CHARACTERIZATION OF PHYSICAL AND STRENGTH PROPERTIES OF SELECTED ROCKS OF SWABI AND SURROUNDING AREAS, KP PAKISTAN

By

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C E R T I F I C A T E

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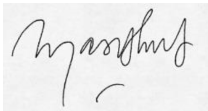
Co-Supervisor	Dr. Waqas Ahmad	
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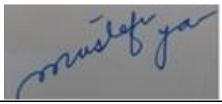
External Examiner	Mr. Mustafa Yar	
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DEDICATION

To my beloved father and mother

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First of all I am very grateful to the **Almighty Allah** who bestowed me with good health, wellbeing and the ability to successfully complete this research work.

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Regards

Muhammad Luqman

ABSTRACT

The purpose of this study is to investigate physical, strength and petrographic features of rocks of District Swabi and surrounding areas. Moreover this study was aimed to find out how physical and strength properties and petrographic features change with one another and to find out if a meaningful correlation was present between direct and direct strength tests of the rocks. Two bulk rock samples for each formation/lithology were collected. The rocks included Nikani Ghar Marble, Ambela Granite, Shewa-Shahbazgari Granite and Utla Granite and marble, limestone and dolomite of Nowshera Formation. Bulk rock samples were cut into different test specimens. Cube samples were prepared for UCS, UPV and physical tests while block rock samples were prepared for PLT according to ASTM specifications. Similarly two thin sections were made for each rock type. Physical and strength tests and petrographic studies were performed at NCEG Peshawar. Results of physical and strength properties showed that the rocks can be confidently recommended for use in engineering projects. UCS of the rocks ranged between 51.1 and 294 MPa, PLT ranged between 2.86 and 10.03MPa, Hr ranged between 36.9 and 64.3, OD-UPV ranged between 1869.5 and 4765.8m/s , while SSD-UPV ranged between 4185.7 and 6059.3 m/s. Similarly water absorption of the rocks ranged between 0.37 and 0.86%, specific gravity ranged between 2.6453 and 2.8960, and porosity ranged between 0.142% and 0.32%. Strong correlation was find between UCS and Hr (R-squared=0.95), UCS and PLT (R=0.914), PLT and Hr (R= 0.867) while weaker correlation was present between OD-UPV and Hr (R=0.694, SSD-UPV and Hr (R=0.707), OD-UPV and UCS (R=0.74) and SSD-UPV and UCS (R=0.714). While no meaningful correlation was present between UPV (OD or SSD) and Porosity.

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LIST OF ABBREVIATIONS

ACR	Attock Cherat Range
AG	Ambela Granite
AGC	Ambela Granitic Complex
ASTM	American Society for Testing Materials
CPL	Cross Polarized Light
Hr	Schmidt Hammer Rebound Number
IAEG	International Association for Engineering Geology
ISRM	International Society for Rock Mechanics
SSD	Saturated Surface Dry
KIA	Kohistan Island Arc
MKT	Main Karakoram Thrust
MMT	Main Mantle Thrust
MPa	Mega Pascal
ND	Nowshera Dolomite
NGM	Nikani Gar Marble
NL	Nowshera Limestone
NM	Nowshera Marble
OD	Oven Dry
PLT	Point Load Test
PPAIP	Peshawar Plain Alkaline Igneous Province
PPL	Plain Polarized Light
SG	Specific Gravity
SSG	Shewa-Shahbazgari Granite
SRT	Salt Range Thrust
UCS	Unconfined Compressive Strength
UG	Utla Granite
UPV	Ultrasonic Pulse Wave Velocity
WA	Water Absorption

CHAPTER 1

INTRODUCTION

1.1 General Statement

Pakistan has been bestowed with a variety of rocks. Rocks belonging to sedimentary, igneous and metamorphic group are present here. These rocks are classified into different groups which include important groups of Peshawar Basin and Peshawar Plain Alkaline Igneous Province (PPAIP). The rocks that were studied in the course of current study belonged either to Peshawar Basin or PPAIP. These included Nowshera Formation (limestone, dolomite and marble) and Nikani Ghar Formation (marble) of Peshawar Basin and Ambela, Shewa-Shahbazgari and Utla Granites of PPAIP.

Rocks were studied in terms of physical and strength properties and petrographic features. Physical properties included water absorption (WA), specific gravity (SG) and porosity while strength properties included unconfined compressive strength test (UCS), point load index test PLT), Schmidt hammer rebound number test (Hr) and ultrasonic pulse wave velocity test (UPV). These properties are very important because they affect the strength of rocks directly or indirectly. Strength is an important parameter in deciding whether a rock should be used or not in an engineering project. It was studied that how physical and petrographic features affect the strength of rocks and how these features relatively change to one another. Moreover physical and strength properties were correlated with one another to find out if a meaningful relation was present between these properties.

1.2 Previous Work

The rocks that were examined in the course of current study have drawn attention of many researchers who have studied these rocks in different contexts. A brief overview of those studies has been given as follows. Rafiq and Qasim (1989) studied petro-chemistry of Ambela Granitic Complex (AGC) and divided these rocks into three different groups. Din et al. (1997) have correlated strength of Ambela Granitic Complex and limestone. A detailed account on engineering properties of AGC have been given by Sajid et al. (2013). The UCS values indicate that rocks of AGC are moderately strong. Similarly the values of their WA are low and SG high enough to consider them suitable for use as construction material in engineering projects (Sajid et al., 2013). Sajid and Arif (2014) have studied the effects of petrographic features on the engineering properties of Utla Granites. The UCS values indicate that Utla Granites are moderately strong from engineering perspectives. It is observed commonly that fine grained rocks are stronger than coarse grained rocks, but a contrasting result was drawn by Sajid and Arif (2014) for Utla Granites. The coarse grained rocks showed higher strength values than fine grained rocks. The low strength of fine grained granites than the coarser ones can be explained by water absorption and porosity values for fine grained granites, which are much higher than that of coarse grained granites. The surge in water absorption and porosity values are due to large scale recrystallization, as is obvious from the deformational features observed during petrographic study (Sajid and Arif, 2014). Sajjad et al. (2018) have studied strength parameters of rocks from different areas of Khyber Pakhtunkhwa including Shewa-Shahbazgari Complex. They observed that both the uniaxial compressive strength and tensile strength are highly dependent upon the grain size of the rocks. The strength of granites (Shewa-Shahbazgari Complex) decreases with increase in grain size. Ambela Granite have comparatively higher strength values than granite of Shewa-Shahbazgari Complex (Sajjad et al., 2018).

Geo-mechanical properties of marble deposits from Nikani Ghar Formation and Nowshera Formation have been studied by Iqbal and Abrar (2016). They observed a direct linear relation between water absorption, porosity and calcite maximum grain size for these rocks. They noted that water content in Nikani Ghar and Nowshera Formations was relatively low due to lower porosity.

Naeem et al. (2014) have studied strength properties and petrographic characteristics of Margalla Hill Limestone and Lockart Limestone. They observed a direct relationship between UCS and calcite content. Calcite content in both limestones are comparable but bio-clasts are relatively higher in Margalla Hill Limestone as compared to Lockart Limestone. The porosity of these rocks ranges between 1 and 2.1%. It was observed that porosity increases with increase in bio-clasts content. A significant positive linear relationship between calcite contents and UCS of Margalla Hill and Lockart Limestone has been observed.

1.3 Location and Accessibility

All the formations that were studied in the course of current study lie around 30 km or less from village Shewa of District Swabi. Village Shewa lies about 20 km west of main Swabi. District Swabi can be approached from Islamabad through Peshawar-Islamabad motorway (M1) via Anbar interchange. Main Swabi city lies around 15 km north of Anbar interchange.

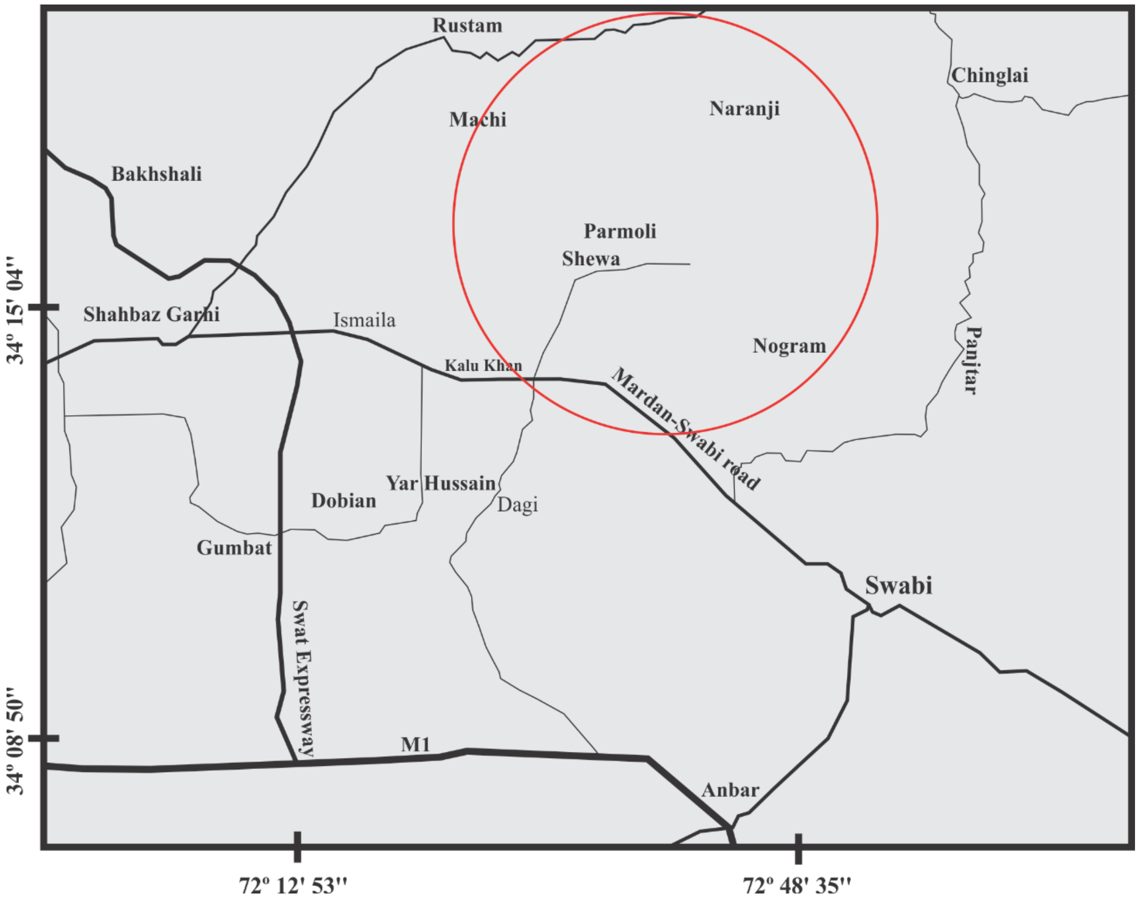

Figure 1.1 Accessibility map of the study area (the red circle encompasses the study area).

1.4 The Present Study

The current research work is intended to find out field, petrographic, physical and strength properties of different rocks of District Swabi and of the surrounding areas. These include Sedimentary rocks of Nowshera Formation (limestone, dolomite); igneous rocks of Shewa-Shahbazgari Complex, Ambela Granite and Utla Granite; and metamorphic rocks of Nikani Ghar Formation (marbles) and Nowshera Formation (marbles).

1.5 Aims and Objectives

Igneous rocks of the study area are studied frequently by many researchers in terms of physical and strength properties while metamorphic and sedimentary rocks have earned little attention of the researchers. Moreover no one has tried to establish a relation between direct and indirect strength tests on the basis of the rocks of the study area. Main objectives of the current study are:

- To identify the physical, strength and petrographic characters of selected rocks of district Swabi and surrounding areas.
- To find out reliance of physical and strength properties on petrographic characters of the subject rocks.
- To establish a relation between different types of direct (UCS, PLT) and indirect (Hr, UPV) strength tests, using regression analysis.

CHAPTER 2

LITERATURE REVIEW

2.1 Geology of Northern Pakistan

There are three distinct tectonic domains in northern Pakistan which are Indian Plate, Kohisatn Island Arc and Eurasian Plate (Fig. 2.1).

Indian Plate was a part of ancient continent of Gondwana. It was detached from other fragments of Gondwana about 130 Ma and started moving towards north (Johnson et al., 1976; Powell et al., 1979). This detachment was followed by wide scale sea floor spreading and widening of Indian Ocean at the expense of Neo-Tethys, the ocean that separated the subcontinent from Eurasia (Treloar and Rex, 1993). Due to intra oceanic subduction in the Neo-Tethys a number of volcanic arcs (Kohistan-Ladakh, Nuristan and Kandahar) originated during the Cretaceous period (110-90Ma) (Treloar and Rex, 1993; Searle, 1991).

Due to northwards movement Indian Plate ultimately collided with Kohistan Island Arc (KIA) which resulted in the origination of Main Mantle Thrust (MMT) (Coward et al., 1999). (Searle et al., 1999) have reported collision between KIA and Eurasian in late Cretaceous. Both of these have collided along Main Karakoram Thrust (MKT). Coward et al. (1986) have divided KIA into six units from south to north which are given as: a) Jijal Complex, b) Kamila Amphibolite, c) Chilas Complex, d) Kohistan Batholith and Gilgit Gneisses, e) Chalt Volcanics and f) Yasin Group Metasediments.

As oceanic crust of Neo-Tethys was subducitng continuously beneath KIA and Eurasia, it resulted in complete depletion of the foremost oceanic edge of the Indian Plate, and its ultimate collision with leftovers of KIA and then with Eurasian Plate (Coward et al., 1986). The most remarkable consequence of this impact is the world's highest mountain ranges, the Himalayas. Dietrich et al. (1983) consider Himalayas-Karakoram-Hindukush ranges in the northern Pakistan a wide-ranging collision zone between the Eurasian Plate and Indian Plate.

Geology of Indian Plate is diverse. Different regions of Indian Plate contain rocks belonging to different geologic periods. The rocks of Indian Plate in Pakistan are divided into two zones by Khairabad Fault (Coward et al., 1988). One is called Internal Metamorphosed Zone, which is northern zone between Khairabad Fault and Main Mantle Thrust (MMT) while the other, which is southern zone, is called External Un-metamorphosed or Low-grade Metamorphic Zone (Treloar et al., 1989). Farther to the south, these rocks are separated by MBT from Tertiary fore-land basin deposits. Treloar et al. (1989) have divided the internal zone of the Indian Plate into six different crustal nappes which include Upper Kaghan, Lower Kaghan, Besham, Swat, Hazara and Bannu.

The Indian plate is sectioned into three different tectonic units by Treloar et al. (1991). These are given as internal metamorphic unit, external un-metamorphosed unit or low grade metamorphic unit, and the foreland basin sediments, from south to north. The first unit consists of cover and basement sequences which are separated by Khairabad Fault from the external zone un-metamorphosed to low grade metamorphic Precambrian sediments and dominantly Mesozoic to Eocene Tethyan shelf sediments. Further to the south, these rocks are separated from Tertiary foreland basin deposits by MBT (Treloar et al., 1991).

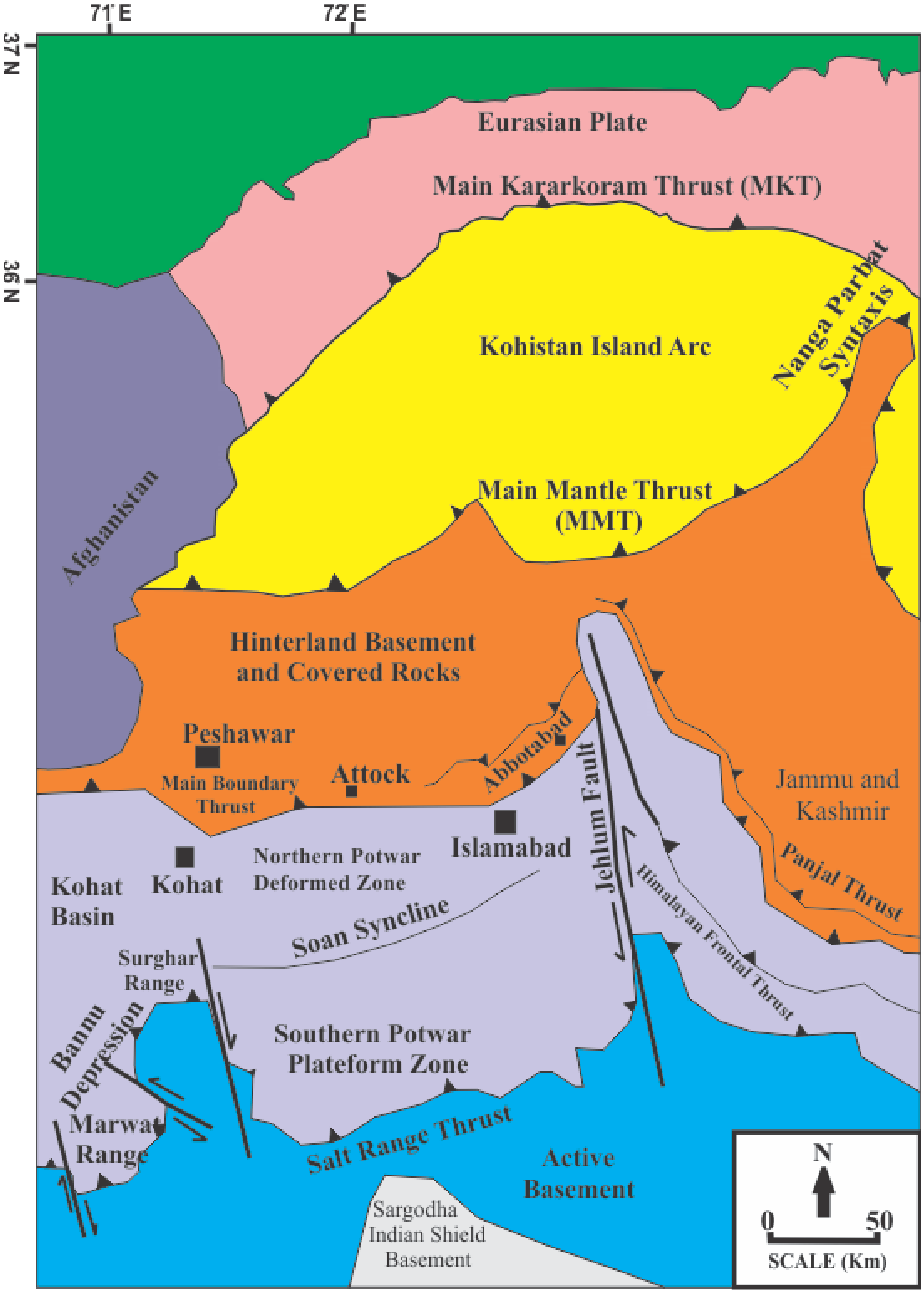

Figure 2.1. Geology of north-eastern Pakistan (redrawn after Kazmi and Rana, 1982).

2.2 Geology of Peshawar Basin

The Peshawar Basin lies at the southern margin of the Pakistan Himalaya. It lies between active front of the Himalayan deformation at the Salt Range Thrust (SRT) and Main Mantle Thrust (MMT). MMT is a junction between Indian Plate and KIA. Peshawar Basin is bounded by the Attock-Cherat Range (ACR) to the south and Gandghar and Khyber ranges to the east and west respectively. It is surrounded by Malakand Granite on the north and on the north-west and north-east by Warsak and Ambela Granitic Complexes. The rocks of Peshawar Basin range in age from Precambrian to early Mesozoic and consist of Igneous, Sedimentary and Metamorphic rocks (Khan et al., 1990; Kazmi and Jan, 1997). Burbank & Tahirkheli (1985) have attributed the origin of Peshawar Basin to the rising of Attock-Cherat Ranges (ACR) in Plio-Pleistocene as a result of which a thick pile of 300 meter was deposited in response to ponding of drainage by the rising ACR. Map of eastern Peshawar Basin (area of interest) is given in fig. 2.2.

As the rocks of the Peshawar Basin are easily accessible from different parts of the country, therefore a lot of research work has been conducted in the past from different aspects. The first geologic account of the rocks of the southern Peshawar Basin was given by Coulson (1936). In 1962 Martin et al. also studied rocks of north-eastern Peshawar Basin from geological point of view. In 1986 Pogue and Hussain gave a revised stratigraphic nomenclature of the rock of southern Peshawar Basin. In 1992 Khan studied the stratigraphic and structural set up of rocks of north-eastern Peshawar Basin.

