GEOTECHNICAL INVESTIGATION OF SANDSTONE FROM MURREE FORMATION SHAHDARA AREA ISLAMABAD, PAKISTAN

A thesis submitted to Bahria University, Islamabad in partial fulfillment of the requirement for the degree of BS in Geology

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DEDICATION

We would like to dedicate our thesis to our beloved Parents and venerable faculty members who supported us for their unceasing encouragement and cooperation helped us to complete this task and throughout our academic career.

ABSTRACT

The Murree Formation is of Miocene age, which is well exposed in Shahdhara village near Islamabad. The main aim was to carry out the geotechnical investigation of Murree Formation sandstone. Ten bulk samples were collected for detailed analysis. Extensive thin section study is carried out determining various mineralogical properties followed by mechanical test such as Uniaxial Compressive Test. Specific gravity, and water absorption test were also employed on the sandstone samples to further access their mechanical characteristics. The mechanical and mineralogical properties were then correlated for the determination of strength qualities. Thorough fractures analysis is carried out of Murree Formation determining extent and relation of fractures with each other. After analyzing physical properties, mechanical properties, and other essential properties of rock strength, the result obtained showed that the sandstone rocks are moderately strong for use in construction.

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We are extremely thankful to respective staff at Steel Testing Laboratory, University of Engineering and Technology, Taxila and National Centre of Excellence in Geology (NCEG) Peshawar for facilitating us in thin sections photographs. We are also thankful to our parents for their consistent encouragement, belief in our abilities, prayers, and their endless love and affection which kept us motivated.

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CHAPTER 1
INTRODUCTION

1.1 General Introduction

Murree Formation is Miocene age is a member of Rawalpindi group, which is named after the district Rawalpindi. The name Murree Formation was approved by stratigraphic committee of Pakistan after its type locality Murree hills in Rawalpindi, District. Murree formation consists of dark red to maroon color siltstone and clay inter-bedded with red, brown and grey color sandstone (Kazmi and Jan, 1997).

1.2 Location and Accessibility

The study area is located at Shahdara village, Islamabad. Shahdara lies 10km away from President house north-east in Margalla hills. The values of Latitude and the Longitude are 33° 75′ 70 N, 73° 16′ 64 E and 33° 77′ 65 N, 73° 17′ 30 E. The area is well accessible from Islamabad through a network of metaled roads and all means of transportation facilities.

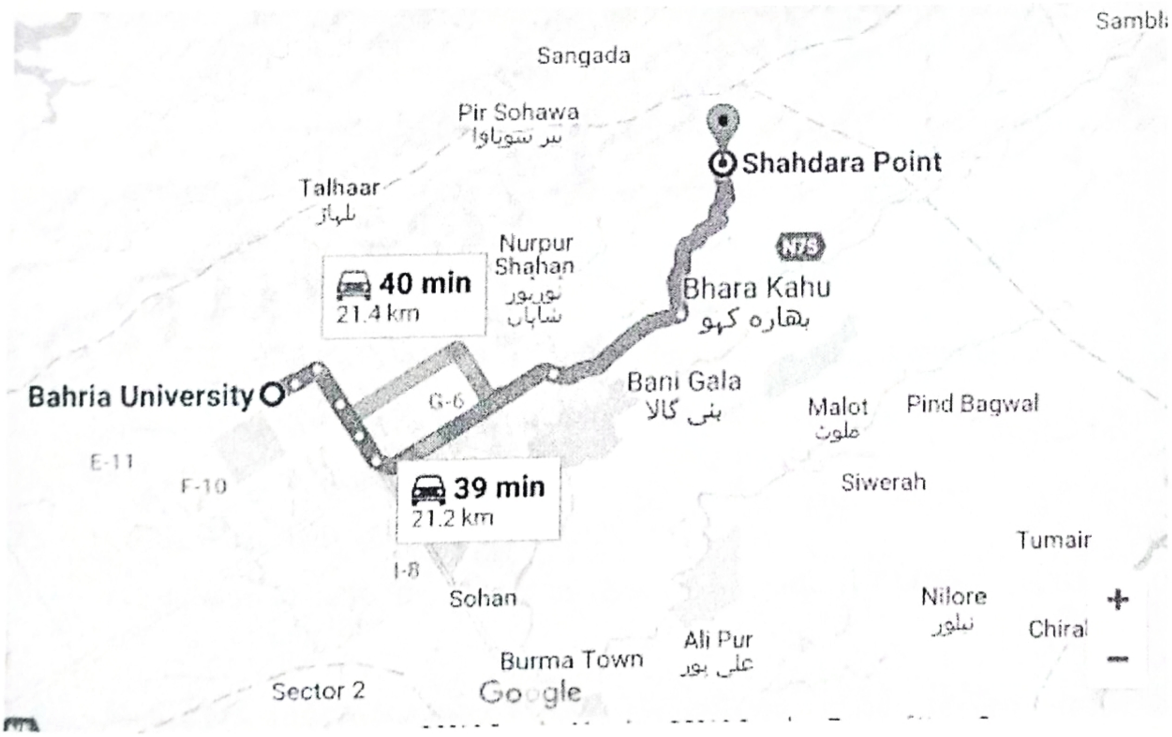

Figure 1.1. Location and accessibility map of study area. (Google maps)

1.3 Climate and Geography of the Area

The study area is located in the semi-arid region of Pakistan, where summers are generally hot with an average maximum temperature of 42 °C, while winters are extremely cold. The climate of the area is similar to that of Islamabad. Shahdara hosts many fountains and water falls and is an important picnic destination for many locals and outside visitors. Winter season last from November to February, spring from March to April, summer from May to June , Autumn from September to October while monsoon last for July to August. Study field can be organized and carried out in any part of the area and season. The outcrop host many distinct features and geologic variations.

1.4 Aims and Objectives

The present study is aimed at presenting and carrying out a detailed geotechnical investigation of the sandstone unit of Murree Formation. The geotechnical study aimed at achieving interpretation of the mechanical and petrographic features and there mutual correlation with particular emphasis on the following objectives:

1. Classification of Murree sandstone on the basis of Petrographic study.
2. Textural and mineralogical maturity.
3. Determination of the mechanical properties of the Murree sandstone and fracture analysis.

1.5 Methodology

The present study was carried out through the following methodologies:

1. Collection of bulk sandstone samples from the study area.
2. Thin section preparation.
3. Mechanical/strength test such as UCS.
4. Correlation of petrographic and mechanical properties of Murree sandstone.

1.5.1 Fieldwork and Laboratory work

Extensive field work was carried out to the study area in order to observe the outcrop and to collect fresh sandstone rock samples from the bed rock for microscopic study and determining mechanical properties (Fig 1.2). Different stratigraphic and lithological units and variations were identified on the basis of their distinguishing properties.

Bulk sandstone samples were then cut into blocks for the uniaxial compressive test which was carried out at the Steel Testing Laboratory of UET, Taxila. Thin sections for petrographic study of sandstone samples were prepared. Specific gravity, water absorption and porosity of sandstone samples were determined in chemistry laboratory at Bahria University, Islamabad.

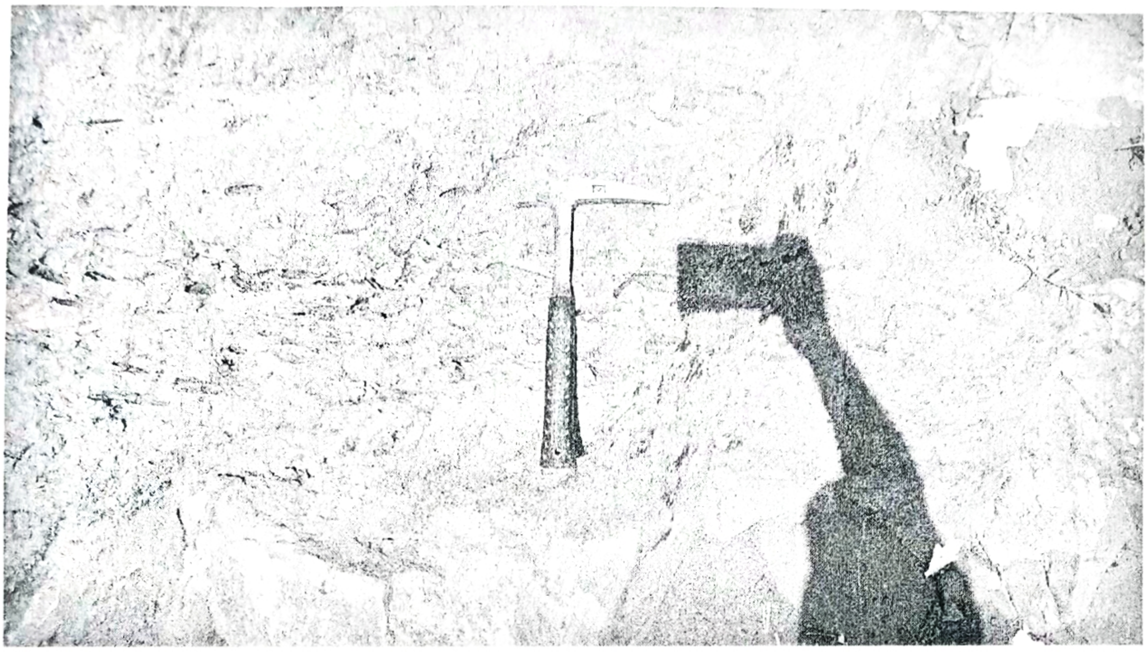

Figure 1.2 Conglomerate beds observed in Murree Formation

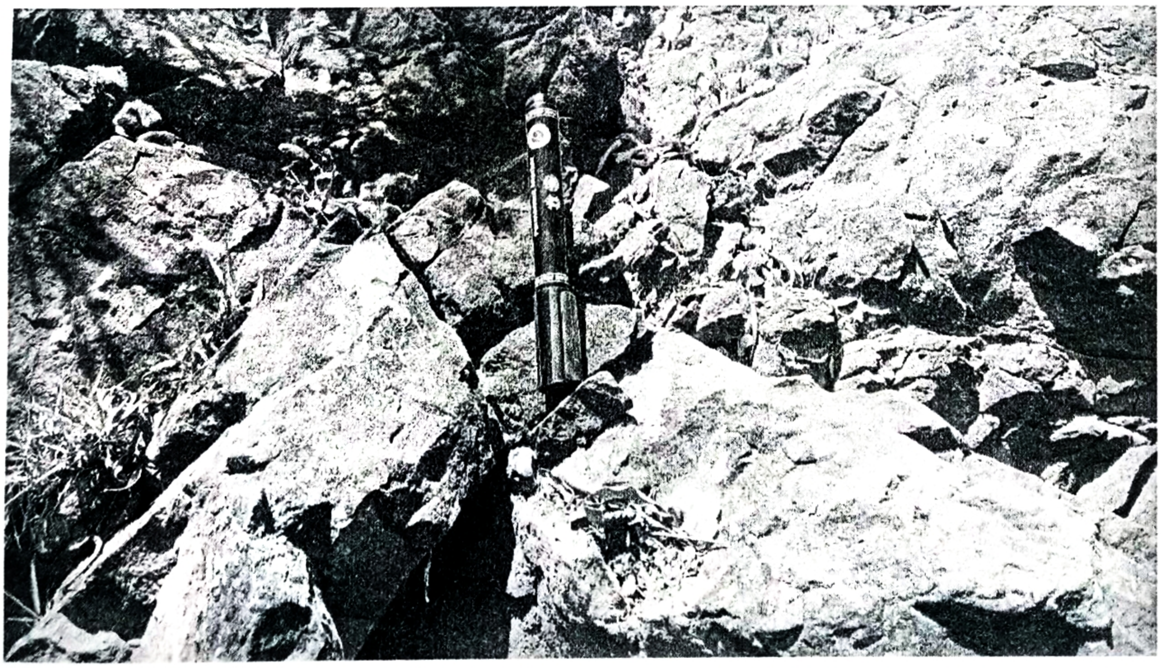

Figure 1.3 Highly fractured Murree sandstone observed during field

CHAPTER 2

STRATIGRAPHY AND TECTONIC OF PAKISTAN

2.1 Tectonic setting

Himalaya, the youngest and perhaps the most magnificent of all the continent-continent collisions on the earth was created due to the collision involving Eurasian plate in the north with the Indian plate in the south at about 65-50 Ma (Gansser, 1964; LeFort, 1975; Molnar and Tapponier, 1975; Fraser et al., 2001).

