PETROGRAPHY AND GEOCHEMISTRY OF SANDSTONE OF THE KAMLIAL FORMATION, ISLAMABAD EXPRESSWAY SECTION, ISLAMABAD, PAKISTAN

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Department of Earth and Environmental Sciences

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APPROVAL FOR EXAMINATION

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DEDICATION

To my beloved parents and siblings

Acknowledgments

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ABSTRACT

The area of investigation is exposed along the Express Highway Islamabad near Korang Bridge. The Miocene Rawalpindi Group including the Kamlial and Murree formations and Quaternary deposits are exposed. The Kamlial Formation, which is the focus of this study contains abundant quartz, which is fractured and oriented as micro-lenses along with K-feldspar as microcline, micro-perthithe, orthoclase and sanidine, and albite to andesine plagioclase feldspar indicating felsic plutonic and volcanic rocks protoliths. Besides, the presence of pyroxenes and amphiboles also indicate mafic volcanic and or plutonic rocks source. Traces of garnet, epidote, chlorite, biotite, muscovite, vermiculite may show metamorphic origin of the clasts. The orientation of the grains and bending in mica indicates that the formation has undergone through deformation due to shearing. Based on geochemistry, the sandstone of the Kamlial Formation is mainly litharenite which shows fluvial depositional environment. It illustrates recycle oceanic island arc tectonic origin and provenance of Himalaya and Kohistan Island arc.

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LIST OF ABBREVIATION

MZT	-	Master degree Zaki and Tahseen
Q	-	Quartz
F	-	Feldspar
RF	-	Rock Fragment
Qz	-	Quartz
Bt	-	Biotite
Cal	-	Calcite
Ep	-	Epidote
Fsp	-	Feldspar
Opq	-	Opaque Mineral
Mag	-	Magnetite
Kfs	-	K-feldspar
Pl	-	Plagioclase
Grt	-	Garnet
SDFTB	-	South
NCEG	-	National Centre of Excellence in Geology
MBT	-	Main Mantle Thrust
MKT	-	Main Karakoram Thrust
SRT	-	Salt Range Thrust
SDFTB	-	Southern Deformed Fold and Thrust Belt
N	-	North
S	-	South
E	-	East
W	-	West
M	-	Miters
Km	-	Kilometer
XRD	-	X-Ray Diffraction
AAS	-	Atomic Absorption Spectroscopy

CHAPTER 1

INTRODUCTION

1.1 Background

Sandstone is a siliciclastic sedimentary rock which consists of quartz, feldspar and lithic fragments. The sandstones, which are the molasses deposits are essentially present in the Miocene Rawalpindi Group (Kamlial and Murree formations) that belong to sub-Himalaya of the Northwestern Himalayan fold and thrust belt. This belt is divided into Kohat-Bannu and Potwar sub-basins (Kadri, 1995; Raiverman, 2002).

The Miocene Kamlial Formation of the Rawalpindi Group crops out in Islamabad along Express Highway near Korang Bridge, Gulberg Housing Society (Fig. 1). It is bounded by latitudes 33º35´10” to 33º35´24” N and longitudes 73 º 8´ 34’’ to 73º 8´43’’E. The formation occurs on top of the Murree Formation and consists of intercalated sandstone, siltstone, shale and conglomerates (Shah et al., 2000; Shah, 2009). The Kamlial Formation has also been investigated in other parts of the country viz., in Kashmir Basin along the Kohala–Bagh road section, Muzaffarabad for zircon ages (Rehman et al., 2022), southwest Kohat plateau for paleoclimate and source lithology of the western Himalaya using petrographic and geochemical approach (Ullah et al., 2006, 2015) and kinematics and tectonic fractures at Khushalgarh area (Sayab and Jadoon, 2005). On the basis of petrographic study Khan et al. (2017) gave to the Kamlial Formation igneous origin for the source rock composition.

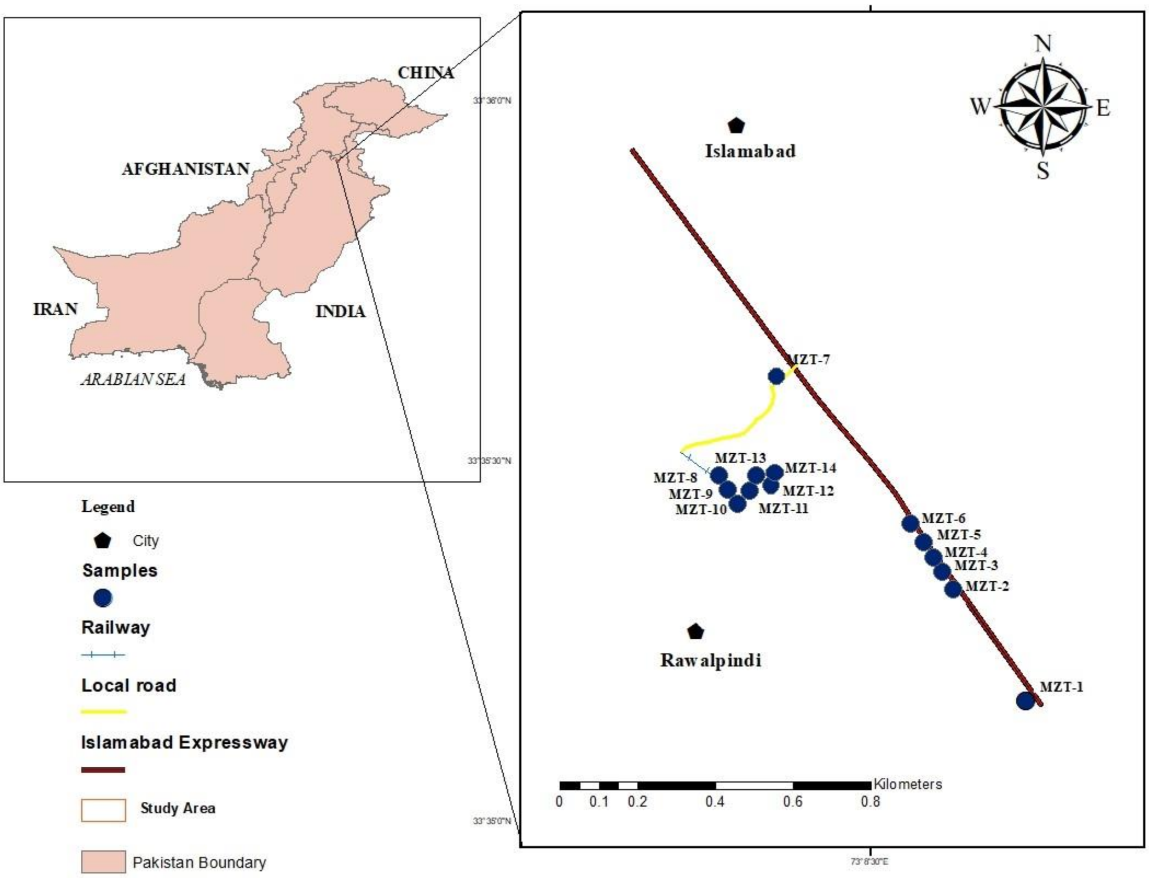


Figure 1.1 Sample location and accessibility map of the study area.

1.2 Previous work

The Kamlial Formation has been studied by many works in the past. Ullah, K. (2009) reported different lithofacies of the Kamlial Formation which were possibly deposited by sandy bed load or a major mixed load river. He also suggested that the characteristics of quartz in the Kamlial Formation is partly derived from medium and high grade metamorphic rocks, with little contribution from low grade metamorphics.

Rehman et al. (2022) presented for the first-time detrital zircon U-Pb geochronology supported with sandstone petrography of the middle to late Miocene Kamlial Formation to constrain the provenance and its implications for Himalayan exhumation in the western Himalayas, Pakistan. He also suggested that the sediments of the Kamlial Formation were mainly sourced from the Himalayan tectonostratigraphic zones.

Sayab and Jadoon (2005) reported that the sandstone of the Kamlial Formation in Khushalgarh, northern Pakistan underwent bedding-parallel extension during folding. He also reported that there are NE-SW trending fractures developed during folding and NW-SE fractures developed late in the folded history.

Khan et al. (2017) placed the sandstone of the Kamlial Formation as feldspathic lithwacke with mineralogical maturity (Q/F = 4.8). They also reported that the carbonates are the major cementing material.

1.3 Aims and objectives

This study aims to conduct petrological study including petrography and geochemistry on sandstones of the Kamlial Formation for knowing its source composition and the environment of deposition, which has not been done in the proposed area of investigation in the past.

1.4 Methodology

1.4.1 Field work

Field work was carried out along the Islamabad Express Highway near Korang Bridge area to study the Kamlial Formation (Fig. 1.1). A total of 15 rock samples of sandstone unit were collected for petrographic and geochemical studies. Among these 15 rock samples, 14 were selected for thin-section preparation and 5 for geochemical analysis.

1.4.2 Laboratory work

Five samples were selected for Atomic Absorption and XRD analysis. Thin-section preparations were carried out in Pakistan National Museum of Natural History, Islamabad. The Atomic Absorption and XRD analyses were performed in National Center of Excellence in Geology, University of Peshawar and the Institute of Earth and Applied Sciences, University of Sindh, Jamshoro.

CHAPTER 2

GEOLOGICAL SETTING AND STRATIGRAPHY

2.1 Regional geological and tectonic setting

Pakistan lies in a region where Indian, Arabian and Eurasian continental plates are exposed. Due to collisional tectonics between the Indian and the Asian continental plates, the Himalayan mountain chain formed. The Himalaya mountain chain comprises Sub Himalaya, Lesser Himalaya, and Higher Himalaya (Burrard and Hayden, 1908). There are three regional faults, viz., the Main Central Thrust (MCT), Main Boundary Thrust (MBT) and Salt Range Thrust (SRT) present in between these tectonic regimes of the Himalayan region. Based on distinctive physiography and stratigraphy, these faults further divide the northern montane area into five litho-tectonic belts as shown in the (Fig. 2.1). These geological belts from north to south include Karakorum micro-continental plate, Kohistan- Ladakh island arc, Northern and Southern Deformed Fold Thrust belts and Punjab foredeep (Ahmad, 2004).

As the investigated area lies in Southern Deformed Fold and Thrust belt (SDFTB) of the Sub Himalaya, therefore, only the SDFTD is discussed in the following paragraphs.

2.1.1 Southern Deformed Fold and Thrust Belt (SDFTB)

The SDFTB constitutes early Miocene age syn-orogenic thick deposit of fluvial sediments in east-west orientation Deposition of syn-orogenic sedimentation took place in this belt in Early Miocene. The Potwar sub-basin is part of SDFTB which is present to the east and Kohat and in the Trans Indus ranges. The deformation in the Potwar sub-basin is restricted to ~ 150 km wide zone in north south direction (Kazmi and Rana, 1982) (Fig. 2.1). In the south of

SDFTB, Salt Range Thrust is present and to the north it is surrounded by Hazara Kalachitta Ranges (Leather, 1987; Baker et al., 1988).

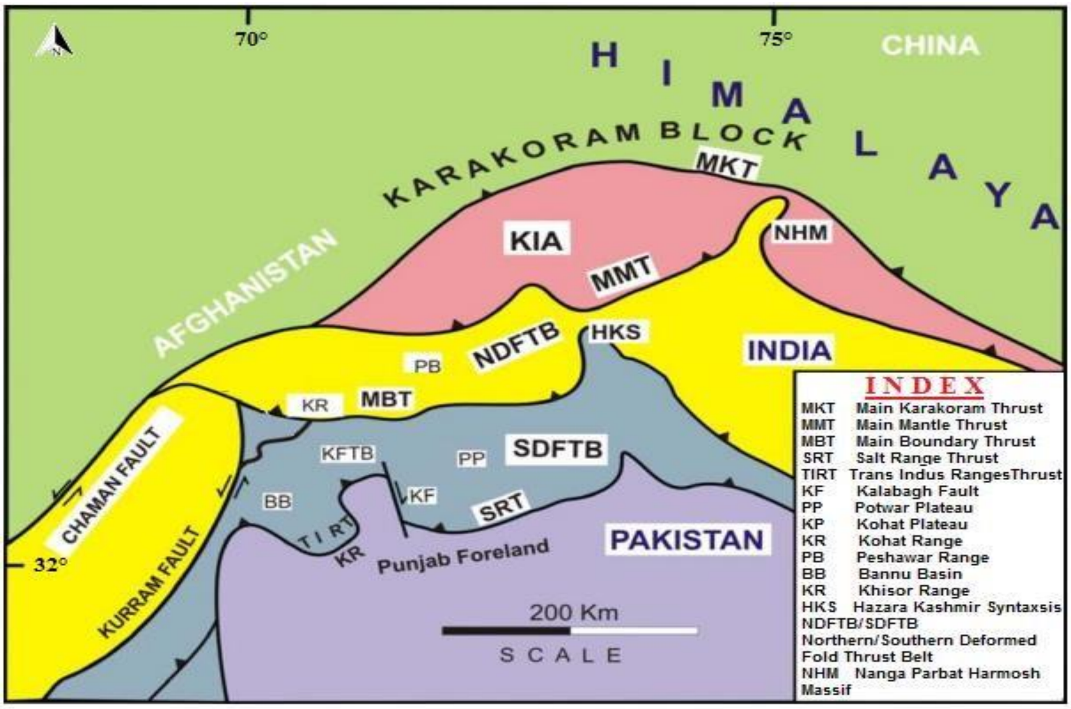


Figure 2.1. Tectonic map demonstrating major structural features of northern Pakistan (Kazmi and Rana, 1982).

Kohat sub-basin delineates the SDFTB towards west. In late Miocene, there is a southward advancement of deformation in the area. In the north of Kohat sub-basin, MBT is exposed thus bringing heavily distorted Mesozoic sedimentary rocks exposed in Kohat Range over the Eocene-Miocene sediments of Kohat sub-basin (e.g., Yeats and Hussain, 1987).

2.2 Stratigraphy of the Rawalpindi Group

The Rawalpindi Group represents Miocene-Pliocene foreland basin succession of molasse deposits exposed in the Potwar Plateau region of Pakistan. The group is divided into Murree and Kamlial formations. These formations can be exposed in many parts of the country such as; Potwar, Hazara and Kashmir areas, while only Kamlial Formation thins out to the south and exposes in Salt and Surghar ranges (Ullah, 2009).

2.2.1 Murree Formation

The Murree Formation is the lower of the two formations, and comprises interbedded sandstone, shale and conglomerate. The sandstone is typically coarse to medium grained, and is often reddish or purplish. The shale is typically gray or green, and is often micaceous. The conglomerate contains clasts of a variety of rock types, including quartz, quartzite, and limestone. The Murree Formation deposited in fluvial, lacustrine, and deltaic environments. The presence of red beds suggests that the climate was arid or semi-arid during deposition (Yar et al., 2021). This stratum in the research area contains conjugate joints with strike and dip of N70ºE 80ºSW and intraformational conglomerate in between sandstone (Fig.2.2).

Figure 2.2 Field photographs showing conjugate joints in the sandstone within Murre Formation.

2.2.2 Kamlial Formation

The Kamlial Formation is younger to the Murree Formation and overlies on it. This formation comprises medium to fine grained sandstone, and siltstone, mudstone, shale and conglomerate. The sandstone is typically greenish, and the shale is light maroon. The siltstone is often laminated and contains fossils of plants and insects. The Kamlial Formation is considered fluvial, lacustrine, and floodplain deposit. The presence of plant and insect fossils suggests that the climate was more humid during deposition (Rehman, 2008).

A shear zone of shale marks the contact between the Kamlail and Murree formations along Islamabad Expressway near Korang Bridge (Fig. 2.4). Structures such as cross bedding, graded bedding and conjugate joints are seen (Fig. 2.5 A and B). In the study area, the rock units strike N70E and dip 75 to 85 SE. Local variations in the strike and dip are recorded. Here, the Kamlial Formation lies below the Murree Formation due to overturned plunging fold. The folded structure is quite visible in the Murree Formation exposed in the area of investigation (Fig. 2.5.C).

Figure 2.3 Field photography showing Contact of Kamlial Formation with Murree Formation along Islamabad Expressway near Korang bridge.

