MINERALOGICAL AND GEOTECHNICAL CHARACTERISTICS OF SANDSTONE OF THE MUREE FORMATION, ISLAMABAD SECTION, ISLAMABAD, PAKISTAN

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01-262211-002

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Department of Earth and Environmental Sciences

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DEDICATION

To my beloved parents and siblings

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ABSTRACT

The Murree Formation is a part of the Miocene molasses deposits of the Rawalpindi Group that crops out in Islamabad, Pakistan. The rock sequence of the formation consists of a series of alternating beds of sandstone, siltstone and shale with subordinate marls and conglomerates. The sporadic exposures of the formation occur south of the Main Boundary Thrust (MBT) at Shah Allah Ditta, Barakahu, around Rawal Dam, G and H Sectors of Islamabad and along the Srinagar Highway. The sandstone of the Murree Formation is predominantly fine - to medium- grained and moderate to poorly sorted. The rock contains angular to sub-angular quartz (30-55 vol.%) and feldspar (2-3.5 vol.%) with abundant rock fragments (20-51 vol.%). The cementing material is calcite which constitutes (14-28 vol.%). The relative abundances of quartz, feldspar and rock-fragments suggest the sandstone of the formation as sub-mature whereas the presence of calcite matrix and angular grains of quartz place it texturally as immature. The observed accessory minerals include epidote, monazite and tourmaline. The sandstone, on the basis of quartz, feldspar and rock fragments classify as litharenite and recycled orogenic in the (Q-F-LF) ternary plots, which might have formed due to rapid deposition in the tectonically deformed areas. For knowing the potential of the sandstone of the Muree Formation for utilization as the geotechnical properties obtained include uniaxial compressive strength (50.9-16.1), uniaxial tensile strength (8.19-2.31), specific gravity (2.67-2.636) and water absorption (0.59-0.25). Based on the research study, sandstone of the Murree Formation is considered suitable for dimension stones and construction material.

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LIST OF ABBREVIATION

HT-Hussein and Tahseenullah khan

Bt - Biotite

Cal - Calcite

Ep - Epidote

Fsp - Feldspar

Opq - Opaque Mineral

Qz - Quartz

Tur - Tourmaline

Rf - Rock Fragments

NCEG - National Centre of Excellence in Geology

MBT - Main Mantle Thrust

MKT - Main Karakoram Thrust

UCS-Unconfined uniaxial strength

UTS-Unconfined Tensile strength

ITS-Indirect Tensile Strength

SG-specific gravity

WA-Water absorption

CHAPTER 1

INTRODUCTION

1.1 Preamble

The Miocene Murree Formation of the Rawalpindi Group crops out in Islamabad, Pakistan. The study area is located in Islamabad, Pakistan (Fig. 1.1). It is bounded by latitudes 33º 38´ to 33 º 39´ N and longitudes 73 º 00´ to 73 º 01´ E. The formation consists of inter-bedded sandstone, siltstone, shale and conglomerates (Shah et al., 2000; Shah,2009). The sporadic exposures of the formation occur south of the Main Boundary Thrust (MBT) at Shah Allah Ditta, Barakahu, around Rawal Dam, G- and H Sectors of Islamabad and along the Srinagar Highway. The sandstone of the Murree Formation has been investigated for its geotechnical characteristics at Jena Kor area and Peshawar basin by Yar et al. (2021) and for engineering geological properties at lower Topa section, Murree (Malik and Rashid, 1997). Outcrops of the sandstone of Murree Formations are also exposed near the National Police Academy and along the Srinagar Highway in Islamabad, which are selected for rock sampling due to easy access and fresh exposures for petrography and geotechnical testing.

This study aims to conduct mineralogical and geotechnical studies of sandstone of the Murree Formation for knowing its suitability in the construction industry and to correlate it with similar studies carried out in different parts of the country.

Figure 1.1 Samples location map of the study area, Islamabad-Rawalpindi

1.2 Previous Work

The Murree Formation comprises red and purple clay and purple grey to greenish grey sandstone, and minor intra-formational conglomerate (Shah, 2009). It is extensively exposed in the Kohat-Potwar sub-basins and in Kashmir basin (Shah, 2009; Iltaf, 2017). The formation is ~ 3030 m thick in northern Powar and thins out up to ~ 9 m in in western Banda Daud Shah area of Kohat. The upper contact with the Kamlial Formation is transitional and unconformable with lower Eocene Kuldana Formation (William et al., 1985; Shah et al., 2000).

1.3 Objectives

Sandstone is generally considered a durable material to resist the weathering effects. The variation in grain size and mineralogy affect the durability of rocks. Therefore, to know this fabric and mineralogical variability and its suitability for construction purposes, following objectives are streamlined for this study area.

1.To carry out mineralogical study through petrography
2.To evaluate the mechanical and physical properties
3.To establish the correlation between mineralogical and physico-mechanical properties of the sandstone for knowing the suitability as a construction material.

1.4 Methodology

1.4.1 Fieldwork

Fieldwork was conducted in the Murree Formation to obtain geological data and collecting rock samples for knowing the mineralogy through thin section study and geotechnical attributes of the Murree Formation. Five representative rock samples were collected near the area adjacent to National Police Academy and along the Srinagar Highway in Islamabad for petrographic and geotechnical analyses. A few geologically important features were photographed.

1.4.2 Laboratory Work

The laboratory work includes petrography and geotechnical analysis. Geotechnical analysis comprises a uniaxial compressive strength test, splitting tensile strength test or indirect tensile strength test (Brazilian) on cubic rock samples, and specific gravity test. Five representative rock samples were prepared for petrographic studies, and geotechnical analysis. Impregnated blue dye thin sections and geotechnical tests were performed at NCE in Geology, University of Peshawar. Petrographic study was executed in the Earth and Environmental Sciences department, Bahria University, H-11 Campus, Islamabad.

CHAPTER 2

REGIONAL GEOLOGY TECTONIC SETTING

2.1 Geological Setting

Pakistan lies in a region where Indian, Arabian and Eurasian continental plates are exposed. Due to collisional tectonics between the Indian continental plate and the Asian continental plate, Himalayan mountain chain formed. The Himalaya mountain chain is further divided into Sub Himalaya, Lesser Himalaya, and Higher Himalaya (Burrard and Hayden, 1908). The area of investigation occurs in Sub-Himalaya.

The Main Karakorum Thrust (MKT), Main Mantle Thrust (MMT), Main Boundary Thrust (MBT) and Salt Range Thrust (SRT) are the regional thrust faults present in Himalaya. 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 paragraph.

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 sediment took place in this belt in Early Miocene. The SDFTB is divided into Potwar sub-basin, 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. 2.2). 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).

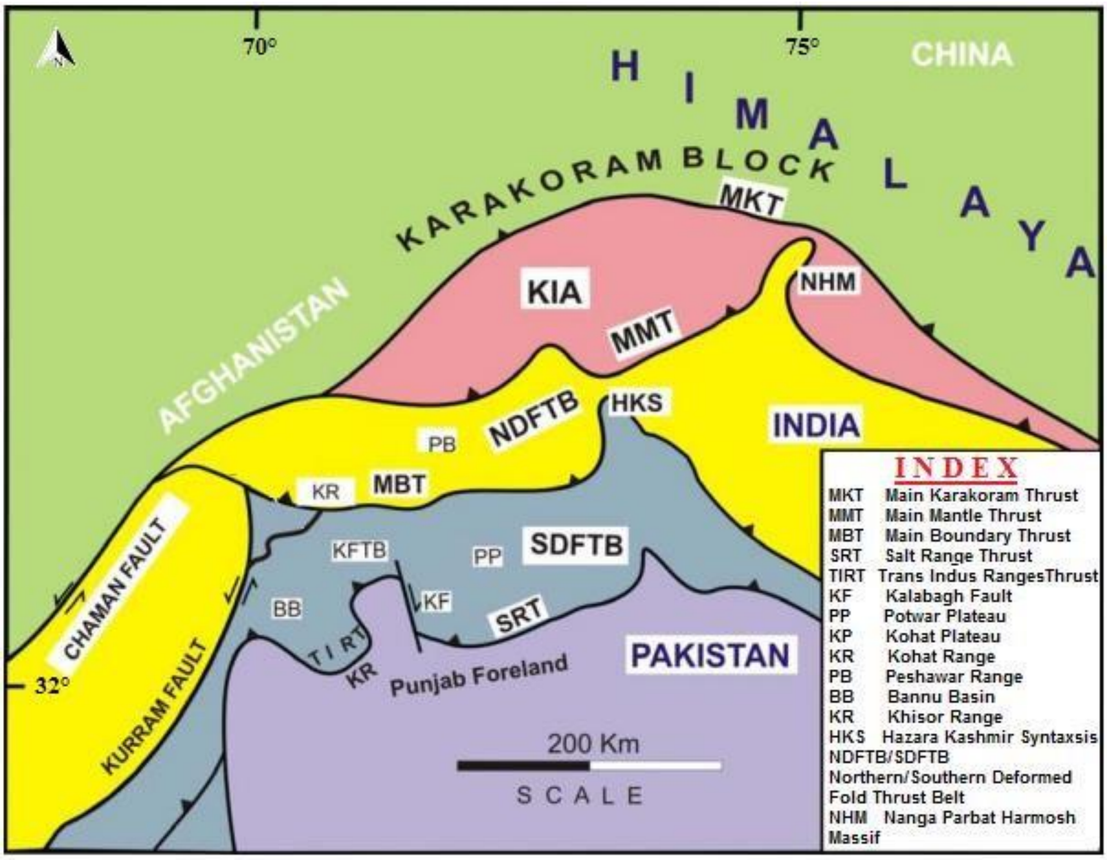


Figure 2.1 Tectonic map of northern Pakistan (Pegler and Das, 1998)

