CORELATION OF PETROGRAPHIC AND MECHANICAL PROPERTIES OF MALAKAND GRANITE, MALAKAND, KHYBER PAKHTUNKHWA, PAKISTAN

BY

ABDUS SALAM

UMAIR ALI

WAFI ULLAH TANVIR KHAN

Department of Earth and Environmental Sciences

Bahria University, Islamabad

2019

ABSTRACT

The use of the granite is increasing day by day in construction industry. Therefore, the mechanical properties of Malakand granite were investigated to estimate the strength and give recommendations in designing safe structures. The present research deals with the investigation and correlation of compressive strength, specific gravity and water absorption of granite from different localities of Malakand, KP, Pakistan. Malakand Granite with distinct petrographic features have been tested to examine the influence of textural characteristics on the variation of their respective strength. Comparison of petrographic observations before and after the strength tests and the relationship of fracture propagation with mineral boundaries specify vital impact of textural variation in evaluating the mechanical behavior of granites. The important textural features include average grain size of rock, grain boundary recrystallization, and maximum grain size of major rock forming minerals, mean grain size of cleaved minerals, mineral exsolution and variation of grain size within a rock. The petrographic observations, however, are more effective to describe the strength variation of granites having analogous weathering grade as change in degree of weathering has a dominant effect on rock mechanics.

ACKNOWLEDGEMENTS

This thesis came into the present form due to the assistance and leadership of many people. We are grateful and we pay gratitude to those who supported and helped us out in making this documentation possible.

We express our profound sense of admiration to our supervisor Mr. Mumtaz Ali Khan, Assistant Professor, Department of Earth and Environmental Sciences, Bahria University Islamabad, who mentored us throughout the research and gave us directions that helped us make this documentation possible. We are also thankful to Mr. Saqib who helped us in the achieving our current research work. Also, we are much obliged to Prof. Dr. Tahseenullah Khan, Head of the Department, Earth Sciences.

In the end we would like to recognize our family for their support throughout our academic concern. Their prayers, best wishes and their confidence in us boosted our performance and helped us in overcoming our fears. We do acknowledge all those who have helped us directly or indirectly in the successful completion of our research work.

CONTENTS

CHAPTER 4

GEOMECHANICAL PROPERTIES OF MALAKAND GRANITE

CHAPTER 5

PETROGRAPHIC ANALYSIS OF MALAKAND GRANITE

FIGURES

TABLES

Page

CHAPTER 1
INTRODUCTION

1.1 Introduction

Pakistan is prolific in granitic rocks where several continental scale belts traverse the northern parts of the country in Himalayas and Trans-Himalayas. They include, from north to south, Khunjerab Pamir granitic belt, Karakoram belt, Kohistan granitic belt and Higher Himalayan granitic belt. Their broad mineralogical and geochemical characterizations are done to varying degrees. The Malakand granite is well exposed along roadside of Dir - Malakand road, KP, NW Pakistan.

1.2 Study area

The altitude of Malakand is approximately 561m-1055m above the sea level. The study area is present between latitude 34.568314° N and longitude 71.929794° E as shown in figure 1.1. This study lies in the Peshawar basin. The southern part of Malakand is present on Indian continental plate, where the Quartzite, Precambrian to Mesozoic Argillites, and Limestone are present that represent a history of shelf depositional environment intruded by various erosional unconformities (Pogue et al., 1992). The rock succession could be observed towards north converting into higher grade that reach the highest point in a dome shape structure where these rocks are metamorphosed into the Kyanite grade. The north boundary of the dome ends at a fault that is known as MMT or Main Mantle thrust. The Indian plate rocks are distinct from the amphibolite by these mélange zone rocks and are examined to belong to the Mesozoic island arc complex (Tahirkheli et al., 1979). This research examines the Geotechnical and petrographic analysis of the Malakand Granite to interpret whether the rocks are suitable to be used in construction and building materials.

The rock units that are exposed in this region are a part of Swat granites so this Swat granite that is also known as Swat Malakand granite are well exposed at several places such as Besham, Chakdara, Chingllai, Kott, Illum-Karaker, Malakand and Saidu-Paroona. These Swat-Malakand granites are metamorphosed to a large extent that results in developing of gneissic and augen structures in various places. At some places un-deformed granites can be seen such as in Chakdara, Mallakand and Besham. The augen gneisses could be distinguished by the large feldspar grains present in the groundmass of feldspar, quartz, biotie and muscovite whereas the granites that are undeformed are marked by the non-foliation that contain almost same modal composition. Hornblende, sphene and garnet grains are also present in these granites.

While considering the geochemistry, the fresh developed Swat-Malakand granites are subalkaline and peraluminous in nature. Some of the granitic rocks are also metaluminous and peralkaline. The Swat Malakand granites potrays fractionation of biotite, K-feldspar and plagioclase while looking at the binary variation diagrams.

The geochronological details acquired for the Swat-Malakand granites denied Precambrian age as it is reported previously. The best estimated age of the Chakdarra granite gneisses is 213 ± 24 Ma as it is not well observed and studied. So it is suggested that the Chakdara granite gneisses age is upper Triassic. While the data suggests that the Illum-Karaker granite gneisses age is 260 ± 52 Ma..

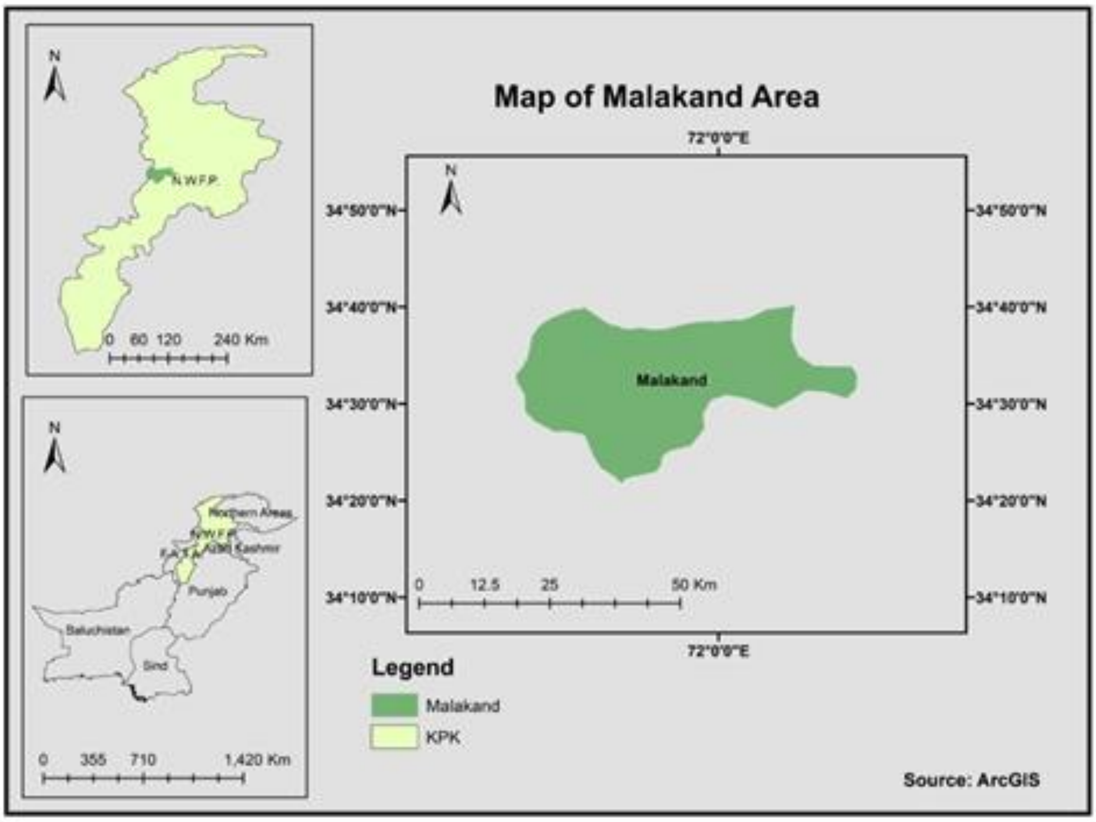

Figure 1.1. Shows the location map of our study area (ArcGIS).