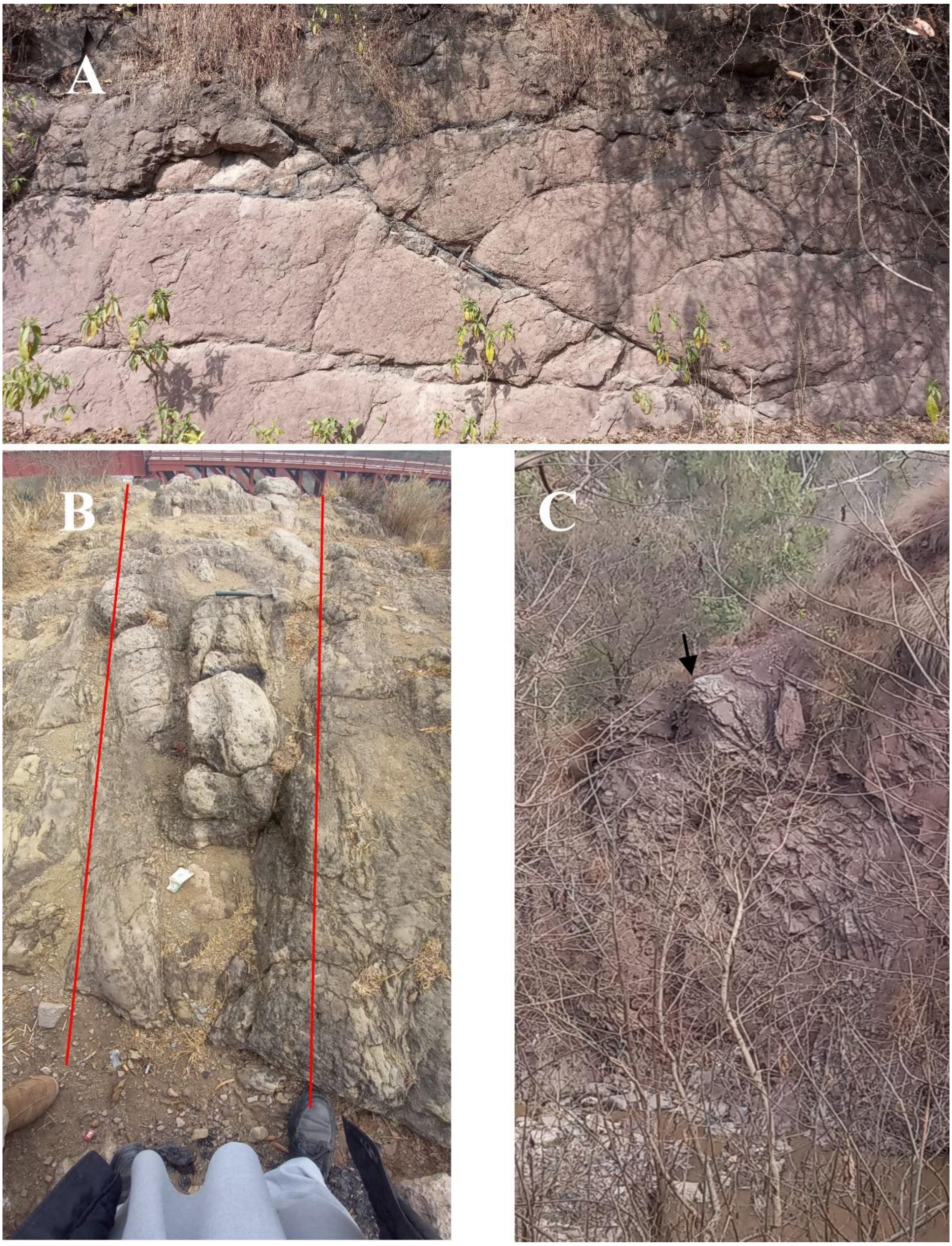


Figure 2.4 Field photography showing (A) Conjugate joints in the sandstone bed, (B) Cross bedding and truncation of conglomeratic beds in the Kamlial Formation, (C) Anticlinal fold (black arrow) and shear zone within the Murree Formation.

2.3 Stratigraphic relationship

The Murree Formation overlies the Surghar Group, a succession of marine limestone and dolomite deposited during the Paleocene and Eocene epochs. The contact between the two formations is a disconformity, indicating a period of non-deposition or erosion. The Kamlial Formation overlies the Murree Formation, and is unconformably overlain by the Quaternary deposits such as the Potwar clay. The unconformity indicates a period of uplift and erosion prior to deposition of the Quaternary deposits. The geological succession with brief description of each rock units is given below (Table 2.1; Fig. 2.6).

Table 2.1: Generalized stratigraphic column of the Rawalpindi area Potwar Plateau region, (after Iqbal et al. (2007). Shaded bands mark stratigraphic gaps (unconformities)

AGE	**GROUP**	**FORMATION**	**LITHOLOGY**
MIOCENE	Siwalik	Nagri	Sandstone and subordinate claystone and conglomerate
		Chinji	Claystone and sandstone
	Rawalpindi	Kamlial	Calcereous sandstone and claystone
		Murree	Sandstone, siltstone and claystone
OLIGOCENE UNCONFORMITY			
EOCENE	Charrat	Kuldana	Marine and continental claystone, marl, limestone, and minor sandstone

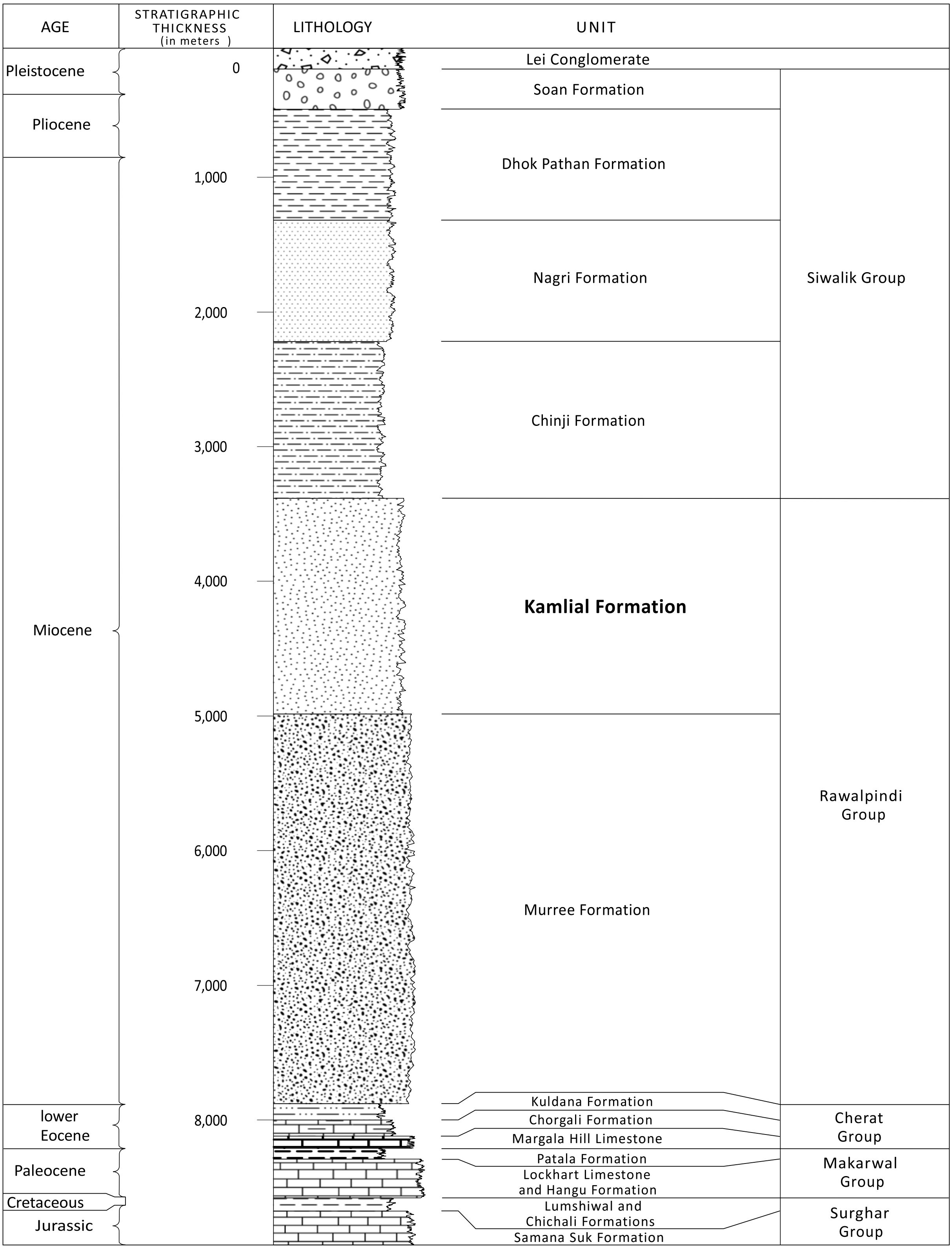


Figure 2.5 Stratigraphic chart of the Siwalik Group including the Murree and Kamlial Formations (after Warwick et al., 2007).

In the area of investigation, the Murree Formation is underlain by the Kamlial Formation with nearly vertical dip and overlain by the Potwar clay. About 300 m long east-west cross section shows (Fig. 2.7) lithological variation in the Murree Formation, which was previously reported as the Kamlial Formation (Hussain et al., 2000).

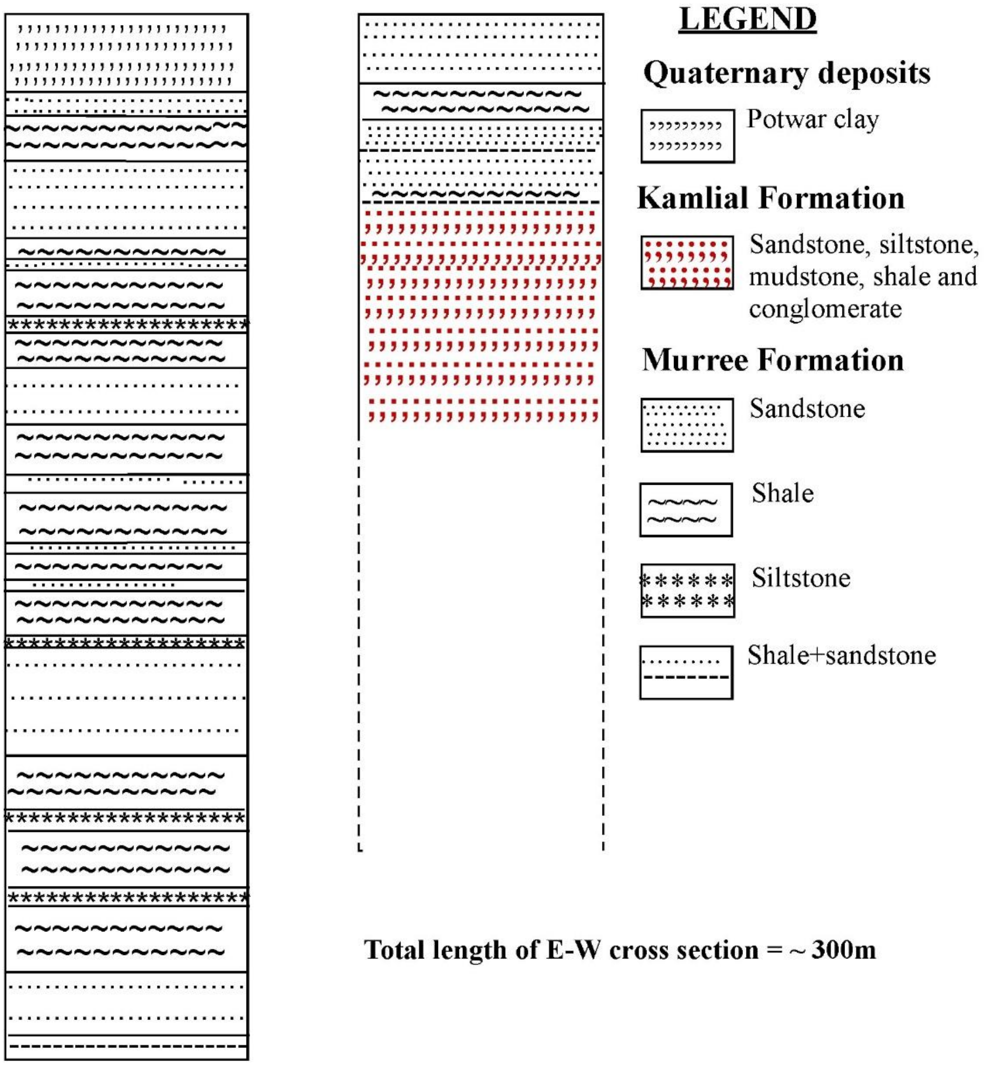


Figure 2.6 Roadside east-west cross section of the out crop along the Islamabad Express Highway near Korang Bridge, Islamabad

CHAPTER 3

PETROGRAPHY

3.1 Petrographic description

Petrography deals with the study of rocks in thin sections for the identification of minerals, texture and history of mineralization, sedimentation, metamorphism and deformation. Here, the petrography of sandstone is meant to determine the tectonic settings and the environment of deposition on the basis of quartz, feldspar, rock fragments, and cement and accessory minerals. The following paragraphs highlight the composition of the sandstones from both the Kamlial and Murree formations.

3.2 Petrographic analysis

Petrographic work has been done on 14 rock samples (six from Murree Formation from MZT-1 to MZT-6) and eight from Kamlial Formation from MZT-7 to MZT-14) whose volume percentages are listed in Table 3.1. The observations recorded are given below.

3.2.1 MZT-1

The rock is inequigranular fine to medium grained and well to moderately sorted. Quartz is anhedral to subhedral, fractured, and abundant (Fig. 3.1). It is composed of both monocrystalline and polycrystalline quartz. Monocrystalline quartz exceeds in volume as compared to the polycrystalline quartz (Fig. 3.1). K-feldspar is microcline and perthite. Rock fragments are visible. Chlorite and zircon are in minor concentration. Other accessory minerals include muscovite, biotite, opaque, garnet and amphibole. Cementing material is ferruginous clay.

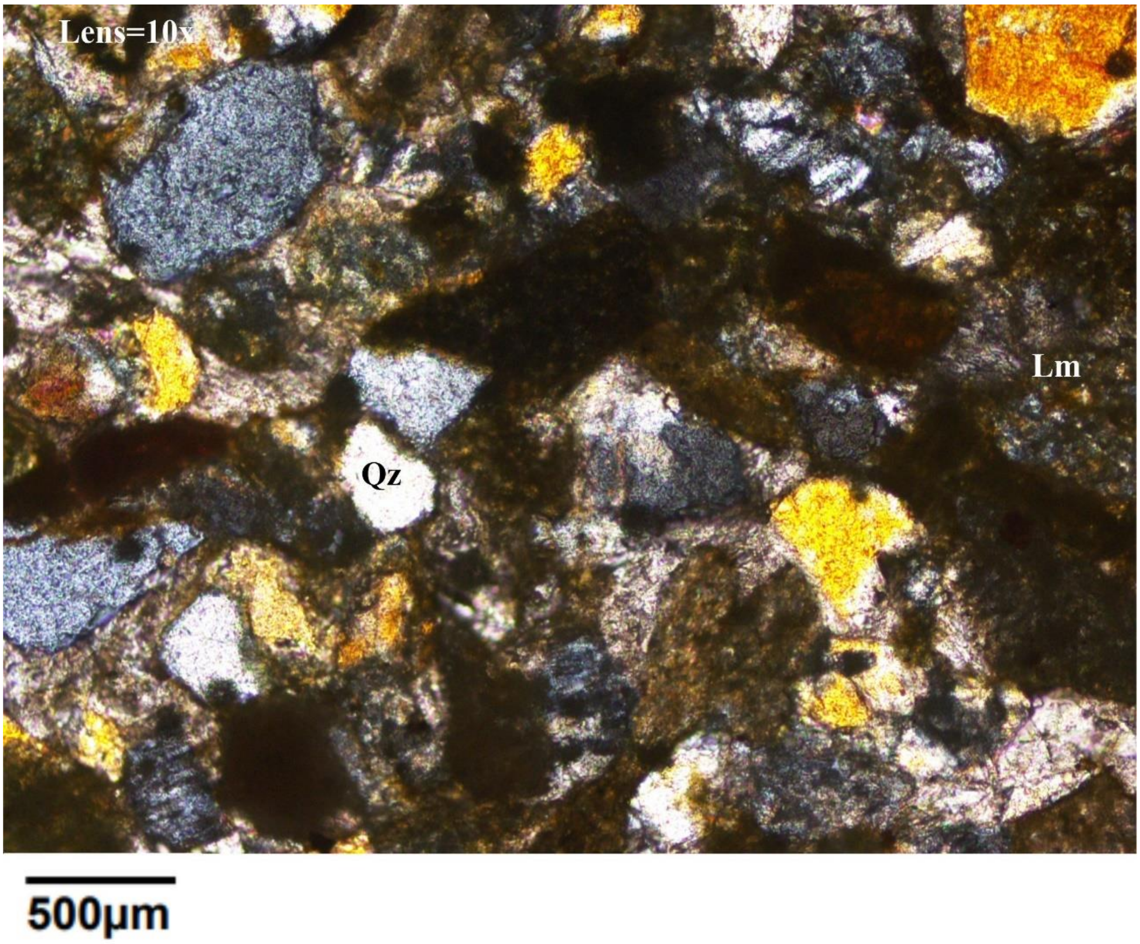


Figure 3.1 Photomicrograph showing quartz (Qz) and metamorphic lithic fragment (Lm) in crossed polarized light. Mineral abbreviations are after Whitney and Evans (2010).

3.2.2 MZT-2

The sandstone is medium grained, granular and well sorted (Fig. 3.2). Monocrystalline and polycrystalline quartz are seen. Quartz grains are anhedral and subhedral. Monocrystalline quartz is more abundant as compared to polycrystalline quartz. Microcline potash feldspar is observed. Rock fragments are also found abundantly. Clay is the cementing material while ground mass of calcite is found in minor. Other minerals include plagioclase, muscovite, biotite and chlorite. Traces of sericite and opaque minerals are also found.

