*Pak. J. Engg. & Appl. Sci. Vol. 20 January,* 2017 (*p.* 69–78)

# Petrographic and Mechanical Properties of Sandstone from Murree Formation, Jena Kor Area, Peshawar Basin. A Case Study

Mustafa Yar[1*], Mohammad Arif[2], Arif Khan Afridi[3], Muhammad Saeed[3], Muhammad Ziad[3], Arshad Ali[4]

1. Department of Earth and Environmental Sciences, Bahria University, Shangrilla road, E-8, Islamabad, Pakistan
2. Department of Earth Sciences, CIIT, Abbottabad, Pakistan
3. Department of Geology, University of Peshawar, Peshawar, Pakistan
4. Graduate Researcher Faculty of Environmental Sciences, Czech University of Life Sciences, Prague, Kamycka 129Praha 6-Suchdol, 16521, Czech Republic

* **Corresponding Author:** E-mail: mustafa.afridi@yahoo.com

## Abstract

*The Murree Formation is a part of the Miocene molasse sequence of the Peshawar Basin and consists of a series of alternating beds of sandstone, siltstone and shale with subordinate marls and conglomerates. In the present study Murree Formation lies at the Southern margin of Peshawar Basin, Jena Kor area, FR Peshawar. The primary focus of this research is sandstone of the respective formation, which is predominantly fine to medium-grained and moderately to well-sorted. The framework grains (quartz, feldspar and rock fragments) are angular to sub-angular to sub-rounded. Their relative modal abundance and petrographic features reflect the Murree Sandstone is mineralogically submature and texturally immature. The observed heavy minerals include chlorite, zircon, epidote, rutile, illmenite, chromite, sphene, apatite and tourmaline. The sandstone contains an average matrix abundance of 36% and hence classified as wacke. The relative proportion of framework grains of most of the samples lie in the category of arkosic wacke. In order to assess the potential of Murree Sandstone for use in construction, uniaxial compressive strength (77.07±21.61), uniaxial tensile strength (11.53±2.24), shear strength, porosity (1.21%), specific gravity (3.12) and water absorption (0.389%) of three bulk samples were determined. On the basis of these results obtained, sandstones of Murree Formation are regarded as appropriate for construction purposes.*

**Key Words:** Petrography, Murree Formation, Mechanical Properties, Jena Kor, Pakistan

## 1. Introduction

Sandstone is one of the most abundant rock type found in nature. Petrographic studies of sandstone give useful information about classification, provenance determination and diagenetic modification (Pettijohn et al., 1987). Murree sandstone is the main focus of present research. According to Zeitler (1985) the uplifting of the Himalayan orogenic belt increased enormously during the Miocene times that swiftly exposed deep-seated crystalline rocks (metamorphic and igneous rocks) to the surface (Zeitler, 1985). This resulted in the deposition of the Murree Formation of Miocene age.

The aim of the present study is to investigate relationship between strength and petrographic detail of sandstone from the exposure of the Murree Formation in the Jena Kor area located at the southern margin of the Peshawar Basin (Figure 1). Conflicting results have been reported by various researchers regarding about the strength of sandstone. Previous studies suggest that the geomechanical properties of sandstones vary widely and depend on several parameters. These include grain size, packing density, packing proximity, degree of interlocking, type and length of grain contact, type and abundance of cement/matrix, sorting and mineralogical composition. In this research petrographic details have been utilized for the purpose of characterization on the basis of modal mineralogy, grain size, assessing the degree of sorting and extent of textural and mineralogical maturity. In addition, geo-mechanical properties are determined and compared to (i) evaluate potential of the Murree Sandstone for use as construction material and (ii) assess their dependence on petrographic details.

## 2. Samples and Methodology

### 2.1 Field Work

Fifty two samples of sandstone were collected from the entire exposed thickness of the Murree Formation in the study area for petrography with an