The Himalaya originated as a result of the separation of the Indian plate from the mother Gondwana land and its northward drift at about 130 Ma ago (Johnson et al., 1976). As a result of this northward drift of Indian plate the Neo-Tethys started shrinking which was located between the Indian and Eurasian plates (McKenzie and Slater, 1976). An intra-oceanic subduction generated Nuristan, Kandahar and Kohistan-Ladakh arcs at the time of Neo-Tethys closure (Treloar and Izzat, 1993; Searle, 1991). For a time of almost 40 Ma, this arc magmatism continued (Petterson et al., 1985). The Kohistan-Ladakh arc collided onto the Eurasian plate in the north forming an Andean type of continental margin as a result of the back arc basin closure. According to Coward et al. (1986) the collision between Kohistan-Ladakh arc and Eurasian plate gave birth to a boundary named as the Main Karakorum Thrust (MKT) at 70~100 Ma ago. The Main Karakorum Thrust (MKT) separates igneous, meta-sedimentary and deformed sedimentary rocks of the southern Eurasian plate from the Kohistan Island Arc (KIA) terrain situated in the north.

Subduction of the Neo-Tethys continued underneath the Kohistan-Ladakh arc till the complete consumption of the leading edge of the Indian plate that finally collided with the remnant of Kohistan-Ladakh arc (Powell, 1979). This collision occurred between 65~50 Ma and as a result the Main Mantle Thrust (MMT) was formed (Chamberlain and Zeitler, 1996; Tonarini et al., 1993; Maluski and Matte, 1984; Smith et al., 1994).

The litho-tectonic domains of Pakistani Himalayas have been explained briefly;

2.1.1 Karakorum block

Consisting of complex assemblages of heavily deformed sedimentary, meta-sedimentary and igneous rocks of the southern Eurasian plate, Karakorum block lies between Pamir in the north and Kohistan-Ladakh arc in the south. The Karakorum block and Kohistan-Ladakh arc collided with each other 70~100 Ma ago and gave birth to MKT (Yoshida et al., 1997; Treloar et al., 1989).

2.1.2 Main Karakorum thrust

The Main Karakorum Thrust (MKT) is making the southern boundary of Karakorum blox ck. In northern Pakistan MKT is present as a major tectonic feature. The main Karakorum thrust has resulted from collision of the north lying Karakorum plate and southward Kohistan Island Arc (KIA) (Tahirkheli, 1979, 1982, 1983). Pudsey et al. (1985) named it as Northern Suture.

2.1.3 Kohistan island arc

The northward drift of Neo Tethys beneath Eurasian plate in the time period of late Jurassic to Cretaceous led to the development of the Kohistan Island Arc (Hamidullah and Onstot, 1992; Searle et al., 1987; Tahirkheli, 1979). The Indian plate is separated from the overlying Kohistan Island Arc marked by a suture zone characterized by the presence of blue schist facies rocks. Volcanic rocks, calc-alkaline plutonic, ultramafic and mafic comprise of a thick cover of 40 km and cover 36000 km2 in western Himalaya, Karakorum and Hindukush constitute the Kohistan Island Arc (Hamidullah and Onstot, 1992). The orientation of the arc is east west comprising of plutonic and volcanic rocks with subsidiary sedimentary rocks, which are deformed and metamorphosed to some degree. The north south trending Nanga Parbat Haramosh Massif divides the arc further into Kohistan and Ladakh arcs and Indian plate is lying under it (Seeber and Armbuster, 1979). Kohistan Island Arc is bordered by MKT and MMT in the north and south respectively, and join each other in Tibet and India laterally to form a distinct suture, the Indus Tsangpo Suture Zone (Ahmad, 2003). Both these faults join together to merge in the left lateral Kunar fault in the vicinity of Afghanistan (Ahmad, 2003).

2.1.4 Main Mantle thrust

The Main Mantle Thrust (MMT) lies in the north of the Northern Deformed Fold and Thrust Belt (NDFTB). It involves the lower crust and is dipping towards north between 25-45° (Bard, 1983; LeFort, 1975; Malinconico, 1986). However, the formation of MMT did not stop the convergence and continued at a rate of 5mm per year since Eocene that resulted in continent-arc-continent collision (Karakorum-Kohistan-India) (Patriate and Achache, 1984).

2.1.5 Northern deformed fold and thrust belt

Comprising of heavily deformed sedimentary, meta-sedimentary and igneous rocks, the Northern Deformed Fold and Thrust Belt (NDFTB) is bordered by MMT in the north and MBT in the south distinguishing it from the south lying Southern Deformed Fold and Thrust Belt. The NDFTB is stretched from Kurram region near Afghan border in the west up to the Kashmir basin in the east (Khan, 2011). The Main Boundary Thrust (MBT) and the Salt Range Thrust (SRT) are the major members of this fault system (Yeats and Hussain, 1987; Zeitler, 1985; Zeitler, 1982).

2.1.6 Main boundary thrust

The Main Boundary Thrust (MBT) is extended along the front of the northern fold and thrust belt around Hazara-Kashmir syntaxes from northeast to southwest, representing the southward migration of Himalayan deformation from the site of MMT in the north. The hanging wall of MBT carries the pre-collisional Paleozoic and Mesozoic sedimentary and meta-sedimentary rocks of the Northern Deformed Fold and Thrust Belt and post collisional folded Miocene foreland basin deposits in its footwall (Khan, 2011). According to Seeber and Armbuster (1979); and Yeats and Lawrence (1984) the MBT is connected to the Hazara and Murree faults that bound the northern margins of Hazara and Kalachitta range.

2.1.7 Southern deformed fold and thrust belt

The Southern Deformed Fold and Thrust Belt (SDFTB) rim the Himalayan mountain belt from Ganges delta in India up to the South Waziristan Agency in Pakistan. It is oriented east west and is underlain by a thick pile of fluvial sediments. The southern deformed fold and thrust belt is further divided into Kohat Plateau in the west and Potwar Plateau in the east of Indus River. Potwar Plateau comprise internally less deformed fold and thrust belt with approximate width of 150 km in north south direction (Kazmi and Rana, 1982). Salt Range Thrust (SRT) and Trans Indus Range Thrust (TIRT) lies in the south of the SDFTB separating it from Punjab Foredeep. Deformation is mostly restricted to the Northern Potwar Deformed Zone (NPDZ), which is located in the north of the Plateau (Baker et al., 1988; Leather, 1987). The SRT & TIRT represent an active deformational front along which Cambrian to Paleocene rocks are thrust onto the Punjab Foredeep in the south (Ahmad, 2003). Kohat Plateau is located in the extreme west of the Southern Deformed Fold and Thrust Belt (Khan, 2011). The successive southward deformation took place in the Late Miocene in the Plateau.

2.1.8 Punjab fore deep

The Punjab Fore deep rims the southern-most extension of Himalayan mountain chain in Indo-Pakistani shield. Unconsolidated Quaternary sediments overlie the Punjab Fore deep and are the present day epicenter for the eroded debris from the Himalayan chains in the north (Ahmad, 2003).

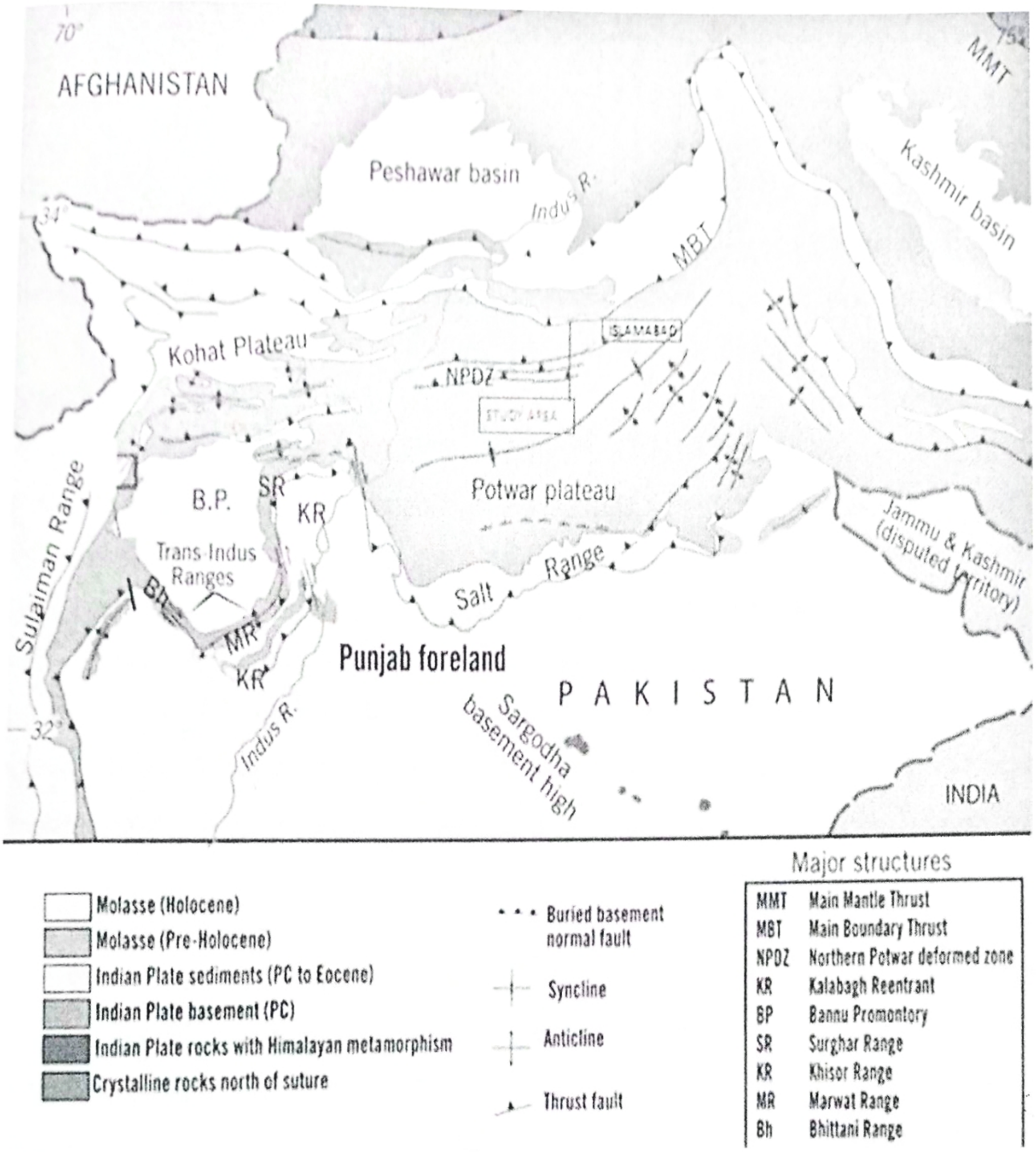

Figure 2.1 Tectonic map of Northern Pakistan (after Kazmi and Raza, 1982).