1.3 Accessibility and climate

The study area is easily accessible from Islamabad trough M1 motorway. It is at a distance of approximately 200 km from Islamabad. The map below shows the route followed to reach from Islamabad to Malakand tunnel (Figure 1.2).

The climate of the study area (Malakand pass) is warm and temperate. It is moderate which means it is not too cold or too hot. The rainfall mostly occurs in winters. It gets moderately hot in summer and moderately cold in the winter.

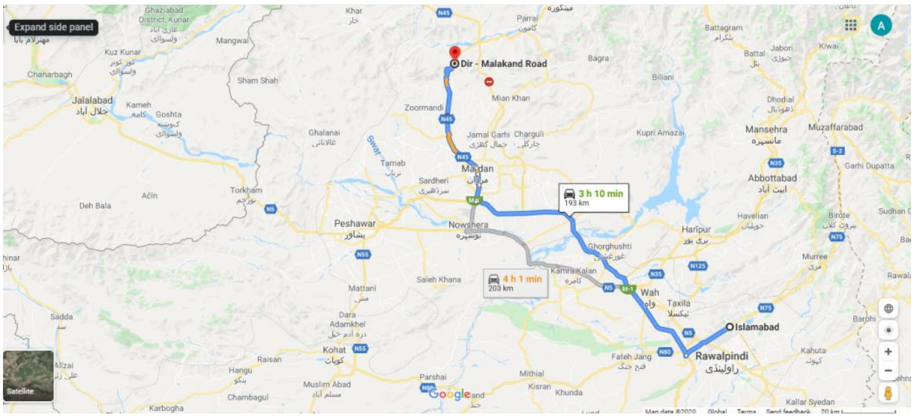

Figure 1.2. Road map showing route from Islamabad to Malakand.

1.4 Objectives

The main theme of this research includes understanding the mechanical and petrographic analysis of Malakand granite.

(i) To test the mechanical strength of Malakand granite.

(ii) To investigate Geomechanical properties of Malakand granite including conducting laboratory tests for determination of the tensile strength, specific gravity, water absorption and compressive strength of the collected rock samples.

(iii) To study the Petrographic analysis of Malakand Granite.

1.5 Methodology

The methodology applied in this research work is as follows:

(i) Field work done to collect rock samples.

(ii) UCS test was conducted on rock samples in order to measures strength and the stress-strain characteristics of the rock.

(iii) Water absorption and specific gravity tests conducted in order to study the other Geotechnical properties of Malakand Granite.

(iv) Petrographic analysis was conducted in order to find concentration of minerals and grain distribution.

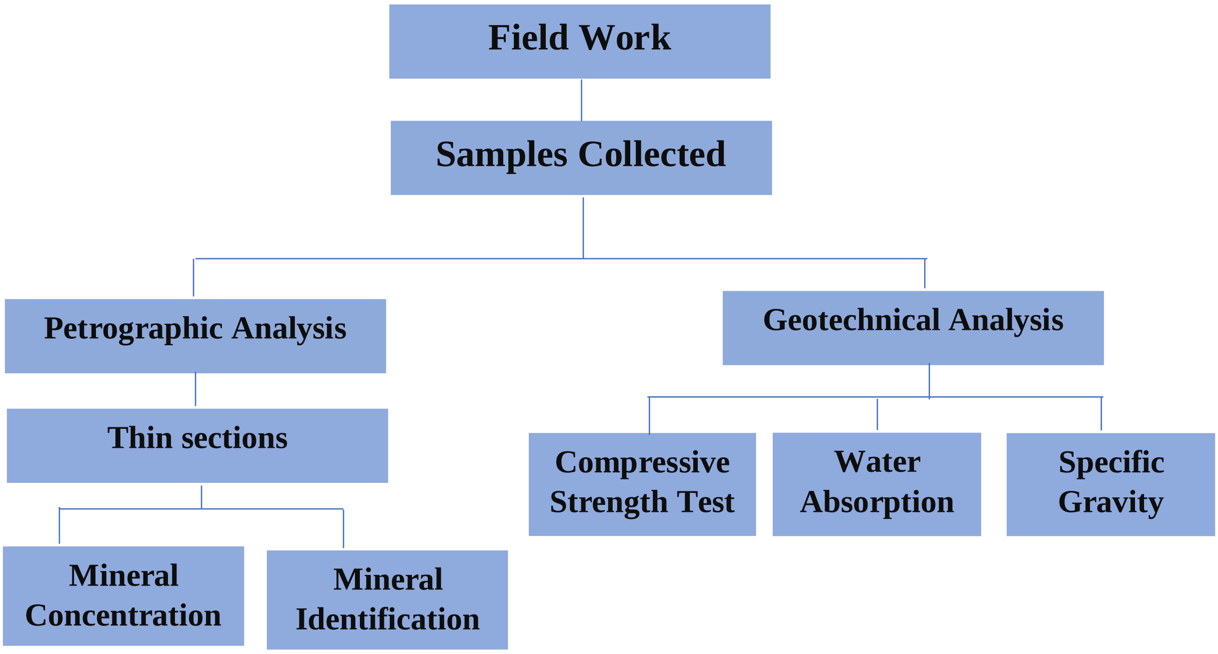

Figure 1.3 shows the flow chart of methodology adopted.

1.6 Equipment

Figure 1.4 shows equipment used in the field and research work is as follows.

(i) Geological hammer

(ii) Measuring tape

(iii) Hand lens

(iv) GPS

(v) Optical microscope

(vi) Thin sections

Figure 1.4. Geological field equipment.

1.7 Field observations

The outcrop showed dark gray to blackish in color as it is shown in figure 1.4. Occasionally brownish coloration is also visible due to hematization whereas, the fresh sample of the sample showed whitish gray color, shown in figure 1.5. It is a medium to coarse-grained with sub equigranular to equigranular in shape. Texture and grain size are one of the important parameter as they have important correlation with strength and durability of rocks. It has porphyritic texture. The lithological composition mainly consists of quartz rich Ganite.

Figure 1.5. Weathered color of the Malakand granite.

Figure 1.6. Fresh color of the Malakand granite sample.

CHAPTER 2

REGIONAL GEOLOGY AND TECTONICS

2.1 Geology and tectonics of Swat-Peshawar basin

The Malakand and surrounding areas consist of three major tectonostratigraphic zones (Kazmi et al., 1986). From north towards south, these zones are classified as:

(1) The Kohistan island arc sequence (Jan, 1977).

(2) The Indus suture mélange terrain or zone (Kazmi et al., 184).

(3) The shelf sediments of the Indo-Pakistan plate.

The sediments that are present in shelf or platform are basically pelitic, calcareous, graphitic, and psammitic in nature which were deposited and accumulated on the northern boundary of the Gondwanaland before and after its Permo-Triassic split. These rock sequences have an age range from late Precambrian to upper Mesozoic. The upper Paleozoic granitic plutons have interrupted the older parts of this section (Le Fort et al., 1980). In the region of Swat, the stratigraphy of these rocks succession or sequence has been studied by many researchers since the field work done by Martin et al,. 1962. The lower Swat-Buner schistose group of Martin et al., 1962 was divided into the Swat granite gneisses, Manglaur schist, Alpurai schist, Saidu schist, and the Indus melange group by by Kazmi (1984). Three different types of sediments were determined in lower Swat-Buner region, these sediments are as classified as follows:

(i) Twice metamorphosed crystalline schist which is of Precambrian age (Manglaur).

(ii) Once metamorphosed shelf sediments (Alpurai) of Paleozoic age

(iii) Once metamorphosed Indus flush sediments (Saidu).

According to this new study, the Swat granite gneisses interrupted into the Manglaur schist, and both are unconformable overlain by Alpurai schist sequence (Palmer and Rosenberg 1985). The tourmaline granite gneisses intrude the bottom part of the Alpurai schist and an unconformity is determined. The Alpurai schist unit has further been subdivided by Di Pietro and Lawrence into four different members that are as follows:

(a) The Marghazar member is at the base and is composed of a variable sequence of alkali feldspar containing psammitic schists, phlogopite-bearing-calc schists, garnetiferous pelitic schists, and quartz-hornblende. The amphibolite layers of Martin et al., 1962 lies at the top of the Marghazar.

