements are related to the detrital minerals in the rock while others were concentrated by the organic matter and were released when the organic matter was later degraded by microorganisms or inorganic processes during diagenesis. Therefore no relationship between trace elements and organic carbon or sulphur is present. Probably several agents were involved in the enrichment of the trace elements at the upper level of the graphitic-metapelites below the evaporite sequence. The alternation of the evaporite sequences in the graphitic-metapelites indicates transgression and regression of the sea during sedimentation.

Chapter-6

CONCLUSION

Graphitic-metapelites are widely distributed in various precambrian formations of NW Pakistan and Azad Kashmir in the region bounded by MMT in the north and MBT in the south. These rocks occur in the form of continuous/discontinuous beds lenses and streaks. The rocks are highly radioactive at places and show general increase in background radioactivity. The radioactivity is mostly concentrated in the upper weathered and ozidized part below the evaporite sequence and is caused by the presence of U, Th, their daughter products and K^{40}. Removal of the accumulated daughter products and uranium by acidic groundwater cause seasonal variation in radioactivity in these rocks. Trace elements associated with uranium, organic carbon and sulphur also indicate their concentration in the upper part of the graphitic-metapelites. Unlike most black shale deposits, the trace elements in the studied rocks do not indicate any relationship with organic carbon. The absence of relationship among the trace elements including uranium and organic carbon is explained by the association of some of the elements with the detrital mineral fraction of the rocks while others were liberated by the degrading organic matter during diagenesis. Trace elements/organic carbon and sulphur ratios are very high for the studied rocks compared to other black shale deposits due to their low organic carbon and sulphur contents. However, these higher ratios associated with Fe/S relationship may suggest that sulphidization of Fe had played some part in the concentration of these elements.

The studied graphitic-metapelites are regarded as metamorphosed black shale deposits. These are characterized by fine grain size, dark colour due to organic carbon, and strong iron oxidation particularly along fractures, and are generally classified as argillaceous-siliceous black shales. They are associated with quartzite of continental origin and marine argillaceous-siliceous schistose sequence and evaporite deposits which suggest their deposition in the transitional environment. Higher organic carbon in the samples from Tarbela area indicates higher organic activity in a more aerated transitional environment.

Compared to the metal-rich black shale deposits, the graphitic-metapelites of Thana and Tarbela areas are more enriched in Ba, while the rocks at Reshian area indicates equall enrichment of the element as the black shale deposits. The Tarbela rocks are more rich in V compared to the V-Rich black shale deposits. The Kaghan area rocks are more enriched in Pb while those from Reshian area are equally enriched as the Pb-rich black shale deposits. Deposition of the elements from normal seawater and concentration by living planktons in oxgenated near-shore transitional environment associated with detrital mineral input, is considered to explain the distribution of the elements in the studied graphitic-metapelites.

Studies of the distribution of uranium in the graphitic-metapelites show that, like other black shale deposits, these present a huge potential source of uranium from where uranium is leached and transported by the running groundwater. The role of metamorphism has not been significant to remobilize uranium and concentrate along weak zones or elsewhere in these rocks in the studied areas. Supergene uranium concentration has not been found at depth probably because of the absence of any evidence of large scale uranium remobilization, the acidic nature of the groundwater and structural complexity of the area.

Appendix

NORMATIVE MINERALS CALCULATION PROCEDURE

The normative mineral composition of the samples from graphitic-metapelites of Pakistan and Azad Kashmir is based on chemical, petrographic and X-ray diffraction analyses. The procedure given by Stribrny et al., (1988), for sedimentary rocks, has been primarily followed, but due to change of the rock types from sedimentary into metamorphic, some modifications have been made in the given procedure.

The weight percentages of the different elements or oxidic molecules are converted to the corresponding minerals in relation to their atomic or molecular weights as follows:

1. P_2O_5 allotted to apatite.
2. TiO_2 to ilmenite and rutile.
3. Na_2O to albite.
4. MgO has been allotted to chlorite, but where muscovite and biotite appear, it has been equally divided between the latter two.
5. K_2O has been allotted to muscovite and biotite. In cases where K-feldspar is present, some K_2O is also allotted to K-feldspar.
6. SiO_2 (minus SiO_2 of albite, chlorite, muscovite, biotite, sillimanite/kyanite) to quartz.
7. Al_2O_3 (minus Al_2O_3 of albite, chlorite, muscovite, biotite) to sillimanite/kyanite.

