An Investigation of Petrographic Characteristics and Physico-mechanical Properties of Utch Khattak Formation Exposed in the Gudwalian Section, Gandghar ranges, Pakistan.

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CERTIFICATE

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ABSTRACT

A large exposure of Utch Khattak limestone in the Gudwalian section, Gandghar ranges, District Haripur was investigated petrographically, Physio-mechanically and geochemically in order to evaluate the strength and durability as a source aggregate for construction projects. Utch Khattak limestone is quietly distinctive, thin to medium bedded, fine to medium grained and bluish grey to dark grey in color. Petrographically, the Utch Khattak limestone has classified on the basis of Dunham classification as a mudstone. According to the petrographic study, the fracture is filled with calcite and ferrous minerals, quartz and dolomite are found in very small amount in the form of fine grain, while other deleterious minerals were not observed during this investigation which can affect the strength, durability and suitability of an aggregate. Similarly, the geochemistry of the study rock has revealed that CaO ranging from 48.29% to 53.67% by weight, SiO_2 1.21% to 2.56%, $Al_2\ O_3$ 0.49 to 0.95%, and other oxide such as K_2O, P_2O_5, Fe_2O_3 present less than 1% by weight. The range of loss on ignition is from 40.15% to 42.14%, which indicate that these geochemical values for the concrete aggregate are in suitable range.

Additionally, the average values of Los Angeles Abrasion test (25.53%) and impact value test (15.33%). Similarly, the average values of bulk saturated surface dry specific gravity 2.68%, water absorption 0.40%, bulk unit weight 1.68 gm/cc, Point Load test 7.28 KN, soundness test 4.09%, and unconfined compressive strength test 67.03MPa, are within ASTM limit. Furthermore, Mechanical characteristics such as UCS and PLT were compared statistically with petrographic characteristic through linear regression analysis. The amount of calcite has direct relationship with strength and durability of aggregate which means increase in concentration of calcite increase the value of UCS and PLT. On the other hand, greater the pore spaces and bioclasts within the carbonates lower will be the strength and durability of an aggregate. However, Utch Khattak Formation of Gudwalian section has a smaller number of pore spaces and bioclasts which depicts its suitability as an aggregate in heavy engineering projects. Hence, for the conformation of strength, durability and suitability of Utch Khattak Formation of Gudwalian section physico-mechanical properties were statistically compared through linear regression analysis. Thus, all the parameters i.e., petrographic, geochemical, and geotechnical investigations have revealed that Utch khattak limestone is an acceptable aggregate supply for construction industries.

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CHAPTER 1
INTRODUCTION

1.1 Introduction

Limestone is one of the most important rock which largely composed of calcium carbonate ($CaCO_3$). The most Important constituents of calcium carbonate ($CaCO_3$) are calcite, dolomite, and also having minor amount of other trace elements in the form of oxides. Limestone may be chemically, biochemically precipitated or mechanically settled with the growth of bedding (R.C. Selley, 2005). However, as a rock aggregate, limestone is the major source for mega engineering projects and for the construction of mega infrastructures. A suitable quantity of cements and aggregate accounts, bulk of the total mass for the concrete (Kosmatka et al., 2011). Aggregate materials which may be coarse to medium-grained that can be formed by natural way from sedimentary, igneous and metamorphic rocks or man-made called (geosynthetic aggregates). Aggregate are utilized as a strengthening agent, cost effective, imparting support to the composite components and minimizing shrinkage. Although the concrete mixture consists of aggregate which can make up to about 70% of the volume (Neville and Brooks, 1999). The aggregate which also called dressed stones used in the construction of structures such as in bridges, retaining walls, foundations, sea barriers, crushed rocks, ballets, and railroads. The quality of aggregate is determined by the qualities of the source rock (Koukis et al., 2017). Source rocks and its physico-mechanical properties affect by subsequent processes such as faulting, folding, weathering and hydrothermal activities (Abd El-Aal et al. 2021; Zhou et al., 2021). However, in petrographic analysis aggregate components like mineralogy, texture, bio clasts, micro cracks affect aggregate quality. Constituents of minerals such as hardness, porosity, chemical stability and composition also impact on qualities of aggregate (Naeem et al., 2014; Hamdi et al., 2015; Petrounias et al., 2018; Sun et al., 2021), while in contrast within the carbonates of the Utch Khattak Formation of Gudwalian section they are less weathered and having no prominent hydrothermal activities were observed which affect the durability and strength of the carbonates.