Martin et al. (1962) sub divided the rock sequence of northeastern Peshawar Basin into two groups. These groups are: i) Swabi-Chamla Sedimentary Group and ii) Lower Swat-Buner Schistose Group. Swabi-Chamla Sedimentary Group rocks are present south of the Lower Swat-Buner Schistose Group (Siddique et al., 1968). The rocks of Swabi-Chamla Sedimentary Group range from Paleozoic to Mesozoic in age (Pogue et al., 1992). Pogue et al. (1992) have included rocks of Tanawal Formation, Anbar Formation, Misri Banda Quartzite, Panjpir Formation, Nowshera Formation, Jafar Kandao Formation, Karapa Schist, Kashala Formation and Nikani Gar Formation in Swabi-Chamla Sedimentary Group. Coulson (1936) included rocks of Southern Peshawar Basin in Attock Slate and assigned Pre-Cambrian age.

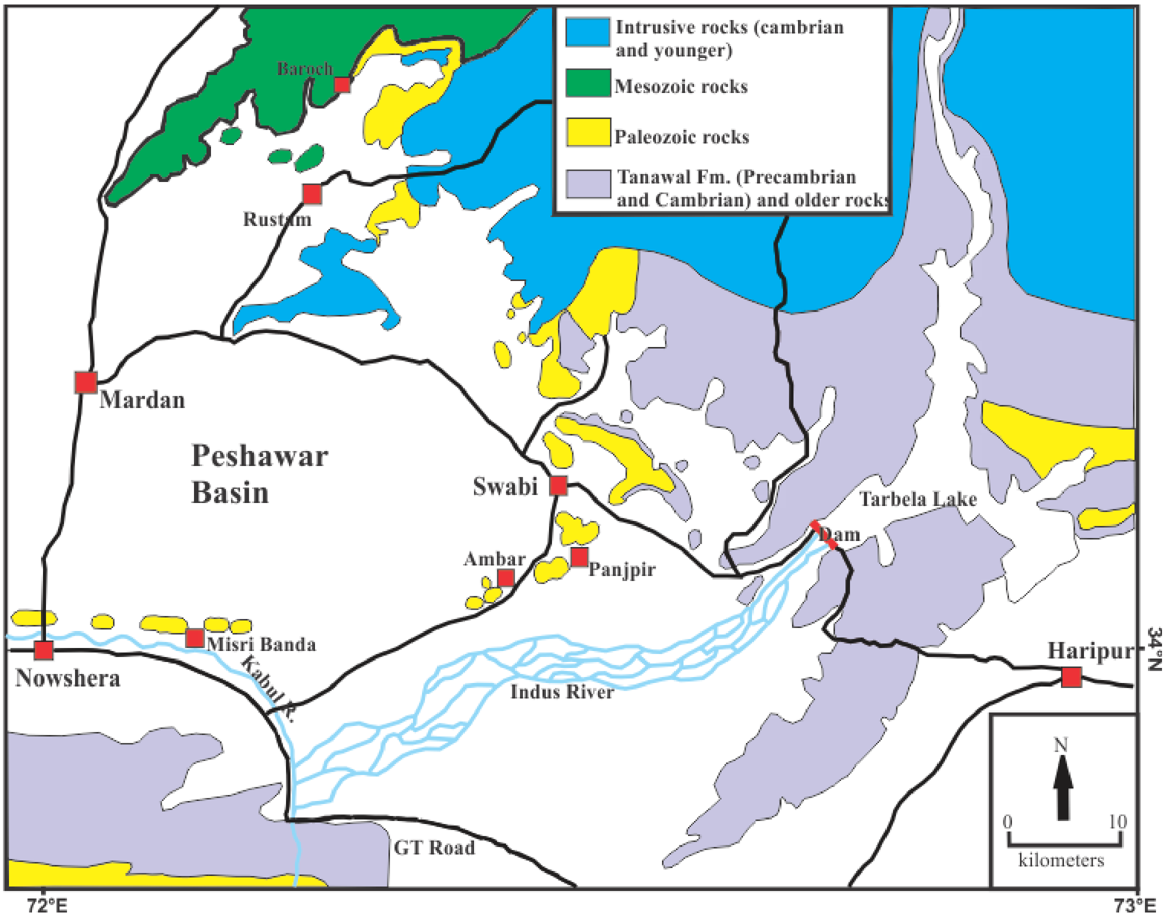

Figure 2.2 Geological map of eastern Peshawar Basin (after Pogue et al., 1992).

2.3 Peshawar Plain Alkaline Igneous Province (PPAIP)

Peshawar Plain Alkaline Igneous Province (PPAIP) is a group of igneous rocks that extend from Peshawar to Afghanistan. The province is composed of ten occurrences (Kempe and Jan, 1980; Kempe, 1983). These include granites of Ambela, Shewa-Shahbazgari and Utla (see fig. 2.3) as well as rocks from Loe Shilman, Sillai Patti, Tarbela, Malakand and Warsak etc.

Kempe and Jan (1970) were the first to give idea of existence of an alkaline igneous province. There idea was based on the occurrence of alkaline igneous rocks in Warsak, Shewa-Shahbazgari and Tarbela area. Later on findings of Ahmad and Ahmed (1974) on Ambela Granite, Chaudhry et al. (1974) on Malakand Granite, Jan et al. (1981) on Carbonatite Complex in Shilman and Ashraf and Chaudhry (1977) on carbonatite of Sillay Patti provided materials to believe that the province was present on a large area between river Indus and Torkham border.

On the basis of K-Ar dating from Koga and Warsak area Kempe and Jan (1980) have analyzed that PPAIP was associated with tertiary rifting.

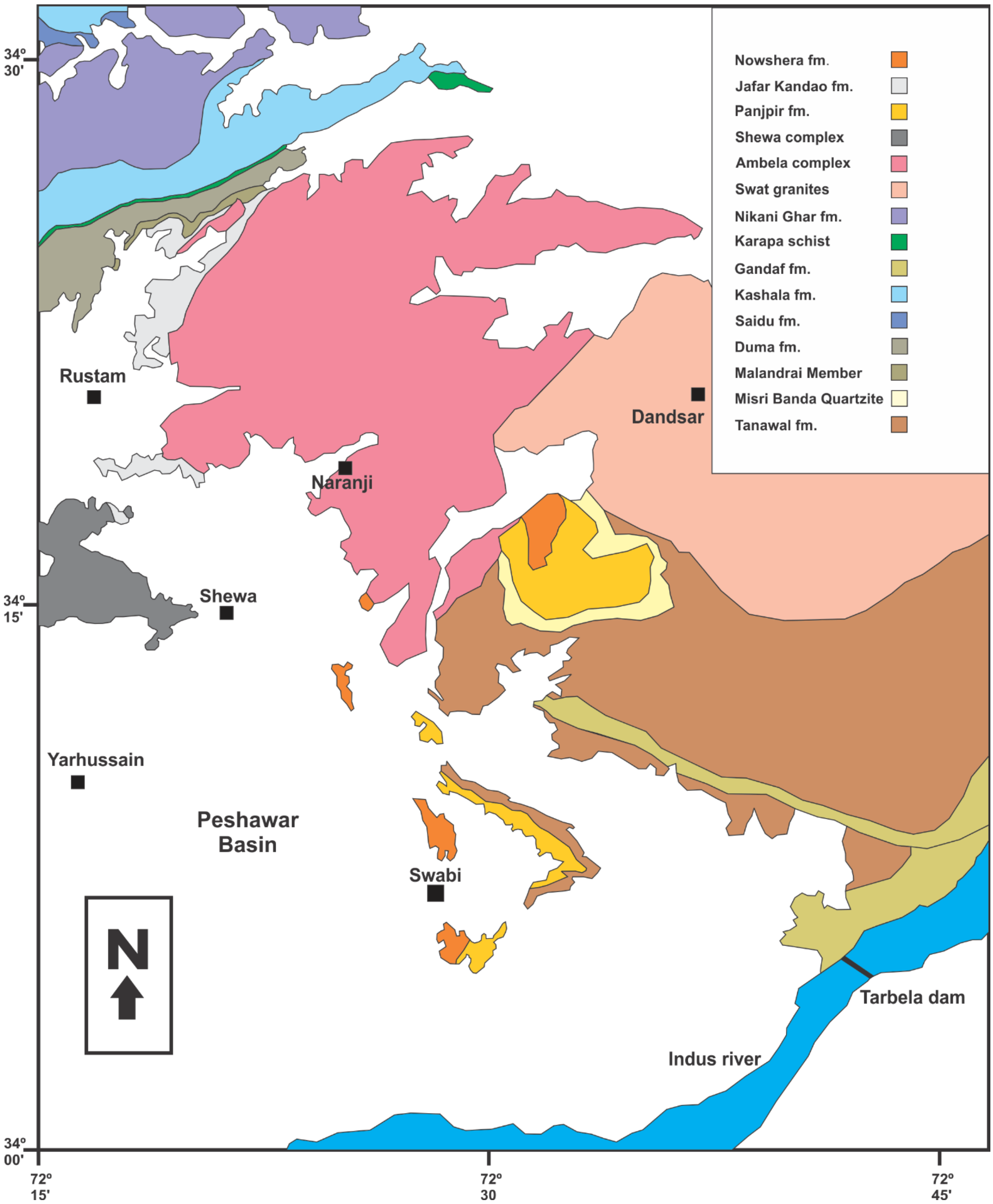

Figure 2.3 Map showing eastern rocks of Peshawar Plain Alkaline Igneous Province and Peshawar Basin (redrawn from Hussain et al., 2004)

2.4 Geology of Formations of Study Area

2.4.1 Nowshera Formation

The name Nowshera Formation was given by Stauffer (1968) to fossiliferous carbonates that lie beneath the Misri Banda Formation and above the Panjpir Formation. This formation constitutes the youngest Paleozoic sedimentary rocks exposed between the Nowshera and Swabi area (Pogue et al., 1991). Before Stauffer (1968) these rocks were known either as Kala Limestone or Maneri Marble see Martin et al. (1962).

The Nowshera Formation consists majorly of dolomite, limestone and marble with calcareous and dolomitic quartzite and calcareous argillite. Stauffer (1968) has divided this formation at its type locality into three sub groups. These groups are given as: i) Reef Core, ii) Carbonate containing reef breccia or fossil debris and iii) Carbonate containing fewer or no fossils

Talent and Mawson (1979) have assigned early Devonian age to the formation. Their analysis was based on the discovery of microfossils and conodonts from lower part of the formation.

2.4.2 Nikani Ghar Formation

Type locality of Nikani Gar Formation is present in district Buner. This formation consists majorly of fine to coarse grained crystalline and dolomitic marble. The formation also includes thin beds Nikani Ghar Formation consists primarily of white to dark grey, thick bedded to massive, fine to coarse grained crystalline marble and dolomitic marble. The formation also includes thin beds of schist, quartzite and schistose marble (Kazmi and Jan, 1997). Nikani Gar Formation overlies Kashala Formation. These two formations are hard to be identified due to similarities in lithology. However both can be separated from each other on the basis of result of weathering. Upon weathering Nikani Gar Marble becomes whitish while Kashala Formation orange brown in colour.

Age of Nikani Gar Marble is still not confirmed but from the age of underlying Kashala Formation Pogue et al. (1992) have assumed late Triassic to Jurassic age to Nikani Gar Marble.

2.4.3 Shewa-Shahbazgari Complex

Shewa-Shahbazgari Complex is located between district Swabi and Mardan. The complex consists of acidic and basic rocks including micro porphyry, meta-gabbro, meta-dolerite and local quartz monzonite and porphyritic micro granite. Common minerals in acidic rocks are orthoclase, perthite and plagioclase together with riebeckite and aegirine indicating alkaline characters. While common minerals in basic rocks are hornblende, clino-pyroxene, magnetite, biotite, epidote and apatite (Irshad et al., 1990).

Coulson (1936) has correlated these rocks with Warsak Granite and assigned Mesozoic age to these rocks. While Bakhtiar and Waleed (1980) along with some other researchers like Chaudhry et al. (1976) and Ahmad and Ahmed (1974) have assigned early Tertiary to late Cretaceous age to the rocks of the complex.

2.4.4 Ambela Granite

Ambela Granite is the largest body of PPAIP which has covered an area of about 900km. It lies in NW Pakistan and ranges from middle to late Paleozoic in age. On the basis of petrographic and geochemical studies Rafiq and Jan (1989) have divided the rocks of the complex into three distinct groups. First group consists of granite and alkali granites and makes about 70% part of the complex. Second class consists of quartz syenite, feldspathoidal syenite, ijolite and carbonatite. While third group is composed of dolerite and lamprophyre dykes and makes about 5% part of the complex.

Arif et al. (2013) have divided rock of Ambela Complex into 3 groups on the basis of petrographic studies. These are a) alkali granite, b) mega porphyritic quartz syenite and c) nepheline syenite.

Physical and strength properties of ACG have been studied by Arif et al. (2013). They have recommended these rocks for use in construction projects on the basis of UCS, specific gravity and water absorption values. They have placed these rocks in moderately strong category of Anon’s classification of rocks on the basis of UCS. They have find somewhat negative correlation between UCS and water absorption. While UCS and specific gravity have not shown a meaningful relation.

2.4.5 Utla Granite

Utla Granites are situated in the northern part of the Indian Plate, east of Ambela Granite. These granites are separated from KIA to the north by Main Mantle Trust (MMT) (Searle et al., 1999). Ambela Granites intrude pre-Cambrian meta-sedimentary Tanawal Formation (Sajid and Arif, 2014). Utla Granites are in spatial continuity with the AGC, an eastward extension (Rafiq and Jan, 1988).

Utla Granites have been divided by Arif and Sajid (2014) into three groups on the basis of petrographic characteristics/texture. These are 1) Mega-crystic Coarse-grained Granite, 2) Foliated Coarse-grained Granite and 3) Fine-grained Granite.

2.5 Petrographic, Physical and Strength Properties of Rocks

Physical and strength properties of rocks are considered of great importance in context of engineering projects. These properties of rocks mainly depend upon petrographic features like grain size, mineral contents, packing and sorting of grains, cementing materials and discontinuities. Willard et al. (1969) have described the effects of aforementioned petrographic features on strength of rocks. Similarly Kahraman (2015) has studied the effects of porosity and anisotropy on strength properties of rock. Where he has find out an inverse relation between porosity and strength properties like UCS, UPV and Hr.

There are two types of tests to know about strength of rocks a) direct strength tests b) indirect strength tests. Direct tests give value of strength directly while indirect tests do not give it directly, however, strength of rocks can be predicted from these tests. Direct tests include UCS and UTS while indirect tests include UPV, HR and PLT. In comparison of direct tests indirect tests are easy, fast and economical to perform. Direct tests require particular test specimen preparation and highly sophisticated testing equipment while on the other hand equipment required for indirect tests is not highly sophisticated and is portable in many cases. That is why nowadays researchers frequently predict strength of rocks indirect tests like UPV, PLT and Hr.

Out of indirect tests Schmidt hammer (Hr) is most commonly used to infer about strength of rocks. Katz (2000) has reported development of Schmidt hammer in 1948. Schmidt hammer has many kinds out of which two are very important – N-type and L-type. These two hammers are frequently used for determination of rock hardness. They both differ from each other only by impact energy. Type-L has an impact energy of 0.735Nm while type-N has 2.207 Nm. Gotkan (2015) considers type-N hammer for concrete testing while type-L for rock testing.

Many researchers have tried to predict UCS from Hr. Sachpazis (1990) obtained a strong relationship (R=0.96) between UCS and Hr for carbonate rocks when the density of rocks was considered. Similarly Deere and Muller (1996) discovered that correlation improves if the density of rocks was multiplied with Hr reading and then correlated with UCS.

2.6 Correlation between Direct and Indirect Strength Tests

Strength is very important parameter for designing an engineering project. So it is vital to know about strength of rocks (used in building or ground rock) before an engineering project. UCS is the test frequently used to measure strength of rocks but as discussed above it is an expensive and time consuming process. Therefore indirect tests which are affordable and easy to perform are used to predict strength of rocks. Moreover the equipment required for indirect tests is portable and less sophisticated. That’s why many researchers have tried to find out UCS from other simple tests. Researchers have frequently correlated UCS vs PLT, Hr and UPV and derived equations that can be used to calculate UCS.

2.6.1 Correlation between UCS and Hr

Kahraman and Kesimal (2014) have correlated UCS of rocks with Hr. they have obtained a strong correlation between the two with R-squared= 0.95. Before them Yagiz (2009) has also correlated UCS with Hr for carbonates and metamorphic rocks and has obtained a good correlation of R-squared= 0.92. Similarly Aydin and Basu (2005) have also obtained a strong correlation of R-squared= 0.93 while correlating UCS and Hr of granites.

2.6.2 Correlation between UCS and PLT

Point Load Test (PLT) is a cost effective alternative method to indirectly obtain UCS and can be conducted on rock sample without using any special sample preparation. PLT is practically used in geo-technical engineering to determine rock strength index because of its simplicity and rapidity it is widely correlated with UCS by many scientists to derive a possible relation between the two. ISRM (1985) has stated that the ratio between UCS and PLT ranges between 20 and 25 but it is worth mentioning that many scholars have found different ratios. For example based on various rock samples Karaman et al. (2005) have derived a relation between UCS and PLT in which UCS was equal to almost 11 times of PLT (UCS=10.91PLT+27.41). Similarly Heidari et al. (2012) have derived a relation between UCS and PLT for Gypsum where UCS was equal to almost 5 times of PLT (UCS= 5.575 PLT+21.92) which is once again not in accordance with the ISRM (1985). But Kahraman and Keisman (2012) have derived a relation between UCS and PLT for various rocks in which UCS is equal to almost 20 times of PLT (UCS=20.48PLT-5.146) which is according to ISRM (1985) specification.

2.6.3 Correlation between UCS and UPV

Ultrasonic pulse velocity (UPV) is another non-destructive indirect test which has been frequently used to evaluate UCS of rocks. Chary et al. (2006) have reported that UPV can be used to guess strength of rocks. Yilmaz et al. (2014) have assessed strength properties of rocks using UPV. Similarly Jiang et al. (2020) have evaluated strength properties of cemented paste backfill on the basis of UPV. They have observed that samples with higher UPV values tend to have greater strength values and vice versa.

2.6.4 Correlation between Hr and UPV

Schmidt hammer rebound number (Hr) is affected directly by hardness of rock which is affected by factors like mineral content, packing, degree of weathering, porosity and specific gravity etc. similarly UPV of rock is also affected to a higher extent by almost the same factors which affect Hr.it means that Hr and UPV for same rock may have a meaningful relation with each other. It is generally observed that rocks having higher values of Hr mostly have higher values of UPV and vice versa. In literature no significant work is present where scholars have tried to correlate Hr and UPV of rock.

2.6.5 Correlation between PLT and Hr

Point load strength test (PLT) is another important indirect test. It is used to get an insight into UCS of rocks because it is affordable and easy to perform as compared to UCS test. Though PLT is a fast way to guess about strength of rock still it is not more convenient than Hr. It would not be a spare attempt to establish a relation between Hr and PLT. In literature no well-reputed work is present where researchers have tried to establish a correlation between PLT and Hr.

CHAPTER 3

METHODOLOGY

3.1 General Overview

The procedures and methods that had been adopted while carrying out different tests and studies during the present research work are briefly described in this chapter to build foundation for their results in the following chapter. All of the research was carried out in a proper order and sequence which is given in fig 3.1.

3.2 Field Work

Field works were carried out to collect bulk samples (fig 3.2) from the desired formation. While collecting bulk samples, it was ensured that the bulk samples must not be weathered and fractured. Similarly while collecting samples, the size of the bulk sample was chosen big enough to give designed specimens for rock testing. Every bulk samples was carved into three cubes of three inch edge length, one cube of six inch and small blocks for PLT and thin section preparation.

3.3 Rock Cutting and Specimens Preparation

Bulk samples were cut into different shapes (blocks) (fig 3.3) following specific criterion for each test. The standards which were followed in performing physical and strength tests are mentioned in their respective test procedure. Each bulk sample was cut into one cube having edge length of six inches for Hr, three/four cubes having edge length of three inches for UCS and physical tests, two blocks of different dimensions for PLT and one small block having dimensions of 1×1×2 inches for thin section preparation. Cutting of bulk samples was carried in Galaxy Marble Factory Shewa Adda, Swabi. After cutting the specimens were carried to NCEG, Peshawar for testing.