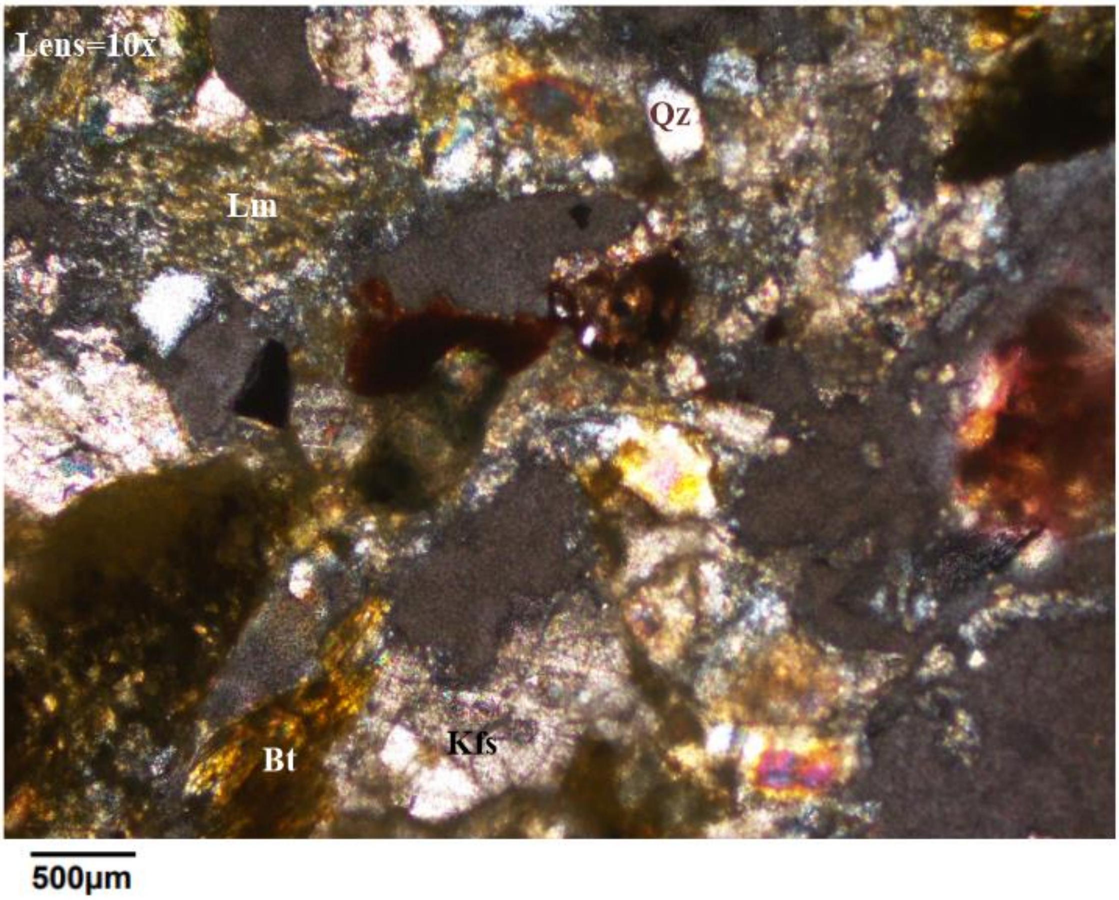


Figure 3.2 Photomicrograph showing quartz (Qz) potassium feldspar (Kfs) biotite (Bt) and metamorphic lithic fragments (Lm) in crossed polarized light

3.2.3 MZT-3

The rock sample is inequigranular fine - to medium grained, well to moderately sorted and partially oriented in one direction. Quartz is anhedral to subhedral, fractured, oriented and abundant (Fig. 3.3). It is composed of both monocrystalline and polycrystalline quartz. The ratio of monocrystalline is more than the polycrystalline quartz. Microcline feldspar is observed in less proportion comparatively to the rock fragment. Chlorite and zircon are rare and sericitization is more. Other minerals include muscovite, biotite, opaque and amphibole. Cementing material is clay (Fig. 3.3).

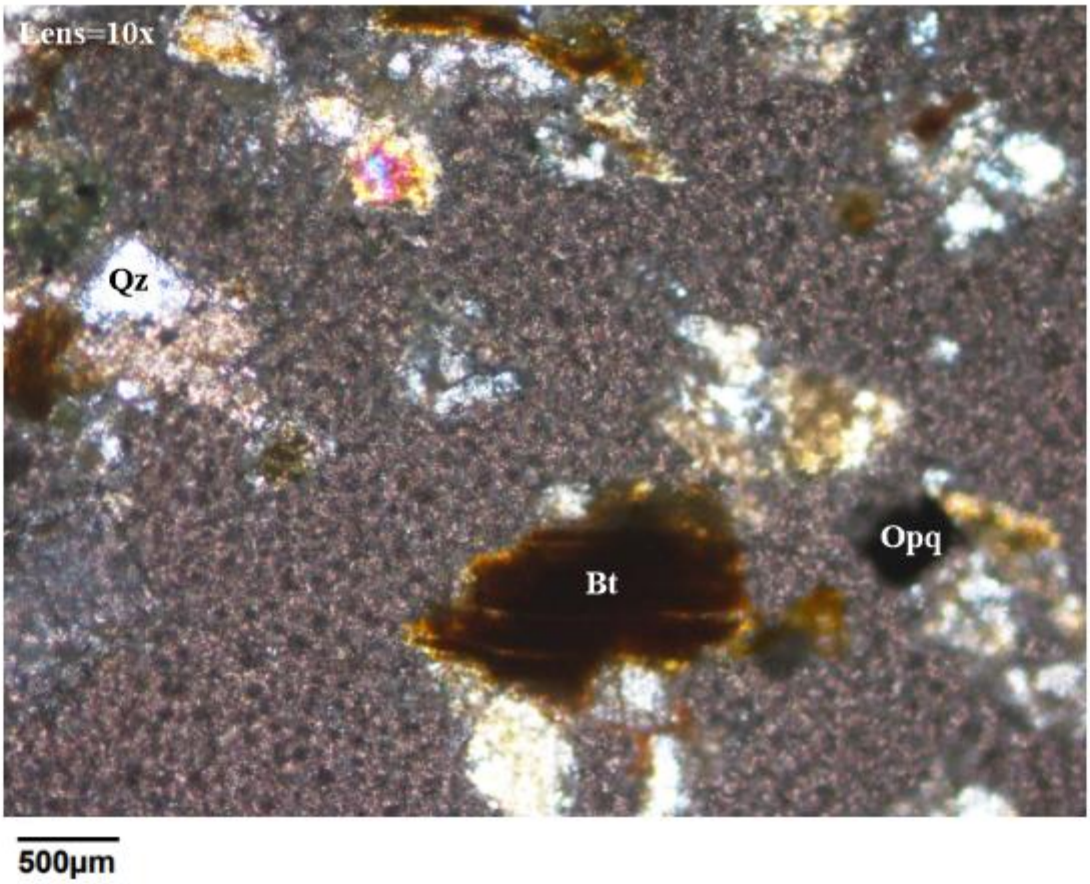


Figure 3.3. Photomicrograph showing quartz (Qz), biotite (Bt), and opaque mineral (Opq) in crossed polarized light. The cementing material is clayey substance.

3.2.4 MZT-4

The rock is medium grained, well sorted, oriented and deformed. Quartz is found both monocrystalline and polycrystalline which are anhedral to subhedral (Fig. 3.4). Quartz is fractured, and oriented. Monocrystalline quartz is more common than polycrystalline quartz. Potassium feldspars are microcline and micro-perthite. Lithic fragments are more abundant. In this sample calcite is acting as the cementing material. Folded muscovite and biotite are observed. Other minerals include zircon, opaque and sericite which occur in trace amount.

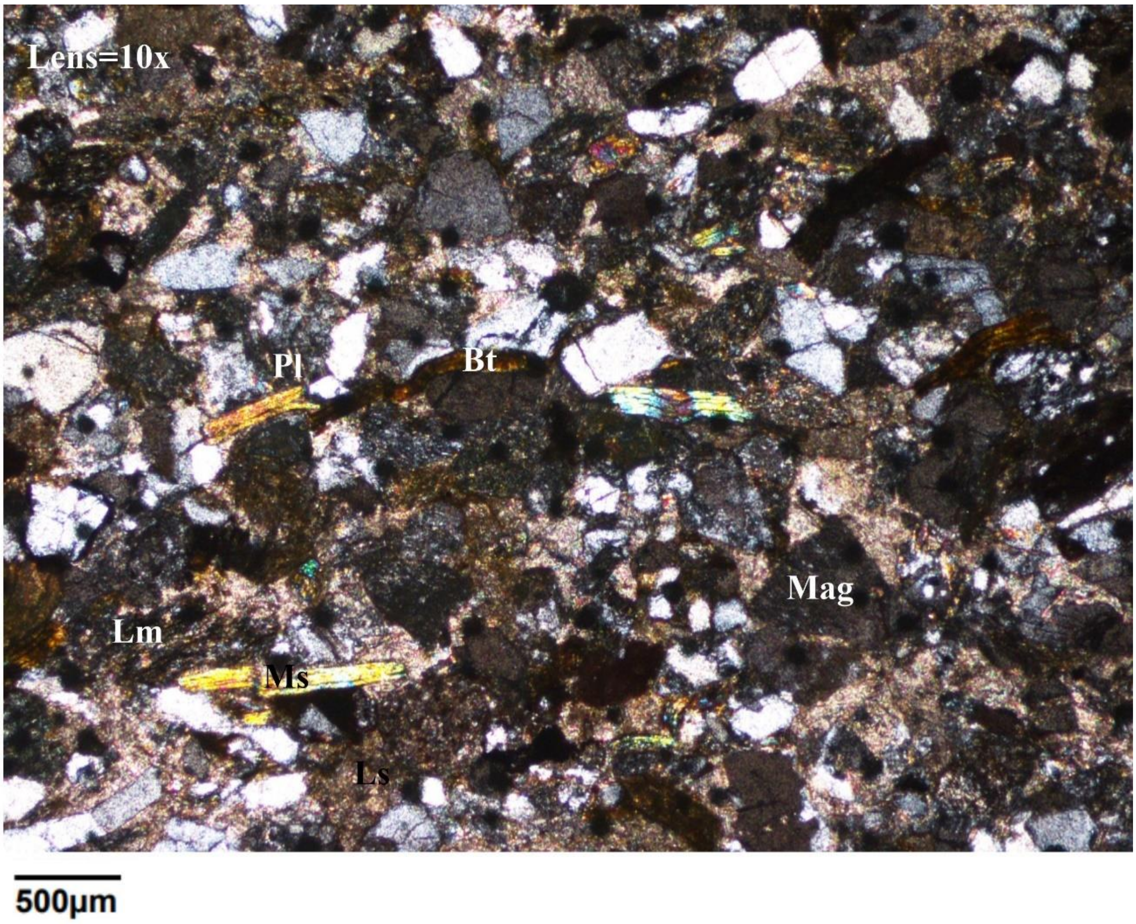


Figure 3.4 Photomicrograph showing biotite (Bt), muscovite (Ms), magnetite (Mag), plagioclase (Pl) and metamorphic lithic fragments (Lm) in crossed polarized light

3.2.5 MZT-5

The rock is medium to fine grained and poorly sorted. Quartz is found as both monocrystalline and polycrystalline which are partly oriented (Fig. 3.5). The amount of monocrystalline is more than the polycrystalline quartz. Rock fragments and microcline feldspar are observed. Traces of clinopyroxene are also seen. Clay is the cementing material. Other accessory minerals include chlorite and opaque minerals.

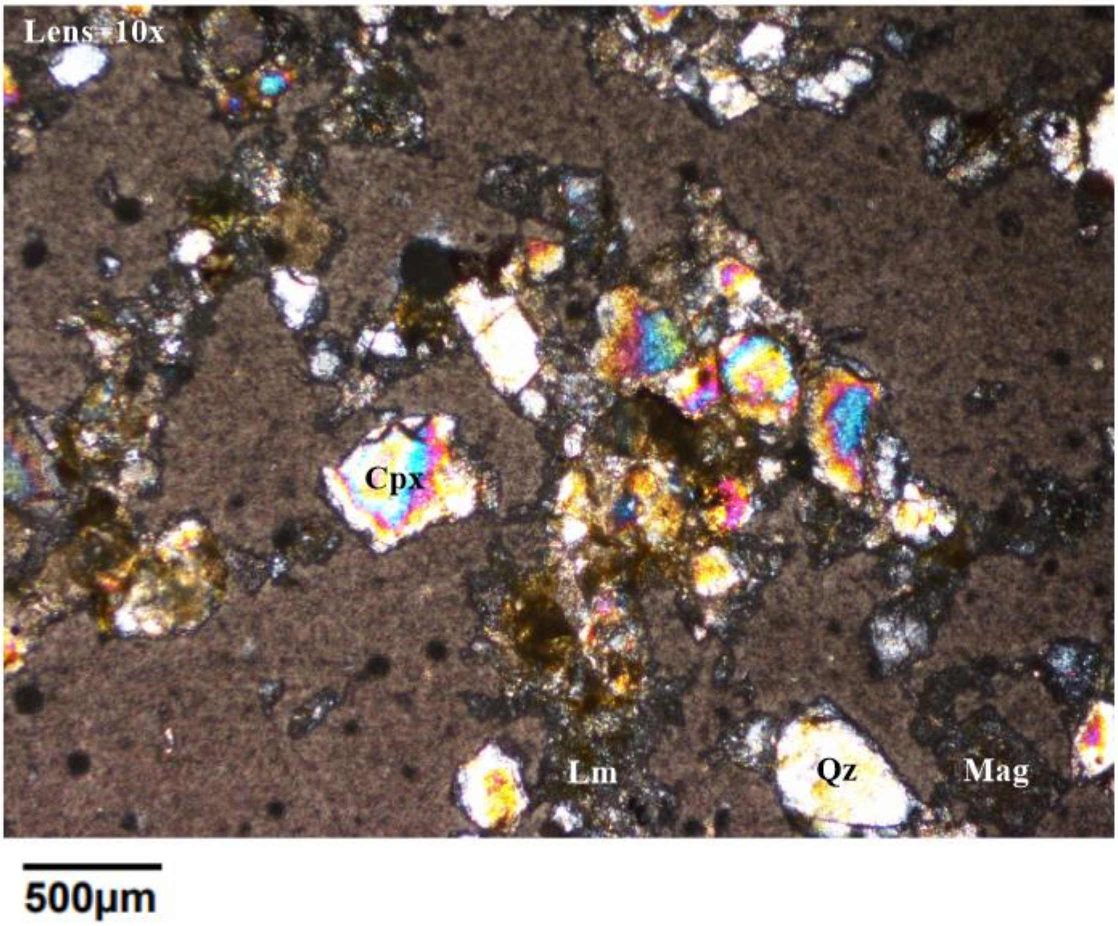


Figure 3.5. Photomicrograph showing quartz (Qz), clinopyroxene (Cpx), magnetite (Mag) and metamorphic lithic fragments (Lm) in crossed polarized light.

3.2.6 MZT-6

The sample is medium grained and poorly sorted (Fig. 3.6). Quartz is found as both monocrystalline and polycrystalline. Quartz is abundant, fractured, and oriented. Monocrystalline quartz is more common than polycrystalline quartz. Potassium feldspar microcline feldspar. Lithic fragments are common. In this sample clay and hematite are acting as cementing material. Biotite and muscovite are also observed and deformed. Other accessory minerals include zircon, opaque and sericite which is observed as trace.

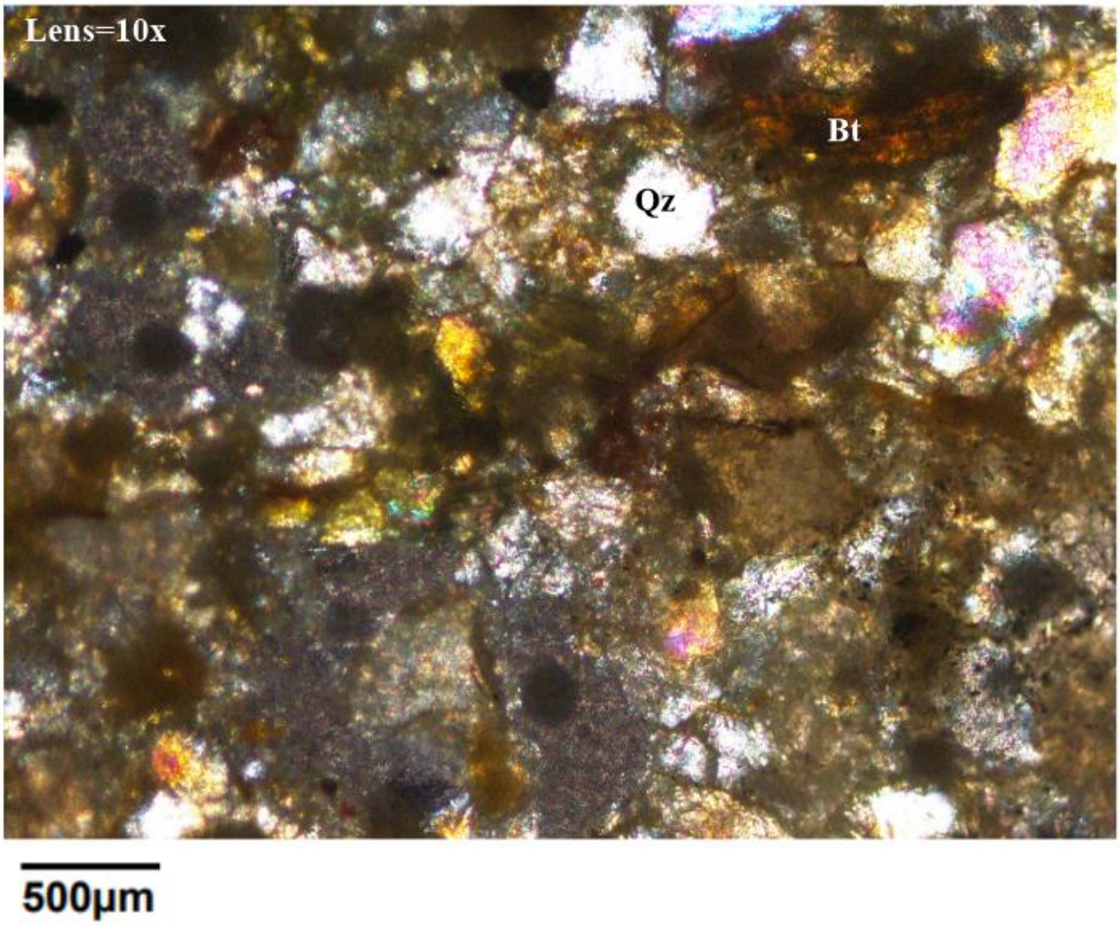


Figure 3.6 Photomicrograph showing quartz (Qz) and bended biotite (Bt) in crossed polarized light

3.2.7 MZT-7

The rock is medium grained, inequigranular, partially oriented and poorly sorted (Fig. 3.7). Quartz is seen abundantly in both microcrystalline and polycrystalline. Monocrystalline quartz is more common. Potassium feldspar is seen as a microcline. Lithic fragments are also present. Epidotes and tourmaline are observed. Calcite acts as matrix and ground mass while clay is the cementing material. Other accessory minerals include glauconite, zircon, chlorite, sericite, and iron oxide bearing minerals.