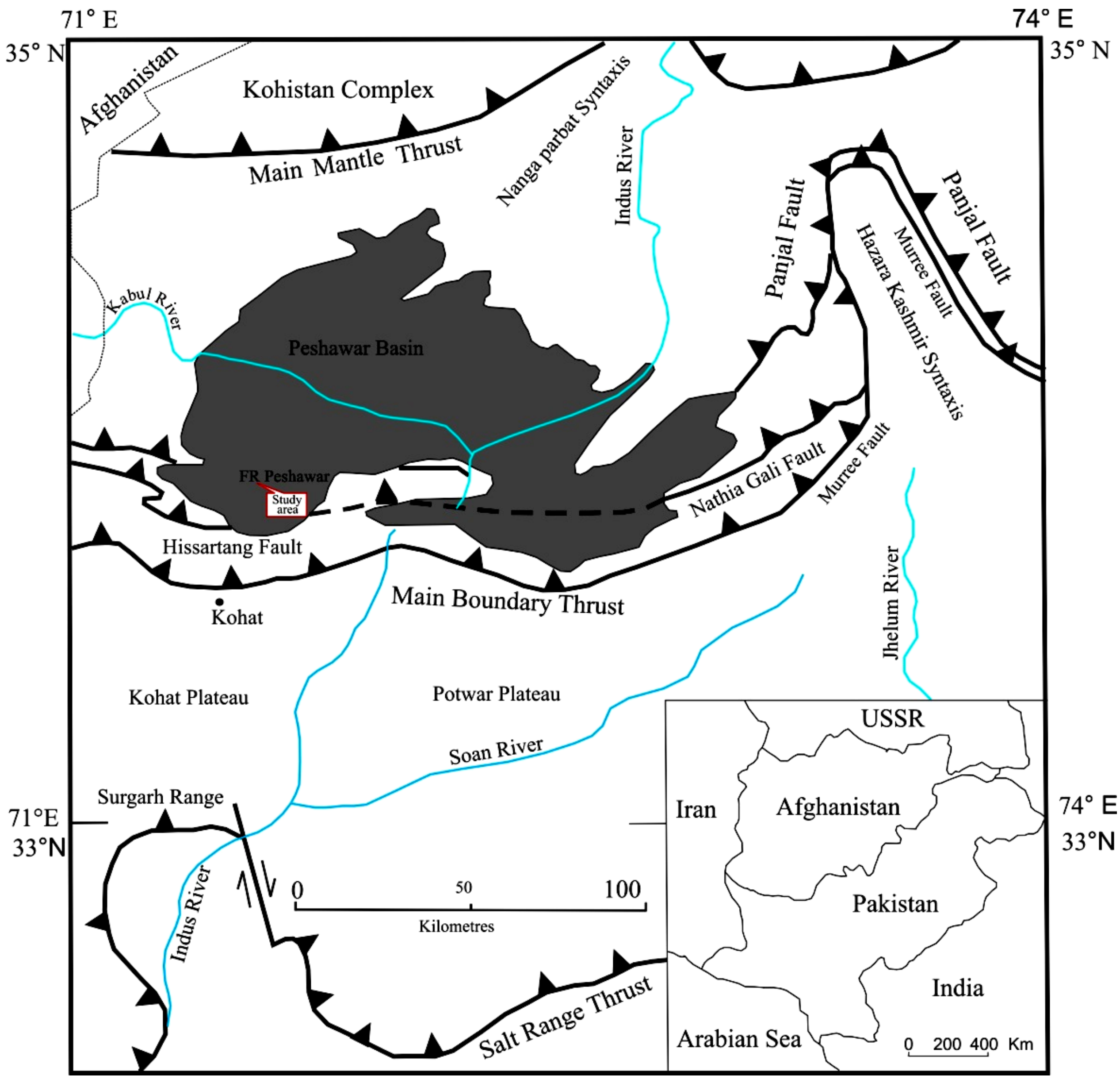


**Fig. 1** Regional tectonic map of Pakistan showing major tectonic features (after Kazmi and Rana, 1982). The box demarcates the study area

average interval of 30m while three bulk samples were collected for geotechnical analysis.

## 2.2 Laboratory work

Forty five of the collected samples were made into thin sections for detailed petrographic studies. The standard thin section technique with a thickness of approximately 30 μm is applied to examine the composition of the samples. In order to determine physico - mechanical properties for geo - technical evaluation, core samples are obtained with the help of core drilling machine form the bulk samples.

### 2.2.1 Uniaxial compressive strength (UCS)

The UCS is a unidirectional stress applied on a cylindrical core sample which may be regarded as the highest stress that a specimen can hold (Bell, 2007). The robustness of a stone is a measure of its capability to resist weathering, maintain its original size, shape, strength and appearance for a long period of time that determine whether or not a rock will be suitable for construction (Sims, 1991). Rocks with compressive strength of 35MPa are generally considered satisfactory for use as a building stone (Bell, 2007).

#### 2.2.2 *Uniaxial tensile strength (UTS)*

The UTS of a rock is its resistance to bending and tends to be less than its compressive strength (Bell, 2007). The uniaxial tensile strength (UTS) of the Murree Sandstone was determined by the indirect or Brazilian method using disc-shaped samples with thickness to diameter ratio of 0.5 (e.g. Arif et al., 1999)

#### 2.2.3 Shear Strength

The shear strength of the Murree Sandstone was calculated by indirect method by plotting the UCS values on positive x-axis and the UTS values on the negative x-axis in the form of Mohr circles. A common tangent to these two circles yields the values of cohesion (C) and the angle of internal friction ($\varphi$). The vertical distance from the origin of x and y-axes to the point of intersection between the tangent and y-axis is a measure of cohesion. The angle between the tangent and the horizontal or x-axis is the angle of internal friction.

#### 2.2.4 Specific Gravity, Porosity and water absorption

Blyth and DeFreitas (1974) have proposed that rocks with specific gravity $\geq$ 2.55 are suitable for heavy construction works.

For simplicity regular cube-shaped samples were prepared for determining the porosity and water absorption values of the Murree Sandstone. First, each of the samples was weighed in air and then put in a water container for 24 hours. The saturated sample was weighed in air and then in water. After noting the readings, the porosity (P) and water absorption (WA) were calculated as follows:

$$P (\%) = [(W_2 - W_o) \div (W_2 - W_1)] \times 100$$

$$WA (\%) = [(W_2 - W_o) \div W_o] \times 100$$

Where

$W_2$ = Saturated weight in air
$W_1$ = Saturated weight in water
$W_o$ = Dry weight in air

## 3. Petrography

### 3.1 Modal composition

Quartz is the most abundant framework constituent in the studied samples and ranges from 10 to 43 modal percentages (Table 1). Some of the quartz grains display uniform and others undulatory extinction. The medium-sized quartz grains usually contain inclusions of sphene, zircon and/or epidote, but the fine-grained quartz is generally free of inclusions.

Some of the quartz grains contain carbonate (calcite)-filled micro-fractures (Figure 2A).

Feldspar is the second most abundant framework constituent in the studied samples with an average abundance of 11% (Table 1). Plagioclase is more abundant than alkali feldspar. Sericitization has made proper recognition of some of the feldspar grains. The alkali feldspar is mostly orthoclase. Besides, grains of perthitic alkali feldspar also occur in some of the studied samples. The grains of feldspars are angular to subangular and devoid of inclusions. The plagioclase grains display polysynthetic Albite and/ or combined Carlsbad–Albite twinning and sericitization (Figure 2B).

Rock/lithic fragments constitute 11 modal percentages of the studied samples. They consist of quartz-mica schist, quartzite, carbonate (micrite), chert, igneous rocks and mudstone (Figure 2C, D). Both muscovite and biotite occur in the studied samples (Figure 2E, F). Muscovite is much more abundant than biotite. The deformed flakes of muscovite show undulatory extinction. Biotite is brown, reddish brown and yellowish brown and strongly pleochroic (Figure 3). Biotite occurs in only a few of the thin sections. Scarcity of biotite is partly due to its alteration to chlorite.

Reddish brown hematite and dark black magnetite occur in all the samples (Figure 2G). Other accessory minerals observed in the studied chlorite and chromite (Figure, 2H, I).