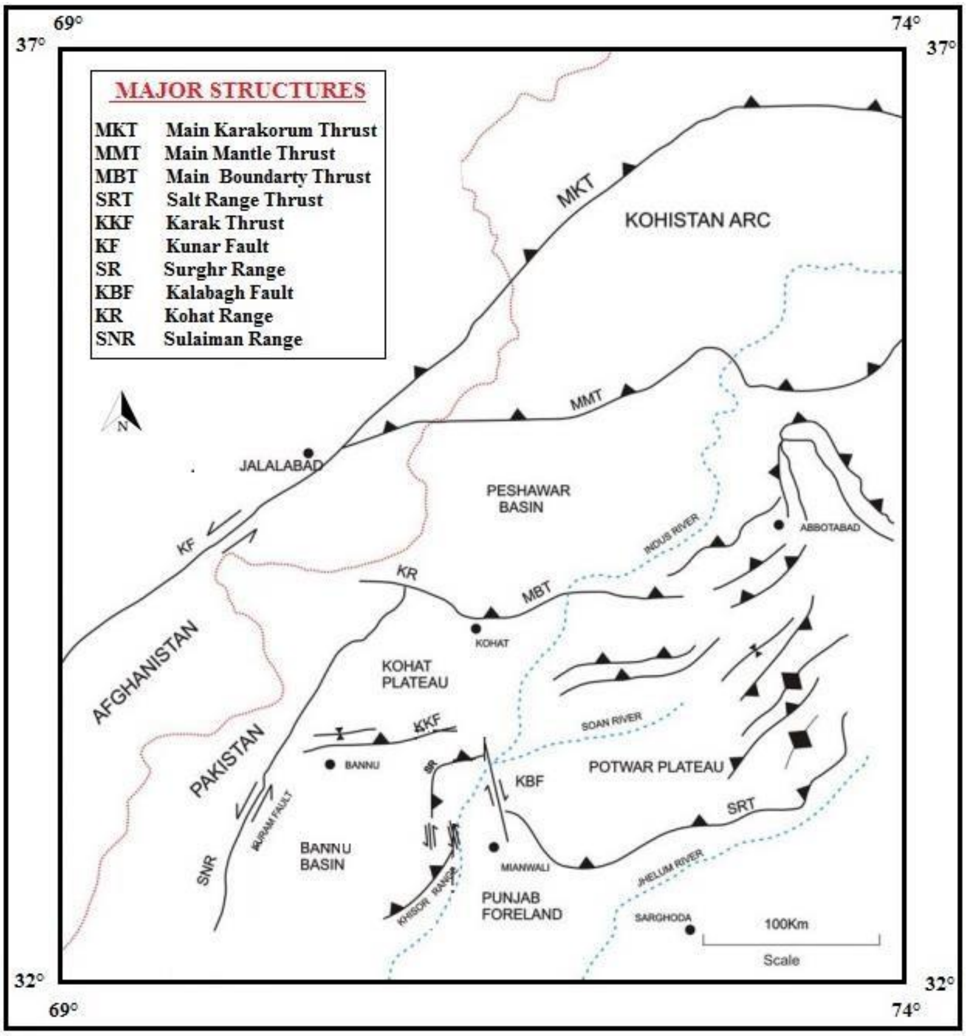


Figure 2.2. Tectonic map demonstrating major structural features of northern Pakistan (Kazmi and Rana, 1982).

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 deformed Mesozoic deposits of Kohat Range over the Eocene-Miocene sediments of Kohat sub-basin (e.g., Yeats and Hussain, 1987).

CHAPTER 3

STRATIGRAPHY

3.1 Introduction

The rocks exposed in Rawalpindi area includes the Molasse deposits of Rawalpindi and Siwalik groups. Five formations have been drilled in Kallar-X-1 well in Kallar Syedan area, including Nagri and Chinji formations (Siwaliks group of Miocene age), Kamlial and Murree formations (Rawalpindi group of Miocene age) and Kuldana Formation (Charat group of Eocene age). The Murree Formation extends to Kohat-Potwar sub-basins the Salt Range, the Hazara-Kashmir syntaxis, Jammu and Kashmir, and the North Indian plains. The Lockhart, Patala and Murree formations lie conformably on top of the Cretaceous sedimentary deposits in the Hazara-Kashmir syntaxis between Balakot and Muzaffarabad. The Murree Formation is overlain by shallow marine deposits of late Paleocene to early Miocene age.

According to Pilgrim (1910) and Pinfold (1918), the Murree Formation represents continental deposits. Based on conglomerate occurrences of the Murree Formation on the northern Potwar Plateau, this formation was named as the Fatejang Zone by Pinfold (1918). The geological succession with brief description of each rock units is given below (Table 3.1; Fig. 3.1)

Table 3.1: 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 sub-ordinate 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

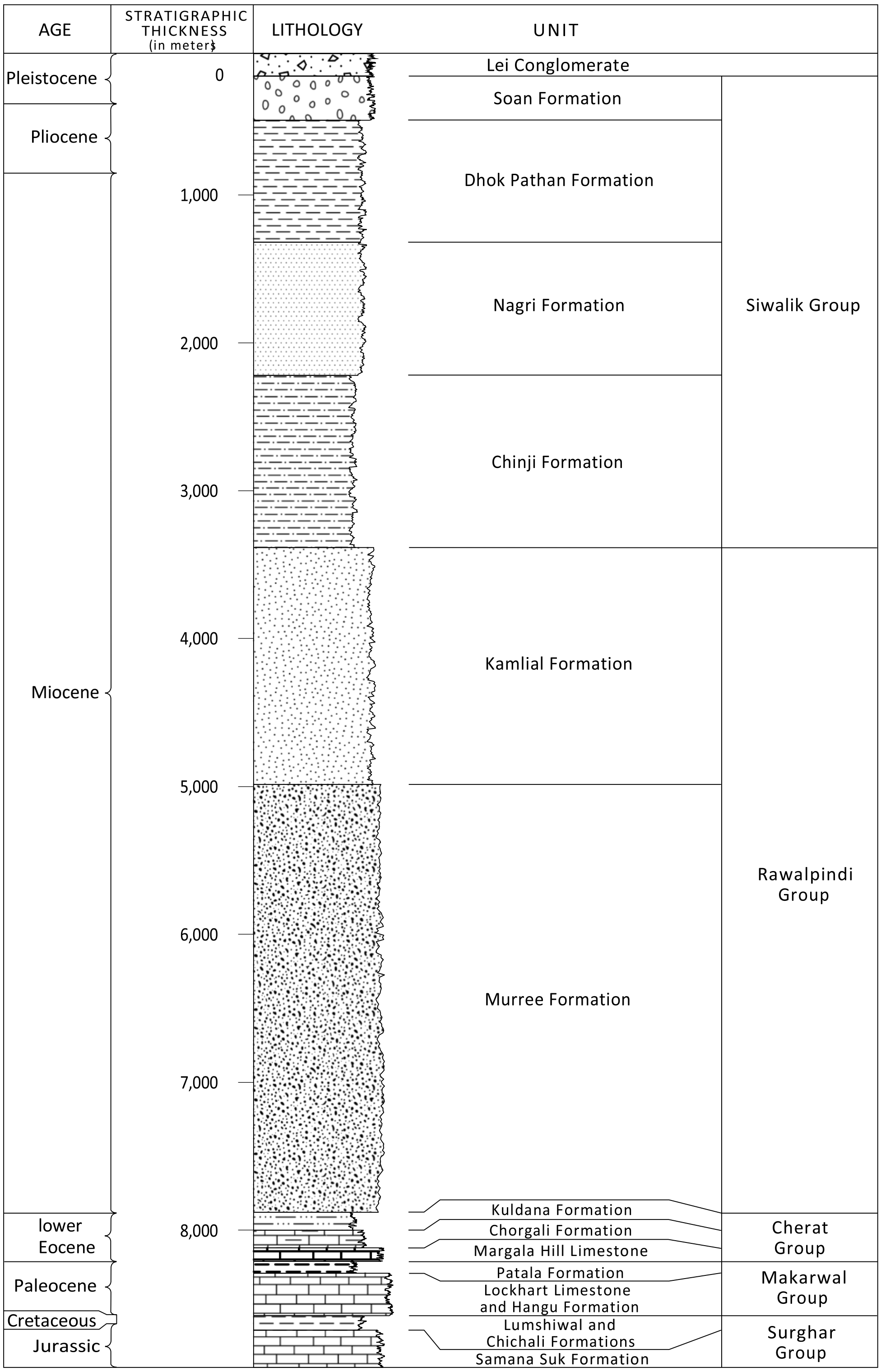


Figure 3.1 Stratigraphic chart of the Siwalik Group including the Murree Formation (after Warwick et al., 2007)

CHAPTER 4

FIELD OBSERVATIONS

4.1 Field Observations

The Murree Formation in the area of investigation covers an area of about 4 km^2. The formation consists of inter-bedded sandstone, siltstone, shale and conglomerates. The beds strike N60° W and dips 10° SW and at places N80°W and dips 20° NE. The Murree sandstone is interbedded with shale, conglomerate and show deferential weathering (Figs. 4.1 to 4.3).