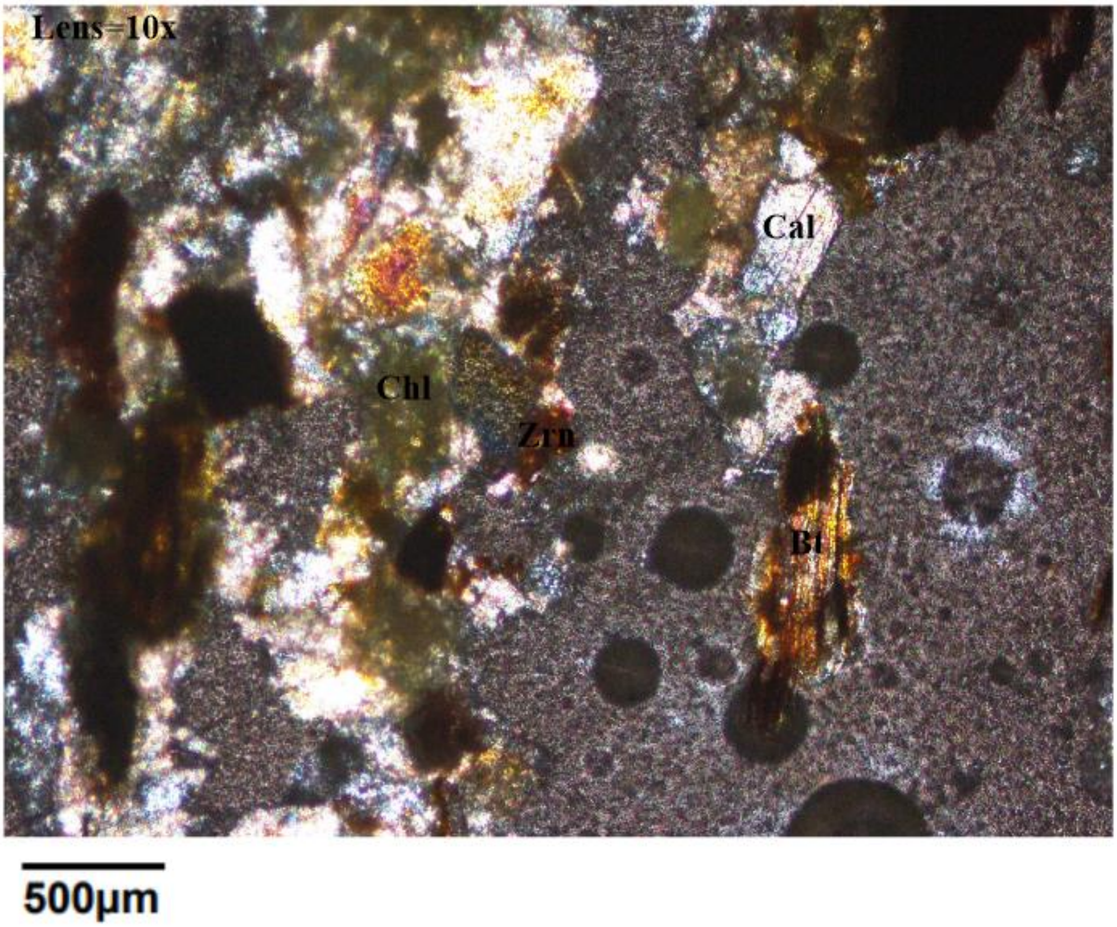


Figure 3.7 Photomicrograph showing chlorite (Chl), zircon (Zrn), calcite (Cal) and biotite (Bt) in crossed polarized light

3.2.8 MZT-8

This sandstone is coarse to medium grained and inequigranular (Fig. 3.8). The rock is also fractured and microfractures are occupied with calcite. Quartz is the dominant mineral, and it is found as monocrystalline and polycrystalline. Boundaries of quartz are very sharp. Microcline feldspar is partially altered into sericite and appears brown. Rock fragments are in more proportion compared to feldspar. Mica minerals including biotite and muscovite are observed. Mostly these are bent. Other minerals include ferruginous and opaque minerals. Calcite is found in matrix as well as ground mass, while clay is found as the cementing material.

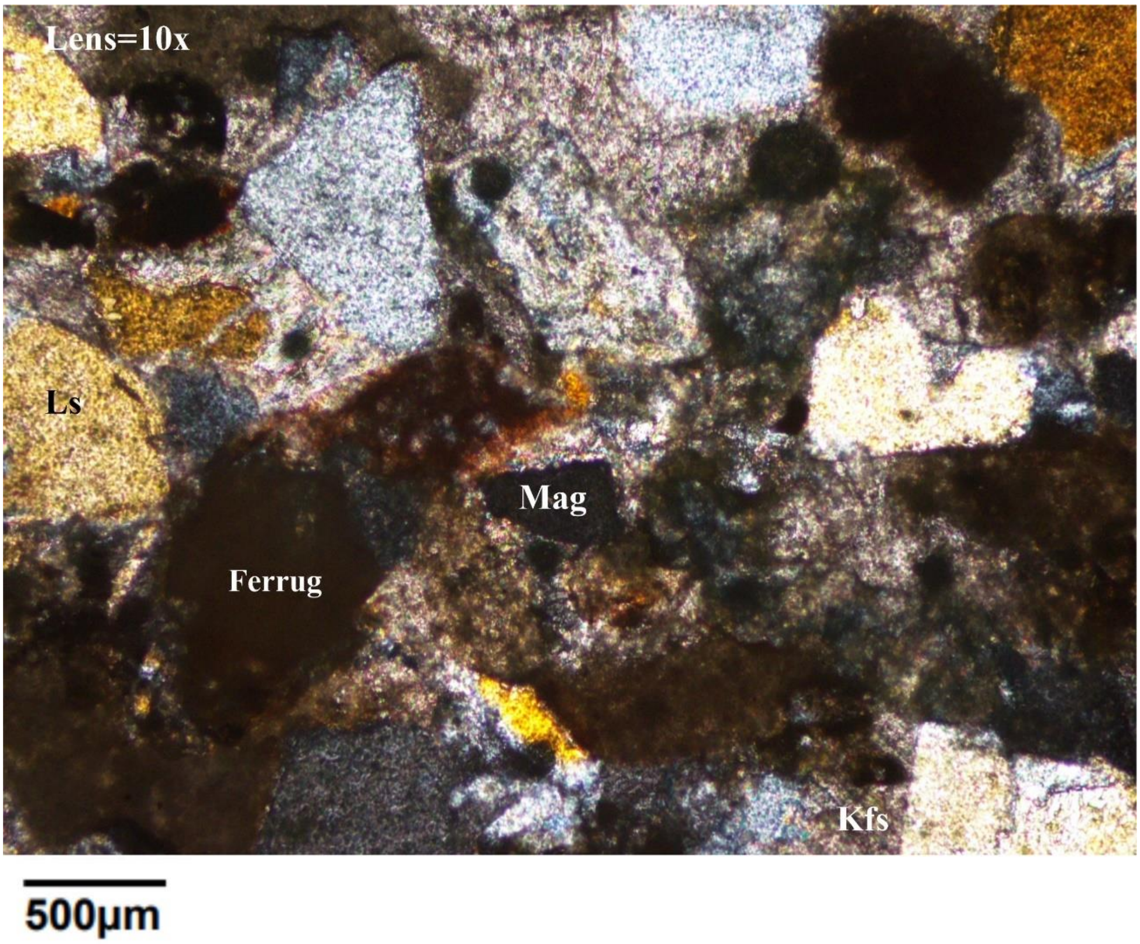


Figure 3.8 Photomicrograph showing potassium feldspar (Kfs) magnetite (Mag), ferruginous material (Ferru) and sedimentary lithic fragments (Ls) in crossed polarized light

3.2.9 MZT-9

The rock is coarse grained and inequigranular. Quartz is anhedral and the common mineral (Fig. 3.9). Quartz occurs as monocrystalline and polycrystalline. Both microcline and perthitic feldspar are observed which are partially altered into sericite. Rock fragments are common compared to feldspar. Folded biotite and muscovite are seen. Other accessory minerals include: epidote, chlorite, zircon traces and opaque minerals. The rock contains clay as ground mass and calcite as cementing material.

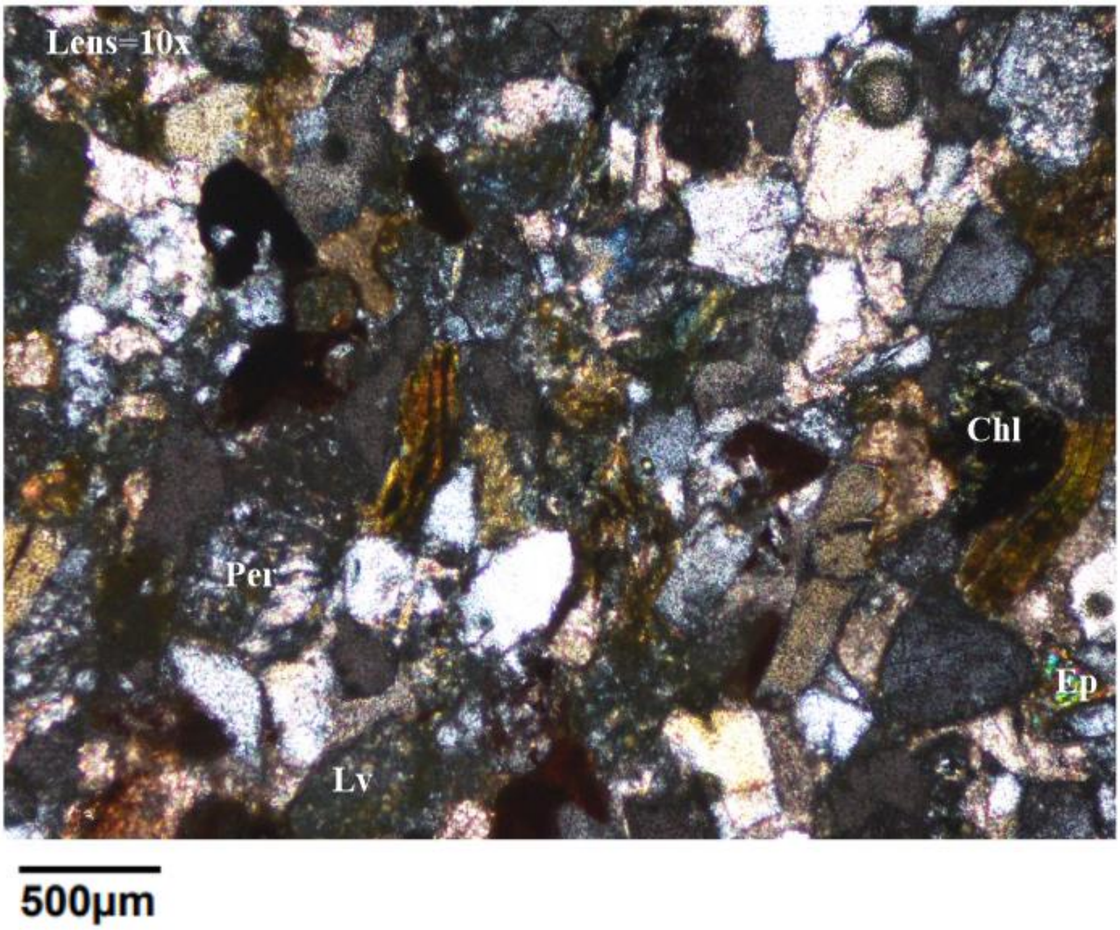


Figure 3.9 Photomicrograph showing epidote (Ep), perthite (Per), chlorite (Chl), and volcanic lithic fragments (Lv) in crossed polarized light

3.2.10 MZT-10

The rock is inequigranular fine to medium grained, poorly sorted and partially oriented in one direction (Fig. 3.10). Quartz is anhedral to subhedral, fractured, oriented and abundant. It is composed of both monocrystalline and polycrystalline quartz. The amount of monocrystalline is more than the polycrystalline quartz. Microcline feldspar is observed in less proportion comparatively to the rock fragments. Chlorite and zircon are minor and sericitization is intense. Muscovite and biotite are bent. Other accessory minerals include epidote, opaque and ± garnet. The sandstone contains more matrix of clay and it is also the cementing material.

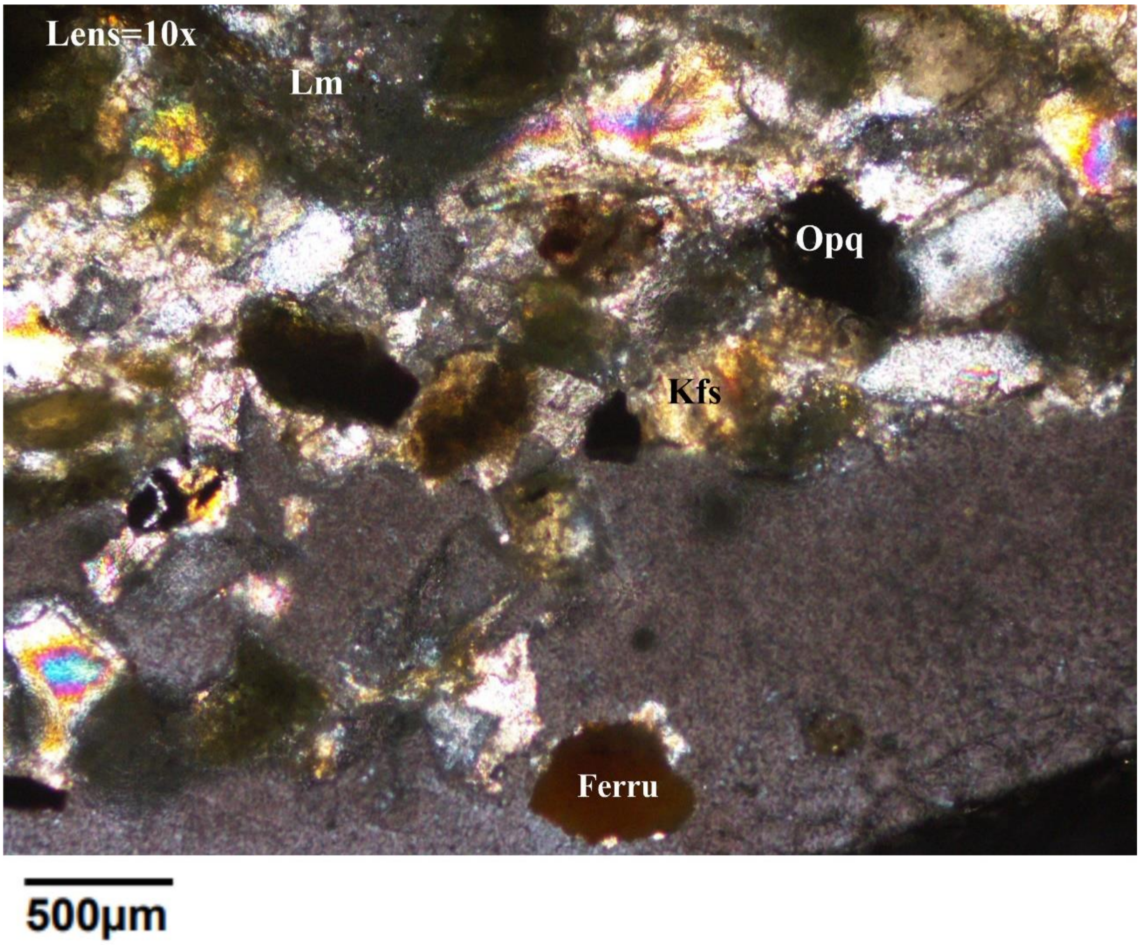


Figure 3.10 Photomicrograph showing potassium feldspar (Kfs), ferruginous material (Ferru), opaque mineral (Opq) and metamorphic lithic fragments (Lm) in crossed polarized light

3.2.11 MZT-11

The rock is medium to coarse grained, inequigranular, well sorted and partly oriented. Quartz is found as monocrystalline and polycrystalline which are angular to subhedral fractured, and oriented (Fig. 3.11). Monocrystalline quartz is more common than polycrystalline quartz. Potassium feldspar occurs as microcline and micro-perthite. Lithic fragments are more abundant than potash feldspar. In this sample calcite is acting as cementing material. Folded muscovite and biotite are observed. Other accessory minerals include zircon, opaque and sericite.

Figure 3.11 Photomicrograph showing quartz (Qz), muscovite (Ms), plagioclase (Pl), metamorphic lithic fragments (Lm) and volcanic lithic fragments (Lv) in crossed polarized light

3.2.12 MZT-12

The rock is medium to fine grained, poorly sorted and inequigranular. Quartz is the common mineral with no orientation (Fig. 3.12). Monocrystalline quartz is more abundant as compared to polycrystalline quartz. Potassium feldspar occurs microcline and micro-perthite. Lithic fragments are more abundant than potash feldspar. Clay is acting as matrix as well as cementing material. Other minerals include biotite, muscovite, traces of zircon, epidote, and opaque minerals.