Physico-mechanical properties of a rock depends upon the origin of rocks, geological history and subsequent processes like faulting, folding, joints, weathering and hydrothermal alteration. Therefore, geological parameters in term of lithological description have a prime importance to determine engineering properties of an aggregates (Naeem et al., 2014). All the above aforementioned characteristics have the influence on the engineering properties of carbonates. Petrographic evaluation and geochemical examination used for distinguishing between reactive and non-reactive minerals and examination of micro/macro-structural behaviors, reactive rime, carbon dioxide reaction with silica gel in concrete structure (Singh et al., 2007; Ransinchung et al., 2008; Andriani, 2021). Presence of silica, chalcedony and all other cryptocrystalline minerals can cause chemical reaction when introduce with other reactive constituents, while within the carbonates of the Utch Khattak Formation having less than 3% reactive minerals which does not affect the aggregate properties.

Apart from this, geochemical composition of carbonates i.e., the amount of pure calcite enhances the capability of carbonates and other oxides particularly iron oxides within the carbonates can enhance the incompatibility of aggregate for mega engineering projects, while in contrast in carbonates of the Utch Khattak Formation of Gudwalian section the amount of CaO found more than 48% while amount of other trace elements is less than 3% which shows that it can be use in mega construction projects.

Moreover, mineralogical and geochemical composition can have strong influence on the physical parameters of carbonates, but the physical parameters of the Utch Khattak Formation of Gudwalian section are in accordance with standards of ASTM and feasible for used in construction industry.

However, Pakistan is bestowed with extensively exposed deposits of limestone. The physical, thermal, and chemical qualities of limestone and its suitability for the construction sector were studied in several areas of Khyber Pakhtunkhwa (Ghafar et al., 2010; Bilqees et al., 2012; 2015; Rehman et al., 2020; Hassan et al., 2020). Moreover, it is vital to locate new assets of limestones, routinely reachable and economically less costly to assess the existing reserves. The Utch Khattak Formation of Gudwalian section in Gandghar ranges can be used as a supplement for current projects of China-Pakistan Economic Corridor (CPEC) and National High Way Authority (NHA) related future projects which include roads, bridges, and tunnels. In current study the complete investigation is carried out of limestone of Utch Khattak Formation such as petrography, Physico-mechanical and geochemical analysis to evaluate the strength, potential and durability of an aggregate source.

1.2 Location and Accessibility

The research area lies near Gudwalian Dam in Gudwalian village; District Haripur, Khyber Pakhtunkhwa, Pakistan shown in (Figure. 1.1). The proposed research area is located about 2 km away from the main road (Haripur-Sirikot road) toward the eastern side. Abbottabad is located in the Northwest of research region, Taxila in south, Swabi in Northwest, and Murree and Islamabad are in the East and Northeast. The outcrop has E-W extension having approximate location 34^0 0' 48'' N Latitude and 72^0 47' 48'' E Longitude.