3.4 Physical Tests

Physical properties (water absorption, specific gravity and porosity) were find out in Geotechnical lab NCEG, Peshawar. First of all weight in air of the samples was measured with a scale (fig.3.5 a) then weight in water was measured then the samples were placed for twenty four hours in water and then saturated weight of the specimens was measured. Then the specimens were placed in oven (fig 3.5 b) for twenty four hours at 110°C and then oven-dry weight was measured. Physical properties were then find in the following ways.

3.4.1 Water Absorption

$$Water\ absorption(\%) = \frac{saturated\ weight - Oven\ dry\ weight}{Oven\ dry\ weight} \times 100$$

3.4.2 Specific Gravity

$$Specific\ gravity = \frac{Oven\ dry\ weight}{Oven\ dry\ weight - Weight\ in\ water}$$

3.4.3 Porosity (Harrison, 1993 method)

$$Porosity(\%) = \frac{Weight\ in\ air - Oven\ dry\ weight}{Weight\ in\ air - Weight\ in\ water} \times 100$$

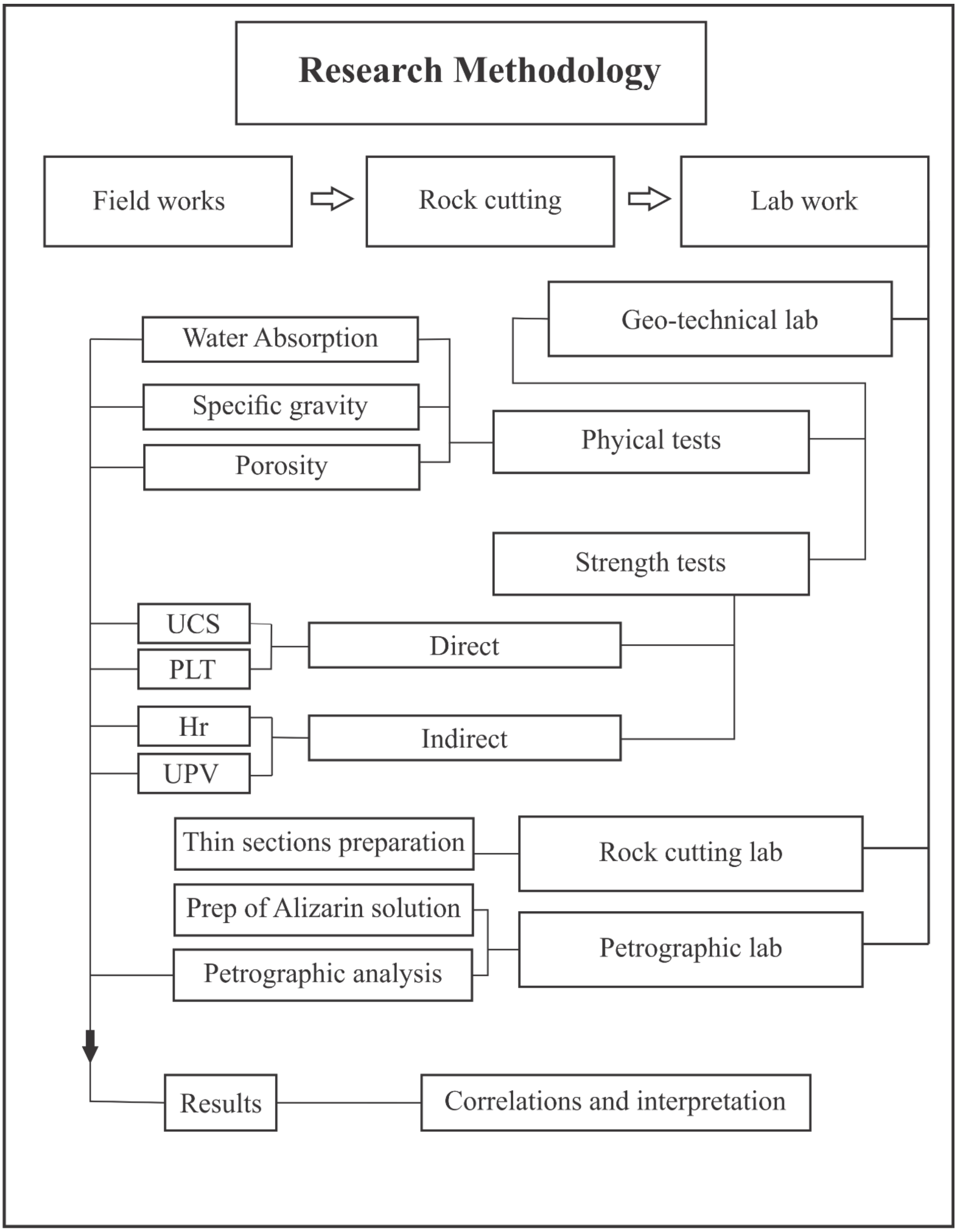

Figure 3.1. Flow chart diagram of Research Methodology.

3.5 Strength Tests

3.5.1 Ultrasonic Pulse Wave Velocity Test (UPV)

For finding UPV values CONTROLS Model 58-E4800 tester was used. The frequency of the tester was set on 10/s. The tester gave transit time for pulse wave through rock specimen in micro-seconds which were then converted into seconds for further calculation.

Prior to conducting tests on the rock specimens, it was verified if the UPV tester had been working properly and a zero-time adjustment was performed. While performing the tests every time the transducers of the tester were placed opposite to each other on the specimen as shown in figure 3.4 (b). If the transducers are not in line with each other then it will affect the results because the distance on which the wave travels will be larger than the actual width of the rock specimen. Coupling agent (gel) was applied on transducer's faces as well as on the rock specimens to ensure proper contact between transducers and the rock specimens. The faces of the transducers were firmly pressed against the surfaces of the rock specimens until a stable reading was displayed on the tester. The reading on the tester was noted which was transit time for the pulse wave through the rock specimen. Velocity of the pulse wave was calculated by using formula v= s/ t. Where *s* is width of specimen in meter and *t* is reading on the tester converted from micro sec to sec. Three readings were taken and averaged to get UPV value for each specimen.

UPV tests were carried first on saturated-surface-dry specimens (SSD-UPV) and then on oven-dry specimens (OD-UPV).

3.5.2 Unconfined Compressive Strength Test (UCS)

UCS of the specimens was find out by CONTROLS' universal testing machine given in fig 3.5 (C). Load capacity the machine was 50kN and its displacement speed was 30mm per hour.

Three cubes having edge length of 70mm in accordance with ASTM C-170 were prepared from each bulk rock sample (six specimens for each formation). The faces of these specimens were made smooth because rough surfaces can affect UCS values negatively. Moreover the specimens were placed in oven at 110°C for 24 hours to get them oven-dried because water content of the specimens lead to miscalculation in measuring UCS value.

These specimens were subjected to increasing load until the failure occurred. The load at the failure was noted and then divided by the surface area of the sample to get pressure in psi for each specimen. These values were then converted into MPa which are given in table 4.9.

3.5.3 Schmidt Hammer Rebound Number (Hr)

L-type of Schmidt hammer, having an impact energy of 0.735 Nm was used for finding out Hr values.

One cube specimen having edge length of 15cm was prepared from each bulk rock sample according to ASTM D 5873-14.

Prior to each testing sequence the hammer was calibrated using steel anvil supplied by the manufacturer. The calibration readings were falling within the range provided by the manufacturer. The hammer was oriented vertically downward with the bottom of the piston at right angle to and in firm contact with the surface of the test specimen each time a reading was taken as shown in fig 3.5 (D). As suggested by ASTM D 5873-14, ten rebound values were recorded from each specimen. These readings were then averaged and each single reading that was different from the average by more than 7 units was discarded and the remaining readings were once again averaged to get final Hr values.

3.5.4 Point Load Index Strength Test (PLT)

Representative block sample were prepared from bulk samples for calculating point load strength of the rocks. PLT were carried on CONTROLS' point load testing machine (fig. 3.4 A) according to ASTM D 5731. Dimensions of the blocks were in accordance of ASTM D 5731. As the thickness of most blocks was not 50mm so a thickness correction was made to PLT values as suggested by ASTM D 5731. Final results of PLT are given in table 4.9.

3.6 Thin Sections Preparation

Block samples having dimensions of 1×1×2inch were cut from bulk rock samples. Thin sections were prepared from these block samples in Rock cutting and thin section lab of NCEG according to ASTM specifications.

3.7 Preparation of Alizarin Red Solution

Alizarin red solution was prepared in petrographic lab of NCEG in order to differentiate between limestone and dolomite of Nowshera Formation. Steps taken to prepare standard Alizarin red solution are given below

- 100 ml of distilled water was taken in a glass beaker.
- 2 ml of conc. HCl was added to the beaker
- Then 1 gm Alizarin red was added to the water.
- At last 5gm of Potassium ferricyanide was added to the beaker.
- The solution was stirred through a glass stirrer.
- Thin sections were placed in this solution for 1 minute. Calcite got stained while dolomite did not get stained.

3.8 Petrography

Thin sections were prepared from bulk samples (one from each bulk sample) in order to get an insight into the petrographic properties of the rock. These thin sections were studied in petrographic lab of NCEG. Petrographic features like mineral contents, matrix, cementing material, grain size, sorting, packing and micro-fractures etc. were noted during petrographic studies. More over the possible effects of petrographic features on physical and strength properties were also noted and the physical and strength properties have been justified on the basis of petrographic studies.

3.9 Correlation between Different Tests Result

The results of different tests were analyzed using IBM SPSS Statistics 26.0. Linear, exponential, power and logarithmic curve fitting calculations were performed and the best estimated equation with highest coefficient of determination (R-squared) was selected. These equations were then used to estimate dependent variables. Estimated and measured values were correlated via the same software and Pearson's coefficient of correlation (r) was determined for each correlation. Following correlations were made: UCS vs Hr, UCS vs PLT, PLT vs Hr, OD-UPV vs Hr, SSD-UPV vs Hr, UCS vs OD-UPV and UCS vs SSD-UPV. Details of these correlations are given in chapter 4.

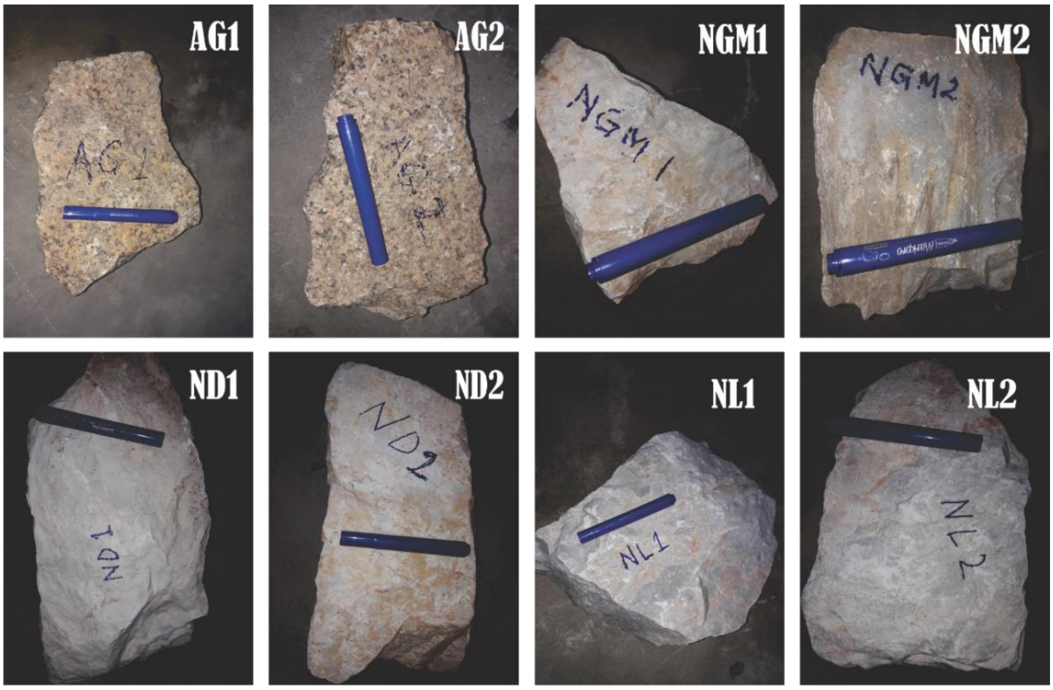

Figure 3.2. Bulk rock samples.

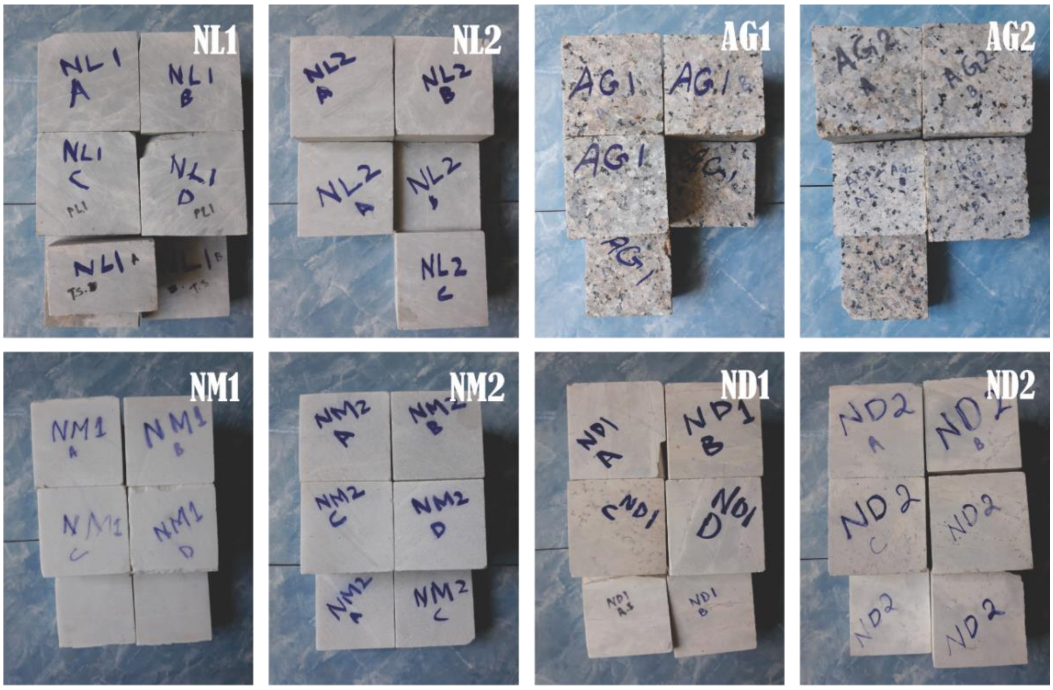

Figure 3.3. Specimens (cut from bulk rock samples) on which various tests were performed.

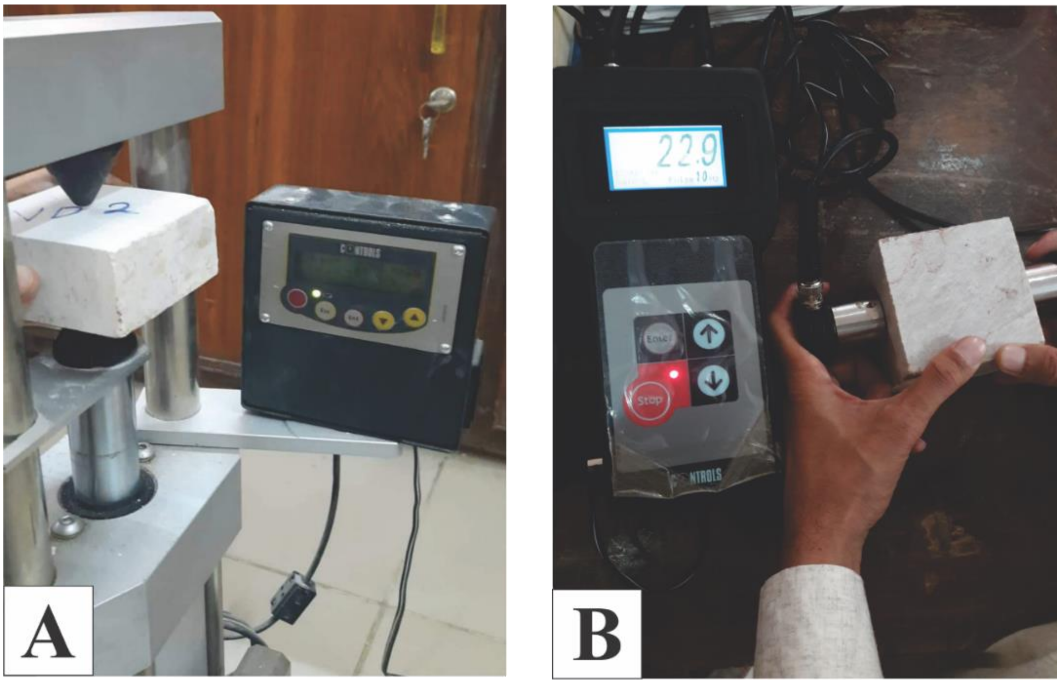

Figure 3.4. Testing of specimens (A) PLT testing, (B) UPV testing.

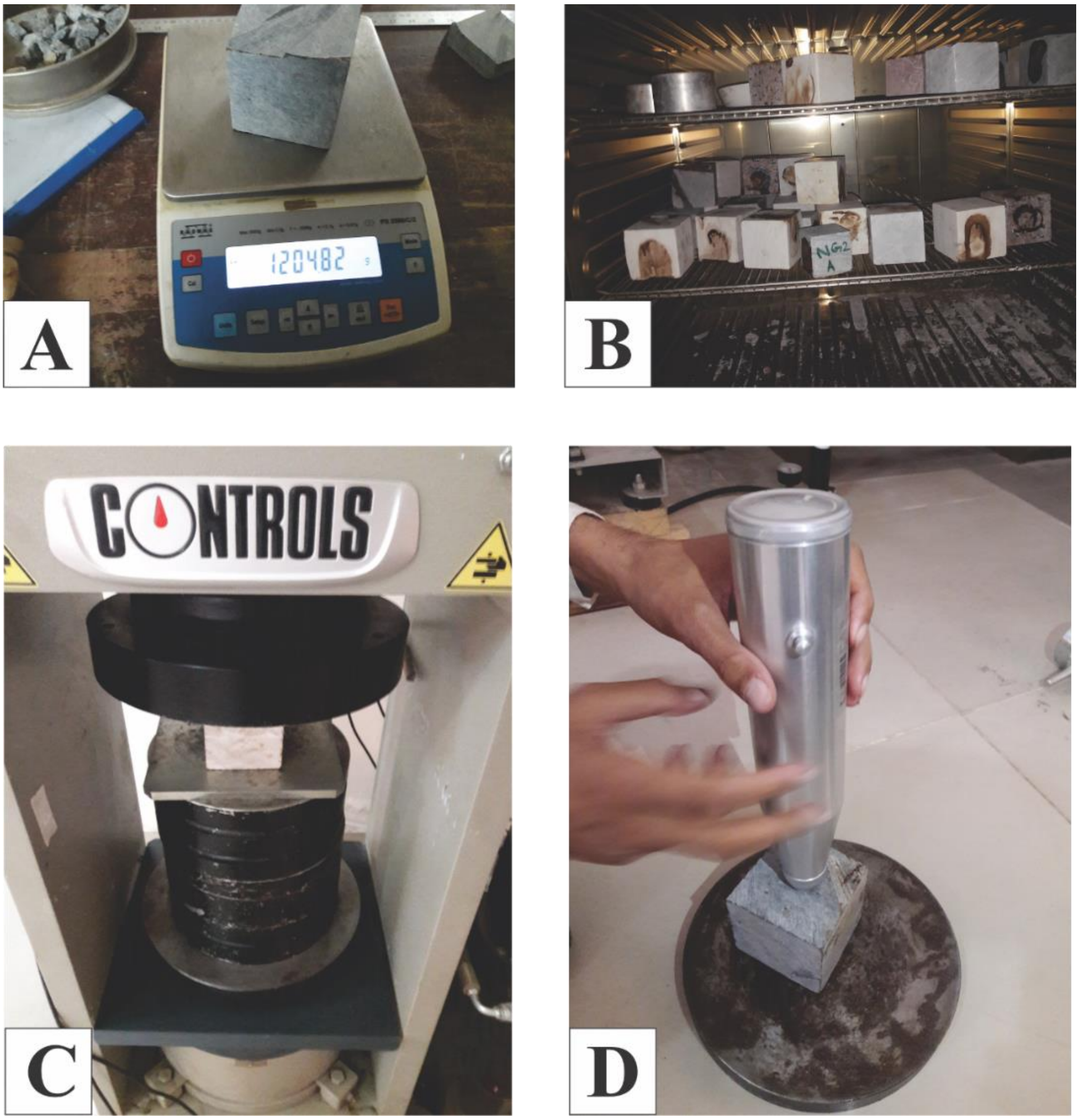

Figure 3.5. Testing of specimens (A) weighing of specimen, (B) specimens in oven (C) UCS testing, (D) Schmidt hammer testing.