**Table 1** Modal composition of the Murree Sandstone

| Sample | Quartz | Feldspar | Lithics | Matrix/ cement | Muscovite | Biotite | Chlorite | Zircon | Epidote | Sphene | Rutile | Chromite | Monazite | Apatite | Ilmenite | Iron ore | Q:F |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| MF1 | 12.2 | 1.2 | 6.0 | 77.0 | 0.0 | 0.0 | 1.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 2.7 | 10.2 |
| MF2 | 30.7 | 16.5 | 5.1 | 28.5 | 0.6 | 0.5 | 5.8 | 0.3 | 1.2 | 0.2 | 0.6 | 0.0 | 0.0 | 0.0 | 0.1 | 10.0 | 1.9 |
| MF3 | 43.4 | 21.8 | 3.8 | 11.8 | 0.8 | 0.0 | 7.5 | 0.3 | 0.1 | 0.2 | 0.8 | 0.0 | 0.0 | 0.2 | 0.4 | 10.7 | 2.0 |
| MF4 | 37.0 | 15.9 | 2.1 | 14.1 | 2.4 | 0.0 | 6.9 | 0.7 | 0.1 | 0.0 | 0.3 | 0.0 | 0.0 | 0.1 | 0.8 | 19.8 | 2.3 |
| MF5 | 30.7 | 12.5 | 6.9 | 33.7 | 0.9 | 0.0 | 1.7 | 0.1 | 0.0 | 0.0 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 | 13.4 | 2.5 |
| MF6 | 18.3 | 9.0 | 5.3 | 43.7 | 0.2 | 0.0 | 7.1 | 0.1 | 0.0 | 0.0 | 0.3 | 0.0 | 0.1 | 0.0 | 0.1 | 15.9 | 2.0 |
| MF7 | 14.3 | 2.7 | 3.3 | 62.2 | 0.7 | 0.0 | 7.1 | 0.1 | 0.0 | 0.0 | 0.3 | 0.0 | 0.0 | 0.0 | 0.1 | 9.3 | 5.3 |
| MF8 | 28.9 | 9.4 | 9.9 | 25.7 | 0.7 | 0.0 | 6.3 | 0.7 | 1.1 | 0.1 | 0.7 | 0.0 | 0.0 | 0.1 | 0.2 | 17.5 | 3.1 |
| MF9 | 24.7 | 10.9 | 8.8 | 29.8 | 1.1 | 0.0 | 5.2 | 0.0 | 0.1 | 0.0 | 0.0 | 0.0 | 0.1 | 0.0 | 0.5 | 18.8 | 2.3 |
| MF10 | 27.8 | 3.9 | 7.1 | 41.5 | 0.9 | 0.0 | 8.9 | 0.2 | 0.5 | 0.0 | 0.3 | 0.0 | 0.1 | 0.1 | 0.1 | 8.6 | 7.1 |
| MF11 | 14.7 | 6.2 | 6.5 | 57.0 | 0.6 | 0.0 | 6.6 | 0.0 | 0.1 | 0.0 | 0.3 | 0.0 | 0.1 | 0.1 | 0.3 | 7.6 | 2.4 |
| MF12 | 38.5 | 20.0 | 7.1 | 6.9 | 1.6 | 0.1 | 8.4 | 0.0 | 0.0 | 0.0 | 0.3 | 0.4 | 0.0 | 0.0 | 0.1 | 17.0 | 1.9 |
| MF13 | 29.8 | 17.7 | 1.8 | 27.1 | 0.9 | 0.0 | 6.0 | 0.1 | 0.0 | 0.0 | 0.1 | 0.1 | 0.0 | 0.0 | 0.2 | 16.2 | 1.7 |
| MF14 | 22.8 | 15.2 | 6.4 | 40.0 | 0.6 | 0.0 | 6.1 | 0.2 | 0.0 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.5 | 8.3 | 1.5 |
| MF15 | 22.2 | 11.1 | 4.1 | 42.8 | 0.5 | 0.0 | 6.2 | 0.0 | 0.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.1 | 12.8 | 2.0 |
| MF16 | 22.9 | 12.0 | 2.5 | 35.6 | 0.6 | 0.0 | 6.6 | 0.0 | 0.0 | 0.0 | 0.1 | 0.0 | 0.0 | 0.0 | 0.1 | 19.5 | 1.9 |
| MF17 | 31.8 | 20.6 | 5.4 | 25.9 | 1.2 | 0.0 | 6.6 | 0.0 | 0.0 | 0.0 | 0.2 | 0.0 | 0.0 | 0.0 | 0.0 | 8.8 | 1.5 |
| MF18 | 28.9 | 10.3 | 8.1 | 20.9 | 1.9 | 0.0 | 6.8 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.1 | 23.1 | 2.8 |
| MF19 | 19.8 | 10.9 | 1.2 | 29.3 | 0.7 | 0.2 | 7.3 | 0.2 | 0.8 | 0.0 | 0.2 | 0.0 | 0.0 | 0.0 | 0.1 | 29.4 | 1.8 |
| MF20 | 25.1 | 16.7 | 11.1 | 28.5 | 0.9 | 0.3 | 4.7 | 0.0 | 0.0 | 0.0 | 0.5 | 0.4 | 0.0 | 0.1 | 0.5 | 11.4 | 1.5 |
| MF21 | 13.9 | 6.0 | 2.1 | 58.7 | 0.2 | 0.0 | 7.6 | 0.1 | 0.0 | 0.0 | 0.1 | 0.1 | 0.0 | 0.0 | 0.1 | 11.1 | 2.3 |
| MF22 | 26.3 | 14.7 | 11.3 | 28.8 | 0.3 | 0.0 | 7.4 | 0.1 | 0.2 | 0.0 | 0.2 | 0.0 | 0.0 | 0.0 | 0.0 | 12.1 | 1.8 |