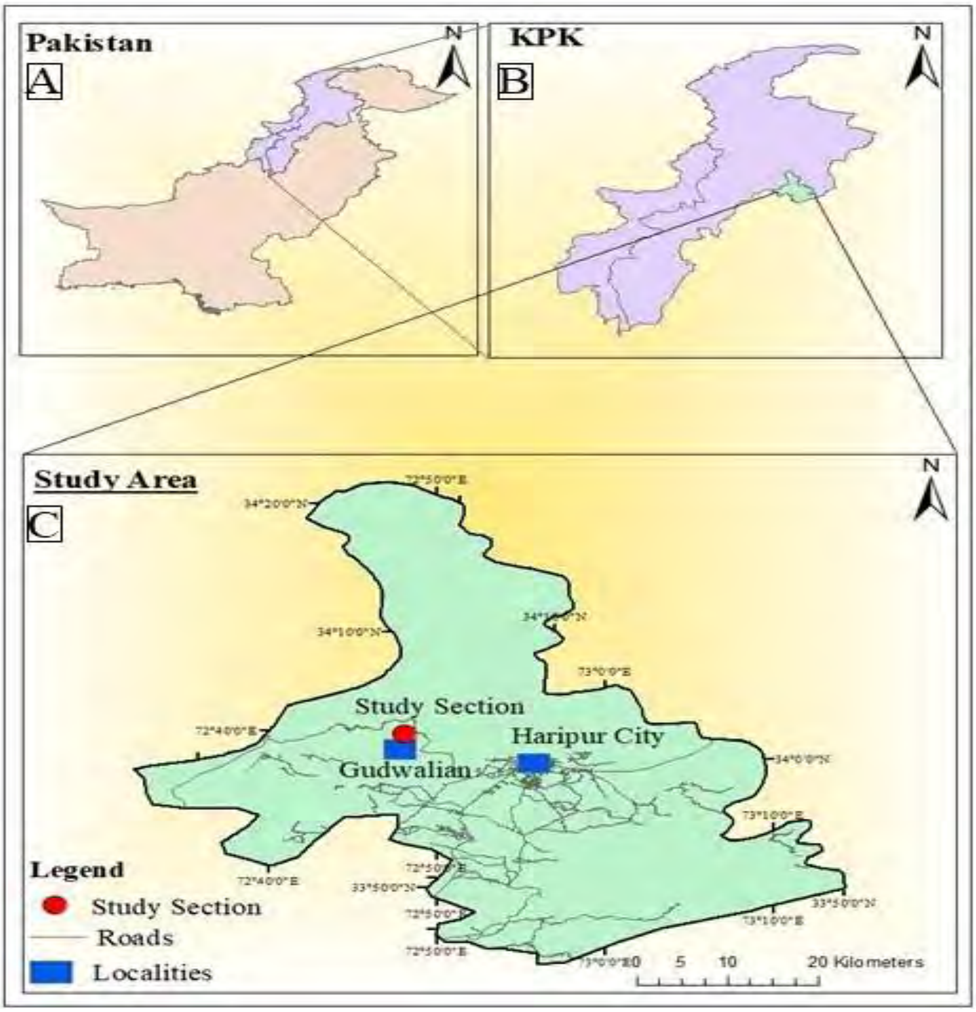

Figure 1.1 location and accessibility map (A) show Pakistan (B) show KPK while (C) show study area.

1.3 Aims and Objectives

The aims and objectives of this research are to evaluate the physical, chemical, mechanical analysis and their impacts on the rock strength of limestone of the Utch Khattak limestone, Gudwalian section, district, Haripur. Limestone of the Utch Khattak Formation of Gudwalian section were elevated petrographically, geochemically and geotechnically to find out its feasibility as a construction aggregate. The objectives of this research work are as followed.

- To carry out detailed petrographic analysis of the collected samples of the Utch Khattak Formation.
- To determine the Physico-mechanical properties of the Utch khattak Formation
- By performing the Geochemical analysis of the Utch khattak Formation for the identification of different elemental oxides.
- To evaluate the impact of Petrographic and Geochemical analysis over the Physico-mechanical properties of the Utch Khattak Formation.