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 Petrographic Analysis

Petrographic features like modal mineralogy, grain size, sorting, grading, packing, porosity, fractures and veins etc. have significant effects on strength and physical properties of rock. The more a rock has hard minerals the higher its strength values will be. Similarly if grains in a rock are well graded and finer the rock will show higher strength values. Moreover presence of fractures and veins negatively affect the strength values of rock. So to evaluate strength properties of rock, petrographic study is very important.

In the course of present work petrographic features like modal mineralogy, texture, alteration, fractures, veins and porosity were studied and compared with strength values of rock. Petrographic study was based on the field and microscopic observations in plain polarised light (PPL) and cross polarized light (CPL) of thin sections in laboratory. The petrographic features of the studied thin sections are described in the following section.

4.2 Detailed Microscopy

4.2.1 Nowshera Limestone (NL)

In field bulk rock samples were dark-grey to whitish-grey in colour. Surface of the samples was fresh with no change in colour and with no visible fractures.

Under the microscope it was observed that sample largely consisted of micrite. The micrite grains were finer and relatively equal in dimension (fig 4.1). A number of fractures were observed. In some places these were filled with quartz (fig 4.2). Sparite crystals were less abundant. These were generally large in size (fig 4.2) and showed double set of rhombohedral cleavages (fig 4.3). The sample consisted dolomite and to a very lesser extent quartz and opaque minerals (fig 4.1 and 4.2). Table 4.1 shows model mineralogy of Nowshera Limestone.

Table 4.1 Modal Mineralogy of Nowshera Limestone.

Rock Sample	**Micrite**	**Sparite**	**Dolomite**	**Quartz**	**Opaque**
NL1	70	15	10	4	1
NL2	65	16	11	6	2

4.2.2 Nowshera Dolomite (ND)

Bulk rock samples were off white to creamy white in colour. There were no visible change in colour of the surfaces and no fractures.

Under the microscope the rock samples were highly fractured (fig 4.5), equigranular and fine grained (fig 4.6). Dolomite and micrite were present in higher percentages while sparite, quartz, and opaque minerals were present in smaller percentages (fig 4.4). Modal mineralogy of Nowshera Dolomite is given in table 4.2.

Table 4.2 Modal Mineralogy of Nowshera Dolomite.

Rock sample	**Dolomite**	**Micrite**	**Sparite**	**Quartz**	**Opaque**
ND1	66	25	5	3	1
ND2	61	29	7	2	1

4.2.3 Nowshera Marble (NM)

In the field bulk rock samples were pure white to milky white in colour. Surface of the bulk sample was fresh with no change in colour.

Under microscope it was observed that the sample consist almost entirely of calcite mineral with minute amount of opaque minerals. The minerals were coarser and equigranular (fig 4.7). It was observed that boundaries of mineral grains were fully developed though some grains with poorly developed faces were also observed. Fractures were abundant throughout the samples and in some places veins were also observed (fig 4.8).

4.2.4 Nikani Ghar Marble (NGM)

In the field bulk rock samples showed grey to dark grey colour. The sample were fresh with no change in colour and with no fractures.

Under the microscope the samples were largely consist of very large grains of calcite with minor amount of quartz. The rock sample were highly fractured and along the boundaries of the grains alteration was observed. Quartz inclusion was also observed. Calcite was coarse grained with well-developed faces (fig 4.9).

4.2.5 Ambela Granite (AG)

In field the bulk rock samples were coarse grained and pinkish in colour. Under the microscope its texture was holocrystalline and equigranular. The grains were medium to large in size. Ambela granite was largely consist of Alkali feldspar while other minerals like biotite, muscovite, plagioclase and quartz were present in small amount.

Quartz of AG was observed to be highly fractured (fig 4.10 and 4.11). Biotite showed strong pleochroism from brown to golden colour (fig 4.11). Muscovite was brighter than biotite and showed no or very weak pleochroism (fig 4.10). Modal mineralogy of Ambela granite is given below.

Table 4.3 Modal Mineralogy of Ambela Granite.

Rock sample	Alkali Feldspar	Quartz	Plagioclase	Biotite	Muscovite	Opaque
AG1	64	12	8	10	5	1
AG2	58	15	10	12	3	2

4.2.6 Shewa-Shahbazgari Granite (SSG)

Bulk rock samples were light grey to dark grey in colour. Microscopic observation of the samples revealed microporphyrytic texture. Large grains were embedded in smaller grains (fig 4.12, 4.13 and 4.14). Mortar texture around plagioclase felspar was observed (fig 4.12). No considerable fractures were observed. Grains were well-gradded with well-formed faces. Quartz crystals were anhedral and inequigranular and showed no undulose extinction. Modal mineralogy of Shewa-Shahbazgari granite is given in table 4.4.

Table 4.4 Modal Mineralogy of Shewa-Shahbazgari Granite.

Rock sample	Quartz	Plagioclase feldspar	Alkali feldspar	Biotite	Muscovite	Opaque
SSG1	78	7	3	5	4	3
SSG2	69	10	6	10	3	2

4.2.7 Utla Granite (UG)

Bulk rock sample were fine grained and light grey to greenish grey in colour. Microscopic observation showed that the samples were inequigranular holocrystalline and micro porphyritic texture (fig 4.15). Micaceous Muscovite was seen arranged in needle like structures (fig 4.16). The rock was very fine grained with no fractures. Large grains of quartz were embedded in finer grains. Modal mineralogy of Utla granite is given in the following table.

Table 4.5 Modal Mineralogy of Utla Granite.

Rock Sample	**Quartz**	**Alkali feldspar**	**Muscovite**	**Biotite**	**Plagioclase**	**Opaque**
UG1	49	21	14	11	4	1
UG2	45	27	12	10	5	1

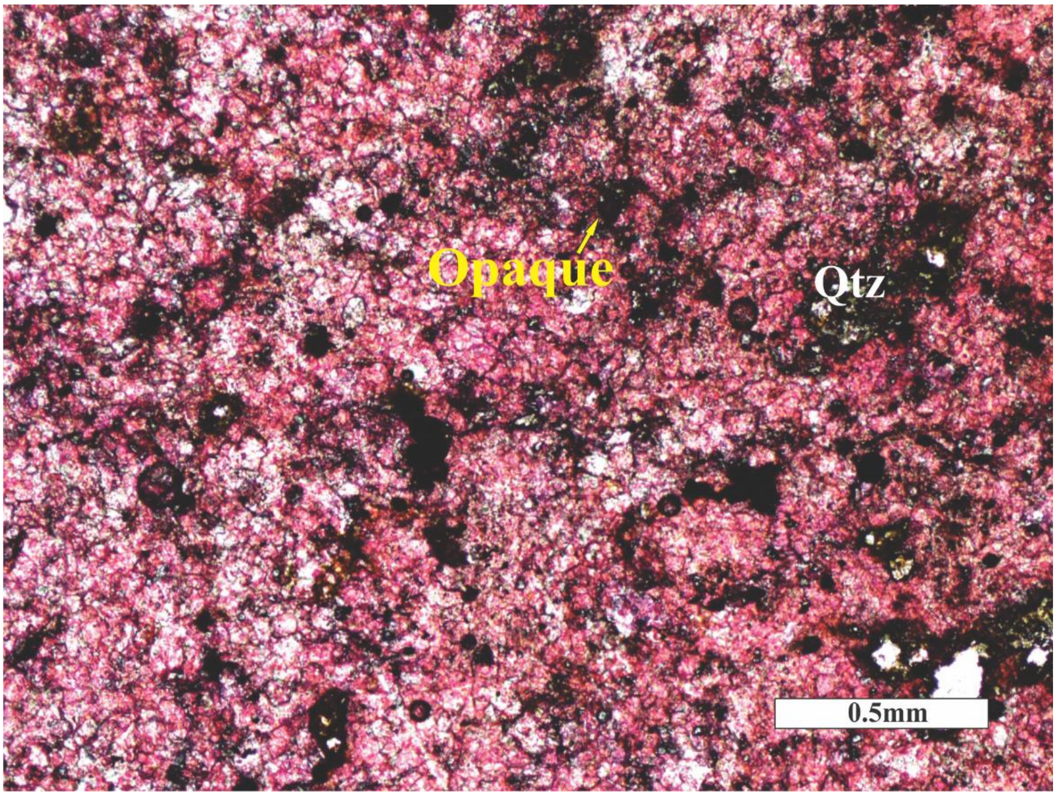

Figure 4.1. Photomicrograph (PPL) of Nowshera Formation (stained with Alizarin solution) showing equigranular texture of rock.

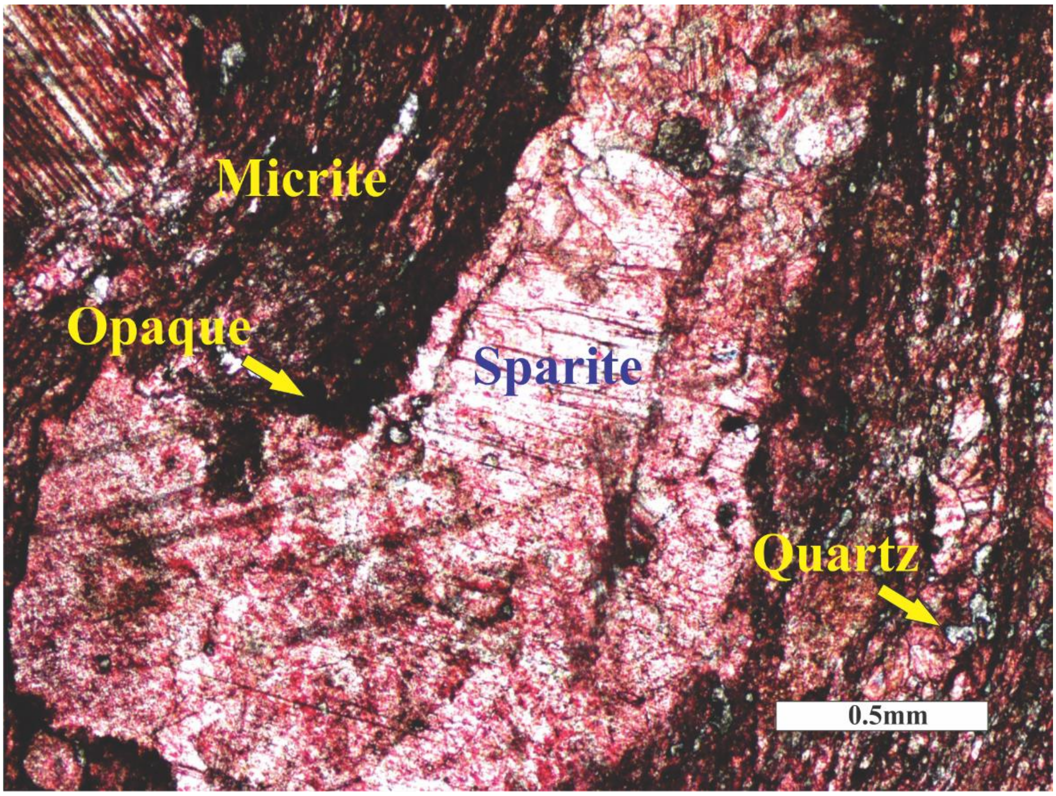

Figure 4.2 Photomicrograph (PPL) of Nowshera Formation (stained with Alizarin solution) showing sparite, micrite and quartz.

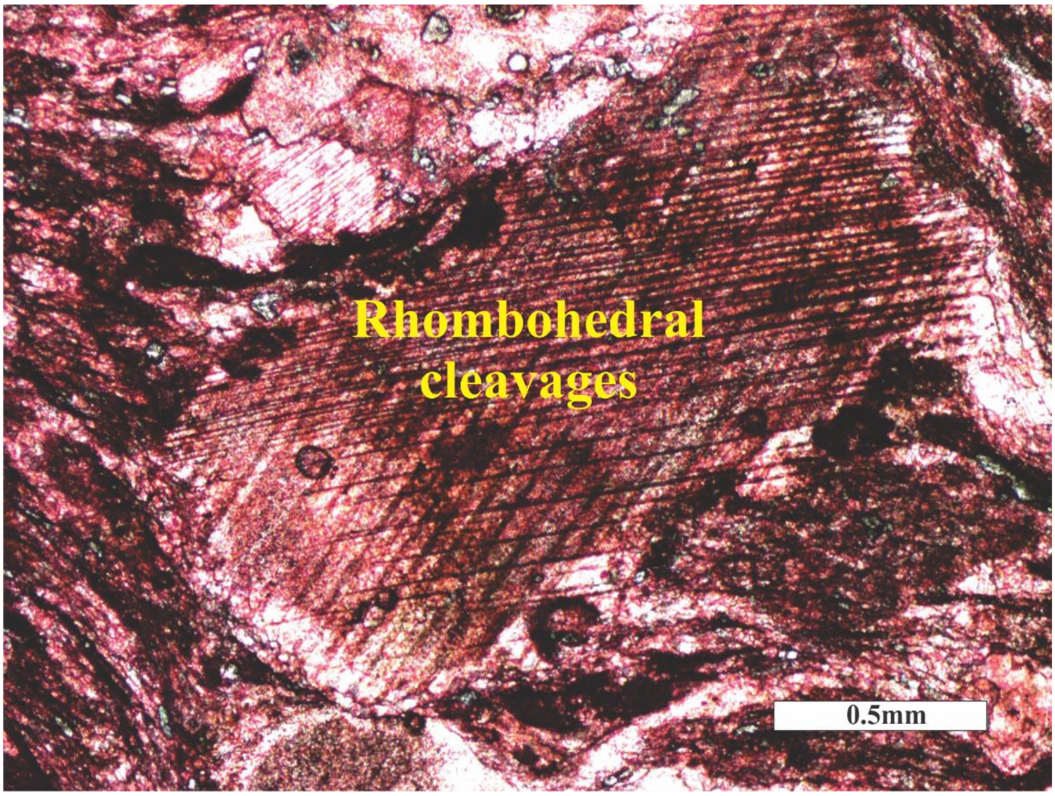

Figure 4.3 Photomicrograph (PPL) of Nowshera Formation (stained with Alizarin solution) showing rhombohedral cleavage in calcite.

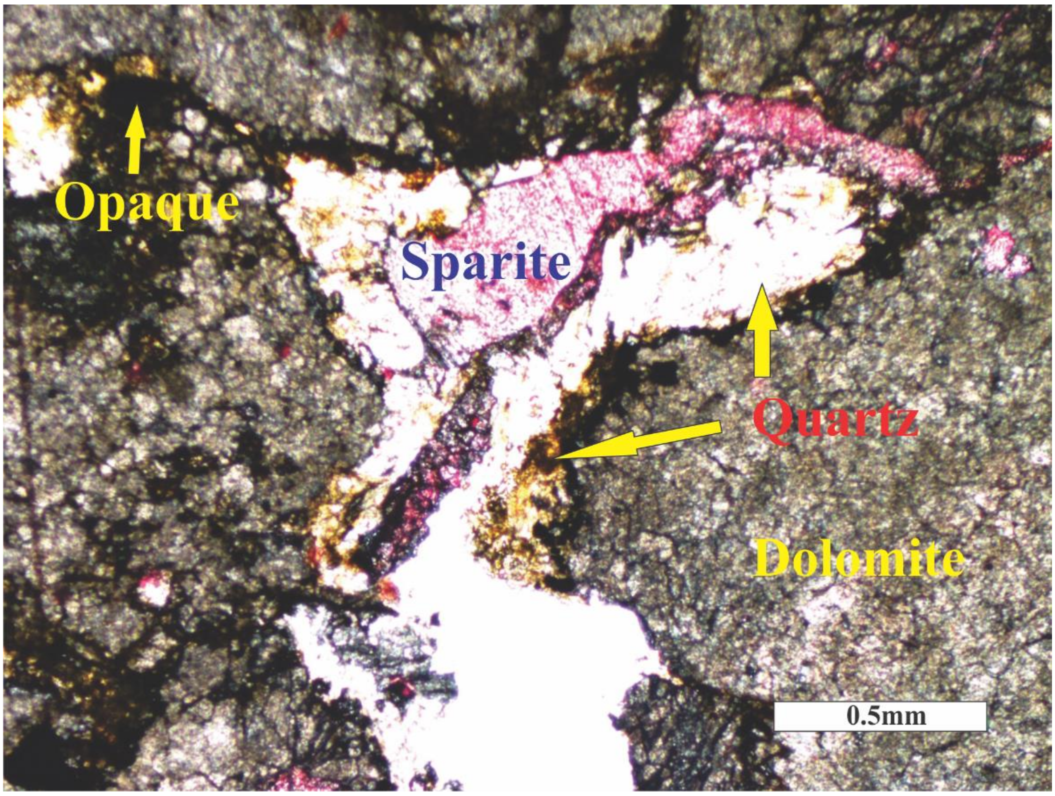

Figure 4.4 Photomicrograph (PPL) of Nowshera Dolomite (stained with Alizarin solution) showing dolomite, sparite, quartz and opaque minerals.

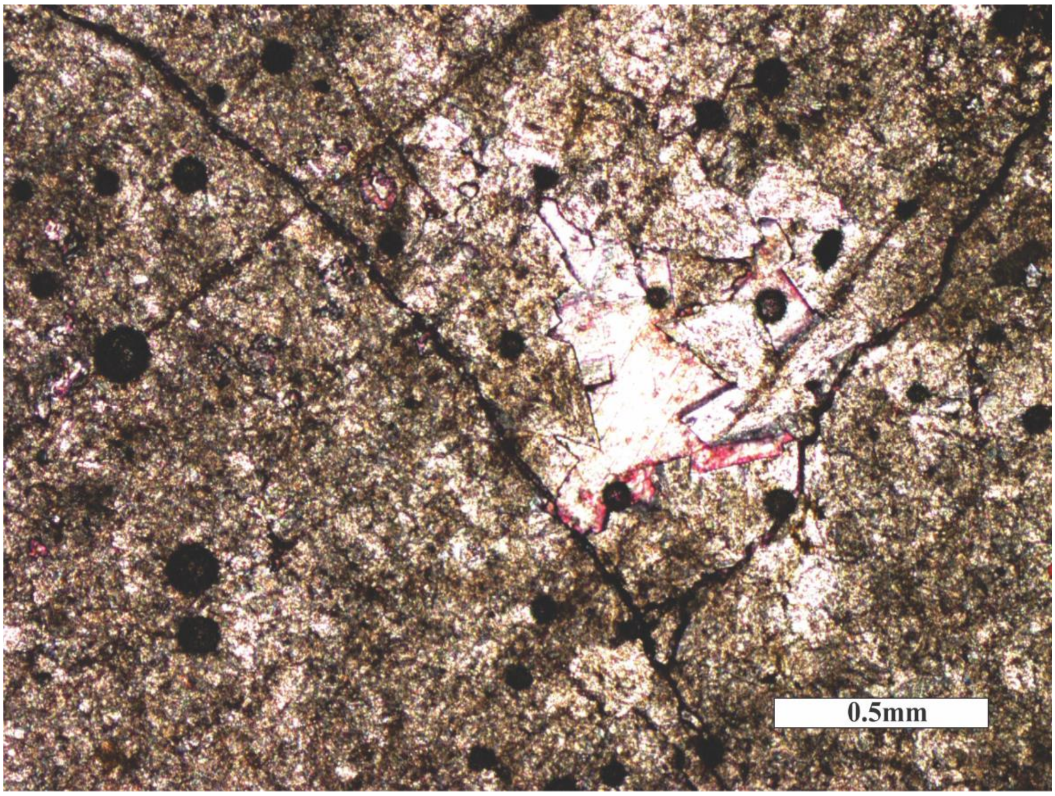

Figure 4.5. Photomicrograph (PPL) of Nowshera Dolomite (stained with Alizarin solution) showing well-formed sparite crystal and fractures.