Figure 4.1 Field photograph showing sandstone interbedded with shale

Figure 4.2 Field photograph showing conglomerate interbedded sandstone

Figure 4.3 Field photograph showing shale of the Murree Formation

CHAPTER 5

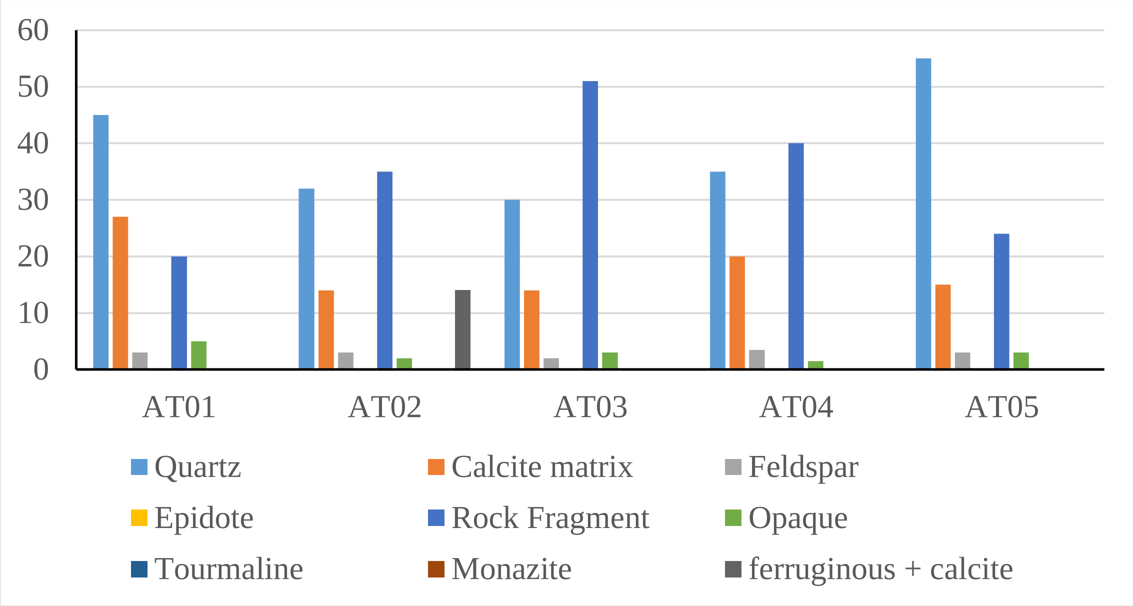
RESULTS AND DISCUSSION

5.1 Petrography

The present petrographic description is based on visual estimates of the identified minerals and the textural details, which are essential parameters used for correlation with the physico-mechanical properties. The mineralogical description of sandstone is given in Table 5.1

Table 5.1: Petrography (vol. %) of the rock samples collected during the field

Samples	AT01	AT02	AT03	AT04	AT05
Quartz	45	32	30	35	55
Calcite (cement)	27	28	14	20	15
Feldspar	3	3	2	3.5	3
Epidote	-	Traces	-	-	-
Rock Fragments	20	35	51	40	24
Opaque	5	2	3	1.5	3
Tourmaline	Traces	-	-	-	-
Monazite	Traces	-	-	-	-
Ferruginous+calcite	-	14	-	-	-



5.1.1 AT (01)

Sandstone is fine- to medium- grained and texturally immature. Quartz is mainly euhedral to subhedral and ranges up to 45% by the volume (Fig. 5.1). Some of the quartz are polycrystalline. Cementing material is calcite. Mostly contacts are straight but sutured contacts are also present, as most of the grains are cement-matrix supported. Cementing material makes up to 27% by the total volume. Sandstone fragments compose quartz, clay material and feldspar and ranges up to 20% by volume (Fig. 5.2). Both alkali feldspar and plagioclase are present and make up to 3% by volume. Opaque minerals occur up to 5% by volume. Tourmaline and monazite occur in traces.

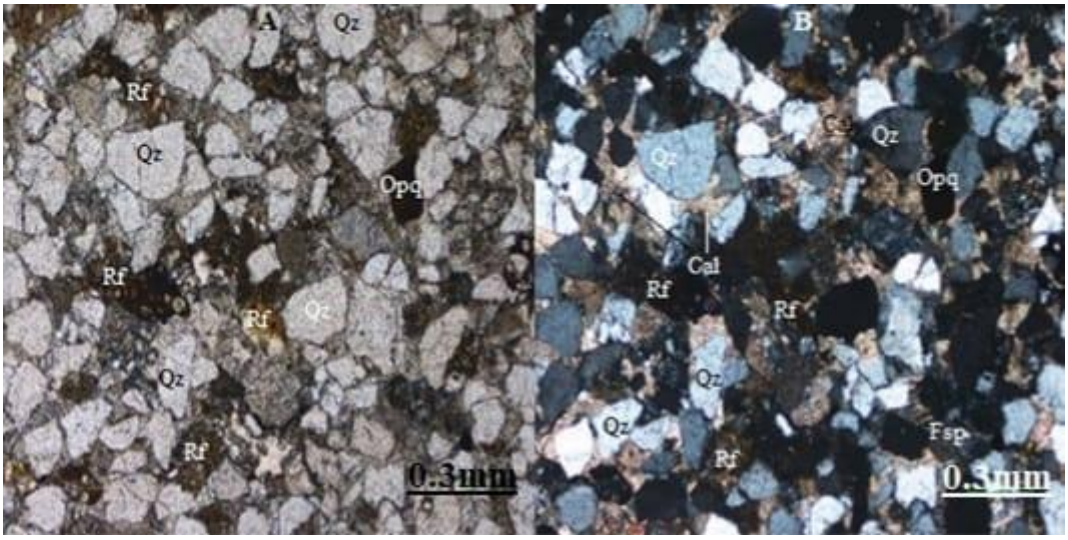


Figure 5.1 Photomicrograph of AT01 showing calcite (Cal), feldspar (Fsp), rock fragments (Rf), and quartz (Qz). Mineral abbreviations are after Whitney and Evans (2010). A: Plane Polarized Light. B: Cross Polarized Light

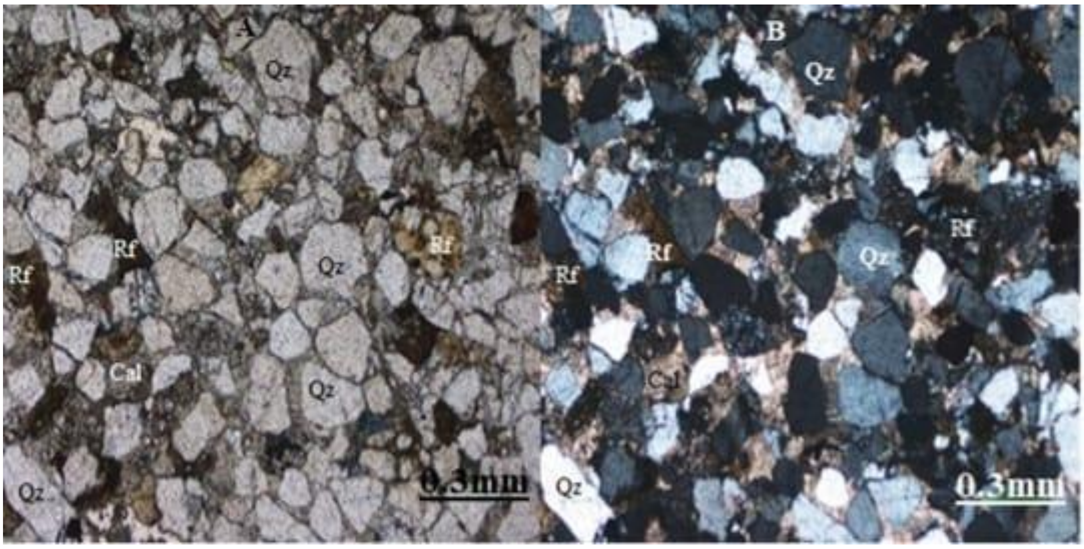


Figure 5.2 Photomicrograph of AT01 showing calcite (Cal), rock fragments (Rf), and quartz (Qz). A: Plane Polarized Light. B: Cross Polarized Light

5.1.2 AT (02)

Sandstone is very fine- to fine- grained and texturally immature. Quartz is mainly non-spherical to angular-sub angular and ranges up to 32% by the volume (Fig. 5.3). Some of the crystals show polycrystalline quartz. Mostly contacts are straight but sutured contacts are also present, as most of the grains are cement-matrix supported. Cementing material is calcite and ferruginous. Cementing material makes up to 28% by the total volume (Fig. 5.3). Both alkali feldspar and plagioclase present and make up to 3% by volume. Opaque minerals occur up to 5% by volume. Epidote occurs in traces.