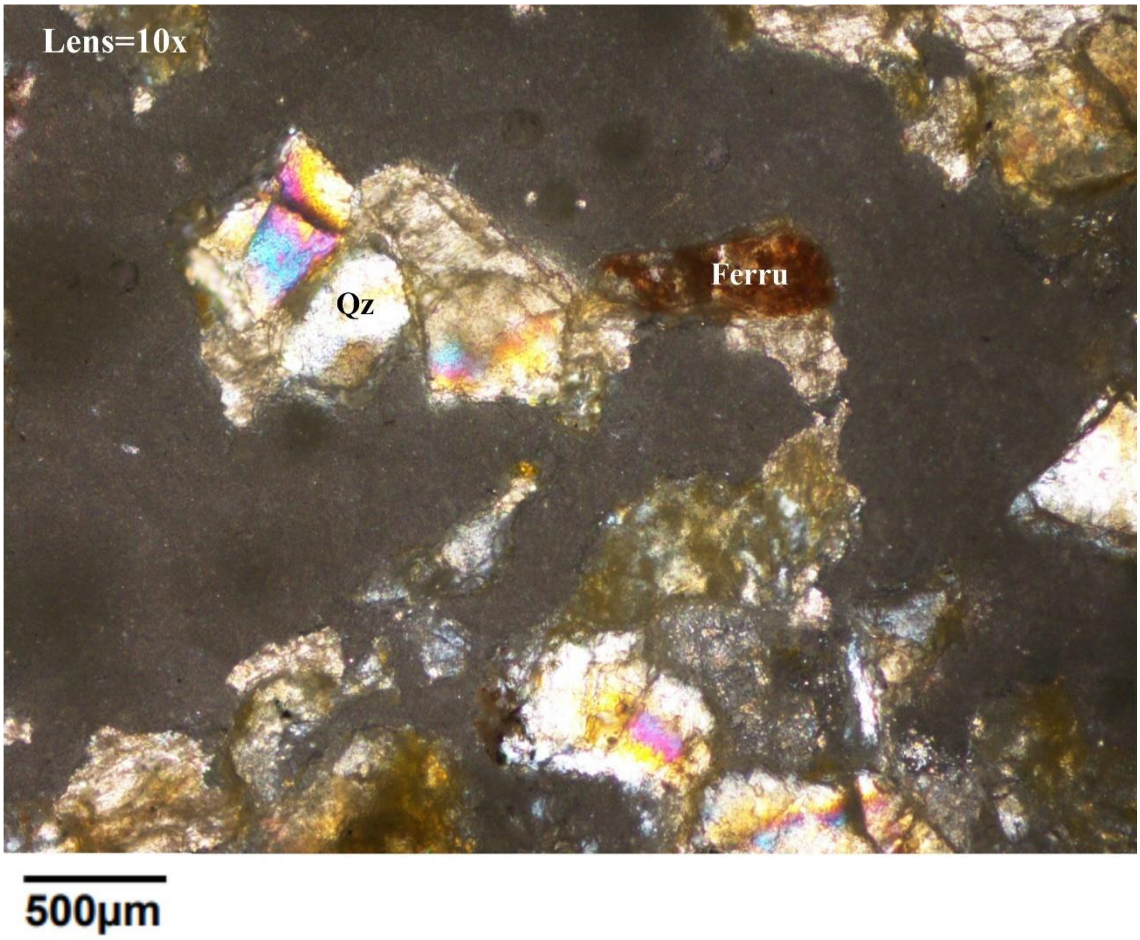


Figure 3.12 Photomicrograph showing quartz (Qz) and ferruginous material (Ferru) in crossed polarized light

3.2.13 MZT-13

The rock is medium grained, inequigranular, well sorted and oriented. Quartz is found as both monocrystalline and polycrystalline, which are anhedral to subhedral (Fig. 3.13). Quartz is abundant and fractured. Monocrystalline quartz is more common than polycrystalline quartz. Potassium feldspar occur as microcline and micro-perthe. Lithic fragments are more abundant than potash feldspar. Clay is acting as the cementing material. Other minerals include epidote, chlorite, muscovite, biotite, and opaque minerals.

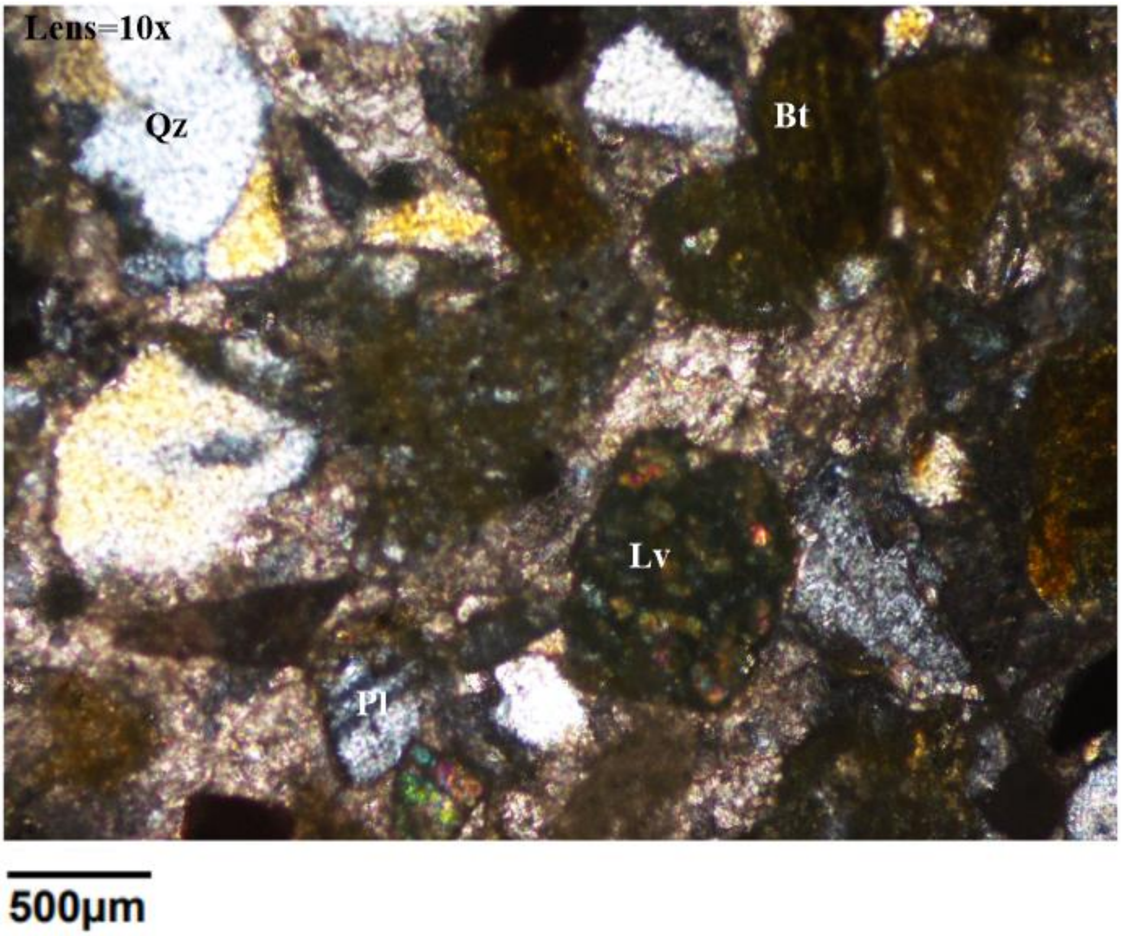


Figure 3.13 Photomicrograph showing quartz (Qz), biotite (Bt), plagioclase (Pl) and volcanic lithic fragments (Lv) in crossed polarized light.

3.2.14 MZT-14

The sandstone shows fine to medium grained, inequigranular, and well sorted (Fig. 3.14). It contains anhedral to subhedral quartz which are fractured and oriented. Both monocrystalline and polycrystalline quartz are noticed but monocrystalline quartz is more abundant. Potassium feldspar is microcline and micro-perthite. Rock fragments are more abundant than potash feldspar. Clay is acting as ground mass. Plagioclase is mainly altered into sericite and a few fresh grains are noticed showing albite twining. Muscovite flakes are presented which are oriented in one direction. Biotite and chlorite are also present but in minor amounts. Other minerals include epidote, zircon traces, and opaque minerals.

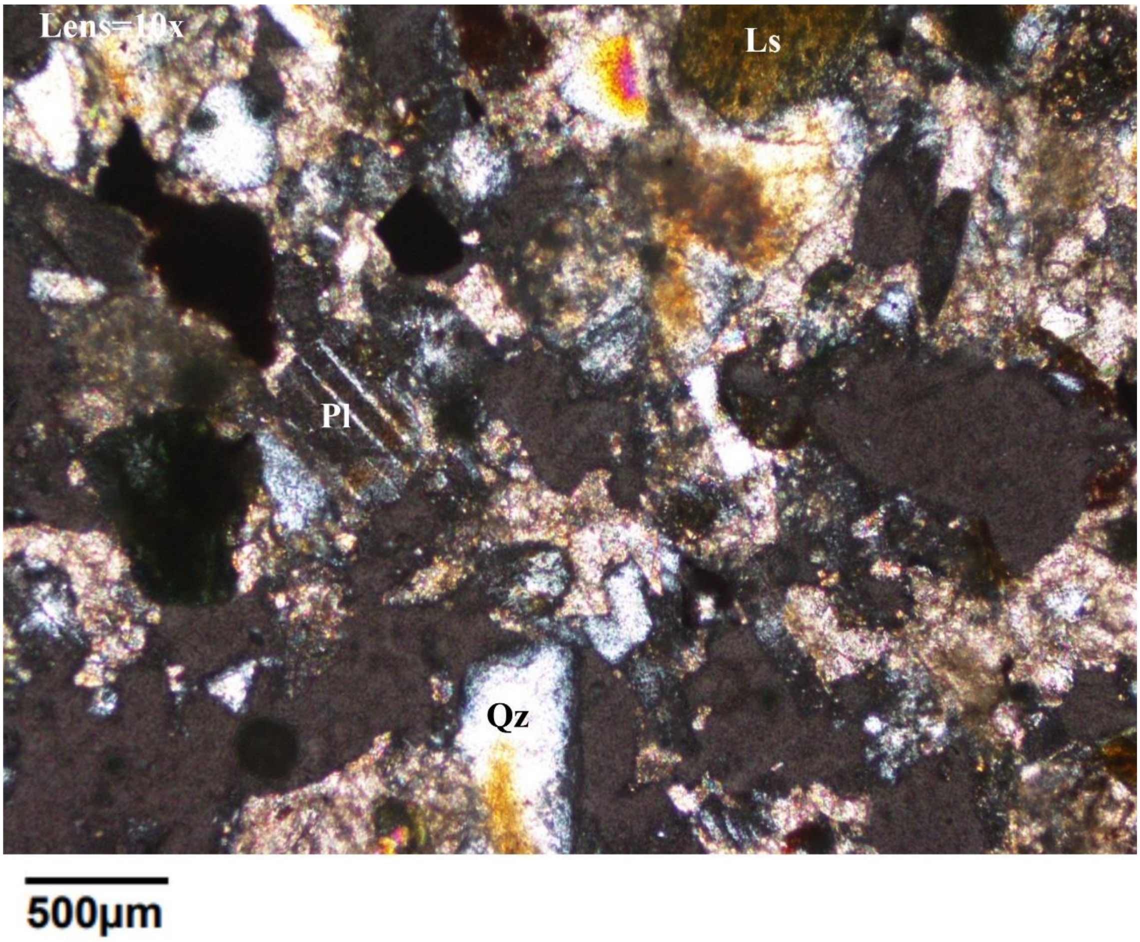


Figure 3.14 Photomicrograph showing quartz (Qz), plagioclase (Pl) and sedimentary lithic fragments (Ls) in crossed polarized light

Table 3.1: Petrography of the Kamlial and Murree sandstones (visual estimates in vol. %)

Samples	Quartz	Feldspar	Rock Fragments	Cementing material	Matrix	Mica	Heavy minerals	Opaque minerals
Murree Formation								
MZT-1	40	4	26	8	10	4	2	6
MZT-2	39	2	27	17	9	2	2	2
MZT-3	28	3	28	18	12	3	5	3
MZT-4	30	4	28	13	10	5	5	5
MZT-5	35	3	29	11	14	0	7	1
MZT-6	36	4	29	9	9	8	2	3
Kamlial Formation								
MZT-7	26	2	36	14	12	4	2	4
MZT-8	37	2	27	10	8	5	8	3
MZT-9	30	2	28	15	10	5	4	6
MZT-10	30	3	27	15	10	5	5	5
MZT-11	30	4	28	13	10	5	5	5
MZT-12	26	5	35	10	12	2	5	5
MZT-13	32	2	26	15	10	5	5	5
MZT-14	40	3	25	10	7	6	5	4

CHAPTER 4

X-Ray DIFFRACTION AND GEOCHEMISTRY

4.1 Introduction

Sedimentation, diagenesis, and composition of sediments may influence the tectonic setting of the depositional environments of sediments (Pettijohn et al., 1972; Bhatia, 1983; Taylor and Mclennan, 1985; Bhatia and Crook, 1986; Roser and Korsch, 1986; Chamley, 1990). Hence, there is a possibility to explore characteristic geochemical affinity for a probable tectonic setting within a geological region (Bhatia, 1983; Bhatia and Crook, 1986; Roser and Korsch, 1986, 1988; Rollinson, 1993). To find out the depositional and tectonic setting of the sandstone of the Kamlial Formation, four rocks (MZT-7 to MZT-10) were analyzed for major elements and mineral nomenclature using Atomic Absorption Spectroscopy (AAS) and X-Ray Diffraction analysis (XRD) respectively. One sandstone sample was also analyzed representing the adjacent Murree Formation (MZT-5) for comparison. Both the formations are from the Miocene Rawalpindi Group.

4.2 X-Ray Diffraction analysis

X-ray diffraction (XRD) is a method employed to ascertain the atomic and molecular arrangement of a crystal. This approach is employed for the purpose of identifying different phases. Additionally, it provides data regarding the dimensions of the unit cell. Rocks are the aggregate of minerals and are variously mixed. X-ray diffraction (XRD) analysis provides information about the composition and distribution of mixed layers in a structure, as well as the characteristics and proportions of the mixed minerals present. Followings are the results of the XRD analysis.

4.2.1 Sample No. MZT-5

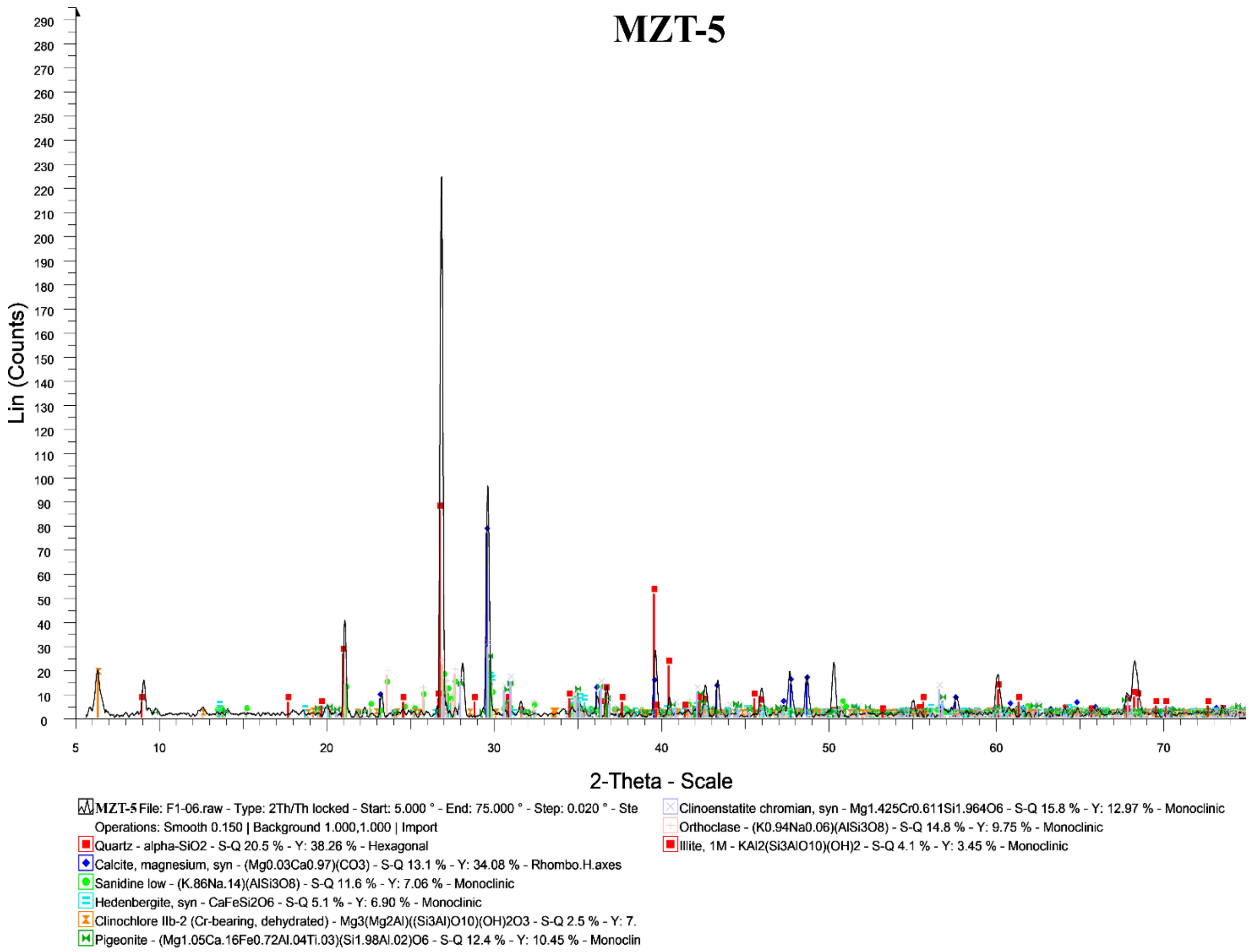


Figure 4.1 X-Ray diffraction of MZT-5 displaying major peaks of quartz, calcite, sanidine, hedenbergite, clinochlore, pigeonite, clinoenstatite, orthoclase and illite.