| MF23 | 25.3 | 15.6 | 2.1 | 34.7 | 1.2 | 0.0 | 9.7 | 0.2 | 0.0 | 0.0 | 0.1 | 0.0 | 0.0 | 0.0 | 0.1 | 11.0 | 1.6 |
| MF24 | 29.6 | 17.1 | 2.1 | 30.9 | 0.9 | 0.0 | 7.9 | 0.4 | 0.1 | 0.0 | 0.1 | 0.0 | 0.0 | 0.0 | 0.1 | 10.9 | 1.7 |
| **MF25** | 41.0 | 8.1 | 7.5 | 26.5 | 0.8 | 0.0 | 2.3 | 0.0 | 0.1 | 0.0 | 0.2 | 0.0 | 0.1 | 0.0 | 0.2 | 13.3 | 5.1 |
| **MF26** | 36.3 | 9.5 | 6.0 | 34.3 | 0.1 | 0.0 | 1.3 | 0.0 | 0.0 | 0.0 | 0.2 | 0.4 | 0.4 | 0.0 | 0.0 | 11.5 | 3.8 |
| **MF27** | 38.1 | 9.5 | 2.8 | 33.4 | 1.6 | 0.0 | 3.9 | 0.3 | 0.0 | 0.0 | 0.1 | 0.1 | 0.0 | 0.0 | 0.0 | 10.1 | 4.0 |
| **MF28** | 29.9 | 7.8 | 6.0 | 40.4 | 0.0 | 0.0 | 1.3 | 0.0 | 0.0 | 0.0 | 0.1 | 0.6 | 0.0 | 0.0 | 0.0 | 13.9 | 3.8 |
| **MF29** | 23.2 | 14.4 | 5.4 | 33.4 | 0.7 | 0.0 | 2.9 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.1 | 0.0 | 0.0 | 18.9 | 1.6 |
| **MF30** | 30.3 | 12.41 | 5.3 | 28.1 | 1.3 | 0.0 | 2.5 | 0.2 | 0.0 | 0.0 | 0.2 | 0.0 | 0.3 | 0.0 | 0.0 | 19.6 | 2.4 |
| **MF31** | 39.0 | 9.4 | 1.7 | 22.9 | 0.7 | 0.0 | 2.0 | 0.1 | 0.3 | 2.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 21.9 | 4.1 |
| **MF32** | 32.4 | 9.1 | 1.4 | 32.2 | 1.1 | 0.0 | 1.0 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.2 | 0.0 | 0.0 | 22.4 | 3.6 |
| **MF33** | 34.5 | 14.8 | 3.1 | 27.7 | 1.3 | 0.8 | 1.6 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 16.3 | 2.3 |
| **MF34** | 40.5 | 9.5 | 2.7 | 24.5 | 3.3 | 0.0 | 0.3 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.1 | 0.0 | 0.0 | 19.5 | 4.3 |
| **MF35** | 38.3 | 9.7 | 4.4 | 39.9 | 0.5 | 0.0 | 1.0 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.1 | 6.0 | 3.9 |
| **MF36** | 21.9 | 9.7 | 6.0 | 40.2 | 0.3 | 0.0 | 1.4 | 0.0 | 0.0 | 0.0 | 0.2 | 0.0 | 0.0 | 0.0 | 0.0 | 20.2 | 2.3 |
| **MF37** | 10.2 | 2.9 | 2.5 | 60.4 | 0.6 | 0.0 | 8.1 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 15.3 | 3.5 |
| **MF38** | 19.1 | 9.8 | 3.6 | 45.1 | 0.6 | 0.0 | 3.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.1 | 18.7 | 1.9 |
| **MF39** | 9.5 | 7.1 | 6.3 | 58.7 | 0.8 | 0.0 | 13.0 | 0.0 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 4.5 | 1.3 |
| **MF40** | 13.4 | 5.6 | 1.1 | 62.1 | 0.8 | 0.0 | 0.4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 16.6 | 2.4 |
| **MF41** | 15.9 | 4.9 | 3.3 | 55.5 | 0.0 | 0.0 | 1.7 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 18.7 | 3.2 |
| **MF42** | 18.3 | 8.3 | 4.3 | 41.5 | 1.5 | 0.0 | 7.3 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.1 | 18.8 | 2.2 |
| **MF43** | 41.7 | 10.2 | 3.4 | 22.6 | 2.0 | 0.0 | 2.0 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.2 | 0.0 | 1.0 | 18.0 | 4.1 |
| **MF44** | 16.1 | 13.2 | 4.3 | 38.6 | 2.9 | 0.0 | 2.0 | 0.0 | 0.0 | 0.0 | 0.3 | 0.0 | 1.0 | 0.0 | 1.0 | 22.3 | 1.2 |
| **MF45** | 20.9 | 9.1 | 3.3 | 34.1 | 2.1 | 0.0 | 0.7 | 0.3 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 27.5 | 2.3 |