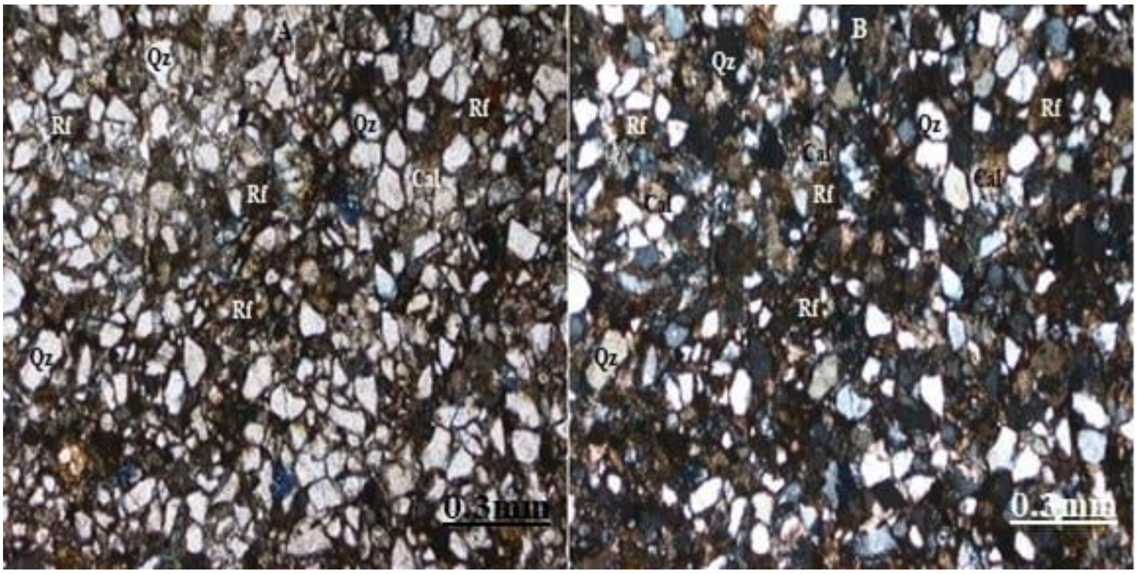


Figure 5.3 Photomicrograph of AT02 showing calcite (Cal), feldspar (Fsp), rock fragments (Rf), and quartz (Qz). A: Plane Polarized Light. B: Cross Polarized Light

5.2.3 AT (03)

Sandstone is fine- to medium - grained and texturally immature. Quartz is mainly angular to sub angular to sub-spherical and ranges up to 30 % by the volume (Figs. 5.4 and 5.5). Some of the crystals show polycrystalline quartz. Cementing material is calcite. Cementing material makes up to 14 % by the total volume. Sandstone fragments compose quartz, clay material and feldspar and ranges up to 51% by volume (Figs 5.4 and 5.5). Both alkali feldspar and plagioclase present and make up to 2 % by volume. Opaque minerals occur up to 3% by volume.

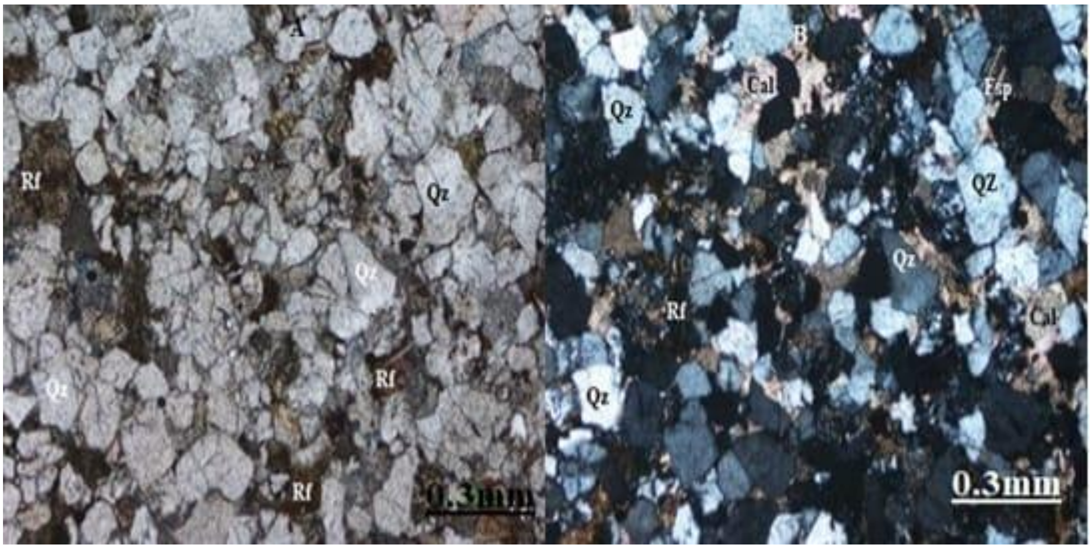


Figure 5.4 Photomicrograph of AT03 showing calcite (Cal), feldspar (Fsp), rock fragments (Rf), and quartz (Qz). A: Plane Polarized Light. B: Cross Polarized Light

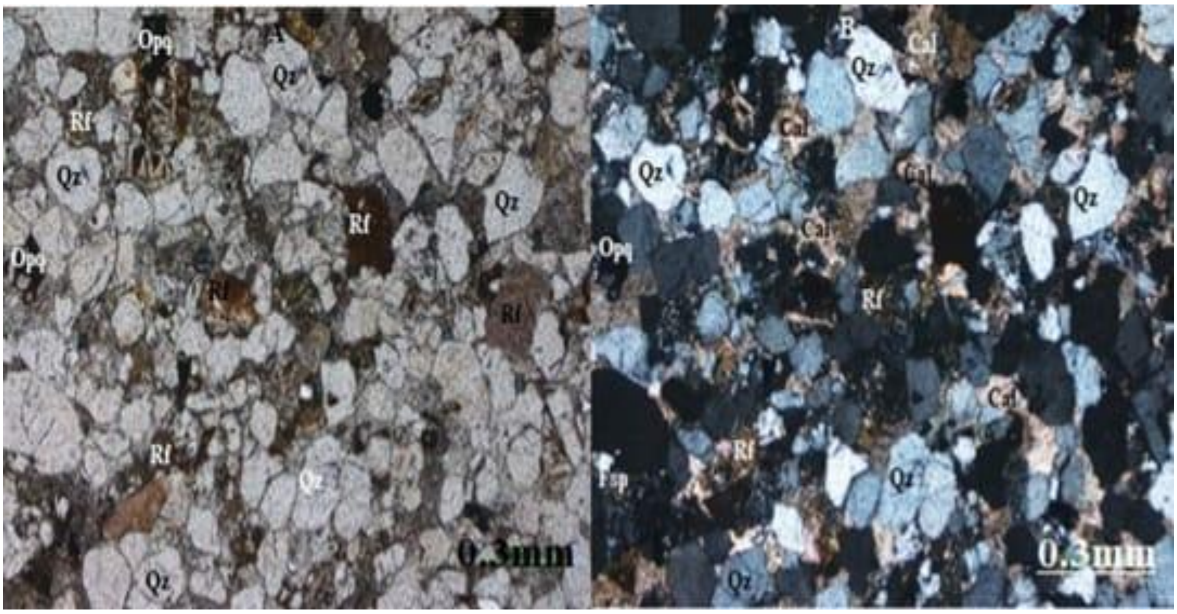


Figure 5.5 Photomicrograph of AT03 showing calcite (Cal), feldspar (Fsp), rock fragments (Rf), opaque mineral (opq) and quartz (Qz). A: Plane Polarized Light. B: Cross Polarized Light

5.2.4 AT (04)

Sandstone is fine- to medium- grained showing texturally immature. Quartz is mainly angular to sub angular to sub spherical and ranges up to 35 % by the volume (Fig. 5.6). Some of the crystals show polycrystalline quartz. Cementing material is calcite. Cementing material makes up to 20 % by the total volume. Both alkali feldspar and plagioclase present and make up to 3.5 % by volume. Opaque minerals occur up to 1.5% by volume.

