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Petrography of Sandstone of Molasse Deposits (Rawalpindi Group) and their tectonic setting from Khairi-Murat Area, Potwar Sub-basin, Pakistan.

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ABSTRACT

Potwar sub-basin is a fault-bounded basin, developed due to the collision of Indian and Eurasian plates. In Khairi Murat area (northeastern part of Potwar sub-basin) Late Eocene (Kuldana Formation) to Recent clastic rock units are exposed at the surface. The Murree Formation is exposed on limbs of Khairi Murat anticline, while the Kamlial Formation is exposed along Dhurnal back thrust. The petrographic studies of sandstones of Murree and Kamlial Formations in Khairi-Murat area indicate that the detritus of the rocks were derived from the rising Himalayas. The provenance study of the sandstones of Rawalpindi Group reveals that the source rocks were mainly derived from low-grade metamorphic and plutonic rocks. The sandstones of Rawalpindi Group contain heavy minerals like tourmaline, epidote, garnet, chlorite, rutile, hornblende and zircon. This complex heavy detritus also indicate that the sediments were derived from igneous and metamorphic source. Tectonically the area is highly disturbed due to Himalayan orogeny. The main faults in the area are the Khairi Murat reverse fault and Dhurnal back thrust. The field and petrographic investigations reveals the effects of Himalayan uplifting and thrusting on sedimentation in the area. The rock fragments and modal composition of the clastic rocks indicates different stages of Himalayan tectonics.

INTRODUCTION

In the Khairi Murat area the exposed clastic rocks range in age from Late Eocene (Kuldana Formation) to Recent (alluviam) rock units. The purpose of the present study is to present a petrological and petrotectonic work of sandstones of Murree and Kamlial Formations with reference to their petrotectonic characterization, provenance determination, diagenetic changes and reservoir properties. Petrography of the various rock units of molasse deposits of Himalayan foreland basins has been carried out by several workers such as Abid et al., (1983); Chaudri, (1970 and 1972c); Bajwa, (1984) and Azizullah and Khan (1997). The petrographic composition of the sediments, especially the sandstone and conglomerate strongly reflects the nature of the source area. For petrographic study 50 representative sandstone samples were collected. This study is based on field mapping, sampling of sandstones of Murree and Kamlial Formations for petrographic analysis to construct provenance and tectonics of the study area. Representative rock samples are selected from each rock unit of Rawalpindi Group to classify and characterize the rock. These samples are collected from the measured sections to know the vertical variations in minerals and also along the strike of rock bodies to find the lateral variations.

REGIONAL TECTONIC FRAMEWORK

Potwar sub-basin is a fault-bounded basin, developed due to the collision of Indian and Eurasian plates. In the Late Eocene time after the deposition of Kuldana Formation, initial Himalayan orogenic movement uplifted the strata and subjected them to weathering throughout Oligocene time. An orogenic foredeep was developed in Miocene, trending northeast southwest. The depocenter was migrated to the southwest in the Plio-Pliestocene time, resulting in the accumulation of molasse deposits (Gee, 1989). The deposit consists of the Rawalpindi and Siwalik Groups, which are over 5000m thick at the axis of the Soan Syncline (i.e beneath the Soan River). The groups as a whole are a body of formations comprising sediments of clastic origin.

Structurally, Potwar sub-basin is bounded by Main Boundary Thrust (MBT) in the north, left lateral Jhelum fault to the east, the Salt Range Thrust to the south and right lateral Kalabagh fault in the west (McDougall and Khan, 1990; Kazmi and Rana, 1982; Figure 1). The faulting in the area is mainly southeast directed imbrications and back steepening. The main faults in the area are the Khairi Murat reverse fault and Dhurnal back thrust (Figure 2). The Dhurnal back thrust (DBT) is a passive back thrust at the margin of Potwar foreland sub-basin (Jaswal, 1990). The DBT is southward dipping back thrust. It lies between the Murree Formation and Kamlial Formation. The resistant beds of Kamlial sandstone have tilted upward along the deformation, developing the northern limb of the Soan syncline. The DBT runs almost parallel to the Khairi Murat fault in NE-SW direction. The Kamlial Formation forms the strike ridges and the fault runs parallel to the strike of the rock units (Siddiqi, 2003).

MURREE FORMATION

Murree Formation mainly consists of monotonous sequence of sandstones, siltstones, shales and subordinate conglomerates and clays (Shah, 1977). In the study area Murree Formation is well exposed along both limbs of Khairi Murat anticline (Figure 2). Sandstone is grey, reddish, hard and calcareous and clay is reddish brown, purple and pink in color. Generally this formation forms hilly terrain and ridges. The sandstone of Murree Formation is fractured and jointed. These fractures are quartz filled; calcite filled, opened at places and highly fractures due to the presence of Khairi Murat fault. The sedimentary structures (flute casts, load casts, cross bedding, rip-ups, ripple marks) in the Murree Formation are well exposed at various places in the field area. The formation represents fluvial environment of deposition and acts as potential reservoir and cap rocks in Kohat-Potwar Basin. Representative rock samples for petrographic studies from lower, middle and upper parts of the Murree Formation were taken (Figure 2; Table 1). On the basis of detailed petrographic analysis, three types of sandstones (microfacies) of Murree Formation are recognized as given below.