1.4 Previous Work

Previously many researchers have worked on the Gandghar ranges but no work was carried out specifically on Utch khattak Formation. The earliest published paper on the geology and comprehensive stratigraphy of the Gandghar mountains was written by Waagen & Wynne, (1872). Geological reconnaissance of northwest Himalayan Ranges reported firstly by Verchere, (1866-67). Furthermore, a detailed study map has been developed for cross section of Hazara which also include Gandghar ranges, at a scale of (1 inch = 8 miles) (Wynne, 1879). Middlemiss (1896), create a more comprehensive map of the Hazara area, with a scale of ½ inch = 1miles, from the western bank of the river Indus black mountains leading to the Kunhar River. Both Wynne and Middlemiss, described the limestone of Gandghar ranges but both of them not clear about the age and stratigraphic position. Gandghar ranges visited by Cotter, (1929) and mentioned Slate series which he correlated with the pelitic series of Attock slates. He given Cambrian to Pre-Cambrian age to these slates. Three stratigraphic unit were described by Khan et al., (1949), in the Gandghar ranges a) Hazara slates series b) Infra Triassic limestone c) Tanawal Quartzite.

In Pakistan, Margalla Hill Limestone are extensively in use for the construction of infrastructures along with this researcher have worked on different carbonates exposed in Pakistan i.e Lockhart Limestone, Kawagarh Formation, and lakhra Limestone etc (Alli et al., 3023; Naeem, Mustansar, et al., 2014). But on the Utch Khattak Formation of Gudwalian section no such work has carried out till now, therefore Utch Khattak Formation of Gudwalian section has evaluated petrographically, geochemically and physico-mechanically in order to establish its use for mega engineering projects and for construction of heavy infrastructures.

Following a systematic geological investigation of Gandghar mountains were mapped by Pakistan Geological Survey, in partnership with the United States Geological Survey during (1961;1965). Gandghar ranges have Precambrian on its eastern side and Silurian Devonian on the western half mentioned by Calkins et al., (1975). Tahirkheli (1971), published the first detailed map of entire Gandghar ranges. He proposed that all rocks in the Gandghar ranges of Paleozoic age and correlated with laterally extended lithological similar unit Attock-Cherat ranges and southern Hazara.

CHAPTER 2
GEOLOGICAL SETTING

2.1 Regional Geological Setting

The supercontinent called Pangea started splitting at the age of Jurassic and consequently divided into two parts i.e. Gondwana and Laurasia. The breakup of Gondwana nearly 167-MA ago lead to evolution of Indian Ocean (Royer and Coffin, 1992) Indian Plate which was separated from the Gondwana which was part of single super continent Pangea surrounded by gigantic ocean called Panthalassa ocean.

Indian Plate 165-MA ago exposed to tectonic evolution, subsequently followed by plate tectonic sea-floor spreading, continental breakup, volcanism, faulting, subduction, abduction, orogeny and collision of tectonic plates (Chatterjee, 2013). Indian plate located on the eastern side of Gondwana (Valdiya 1977; 1980). Gondwana name was given due to the city located in India and discovery of plant fossil named Glossopteris (Krishnan et al., 1970; Smith et al., 1973; Wadia et al., 1964).

Indo-Pak Plate geologically consist of mainly three divisions from north to south given below.

Himalayas.
Himalayan Fore Deep Basin.
Peninsular region (Searle, 1986).

The largest and the World most active collision has taken place in the Himalayan. Western extremity of Himalayan platform and Thrust belt of Himalayan start from Burma (eastern part) to India, Nepal, Tibet (southern part), Pakistan (Northern part), extended to Afghanistan and Iran (central part). Erosional product of Himalayan fold and thrust belt present in south such as Punjab plain (Pakistan) and Ganga Basin (India i.e. active Fore deep zones). Transport direction of these erosional product is southward (Bhargava, O. N; Singh, B. P, et al., 2021).