2.2 Local Geology of Islamabad

Islamabad lies in the northern half of the Potowar sub-basin, therefore major controlling factor of the geology and tectonics is the convergence of the Pakistan-India and Eurasian tectonic plates and there collision about 20 Ma. ago. This event produced complex structures and stratigraphy in the Rawalpindi and islamabad area. Many geologic events of various ages have been grouped together on the basis of their physical, and much of the structural detail has been omitted due to structural complexities

2.2.1 Stratigraphy

The sedimentary rocks of Islamabad and Rawalpindi area record a long period of gentle geologic fluctuations and slow deposition while the Pakistan-India tectonic plate drifted northern across the Indian Ocean, followed by much more vigorous tectonic processes and rapid deposition in the shorter period since the Pakistan-India and Eurasian plates converged. Consequently, the 150-million-years (m.y.) period from deposition of the Samana Suk Formation (Middle Jurassic) to the beginning of deposition of the Murree Formation (lower Miocene) to the is represented by only about 675 m of primarily marine sedimentary rocks, whereas the last 20 m.y. are represented by more than 7,572 m of continental sedimentary rock. During the uplift and structural deformation of the last 1.5 Ma, erosion has dominated over deposition, so that the only sediments preserved are thin, discontinuous bodies of alluvium and eolian silt.

Rawalpindi Group lies in the Himalayan fold belt, the lower part of molasses sequence is referred to as the Rawalpindi Group. It comprises Murree Formation at the base and Kamlial Formation at the top. The age of this Group is Miocene. (Johnson and others, 1985).

2.2.1.1 Murree Formation

The Murree Formation is comprised of a dark red to maroon color siltstone and clay interbedded with red, brown and grey color sandstone. The claystone is purple to dark red and contain lenses of pseudo-conglomerate. The sandstone and claystone is of continental origin. The measured thickness ranges from 2,000 to 2,895 m in the area. The age of this formation is lower Miocene. The Shahdara (Islamabad) is geologically located on Murree Formation of northern Potwar basin.

2.2.1.2 Kamlial Formation

The Formation is composed of dark gray to greenish grey sandstone about 75%, inter-bedded with dark red to maroon color siltstone about 20% and subordinate intra-formational conglomerates. The sandstone of Kamlial exhibits weathering that gives rubbly appearance. The sandstone is fine to medium grained, multistoried, cross-bedded, channelized and intercalated with lenses of intra-formational conglomerates or with thin layers of clay. The formational thickness varies from 50 to 650m. Age of this formation is lower to middle Miocene (Johnson and others, 1985)

Table 2. 1 Stratigraphic column of study area

Age		Group	Formation	Type locality	Lithology
Tertiary	*Miocene*	*Rawalpindi Group*	Kamlial Formation	Kamlial, District Attock	Dark brick-red medium to coarse grained sandstone and contains interbeds of hard purple shale and yellow and purple interformational conglomerate
			Murree Formation	Dhok Maiki, District Attock	Red and purple clay and purpl, grey and greenish grey sandstone with subordinate intraformational conglomerate. The basal strata of formation consists of light greenish grey calcareous sandstone and conglomerate.

CHAPTER 3

PETROGRAPHY

3.0 Petrography

Petrography is the branch of geology dealing with the description and systematic classification of rocks, especially by microscopic examination if thin sections. Petrography is a subfield of Petrology. Rock samples are first observed at field with naked eye and hand lens. Detailed study is carried out with the help of thin-sections which reveal a greater detail of textures, structure and components that make up the rock samples. Thin-sections are studied under polarizing microscope.

3.1 Petrography of Murree Sandstone

The petrographic study of Murree Sandstone exposed at Shahdhra Village, Islamabad is based on the ten representative thin-sections selected from different stratigraphic levels across the formation, where lithological variations occurred. The data obtained from this petrographic study provides information about grain size, sphericity, sorting, roundness/angularity properties, model mineralogy, and diagenetic changes of the Murree Sandstone. During the course of petrographic study the framework grains, matrix and cement were identified and relative abundance of each was determined by visual estimation, in comparison with visual estimation charts given by (Folk, 1951).

3.2 Texture

The accumulation of grains which are produced by the weathering and erosion of pre-existing rocks in the origination of small scale features called sedimentary textures. Texture refers to the size, shape, and three dimensional arrangements of the particles. Textural properties of each sample are given in appendix (Table 1).

The observation of petrographic study is divided into respective numbers according to which the sandstone samples were collected from the field at different locations.

Table 3.1 Textural detail of Murree Sandstone

S. No	Grains size	Roundness	Sphericity	Sorting
T-1	Medium	Sub-rounded	Low sphericity	Well
T–2	Medium	Sub-rounded	Low sphericity	Well
T–3	Very fine	Sub-rounded	Low to high spherical	Well
T–4	Medium	Sub-rounded	Low to high spherical	Moderate
T-5	Fine	Sub-rounded	Low sphericity	Moderate
T-6	Very Fine	Sub-rounded	Low to high spherical	Well
T–7	Medium	Sub-rounded	Low to high spherical	Poorly sorted
T-8	Medium	Sub-rounded	Low sphericity	Moderately well sorted
T-9	Medium	Sub-rounded	Low to high spherical	Well
T-10	Medium	Sub-rounded	Low sphericity	Moderate to poor Sorting

3.2.1 Grain Size

Grain size is the diameter of the individual grain particles of the rock that make it up, measured by maximum grain diameter. Wentworth scale is the most common way of measuring grain size diameters. Murree sandstone samples observed were having fine to medium grain size, shown on (Fig 3.2).

3.2.2 Sorting

Sorting is the similarity and distribution of grains within a sample. Sorting is another very useful characteristic in grain size distribution. Sorting ranges from poorly sorted to well sorted. Well sorted sample have all the grain particles alike and shows little variation in the grain size distribution, whereas poorly sorted sample shows a large deviation in grain size distribution. Sedimentary processes such as wind, waves etc can also be known with sorting. Murree sandstones samples range from moderate to well sorted, shown on (Fig 3.2).

3.2.3 Grain Shape

Sedimentology defines the grain shape in the form of sphericity and roundness. Roundness (or angularity) defines the extent of smoothness or sharpness of the edges of particles. Grains with sharp, jagged edges and corners are called very angular while those possessing smooth rounded edges are called well rounded grains. Sphericity of grain is a measure of how closely the overall shape approaches the form a sphere. Samples from Murree sandstone were measured with a new roundness scale for sedimentary particles (Powers, 1953). Spherical grains have high sphericity, whereas rod-shaped or tabular are characterized with having low sphericity. Sphericity is more or less low in all samples of the Formation as observed in the thin-sections under microscope; details are given in the appendix (Table 3.l).

3.3 Mineralogy

The microscopic study of thin-sections of Murree sandstone reveals that quartz, feldspars, and rock fragments are present as framework grains. Accessory minerals include, micas (both muscovite and biotite), opaque minerals, and chlorite. The results, after detailed examination of thin-sections, are given in appendix (Table 3.2). Further detailed description of minerals is as follows.

3.3.1 Framework Grains

(a) Quartz

Quartz is the most abundant grain type in sandstone. Quartz is present as dominant framework grains in the Murree Formation. The overall percentage of the quartz ranges from 22%-69% shown in appendix (Table-3.2). Quartz is present both in monocrystalline and polycrystalline forms (Fig 3.3, C and D). Monocrystalline quartz are the most dominant framework grains in the observed Murree Sandstone samples. Mostly monocrystalline quartz grains are present with uniform and other with undulose extinction. Polycrystalline quartz grains are also present in very low percentage as Compared to monocrystalline quartz mostly polycrystalline quartz is composed of many small crystals within a grain having different boundaries, or are made up of a number of crystals in different orientation (Adams et al., 1991).

(b) Feldspars

Feldspars are the second major abundant grains in sandstones. Feldspars are the second most abundant grains in the Murree Sandstone. The overall volume percentage of total feldspar including plagioclase and k-feldspars, ranges from 8% to 29%. Alkali feldspar are more common than plagioclase feldspar, partly because they are more resistant to chemical weathering (Adams et al., 1991). The amount of alkali feldspar was more dominant than plagioclase feldspar in Murree sandstone. Overall percentages are given in appendix (Table 3.2) for albite and k-feldspar. Alkali and plagioclase feldspar are differentiated form each other on the basis of twining. Mostly plagioclase shows albite (multiple twining), microcline shows cross-hatch twinning (Fig 3.4 A), and K-feldspar shows Carlsbad (simple twinning). Some altered feldspar grains are also present (Fig 3.4 B).

(c) Rock Fragments

The thin-section study of Murree sandstone give results of many different rock fragments, mainly metamorphic and sedimentary rock fragments were present. Rock fragments are components of pre-existing rocks. Rock fragments are present in a small proportion as compared to other framework grains. The overall percentage ranges from 7%-39% given in appendix (Table 3.2). Quartz-mica-schist (Fig 3.5, D) are present as rock fragments in the Murree Sandstone.

3.3.2 Accessory Minerals

Among accessory minerals micas, chlorite and opaque minerals are most dominant in the Murree Sandstone, and these are present. Chlorite is present as detrital flakes usually derived from metamorphic rocks through alteration. Thin section study of chlorite shows low relief and low birefringence, interference show a characteristic of midnight blue to black. Paleochroism color range from green to pale yellow. Chlorite amounts to 1.9%-7% in the studied thin-sections. Opaque minerals include magnetite and hematite and amounts 1.2%-8%. Mica ranges from 1%-6.6%.

3.3.3 Matrix

Matrix is a fine grain material that fills interstitial spaces between framework grains. The upper size limit of material in sandstones considered to be matrix is arbitrary and debatable; however, a maximum size of 0.03 mm appears is favored by many workers in sandstones (Boggs, 2009). The matrix may be primary or secondary. Earlier workers assumed that matrix present in the sandstones are detrital, i.e. it was sedimented along with framework grains at the time of deposition. That point of view has undergone considerable revision. It is now believed that most transport and depositional processes separate clay size grains from coarser detritus, so, the most sand when initially deposited contain a very little if any matrix (Adams et al., 1991).

3.3.4 Cements

Cementation is the principal process leading to porosity reduction in sandstones, the most common cements being quartz, calcite, and clay minerals. Calcite cements in sandstones are usually fairly coarse-grained. Cement crystals may be of any size up to or larger than the sizes of the pores they fill. The cementing material in Murree sandstone is calcite which is highly abundant.

Table 3.2 Visual estimation of studied thin sections

Quartz	Feldspar	Matrix/ Cement	R.F	Ore	Chlorite	Mica
27%	19%	30%	14%	3%	4%	3%
32.4%	19%	23.6%	13%	5%	2%	5%
55%	8%	17%	10%	5%	3.4%	1.6%
29.5%	18%	20.4%	14.5%	5.6%	5.4%	6.6%
45.8%	21%	13.2%	11%	5.5%	1.9%	1.6%
56%	8%	16%	7%	8%	-	5%
39.5%	25%	16.2%	10.1%	1.2%	7%	1%
25%	15%	34.8%	10%	8%	3.6%	3.6%
30%	20%	24%	20%	3%	2%	1%
22%	19%	20%	29%	4%	2%	4%

3.4 Sandstone Classification

Sandstone classification require the estimation of principal grain types and percentages thus thorough thin section study is required. The classification of sandstone is based on microscopic study of thin sections. A rough estimate of the frame work components can be obtained by comparing the sandstone field of view under microscope with the percentage estimation comparison charts.

There classification schemes use a triangular diagram with end members of quartz (Q), feldspar (F), and rock-fragments (RF). The triangle is divided into various fields, and rocks with an appropriate model analysis are given a particular name. In widely used simple classification of (Pettijohn et al., 1987), given in (Fig 3.1) Sandstones are divided into two major groups based on texture, that is, those sandstones containing more than 15% fine-grained matrix are the greywackes. For the arenites, the term Quartz arenite is used to those with 95% or more quartz gains. The term arkosic wacke is used for arkoses with a significant proportion of matrix. Quartz wacke is not a common rock type, is dominantly quartz plus some matrix. This classification is concerned primarily with the mineralogy of sediment and presence or absence of the matrix.