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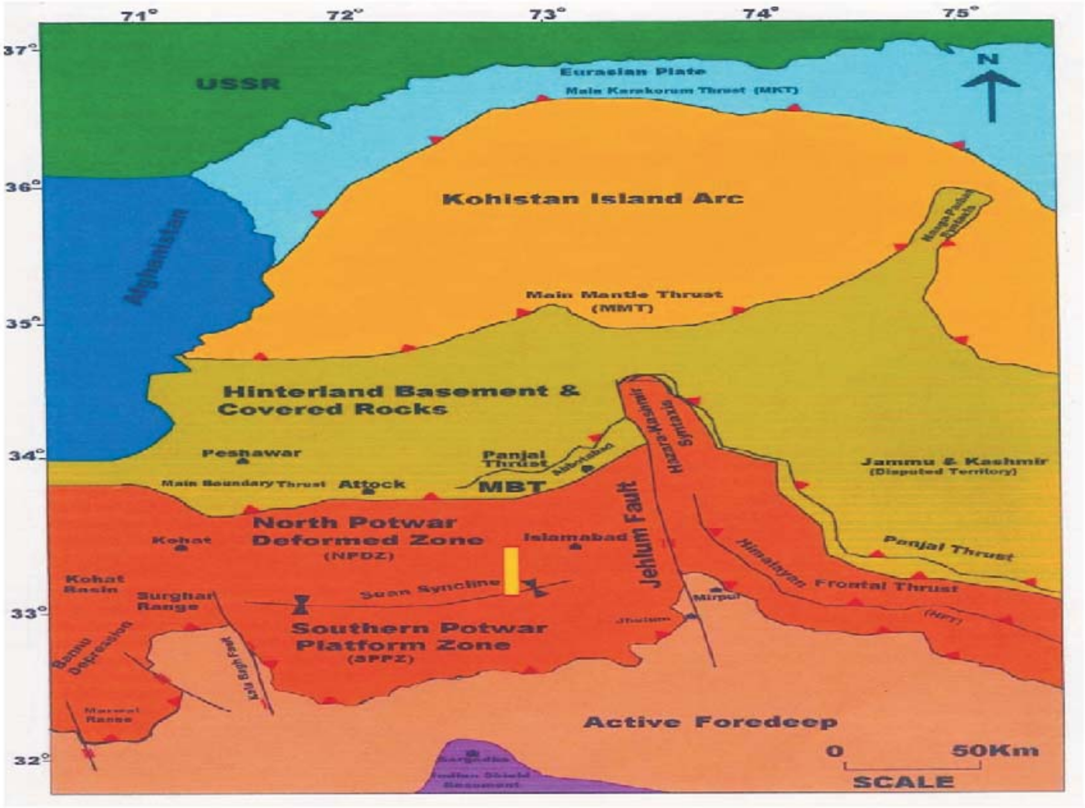

Figure 1- Regional Tectonic map of Northwest Himalayas of Pakistan. The rectangle shows the location of Khairi Murat area (modified after Khan et al., 1986).

Table 1- Modal Percentage Composition of Sandstone of Murree Formation

S. No.		Sample No.	Mon. Q	Pol Q	Pl.	Mcl	L	Ca	Mus	Bt	Tm	Clay Mineral	Zr	Ep	Gt	Ore Minerals	Classification (McBride, 1963)	Provenance (Dickinson *et al.*, 1983)
1	Upper part	**TR$_{12}$**	30	05	05	04	25	17	03	02	02	01	--	02	Traces	05	Feldspathic litharenite	Recycled Orogen
2		**TR$_{10}$**	30	06	06	03	27	20	02	01	--	--	--	01	01	03	Feldspathic litharenite	Recycled Orogen
3		**TR$_{13}$**	25	08	04	04	26	20	02	01	--	--	--	02	--	08	Feldspathic litharenite	Recycled Orogen
4		**RL$_{1}$**	35	10	03	02	22	14	02	01	01	--	--	01	--	08	Feldspathic litharenite	Dissected Arc
5		**RL$_{4}$**	20	08	10	07	25	10	02	02	--	--	--	02	01	12	Feldspathic litharenite	Recycled Orogen
6		**RL$_{2}$**	25	05	06	03	35	08	02	03	01	--	--	01	--	10	Feldspathic litharenite	Dissected Arc
7	Middle part	**TR$_{3}$**	27	05	03	02	24	23	03	02	--	--	--	02	01	08	Feldspathic litharenite	Dissected Arc
8		**TR$_{11}$**	25	10	02	02	32	12	03	03	01	--	--	02	--	08	Feldspathic litharenite	Recycled Orogen
9		**Pt$_{8}$**	35	10	03	02	10	20	03	10	01	--	--	01	01	04	Feldspathic litharenite	Dissected Arc
10		**TR$_{5}$**	22	12	08	06	10	30	03	01	01	--	--	02	--	05	Litharenite	Recycled Orogen
11		**RL$_{6}$**	14	04	06	02	24	35	03	02	01	--	--	02	01	05	Litharenite	Recycled Orogen
12		**RL$_{5}$**	15	03	06	03	20	40	03	02	01	--	--	01	01	05	Litharenite	Recycled Orogen
13	Lower part	**Pd$_{3}$**	25	10	08	04	16	--	07	04	01	20	--	01	01	03	Litharenite	Recycled Orogen
14		**Pd$_{4}$**	40	10	07	08	08	10	03	07	02	--	--	01	--	04	Sub litharenite	Recycled Orogen
15		**Pc$_{4}$**	30	10	03	02	30	--	05	03	01	12	--	01	01	02	Lithic subarkose	RecycledOrogen
16		**Pc$_{14}$**	**25**	05	12	02	2	20	05	04	02	--	--	01	01	03	Lithic subarkose	Recycled Orogen