Average composition

| | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Average** | 26.4 | 10.9 | 4.8 | 36.4 | 0.9 | 0.0 | 4.8 | 0.1 | 0.1 | 0.1 | 0.7 | 0.0 | 0.1 | 0.0 | 0.2 | 15.1 | 2.9 |
| **Sdev** | 9.4 | 4.8 | 2.6 | 14.5 | 0.6 | 0.1 | 3.1 | 0.2 | 0.3 | 0.3 | 3.4 | 0.1 | 0.2 | 0.0 | 0.3 | 5.9 | 1.7 |

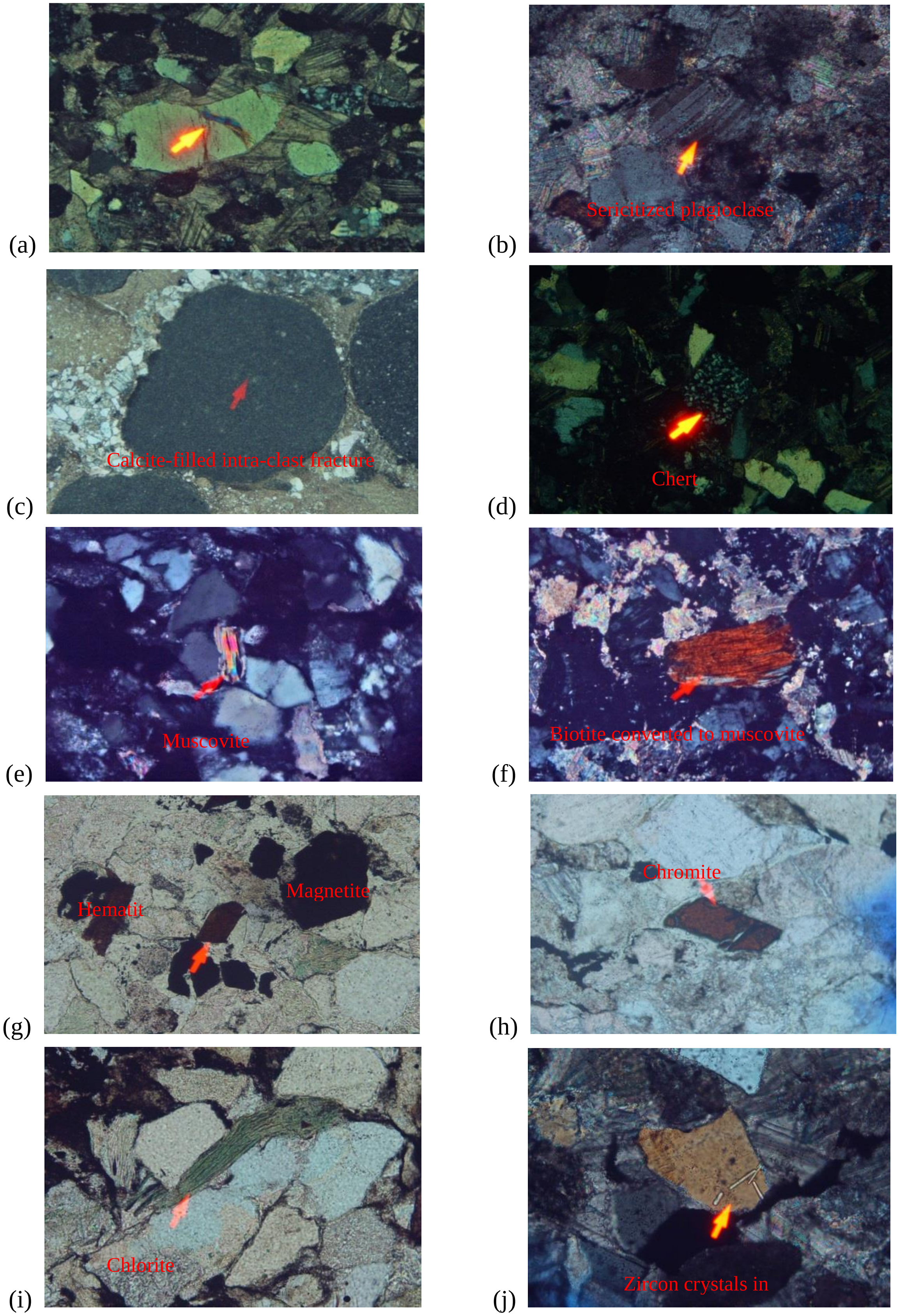


**Fig. 2** Photomicrographs illustrating compositional char acteristics of the studied samples.

## 3.2 Texture Detail

Murree Sandstone is mostly fine to medium-grained in the study area, same grain size is noted by Malik and Rashid (1997) in Lower Topa, however some of the samples especially those from the upper part of the formation are fine to very fine-grained (Figure 3). The detrital grains in most of the studied sandstone samples are sub-prismoidal to spherical. A few of them contain mostly prismoidal sand grains (Figure 4). Some of the samples from the upper part are well to very well sorted, while most of the others are moderately sorted to well-sorted. The roundness of clasts ranges from angular through sub-angular to sub-rounded. However, majority of the grains are angular to sub-angular (Figure 4). The boundaries among the grains of quartz and feldspar in the studied thin sections are tangential, long, concavo-convex and sutured. The elongated grains of essential minerals and mica (muscovite) lie along bedding planes, but intense deformation has made them inclined to the bedding plane as revealed by detailed thin section studies. The fabric is mostly matrix supported.