4.2.2 Sample No. MZT-7

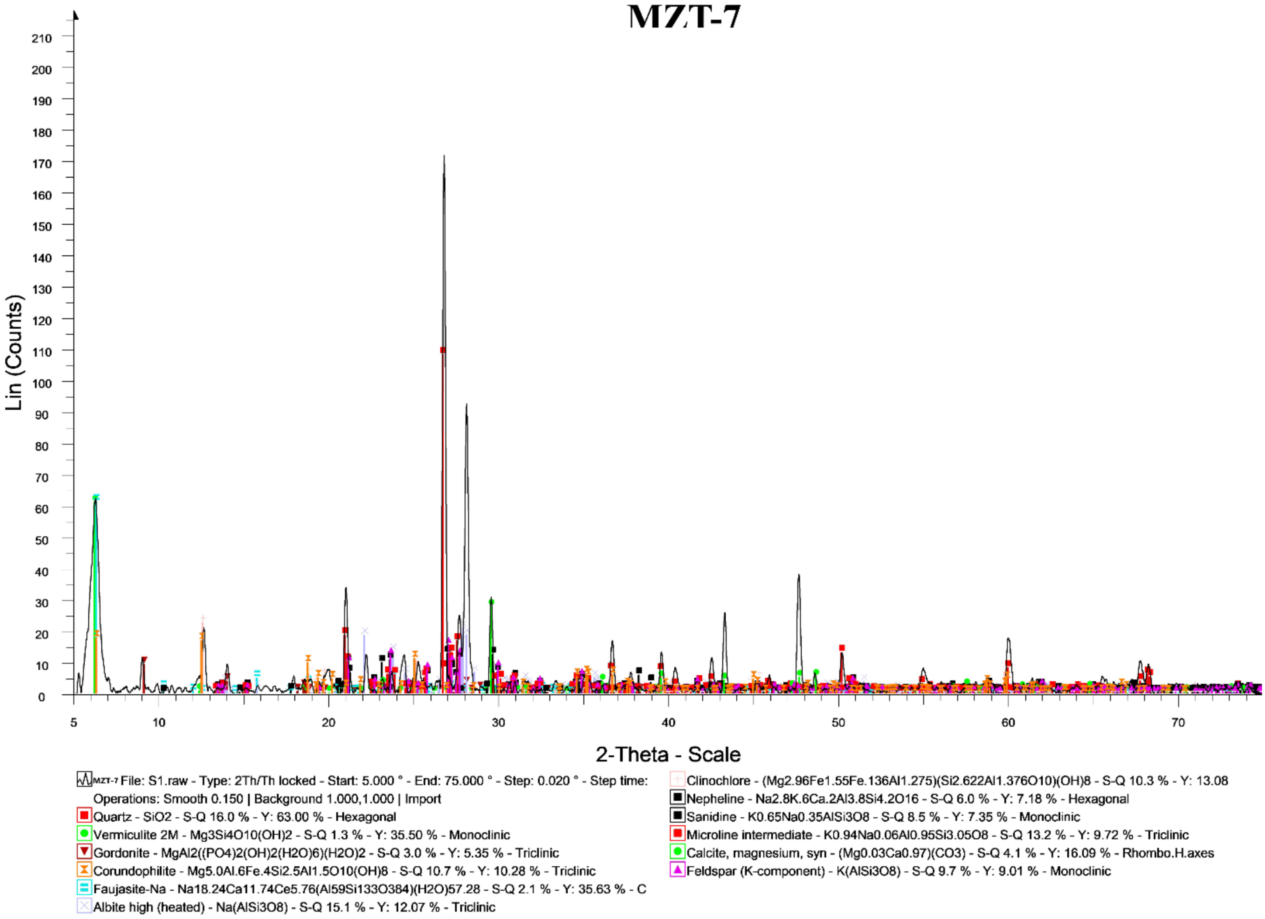


Figure 4.2 X-Ray diffraction of MZT-7 displaying major peaks of quartz, vermiculite, albite, clinochlore, nepheline, sanidine, microcline, clacite-Mg, and feldspar.

4.2.3 Sample No. MZT-8

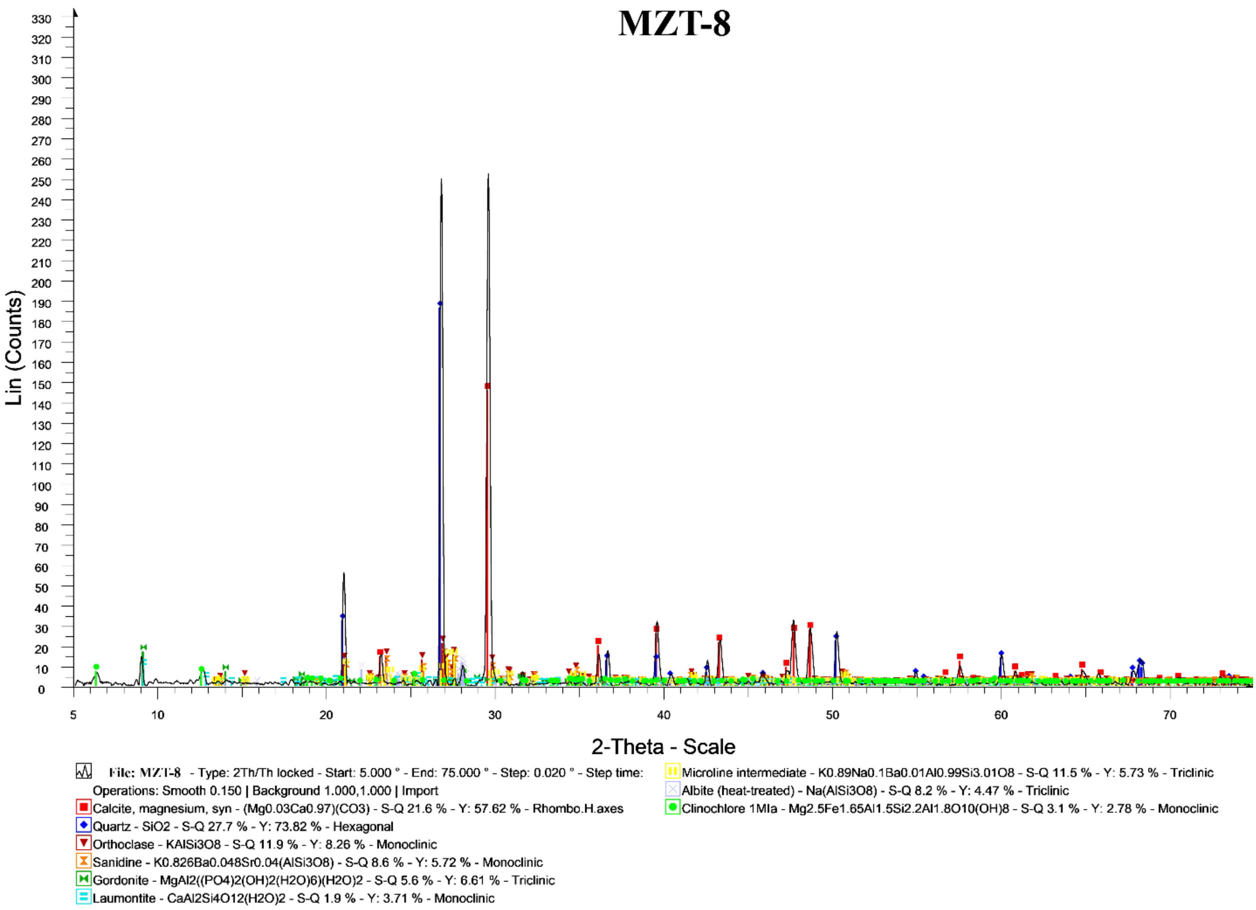


Figure 4.3 X-Ray diffraction of MZT-8 displaying major peaks of calcite, quartz, orthoclase, sanidine, laumontite, microcline, albite, and clinochlore.

4.2.4 Sample No. MZT-9

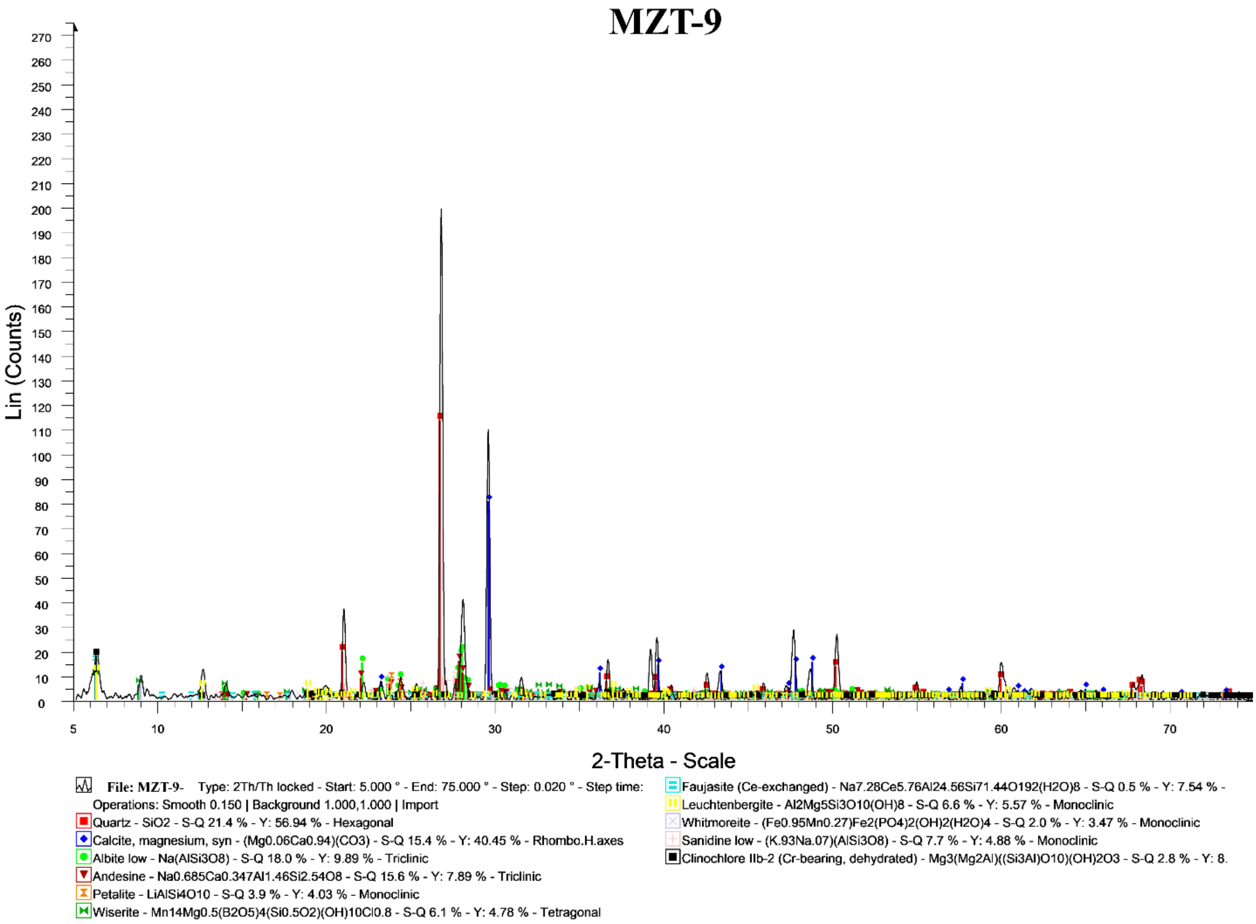


Figure 4.4 X-Ray diffraction of MZT-9 displaying major peaks of quartz, albite, andesine, sanidine, and clinochlore.

4.2.5 Sample No. MZT-10

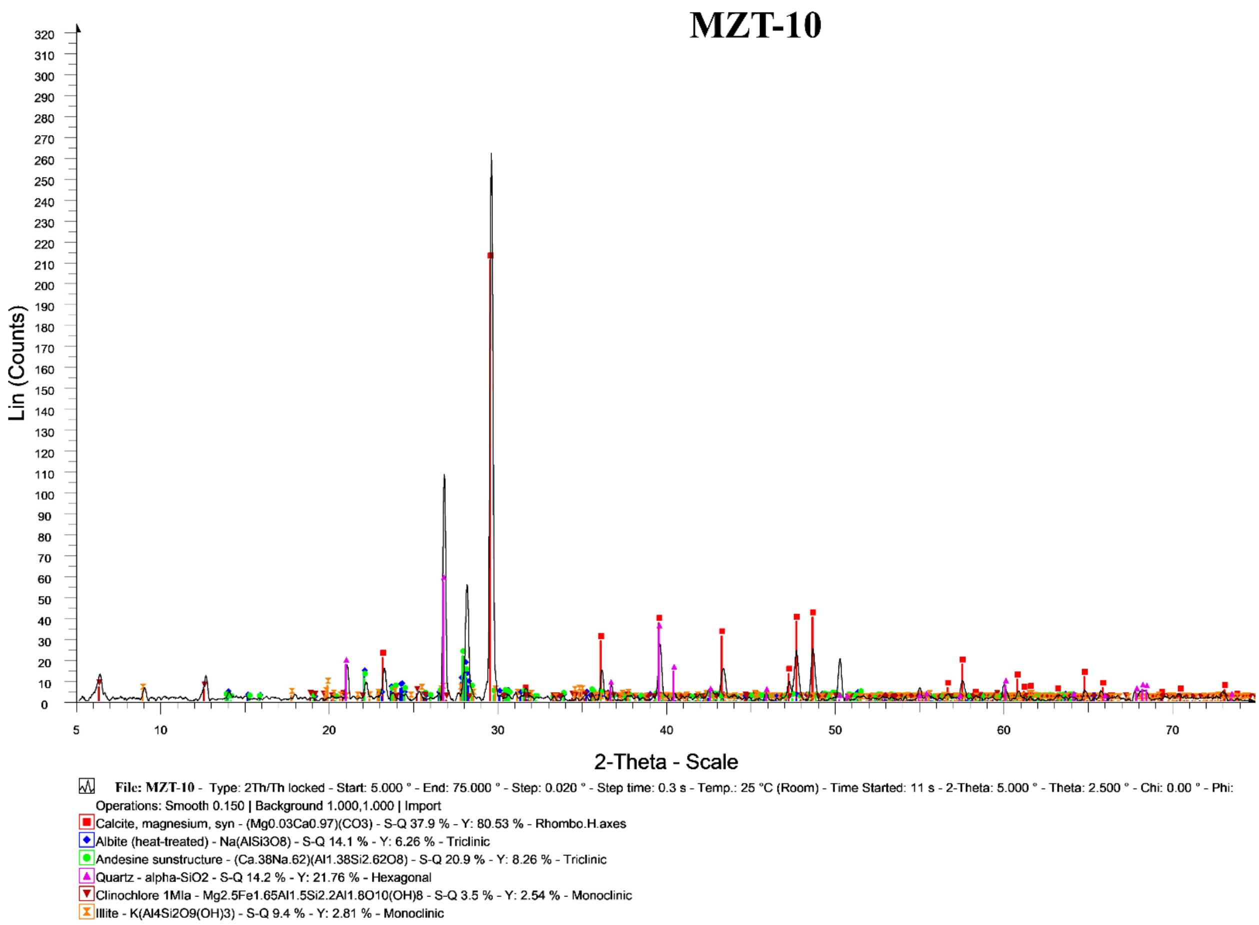


Figure 4.5 X-Ray diffraction of MZT-10 displaying major peaks of calcite, albite, andesine, quartz, clinochlore and illite.

4.3 Geochemistry

4.3.1 Atomic Absorption Spectroscopy (AAS)

Geochemistry is conducted by the utilization of the Atomic Absorption Spectroscopy (AAS) technique, specifically for the analysis of major elements (as shown in Table 4.1). The purpose of the study is to ascertain the origin, level of maturation, geologic setting, and ancient climate conditions of the Kamlial Formation. The analysis is conducted on five sandstone samples obtained within the geographical coordinates of latitude 33°35'17"N to 33°18'86"N and longitude 73°8'38"E to 73° 8'21.13"E.