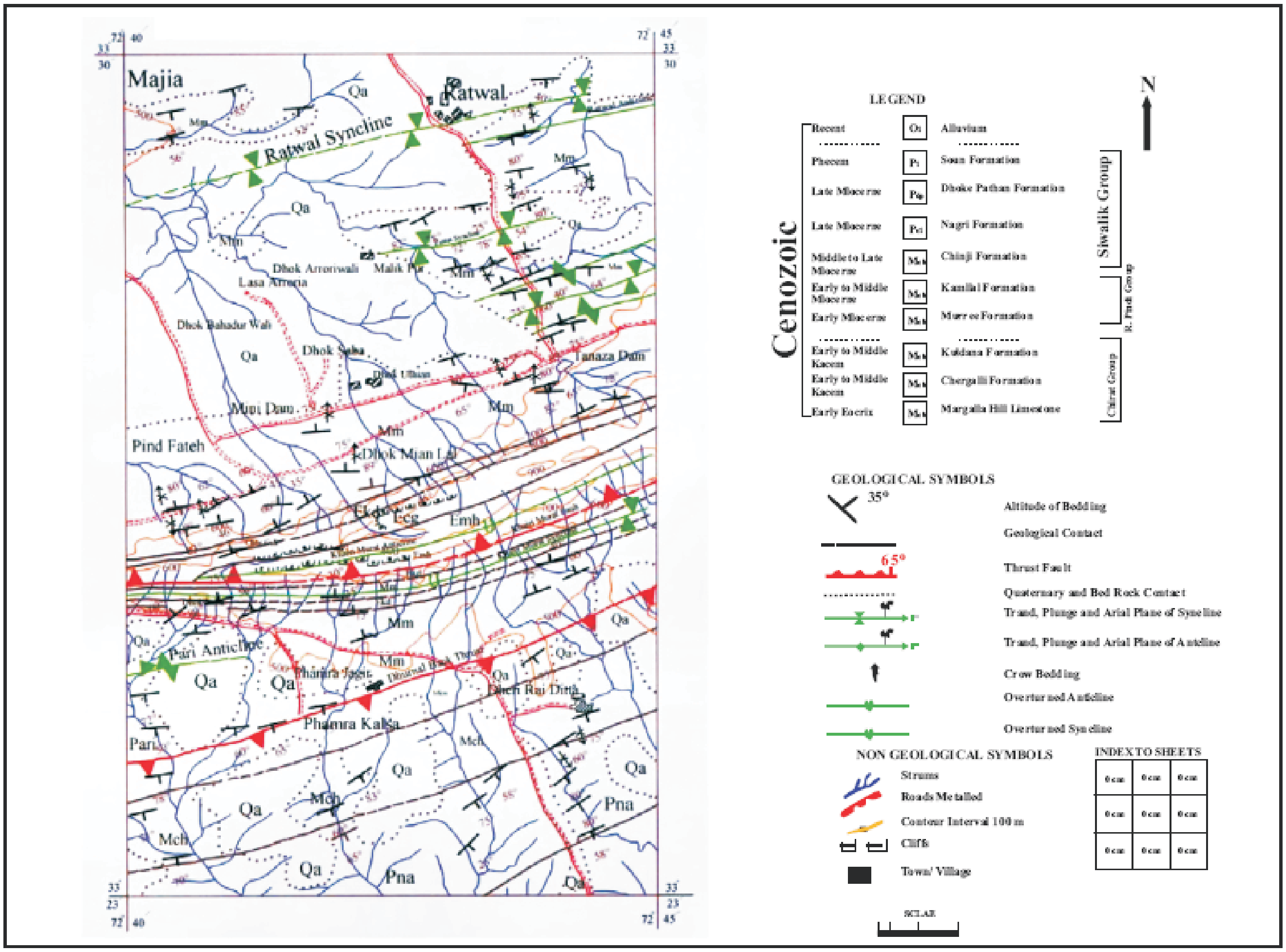

Figure 2 - Geological map of Khairi Murat area District Fatehjang Potwar Sub-Basin Pakistan.

1) Feldspathic Litharenite

Nine samples (TR10, TR12, TR13, RL1, RL2, RL4, TR3, TR11 and Pt8) of Murree Formation are recognized as feldspathic litharenite (Figure 4; Table 1). In study area, this facies is composed of sandstone interbedded with red clays. The colour of sandstone is greenish to light grey and weathered colour is rusty brown to dark grey and it is fine grained and hard.

Microscopic Features

The study of thin sections from the samples of this facies show that feldspathic litharenite is texturally immature as shown by generally coarse grained texture, angular to poorly rounded grains and the frequent presence of detrital matrix. In thin sections, quartz grains are dominantly monocrystalline with subordinate polycrystalline quartz. Some quartz grains show undulose extinction. Grain contacts are dominantly sutured and concavo-convex (Figure 3B) and some boundaries of grains form irregular surfaces or corroded margins. Feldspar grains with a few exceptions are mainly K-feldspars, generally microcline, orthoclase and sodic plagioclase (albite). Both fresh and altered feldspar grains are present in thin sections. Lithic fragments are derived from igneous and metamorphic rocks such as granites, quartz mica schists and garnet mica schist. They are associated with lithics of sedimentary rocks originating from intraformational reworking of the feldspathic suite itself, such as red shales, fine-grained feldspathic arenites and occasionally older limestones and dolomite and even chert. Large detrital, deformed flakes of micas consist of relatively stable muscovite and unstable biotite is also present throughout the rock samples. They are aligned parallel to bedding (Figure 3B and C). Minor accessory minerals in feldspathic litharenite include tourmaline, rutile, garnet, magnetite and ilmenite. Yellow green tiny grains of epidote are present. Volcanic rock fragments may also contain epidote grains, which are generally fine grained. Tourmaline occurs as green, fine-grained, sub angular showing moderately pleochroism from brownish green to dark greenish brown (Figure 3D). Garnet grains are rarely present in the studied thin sections and these are colourless to light pink, sub angular to sub rounded grains. Cementation of many feldspathic litharenite occurs by means of variable combinations of overgrowths on quartz and feldspar grains and pressure solution processes. In some thin sections of feldspathic litharenite calcite is more frequently present as cementing material (Figure 3A). Calcite cement has microcrystalline aggregates, mosaic of anhedral to sub-hedral crystals, single crystals twinned or not, or single crystals enclosing several quartz and feldspar grains. Marginal replacement of quartz and feldspar grains by various types of carbonate cements (calcite/dolomite) is wide spread. Texturally rock samples of feldspathic litharenite are matrix supported as well as grain supported. In some rock samples the detrital matrix present in feldspathic litharenite consists of clay minerals that are beyond the resolution power of the petrographic microscope. The matrix constituents probably include kaolinite, illite or sericite (Figure 3B and C).

Provenance

Feldspathic litharenite, which occurs in the entire geologic column, has an obvious feldspar rich source area characterized by predominant k-feldspar consisting of granite, gneisses and other high rank metamorphic rocks. According to Dickinson et al., (1983), mean composition of sandstone suits derived from various source areas controlled by plate tectonics in distinct and separate field on QFL triangle diagram (Figure 5). Feldspathic litharenite contains more feldspar and lithic fragments. The petrographic data of five samples (TR10, TR12, TR13, TRI1 and RL4) of feldspathic litharenite when plotted on QFL provenance discrimination diagram of Dickinson et al, (1983) fall in the field of recycled orogen (Figure 5). The samples are composed of clasts of sedimentary and metamorphic rocks, with a minor amount of volcanic rock fragment. The petrographic data suggest that the source area consists of sedimentary, metamorphic and volcanic rocks. The area was uplifted and underwent erosion as a result of Himalayan orogeny and ultimately became the source for supply of these clastic sediments. Four samples of feldspathic litharenite fall in dissected arc (Figure 5). Dissected arc is sub field of magmatic arc where erosion has penetrated batholiths beneath volcanic cover and thus originating more volcanic-plutonic sands of quartzo feldspathic composition.