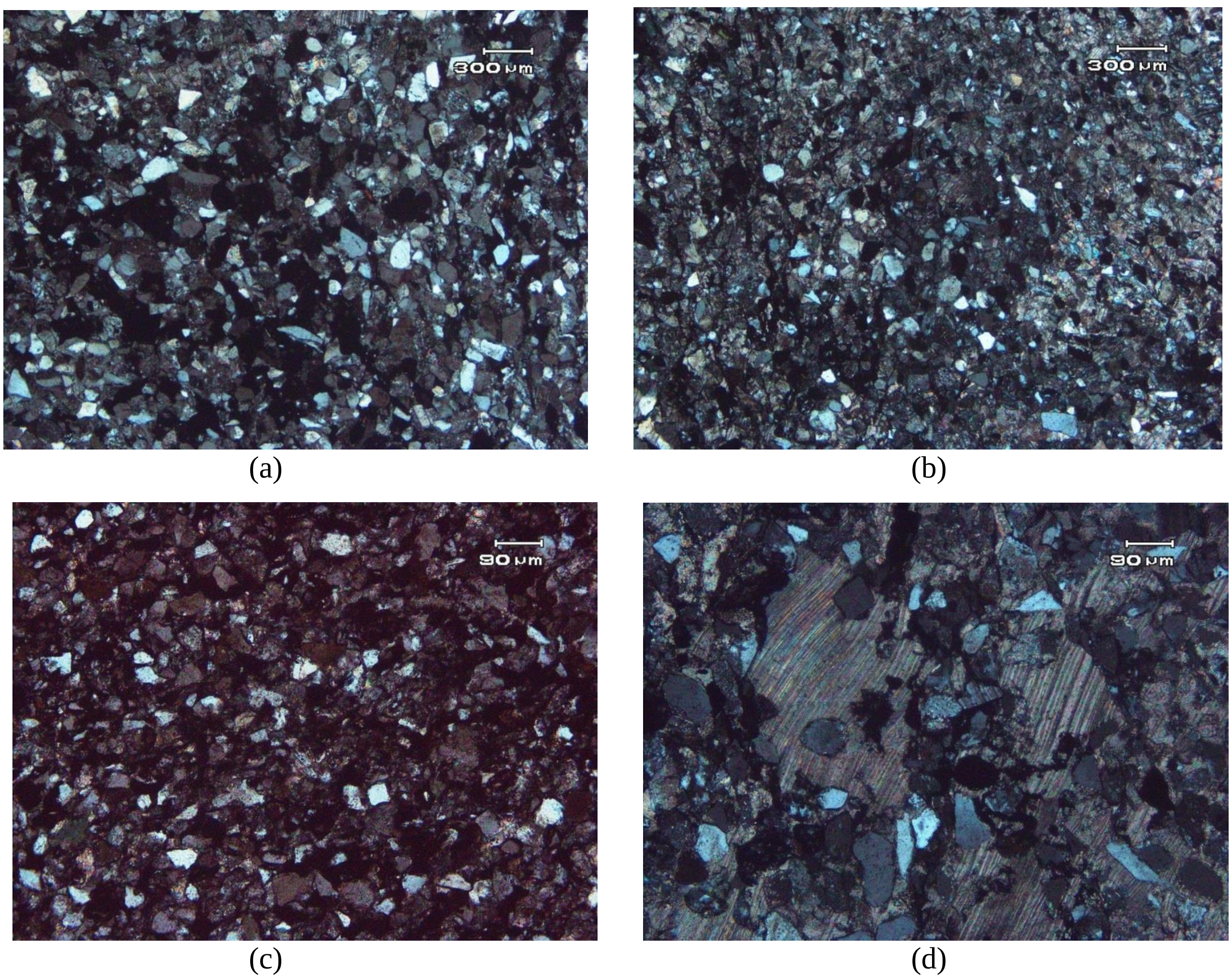


**Fig. 3** Photomicrographs (XPL) showing textural details of the studied samples: (a) fine-grained, sub-angular to sub-rounded, prismoidal to sub-spherical clasts dispersed in ferruginous matrix and carbonate cement; (b) fine to very fine-grained, sub-rounded to rounded, sub-spherical to spherical clasts sparsely dispersed in abundant carbonate and subordinate ferruginous cement; (c) very fine-grained, sub-angular to rounded, sub-spherical to spherical clasts sparsely dispersed in abundant ferruginous matrix and carbonate cement; and (d) fine-grained, angular to rounded, prismoidal to spherical clasts sparsely dispersed in abundant carbonate and minor ferruginous cement. The deformed character of the carbonate is observable.

### 3.3 Maturity

The modal composition and textural properties are the most important parameters that determine the maturity of sandstone. The mineralogical maturity of sandstones is determined by their quartz to feldspar ratios (Pettijohn et al., 1987). Although the abundance of quartz is generally greater than other framework elements, the presence of appreciable amounts of plagioclase and considerable quantity of rock fragments makes the Murree Sandstone mineralogically submature. The textural maturity of sandstone depends upon the matrix proportion, degree of sorting and roundness of its framework constituents. According to Prothero et al. (2004), sandstone is texturally immature if the proportion of clay size material (matrix) exceeds 5 %, irrespective of the degree of sorting and roundness. The high proportion of matrix, moderate to well sorting and low degree of roundness all suggest that the Murree Sandstone is texturally immature. In addition to quartz and feldspars, the studied samples contain rock fragments, chlorite, muscovite, biotite, zircon, epidote, monazite, tourmaline, sphene, apatite and iron ore(s) as framework constituents. An average matrix abundance of 36%, the Murree sandstone is classified as wacke. Malik and Rashid (1997) reported almost the same amount of matrix (30-45%) from the exposure of Murree Formation at Lower Topa, Punjab. Most of the sandstone samples from the present study fall in the range of arkosic wacke according to Pettijohn et al. (1987) proposed scheme of sandstone while five plots in the field of lithic wacke (Figure 4).