Table 4.1: Major elements chemistry of sandstones of the Kamlial and Murree formations

MAJOR ELEMENTS (wt. %)					
S.NO	**MZT-5***	**MZT-7**	**MZT-8**	**MZT-9**	**MZT-10**
SiO_2	65.8	68.58	63.78	67.17	62.56
Al_2O_3	15.26	15.19	16.93	15.7	17.91
Na_2O	0.73	0.34	0.5	0.34	0.88
K_2O	2.09	2.4	1.3	2.42	1.5
CaO	9.64	5.1	6.86	8.97	7.53
Fe_2O_3	0.87	1.51	3.24	0.48	2.84
MgO	3.31	3.82	4.10	2.66	4.91
TiO_2	0.28	0.46	0.33	0.48	0.39
MnO	0.05	0.16	0.21	0.1	0.23
P_2O_5	0.37	0.24	0.34	0.14	0.47
LOI	1.37	1.89	1.034	1.38	0.624
Total	98.9	98.18	95.38	99.37	97
SiO_2/Al_2O_3	4.31	4.51	3.77	4.28	3.49
K_2O/Na_2O	2.9	7	2.6	7.1	1.7
Log (SiO_2/Al_2O_3)	0.65	0.58	0.63	0.54	0.63
Log (Na_2O/K_2O)	-0.85	-0.41	-0.85	-0.23	-0.46
$MgO+Fe_2O_3$	4.18	5.33	7.34	3.14	7.75
$Al_2O_3+Na_2O+K_2O$	18.08	17.93	18.73	18.46	20.29

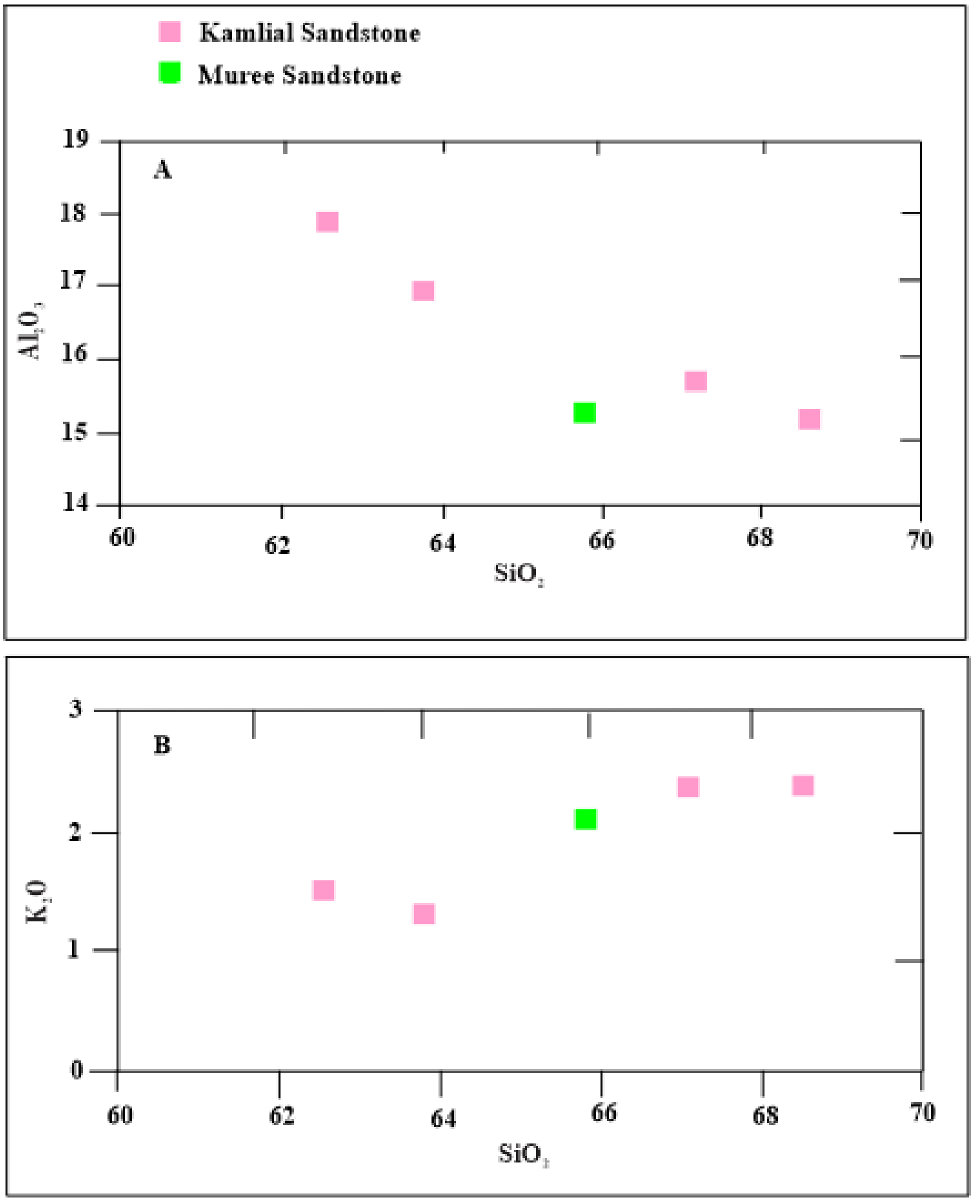
MZT-5* Murree Formation.

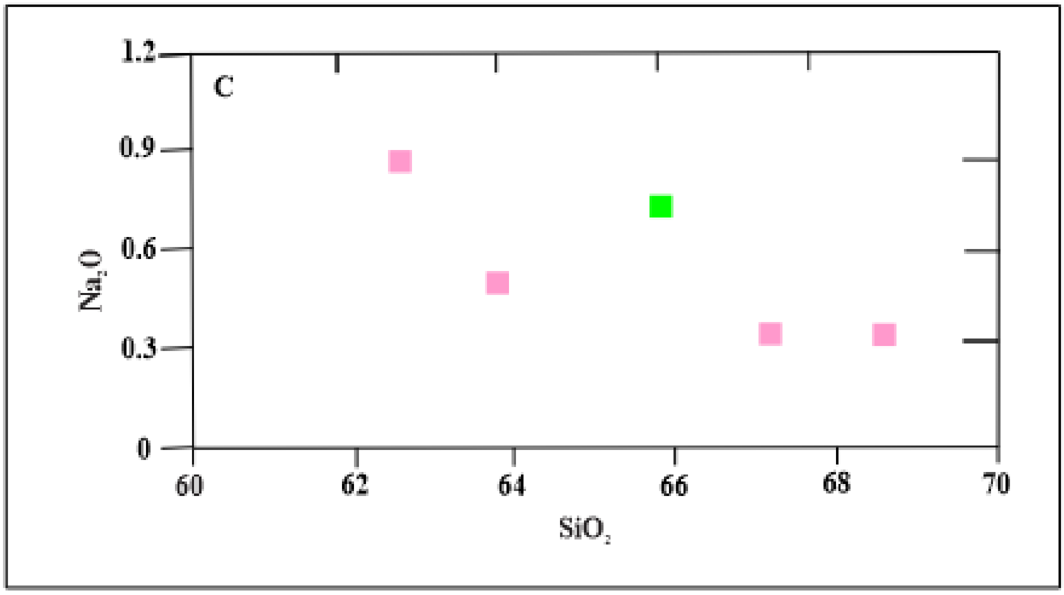
4.3.2 Major elements chemistry of the Kamlial Formation

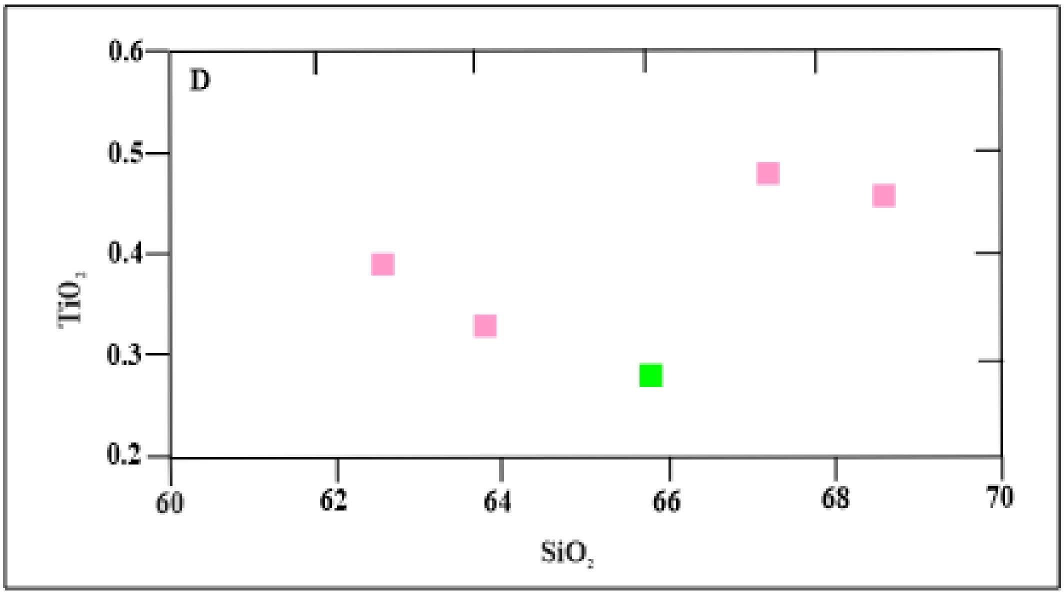
Four samples of the Kamlial Formation show SiO_2 content ranging from 62.56-68.58 wt. % (Table 4.1). The second most abundant element oxide is the Al_2O_3 ranging from 15.19-17.91 wt. %. Element oxides concentration include CaO (5.1-8.97 wt. %.), Fe_2O_3 (0.48-2.84 wt. %) and K_2O (1.3-2.42 wt. %). Other element oxides viz. TiO_2, MnO, MgO, Na_2O, and P_2O_5 occur in minor amounts.

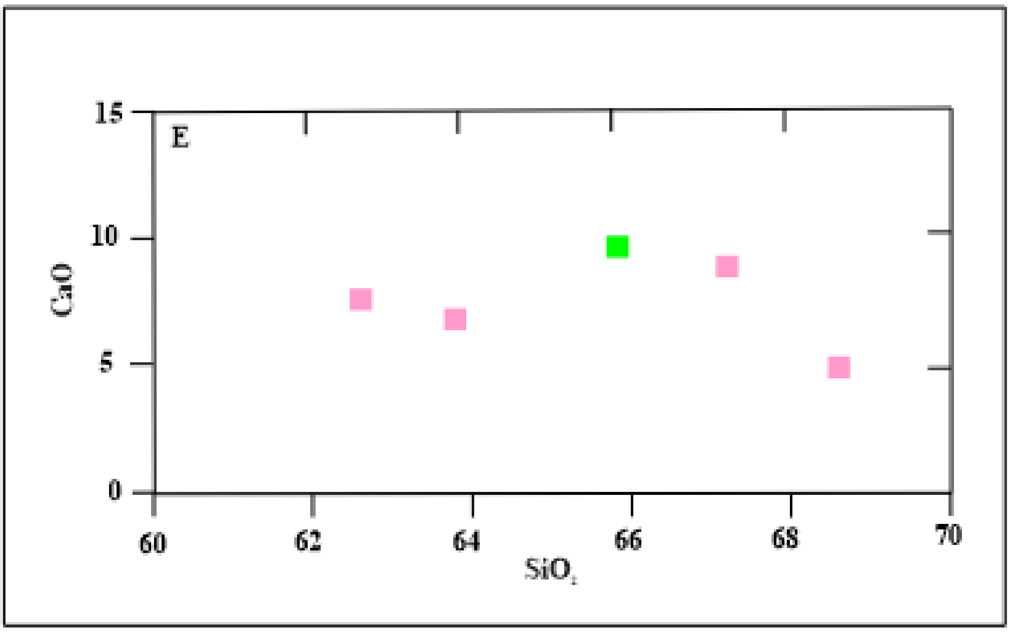
4.3.3 Cross-plot of SiO_2 against other oxides

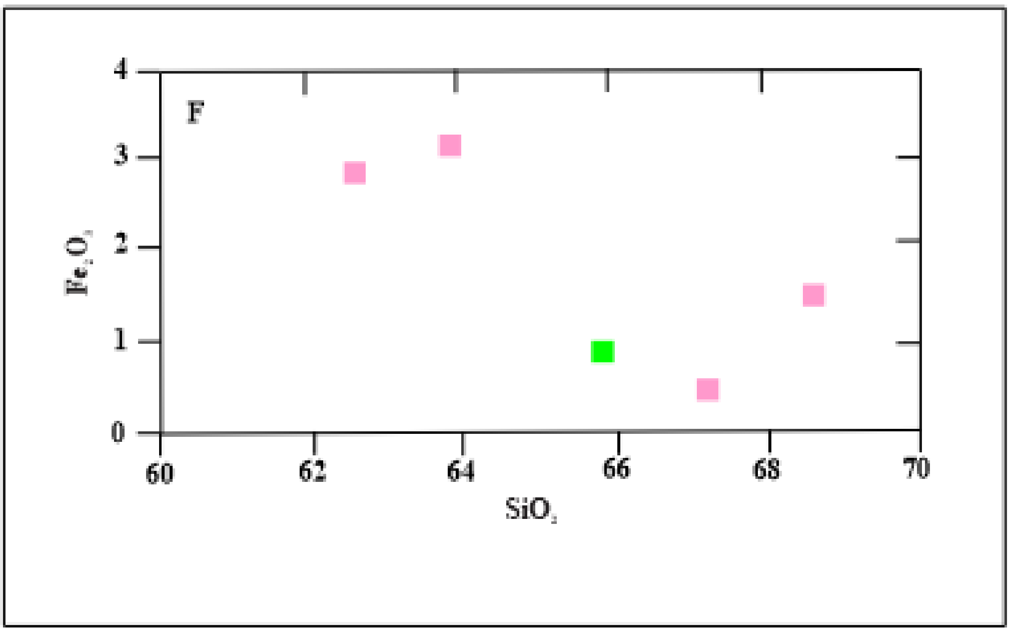
Binary diagrams are very useful for determining variation among various oxides. Positive and negative correlations are seen among the oxides when plotted against SiO_2 (Figs. 4.6 A-I).

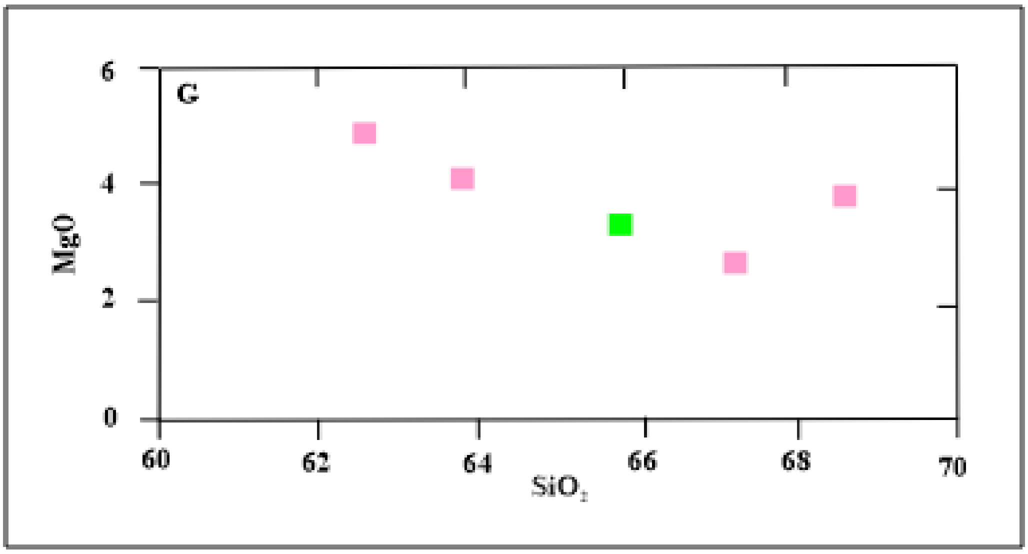

Kamlial Sandstone
Muree Sandstone
A
19
18
17
16
15
14
Al_2O_3
60
62
64
66
68
70
SiO_2
B
3
2
1
0
K_2O
60
62
64
66
68
70
SiO_2

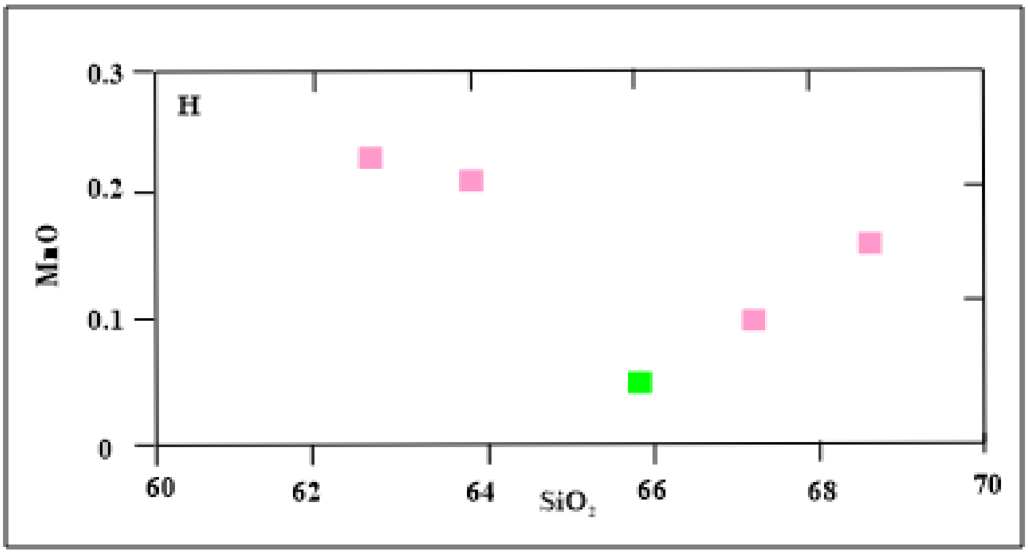

C
1.2
0.9
0.6
0.3
0
Na_2O
60
62
64
66
68
70
SiO_2


D
0.6
0.5
0.4
0.3
0.2
TiO_2
60
62
64
66
68
70
SiO_2


E
CaO
SiO2
0
5
10
15
60
62
64
66
68
70


F
Fe2O3
SiO2
0
1
2
3
4
60
62
64
66
68
70


G
MgO
6
4
2
0
60
62
64
66
68
70
SiO2


H
MnO
0.3
0.2
0.1
0
60
62
64
66
68
70
SiO2

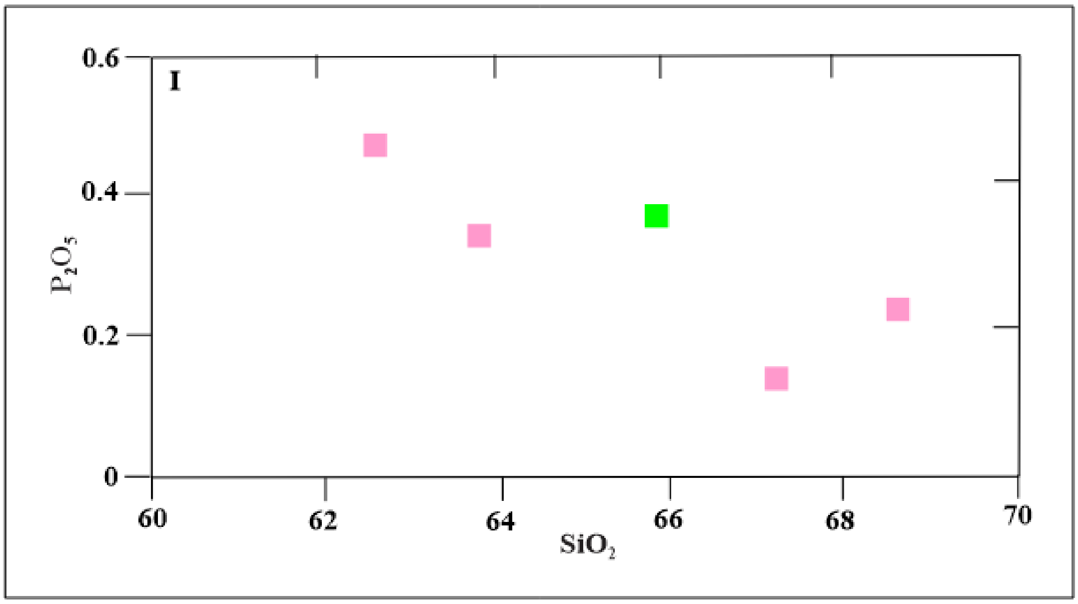


Figure 4.6 Binary variation diagram (A to I) showing distinct groups of rocks of the Kamlial Formation and Murree Formation.