2) Litharenite

According to QFL diagram (McBride, 1963) of Murree Formation four samples (TR5, RL6, RL5 and Pd3) are recognized as litharenite and one sample (Pd4) recognized as sub litharenite (Figure 4 Table 1). The sandstone of this facies is greenish to light grey and grayish maron to reddish maron. These are medium to coarse grained, hard and calcareous sandstones.

Microscopic Features

The litharenite contain 25% or more lithic grains exceeding feldspar grains. In these rocks lithic fragments are of sedimentary, metamorphic, igneous and volcanic rocks. However average litharenite of Murree Formation are mixtures of low-grade metamorphic and sedimentary rocks. The thin sections of this micro facies clearly show that clasts were derived from shales, siltstones, phyllites, slates and mica schist. Quartz grains are common and exhibit wavy extinction and poly-crystallinity indicating the low-grade metamorphic origin (Figure 3E). The thin section study reveals that quartz grains are well rounded but angular to sub angular grains are also common (Figure 3F). The well-rounded quartz grains were probably derived from quartz arenite or multi-cycle sandstone. The angularity of the grains reflects near source area. In litharenite, feldspar is present in relatively small amount (58%). Plagioclase is largely predominant over k - feldspar. The older sedimentary or low-grade metamorphic rocks are responsible for the small amount of feldspar in litharenite. Detrital micas (2-9%), with muscovite more common than biotite, are frequent constituents of litharenite, which probably derived from metamorphic source. Mica flakes are frequently deposited parallel to bedding and particularly susceptible to deformation by compaction between more resistant constituents. An extremely varied suite of heavy minerals occurs in litharenite including tourmaline, epidote and garnet. In litharenite, the most common cements are calcite and quartz and subordinate amount of authigenic clay minerals. Calcite cement displays a wide spectrum of textures i.e. microcrystalline mosaic or randomly associated anhedral to subhedral crystals and cavity filling textures. In sample no. Pc4 sericite and other clay minerals developed elongated fabric due to the presence of Khairi Murat thrust (Figure 3G). Mica flakes are also deformed and elongated in the same direction.

Provenance

Litharenite is one of the most common immature sandstones. Litharenite reflects provenance in the most effective manner because lithics carry by themselves the obvious proofs of their origin more than any other kind of monomineralic grain does. When the petrographic data of these rocks are plotted on QFL provenance discrimination diagram of Dickinson et al., (1983), the data fall in the field of recycled orogen (Figure 5). Litharenite occur as alluvial deposits that fill post orogenic frontal basins, generaly called molassic basins.

3) Lithic Subarkose

Two samples (Pc4 and Pc14) are recognized as lithic subarkose according to QFL diagram (Figure 4, Table 1). The fabric of this facies are brownish, grayish, coarse grained and soft.

Microscopic Features

The study of thin sections from the samples of this facies shows that these are well-sorted sandstone having a grain supported as well as matrix supported fabrics. Both monocrystalline and polycrystalline quartz grains are present having sutured and concavo-convex contacts. Grains are sub-angular to sub-rounded (Figure 3H). Undulatory quartz is also present. Some quartz grains are fractured. Feldspar grains are mainly plagioclase and microcline. Both fresh and altered feldspar grains are present in thin sections (Figure 3I). Lithic fragments are derived from igneous and metamorphic rocks such as granites, mica schists and also sedimentary rocks such as shales and carbonates. Deformed flakes of mica are also present and scattered throughout the rock. Minor accessory (heavy) minerals are also present in lithic subarkose including tourmaline and epidote. Tourmaline shows pleochroism from pink to light green. Single aggregate of tourmaline is also present. The cement in the rocks is calcite. It is a microcrystalline mosaics of anhedral to sub hedral crystals. Marginal replacement of feldspar and quartz grains due to corrosion of calcite is also observed. Authigenic overgrowth of quartz crystal is also present (Figure 3H).