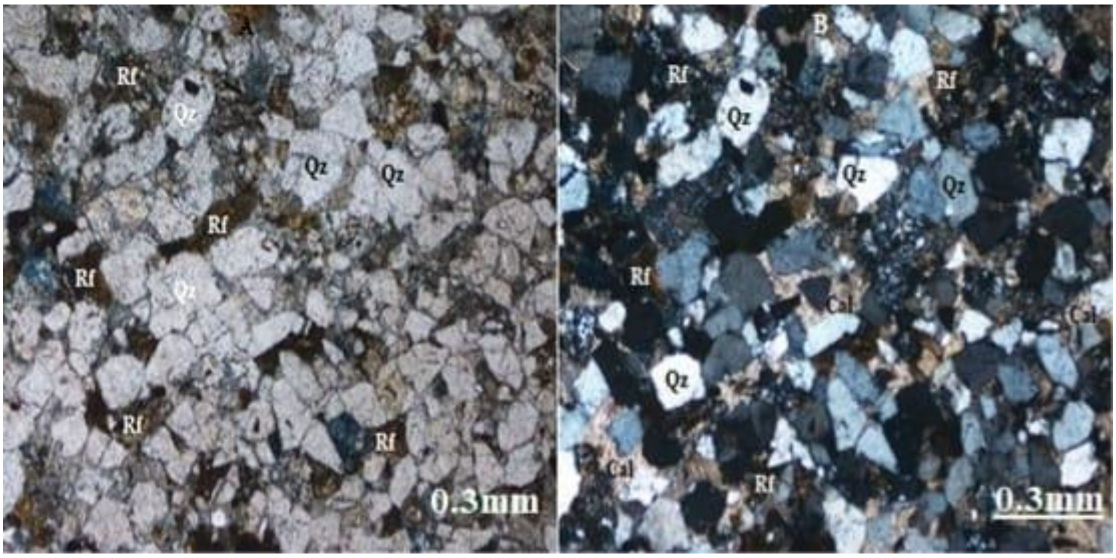


Figure 5.6 Photomicrograph of AT04 showing calcite (Cal), feldspar (Fsp), rock fragments (Rf), and quartz (Qz). A: Plane Polarized Light. B: Cross Polarized Light

5.1.5 AT (05)

Sandstone is fine- grained showing texturally immature. Quartz is mainly angular to sub angular to sub spherical and ranges up to 55% by the volume (Figs. 5.7 and 5.8). Some of the crystals show polycrystalline quartz. Cementing material is calcite. Cementing material makes up to 15 % by the total volume. Sandstone fragments compose quartz, clay material and feldspar and ranges up to 25% by volume. Both alkali feldspar and plagioclase present and make up to 3 % by volume. Opaque minerals occur up to 3 % by volume.

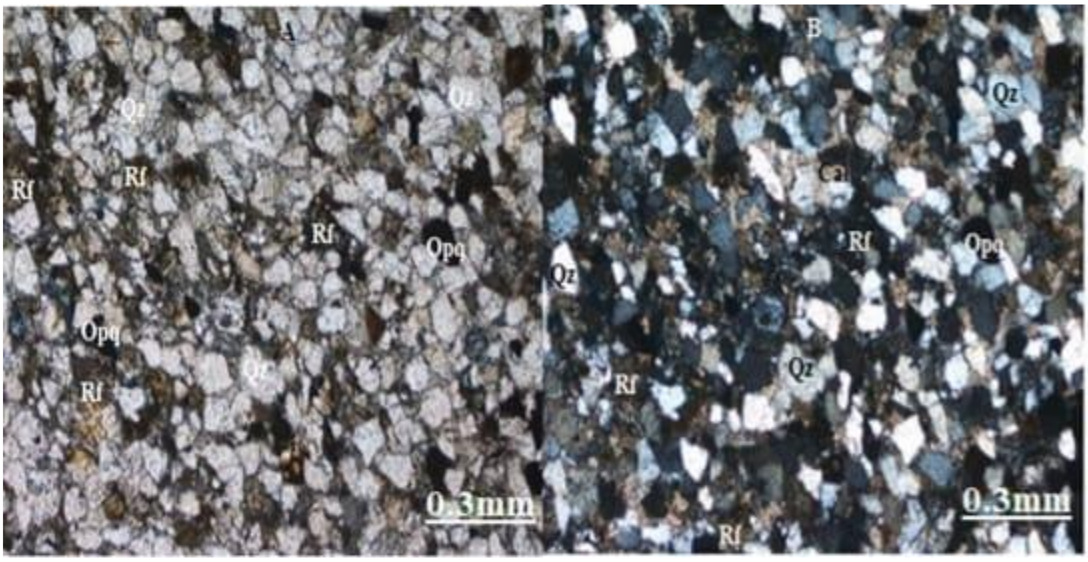


Figure 5.7 Photomicrograph of AT05 showing calcite (Cal), feldspar (Fsp), rock fragments (Rf), and quartz (Qz). A: Plane Polarized Light. B: Cross Polarized Light

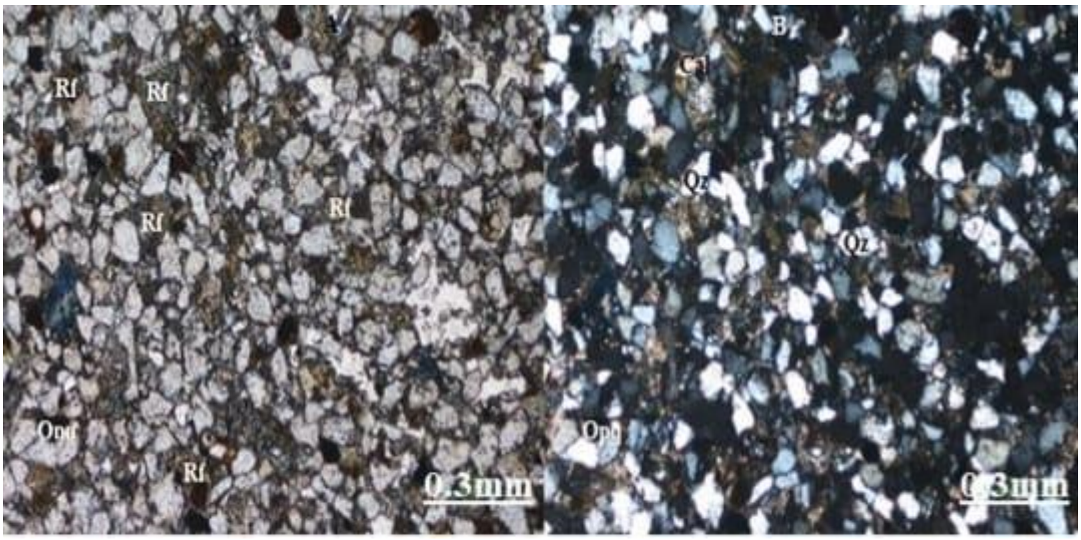


Figure 5.8 Photomicrograph of AT05 showing calcite (Cal), feldspar (Fsp), rock fragments (Rf), and quartz (Qz). A: Plane Polarized Light. B: Cross Polarized Light

5.2 Geotechnical Analysis

The strength of Murree sandstone has been investigated through geotechnical tests in order to determine whether it is reliable for use in construction. Geotechnical studies such as UCS (Uniaxial Compressive Strength), UTS (Uniaxial Tensile Strength), Water Absorption, and Specific Gravity have revealed the strength of well-developed rock and highly worn joints. These tests were all performed in the geotechnical labs. The results of the tests are listed below.

5.2.1 Physico-mechanical Properties

Physico-mechanical properties analysis was conducted at National Centre of Excellence in Geology (NCEG), University of Peshawar. Following tests were performed.

5.2.1.1 Uniaxial Compressive Strength (UCS) ASTM D-2938

The greatest stress that a specimen can withstand is the UCS, which is a uni-directional stress applied to a cubic rock sample. The values of UCS in the sandstone of Murree Formation are displayed in table 5.2. The Murree sandstone has a maximum strength value of 50.9 MPa and a minimum strength value of 16.1 MPa

5.2.1.1.1 Testing Procedure

Placed the rock sample on the load frame's base plate, i.e., put between the end plates (Fig. 5.9). A hardened steel ball was placed on the bearing plate. The specimen's center line was then adjusted such that the steel ball and the proving ring were in the same plane. For estimation the rock sample’s vertical compression, fixed a dial gauge. A suitable vertical displacement was achieved by adjusting the gear position on the load frame. Started applying the load, and after every 5 mm of compression, noted the readings on the proving ring dial and compression dial. Till failure was completed, kept loading. Produced a diagram of the rock sample's failure pattern.