3.5 Classification of Murree Sandstone

To plot the data in the classification scheme discussed above, the percentage values of Quartz, Feldspars, cement and matrix and Lithics are normalized to 100 percent. On the basis of matrix percentages and normalized values all the samples observed fall in the category of "Arkosic Wacke".

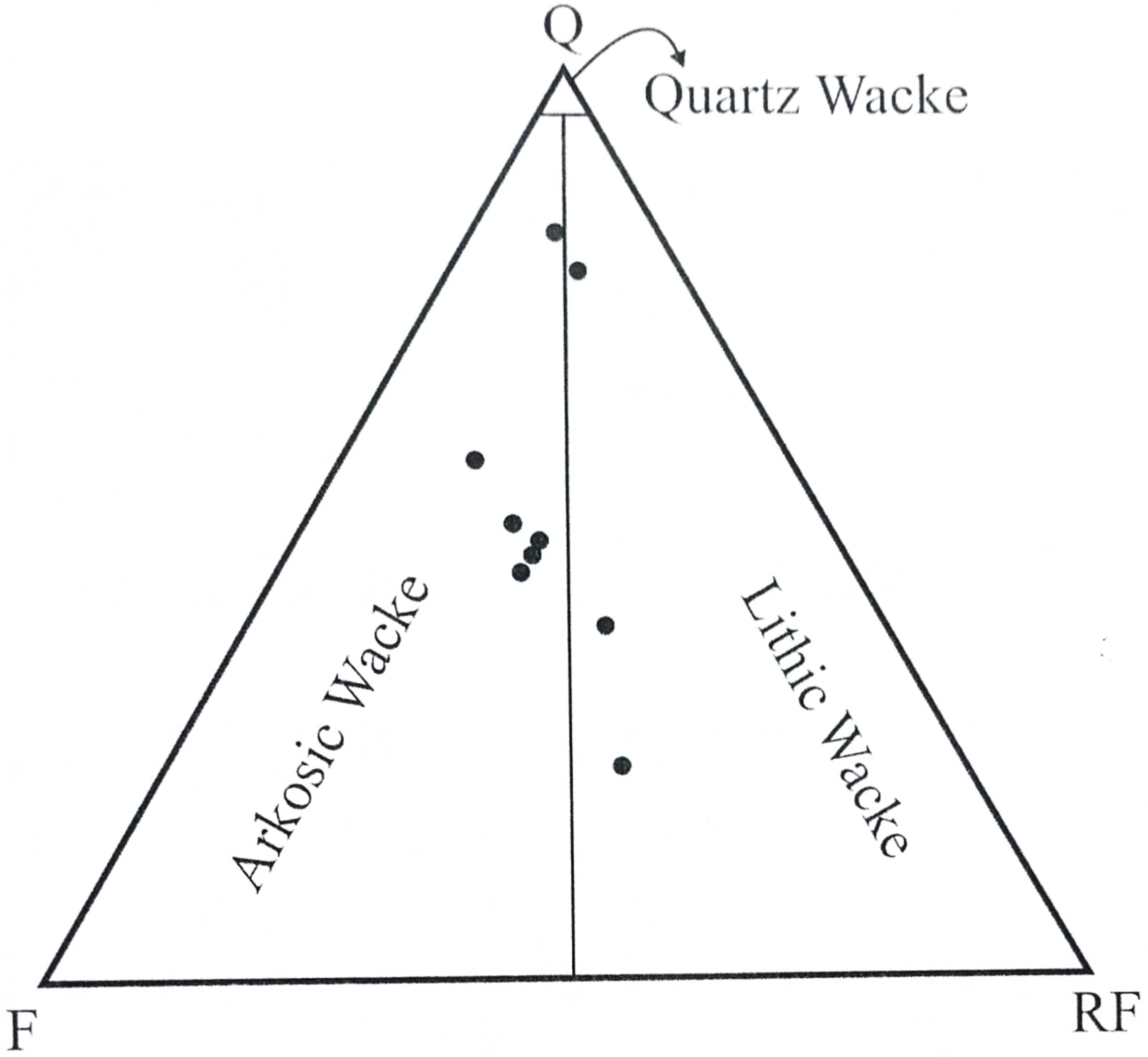

Fig 3.1 Modal composition of studied samples plotted in sandstone classification scheme Pettijohn et al (1987).

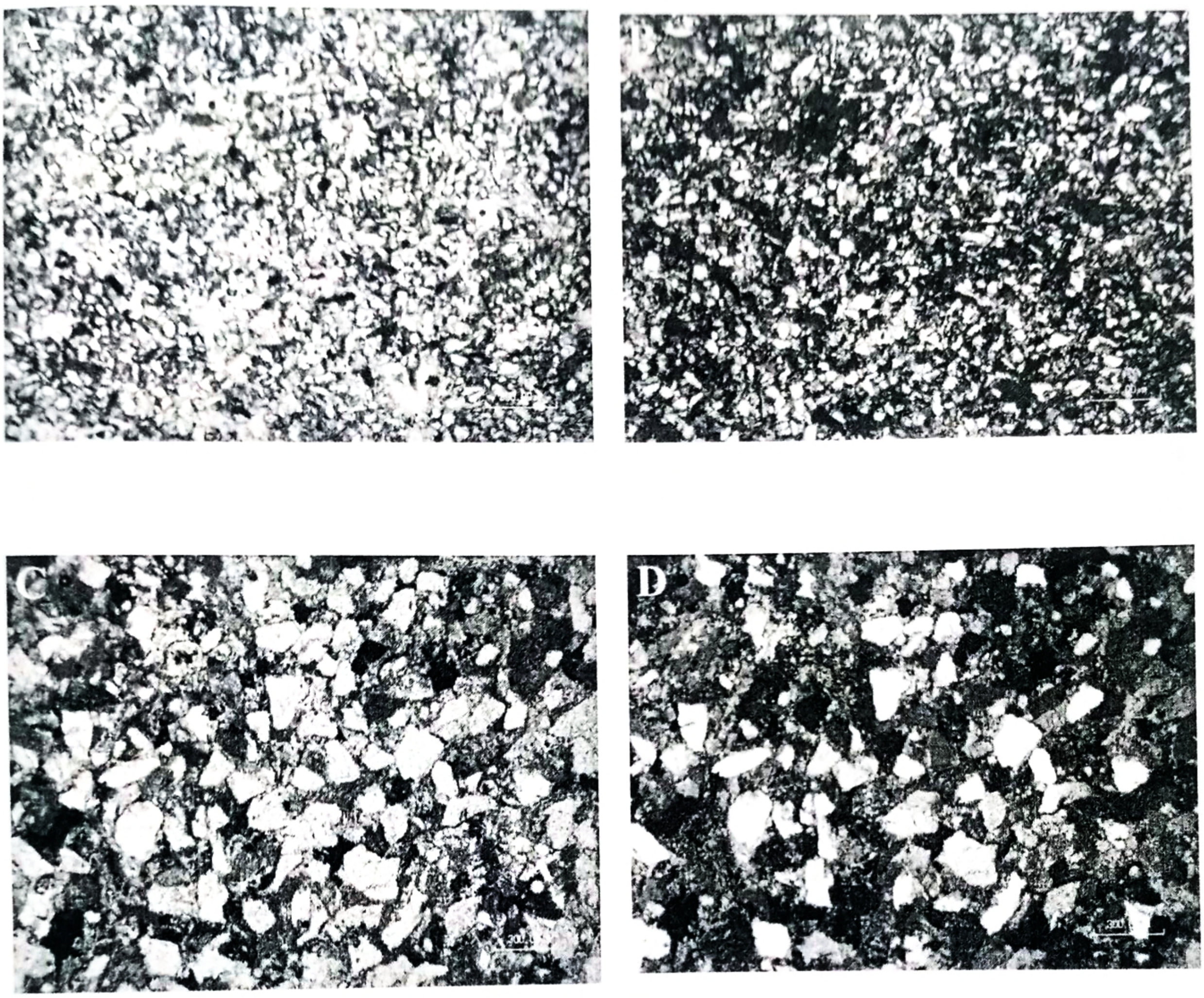

Fig 3.2 A (PPL,) showing very fine grain, sub-angular to sub-rounded, moderately well sorted sandstone, B (XPL,) showing very fine grain, sub-angular to subrounded, moderately well sorted sandstone, C (PPL,) showing medium grain, subrounded, well sorted sandstone, D (XPL,) showing medium grain, subrounded, well sorted sandstone.

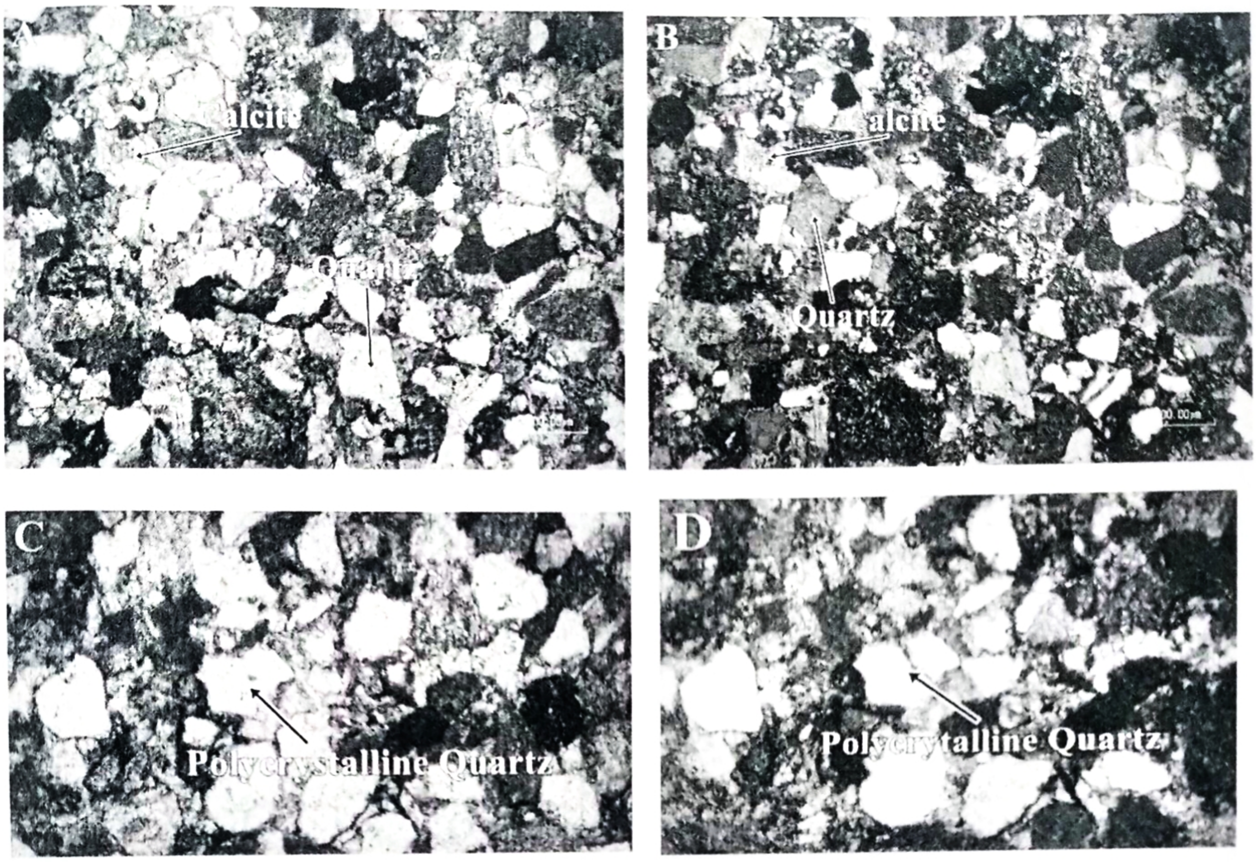

Fig 3.3. A (PPL), B (XPL) Showing (a) Quartz with sub angular grain, (b) calcite as cementing material, C (PPL) showing polycrystalline quartz grain , D (XPL), showing polycrystalline quartz grain