(b) The Kashala member overlies the Marghazar member and is composed mainly of garnetiferous calc-schists, calc-phyllites and marble.

(c) Most of the overlying Saidu member is composed of graphitic phyllites.

(d) The Nikani Ghar member is a thick rock sequence of marbles and dolomitic marbles. It is stratigraphically correlated with the Saidu member (Ahmad et al., 1988).

The Alpurai formation can be traced towards south into fossiliferous sequence (strata) near Baroch (Pogue and Hussain, 1988). Lawrence et al., 1985 investigated a large overturned orthogneiss nappe in the rock sequences of the lower Swat-Buner region. Rosenberg and others (1985) noted three different stages of deformation (D1, D2, D3) in the rock sequences southward of the MMT.

Southward of the MMT, the lower Swat rock sequences consists of granites of various ages from Precambrian to Tertiary. The Swat granitic gneisses composed of various individually named plutons which intrude the Manglaur formation. The Choga granite is at the east of lower Alpurai village east of Shang la Pass (Martin and others, 1962). The Loe Sar granite is towards the south of Manglaur, and the Ilium granite exists at south of Mingora (Palmer-Rosenberg, 1985; Ahmad, 1986). These granites are called the Swat gneisses (Lawrence et al., 1989). Ages of these granites are not known. Researchers consider that the Mansehra granites and gneisses in Hazara, Pakistan are related to the Sawat gneisses. Le Fort et al., 1980 reported a late Cambrian rock Rb/Sr date of 516 ±16 Ma for the Mansehra granite. The precambrian silica rich schists of staurolite to sillimanite named the Tanawal Formation were interrupted by the Mansehra formation (Calkins et al., 1975). These silica rich schists look alike the Manglaur schist. If the suggestion of corelation and the Rb/Sr dates are true, the Swat gneisses and the Manglaur schist of Precambrian intruded it at same time that is in early Paleozoic age.

Along with Swat gneisses, younger tourmaline granite gneisses and biotite granite-granodiorites occur as well. The succession is intruded by the Tourmaline gneisses mainly across the unconformity that exists beneath Alpurai group. Based on metamorphic intrusion with the Kashala, these types of granites are considered Paleogene in age as discussed by Ahmad, 1986 and Di Pietro, 1990. A muscovite date of 23 Ma for the Malakand granite is reported by Maluski and Matte (1984). Towards southeast of the Swat, The biotites obtained from the Loe Shilman and Silai Patti carbonatites gives approximately 30 ± 3 Ma as determined from the K-Ar age (Le Bas et al., 1987). Close to Baroch, the Kashala formation is intruded by the biotite granites of the Ambela complex intrude. Moreover, towards south the Rb/Sr age determines the Koga carbonatite present in the Ambela complex shows age range of almost 297-315 Ma (Le Bas et al., 1987). The radiometric ages ranging from the Cambrian to Lower Ordovician were investigated from various granitic gneisses that are present in the Lesser Himalayas (Le Fort et al., 1980). Hence, the age of the younger granites had been interpreted and is not yet well determined.

Indus Suture Zone consists of mélanges that are of various oceanic origins. Lawrence et al.,1983, and Kazmi et al.,1984, divided these into three fault bounded mélange zones that are discussed as follows:

(a) The Mingora ophiolitic mélange that is composed of tectonicized sediments of talc, carbonate, serpentinite, greenstone meta-basalts, green schist meta-pyroclastic rocks, meta-gabbro, meta-sediments and meta-cherts, that had been metamorphosed with the underlying meta sediments of the Indian plate. Its mineral and rock constituents show epidotic amphibolite metamorphic facies (Lawrence et al., 1989; Di Pietro, 1990). From norsth it is bounded by the Kohistan reverse fault and from the south side by the Kishora fault.

(b) The Charbagh greenschist melange, consisting of greenstone metabasalts, and greenschist-facies metapyroclastic rocks with minor tectonized layers and wedges of metasedimentry rocks, that are crops out between Charbagh and Shang la Pass. It consists of Mingora ophiolite mélange in the south while towards north a major thick tectonic wedge between the overlying Shang la blueschist melange is present.

(c) The Shang la blueschist melange is best exposed in the vicinity of Shang la Pass and is recognized by blocks of glaucophane and crossite-bearing blueschist (Shams et al., 1980; Jan, 1985), metavolcanic rocks and schists with smaller lens shaped masses of serpentinite, metadolerite, metagreywacke, metachert and marble (Kazmi et al., 1984).

Metamorphism associated with these blueschists represent pressure conditions of approximately 7 Kb at a temperature of about 3800℃ on the basis of its mineralogical composition (Jan et al.,, 1981). Isotopic dates on the blue schist metamorphism have a K/Ar represents age of 84±.1.7 Ma for the muscovite from a meta-sedimentary kind blue schist near Topsin (Shams, 1980). Maluski and Matte (1984) received 40Ar/39Ar date of 83.512 Ma on phengite in a blue schist block.

Kazmi et al.,1983 discovered fossil content of Jurassic to middle Cretaceous age from a limestone block in the Kabal area. According to these ages, the blue schist metamorphism is thought to be late Cretaceous in age and related to subduction adjacent to the Kohistan andesitic arc (Coward et al., 1986).

The Kohistan arc rock sequence represents an andesitic arc terrain. In Swat, adjacent to the MMT, it consists of southern amphibolite belt which extends from southwest of the Nanga Parbat Haramosh massif along Babusar Pass, Kohistan, and Dir to eastern Afghanistan (Tahirkheli et al., 1977).

The southward amphibolite belt includes 7-8 km of various folded fine grained to coarse grained banded or homogeneous amphibolite, flaser gabbro and blastomylonitic amphibolites. The layered or banded amphibolites are locally migmatitic with quartzofeldspathic intrusions. The sequence encloses large patches of mafic or ultramafic rocks such as diopsidites, harzburgites, dunites and garnet spinel diopsidites from its lower part which is bounded by some amphibolitized or garnetiferous noritic gneiss also known as pyroxene granulites. In Sawat valley these are known as the north Mingora complex while along the Indus valley these are called as the Jijal-Pattan complex (Jan, 1977; Jan and Howie, 1981). The Jijal granulite also indicates metamorphosed norites, with subordinate quartz diorites (Jan, 1979c), olivine gabbro, troctolites, feldspathic gabbros, olivine anorthosites and pyroxenites. The pyroxene granulites are affected by various stages of metamorphism and deformation (Jan, 1980). P-T estimates (T=600° C, P=10-14 Kb) for these rocks shows an oceanic or suboceanic instead of a continental geothermal regime (Jan, 1980).

Our study area composed of the Main Mantle Thrust zone also known as MMT. The area also contains the sediments from the Indian plate. The sediments from the Indian plate sequences that are visible or exposed belong to the Alpurai group and the Saidu schist which are overlain bythe Indus suture melange zone. The Alpurai group could be identified by looking at the Marghazar, Kashala, and the Saidu formations. The Marghazar formation is well exposed that is thrust over the Saidu graphitic phyllites. It has the shape of a small wedge. The Nikani Ghar formation could not be seen as it is not exposed there and belong to the overlying unit of Alpurai group. The Chakdara pluton which contains tourmaline rich granite gneiss is in contact with the Kashala formation of the Alpurai group. Contact existing between Chakdara pluton and Alpurai group is not obvious and clear, as one cannot say whether it is an unconformity, a regular fault, or belong to sheared unconformity.

Mingora ophiolitic melange extension is the Indus melange group sequence towards west that exists as an oceanic suit in shape of thrust sheets that consists of serpentine and talc carbonate. It belongs to the metavolcanics and metasediments between the different tectonized units such as schist and phyllites. Emeralds are also spotted in the talc-carbonate blocks near Garai village (S. Hussain et al., 1990). The Kohistan arc amphibolite over thrusts the Indus melange sequence (group).