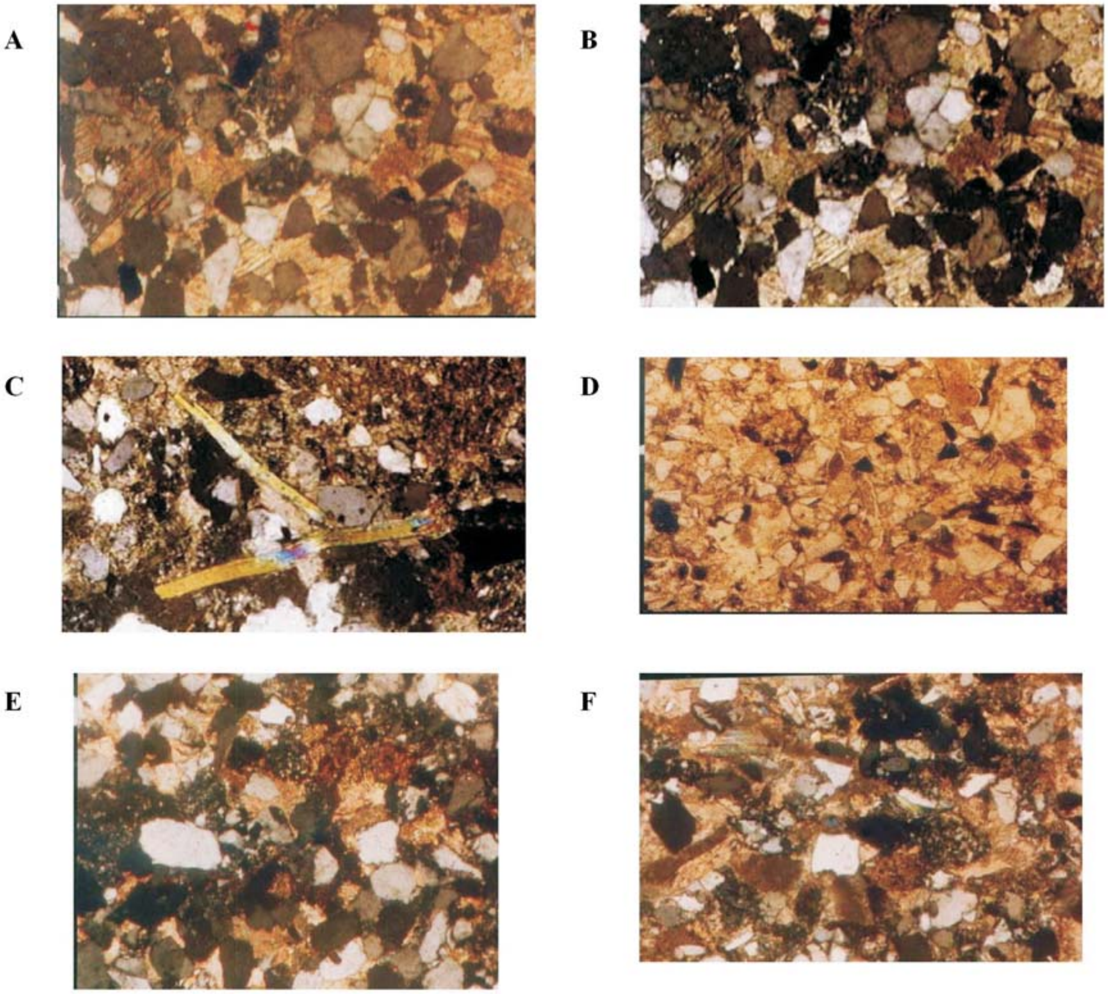

Figure 3 - Photomicorgraphs, (A) Feldspathic litharenite of Murree Formation showing growth of calcite crystals between the pore spaces and red colored epidote inclusion in quartz grain at upper central portion. (B) Feldspathic litharenite of Murree Formation showing flakes of mica and growth of clay minerals. (C) Feldspathic litharenite of Murree Formation showing large flakes of biotite. (D) Feldspathic litharenite of Murree Formation showing angular to subangular quartz grains. Note a sub-rounded grain of tourmaline at lower right portion (E) Litharenite of Murree Formation showing growth of clay minerals between the pore spaces. Note poly crystalline quartz at central portion. (F) Litharenite of Murree Formation showing corroded margins of quartz grains and growth of calcite and clay minerals between the pore spaces. (G) Litharenite of Murree Formation showing impact of compaction by sutured quartz grains and crystallization of clay minerals between the pore spaces. (H) Lithic subarkose of Murree Formation showing close packing of quartz grains and authigenic overgrowth of silica around quartz grain. Note the epidote crystal at the upper central part. (I) Lithic subarkose of Murree Formation showing plagioclase at upper central part and quartz grains embedded in calcite cement. (J) Feldspathic litharenite of Kamlial Formation showing large crystals of plagioclase. Note the brown biotite and blue epidote crystal at central left part. (K) Feldspathic litharenite of Kamlial Formation Plagioclase and microcline grain are at central part and biotite present at lower left portion. (L) Feldspathic litharenite of Kamlial Formation showing garnet in central portion, green tourmaline in lower central portion and red epidote in lower left portion. (M) Feldspathic litharenite of Kamlial Formation showing green tourmaline at central left portion. (N) Litharenite of Kamlial Formation showing biotite mica schist lower central portion and overgrowth of silica around quartz crystal. (O) Kamlial Formation showing igneous rock fragments in upper left portion and well cleaved calcite cement.

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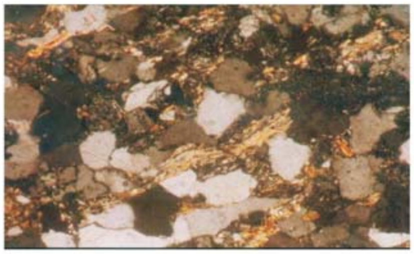

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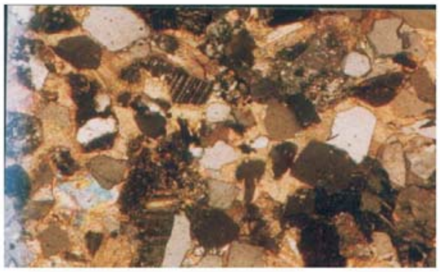

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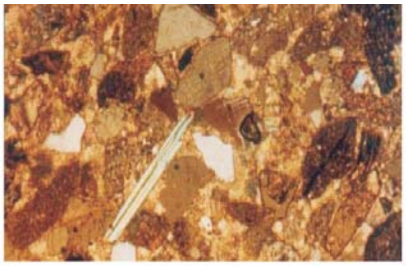

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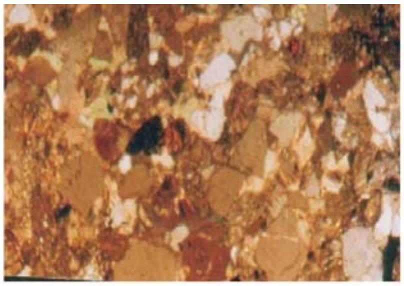

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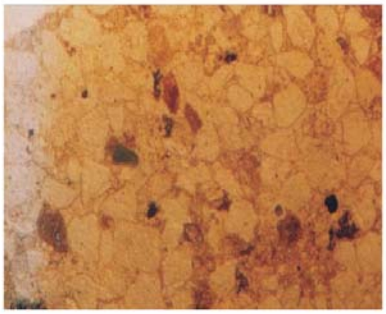

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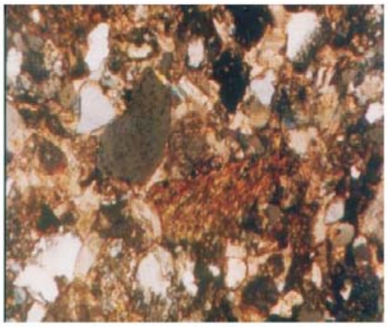