8. Organic carbon remains as organic carbon.

9. Sulphur goes to pyrite.

10. The percentages of the normative minerals are added up. This sum should be equivalent to the sum of the bulk chemical analyses.

11. The organic carbon of each individual sample is substracted from the total normative mineral composition and the remaining composition is recalculated to 100 (Q + P + C = 100). The compositions are then plotted on a double triangle with Q for quartz, P for phyllosilicates and C for carbonates and the remaining minerals. Samples with more than 1% organic carbon are plotted in the upper part of the double triangle and those containing less than 1% organic carbon are plotted in the lower part of the double triangle.

REFERENCES

Ahmad, I., Rosenberg, P.S., Lawrence, R.D., Ghauri, A.A.K., and Majid, M., 1987. Lithostratigraphy of the Karakar Pass section, south of the Main Mantle Thrust, Swat,N.W. Pakistan. Geol. Bull. Univ. Peshawar, 20, 199-208.

Ashraf, M., and Chaudhry, M.N., 1985. Crystalline graphite deposits of Agra-Sillaipatti area, Malakand Agency, NWFP Pakistan. Kashmir Jour. Geol., 3, 1-11.

Baig, M.S.A., and Butt, K.A., 1972. Uranium prospects in Hazara district a preliminary report. AEMC Lahore (Restricted).

Baig, M.S., and Lawrence, R.D., 1987. Precambrian to early Paleozoic orogenesis in the Himalaya. Kashmir Jour. Geol., 5, 1-22.

Baig, M.S., Lawrence, R.D., and Snee, L.W., 1988. Evidence for late Precambrian to early cambrian orogeny in northwest Himalaya, Pakistan. Geol. Mag. 125(1), 83-86.

Baig, M.S., Snee, L.W., and Fortune, R.J., 1989. Timing of Pre-Himalayan orogenic events in the northwest Himalaya: $^{40}Ar/^{39}Ar$ constrants. Kashmir Jour. Geol., 6, 29-40.

Baig, M.A.S., Qamar, N.A., Khalid, H.W., Paracha, F.A., & Ahmad, J., Undated. A report of radiometric survey and regional geology of Thakot-Besham and adjoining areas and evaluation of anomalous radioactivity in Jabagai - Shaltai and Batkot areas. AEMC/Geo-36, AEMC Lahore, Pakistan.

Bates, T.F., and Strall, E.O., 1957. Mineralogy, Petrography and radioactivity of representative samples of Chattanooga shale. Geol. Soc. Amer. Bull., 68, 1305-1314.

Bell, R.T., 1978. Uranium in black shales-Areview. In Uranium deposits, their mineralogy and origin: M.M. Kimberley (ed.), Univ. Toronto Press, Toronto, Canada.

Beus, A.A., 1976. Geochemistry of the lithosphere. Mir Publishers, Moscow, U.S.S.R.

Bossart, P., Dietrich, D., Greeco, A., Ottiger, R., and Ramsay, J.G., 1988. The tectonic structure of the Hazara-Kashmir syntaxis, southern Himalayas, Pakistan.Tectonics,7(2), 273-297

Buryark, V.A., and Khabarovsk, 1990. Genetic types of mineral deposits of black shale strata. In Metalliferous black shales: J.Pasava and M.Sobotka (eds.). IGCP Project 254, Newsletter 2, Geol. Surv. Praugue, Chzechoslovakia.

Butt, K.A., 1981. Hydrothermal phenomenon associated with Lahore Pegmatoid/ granite complex, Kohistan. Geol. Bull. Univ. Peshawar, 14, 85-93.

Butt, K.A., 1983. Petrology and geochemical evolution of Lahore pegmatoid/ granite complex, northern Pakistan, and gnesis of associated Pb-Zn-Mo and U mineralization. In Granites of Himalayas, Karakorum and Hindukush: F.A. Shams (ed.). Inst. Geol. Univ. Punjab, Lahore, 309-322.

Butt, K.A., 1989. Release of uranium through cataclastic deformation of Mansehra granite-gneiss and its precipitation in the overlying intramountain basin in north Pakistan. In uranium deposits in magmatic and metamorphic rocks. Proceedings of a technical committee meeting on uranium deposits in magmatic and metamorphic rocks, Salamanka, 29 Sep. - 3 Oct. 1986, IAEA-TC-571/9, IAEA Vienna, 155-166.