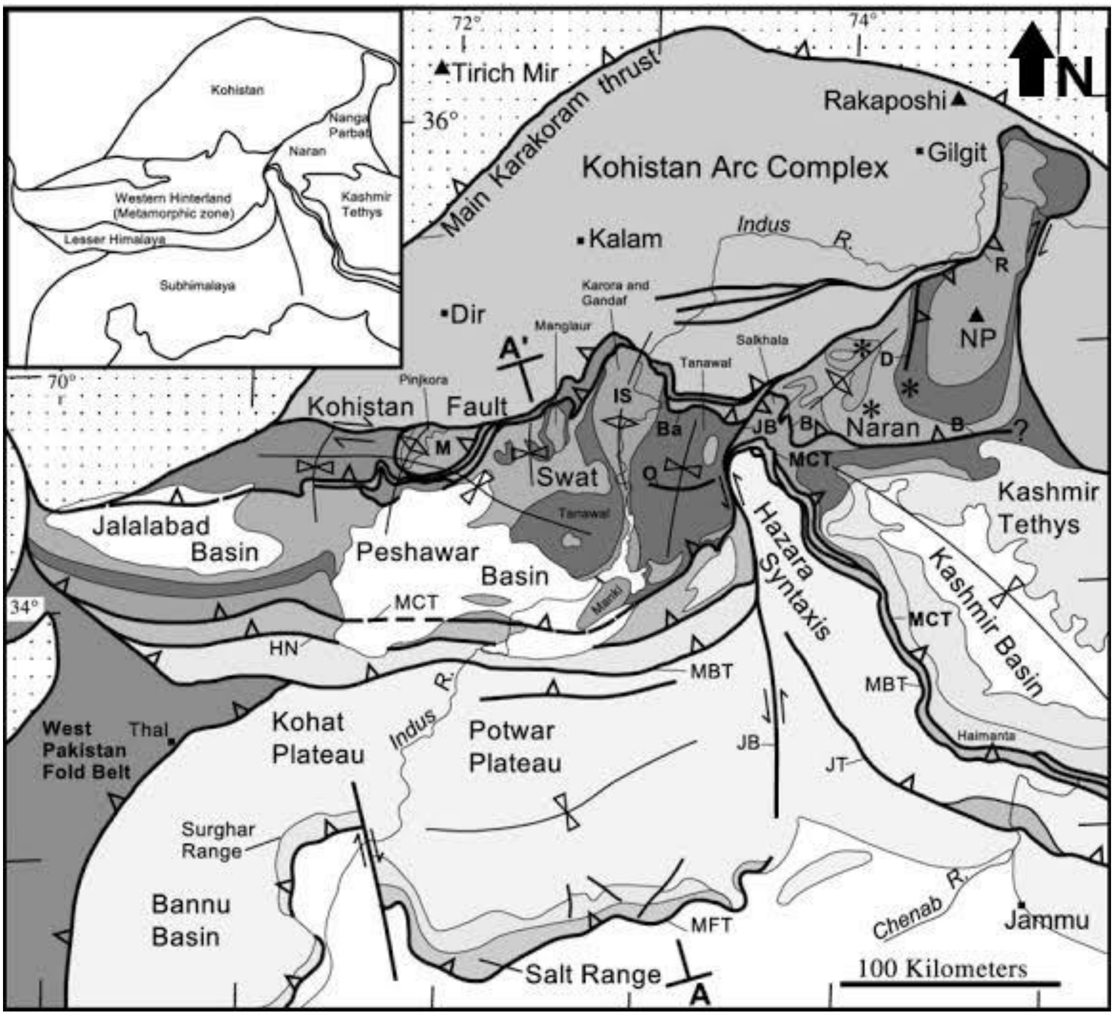

Figure 2.1. Detailed tectonic map of western Himalayas (Joseph and Kevin, 2004).

2.2 Regional geology

In order to fully understand the tectonic framework of north Pakistan, a prerequisite in understanding the tectonic setting of Malakand granite and granite gneiss complex, a comprehensive note on pre- and post-Himalayan history is being presented:

At First, the southern margin of Indian plate was collided with the Karakoram block while moving towards north that followed by Afghan block. The Kohistan Island Arc finally came in contact with the system which is enclosed by Main Kharakhoram Thrust (MKT) in the north. In the south it is enclosed by the Main Mantle Thrust (MMT) as shown in Figure 2.2. The Himalayan orogenic belt was formed as a result of collision between the northward movement of Indian Plate that collided with the Eurasion plate It is also the youngest mountain chain in the world (Figure 2.2).

Various micro continents present near to the Gondwanaland plus several one island arcs are involved in this Indo-Eurasia continental collision. These arcs are formed during Mesozoic Era in the north of the Indian Plate.

MMT that is also known as Indus Tsangpo Suture Zone (ISZ) was developed as a result of subduction and collision of Indian Plate during Eocene time beneath the KIA also known as the Kohistan Island Arc. The ocean between the two plates enclosed in the Eocene time at the site of MMT or ISZ. Towards the southwest in India and Tibet, the Main Mantle and Main Karakorum Thrust merge together and developed the Indus-Tsangpo Suture zone. To the southwest in north Pakistan right lateral Sarobi Chamman fault is developed as MKT and MMT merge (Figure 2.2). Due to major collisional zones (MMT and MKT), the northern Pakistan is considered as tectonically active area.

This collision resulted in the deformation of Indo-Pak subcontinental crustal Plate internally, developing the Himalayan thrust belt and forland at the north Pakistan. This deformed belt is approximately 300 kilometers wide and is located towards south of MMT. It also contains the Malakand granite and granite gneiss complex (Figure 2.3). The major members of this fault system are the Main Boundary Thrust and the Salt Range Thrust.

The foreland basin is bordered by the MBT in the NW Pakistan where it exists east to west but turns towards north near Jehlum river, there it is known as the Hazara-Kashmir Syntaxis (Figure 2.3). The foreland fold and thrust belt is intersected by two internally northward dipping thrust faults that are Main Central Thrust or MCT toward the North and MBT in the south in the central Himalayas (Figure 2.3). Main Frontal Thrust of the central Himalays lateral equivalent is the Salt Range

Thrust present in the southwestern region of the Pakistani Himalaya. The Panjal and Nathiagali faults, demarcate the western limit of the Hazara-Kashmir Syntaxis. Various areas like Salt Range, Bannu and southern Potwar that are active deformational front, have seismic activity of about ≥4.0 Mw is as a result of the thick Precambrian salt. Some fault segments such as Hinterland zone are more seismically active shown by the clustering of events in precise parts along the major faults. The detailed seismic study of the region shows that approximately seismicity of ≥4.0 Mw is associated to blind and surface faults.

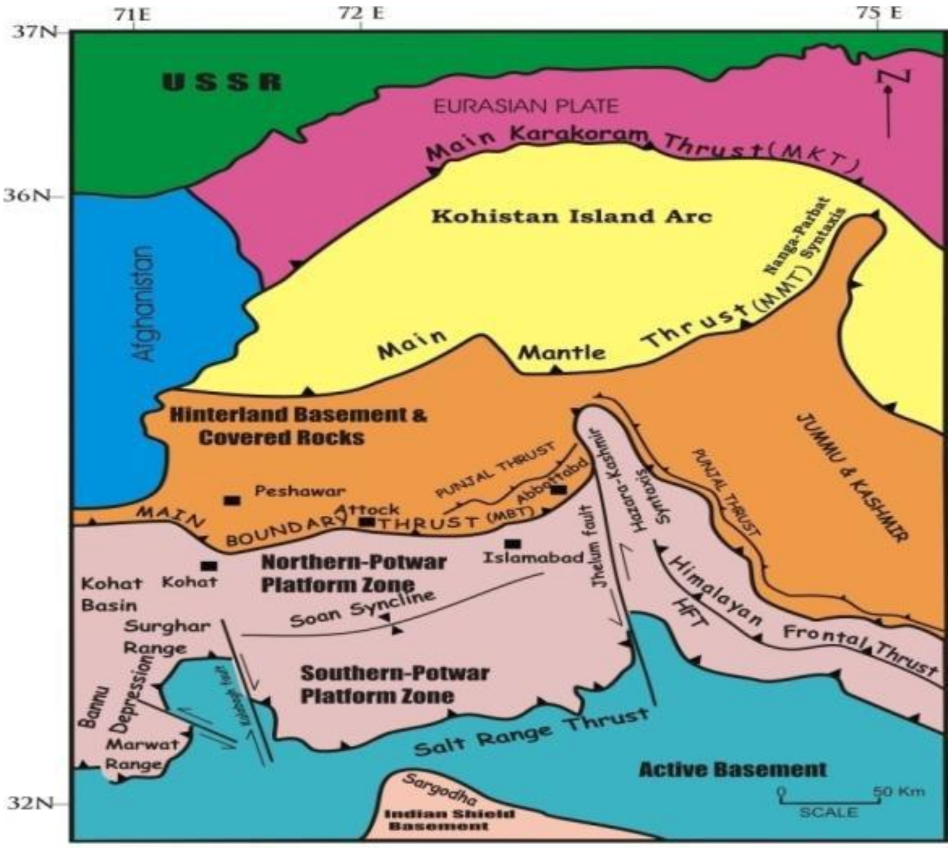

Figure 2.2. Detailed tectonic map showing northwest region of Himalayas in Pakistan (Baig and Lawrence, 1987; Monalisa and Khawaja, 2004).