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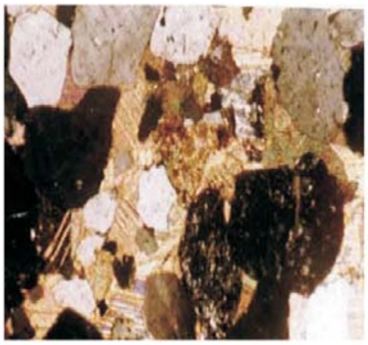

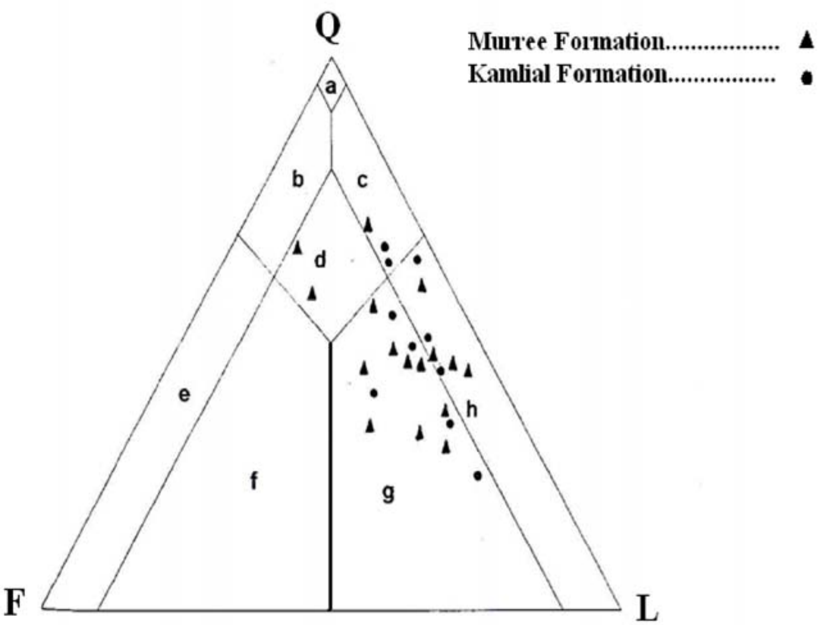

Figure 4 - Modal composition of the sandstone of Murree and Kamlial Formations on the Q (quartz) F (feldspar) L (lithic) triangular diagram (modified after McBride, 1963). The fields are

a)Quartz arenite
b)Sub-arkose
c)Sub-lith arenite
d)Lithic sub-arkose
e)Arkose
f)Lithic arkose
g)Feldspathic lith arenite
h)Lith arenite

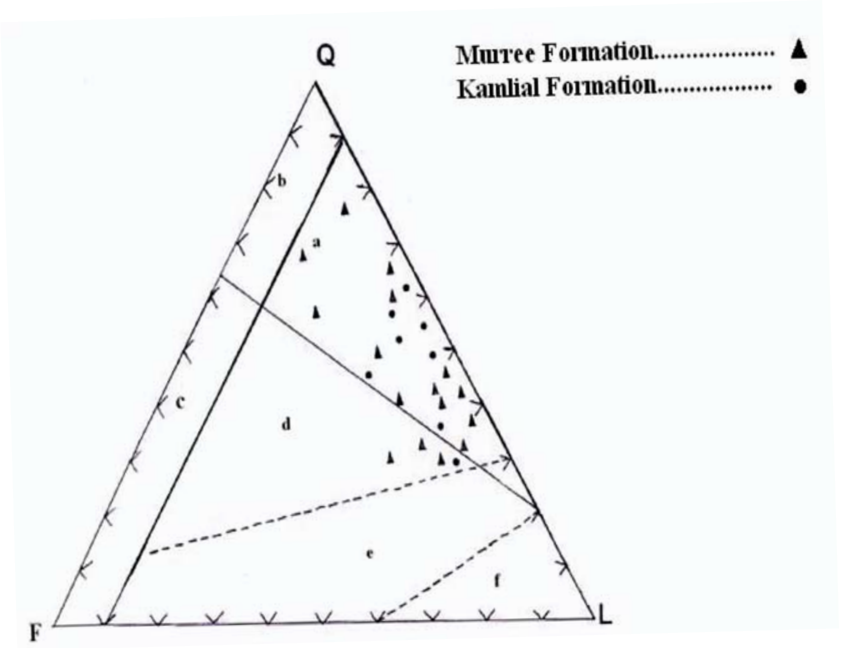

Figure 5 - QFL Provenance Discrimination diagram (Dickinson et al., 1983) of Rawalpindi Group.

a)Recycled orogen
b)Transitional continent
c)Basement uplift
d) Dissected arc
e) Transitional arc
f) Undissected arc

Provenance

On the QFL provenance discrimination diagram of Dickinson et al., (1983) the modal data fall into the field of recycled orogen (Figure 5, Table 1).

Diagenesis

Sandstone of Murree Formation in the study area is dominantly feldspathic litharenite, litharenite and lithic subarkose. Due to immature composition of this sandstone calcite cementation is the most common cement and predominantly the main agent of pore space reduction. The second most common diagenetic product is the closer packing of grains due to mechanical compaction (indicating by sutured and concavoconvex contacts; Figure 3H) and tight mosaic of interlocking crystals due to probably deep burial processes of pressure solution. The third significant common pore filling material is overgrowth of authigenic quartz. Quartz overgrowth shows that their precipitation occurred soon after deposition, at shallow depths, before any appreciable compaction of the detrital quartz grains took place. Diagenetic albitization of k-feldspar is also observed in some rock samples. Partial replacement generates perthetic intergrowth of albite. Sericitization process is also observed in which feldspar grains altered into clay minerals.

Reservoir Properties

Primary porosity of sandstones of Murree Formation is gradually reduced and even obliterated by processes of mechanical compaction, pressure solution and overgrowths on quartz followed by precipitation of interstitial and partially replacive carbonate and clay mineral cements. Partially dissolution of framework grains and cement constituents generate irregularly shaped pores that often show patches of remnant materials adjacent to them that have corroded margins. Subsequent dissolution of the cement, which is cavity filling or partially replacive, generated secondary porosity between the loosely packed grains. By combination of the various types of secondary porosity, sandstone of Murree Formation may reach a good percentage of secondary porosity, thus making them good reservoir.