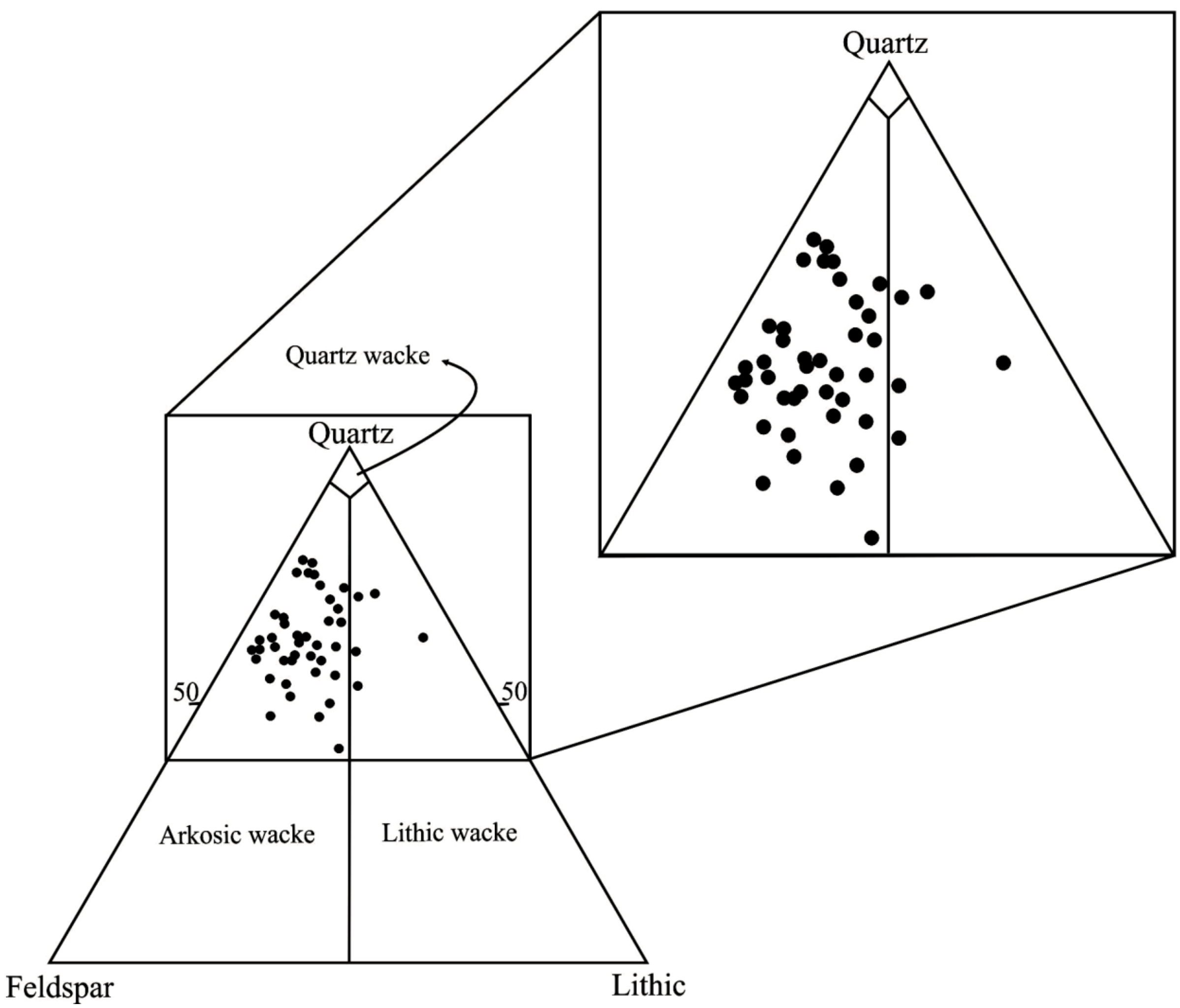


**Fig. 4** Petrographic characterization of the studied samples following Pettijohn et al. (1987).

## 4. Results of Mechanical Properties

With compressive strength values ranging from 54.49 to 98.03 MPa (Table 2), the examined Murree Sandstone falls in the category of strong rocks as defined by Anon (1977).

The UTS values of the Murree Sandstone range from 9.2 to 13.7 MPa as shown in Table 2. The average values of cohesion and angle of internal friction of the Murree Sandstone are 14MPa and 47º, respectively with an average specific gravity of 3.12 (Table 2). The average values of porosity and water absorption of the investigated samples are low given in Table 2.

## 5. Discussion

The following are the important petrographic parameters that are believed to affect the UCS of sandstones (Shakoor and Bonelli, 1991).

### 5.1 Cement

Conflicting results have been reported by various researchers. Vutukuri et al. (1974) have found that rocks with silica cement are the strongest, followed by those with calcite cement, ferruginous material and, at last, the clayey binder. With calcite as the binding material, the sandstone is the second most durable after silica-cemented sandstone. Fahy and Guccione (1979) and, Shakoor and Bonelli (1991) noticed positive correlation between UCS and amount of cement/ matrix. Contrarily, Ulusay et al. (1994) and Zorlu et al. (2004) found inverse relationship between these two parameters. A study of the Sherwood Sandstone in England has led Yates (1992) to suggest that strength depends upon the extent of cementation and compaction.

### 5.2 Degree of Roundness

Shakoor and Bonelli (1991) observed a fairly positive correlation between UCS and percentage of angular grains, while Ulusay et al. (1994) found a strong positive relation between UCS and the ratio of angular grains to rounded grains, i.e. UCS increases with increasing angularity of the frameworks. However, neither of these studies could find any correspondence between UCS and sphericity. Negative correlation between UCS and percentage of rounded grains can be reasonably predicted, while that between the UCS and percent angular grains should be positive (Zorlu et al., 2008). Accordingly, Fahy and Guccione (1979) reported a negative relationship between UCS and roundness, but found an extremely strong positive relationship between UCS and sphericity.

### 5.3 Packing Density

Shakoor and Bonelli (1991) and Bell and Culshaw (1998) did not find a significant relation between the UCS and packing properties. However, a slightly positive relationship between UCS and both packing density and packing proximity was observed by Ulusay et al. (2004) and Zorlu et al. (2004).

### 5.4 Grain Contacts

Tangential inter-granular contacts occur in loosely packed sediments whereas concavo-convex and sutured contacts occur in rocks that have undergone considerable compaction during burial (Blatt, 1982). Hence high UCS is expected from rocks with sutured or concavo-convex inter-grain contacts (Zorlu et al., 2008). Correspondingly, Shakoor and Bonelli (1991) and Ulusay et al. (1994) have reported a strong positive correlation between the UCS and concavo-convex and sutured type contacts.

### 5.5 Degree of Sorting

Tamrakar et al., (2007) have noticed that the composition/ type, shape (sphericity) and degrees of roundness and sorting have a little influence, if at all, on the mechanical and physical properties of the Siwalik Sandstone. Alternatively, the nature of cementing material seems to have been significant in determining strength of the Siwalik Sandstone (Tamrakar et al., 2007).

### 5.6 Percentage (modal abundance) of quartz grain

A positive correlation between UCS and percentage of quartz in sandstones is expected and actually observed by several workers (Bell and Lindsay 1999; Zorlu et al., 2004, 2008). In contrast, Bell (1978), Fahy and Guccione (1979), Shakoor and Bonelli (1991) and Ulusay et al. (1994) did not find any meaningful correlation between UCS and percentage of quartz.

**Table 2**. The strength and physical properties of the Murree Sandstone

| S. No. | UCS (MPa) | UTS(MPa) | UCS:UTS | Specific Gravity | Water absorption | Porosity |
|---|---|---|---|---|---|---|
| 1 | 54.49 | 9.2 | 5.9 | 3.12 | 0.389% | 1.21% |
| 2 | 78.71 | 11.5 | 6.8 | | | |
| 3 | 98.03 | 13.7 | 7.2 | | | |

**Table 3**. Comparison between samples of the Murree Sandstone from Jena Kor (FR Peshawar) and Lower Topa (Murree), Pakistan

| Property/ Component | Jena Kor area (this study) | Lower Topa (Malik & Rashid, 1997) |
|---|---|---|
| Grain size | Very fine to medium | Fine to medium |
| Degree of sorting | Moderate to very well (95 %) | Poor |
| Angularity | Angular through sub-angular to sub-rounded | Angular to sub-rounded |
| Quartz | 9.5-43.4 % | 30-50% |
| Other clasts | 10.9-55.0 % | 5 to 10% |
| Deformed micas | Present | Present |
| Total clasts | 23.1-93.5 % | 35-60% |
| Matrix/ cement | 6.9-77.0 % | 30-45 % |
| Matrix/ cement composition | Calcite and iron oxide | Clay and calcite |
| UCS (MPa) | 54.5-98.0 (77.07±21.61) | 56-86 |

The UCS values of the samples under investigation vary widely (Table 2). A detailed comparison with samples representing the Murree Sandstone exposed at Lower Topa reveals that the Murree Sandstone at Jena Kor area displays greater variation in terms of both strength and petrographic details (Table 4). Worth noting is the variation in the relative proportion of clasts including both quartz and matrix/ cement. Secondly, whereas the Lower Topa samples are poorly sorted, most of the Jena Kor samples are moderately sorted to well-sorted.