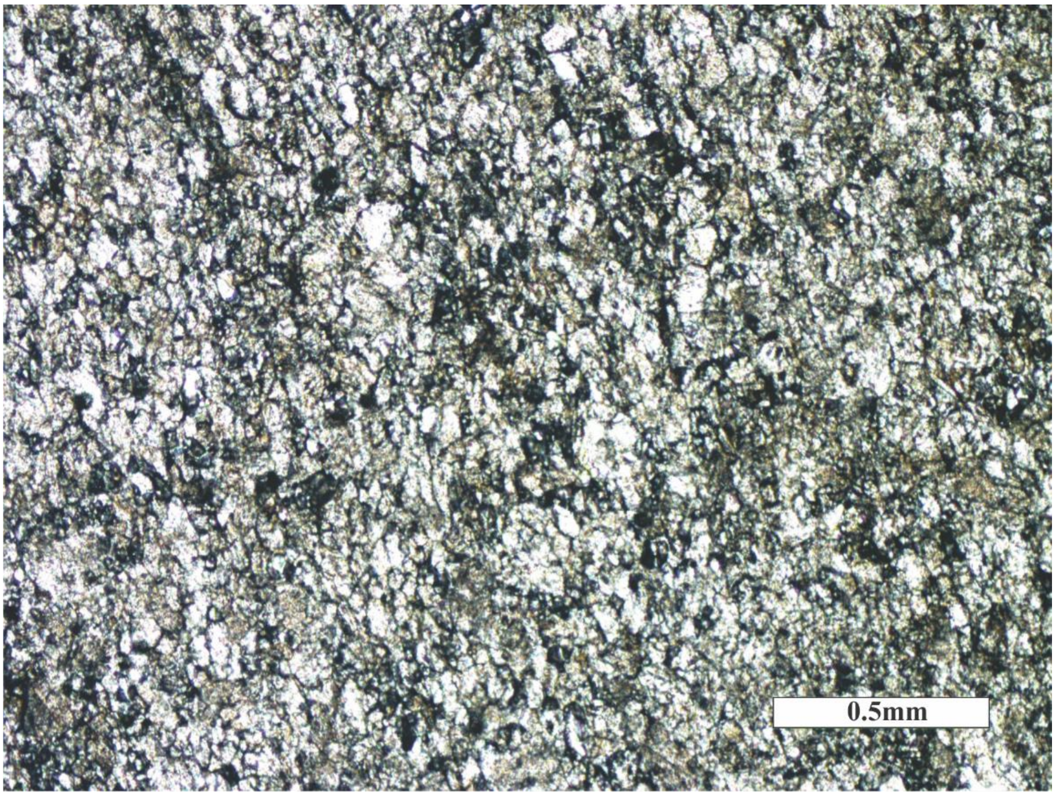

Figure 4.6. Photomicrograph (PPL) of Nowshera Dolomite (stained with Alizarin solution) showing fine-grained dolomite.

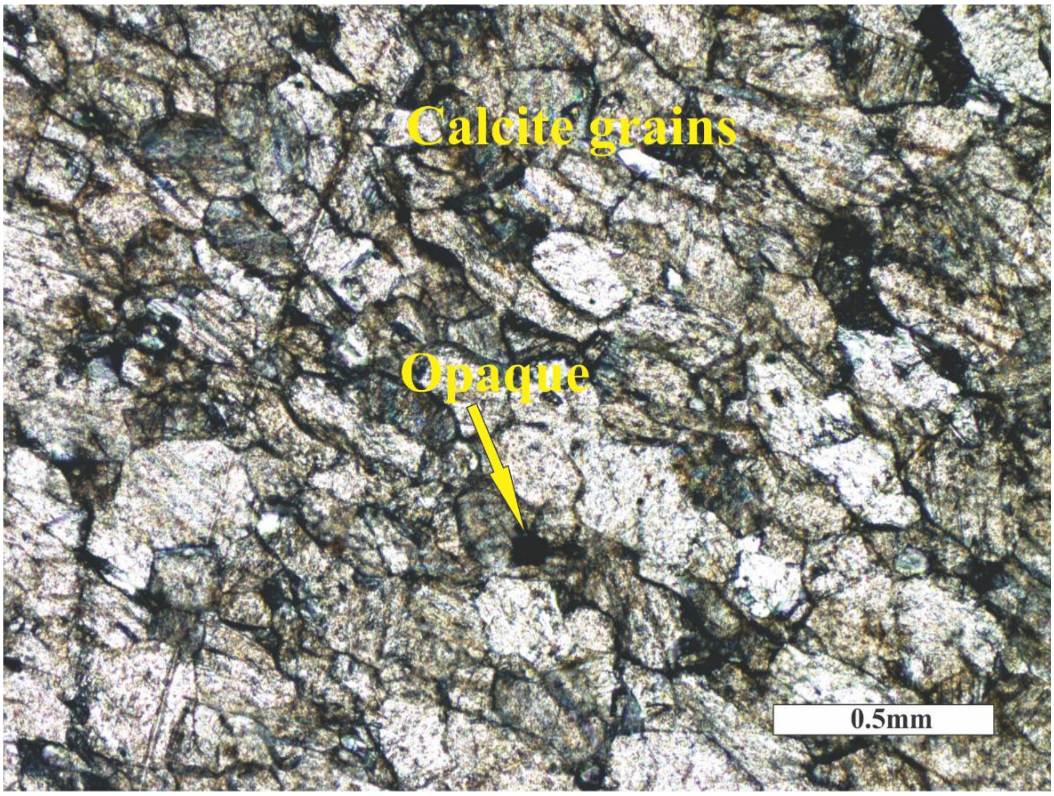

Figure 4.7. Photomicrograph (PPL) of Nowshera Marble showing equigranular and coarser texture.

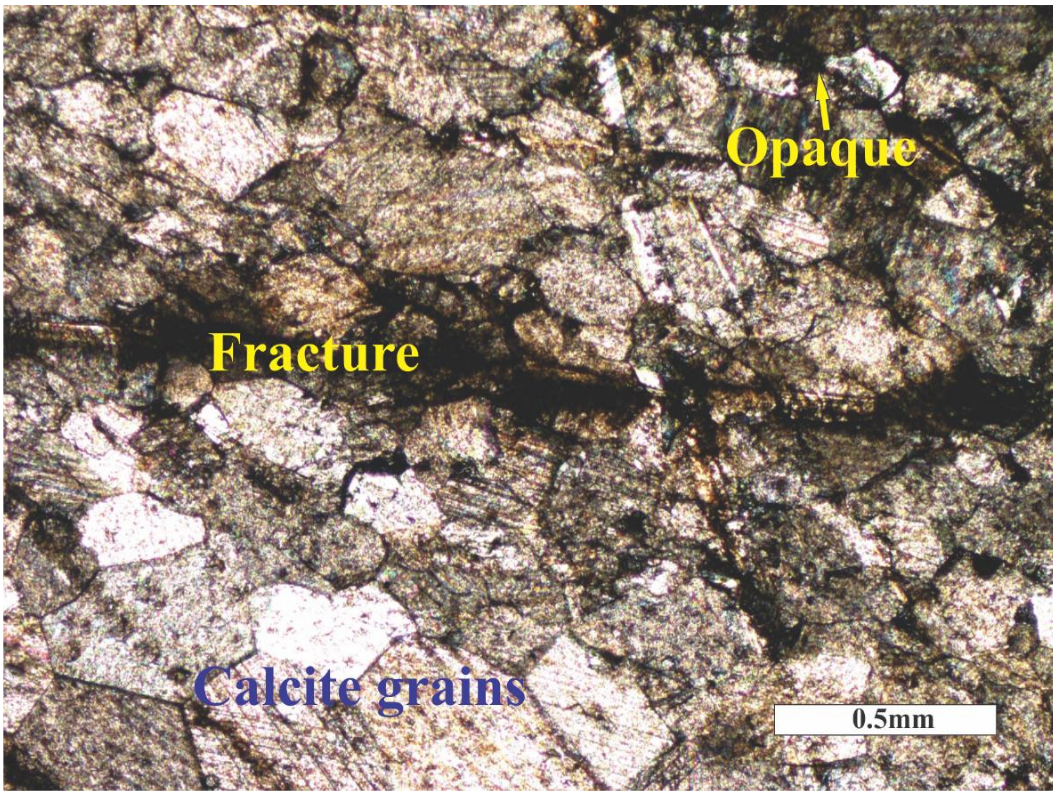

Figure 4.8. Phtomicrograph (CPL) of Nowshera Marble showing fracture and opaque minerals.

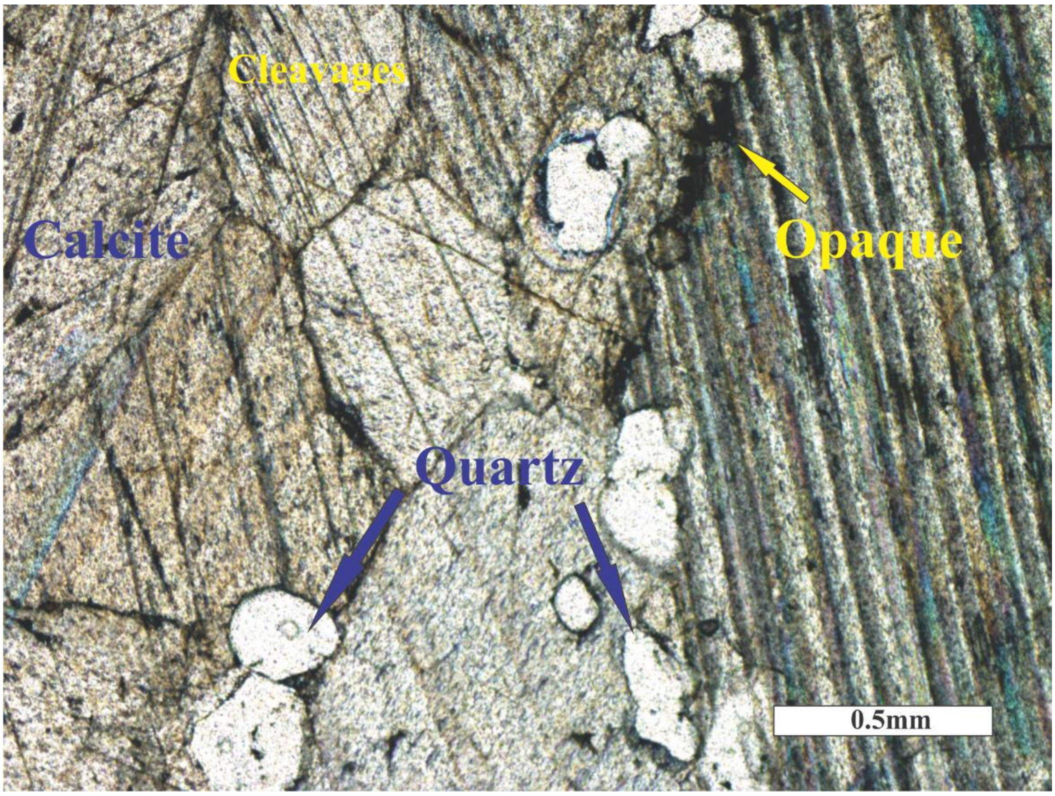

Figure 4.9. Photomicrograph (PPL) of Nikani Ghar Marble showing larger calcite grains with quartz inclusions.

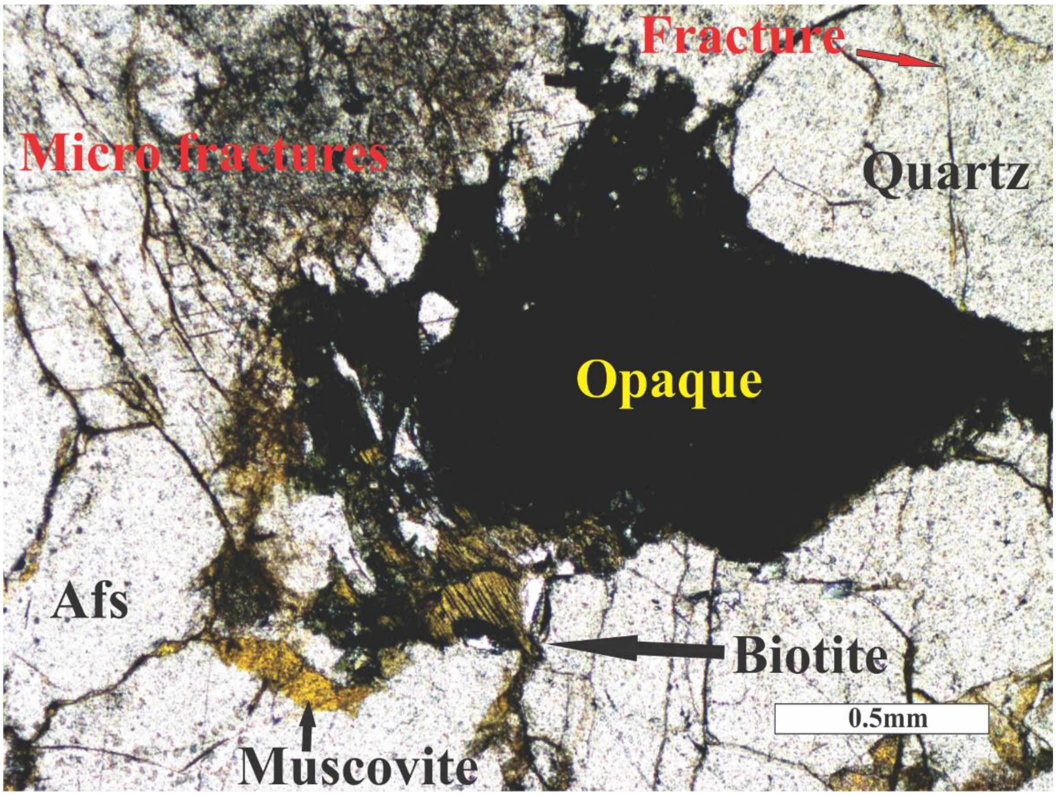

Figure 4.10. Photomicrograph (PPL) of Ambela Granite showing highly fractured grains.

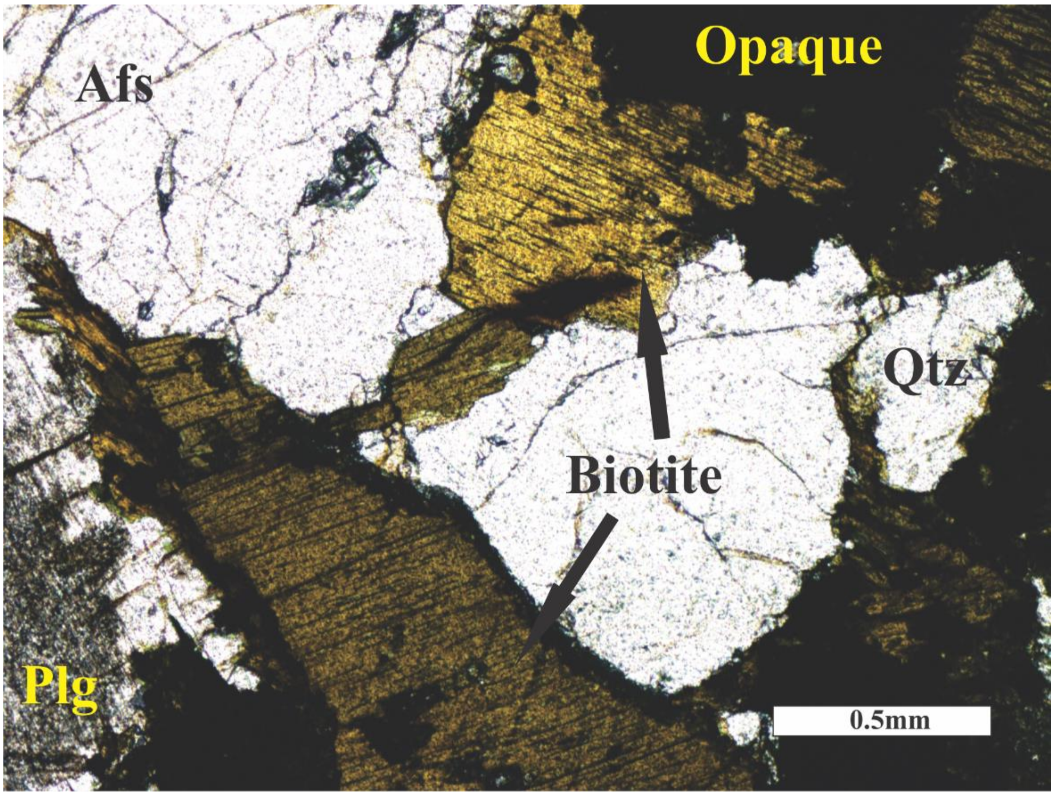

Figure 4.11. Photomicrograph (PPL) of Ambela Granite showing strong pleochroism of biotite.

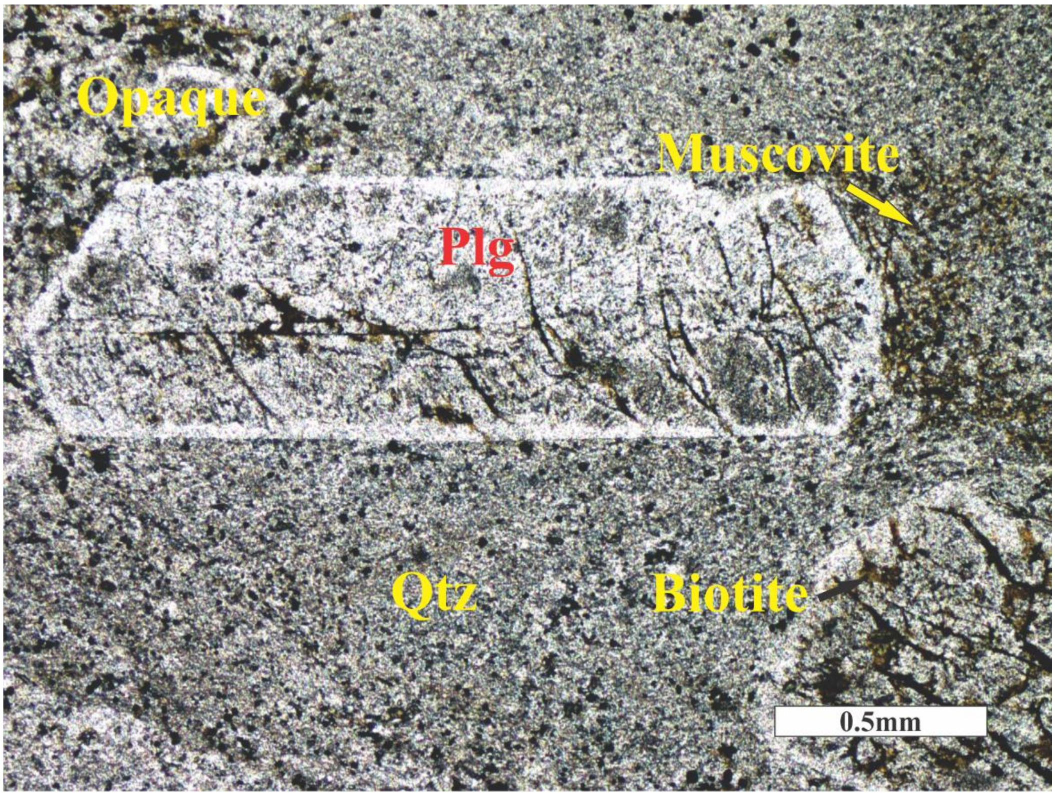

Figure 4.12. Photomicrograph (PPL) of Shewa-Shabazgari Granite showing mortar texture around plagioclase felspar.