KAMLIAL FORMATION

In the study area, Kamlial Formation mainly consists of sandstones, shales and subordinate conglomerates. Representative samples for petrographic studies from lower, middle and upper parts of the Kamlial Formation were taken (Figure 2). On the basis of detailed petrographic analysis, two types of sandstones (microfacies) of Kamlial Formation are recognized as given below.

1) Feldspathic Litharenite

Five samples (DD7, Kp16, Kp17, Kp19 and Kp20) of Kamlial Formation are recognized as feldspathic litharenite (Table 2; Figure 4). In the study area, this facies is composed of greenish, hard and compact sandstone. The rock is medium to fine grained.

Microscopic Features

The study of thin sections from the samples of this facies show that feldspathic litharenite is texturally coarse grained with angular to poorly rounded grains and contain frequent detrital matrix which is dominantly calcite. In thin sections of this facies, quartz grains are polycrystalline and monocrystalline. Some quartz grains show undulose extinction. Grains contacts are concavoconvex and sutured. Feldspar grains with a few exceptions are mainly K-feldspars, generally microcline, orthoclase and sodic plagioclase (albite) (Figure 3J). Altered feldspar grains are also present indicating the impact of diagenesis. Alteration occurs along twin lamella in albite. Alteration products are clay minerals, epidote and sericite. Lithic fragments are of sedimentary, metamorphic and igneous rocks such as granites, quartz mica schists and garnet mica schist. The clasts of sedimentary rocks were derived from intraformational reworking of the feldspathic suite itself, such as red shales, fine-grained feldspathic arenites and extra formational limestones, dolomite and chert. Tiny grains of epidote are present in this facies abundantly as compared to the Murree Formation. The colour of epidote is yellow green and show pleochroism. Deformed flakes of micas consist of muscovite and biotite are also present (Figure 3K). Minor accessory minerals in feldspathic litharenite include tourmaline, garnet, magnetite and ilmenite. Tourmaline occurs as green, fine-grained and sub angular showing moderately pleochroism from brownish green to dark greenish brown (Figure 3L and M). In feldspathic litharenite cementing material is mainly calcite. Calcite cement has microcrystalline aggregates, mosaic of anhedral to sub hedral crystals. Marginal replacement of quartz and feldspar grains by calcite cement is wide spread. Texturally all rock samples of feldspathic litharenite with a few exceptions are matrix supported.

Provenance

Mean composition of sandstone suits derived from various source areas controlled by plate tectonics in distinct and separate fields on QFL triangle diagram (Dickinson et al., 1983). Feldspathic litharenite contain more feldspar and lithic fragments. The provenance of four samples (DD7, Kp16, Kp19 and Kp20) of feldspathic litharenite is recycled orogen (Figure 5). A source area of this type mainly consists of sedimentary and metamorphic rocks as indicated by rock fragments. One sample of feldspathic litharenite falls in transitional arc (Figure 5). Transitional arc is sub field of magmatic arc.

2) Litharenite

According to QFL diagram (McBride, 1963) of Kamlial Formation three samples (Kp14, Kp15 and Kp18) are recognized as litharenite and two samples (DD5 and DD4) as sub-litharenite (Figure 4; Table 2). The sandstones of this facies are medium to coarse grained, greenish to light grey, hard and calcareous.

Microscopic Features

Litharenite contain 25% or more lithic grains exceed to the proportion of rock fragments and feldspar grains. The study indicates that the rock fragments are of sedimentary, metamorphic, igneous and volcanic rocks. The thin sections of this facies indicate that clasts were derived from shales, siltstone, phyllite, slates and mica schist (Figure 3N). Quartz grains show straight extinction as well as wavy extinction and poly-crystallinity indicating the low-grade metamorphic origin. Feldspar (12-20%) present in relatively small amount consisting of plagioclase and k-feldspar (albite, microcline). Detrital micas (1%-4% muscovite and biotite) are frequent constituents of litharenite, which probably derived from metamorphic source area. Different types of heavy minerals occur in litharenite including tourmaline, epidote and garnet. In litharenite, the most common cement is calcite. Calcite cement displays a wide spectrum of textures i.e. poikilitic texture in which large crystals of calcite interlock irregularly, each enclosing many framework grains, randomly associated anhedral to subhedral crystals and cavity filling textures (Figure 3 O).

Provenance

Litharenite reflects provenance in the most effective manner because lithics carry by themselves the obvious proofs of their origin more than any other kind of monomineralic grain does. In QFL provenance discrimination diagram of Dickinson et al., (1983), all rock samples of litharenite fall in recycled orogen (Figure 5). Diagenetic processes involved in sandstone of Kamlial Formation are feldspar alteration, quartz and carbonate cementation and authigenic clay cementation.

Reservoir Properties

The sandstone of Kamlial Formation displays the same diagenetic features as Murree Formation and also developed secondary porosity under similar conditions, thus making them potential reservoir rock.

PROVENANCE OF RAWALPINDI GROUP ON THE BASIS OF ESSENTIAL AND HEAVY MINERALS AND CLASTS OF THE PALEOCHANNEL.

The exposed molasse sequences along Khairi-Murat Range have direct relationship with uplifting episodes of the Himalayas present to the north. The structural deformation is due to ongoing collision between the Eurasian and Indian plates. The field investigations and petrographic studies of the rock samples of sandstone indicate that the detrital material of these rocks was eroded away from rising Himalayas and deposited in Kohat-Potwar foreland basin. The molasse deposits are the result of collision between the Indian and the Eurasian plates (Powell, 1979). Collision between India and Eurasia began close to the Paleocene / Eocene boundary and during Miocene the Himalayas came under erosion as manifested in the Murree and Kamlial Formations. Interpretation of the petrographic data in relation to the evaluation of the source area has shown some interesting results. Petrographic data have been plotted on the QFL provenance diagram of Dickinson et al (1983). These diagram show that the QFL, have their provenance mainly from the suture belt, dissected arc and recycled orogen. These provenance studies are also supplemented with the study of heavy minerals and paleochannel clasts.