Butt, K.A., Chaudhry, M.N., and Ashraf, M., 1985. Evidence of an incipient paleozoic ocean in Kashmir, Pakistan. Kashmir Jour. Geol. 3, 87-102.

Butt, K.A., Khan, T.M., Shah, M.S., and Humayun, Q., 1988. Uranium exploration at Reshian (Azad Kashmir). A progress report. AEMC, Hardrock Division, Peshawar.

Butt, K.A., and Qammar, N.A., 1977. Evaluation of anomalous radioactivity in Thakot area, Distt. Hazara, Pakistan. AEMC/Geo-9, AEMC, Lahore Pakistan.

Butt, K.A., and Qammar, N.A., 1978. Radiometric survey of graphitic schist zones of Salkhala Series in Kaghan Valley, District Mansehra. AEMC/ Geo-20, AEMC, Lahore, Pakistan.

Calkins, J.A., Offield, T.W., Abdullah, S.K.M and Ali, S.T., 1975.Geology of the southern Himalaya in Hazara, Pakistan and adjacent areas. U.S. Prof. Paper 716-C, 29 P.

Cameron, E.M., and Garrels, R.M., 1980. Geochemical compositions on some Precambrian shales from the Canadian shield. Chem. Geol. 28, 181-197.

Chaudhry, M.N., Ashraf, M., Hussain, S.S., and Iqbal, M., 1976. Geology and Petrology of Malakand and a part of Dir. (Toposheet 38 N/14). Geol. Bull. Univ. Punjab, 12, 17-39.

Chaudhry, M.N., and Ghazanfar, M., 1991-92. Some Tectonostratigraphic observations on northwest Himalaya, Pakistan. Preprint Pak. Jour. Geol., Pun. Geol. Soc.

Convey, R., Leventhal, J., Glassock, M., and Hatch, J., 1987. Origins of metals and organic matter in Mecca Quarry shale and stratigraphically equivalent beds across the midwest. Econ. Geol. 82, 915-937.

Coward, M.P., Windley, B.F., Broughton, R.D., Luff, I.Q., Petterson, M.G., Pudsey, C.J., Rex, D.C. and Khan, M.A., 1986. Collision tectonics in the NW Himalayas. In Collision Tectonics (M.P. Coward and A.C. Ries, eds.) Geol. Soc. London, Spec. Pub. 19, 203-219.

Coward, M.P., and Butler, R.W.H., 1985. Thrust tectonics and the deep structure of the Pak istan Himalayas. Geology, 13, 417-420.

Dostal, J., and Capedri, S., 1978. Uranium in metamorphic rocks. Contr. Mineral. Petrol., 66, 409-414.

Ferry, J.M., 1987. Metamorphic hydrology at 13 km depth and 400-500^{o}C. Amer. Mineral., 72, 39-58.

Ghazanfar, M., Baig, M.S., and Chaudhry, M.N., 1983. Geology of Tithwal-Kel area, Neelam Valley, Azad Jammu and Kashmir. Kashmir Jour. Geol., 1(1), 1-10.

Ghazanfar, M., and Chaudhry, M.N., 1985. Geology of Bhunja-Batkundi area, Kaghan Valley, District Mansehra, Pakistan. Geol. Bull. Univ. Punjab, 20, 76-105.

Ghazanfar, M., and Chaudhry, M.N., 1986. Reporting MCT in NW Himalayas, Pakistan. Geol. Bull. Univ. Punjab, 21, 10-18.

Greco, A., 1986. Geological investigations in the Reshian area (Jhelum Valley, State of Azad Jammu and Kashmir). Kashmir Jour. Geol., 4. 51-65.

Hylland, M.D., Riaz, M., and Ahmad, S., 1988. Stratigraphy and structure of the southern Gandghar range, Pakistan. Geol. Bull. Univ. Peshawar, 21, 1-14.

Jan, M.Q., and Tahirkheli, R.A.K., 1969. The geology of the lower part of Indus Kohistan (Swat), West Pakistan. Geol. Bull. Univ. Peshawar, 4, 1-13.

Jones, C.A., 1978. Uranium occurrences in sedimentary rocks exclusive of sandstone. In Geological investigations of environments favourable for uranium deposits: G.Mickle and G.W.Mathews.(eds.). U.S. Deptt of Energy, U.S.A.