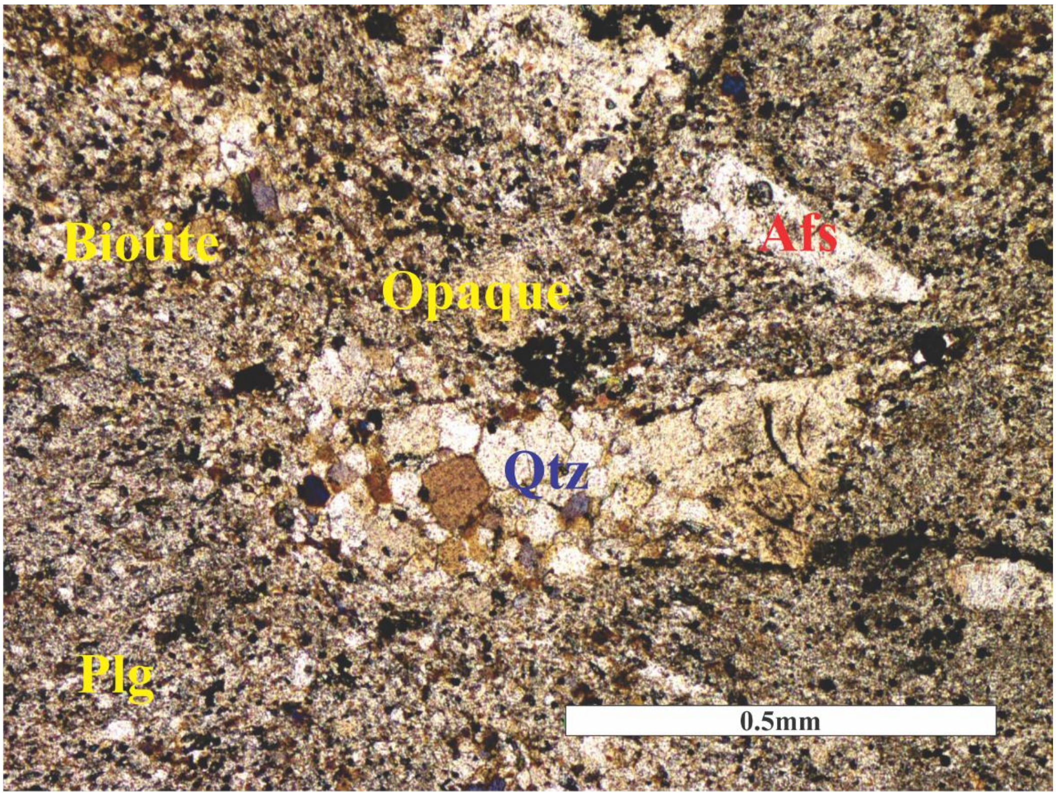

Figure 4.13. Photomicrograph (CPL) of Shewa-Shahbazgari Granite showing well gradded texture of rock.

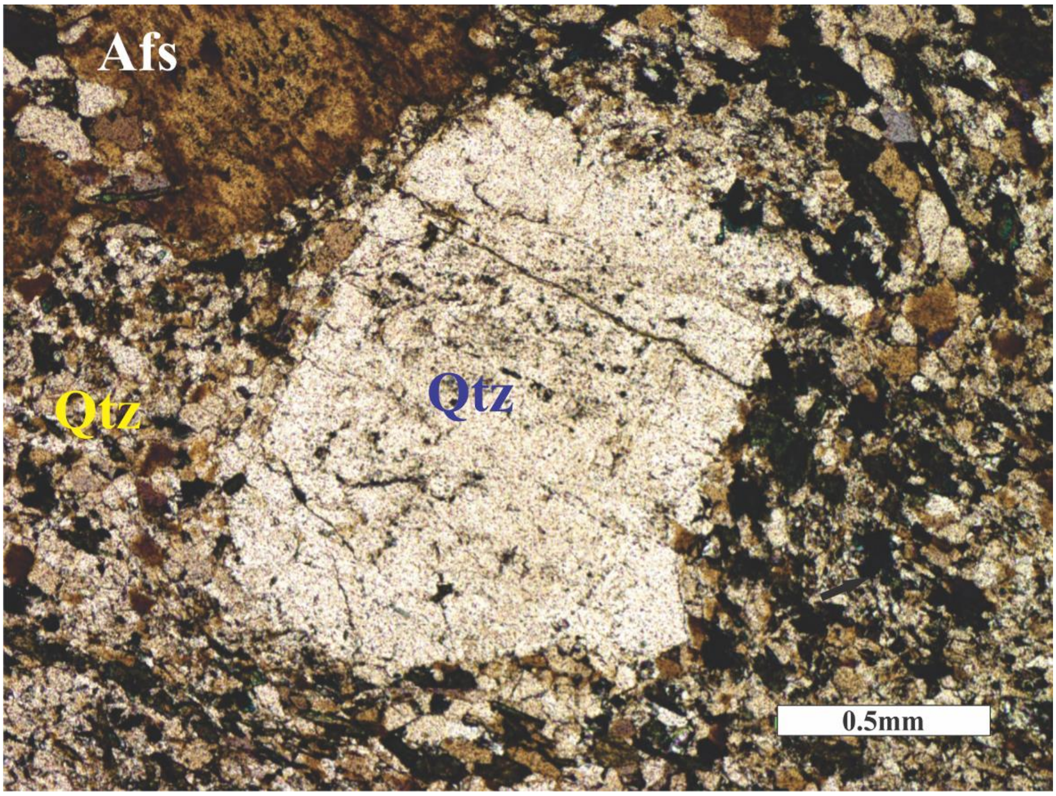

Figure 4.14. Photomicrograph (CPL) of Shewa-Shahbazgari Granite showing porphyritic texture of rock.

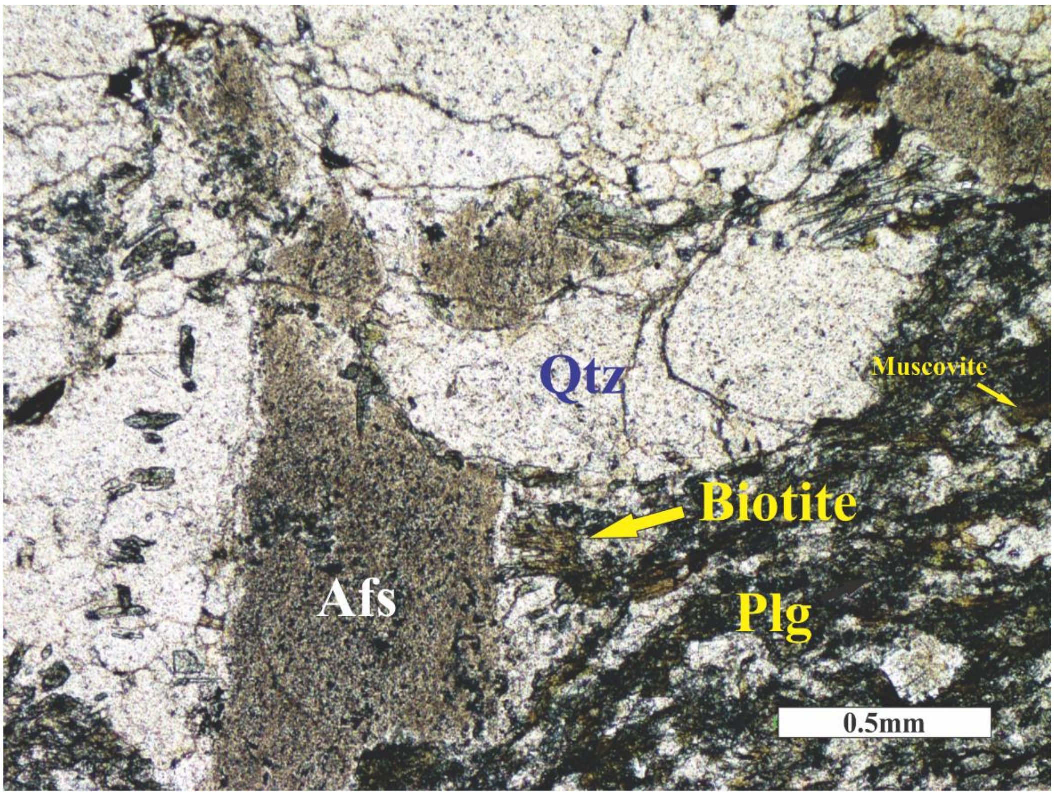

Figure 4.15. Photomicrograph (PPL) of Utla Granite showing fine and well-gradded texture of rock.

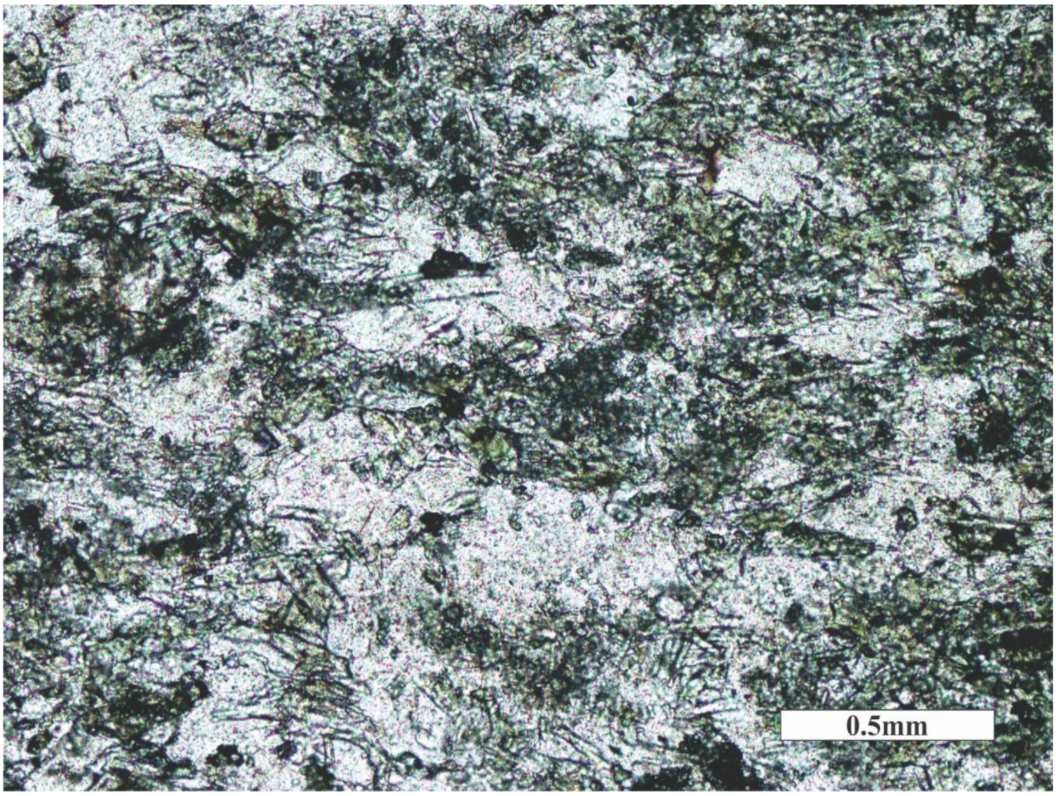

Figure 4.16. Photomicrograph (PPL) of Utla Granite showing needle like arrangement of muscovite.

4.3 Physical and Strength Properties

Physical and strength properties are very important from engineering point of view. Prior knowledge of these properties in designing engineering projects, whether on ground or underground, help in the best possible way. Knowledge of these properties can help to one to infer the response of a certain rock in a particular project on the basis of which one can decide confidently whether the rock can be used in the project safely or not. A number of tests given in table 4.7 and 4.9 were carried out to know about the physical and strength behaviour of rocks.

4.3.1 Water Absorption

Values of water absorption are given in table 4.7. AG has the highest value (0.86%) while SSG has the lowest value (0.37%) of water absorption. On the basis of petrographic study, higher value of water absorption of AG can be attributed to wide fractures and abundant pore spaces among coarse grains while SSG was fine grained with lower porosity.

Generally the rock having water absorption values smaller than 2 are considered safe to be used in engineering projects in terms of water absorption (ISRM, 1981) (Table 4.6). It shows that WA values of studied rocks are well below the permissible range for usage as a construction material. Moreover all the rock fall in strong rock (WA ranges between 0.2 and 1%) category on the basis of the said standard.

Table 4.6 ISRM (Brown, 1981) Classification of Rocks on the Basis of Water Absorption Values.

S. no.	**WA %**	**Classification**
1	0-0.2	Extremely strong
2	0.2-1	Very strong
3	1-2	Strong
4	2-3	Medium strong
5	>3	Weak

4.3.2 Specific Gravity

Values of specific gravity of the studied rock samples are described in table 4.7. SSG showed highest (2.896) while AG gave lowest value (2.6453) for specific gravity. Table 4.7 shows description of specific gravity of rocks. Highest value of SSG can be described on the basis of petrographic study as it has finer grain and the grains were well packed while AG was coarse grained and highly micro-fractured.

Table 4.7 Classification of Specific Gravity of rocks (Anon 1979).

S.no.	Specific gravity	Term
1	<1.80	Very low
2	1.80-2.20	Low
3	2.20-2.55	Medium
4	2.55-2.75	High
5	>2.75	Very high

4.3.3 Porosity

Values of porosity are given in table 4.7. NGM showed highest value for porosity while SSG showed smallest value. Description of porosity of rocks is given table 4.8. All the samples are suitable for use in construction projects according to Anon (1979) which consider rocks having porosity value less than 5% suitable for use in construction projects.

Table 4.8 Classification of Porosity of rocks (Anon 1979).

S.no.	Porosity (%)	Term
1	>30	Very high
2	30-15	High
3	15-5	Medium
4	5-1	Low
5	<1	Very low

Table 4.9 Results of Physical tests.

S. No.	**Sample**	**Water absorption %**	**Specific gravity**	**Porosity %**
1	AG	0.86	2.65	0.177
2	NL	0.565	2.86	0.164
3	ND	0.70	2.83	0.147
4	NM	0.64	2.73	0.16
5	NGM	0.81	2.72	0.32
6	SSG	0.37	2.90	0.142
7	UG	0.68	2.83	0.161

4.3.4 Unconfined Compressive Strength Test (UCS)

UCS was performed on six or more cubic specimens for each formation. The results of UCS on specimens were averaged to obtain UCS value for each formation. The results of UCS for each rock are given in table 4.9 it is obvious from the table that SSG has greatest unconfined compressive strength while NGM has lowest strength. All the samples were moderately strong to extremely strong according to Anon 1979 classification of the rocks on the basis of UCS value (see table 4.8). Both ISRM and IAEG classifications are given in table 4.8 for comparison purpose. All the rocks can be confidently used in construction projects as rocks having UCS greater than 50 MPa (Anon, 1979) (see table 4.8) and 35 MPa (Bell, 2007) are considered safe for engineering projects.

Table 4.10 IAEG and ISRM Classification of Rock on the Basis of Strength.

IAEG (Anon, 1979)		**ISRM (Anon, 1981)**	
Strength (MPa)	**classification**	**Strength (MPa)**	**classification**
<15	Weak	<6	Very low
15-50	Moderately strong	10-20	Low
50-120	Strong	20-60	Moderate
120-230	Very strong	60-200	High
>230	Extremely strong	>200	Very high

4.3.5 Point Load Strength Test (PLT)

Values of PLT are given in table 4.9. It is obvious from the table that SSG has the greatest point load strength (10.03 MPa) while NGM has lowest point load strength (2.86 MPa).

Table 4.11 Results of Strength Tests.

S. No.	Sample	UCS (MPa)	Hr	UPV (oven dry)	UPV (sat)	PLT (MPa) (Is50)
1	AG	104.4	51.7	2336.5	4185.7	4.75
2	NL	112.2	52.8	4765.8	6059.3	5.81
3	ND	75.1	44.1	2949.5	4896.6	3.11
4	NM	56.9	38.6	1869.5	5204.9	2.91
5	NGM	51.1	36.9	3167.5	5475.9	2.86
6	SSG	294	64.3	4381.7	5177.2	10.03
7	UG	130.4	55.1	3926.3	4875.7	8.33

4.3.6 Ultrasonic Pulse Wave Velocity Test (UPV)

UPV tests were carried at two different states, oven dried (OD) and saturated surface-dry (SSD). Results of these are given in table 4.9. NL showed highest values for UPV at both oven-dry (4765.8 m/s) and saturated surface-dry (6059.3m/s) states, while lowest UPV values were recorded for NM (1869.5m/s) at oven dry condition and for AG (4185.7m/s) at saturated surface-dry condition. Description of UPV by Anon (1979) of rock is given in table 4.12.

Table 4.12 Description of UPV of rocks (Anon 1979).

S.no.	V (m/s)	Description
1	<2500	Very low
2	2500-3500	Low
3	3500-4000	Moderate
4	4000-5000	High
5	>5000	Very high

4.3.7 Schmidt Hammer Rebound Number (Hr)

Results for Schmidt Hammer test are given in table 4.9. Shewa-Shahbazgari Granite has greatest Hr strength while NGM has lowest Hr strength. Hr values showed almost a direct relation with UCS of the rocks see table 4.9 and correlation of UCS vs Hr in the upcoming sections.

4.4 Discussion and Relationship between Petrographic Features and Physical and Strength Properties

Effect of modal mineralogy and other petrographic features was studied to know how these properties affect strength of rock. In this regard effects of modal mineralogy were studied for igneous rocks only because sedimentary and metamorphic rocks do not have a variety of minerals like igneous rocks have had.

As we know that quartz and feldspars (alkali and plagioclase) have hardness values ranging between 6 and 7 on Mohs hardness scale while biotite and muscovite micas have hardness values between 2 and 3. So it means if a rock has a greater percentage of feldspars and quartz (harder minerals) than biotite and muscovite (softer minerals) then that rock will be stronger and vice versa. But as obvious from table 4.10 cumulative percentages of harder minerals do not seem to be affecting unconfined compressive strength of rocks in a meaningful way presumably because of greater textural changes. For example AG have a cumulative % of 83 of harder minerals but its UCS value is smaller than the other two granites because AG was more coarse grained and equigranular in comparison with SSG and UG. Moreover micro-fractures were more abundant in AG than the other two granites.

Because SSG and UG have relatively more textural similarities, higher cumulative percentage of harder minerals in SSG seems to have contributed to greater strength value of SSG than of UG. SSG has cumulative % of 87 of harder minerals and have UCS value of 294 MPa while UG have a cumulative % of 75 of harder minerals and have a UCS of 130.4 MP. This shows that mineralogy may have contributed to relatively higher strength of SSG than UG.

The large disparity between UCS values of these two rocks may attributed to textural features as well. SSG was micro porphyritic having a larger portion of very fine grained groundmass while UG was relatively course grained and equigranular. Similarly more fractures were observed in UG than in SSG during petrographic study.

Nikani Ghar Marble showed lowest value for UCS than Nowshera Marble (table 4.9) possibly because of larger grain size and equigranular nature of grains of NGM.

Nowshera Limestone gave higher UCS value than Nowshera dolomite presumably because of finer and well graded grains. Nowshera Dolomite consisted of more dolomite than calcite and as we know that dolomite is more harder (5 to 4.5) on Mohs hardness scale than calcite (3) but still ND showed smaller UCS value than NL it is because of abundant fractures and veins in ND than in NL.

Specific gravity depends upon degree of compactness of rock and cumulative percentage of heavier minerals in that rock. Well compacted rock having a greater percentage of heavier minerals will have greater value of specific gravity.

Shewa-Shahbazgari Granite has greatest value of specific gravity as it contained greater percentage of harder minerals like quartz and feldspar see table 4.10. Moreover Shewa-Shahbazgari Granite was well graded which resulted in its higher compactness. Similarly Shewa-Shahbazgari Granite has low porosity and no fractures. All these factors contributed to its greater specific gravity value.

On the other hand Ambela Granite and Nikani Ghar Marble have lowest specific gravity. Nikani Ghar Marble was coarser grained and the grains were relatively equal. Due to these factors Nikani Ghar Marble showed lowest specific gravity value. Ambela Granite though consisted largely of heavier minerals as like Shewa-Shahbazgari Granite but it still showed lower specific gravity. This can be explained on the basis of equigranular and coarser nature of these rocks. Moreover Ambela Granite had higher porosity value and fractures.

Table 4.13 Modal Mineralogy and UCS and Specific Gravity of Granites.

S. No.	**Granite Rock**	**Cumulative % of Quartz and Feldspars.**	**UCS MPa**	**SG**
1	Ambela	84	104.4	2.6453
2	Shewa-Shahbazgari	87	294	2.8960
3	Utla	75	130.4	2.8310

4.5 Correlation between Different Types of Physical and Strength Tests

A number of correlations were made between different properties (physical and strength) to obtain a correlation. These correlations were made on the basis of bulk rock samples' data. Results of these correlations are discussed as below.