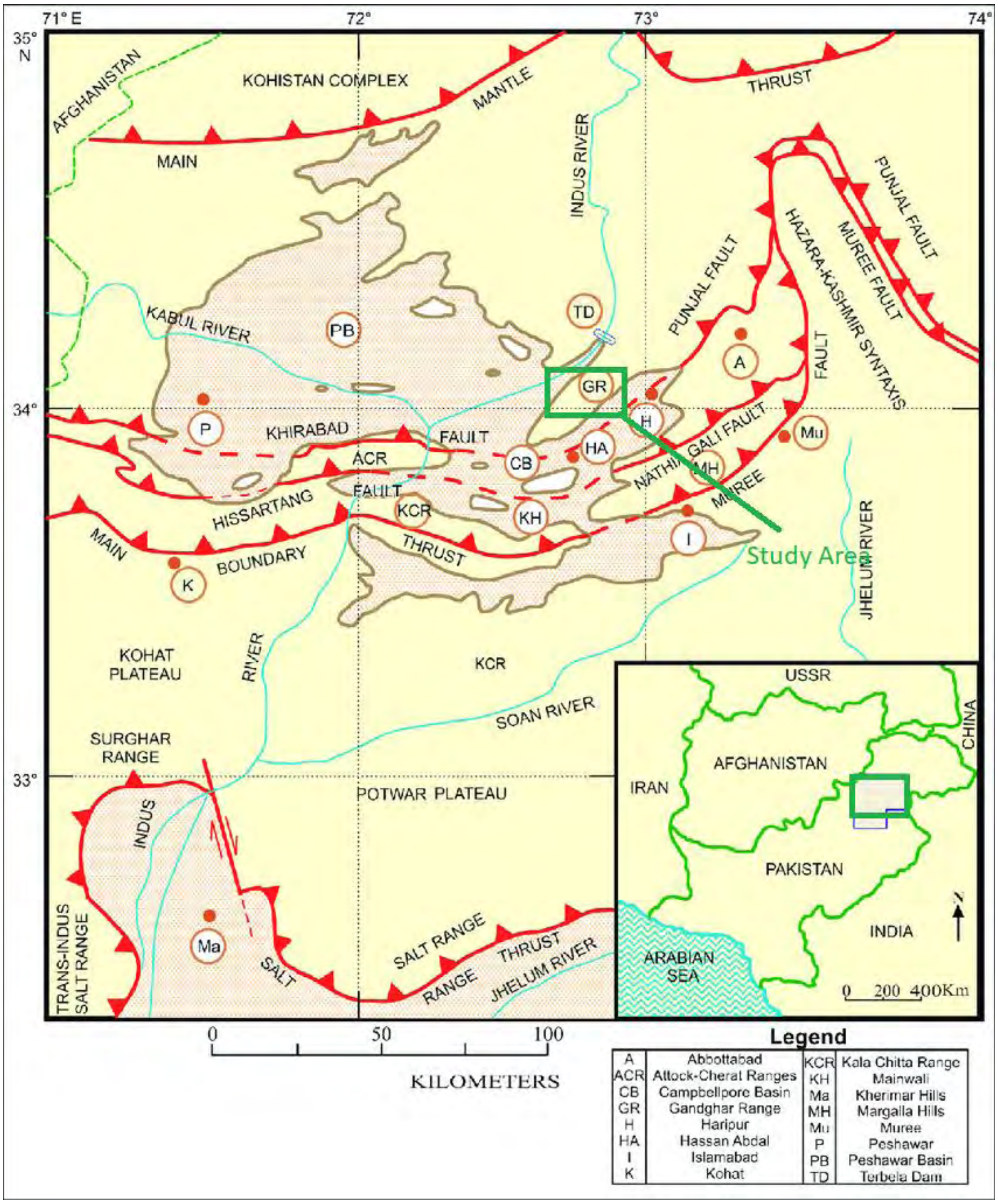

Figure 2.1 Map reflecting regional geological setting of area, modified from (Hylland et al., 1988).

2.2 Major Tectonic Events

Geodynamic setting of Indian Plate and Himalayan orogeny started in the cretaceous time and ended at the Cenozoic time described and presented by Le Fort (1989). Orogeny in the Himalayan region divided into three events. The major tectonic features can be observed in (Figure. 2.1). Initially, intra-oceanic subduction caused by the movement of Indian plate towards north in the Tethyan ocean. This subduction resulted into an Island arc formation called Kohistan-Ladakh Island which resulted into

Paleo Tethyan Sea and Neo Tethyan sea. In middle phase, the oceanic-continental convergence started after the Tethyan division lead toward Tethyan sea subduction under Karakorum Plate and formed Rakaposhi Ophiolites and Karakorum Batholiths and completed in late Cretaceous. In the final phase, Neo Tethyan subduct beneath the Kohistan Ladakh Island Arc which completed in late Eocene, result of this phase is the formation of Shangla Ophiolites.