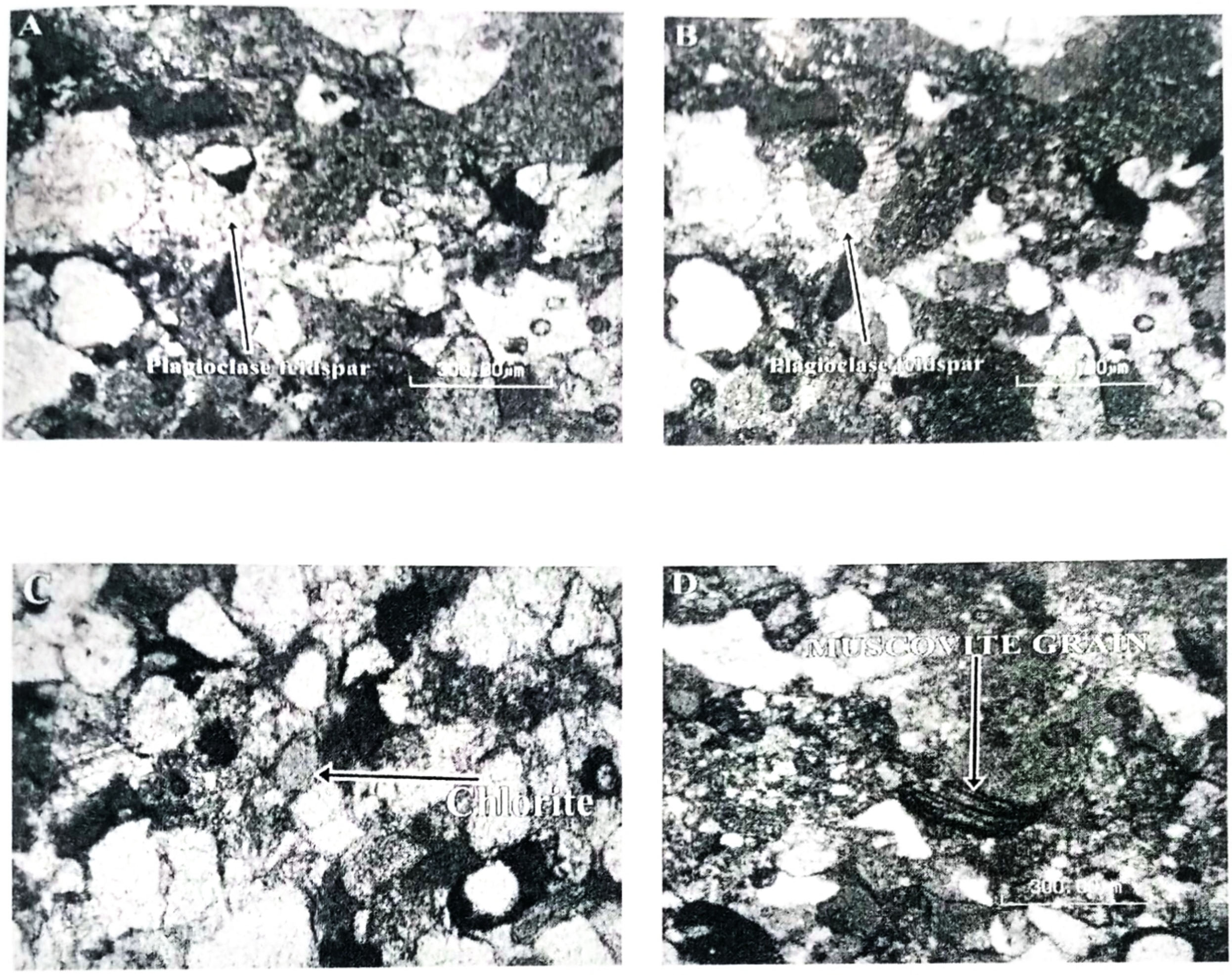

Fig 3.4.A (PPL) showing Plagioclase feldspar, B (XPL) showing Carlsbad twining in plagioclase feldspar, C (PPL) showing chlorite grain, D (XPL) showing muscovite grain

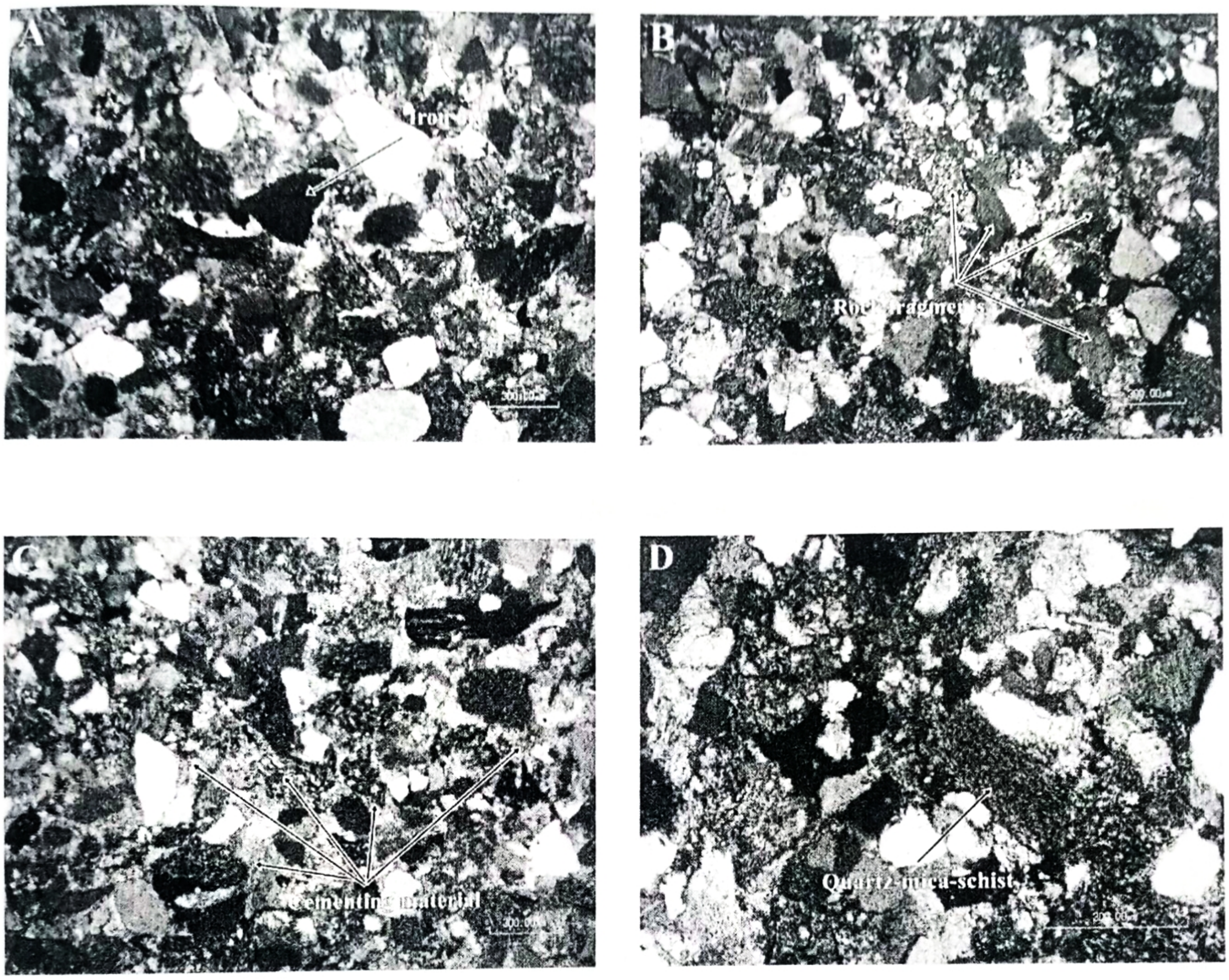

Fig 3.5. A (XPL) showing iron ore, B (XPL) showing various rock fragments i.e. sedimentary and metamorphic, C (XPL) showing cementing and matrix material, D (XPL) showing metamorphic rock fragment(quartz-mica-schist)

CHAPTER 4

MECHANICAL PROPERTIES

4.1 Introduction

Engineering geology is an applied discipline of geology that relies heavily on knowledge of geologic principles and processes. As its name implies, it is an interdisciplinary profession in which the engineering geologist works closely with, and must understand and respond to needs of, the civil engineer. To do so one must be proficient with the properties and uses of earth materials outside those commonly encountered by the practicing geologist (Krynine et al., 1957). Engineering geology is basically the appliance of the geologic sciences to engineering exercise for the purpose of assuring that the geologic factors affecting the location, design, construction, operation and protection of engineering works are recognized and adequately provided for. Engineering geology in which the key information base for engineering activities is knowledge of the geological strata, rock type, rock structure, any alteration of rock-forming minerals, the presence of small and large scale faulting and jointing in the rock, the in-situ stress state and hydrogeological regime and, indeed, any geological parameters that is related to the engineering (Bell,2007). Natural rock environments have intense effect on the engineering structure. In general, this is basically governed by the location of the engineering structure, i.e. whether a structure is being built on the surface, excavation of the surface rock or is underground. Fractures in the rocks govern the strength of near-surface structures while natural in situ stresses govern the stability of deep structures. For example, the stability of dam foundation depends on the nature and spacing of discontinuities (Bell, 2007). Strength of intact rock depends on component mineral strengths and the way they are bound together-by interlocking or cementation. Geological events may affect its mechanical properties and its vulnerability to water penetration and weathering effects. The mechanical properties of an area can be best presented on a map showing different strength characteristics of rock types and associated properties. Site investigation for major structures such as dams, factories, and heavy buildings is one of the main parts of engineering applications and an engineering geologist plays a vital role in integration of geological knowledge and engineering properties.

4.2 Engineering aspect of study area

The main focused area of our study was Murree Sandstone of Lower Miocene age. Murree formation is composed of dark red to maroon color siltstone and clay interbedded with red, brown and grey color sandstone (Kazmi and Jan, 1997). Rocks were fractured to highly intact at different spaces. Fractures were well observable, with filling of calcite veins scattered around the area.

4.3 Scope of rock mechanics

The most important aspect of rock mechanics is to determine the strength of rocks both intact and individual test carried on them. Engineering properties of rocks can well be studied and addressed in rock mechanics which include failure under compressive load and tension. It also include the mode of failure and conditions which influence those failure. Generally there are two common categories for testing rock samples:

1. Field or in–situ testing
2. Laboratory testing of field samples

4.2 Laboratory work

4.2.1 Strength tests

Laboratory testing of rock samples was carried out as determination of mechanical properties was our main concern which include applying compressive force and assessing the mode of failure of rock sample under a given load. Following strength test was carried out in order to find the mechanical properties of rock samples;

1. Unconfined compressive strength test.

Simplest and result oriented test was done on the samples collected which included UCS. The unconfined compressive test was performed on rock samples in the form of cubes. Test were carried out in the steel testing laboratory of UET, Taxila, a Forney universal testing machine was used in this regard.