4.5.1 Correlation between UCS and Hr

Strong correlation between UCS and Hr was obtained as Power equation with R-squared value of 0.946. The equation derived on the basis of regression analysis is given as: UCS= $0.0125(Hr)^{2.3012}$. UCS values were estimated by using the derived equation and compared with respective measured UCS. Pearson's correlation coefficient for correlation between measured UCS and UCS estimated on the basis of Hr is given as: r=0.95.

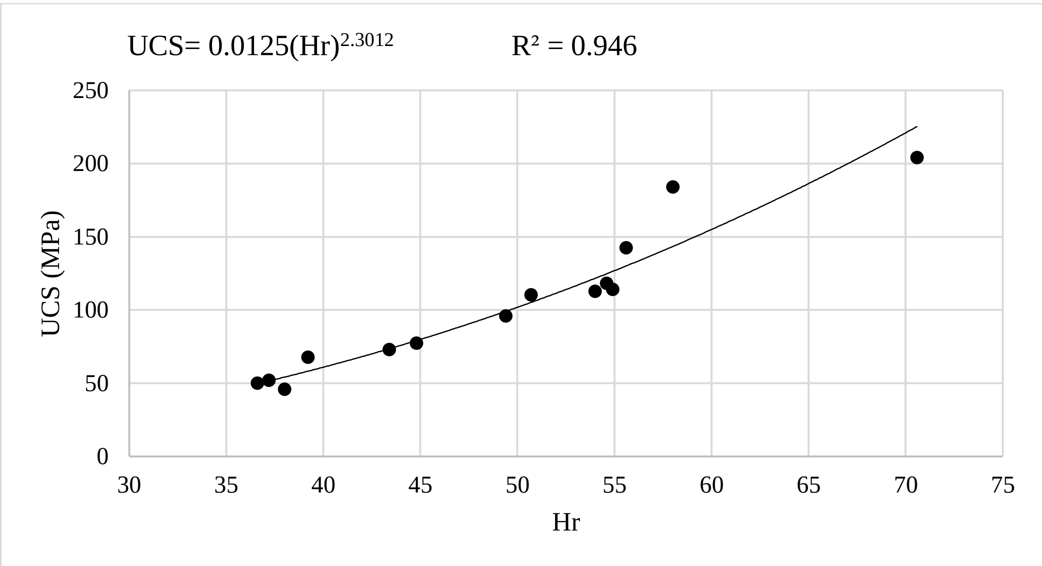

Figure 4.17 Correlation between UCS and Hr

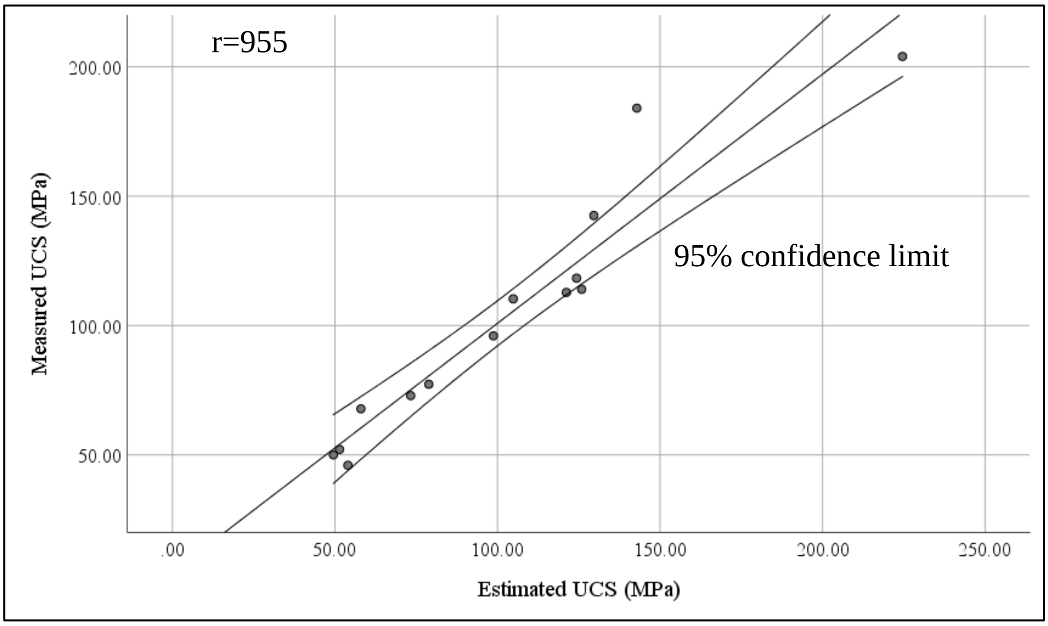

Figure 4.18. Comparison between measured UCS and estimated (upon Hr) UCS with 95% confidence limits.

4.5.2 Correlation between UCS and PLT

Strong correlation between UCS and PLT was obtained as Linear equation with R-squared value of 0.914. The derived equation is given as UCS=16.581(PLT) +13.917. UCS values were estimated by putting values in the derived equation and compared with the measured values. Pearson's correlation coefficient for correlation between measured UCS and UCS estimated on the basis of PLT is given as: r=0.96.

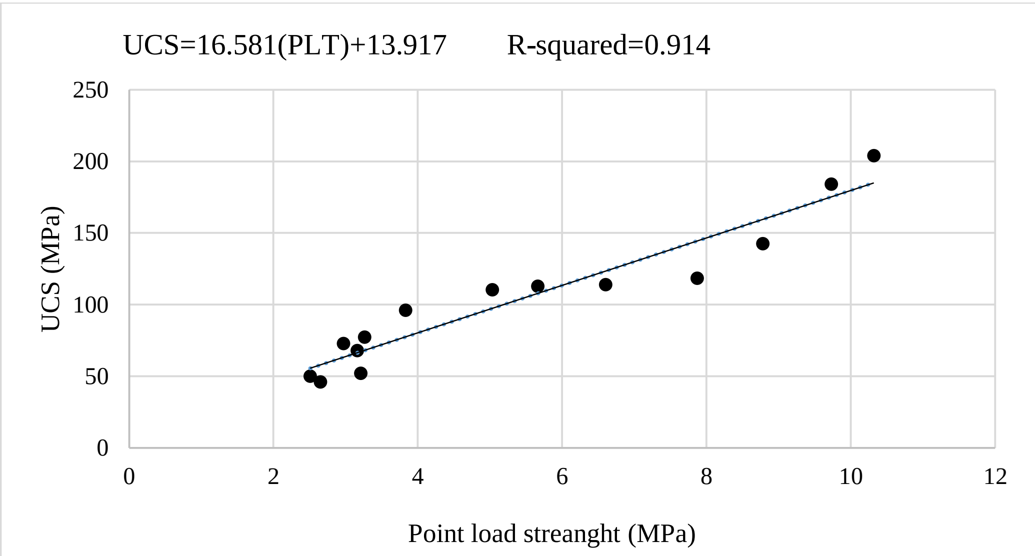

Figure 4.19. Correlation between UCS and PLT.

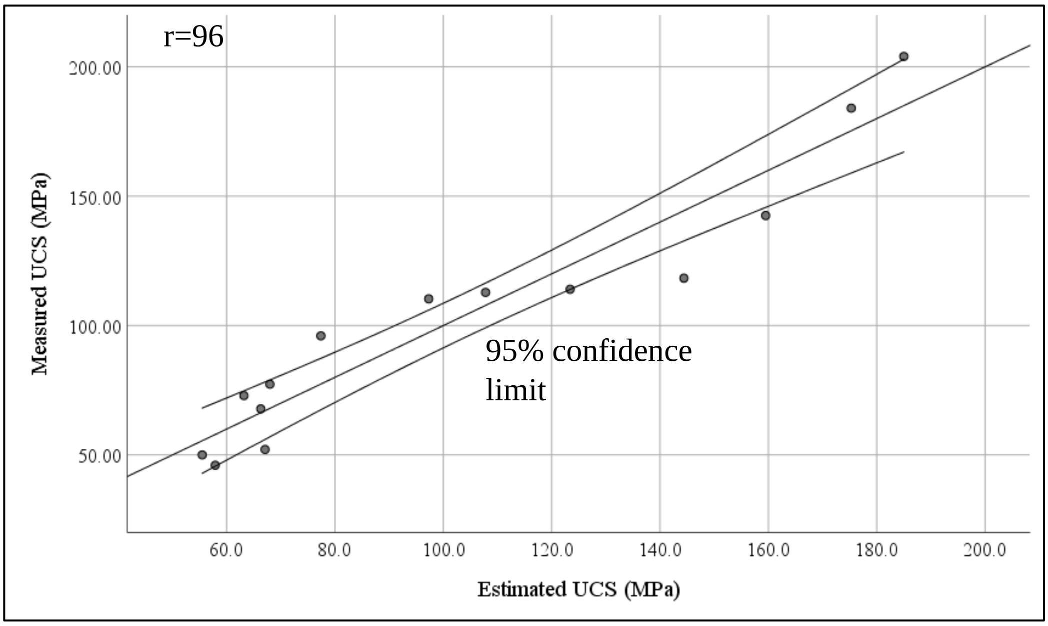

Figure 4.20. Comparison between measured UCS and estimated (upon PLT) UCS with 95% confidence limits.

4.5.3 Correlation between PLT and Hr

Line of best fit for correlation between PLT and Hr was given by Power equation with R-squared value of 0.867. The equation derived by regression analysis is given as $PLT = 0.0004(Hr)^{2.3982}$. By using this equation values of PLT were estimated and then compared with corresponding measured PLT values. Pearson's correlation coefficient for correlation between measured PLT and PLT estimated on the basis of Hr is given as: r=0.91.

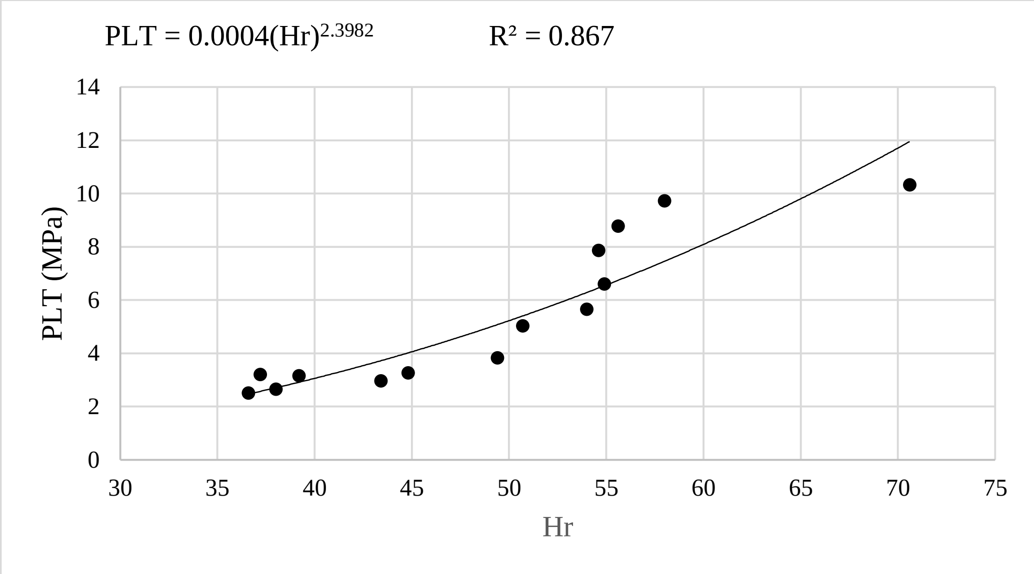

Figure 4.21. Correlation between PLT and Hr.

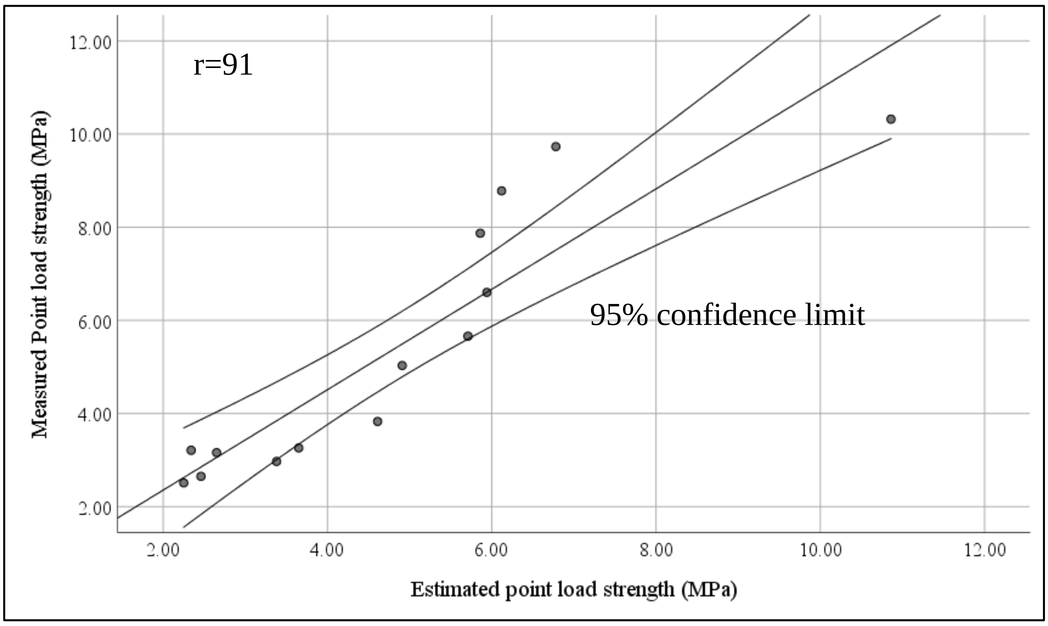

Figure 4.22. Comparison between measured PLT and estimated (upon Hr) PLT with 95% confidence limits.

4.5.4 Correlation between Oven Dry-UPV and Hr

Strong correlation between oven-dry UPV and Hr was obtained as Linear equation with R-squared value of 0.694. Equation derived by regression analysis is given as: OD-UPV=92.192(Hr)-892.6. Oven-dry UPV values were estimated on the basis of this equation and compared with corresponding measured oven-dry UPV values.

Pearson's correlation coefficient for correlation between measured OD-UPV and OD-UPV estimated on the basis of Hr is given as: r=0.83.

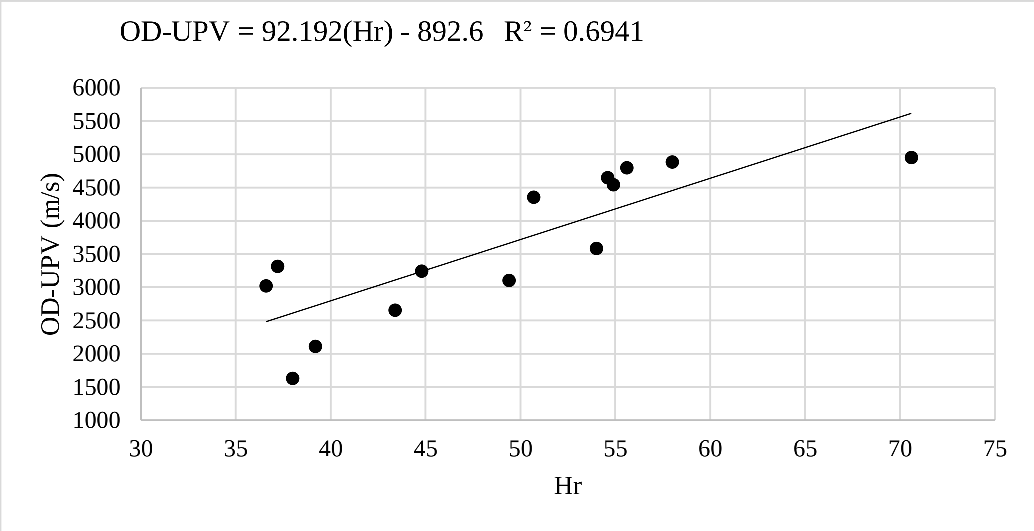

Figure 4.23. Correlation between OD-UPV and Hr.

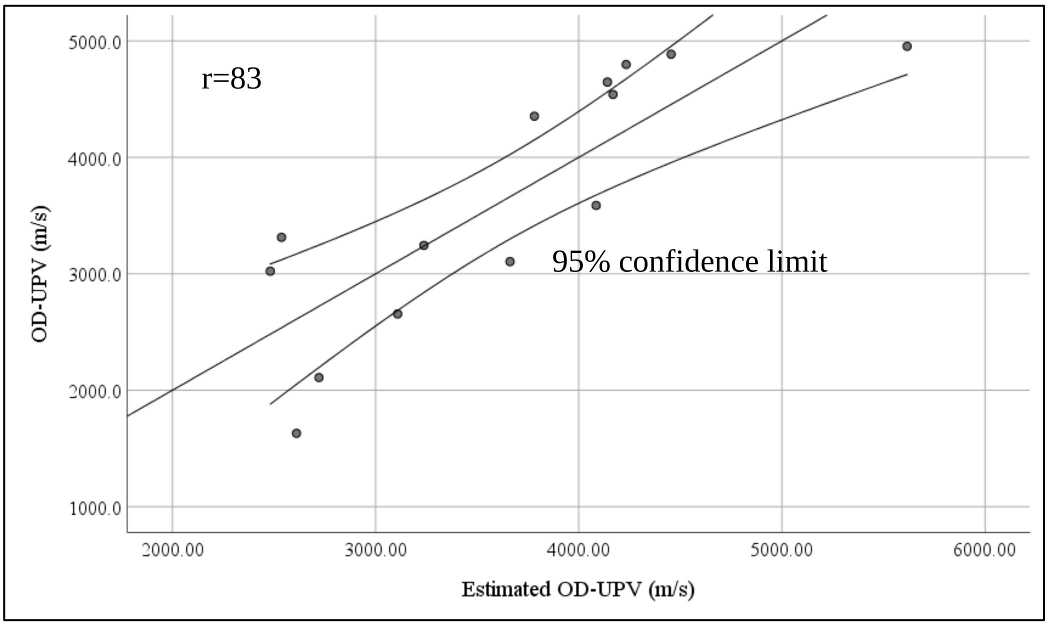

Figure 4.24. Comparison between measured OD-UPV and estimated (upon Hr) OD-UPV.

4.5.5 Correlation between Saturated Surface Dry-UPV and Hr

Strong correlation between saturated surface-dry UPV and Hr was obtained as Linear equation with R-squared value of 0.707. Equation derived by regression analysis is given as: SSD-UPV=53.359(Hr) +2639.6. Saturated surface-dry UPV values were estimated on the basis of this equation and correlated with corresponding measured SSD-UPV values. Pearson's correlation coefficient for correlation between measured SSD-UPV and SSD-UPV estimated on the basis of Hr is given as: r=0.841.

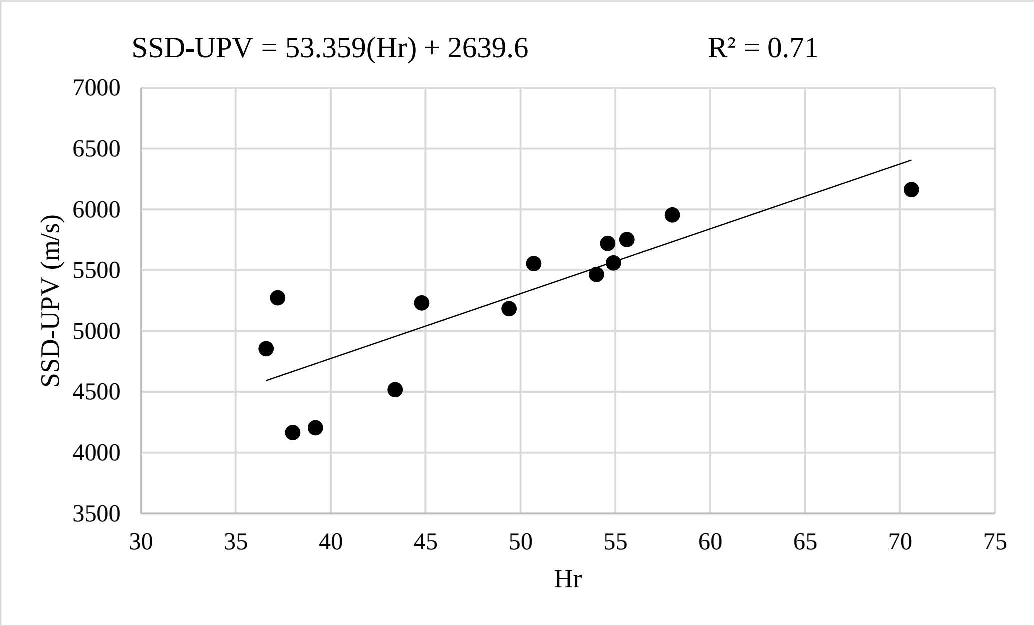

Figure 4.25. Correlation between SSD-UPV and Hr.