Figure 5.9 cubic sample after the UCS test

Table 5.2: UCS values of collector rock sample during the field

Sample Number	Area(in)^2	Load (lbf)	Strength (psi)	Strength (Mpa)
1a	4.8	25192	5248	36.2
1b	4.8	23310	4856	33.5
1c	4.8	28050	5844	40.3
2a	4.8	27234	5674	39.1
2b	4.8	32932	6861	47.3
2c	4.8	27733	5778	39.8
3a	4.8	13267	2764	19.1
3b	4.8	16803	3501	24.1
3c	4.8	14228	2964	20.4
4a	4.8	35411	7377	50.9
4b	4.8	26767	5576	38.4
4c	4.8	14625	3047	21.0
5a	4.8	11220	2338	16.1
5b	4.8	12523	2609	18.0
5c	4.8	11905	2480	17.1

5.2.1.2 Indirect Tensile Strength (ITS) ASTM D-3967

A rock's resistance to bending is measured by its splitting tensile strength, which is typically lower than its compressive strength. By using core samples with a thickness, the indirect or Brazilian technique was used to calculate the Murree Formation sandstone's splitting tensile strength. The Brazilian test was conducted on three separate samples (Table 5.3). The Murree Formation sandstone in the Brazilian test has the greatest strength value of 8.69 MPa, whilst the lowest strength is only 2.31 MPa.

5.2.1.2.1 Testing Procedure

The Brazilian test indirectly determines the tensile strength of rocks used in rock mechanics, which is lower than the compressive strength of rocks as a whole. To conduct the Brazilian and/or Indirectly Tensile Strength test, the following procedures were adopted. The sample was placed into the cell and 0.2-0.4mm adhesive paper was wrapped around its surface (Fig. 5.10). The sample was then placed into the loading device to break down it within 15 to 30 seconds. The maximum loading strength of typical loading devices made for Brazilian tests was 100kN. The rock sample broke along all its diameter (Fig. 5.11).

Calculations

To derive the tensile strength of a single sample the following equation was applied:

$$\sigma_t = \frac{2 * P}{\pi * D * t} = 0.636 * \frac{P}{D * t} \quad [1]$$

Where,

σ_t: The Tensile Strength of the specimen

P: The recorded Load

D: The Diameter of the specimen

t: The Width of the specimen

Figure 5.10 Core sample during the UTS test

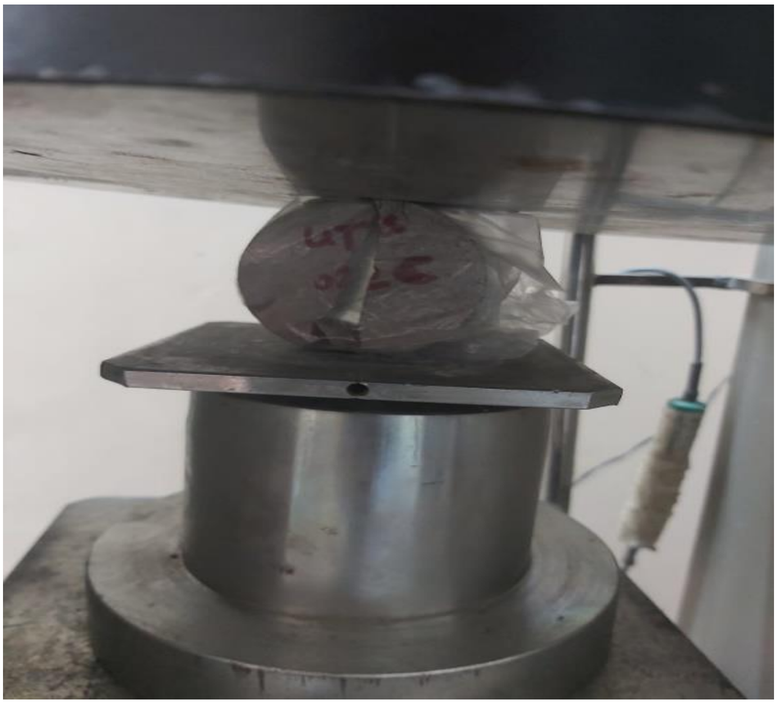


Figure 5.11 Fracture disc sample after UTS test

Table 5.3: ITS values of collector rock sample during the field

Sample Number	Area(in)^2	Load (lbf)	Strength (psi)	Strength (Mpa)
1a	3.2	1872	585	4.03
1b	3.4	1609	473	3.26
1c	3.6	2628	730	5.03
2a	3.3	3919	1188	8.19
2b	3.7	1950	527	3.63
2c	3.5	3382	966	6.66
3a	3.5	4411	1260	8.69
3b	3.8	3382	890	6.14
3c	3.5	2891	826	5.70
4a	3.8	2212	582	4.01
4b	3.5	2366	676	4.66
4c	3.5	2002	572	3.94
5a	3.3	2244	680	4.69
5b	3.8	1275	336	2.31
5c	3.7	1750	473	3.26

5.2.1.3 Specific Gravity and Water Absorption Test of (Rock Cube Sample)

The specific gravity of rocks greater or equal to 2.55 are generally consider suitable for heavy construction works (Blyth and DeFreitas,1974). Finding the source of the water absorption is important because repeated hydration and dehydration causes mechanical disruption in small exposed rock areas, allowing water to infiltrate the rock and increasing and intensifying weathering.

The results of the specific gravity and water absorption tests, displayed in table 3.4, demonstrate that the maximum specific gravity is 2.676, while the lowest specific gravity is 2.636, and the highest water absorption test was 0.41%, with the lowest water absorption capability being 0.30%.

5.2.1.3.1 Testing Procedure

The air dried weight of the rock samples were determined, then the samples were immersed in the water for 24 hours and weighted in water. Rock samples were then placed in an oven for 24 hours to determine the oven-dried weight. Specific gravity was determined by the following formula.

S.G = Oven-dried weight **** Oven-dried weight-weight in water

The feasibility of rocks for construction purposes depends on their specific gravity and it's believed that rocks with specific gravity greater than 2.55(US DOT, 1995) are suitable for use in heavy construction work. The results of specific gravity for the studied rock samples are given in table 5.4.

Table 5.4 SG and WA values of collector rock sample during the field

Sample Number	Weight in air in gram	Weight in water in gram	Oven dry weight in gram	Absorption	%Absorption	Specific gravity
1a	408.46	253.91	407.09	1.37	0.34	2.658
1b	409.29	253.23	407.97	1.32	0.32	2.636
1c	450.78	280.22	449.41	1.37	0.30	2.656
2a	439.05	273.95	437.42	1.63	0.37	2.676
2b	413.88	257.81	412.19	1.69	0.41	2.670
2c	416.14	259.79	414.95	1.19	0.29	2.674
3a	436.20	270.72	434.81	1.39	0.32	2.650
3b	410.88	255.16	409.45	1.43	0.35	2.654
3c	421.62	262.14	420.29	1.33	0.32	2.658
4a	490.64	305.89	489.41	1.23	0.25	2.667
4b	421.95	262.98	420.81	1.14	0.27	2.666
4c	340.52	211.58	339.48	1.04	0.31	2.654
5a	402.82	250.12	401.29	1.53	0.38	2.655
5b	403.43	250.6	401.08	2.35	0.59	2.665
5c	410.27	255.47	408.84	1.43	0.35	2.666

5.3 Discussion

5.3.1 Maturity

The relative abundance of stable and unstable framework grains is referred to as compositional maturity. Sandstone based maturity can be determined in two different ways, i.e. (1) to contain abundant quartz and (2) abundant feldspar (Boggs, 2011). The degree of rounding and sorting of the framework grains, as well as the relative abundance of the matrix, influence the maturity of the texture, e.g., from immature (with much clay and poorly sorted, rounded, and shaped framework grains) to super-mature (little or not any clay, well sorted, and rounded framework grains) (Boggs, 2011). Textural maturity also reflects how much a material has been moved and reworked throughout the sedimentary cycle. Diagenetic events may also have an impact on textural maturity (Boggs, 2011).

The sandstone of the Murree Formation is moderately to poorly sorted and fine- to medium- grained. The framework grains such as quartz, feldspar and rock fragments are angular to sub-angular and to sub-rounded. Their relative abundance and petrographic features reflect that the Murree sandstone is minerlogically sub-mature and immature in texture. Quartz is mainly anhedral to subhedral and ranges up to 55% by the volume. Polycrystalline quartz is also noticed. Cementing material is calcite and ferruginous. Mostly, contacts are straight but sutured contacts are also present, as most of the grains are cement-matrix supported. Cementing material makes up to 14-28% by the total volume. Rock fragments compose, quartz, clayey material and feldspar and ranges up to 51% by volume. Both alkali feldspar and plagioclase feldspars make up to 2-3% by volume. Opaque minerals occur up to 1.5- 5% by volume. Tourmaline, epidote and monazite occur in traces.