4.2.2 Unconfined Compressive Strength Test (UCS)

The unconfined compression test is often included in the laboratory testing program of geotechnical investigations, especially when dealing with rocks. Unconfined compressive test is a simple laboratory test to find the mechanical properties of rocks and soils. This is normally determined by statically loading a cylinder of rock to failure, the load being applied across the upper and lower faces of the sample. The result obtained are in part a function of length-breadth ratio of the sample and of the rate of loading (Hawkes and Mellor, 1970).The compressive strength of sandstone is determined by its porosity. The higher the porosity, lower the strength.

The UCS of the rock is the function of specimen size, shape, confining pressure, height to diameter ratio, rate of loading, porosity of rock and moisture content (Jumikis, 1983). It is calculated in accordance with the procedures given in ASTM D2938, with the length to diameter ratio of 2 by using specific size core samples. The unconfined compressive strength of the specimen is calculated by dividing the maximum load at failure by the sample dimensions.

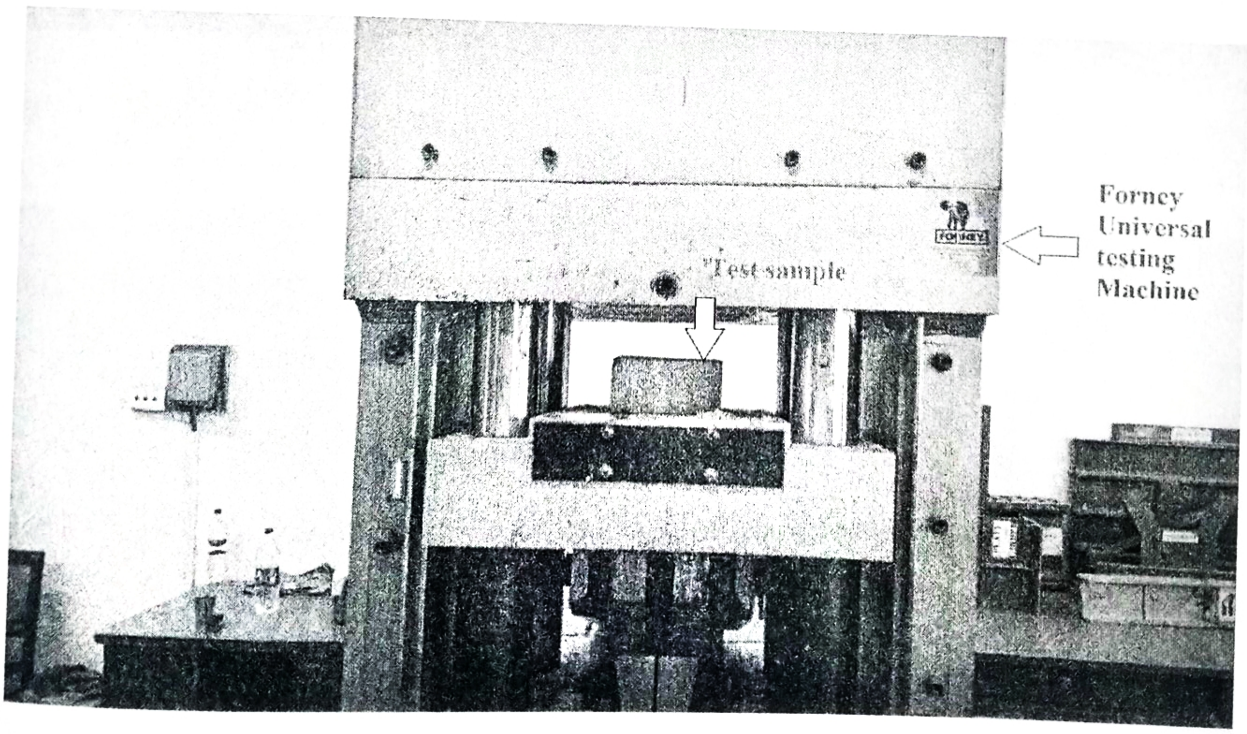

Figure 4.1 Forney universal testing machine with test sample

4.5 Values of compressive test achieved

Various bulk samples of Sandstone were collected from Murree Formation. Compressive test were performed on cubes obtained from those bulk samples. Values of UCS are given below:

Table 4.1. Details of the UCS test

Sample	PSI	Load(KN)	Strength(MPA)
S1	2943	510	20.29
S2	5917	927	40.79
S3	6469	1035	44.60
S4	5106	800	35.20
S5	5281	845	36.41
S6	5687	910	39.21
S7	4468	715	30.80
S8	5617	880	38.72
S9	6581	1053	45.37
S10	4062	650	28.00
S11	11750	1880	81.01

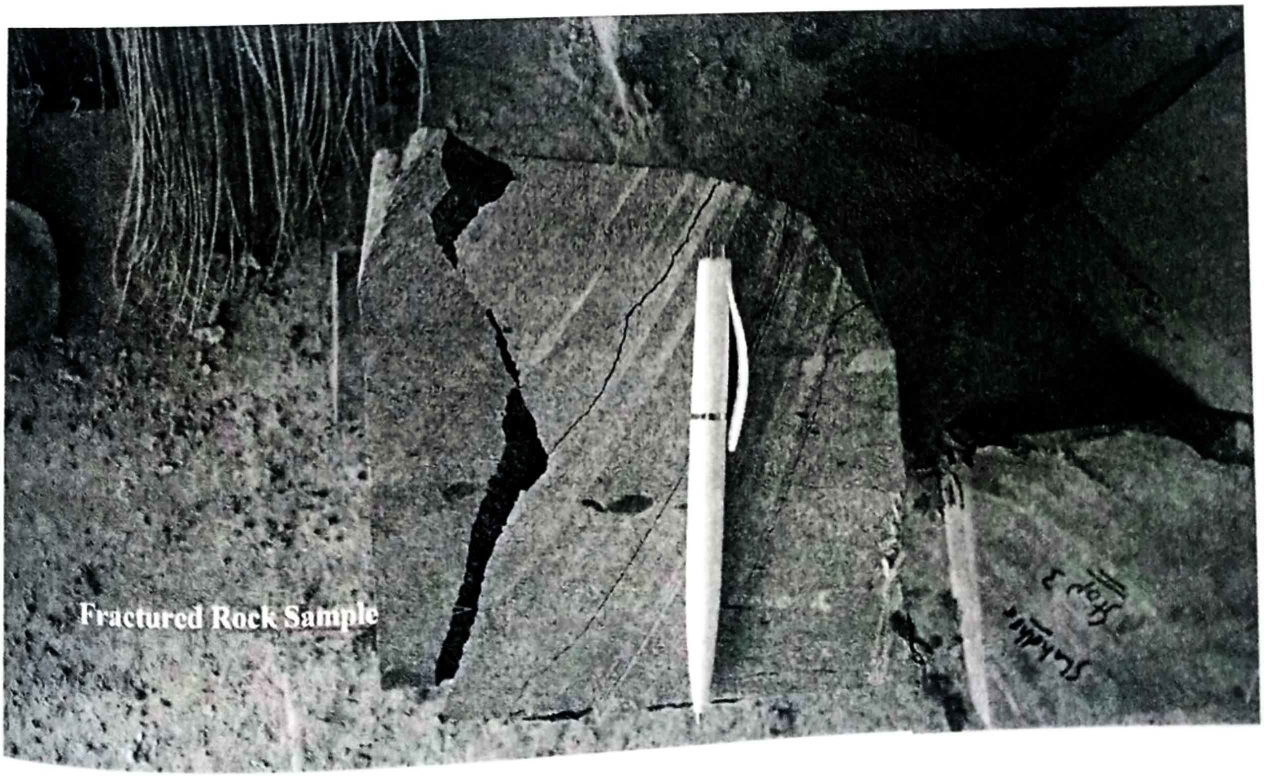

Figure 4.2 Fractured rock sample after UCS test

4.5.1 Result analysis

The studied samples of Murree Sandstone showed the following information.

1. Rock samples are stronger in compression then concrete, according to 28 days of compressive strength achieved by concrete which is 500 kg/sq.cm for D3 class of concrete.
2. UCS values of the rocks samples reveals that these rock are strong.

Table 4.2. Material grading based on Unconfined Compressive Strength (Bell, 2007).

Geological Society (Anon, 1977)		IAEG (Anon, 1979)		ISRM (Anon,1981)	
Term	UCS(MPa)	Term	UCS(MPa)	Term	UCS(MPa)
Very Weak	<1.25	Weak	<15	Very low	< 6
Weak	1.25-5.00	Moderately Strong	15 - 50	Low	6 – 10
Moderately Weak	5.00-12.50	Strong	50 – 120	Moderate	20 - 60
Moderately Strong	12.50-50	Very Strong	120 – 230	High	60 – 200
Strong	50-100	Extreme Strong	Over 230	Very High	Over 200
Very Strong	100-200				
Extremely Strong	Over 200				

4.6 Specific Gravity

Specific gravity is an important physical property of rocks and minerals. Specific gravity is defined as "the ratio of the relative weight or density of a material or rock specimen to the weight or density of an equal volume of water."

True or absolute specific gravity of rock is the specific gravity of the actual rock and or rock grains or solids. Mathematically it can be expressed as;

$$\text{Specific gravity} = \text{Mass} / \text{Density}$$

Various different samples of Murree Sandstone were collected and tested in the laboratory using digital balance. First the dry weight (Wd) of the rock samples were determined, then the samples were immersed in the water and the wet weight (Ww) were determined under suspended condition.

The feasibility of rocks for construction purposes depends on their specific gravity and it is believed that rocks with specific gravity >2.55 (Blyth and Freitas, 1974) are suitable for use in heavy construction work. The results of specific gravity for the studied rocks are given below in Table 4.4

Specific gravity can also be measured from density. In this method first we measured dry weight by using digital balance. Then we took 100 ml of water in a measuring jar or beaker and after that we immersed the samples one by one in the 100 ml of water and note the difference in volume of water. After that we subtract the initial volume of water from the final volume of water and the resultant value is divided by the dry weight of the sample and in this way we get the densities for the selected samples and divide the densities values by density of water to get the values of specific gravities for the study samples.

Table 4.3. Dry density and porosity values (Anon, 1979).

Class	Dry Density	Description	Porosity	Description
1	Less than 1.8	Very low	Over30	Very high
2	1.8 – 2.2	Low	30 – 15	High
3	2.2 – 2.55	Moderate	15 -5	Medium
4	2.55 – 2.75	High	5 – 1	Low
5	Over 2.75	Very High	< 1	Very Low

Table 4.4. Details of specific gravity test on the studied samples.

Sample No.	**Specific Gravity**	**Water Absorption%**	**Porosity%**
S 1	2.6	1.80%	3.01%
S 2	2.64	1.31%	2.09%
S 3	2.73	1.77%	2.94%
S 4	2.26	11.0%	19.47%
S 5	2.58	1.89%	3.13%
S 6	2.66	2.22%	3.68%
S 7	2.36	5.32%	9.1%
S 8	2.78	1.76%	2.16%
S 9	2.42	9.88%	17.12%
S 10	2.65	1.60%	2.60%
S 11	2.64	1.77%	2.90%
S 13	2.6	1.59%	2.66%

4.7 Relationship between Geo-technical and Petrographic Properties

Sandstones have been used as construction materials for a long time and are still being used these days (Hajpal and Torok, 2004). Mineralogical properties influences and predict the mechanical strength of sandstones such as the uniaxial compressive strength. The uniaxial compressive strength is controlled by several reasons such as inherent and environmental characteristics. The inherent properties are defined by the petrographic properties. It includes mineral composition, the void space, the degree of grain interlocking, the packing density and the grain size is known to be affected by the petrographic characteristics (Zorlu et al., 2008). It has been reported in some cases that rocks containing quartz as binding materials are the strongest materials followed by calcite but rocks with clayey binding materials are the weakest of them all (Vutukuri et a., 1974). The shape of grains is another important petrographical property which is usually expressed in terms of roundness or sphericity. There is a strong relationship between the uniaxial compressive strength and the percentage of angular grains present (Zorlu et al., 2008).