2.3 Local geology

In the regional tectonic division of Himalayas, the Malakand granite and granite gneiss complexes belong to the Lesser Himalayan domain. These are intracratonic rocks, which are involved in the Cenozoic Mobile Belt of Himalayas.

The radiometric age data also identifies out that the fission track age of approximately 29.50 ± 1.50 Million years is the age of interruption and intrusion of magma that is carbonatitic in nature and near to the surface level it is Sillai Patti carbonatite complex to superficial. While comparing the uplift sediments covering removal rates of the area with the world data, it shows the presence of after collision extensional regime during Oligocene time in the region that is present south of Main Mantle Thrust. This contradicts the thought of the previous researchers about the emplacement of the carbonatite multifaceted throughout Oligocene at and Sillai Patti and Loe-Shilman region besides reverse faults.

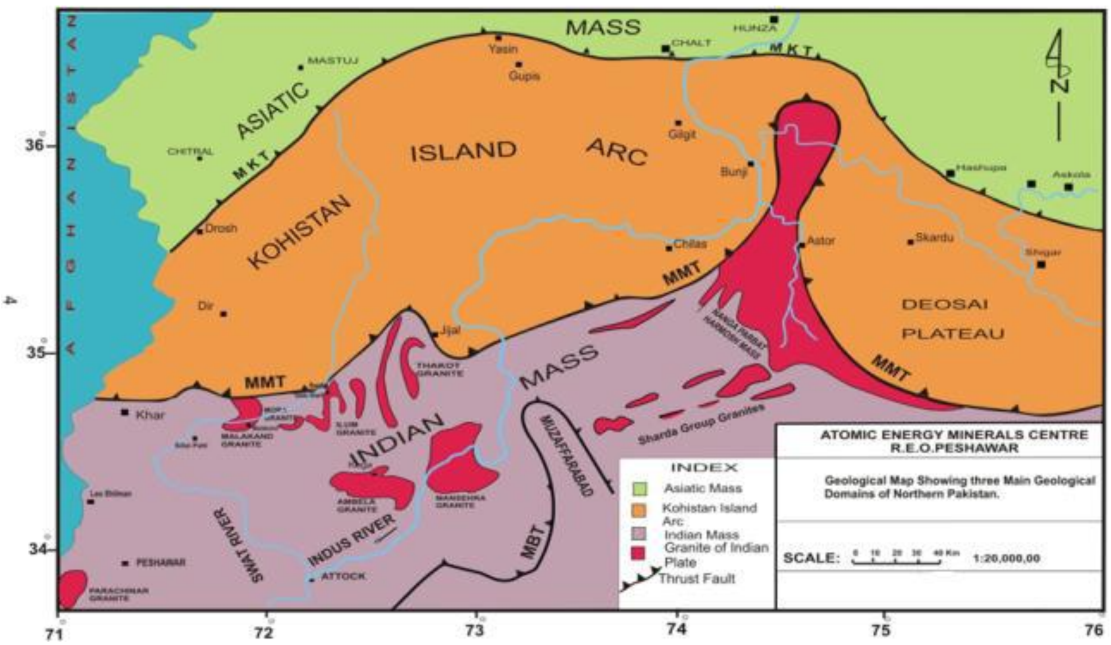

Figure 2.3. Geological map showing three main geological domains of northern Pakistan.

CHAPTER 3
STRATIGRAPHY

3.1 Local stratigraphy

The area of study has been divided into three main terrains that are the Indian shelf sediments, the Kohistan Arc sequence and the indus Melange zone. Ages ranging from Paleozoic to tertiary were given to these rock units (Martin et al., 1962). In this research, the naming scheme presented by Di Pietro (1990) has been followed. The Malakand area consist of the following formations;

(i) Alpurai group

(ii) Marghazar formation

(iii) Kashala Formation

(iv) Saidu Formation

(v) Chakdara granite

3.1.1 Alpurai group

The Alpurai group is overlying the Manglaur formation and Swat gneisses unconformably. Alpurai group was named according to its occurrence in the proximity of lower Alpurai village, which lies at approximately 31 km east of Saidu (Kazmi et al., 1984). Di Pietro (1990) divided this group into four formations: the Marghazar, Kashala, Saidu, and, Nikani Ghar formations. The formation of Marghazar exists at the bottom and it consists of amphibolitic, pelitic, schists, phlogopite marbles, psammitic and amphibolites. Kashala formation consisiting of garnetiferous calc-schists, calc phyllites, marbles and dolomitic marbles overlies it. Overlying the Kashala formation are the black graphitic phyllites of the Saidu formation in the north, and the marbles and dolomitic marbles of Nikanai Ghar formation in the southern part. The Kashala, Marghazar, and Saidu formations have crop outs in the area of study alongside the road.

3.1.2 Marghazar formation

The name of Marghazar formation came from the Marghazar village that is about 6 km south of Saidu. The suggested type locality lies beside Saidu Khwar (creek) and the close by road north and south of Marghazar village (Di Pietro, 1990). This formation is chiefly consists of dark-gray colored eroded phlogopite marble, garnetiferrous muscovite schist, epidote, biotite schist, psammitic schist, feldspathic quartzite, calcite marble, amphibolite schist, amphibolite and rare graphitic schist (Di Pietro, 1990). The the Marghazar formation is interrupted by tourmaline granite gneiss at the lower part. In study area, a small wedge of quartz-rich garnetiferous schist is present south of Nimogram. It is white in color composed of fine-grained quartz, garnet porphyroblasts, and muscovite which defines the foliation. No similar rock type is exposed in other parts of the study area. It is been interpreted to be the garnetiferrous muscovite schist of the Marghazar formation. This small body has been thrust over the Saidu graphitic phyllite.

3.1.3 Kashala formation

The name Kashala formation has been taken from Kashala mountains that are at least 12 km South West of Saidu. The type locality that is suggested is beside the roadcuts at Dop Sar, just south of Saidu (Di Pietro, 1990). It is almost composed of calcareous types of rocks. Quartzites, amphibolite and psammitic schists are not present but the Pelitic schists and argillite occur here (Di Pietro, 1990).

Kashala formation is one of the largest rock unit exposed in the field area. It extends from Ramora along the roadside to near Khazana village. It is also well crop out along the road between Zarikhela and Kabal. The thickness is several hundred meters. It consists about five rock types: calc-mica-garnet schist, schistose marble, white marble, quartzite, and dark-gray colored foliated marble. The calc-mica-garnet schist is the major rock unit. It composed interbeds of gray marbles. The marble strata or layers range from some centimeter to some tens of meters thick. The contact between the marbles and schists are sharp in nature. The calc-mica-garnet schist grades upward into schistose marble. The quartzite bed is exposed near Kohi village and is about two meters thick.

The base of the Kashala formation may not be exposed. It is in contact with the Chakdara granite but the contact in between these two is not much clear as one cannot say that it is a fault, or an intense sheared unconformable sequence. The upper part of Kashala formation is in contact with the graphitic schist of the Saidu formation is gradational.

3.1.4 Saidu formation

The type locality of the Saidu formation is beside the road edges east of Mingora that is almost 1 km north of Saidu (Martin et al., 1962; Kazmi et al., 1984). In the study area the Kashala formation underlies the Saidu formation that is the second largest rock unit. The thickness of this Saidu formation ranges from several tens of centimeter near mélange zone to about hundreds of meters away from the mélange zone in the south.