5.3.2 Provenance of the Murree Formation

Provenance defines the source rocks. Sandstone may comprise of igneous, metamorphic and other sedimentary rock fragments. It is important to know from where, the minerals comprising sandstone come from. The transportation process cannot alone tell about the source rock composition well, but the mineralogical and geochemical composition discriminate the sandstone in different compositional and tectonic domains. Based on grain mineralogy, sandstones are divided into mainly three groups: Quartz arenite, feldspathic arenite, and lithic arenite (Pettijhohn, 1963).

The sandstone of the Murree Formation in investigated area plot in recycled orogen field (e.g., Dickinson et al., 1983) and the ternary plot of Dickinson (1985) (Figs. 5.12 and 5.13) indicating that the sandstone of the Murree Formation might have been derived from recycled orogenic provenance. Stratified rocks can be deformed, uplifted, and eroded in tectonic environments during orogenic recycling (Dickinson, 1985). Critelli and Garzanti (1994) claimed that the main petrographic parameters of the Balakot Formation in the Murree sequence did not significantly change over the course of its deposition, and that igneous and metamorphic rock detritus persevered until the Early Miocene.

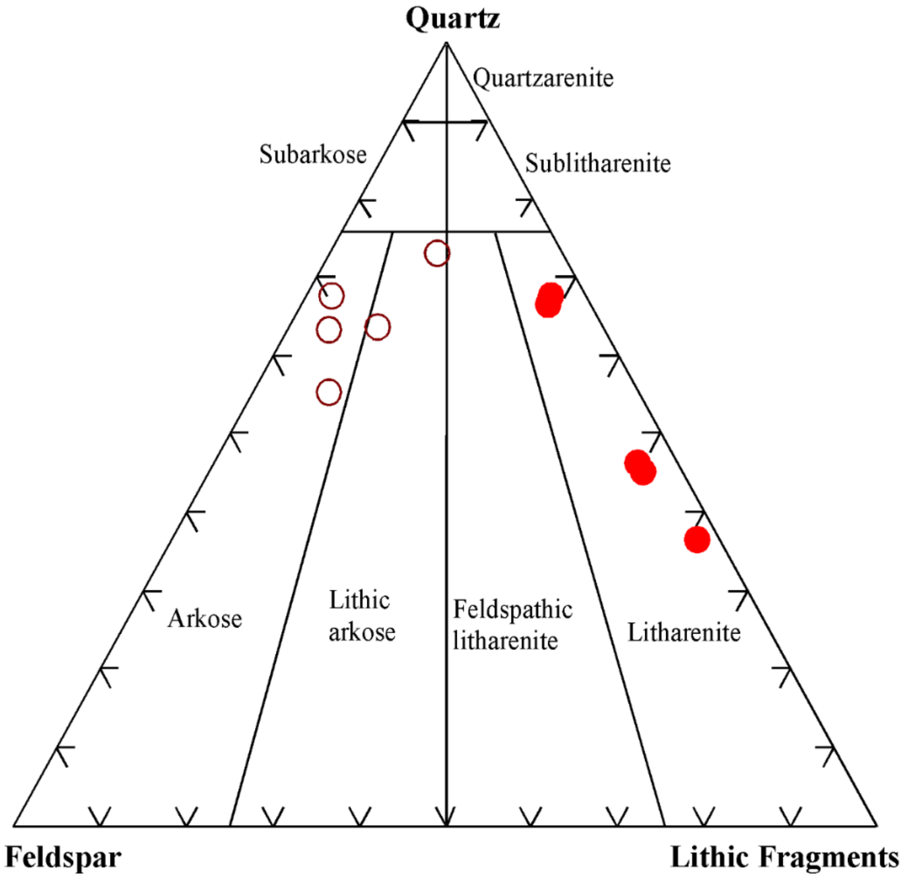


Figure 5.12 Ternary diagram Folk (1968) showing the sandstone of the Murree Formation (filled circles). For comparison, data of Yar et al. (2017) (open circle).

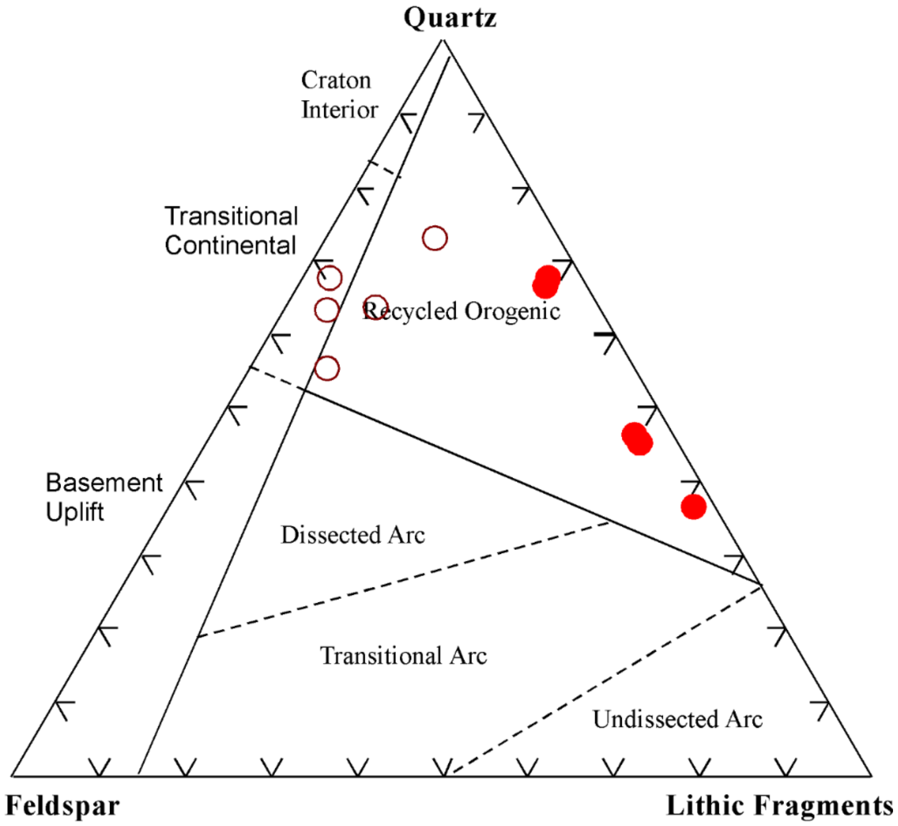


Figure 5.13 Ternary plot of Okada (1971) showing the sandstone of the Murree Formation (filled circles) plotting in Recycled Orogen for comparison, data of Ullah (2009) (open circles).

5.3.3 Depositional Environment of the Murree Formation

The rock fragments in the sandstone of Murree Formation reveal their derivation of mixed provenance, i.e., metamorphic, igneous, and sedimentary rocks. The siliciclastic and carbonate were derived from the Tethyan rock sequence (Mughal et al., 2018). The metamorphic and igneous rock fragments seemed to derive from from the Lesser and Higher Himalaya (Gansser, 1964).

5.4 Correlations between Geotechnical and Petrographic Properties

Regression analysis has been used to determine the relationships between the test data and the results. The process includes drawing a line through the points that is calculated to minimize the squared deviations of the measured points from the line. The relevant equation defines the line, and the value of the R-square, or coefficient of determination, is calculated.

5.4.1 Maximum Correlation

The quartz content shows negative correlation to the ITS and UCS of the tested sandstone (Figs. 5.14 and 5.15). Likewise, the cement or matrix has positive effects on the ITS and UCS of the tested sandstone, and the trend between these parameters is shown in (Figs 5.16 and 5.17).