4.3.4 Geochemical classification

The classification of the sandstones is based on the utilization of geochemical diagrams from the works of Pettijohn et al. (1987) and Blatt et al. (1980). The ternary diagram, as described by Blatt et al. (1980), indicates that the samples under study primarily consist of ferromagnesian potassic-sandstones (Fig. 4.7). Lindsey (1999) suggested that the typical litharenite is located inside the ferromagnesian potassic sandstone zone, based on the data provided by Pettijohn (1963, 1975). Greywacke is found inside the sodic sandstone zone, while the average arkoses are present in the potassic sandstone zone. As discussed earlier, the Kamlial sandstones plot mainly in lithic-arenite zone (Fig. 4.7).

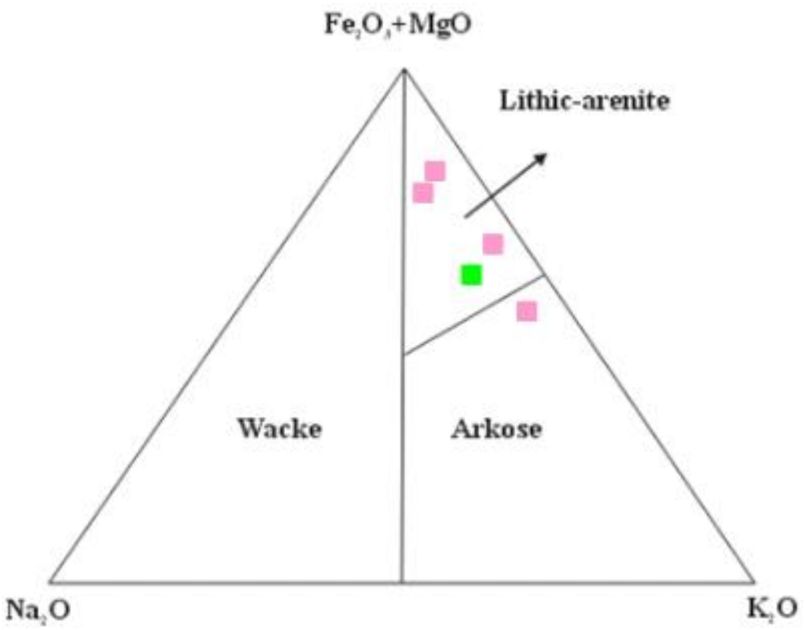


Figure 4.7 Ternary diagram of Na2O-K2O-(Fe2O3+MgO) of sandstones of the Kamlial Formation (after Blatt et al., 1980).

4.3.5 Sedimentation maturity

The ratio of oxide elements, e.g., SiO_2/Al_2O_3 may act an accurate indicator of sediment maturity. Roser et al. (1996) proposed that a SiO_2/Al_2O_3 ratio over 5 could be indicative of rising maturity in the sandstone. The SiO_2/Al_2O_3 ratio of 1.7-7.1 (average= ≈4) and the K_2O/Na_2O ratio of 1.7-7 (average= ≈4) (Table 4.1) indicate mineralogical immaturity of the sandstones of the Kamlial Formation. The immaturity of the sandstone is further evident of the ongoing rise of the region, erosion, inadequate sorting, and limited transportation distance from the source. Figure 4.8 illustrates that all samples plot in the semi-arid region and show a progressive increase in chemical maturity.

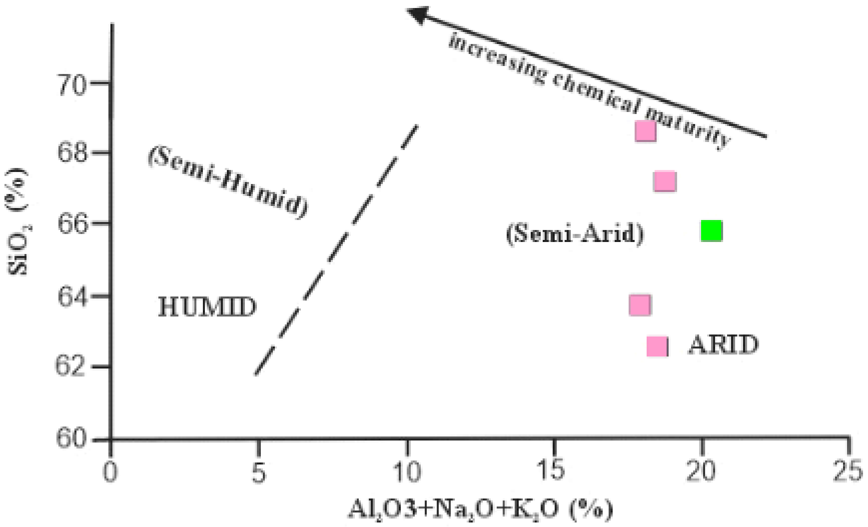


Figure 4.8 Chemical maturity of sandstones of the Kamlial Formation expressed by bivariate plot of SiO_2 verses Al_2O_3+K_2O+Na_2O (after Suttner and Dutta, 1986).

CHAPTER 5

DISCUSSION AND CONCLUSIONS

5.1 Discussion

The classification of tectonic settings for sedimentary rocks can be determined using petrography and geochemistry (e.g. Bhatia, 1983; Roser and Korsch, 1986; Altrin and Verma, 2005). Based on Folk (1968) and Dickinson et al. (1983) models, the sandstone of the Kamlial Formation plots dominantly in litharenite and recycled orogeny fields (Figs. 5.1 and 5.2).

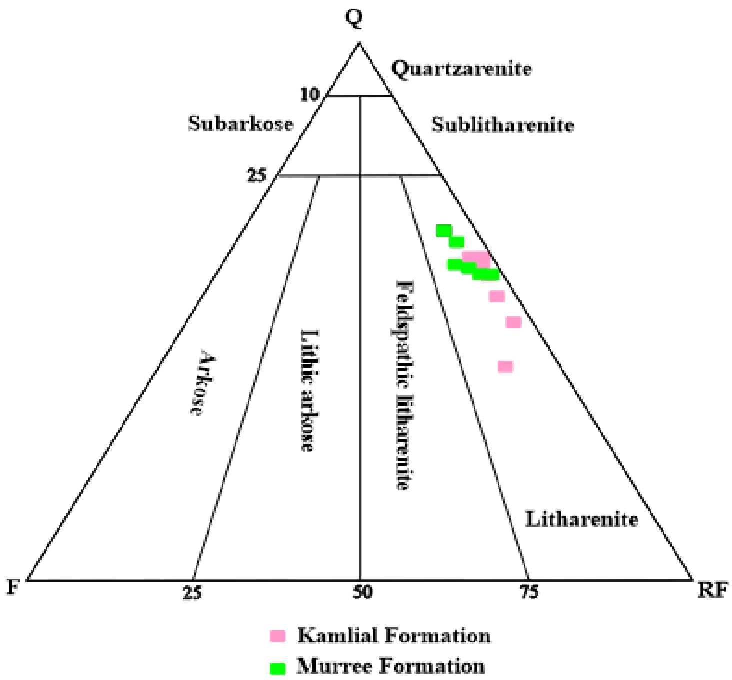


Figure 5.1. Classification of sandstones of the Kamlial Formation based framework grains (quartz, feldspar, rock fragments) (after Folk, 1968). For comparison, sandstone of the Murree Formation is also plotted.

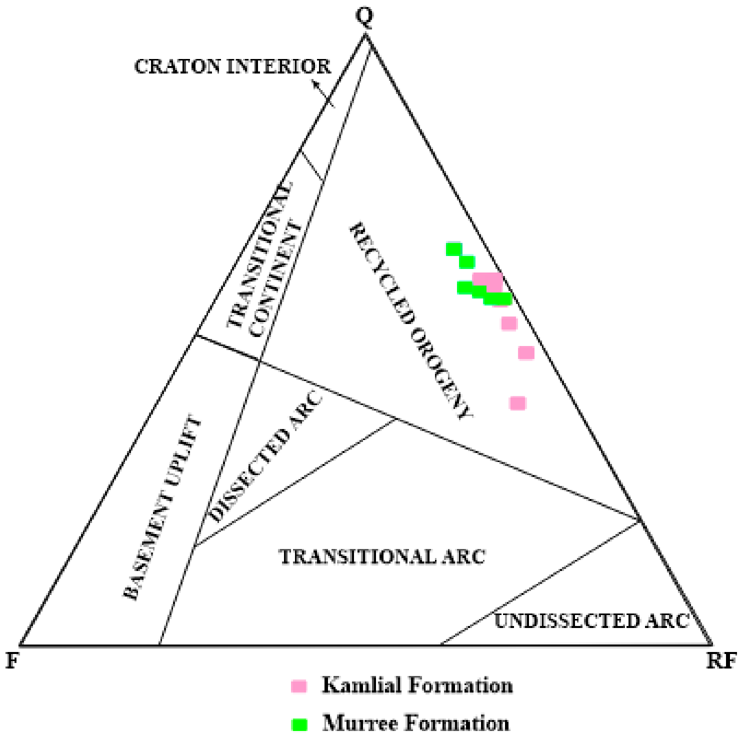


Figure 5.2 Sandstone provenance in tectonic regions (after Dickinson et al, 1983).

Roser and Korsch (1986) utilized a tectonic discrimination plot that utilized SiO_2 and K_2O/Na_2O ratios to differentiate between sedimentary deposits found in active continental margins, passive margins, and oceanic island arcs. This analysis identifies the tectonic environments in which the terrigenous clastic rocks were formed. All sandstone samples of the Kamlial Formation are classified into the category of oceanic island arc field, as shown in Figure 5.3.

The occurrence of feldspar in the Kamlial Formation suggests that the source location experienced either a high relief or an arctic environment (Prothero and Schwab, 2003). The high proportion of alkali feldspar over plagioclase indicates the predominance of granite and acidic gneisses in the source region. However, this characteristic could also be due to the superior chemical stability of alkali feldspar compared to plagioclase during transportation (Tucker, 2001). The presence of microcline feldspar additionally supports the occurrence of granitic and pegmatitic origins. According to Michaelsen and Henderson (2000), most mica flakes are bent, which indicate that they originated from metamorphic or deformed assemblages. The presence of lithic grains of metamorphic origin, as well as grains of epidote and garnet, suggest the same metamorphic origin. The bivariate plot (after Crook, 1974) of Na_2O versus K_2O of the studied samples shows that three samples are quartz rich while the other two samples are quartz intermediate (Fig. 5.4). This demonstrates that they originated from a felsic source.

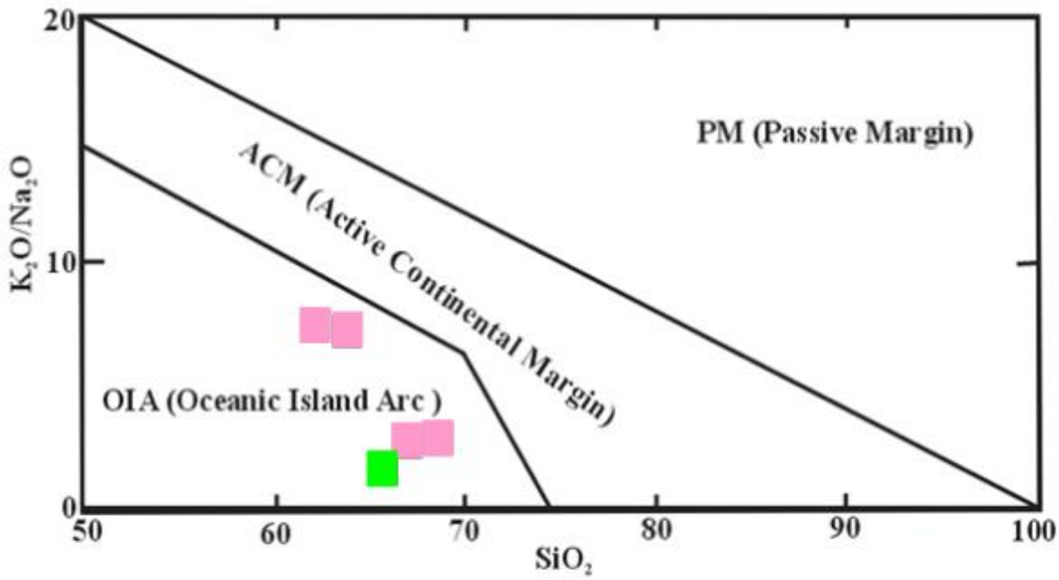


Figure 5.3 Tectonic discrimination plot for sandstones of the Kamlail Formation (after Roser and Korsch, 1986).

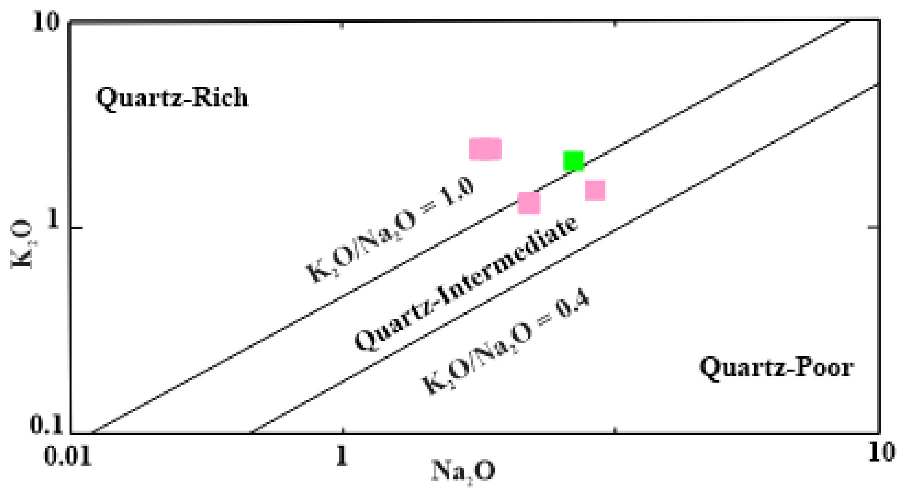


Figure 5.4 Bivariate plot of Na_2O versus K_2O of the Kamlail formation showing quartz content (after Crook, 1974).

5.2 Conclusions

On the basis of the present research study, the following conclusions are drawn.

1. The field study shows the exposure of the Miocene Rawalpindi Group (Kamlial and Murree formations) along the Islamabad Express Highway near Korang Bridge. The Geological Survey of Pakistan Geological map of Islamabad area placed this section as the Kamlial Formation. It is further noted that the Kamlial Formation strikes in NE with dip SE underlying the Murree Formation, which may be due to overturned folding and/or thrust faulting.

2. The Kamlial Formation contains abundant quartz, which are fractured and oriented as micro-lenses along with K-feldspar as microcline, micro-perthithe, orthoclase and sanidine, and albite to andesine plagioclase feldspar indicating felsic plutonic and volcanic rocks origin. Besides, the presence of pyroxenes and amphiboles also indicate mafic volcanic and/ or plutonic rocks source. The presence of metamorphic rock fragments and traces of garnet, epidote, chlorite, biotite, muscovite, vermiculite may show metamorphic origin of the source rocks. The orientation of the grains and bending in mica indicates that the formation has undergone through deformation due to shearing.

3. Based on petrographic and geochemical studies, the sandstones of the Kamlial Formation are litharenite. Cross- and graded bedding in sandstone, occurrence of mudstone and intraformational conglomerate in the Kamlial Formation support fluvial depositional environment. The sandstones of the formation illustrate that the sediments were derived from oceanic island arc, namely the Kohistan island arc and probably from the lesser and higher Himalayas.

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