Provenance of Murree Formation

The petrographic study of sandstone of Murree Formation shows that these are mainly feldspathic litharenite, litharenite, sub litharenite and sub litharkose (Table 1). The provenance of the sandstones is recognized as a recycled orogen as well as dissected arc (Figure 5). The quartz is mainly monocrystalline (14-40%) and polycrystalline (3-12%). Some quartz grains show undulatory extinction. In thin sections of sandstone of Murree Formation polycrystalline quartz and undulatory quartz suggest a metamorphic source. The

Table 2 - Modal Percentage Composition of Sandstone of Kamlial Formation.

S. No.		Sample No.	Mon Q	Pol Q	Pl	Mcl	L	Ca	Mus	Bt	Tm	Clay Mineral	Zr	Ep	Gt	Ore Minerals	Classification	Provenance
																	(McBride,1963)	(Dickenson, *et al.*, 1983)
1	Upper part	**Kp**$_{14}$	35	10	02	01	17	09	01	01	04	--	--	05	01	14	Litharenite	Recycled Orogen
2		**Kp**$_{15}$	22	08	04	01	22	10	02	03	03	11	--	02	--	10	Litharenite	Recycled Orogen
3		**DD**$_{7}$	25	08	04	02	15	10	01	05	02	04	--	03	--	10	Feldspathic Litharenite	Recycled Orogen
4	Middle part	**DD**$_{5}$	36	15	04	02	15	20	01	01	01	--	--	01	01	04	Sub-Litharenite	Recycled Orogen
5		**Kp**$_{16}$	30	08	05	03	22	10	03	04	03	--	--	04	--	08	Feldspathic Litharenite	Recycled Orogen
6		**Kp**$_{17}$	09	06	05	02	32	22	05	05	02	--	--	03	01	08	Feldspathic Litharenite	Transitional arc
7	Lower part	**DD**$_{4}$	30	15	05	01	15	20	01	02	01	--	--	01	--	03	Sub-Litharenite	Recycled Orogen
8		**Kp**$_{18}$	25	08	04	01	20	30	02	02	02	--	--	02	01	03	Litharenite	Recycled Orogen
9		**Kp**$_{19}$	16	12	07	05	18	20	05	05	02	--	--	03	01	06	Feldspathic Litharenite	Recycled Orogen
10		**Kp**$_{20}$	15	05	05	02	25	15	05	05	03	05	--	04	01	10	Feldspathic Litharenite	Recycled Orogen

presence of microcline and plagioclase feldspars (4-18%) show that minor granitic basement rocks were uplifted and eroded during the deposition of Murree Formation. The lithic fragments (8-35%) are of metamorphic and sedimentary origin. The metamorphic clasts found in these rocks are slates, phyllites and quartz-mica schist. The presence of low grade metamorphic clasts in the sandstone of Murree Formation suggests that the detrital sediments of the Murree Formation were mainly derived from the low-grade metamorphic sequence of the orogenic belt in northwest margin of the Indian Plate. However, in some rocks few clasts of garnet mica schist were also observed which indicate that during the deposition of these sediments metamorphic rocks of garnet grade were exposed in the northern margin of the Indian plate. The traces of garnet grains are present in some samples. The presences of garnet grains also indicate that sedimentary material was eroded from the metamorphic rocks of northern margin of Indian plate. Therefore, sediments of the Murree Formation were derived from low-grade metamorphic and sedimentary sequence of the northern periphery of the Indian plate.

Provenance of Kamlial Formation

The sandstone of Kamlial Formation is characterized as feldspathic litharenite, litharenite and sub -litharenite (Table 2) and these are derived from recycled orogen (Figure 5). Quartz occurs as both monocrystalline grains (9-36%) and polycrystalline (5-15%) and some grains show undulatory extinction. In some thin sections of sandstone of Kamlial Formation, polycrystalline quartz of more than 5 individual crystals is present, which marks a metamorphic source. The feldspar includes plagioclase (2-7%) and microcline (1-5%), which are weakly cleaved and can be derived from both igneous and metamorphic sources. The lithics are of the metamorphic and sedimentary origin. The metamorphic clasts include slate, phyllite, chlorite mica-schist and biotite mica-schist. The sedimentary clasts include sandstone, siltstone and shale. These are sub rounded to rounded showing long distance of transportation from the source in the north. The tourmaline (1-3%) and epidote (1-4%) is increased in Kamlial Formation as compared to the Murree Formation. The tourmaline and epidote may be derived from plutonic and metamorphic rocks. This delineates that during the deposition of the Kamlial Formation, the more metamorphic and plutonic rocks eroded during the uplift of the Himalayan orogenic belt in the north.

SUMMARY AND CONCLUSION

The Khairi Murat area is a part of the active foreland-fold-and thrust belt of the Himalayas in northern Pakistan. The molasse sediments of Rawalpindi Group deposited during Miocene, which indicate that detritus of these deposits were derived from rising Himalayas. The provenance study of sandstones of Rawalpindi Group show that the detrital sediments were derived from the metamorphic, volcanic, plutonic and sedimentary rocks from the northern margin of the Indian Plate, Kohistan Island arc and Karakoram Ranges in northern Pakistan. The northern margin of Indian Plate shows a complete sequence of metamorphic rocks including low-grade metamorphic to upper amphibolites and eclogite metamorphic facies. The mineralogical analysis of heavy minerals of the molasse sediments helps to understand the depositional history, provenance and petrographic character of the source area. The heavy mineral suit present in molasse deposit of Khairi-Murat Dulla area consists of the opaque (hematite, magnetite), zircon, tourmaline, rutile, chlorite, garnet, hornblende and epidote. These heavy minerals also indicate that the sediments of molasse deposits were derived from metamorphic, plutonic, volcanic and sedimentary rocks of northern margin of Indian Plate, Kohistan Island arc and Karakoram Ranges. The sedimentary structures and petrographic studies show that the molasse sequence of Rawalpindi and Siwalik Groups were deposited in a subsiding foreland basin, foothill of Himalaya's fold-and-thrust belt under the conditions of rapid erosion and quick deposition. These deposits indicate fluviatile environment of deposition.

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