The petrographic study of Murree sandstone showed many features discussed above which contribute or indicate the uniaxial compressive strength achieved by those samples. Most of the grain size are of medium with very few ranging from fine to medium. Shape of grain size are of sub rounded to low sphericity and well sorted behavior. The cementing material within grains is of calcite. As calcite is the second strongest binding material and samples of Murree sandstone showing high content of calcite as binding material so it is inferred that the high UCS values are achieved due to calcite as binding material followed by other inherent properties such as grain size, sorting and grain shapes.

CHAPTER 5
STRUTURAL ANALYSIS OF FRACTURES

5.1 Introduction

The term fracture is typically used to emphasize the notion that something is broken e.g. any break in a rock; (Gary, 1872). Fractures are the most commonly developed structures, since these are found in all competent rocks. Fractures increase porosity as well as permeability of the rocks.

Fracture is defined as the surface along which rocks breaks due to loss of cohesion (Twiss and Moores, 1992). They are characterized by having two parallel approximately planar surfaces (Pollard and Aydin, 1988).

Development of fractures, in Murree sandstone is very pronounced and sparking for analysis. Fracture analysis is important for evaluating flow parameters. Fracture analysis is a critical tool employed in hydrocarbon exploration as they are responsible for enhancing the reservoir porosity and permeability. Fractures present within the hydrocarbon bearing rocks are generally the product of burial and tectonic loading due to the fact that reservoirs are deeply buried and do not experience significant uplift. Fractures are generally present well before the onset of hydrocarbon generation providing both pathways and barriers to migration. Evaluating the geometric configuration of fractures in a proven reservoir structure is essential for optimized exploration and exploitation in reservoir production.

Fractures often develop in predictable manner around the fold structure. As folds evolve, other processes may operate to complicate fracture pattern and their physical characteristics. Generally fold hinges are heavily populated with fractures and it is a common practice to place well bore on top of these areas to take maximum advantage of advanced fracture development. It is impossible to examine all fractures and fracture related structures that are contained in a given structural domain. Thus standard practice is to evaluate fracturing through detailed structural analysis at selected stations. The strategy is to learn the nature of the overall fracture system through systematic examination of representative subareas within the domain (Davis, 1996).

A sampling station established for fracture analysis is very small compared to the size of the structural domain within which it lies. It is a well exposed fractured bed rock where fractures and fracture related structures are classified and measured. In a restricted sense, stations can be designed as circular or square inventory areas of specified dimensions, or as relatively small sample lines of specified traverse length and direction (Davis, 1996).

5.2. Methodologies of Fracture Analysis

In our study several methods was used for fracture analysis. Total five different locations were selected, representing different parts of the formation. The trends, lengths and widths of the each fracture within the circle were measured. Circles, having radius 18 cm, were traced out on bedding plane by the help of spray and measuring tape. Trends of fractures were measured by using Silva Compass; length was measured by the help of measuring tape. To avoid repetition, each fracture was traced with spray after measuring. Accuracy is very good for length measurement. In practice, there are two basic approaches by which fracture analysis can be done.

1. Selection method.
2. Circle inventory method.

5.2.1. Selection method

Selection method, involves selecting only certain joints for measurement and study. The basis of the selection method is to restrict analysis to joints and shear fractures that are continuous and through-going, and are conspicuously associated with other fractures of similar appearance and orientation. It is neither very easy nor very objective to decide which fracture surface should be measured at each station, and which should be left alone. But in spite of this difficulty, many workers have found the selection method to be practical and useful. The basis of the selection method is to restrict analysis to fracture and fracture related structures that are continuous and through-going, and are conspicuously associated with other fractures of similar appearance and orientation. (Davis, 1996).

5.2.2. Circle inventory method

The second approach, which we might call the inventory method, involves measuring all the fractures present within the inventory circle. First a circle of known or predetermined diameter normally less then 3m is traced out on outcrop of perfectly exposed fractured rock. The circle is drawn with a piece of carpenter's chalk or spray attached to the string of suitable length. Then the orientation and trace length of each fracture within the circle are measured. To avoid measuring the same joint twice, it is helpful to trace out the full length of each joint with chalk after it is measured (Davis, 1996).

5.3. Fracture Analysis

The inventory circle method is used for fracture analysis because it is easy and convenient to use. The road section and stream cutting along which the fracture analysis was carried out. The fracture orientation data is then plotted onto stereographic software and represented in terms of rose diagrams. The rose diagrams of fracture orientation were interpreted to establish major sets of fractures. The flow chart of different steps involved in the present study is shown in (Fig 5.1). These steps of detailed fracture analysis are discussed in detail below.

Detailed fracture analysis was done in the following stages:

1. Data acquisition
2. Data representation
3. Data interpretation

Data acquisition

Two types of fracture data was acquired in the field.

1- Fracture orientation data
2- Fracture description data

Fracture orientation data

The orientation data was acquired in quite systematic way. The road and stream section along which the fracture analysis was carried out, had a length (diameter) of half meter.

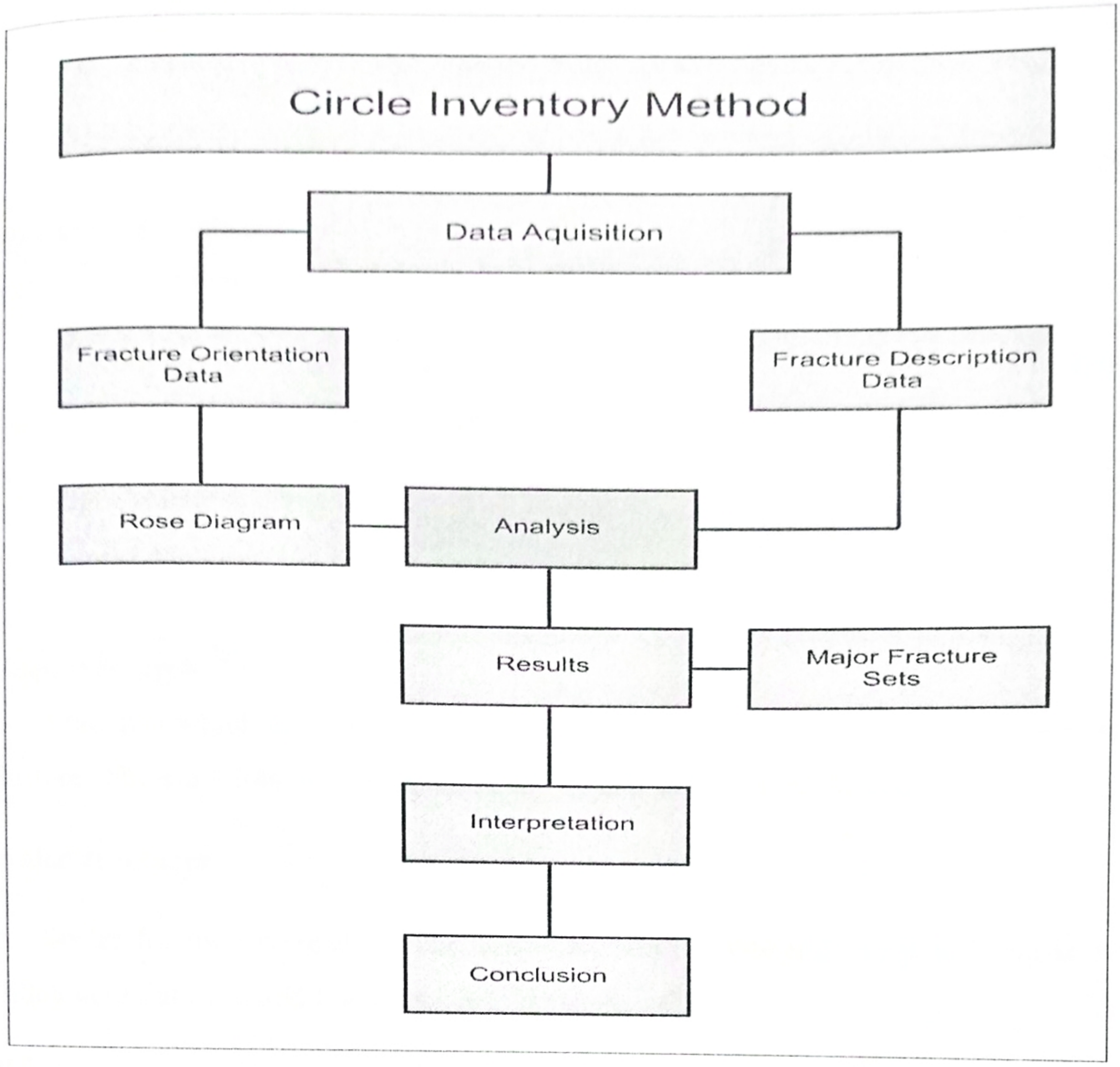

Figure 5.1. Flow chart of fracture analysis methodology.

The Stream section was divided into several stations and each station had a length of approximately 100 to 200 meter. Inventory circles of 18 cm radius were traced out at different points within each station. After that the orientation of each fracture occupying the inventory circle was determined by using compass. Outcrops were generally available in which three dimensional-expression of each fracture surface was clear allowing fracture orientation to be measured in terms of strike and dip. By using this method, a total of 24 fracture orientations were measured along the road section.

5.3.1. Fracture description data

Apart from fracture orientation data, all the physical parameters of each fracture were measured. The physical parameters of each fracture within the circle include fracture length, fracture opening or width. In-situ length, width are measured with the help of simple ruler and measuring tape. For length measurement accuracy was very good but it was satisfactory for width measurement in present case.

For sealed fractures, In addition filling material was determined. Secondly, the cross-cutting relationship between open and sealed fracture was also determined if present within the inventory circle.

Two types of fractures have been observed in the field at appropriate sites that contained a significant number of visible and measurable fractures.

1- Open fractures

2- Sealed fractures

Open fractures

Fractures which are not filled by any material like calcite or other is called open fracture. There are lots of open fracture were observed in the study area.

Sealed fractures

Sealed fractures were also found as in study area. Calcite and clay was found as the filling material in sealed fractures.

Cross-cutting relationship

Most of the fractures are having cross cutting relationship. In this phenomenon, open fractures are cross cutting the sealed fractures which indicate their relative age relationship such that the open fractures are younger than the sealed fractures. However, this relation was not possible to establish at every station.