The Kashala and Saidu formations are repeating each other by folding near Khushmaqam and Chingai villages. The Saidu formation consists of fine to about medium grained dark gray to black colored phyllite. It commonly consists of dark-gray non micaceous and brown schistose marble layers that vary in size from few centimeters to tens of centimeters in thickness. The dark-gray marble is foliated by flattened crystals of calcite. The upper contact of the graphitic phyllite with the phyllite of the melange zone is sharp thrust contact.

3.1.5 Chakdara granite

The Chakdara granite exposed NW of the Swat River. It extends from Chakdara Fort further north into Dir area. It is basically medium-grained and well foliated. The contact of Chakdara granite with Kashala formation is not clear. Near Chakdara and Warsak the strongly foliated granite gneiss underlain by Kashala formation and there is no indication of large magnitude shearing or faulting has been observed along the contact. The parallelism of the foliation in the granite and the Kashala formation confirms that these rocks were distorted together. The age of the Chakdara granite is still uncertain.

Near Uskai village intensive shearing is present at, above, and below the contact. No inter-inclusion of the granite and Kashala rocks were observed. This represents that the relationship of the granite with the Kashala formation is not intrusive, but is either unconformable or a thrust contact in between them. The contact relation between them is open for further study.

3.1.6 Kohistan arc

The Kohistan arc in the area under consideration contains epidote amphibolites. It has a hundred of meter thickness. It extends from Kabal (Swat) up to Dir district in the study area. It has thrust contact with greenstone of melange zone or terrane Brecciation and shearing along this contact rests throughout the area. The amphibolites are being thrust onto the melange rocks.

CHAPTER 4
GEOMECHANICAL PROPERTIES OF MALAKAND GRANITE

4.1 Unconfined compressive strength (ASTM C170-90)

UCS or Unconfined compressive strength could be defined as the maximum stress or pressure that a rock sample can hold or carry under unidirectional stress that is applied to the ends in axial direction of cylindrical or cubic samples.

4.1.1 Methodology

Cube of 4 inches in size are used for this test that were prepared by rock cutting machine. This test can also be duplicated on core shape specimen by smoothing all of its faces to ensure more accurate results where the length to diameter ratio is 2.

4.1.2 Tests conditions

The end surfaces of the specimen should be polished. Gradually increasing stress is applied that is 0.5 and 1.0 MPa/s that is recommended by the International Standards for Rocks and Minerals (ISRM). The test standards that were followed were according to ASTM C170-90. The sample is loaded uniaxialy and the load of the failure (F) was taken by the compressive strength machine. The UCS is calculated as;

$$C = F/A$$

Where,

C= Uniaxial Compressive Strength

F = Force applied that caused failure.

A = cross sectional area of the specimen.

4.1.3 Significance

The behavior of the unconfined compressive strength is influenced by the test conditions under which it is performed. The most important of these is the length of all sides of the cube sample as shown in figure 4.1.

Figure 4.1. shows that the compressive strength test being performed on the cube sample of granite.

4.2 Specific gravity (ASTM C97)

Specific gravity is a dimensionless unit that is characterized as the ratio between the weight of sample of given volume rock to an equal volume of water that is displaced. Specific gravity is mass of solid in relationship to its weight. To find the specific gravity of rocks, we used a weight scale, water, beaker, thread and rock sample as shown in figure 4.2.

4.2.1 Methodology

The standard used in this methodology is of ASTM C-97. First we have to weigh the rock on the scale then approximately half fill the graduated cylinder with water. The exact water volume is then determined using the cylinder scale. Specimen is then put into the graduated cylinder but one has to make sure that sample is completely submerged with water. Take the reading as the water level will rise.

Volume of water is determined in the graduated cylinder once again. Now subtract the initial volume that was noted from the final volume in the graduated cylinder so that we could calculate the exact volume of the rock.

Mass of the rock is divided by its volume in order to calculate the density of the rock. The rock density is then dived by the density of water in order calculate the specific gravity of specimen. So the specific gravity is measured as:

Where,

Gs = Specific gravity

γs = Weight of given volume rock specimen

γw = Weight of equal volume of the water

Figure 4.2. Specific gravity test being performed on the Malakand granite sample

4.2.2 Significance

Several compressive softening experiments on the engineering and construction materials were performed by Morgenstern and Eigen Brod (1974). They found that the rate of softening of the rock sample depended highly upon its origin when put in water. However, they swell slowly that results in decreasing of strength and strength.

4.3 Water absorption (ASTM C97)

Water absorption test is carried out in order to determine how much water a rock could hold. It is actually the quantity of water which could be absorbed by a rock specimen and is measured as water absorption test (Bell, 1992). Its main objective is to calculate the quality and strength of the specimen or material.

4.3.1 Methodology

The methodology adopted in order to calculate the water absorption test was followed according to the ASTM C-97 that recommends sample is at-least dried for 48 hours at 105℃ and is weighed at 46^{th}, 47^{th} and 48^{th} hours as to get exact same weight until the sample is completely dried. The sample is than saturated in water at 20℃ to 25℃ for 48 hours and is weighed again.

Water absorption = (S-D)*100/D

Where,

S = Weight of rock specimen when saturated in water.

D = Weight of rock specimen when it is completely dried.

4.3.2 Significance

As the water is added most of the rocks are softened or get weakened. Pre-water pressure is developed which influence the rock's strength. Greater the water content the greater will be the loss in the strength of the rock.

Compressive strength test, mechanical test measuring the maximum amount of compressive load a material can bear before fracturing. The test piece, usually in the form of a cube, prism, or cylinder, is compressed between the platens of a compression-testing machine by a gradually applied load.

4.4 Results

Following table 4.1 shows the geotechnical tests results that were performed at UET, Taxila, Rawalpindi.

Table 4.1. Shows the results of mechanical tests performed on the samples.

Sr. No	Description	Size	Area (in^2)	Force (KN)	Compressive strength (psi)	Specific Gravity	Water absorption (Percentage)
1	Sample cube (34.568317 N, 71.929794E)	4"x4"x4"	16.00	701	9850	2.646	0.36
2	Sample cube (34.568923 N, 71.930085E)	4"x4"x4"	16.00	658	9246	2.643	0.34
3	Sample cube (34.569709 N, 71.929941E)	4"x4"x4"	16.00	729	10243	2.633	0.27
4	Sample cube (34.571562 N, 71.931197E)	4"x4"x4"	16.00	481	6759	2.608	0.33

CHAPTER 5
PETROGRAPHIC ANALYSIS OF MALAKAND GRANITE

5.1 Petrography

A detailed petrographic investigation was conducted and two representative rock thin sections were used to examine textural and structural characteristics, constituent mineral phase identification, and through visual estimation, modal mineralogical compositions were determined.

Malakand Granite is distinguishable petrographically because of its equigranular and very fresh nature. It is coarse grained, holocrystalline, and is made out of generally same rates of significant mineral constiuents including plagioclase, quartz and K-feldspar. The feldspars show the distinct optical properties associated with them. Moreover, very small signs of alteration and conversion to other minerals are shown and the samples are generally fresh. Quartz showing undulose extinction has ranges according to degree of crystallization from anhedral to subhedral (Figure 5.1). The recrystallization of grain boundaries is absent in Malakand Granite. The percentages of mica rich mineral constituents is smaller.