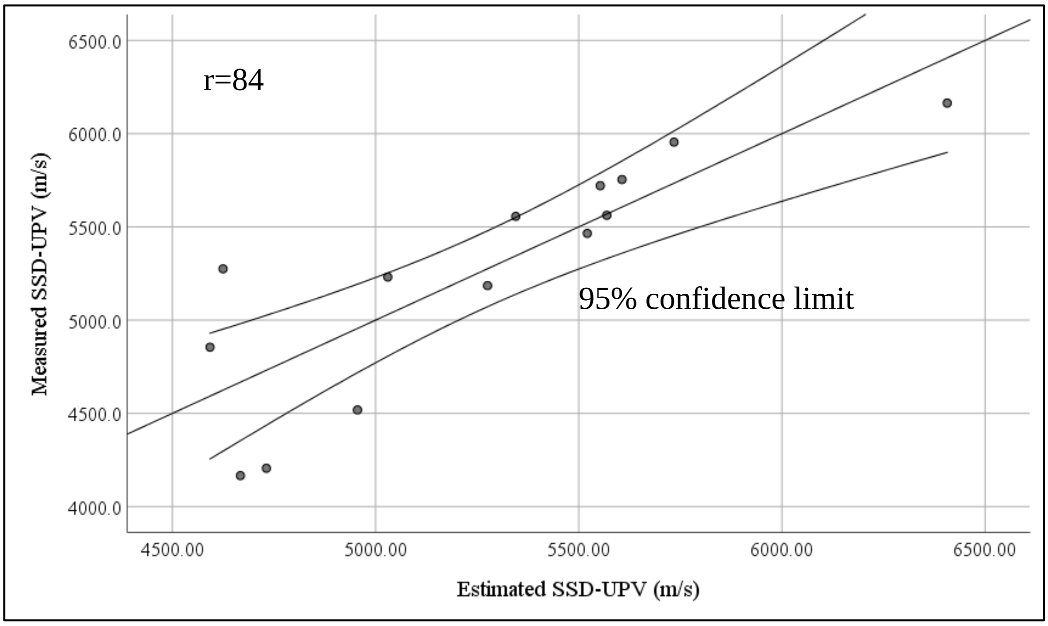

Figure 4.26. Comparison between measured SSD-UPV and estimated (upon Hr) SSD-UPV.

4.5.6 Correlation between Oven Dry-UPV and UCS

Line of best fit for correlation between OD-UPV and UCS was obtained by Exponential equation with R-squared value of 0.75. Equation derived by regression analysis is given as: UCS = $24.161^{0.0004(OD\text{-}UPV)}$. UCS values were estimated on the basis of this equation and correlated with corresponding measured UCS value. Pearson's correlation coefficient for correlation between measured UCS and UCS estimated on the basis of OD-UPV is given as: r=0.92.

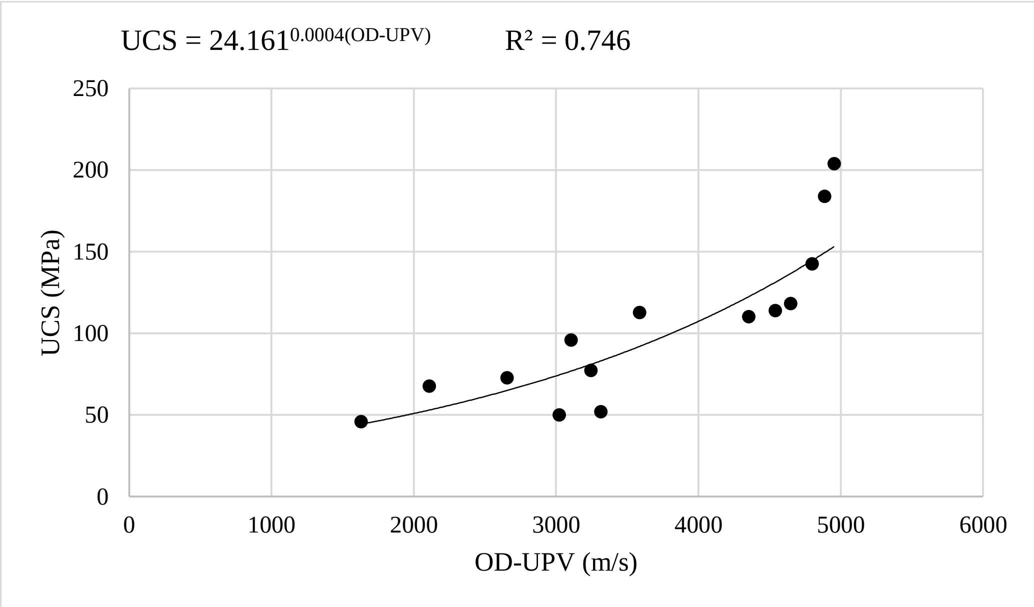

Figure 4.27. Correlation between UCS and OD-UPV.

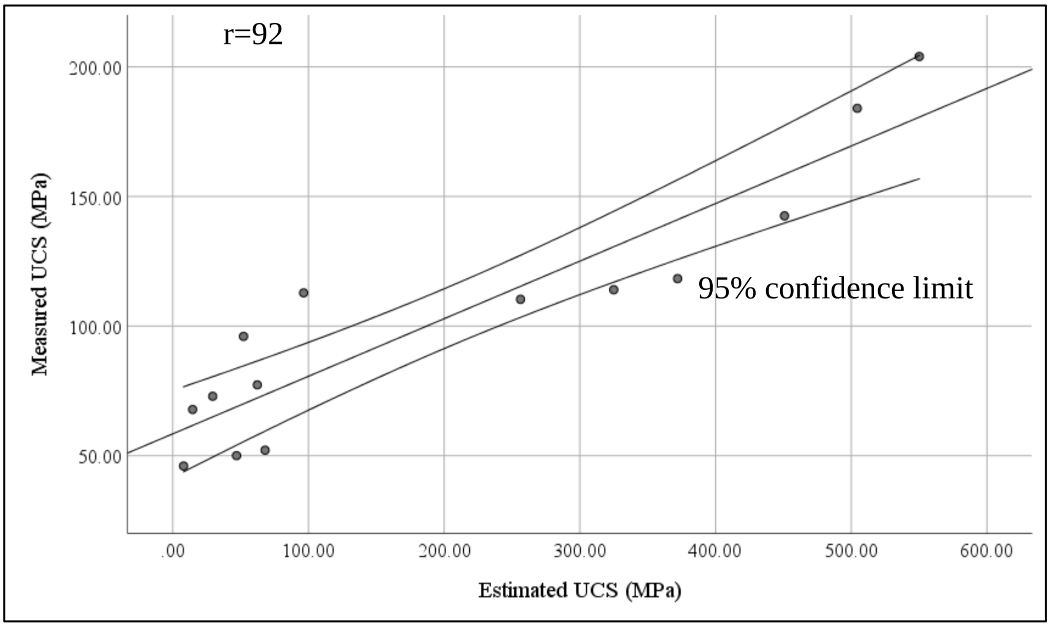

Figure 4.28. Comparison between measured UCS and estimated (upon OD-UPV) UCS with 95% confidence limits.

4.5.7 Correlation between SSD-UPV and UCS

Line of best fit was obtained by Exponential equation with R-squared value of 0.7143. The equation derived by regression analysis given as: UCS = $3.2921^{0.0006(\text{SSD-UPV}}$. UCS values were estimated on the basis of this equation and compared with measured UCS values. Pearson's correlation coefficient for correlation between measured UCS and UCS estimated on the basis of SSD-UPV is given as: r=0.915.

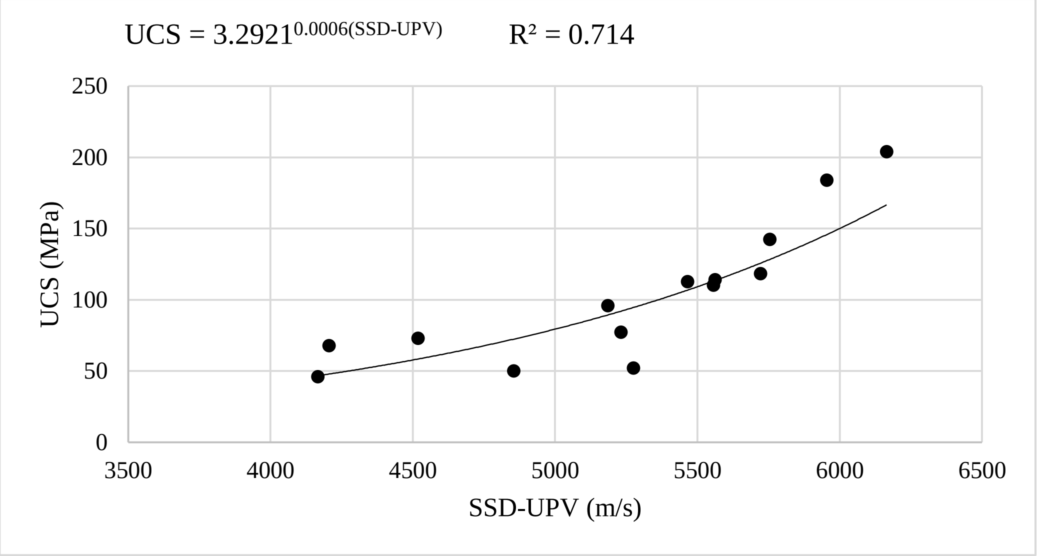

Figure 4.29. Correlation between UCS and SSD-UPV.

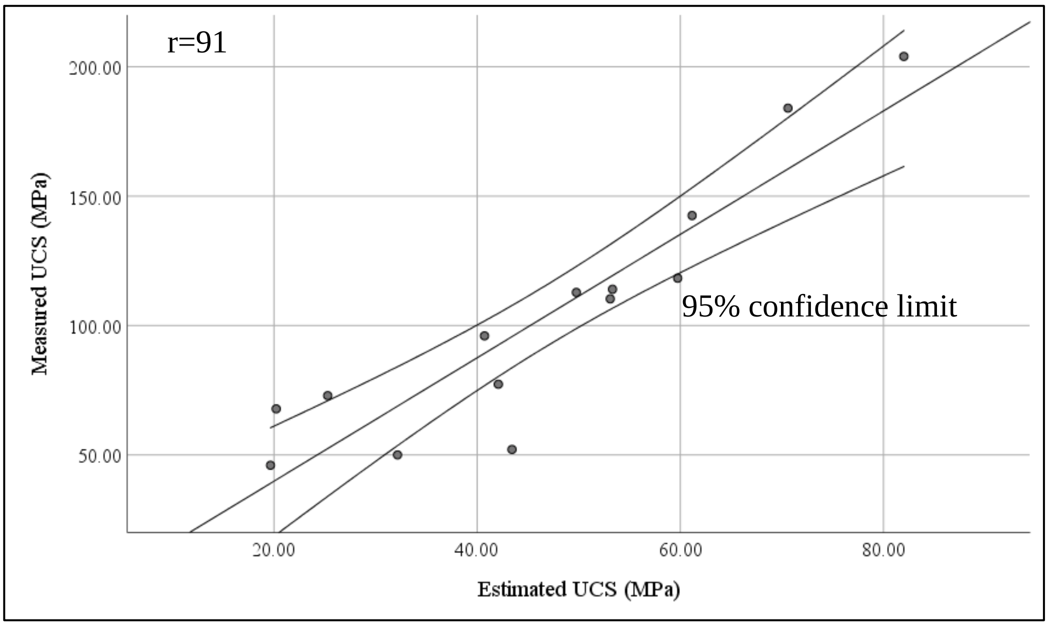

Figure 4.30. Comparison between measured UCS and estimated (upon SSD-UPV) UCS with 95% confidence limits.

CHAPTER 5

CONCLUSIONS

On the basis of this research work the following conclusions are made.

- Values of the physical properties (WA, SG and porosity) of the studied rocks are within the allowed limits of international standards for construction materials. Similarly strength properties like UCS, PLT and Hr of the rocks also ranged between the allowed limits of international standards for construction materials. So keeping physical and strength properties in view these rocks can be confidently used in construction projects.
- Petrographic features significantly affected physical and strength properties. Ambela Granite, though it consisted of hard minerals, showed smaller strength value because of coarse and relatively equal grains and abundant micro fractures. Similarly Nowshera Limestone, due to fine grain size and well graded texture, showed higher strength value.
- A strong correlation was derived between UCS and Hr where R-squared was equal to 0.946. UCS of the rocks can be inferred by using the derived equation. Similarly a strong correlation was present between UCS and PLT where R-squared was equal to 0.914. So PLT can be used to know about UCS of the rocks. This will save money and time. Correlation between PLT and Hr was also strong but the R-squared value was not as greater as for UCS vs Hr and UCS vs PLT. Correlation between UPV (OD and SSD) and Hr was weak and the R-squared value were smaller than 0.75. As the correlation was not strong enough, it is recommended not to analyse UPV of the present rocks from Hr.

REFERENCES

Anon, 1979. Classification of rocks and soil for engineering geological mapping, Part-1 rock and soil materials. *Bulletin of International Association Engineering Geology*, 19, 364-371.

Anon, 1981. Basic geotechnical description of rock masses. International society of rock mechanics commission on the classification of rocks and rock masses. *International Journal Rock Mechanics and Mining sciences and geo-mechanical Abstracts*, 18, 85-110.

Arif, M., Bukhari, S. W. J. H., Muhammad, N., & Sajid, M. (2013). Petrography and physicomechanical properties of rocks from the Ambela granitic complex, NW Pakistan. *The Scientific World Journal*, *2013*.

Aydin, A., & Basu, A. (2005). The Schmidt hammer in rock material characterization. *Engineering Geology*, *81*(1), 1-14.

Bell, F. G. (1992). Description and classification of rock masses. In *Engineering in Rock Masses* (pp. 54-77).

Bignold, S. M., & Treloar, P. J. (2003). Northward subduction of the Indian Plate beneath the Kohistan island arc, Pakistan Himalaya: new evidence from isotopic data. *Journal of the Geological Society*, *160*(3), 377-384.

Burbank, D. W., & Tahirkheli, R. K. (1985). The magnetostratigraphy, fission-track dating, and stratigraphic evolution of the Peshawar intermontane basin, northern Pakistan. *Geological Society of America Bulletin*, *96*(4), 539-552.

Coward, M. P., Rex, D. C., Khan, M. A., Windley, B. F., Broughton, R. D., Luff, I. W., ... & Pudsey, C. J. (1986). Collision tectonics in the NW Himalayas. *Geological Society, London, Special Publications*, *19*(1), 203-219.

Dietrich, V. J., Frank, W., & Honegger, K. (1983). A Jurassic-Cretaceous island arc in the Ladakh-Himalayas. *Journal of Volcanology and Geothermal Research*, *18*(1-4), 405-433.

Hussain, A., Pogue, K. R., Khan, S. R., & Ahmad, I. M. T. I. A. Z. (1991). Paleozoic stratigraphy of the Peshawar Basin. *Geological Bulletin*, 85-97.

Jan, M. Q., & Karim, A. (1990). Continental magmatism related to Late Paleozoic–Early Mesozoic rifting in northern Pakistan and Kashmir. Geol. *Bull. Univ. Peshawar*, *23*, 1-25.

Jiang, L., Zhao, Y., Golsanami, N., Chen, L., & Yan, W. (2020). A novel type of neural networks for feature engineering of geological data: case studies of coal and gas hydrate-bearing sediments. *Geoscience Frontiers*, *11*(5), 1511-1531.

Johnson, B. D., Powell, C. M., & Veevers, J. J. (1976). Spreading history of the eastern Indian Ocean and Greater India's northward flight from Antarctica and Australia. *Geological Society of America Bulletin*, *87*(11), 1560-1566.

Karaman, K., & Kesimal, A. (2015). A comparative study of Schmidt hammer test methods for estimating the uniaxial compressive strength of rocks. *Bulletin of Engineering Geology and the Environment*, *74*(2), 507-520.

Katz, B. J., Dittmar, E. I., & Ehret, G. E. (2000). A geochemical review of carbonate source rocks in Italy. *Journal of Petroleum Geology*, *23*(4), 399-424.

Kazmi, A. H., & Jan, M. Q. (1997). *Geology and tectonics of Pakistan*. Graphic publishers.

Kazmi, A. H., & Rana, R. A. (1982). *Tectonic map of Pakistan 1: 2 000 000: Map showing structural features and tectonic stages in Pakistan*. Geological survey of Pakistan.

Kempe, D. R. C., & Jan, M. Q. (1970). An alkaline igneous province in the North-West Frontier province, West Pakistan. *Geological Magazine*, *107*(4), 395-398.

Khanlari, G. R., Heidari, M., Momeni, A. A., & Abdilor, Y. (2012). Prediction of shear strength parameters of soils using artificial neural networks and multivariate regression methods. *Engineering Geology*, *131*, 11-18.

Pogue, K. R., Wardlaw, B. R., Harris, A. G., & Hussain, A. (1992). Paleozoic and Mesozoic stratigraphy of the Peshawar basin, Pakistan: Correlations and implications. *Geological Society of America Bulletin*, *104*(8), 915-927.

Powell, C. M. (1979). A speculative tectonic history of Pakistan and surroundings: some constraints from the Indian Ocean. *Geodynamics of Pakistan*, *13*, 5-24.

Sachpazis, C. I. (1990). Correlating Schmidt hardness with compressive strength and Young’s modulus of carbonate rocks. *Bulletin of the International Association of Engineering Geology-Bulletin de l'Association Internationale de Géologie de l'Ingénieur*, *42*(1), 75-83.

Sajid, M., & Arif, M. (2015). Reliance of physico-mechanical properties on petrographic characteristics: consequences from the study of Utla granites, north-west Pakistan. *Bulletin of Engineering Geology and the Environment*, *74*(4), 1321-1330.

Searle, M. P., & Tirrul, R. (1991). Structural and thermal evolution of the Karakoram crust. *Journal of the Geological Society*, *148*(1), 65-82.

Searle, M. P., Khan, M. A., Fraser, J. E., Gough, S. J., & Jan, M. Q. (1999). The tectonic evolution of the Kohistan-Karakoram collision belt along the Karakoram Highway transect, north Pakistan. *Tectonics*, *18*(6), 929-949.

Shah, S. I. (Ed.). (1977). *Stratigraphy of Pakistan* (Vol. 12). Director General, Geological Survey of Pakistan.

SHAKOOR, A., & BONELLI, R. E. (1991). Relationship between petrographic characteristics, engineering index properties, and mechanical properties of selected sandstones. *Bulletin of the Association of Engineering Geologists*, *28*(1), 55-71.

Stauffer, K. W. (1968). Silurian-devonian reef complex near Nowshera, west Pakistan. *Geological Society of America Bulletin*, *79*(10), 1331-1350.

Tahirkheli, R. K. (1979). Geology of Kohistan and adjoining Eurasian and Indo-Pakistan continents, Pakistan. *Geol. Bull. Univ. Peshawar*, *11*(1), 1-30.

Treloar, P. J., & Coward, M. P. (1991). Indian Plate motion and shape: constraints on the geometry of the Himalayan orogen. *Tectonophysics*, *191*(3-4), 189-198.

Treloar, P. J., & Izatt, C. N. (1993). Tectonics of the Himalayan collision between the Indian plate and the Afghan block: A synthesis. *Geological Society, London, Special Publications*, *74*(1), 69-87.

Treloar, P. J., Rex, D. C., Guise, P. G., Coward, M. P., Searle, M. P., Windley, B. F., & Luff, I. W. (1989). K-Ar and Ar-Ar geochronology of the Himalayan collision in NW Pakistan: Constraints on the timing of suturing, deformation, metamorphism and uplift. *Tectonics*, *8*(4), 881-909.

Yagiz, S. (2009). Predicting uniaxial compressive strength, modulus of elasticity and index properties of rocks using the Schmidt hammer. *Bulletin of engineering geology and the environment*, *68*(1), 55-63.

Yilmaz, E., Belem, T., & Benzaazoua, M. (2014). Effects of curing and stress conditions on hydromechanical, geotechnical and geochemical properties of cemented paste backfill. *Engineering Geology*, *168*, 23-37.