Circle 1

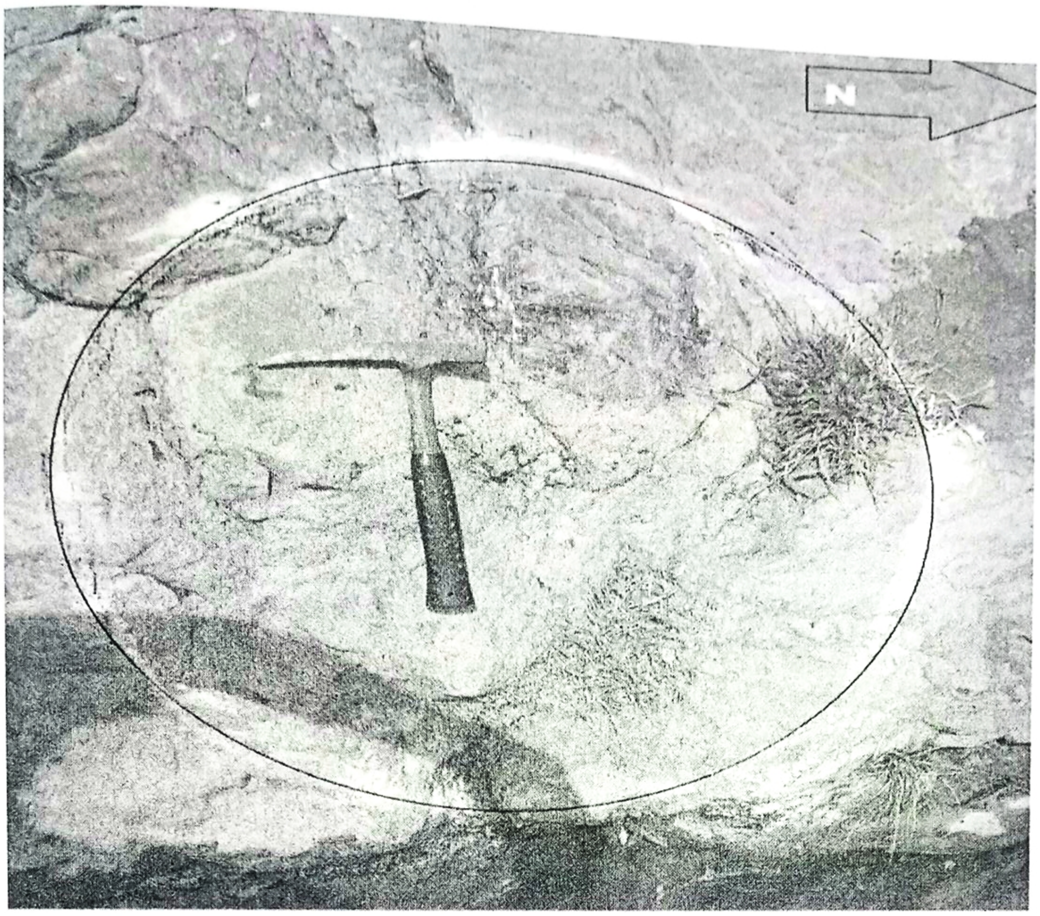

Figure 5.2. Field photograph showing fracture connectivity along stream cut section.

Domain name	Station no	strike	length	pictures	Other features
1	1	085	11 inch	yes	Filled fracture.
		207	12 inch	yes	Filled fracture.
		200	08 inch	yes	Filled fracture
		210	07 inch	yes	Filled fracture

Circle 2

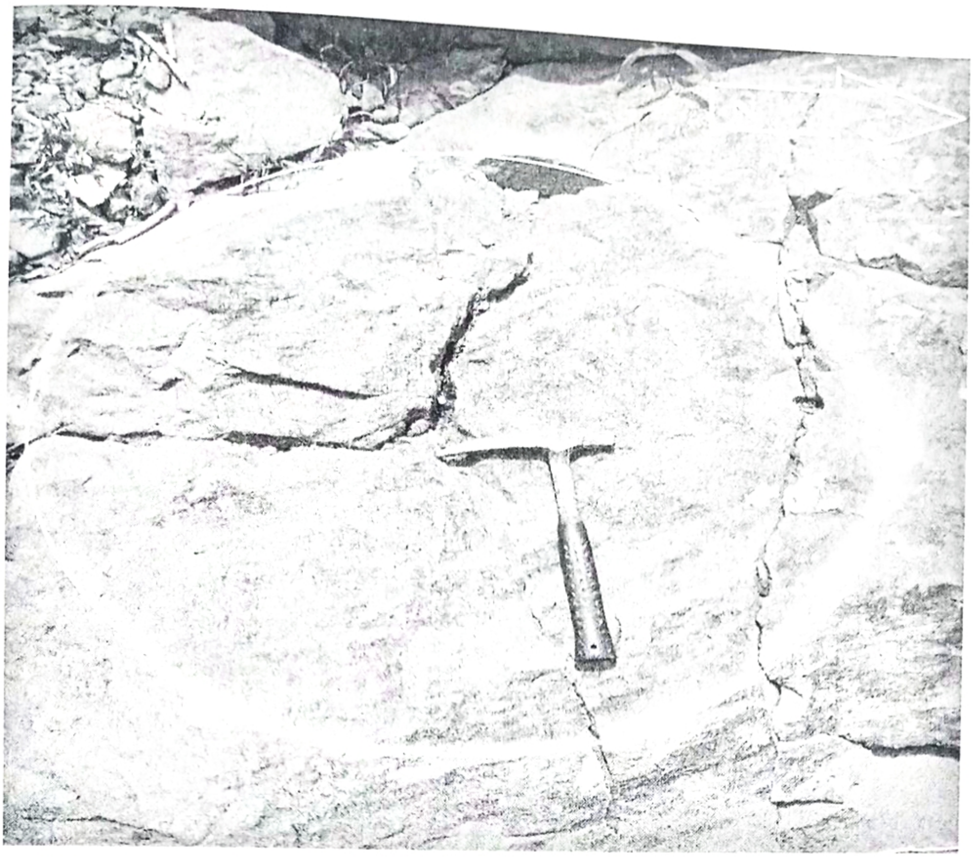

Figure 5.3. Field photograph showing fracture exposed along road section.

Domain name	Station no	strike	length	pictures	Other features
2	2	140	14 inch	Yes	Un filled fracture
		210	7 inch	Yes	Un filled fracture.
		220	7 inch	Yes	Un filled fracture.
		270	14 inch	Yes	Un filled fracture

Circle 3

Figure 5.4. Field photograph showing fracture exposed along stream section.

Domain name	Station no	strike	Length	pictures	Other features
3	3	140	19 inch	yes	Unfilled fracture.
		060	31inch	yes	Unfilled fracture.
		300	22 inch	yes	Un filled fracture.
		330	12 inch	yes	Un filled fracture.

Circle 4

Figure 5.5. Field photograph showing fracture exposed top of the structure.

Domain name	Station no	strike	length	Pictures	Other features
1	4	265	14 inch	Yes	Unfilled
		220	7 inch	Yes	Unfilled
		240	8 inch	Yes	unfilled
		65	14 inch	Yes	unfilled
		55	8 inch	Yes	unfilled

Circle 5

Figure 5.6. Field photograph showing fracture exposed along Stream cut section.

Domain	Station no	strike	picture	Other features	Length
1	5	280	yes	Unfilled	24 inches
		50	yes	Unfilled	34 inches
		250	yes	Unfilled	26 inch
		20		Unfilled	

5.3.2 Data Representation

Orientation data collected during the course of fracture analysis is summarized in rose diagrams. These stereographic diagrams are generated by plotting the data acquired from the field onto stereo stat stereographic software. The fracture orientation diagrams allow sets of fractures to be recognized. For this purpose rose diagrams were preferred as the trends of dominant joint sets are even more readily apparent in rose diagrams.

5.3.3. Data Interpretation

Two types of fracture data is interpreted

1- Interpreteation of fracture orientation data

2- Interpretation of fracture description data

5.3.3.1. Interpretation of Fracture Orientation Data

The fracture orientation data acquired from the field is plotted on stereographic software "stereo stat" to generate stereographic diagrams. Rose diagrams were generate after plotting the fracture orientation data in stereo stat these rose diagrams were then interpreted to evaluate dominant sets of fractures in Fig 5.7.

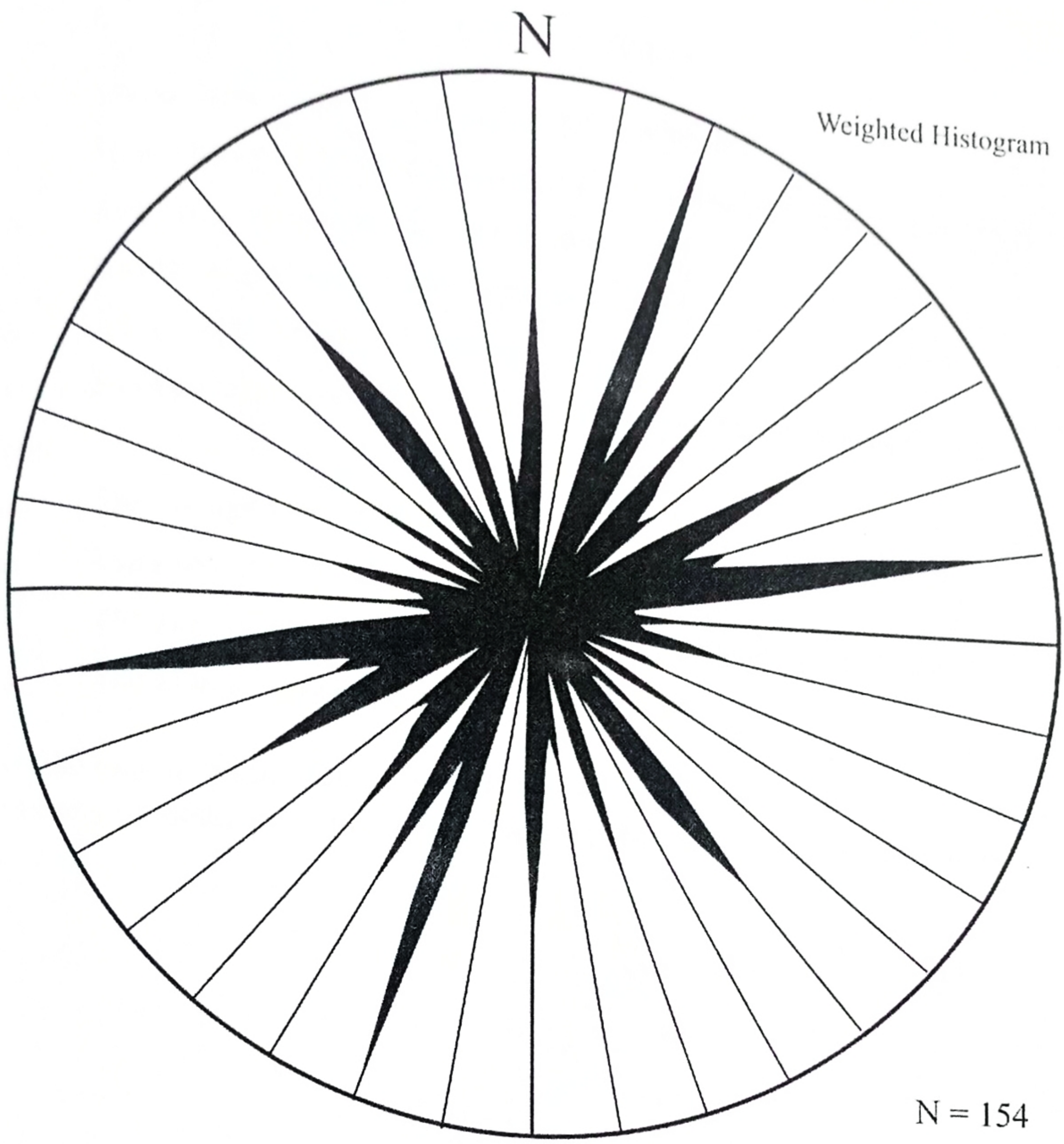

Fig 5.7 Weighted histogram.

CONCLUSIONS

1. Murree Sandstone is classified as Arkosic Wacke.
2. Mineralogically Murree Sandstone is sub-mature and texturally immature.
3. Average grain size is very fine to medium.
4. Sorting ranges from moderate to well sorted.
5. All of the grains are sub-rounded.
6. Mechanical analysis of the Murree Sandstone after several strength tests reveals

that:

a. The average value of Water absorption is 3.22%.

b. The average value of porosity is 5.45%.

c. The average value of uniaxial compressive strength is 40.03 MPA.

d. The average value of Specific gravity is 2.47.

On the basis of mechanical properties and test results Murree sandstone lie in the category of moderately strong rock, hence can be used for construction purposes

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