## 6. Conclusions

Texturally, the Murree Sandstone is immature and mineralogically sub-mature.

The sandstone of Murree Formation is fine to medium grain and moderately to well sorted.

The high UCS (well above 35 MPa), low porosity (1.21%), high specific gravity (>2.55) and low water absorption values makes the Murree Sandstone suitable for construction purposes.

The modal composition, sorting and grain size appear to be controlling the strength of the Murree Sandstone.

All physico-mechanical properties make the Murree Sandstone suitable for use in heavy construction works and hence fall well within the range regarded suitable for use as dimension stone and building material.

## 7. Acknowledgements

The University of Peshawar financed the studies. Samples for both petrographic studies and geotechnical investigation were prepared at the Department of Geology, University of Peshawar. The strength testing was performed at the Department of Mining Engineering, KPK University of Engineering and Technology, Peshawar, while the physical properties were determined at the NCE in Geology, University of Peshawar, Pakistan. Muhammad Sajid, Assistant Professor, Department of Geology, University of Peshawar deserves special thanks for helping in carrying out the mechanical tests.

## 8. References

[1] Pettijohn, F. J., Potter, P. E., & Siever, R. 1987. Sand and sandstone. 2nd edition. Springer-Verlag New York, 618.

[2] Zeitler, P. K. 1985. Cooling history of the NW Himalaya, Pakistan. *Tectonics, 4,* 127-51.

[3] Kazmi, A. H and Rana, R. A., 1982. Tectonic map of Pakistan. Geol. Surv. Pak., Quetta.

[4] Bell, F. G. 2007. Engineering Geology, 2nd edition. Butterworth-Heinemann: an imprint of Elsevier, United Kingdom. 581.

[5] Sims, I. 1991. Quality and durability of stone for construction. *Quarterly Journal of Engineering Geology, 24,* 67-74.

[6] Arif, M., Mulk, A., Mehmood, M. T., & Shah, S. M. H. 1999. Petrography and mechanical properties of the Mansehra granite, Hazara, Pakistan. *Geological Bulletin University of Peshawar, 32,* 41-49.

[7] Blyth, F. G. H., & DeFreitas, M. H. 1974. A geology for engineers. ELBS and Edward Arnold, London.

[8] Malik, M. H., & Rashid, S. 1997. Correlation of some engineering geological properties of the Murree Formation at Lower Topa (Murree District), Pakistan. *Geol. Bull. Univ. Peshawar 30,* 69-81.

[9] Prothero, D. R., & Schwab, F. 2004. Sedimentary Geology, 2nd edition, New York: W.H. Freeman & Company.

[10] Anon, 1977. The description of rock masses for engineering purposes. *Quarterly Journal of Engineering Geology, 10,* 355-388.

[11] Shakoor, A., & Bonelli, R. E. 1991. Relationship between petrographic characteristics, engineering index properties and mechanical properties of selected sandstone. *Bulletin of the Association of Engineering Geologists, 28,* 55-71.

[12] Vutukuri, V. S., Lama, R. D., & Saluja, S. S. 1974. Handbook on Mechanical properties of Rock, Testing Technique and Results Volume 1. Trans Technical Publications, Cluasthal, Germany. 280.

[13] Fahy, M. P., & Guccione, M. J. 1979. Estimating the strength of sandstone using petrographic thin section data. *Bulletin of the Association of the Engineering Geologists, 16,* 467-485.

[14] Ulusay, R., Turrell, K., & Ider, M. H. 1994. Prediction of engineering properties of a selected litharenite sandstone from its petrographic properties using correlation and multi-variate statistical techniques. *Engineering Geology, 37,* 135-157.

[15] Zorlu, K., Ulusay, R., Ocakoglu, F., Gokceoglu, C., & Sonmez, H. 2004. Predicting intact rock properties of selected sandstones using petrographic thin section data. *International Journal of Mechanics and Mining sciences, 41,* 93-98.

[16] Yates, P. G. J. 1992. The material strength of sandstones of the Sherwood sandstone Group of North Staffordshire with reference to micro-fabric. *Quarterly Journal of Engineering Geology, 25,* 107-113.

[17] Zorlu, K., Gokceoglu, C., Ocakoglu, F., Nefeslioglu, H. A., & Acikalin, S. 2008. Prediction of uniaxial compressive strength of sandstones using petrography based models. *Engineering Geology, 96,* 141-158.

[18] Bell, F. G., & Culshaw, M. G. 1998. Petrographic and engineering properties of sandstone from the Snienton Formation Nottinghamshire, England. *Quarterly Journal of Engineering Geology, 31,* 5-21.

[19] Blatt, H., Tracy, R. J., & Owens, D. E. 2006. Petrology (Igneous, Sedimentary and Metamorphic), 3rd edition, W.H. Freeman and Company, New York, 530.

[20] Tamrakar, N. K., Yokota, S., & Shrestha, S. D. 2007. Relationships among mechanical, physical and petrographic properties of Siwalik sandstones, Central Nepal Sub-Himalayas. *Engineering Geology, 90,* 105-123.

[21] Bell, F. G., & Lindsay, P. 1999. The petrographic and geomechanical properties of some sandstone from the Newspaper member of the Natal group near Durban, South Africa. *Engineering Geology, 53,* 57-81.

[22] Bell, F. G. 1978. The physical and mechanical properties of the Fell sandstone, Northumberland, England. *Engineering Geology, 12,* 11-29.

[23] Anon, 1979. Classification of rocks and soils for engineering geological mapping. Part 1- Rock and soil materials. *Bulletin of the International Association of Engineering Geology, 19,* 364-371.