Kazmi, A.H., Lawrence, R.D., Dawood, H., Snee, L.W., and Hussain, S.S., 1984. Geology of the Indus suture zone in the Mingora-Shangla area, Swat, northern Pakistan. Geol. Bull. Univ. Peshawar, 17, 127-144.

Kretz, R., 1983. Symbols for rock forming minerals. Amer. Mineral., 68, 277-279.

Leventhal, J.S., 1991. Comparison of organic geochemistry and metal enrichment in two black shales; Cambrian Alum shale of Sweden and Devonian Chattanooga shale of United States. Mineral. Deposita, 26, 1-10.

Leventhal, J.S., and Hosterman, J.W., 1982. Chemical and mineralogical analysis of Devonian black shale samples from Martin county Kentucky; Caroll and Washington counties, Ohio; Wise county, Virginia and Overton county, Tennessee, U.S.A., Chem. Geol., 37, 239-264.

Malinconico, L.L. Jr., 1989. Crustal shortening in the west Himalaya. Geol. Bull. Univ. Peshawar, 22, 55-64.

Martin, N.R., Siddiqui, S.F.A., and King, B.H., 1962. A geological reconnaissance of the region between the lower Swat and Indus river of Pakistan. Geol. Bull. Punjab, Univ., 2, 1-14.

Noble, E.A., 1963. Formation of ore deposits by water of compaction. Econ. Geol., 58 (7), 1145-1154.

Patriat, P., and Achache, J., 1984. India-Eurasia collision chronology has implications for crustal shortening and driving mechanism of plates. Nature, 311, 615-621.

Peltola, E., 1968. On some geochemical features in the black schists of the Outokumpa area, Finland. Bull. Geol. Soc. Finland, 40, 39-50.

Rehman, M.A., and Chaudhry, M.N., 1981. Geology and Petrography of metamorphic rocks in Mauji and Reshian areas, Distt. Muzaffarabad, Azad Kashmir, Pakistan. Geol. Bull. Univ. Peshawar, 14, 123-139.

Searle, M.P., Windley, B.F., Coward, M.P., Cooper, D.J.W., Rex, A.J., Rex, D., Tingdong, L., Xuchavy, X., Jan, M.Q., Thakur, V.C., and Kumar, S., 1987. The closing of Tethys and the tectonics of the Himalaya. Geol. Soc. Amer. Bull., 98, 678-701.

Sozinov, N.A., 1982. Ore potential of Precambrian black shale formations. Rev. Brasil. Geocien., 12, 506-509.

Stribrny, B., Urban, H., and Weber, H., 1988. The lower Carboniferous black shale formation, a possible source for noble and base metal deposits in the NE Rhenish massif, Federal Republic of Germany. Min. Pet., 39, 129-143.

Tahirkheli, R.A.K., 1971. The geology of the Gandghar range, Distt. Hazara, N.W.F.P., Geol. Bull. Univ. Peshawar, 6, 33-42.

Tahirkheli, R.A.K., 1979a. Geotectonic evolution of Kohistan. Geol. Bull. Univ. Peshawar, 11, 113-130.

Tahirkheli, R.A.K., 1979b. Geology of Kohistan and adjoining Eurasian and Indo-Pakistan continents, Pakistan. Geol. Bull. Univ. Peshawar 11, 1-30.

Tourtelot, H.A., 1979. Black shale - its deposition amd diagenesis. Clay and Clay Miner., 27, 313-321.

Treloar, P.J., 1989. Imbrication and unroofing of the Himalayan Thrust Stack of the North Indian Plate, North Pakistan. Geol. Bull. Univ. Peshawar, 22, 25-44.

Vine, J.D., and Tourtelot, E.B., 1970. Geochemistry of black shale deposits-a summary report. Econ. Geol., 65, 253-272.

Wadia, D.N., 1957. Geology of India (3rd ed.) McMillan & Co. London.

Walther, J.V., and Orville, P.M., 1982. Volatile production and transport during regional metamorphism. Contr. Mineral. Petrol, 79, 252-257.

Wedepohl, K.H., 1971. Kupferschiefer as a prototype of syngentic sedimentary ore deposits. Soc. Mining, Geol., Japan, Sp. Issue, 3, 268-273.

Williams, M.P., 1989. The geology of Besham area, north Pakistan: Deformation and Imbrication in the footwall of the Main Mantle Thrust. Geol. Bull. Univ. Peshawar, 22, 65-82.

Winkler, H.G.F., 1974. Petrogenesis of metamorphic rocks (3rd edition). Springer Verlog, New York.