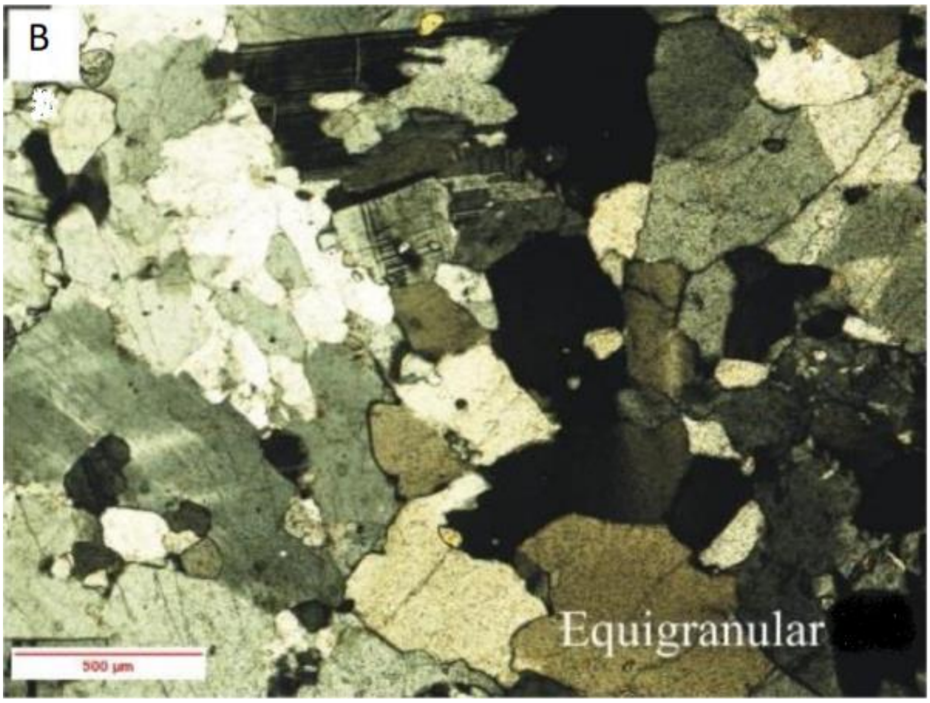

Figure 5.1. Equigranular and fresh feldspar and quartz grains.

5.2 Modal concentration and grain size distribution

Following tables 5.1 and 5.2 show concentration of mineral constituents and distribution of the grain sizes in the studied thin sections.

Table 5.1. Percentages of concentration of minerals in studied rocks.

Sample No.	Quartz	Alkali Feldspar	Plagioclase	Biotite	Muscovite	Others	Voids
1	35.21	28.22	31.02	2.21	3.02	0.32	0.9
2	35.11	28.21	30.64	3.12	2.33	0.59	0.9

Table 5.2. Distribution of grain sizes of samples studied in millimeters.

Quartz			Plagioclase		Alkali feldspar		Biotite	Muscovite	Mean grain size	
Sample No.	Mean size	Max Size	Mean size	Max size	Mean size	Max size	Mean size	Mean size	Minerals forming the rock	Mineral with cleavage
1	14	19	6	11	5	18	0.4	0.2	8.2	5.1
2	14	19	10	12	5	17	0.4	0.1	9.1	6.9

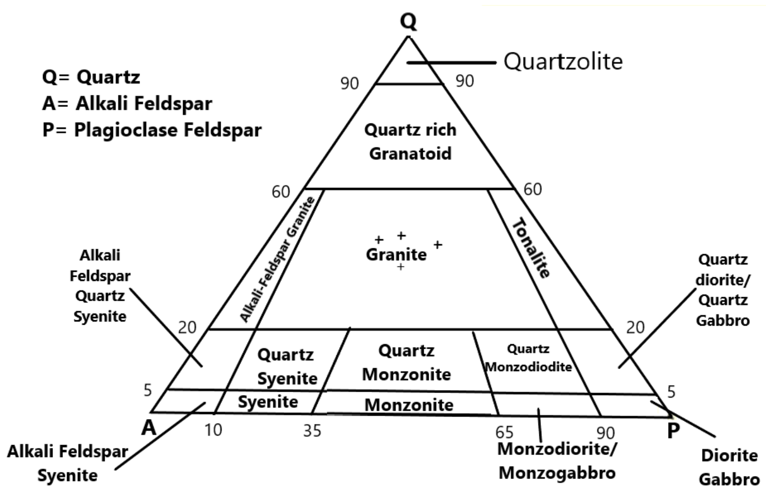

Figure 5.2. Q-A-F Classification of Malakand Granite after IUGS (1973)

So as to portray the significant connections between petrographic highlights and mechanical conduct of the stones contemplated, textural highlights including mean grain size and modular convergence of individual significant mineral (Quartz, K-feldspar, plagioclase) and mean grain size of rocks have been associated.

A solid positive relationship exists between the mineral percentages of K-feldspar with UCS yet results propose that increasing concentrations of quartz and plagioclase brings about negative effects on UCS. In concurrence with present perception, Sousa (2013) depicted negative relation of quartz percentage and quartz to feldspar proportion with the strength of various Portuguese granitic rocks. He additionally portrayed other textural highlights of quartz including quartz-quartz contact, quartz-feldspar contacts and quartz weakening that can contrarily impact the strength of stones in spite of its highest noteworthy mechanical strength. This might be a direct result of the lessening in rock's ability to oblige distortion and an increment in quartz content.

Cracks or fractures will in general engender all the more effectively in rocks with bigger grain boundaries and fine-grained rocks are viewed as possessing more strength than coarse grained rocks. The dependence of mechanical conduct on textural variations has likewise been depicted for other rock sorts as well.

5.3 Quartz

Quartz is most dominant constituent of the rock and its concentration is approximately 35%. It is monocrystalline and show wavy to uniform extinction. Moreover, it is anhedral to subhedral. It is highly resistant mineral and does not show any alteration as shown in figure 5.3.

Figure 5.3. Quartz, feldspar and Bitotite grains shown in cross polarized light with 10X magnification.

5.4 Plagioclase

Plagioclase concentration is approximately 30%. It is subhedral to anhedral in shape and shows polysynthetic twining. It also shows alteration into sericite or kaolin as it is shown in figure 5.3.

5.5 Alkali feldspar

Alkali Feldspar is third in abundance in thin section study. Its concentration is approximately 28%. It includes potash feldspar and microcline. Potash feldspar shows carlsbad twining whereas microcline are cross hatch twin. Sericitization of feldspar has been observed in some samples, as it is susceptible to alteration. Plagioclase commonly shows exsolution lamellea of k-feldspar (Figure 5.4).

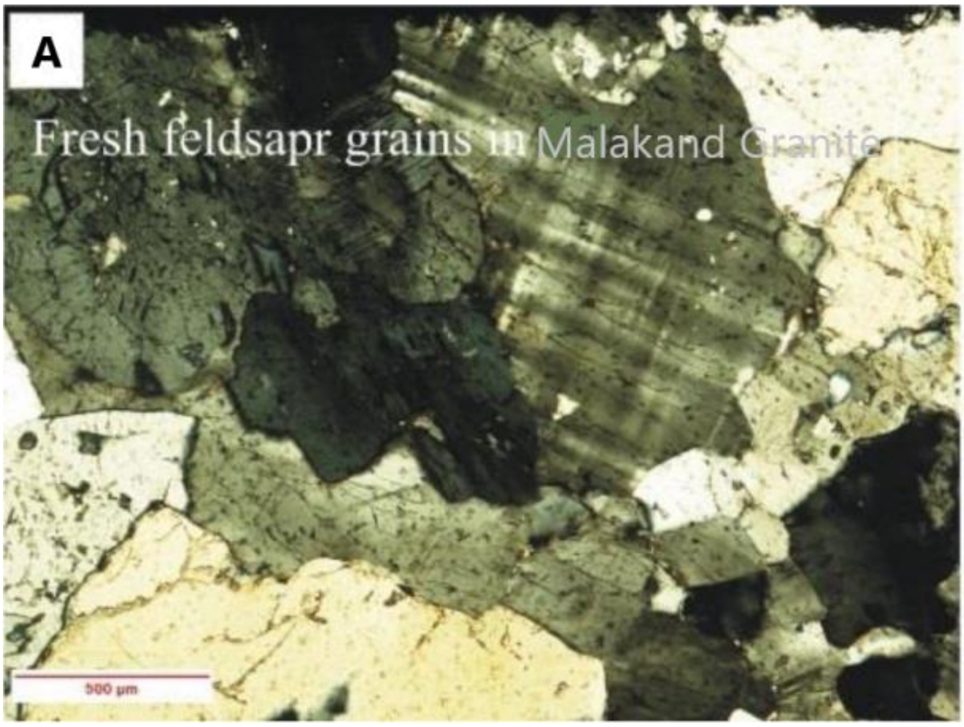

Figure 5.4. Photomicrograph shows fresh feldspar grains.

5.6 Biotite

Biotite ranges from approximately 2% to 3%, it is elongated in shape and brown in color and pleochroic in nature (figure 5.3).