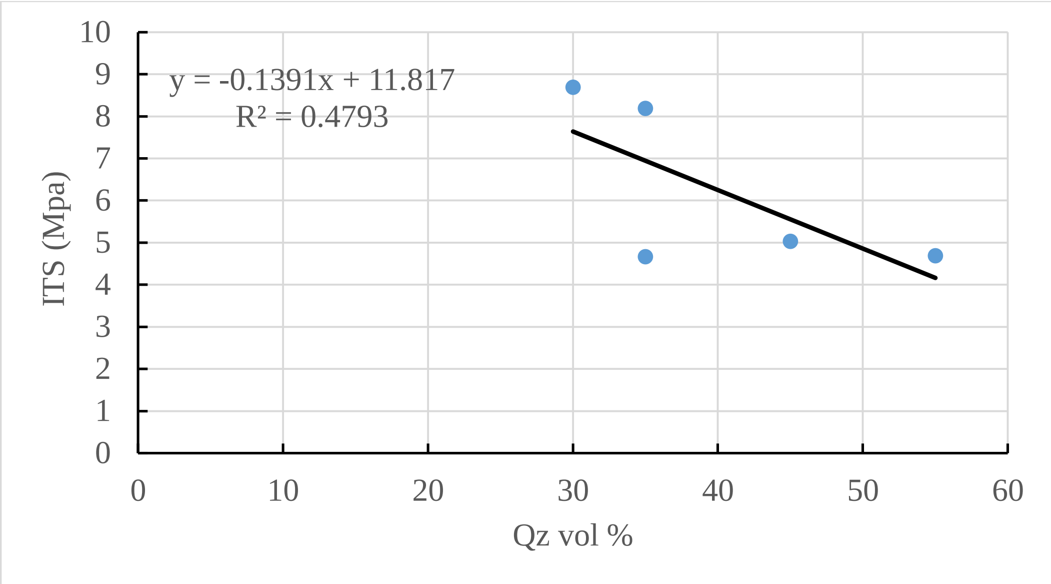


Figure 5.14 Correlation between Quartz and ITS

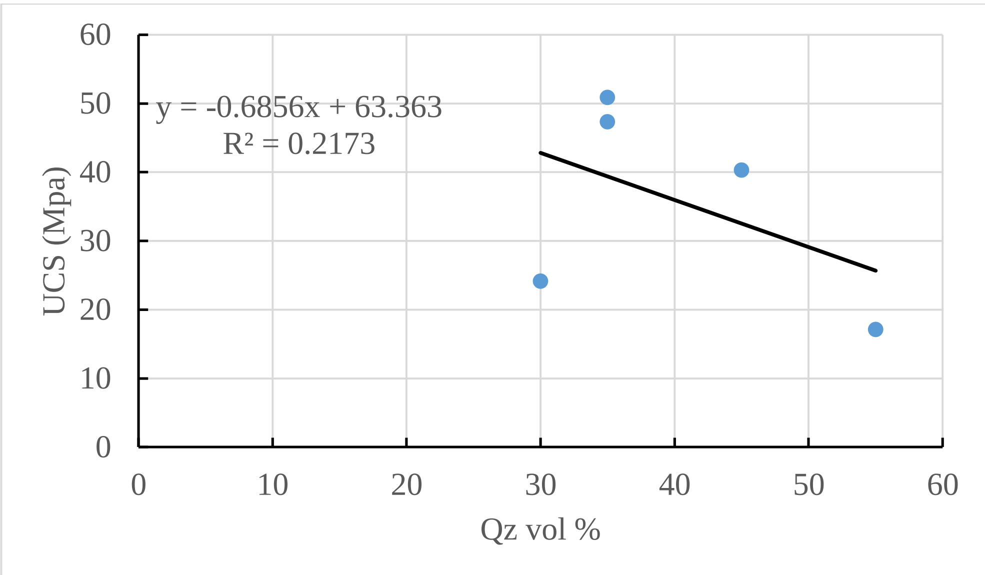


Figure 5.15 Correlation between Quartz and UCS

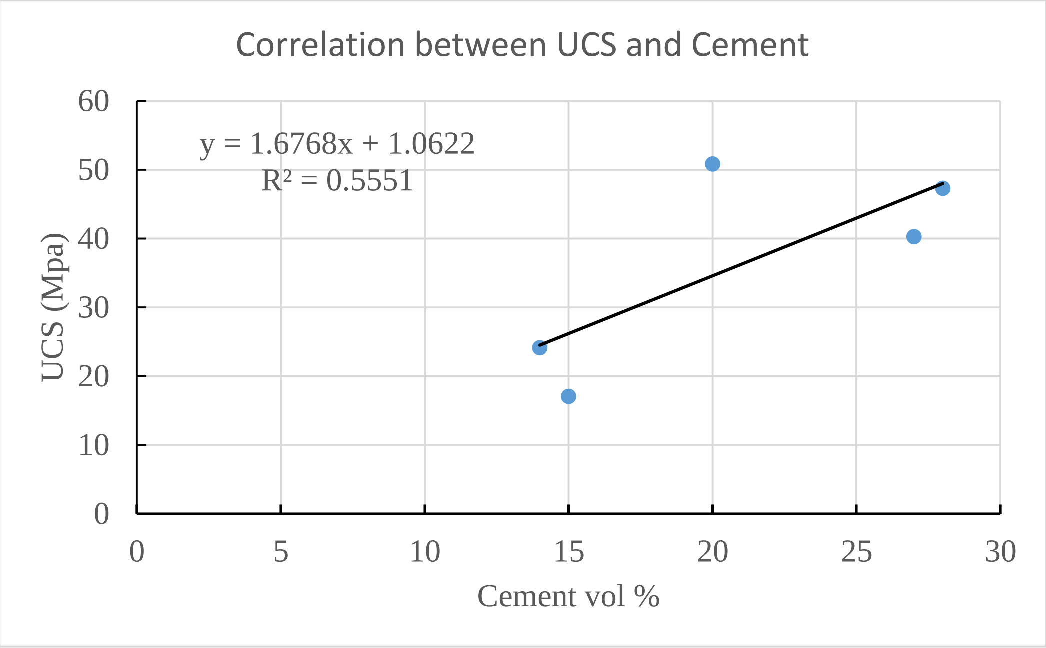


Figure 5.16 Correlation between Cement and UCS

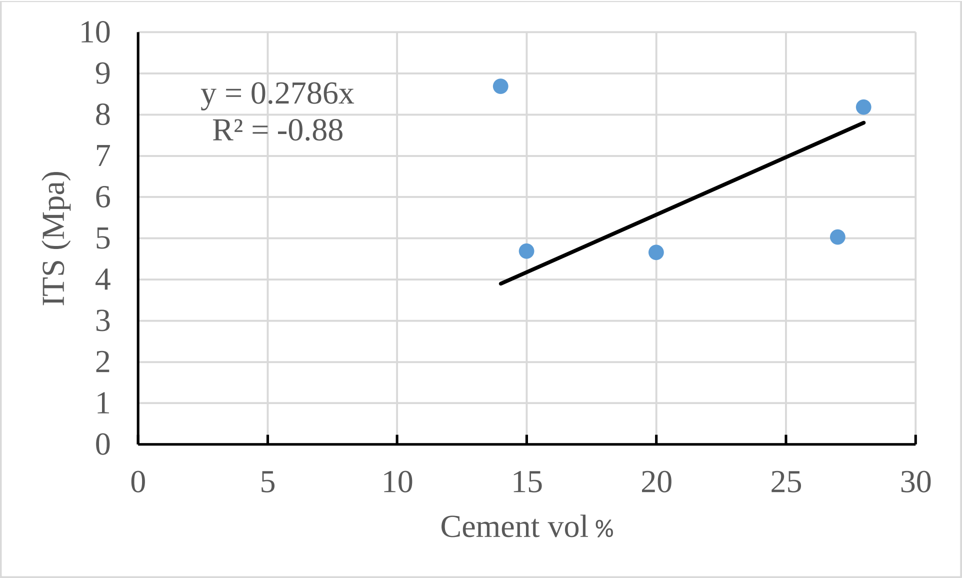


Figure 5.17 Correlation between Cement and ITS

5.4.3 Relationship between Physico-mechanical and Petrographic Properties

Different rocks vary greatly in their strengths. However, the UCS values are considered as being extremely strong for characterization. Similarly, high specific gravity and low water absorption ratings make the rocks suitability for use as construction materials. A number of variables such as abundance of cement and/or matrix, mineralogical composition, grain size, voids, degree of interlocking, type and length of grain contact influence the geo-mechanical properties of sandstones like those under study. The Murree Formatiom sandstone strength values are more significant, because of (i) minute grain size (ii) much indiscretion of their frameworks (iii) uncommon intra-granular deformational characteristics, and (iv) less quantity of matrix material.

The sandstone of Murree Formation shows high specific gravity and lower water absorption values. Comparison of the petrographic and geotechnical values are given in table 5.4.

Table 5.5: Correlation between petrographic and geotechnical characteristic

Area	Petrographic	Value	Geotechnical	Value
Murree Formation	Quartz (modal %	30-55	Average UCS (MPa)	50.9-16.1
	Feldspar (modal %)	2-3.	Average ITS (MPa)	8.19-2.31
	Matrix (modal %)	14-28	Average Specific Gravity	2.676-2.636
	Grain Size	Very fine to medium	Water Absorption (%)	0.59-0.25
	Sorting	Moderate to very well		
	Roundness	Sub-angular to sub-rounded		
	Sutured Contacts	Mostly contacts are straight but sutured contacts are also present, as most of the grains are cement-matrix supported		
	Matrix/ cement composition	calcite and ferruginous		

5.5 Conclusions

Following conclusions can be drawn from the present research study.

1. The relative modal abundance and petrographic features reflect the Murree sandstone as mineralogically sub-mature and texturally immature.

2. The classification of the Murree Formation sandstone is litharenite and belong to recycle orogenic tectonic setting.

3. The maximum and minimum value of water absorption in the sandstone of the Murree Formation is 0.59-0.25 whereas the maximum and minimum values of specific gravity stand as 2.676-2.636. Further, the maximum and minimum values of UCS (Mpa) is 50.9-16.1 and the maximum and minimum value of UTS (Mpa) is 8.19-2.31.

3. Based on the petrographic and geotechnical properties, the sandstone of the Murree Formation is considered suitable for use as dimension stones and as construction material.

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