5.7 Muscovite

Two types of muscovite (approximately 2% to 3%) occur, a primary muscovite represented by large anhedral occasionally kinked flakes with corroded margins, and a secondary muscovite replacing other phases and occupying fractures in quartz and feldspar. Biotite is generally associated with muscovite as shown in figure 5.5 and figure 5.6.

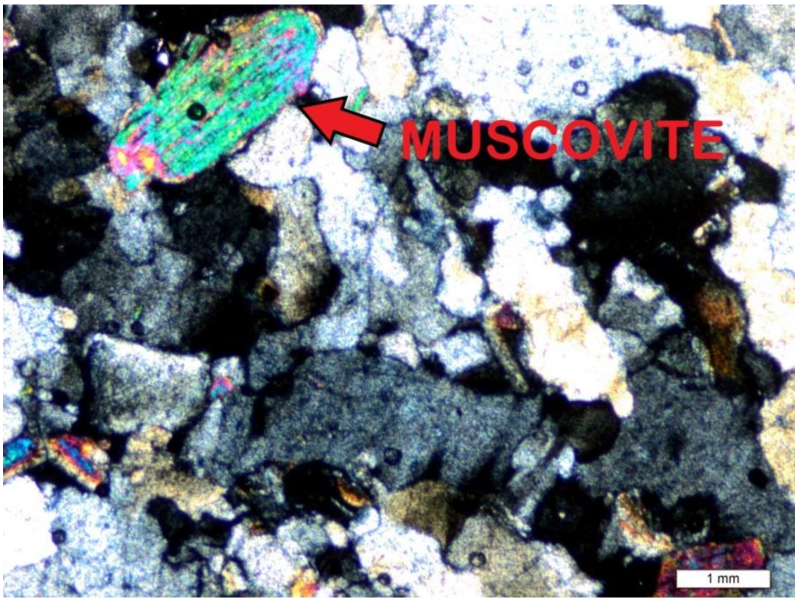

Figure 5.4. Muscovite under cross polarized light.

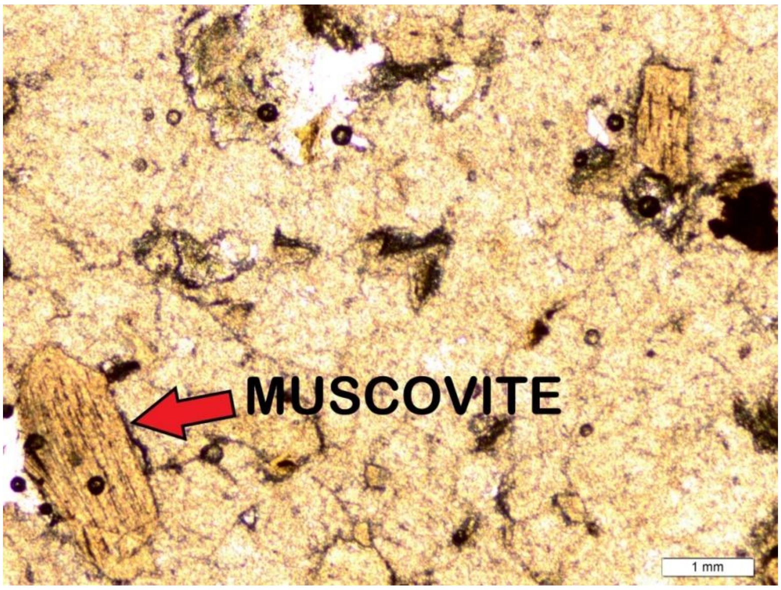

Figure 5.5. Muscovite under plane polarized light.

5.8 Correlation of petrographic and mechanical properties

The significant petrographic highlights controlling quality of rocks incorporate by and large grain size of rock, size and state of individual mineral, percentage centralization of harder minerals, nature of the grain boundaries and the allignment and arrangement of grains. Notwithstanding, a few vulnerabilities despite everything exist which should be appropriately investigated especially concerning the impact of percentage concentrations of individual minerals and the general grain size of rocks.

Increase in the level of deterioration for the most part decreases the mechanical bearing capacity of rocks. Nonetheless, certain variations exist in the mechanical reaction/conduct of rock with comparable grade of weathering. The job of textural variations should be explored properly as a reason for these variations.

Petrographic analysis before and after the tests has been analyzed to distinguish the relation of mineral grains and mineral boundaries with recently formed cracks. The mechanical tests conducted include: unconfined compressive strength and specific gravity. Statistics along with after test petrography, show control of textural properties on mechanical properties.

The significant petrographic attributes impacting mechanical conduct incorporate percentage of minerals and grain size of individual minerals, mean grain size of rock and grain size variation inside a rock. Recrystallization of minerals along boundaries has a positive relation with the strength and quality of rocks. The textural properties, be that as it may, have a significant effect on the strength variation in granites with comparable grades of alteration.

Assessment of the physical and mechanical attributes of rocks is fundamental while thinking about their modern use or potential applications for example for use as building material. Weathering and alteration of rocks can have a negative impact on mechanical behavior and fundamentally change the conduct of rocks in various situations/conditions for example introduction to high humidity/temperature, mechanical burdens and so forth.

The impact of mineralogical concentration and water content on the mechanical conduct of argillite is depicted by Hu et al. (2014). The elastic moduli and strength was seen as fundamentally influenced by rise in clay and water content.

Rigopoulos et al. (2014) researched ultrabasic and basic rocks from Greece to study the connection among mechanical and petrographic highlights. They uncovered that the endurance would in general improve as the proportion between soft and hard minerals, proportion between auxiliary to essential stages and the level of serpentinization. As Basu et al. (2009) surveyed the building qualities of altered rocks from Brazil, they saw that few factors, including mineralogical change, disturbance of existing surface textures and commencement of new splits caused a decrease of solidarity of stones.

The impact of alteration and deterioration on porosity and compressive endurance of different rock sorts from Turkey was introduced by Tugrul (2004). He suggested that small scale cracks formed due to alteration and weathering of rocks were the controlling variables that impacted their physical and mechanical properties. Sajid and Arif (2015) researched the impact of textural assortments on the mechanical conduct of Utla granitic rock from north-west Pakistan. They found that increment in the porosity because of high degree of recrystallization and related mineralogical changes to be liable for decreased value of strength of fine grained rocks.

From the research review, analysts have watched an adjustment in the mechanical conduct with increased alteration grade; be that as it may, noteworthy variation in strength is likewise seen in rocks with comparative alteration grade. The significant target of the current examination and research is to depict the potential elements identified with textural contrasts that are liable for this mechanical variation in rocks with similar alteration grades.

Petrographic properties are analyzed to contemplate the impact of textural variation (grain size, recrystallization, mineral percentages) on the cracking, fracturing and building conduct. Various samples of Malakand Granite were collected and studied from the lower Himalayan system in the north-west of Pakistan and have been utilized to research these variations.

CONCLUSIONS

The connection between textural highlights and variety in the strength and endurance of Malakand Granite has been researched by gathering four samples from various regions. The examined rock specimen are highly altered that delegate of Grade-III alteration. A progression of tests including petrographic analysis, mineralogical variations and strength tests, along with measurable investigations show that textural attributes dominantly affect changing the mechanical conduct of rocks.

Research shows that changes in mineralogy and texture due to alteration procedure and increment in the porosity have an articulated negative impact on the mechanical conduct of rocks independent of its composing materials. Current perceptions and past work on the granitic rocks show the significance of texture according to their mechanical and building properties.

The grain sizes of feldspars, primary rock framing minerals and minerals showing cleavage have a critical detrimental impact on UCS. From petrographic examination of broken samples that had recently been exposed to uniaxial stacking, cracks move along and spread through associating grain boundaries in coarse grained rock samples. In any case, recrystallization along the grain boundaries of minerals can have an articulated beneficial outcome on the building quality of rocks.

Rock alteration affects their quality and building conduct. Notwithstanding, textural qualities significantly affect the studied variation in strength for rocks with comparative grade of alteration. Modified regions with altered minerals can likewise cause special weak areas to form and break easily allowing the commencement of cracks to propagate along these weak zones and present more fragile zones also known as cleavage planes.

The mechanical properties and petrographic analysis of the studies samples proposed that it is to be utilized in light developments, crushed stone, floor material and stabilizer under railroad tracks.

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