2.3 Sub division of the Himalaya (Pakistan)

According to (Gansser, 1981), Himalaya divided in to following divisions.

2.3.1 Sub-Himalayas Zones

Sub Himalayas are the area having Main Boundary Thrust to the north and to the south Main Frontal Thrust is present. This deformation further extended in the east-west direction divided Azad Kashmir in the East while Punjab in the West, in the North-South direction it is divided into Potwar-North deformed area and Potwar-South deformed area. From the North-South direction Sub-Himalayas are further divided into following zones.

a. Northern Potwar Deformed Zones.
b. Soan Syncline Zone.
c. Punjab Platform Zone.

2.3.2 Lesser Himalayas

Lesser Himalayas are deformed area located in between MMT (Main Mantle Thrust/ Indus Suture Zone) toward north and MBT (Main Boundary Thrust) toward South. High grade of metamorphism and high grade of Igneous intrusions are present in this area of deformation. Lesser Himalayas include Hill range, Kala Chitta Range, Nizampur Basin, Hazara Kashmir Basin, Pliocene Precambrian Basin (Haripur and Campbelipor Basin) and Southern Kohistan. In the Western part of Himalayan ranges Precambrian and volcanic rocks of Paleozoic age are present. Overlap of high degree rocks formed from the crystallin central axis targets these sediments (Valdiya 1977; 1980).

2.3.3 Higher Himalayas

Higher Himalayas are highly metamorphosed thick massive sequence of rocks (10 to 15 km) super imposed over Lesser Himalayas. Its base can be marked from central crystalline thrust sheet and MCT (Gansser, 1981). These Himalayas are located in between MMT (Main Mantel Thrust) to the North and MCT (Main Central Thrust) to the South.

2.4 Geological Setting of Study area

Gandghar ranges location is North-East and South-West trending range at the Northwest direction from the Islamabad about 40 km away. A limited barrier forming between Peshawar Basin and Haripur (Paleo-Pleistocene) can be seen in (Figure. 2.1). It is transition between zone of plutonic high metamorphosed rocks in the North and foreland strata (unmetamorphosed) to the south. Northern section of the Attock-Cherat ranges structurally related with Gandghar mountain ranges having a transition record between the Himalayas and foreland strata (Yeats and Hussain, 1987).

Research region lies in the fold thrust belt along southern margins of the Himalayas near to the Campbelipore basin. Kala Chitta ranges situated to the south of study area and to the North Potwar plateau. Molasses are thrusted over the Tertiary marine strata along MBT. Salt Range Thrust is located at southern edge of Potwar Plateau (Baker et al., 1988).

Late Precambrian rocks are exposed along the fold thrust belt lies to the east of study area in the southeast of Hazara (Tahirkheli, 1970). The Peshawar basin fill and the Attock-Cherat hills lies to the western side of study area. The fill of Peshawar basin is mostly composed of Lacustrine deposits like silt with river interbedded gravel, sand, and clasts of Kohistan origin (Burbank, 1983). In the south of Peshawar basin there are three faults separating structural blocks of Attock-Cherat Range. Paleozoic limestone of southern blocks consists of quartzite and argillite (Yeats and Hussain, 1987). The Paleozoic rocks exposed in the vicinity of Nowshera in the south of Peshawar basin can be related to Attock-Cherat ranges on lithological bases. Southern block of Attock-Cherat ranges thrusted over Kala Chatta ranges and Margalla Hill, Triassic to Eocene sequences (Yeats and Hussain, 1987).

2.5 Structural Geology

Three most important structural geological features are present in the study area, which consist of dikes, folds and faults. Basic igneous Dike intruded the study area after specific interval in many places. In study area having three thrust faults and normal faults are dipping toward North.

2.5.1 Gudwalian Fault

Gudwalian fault is in the Gudwalian village, exactly where our study area located about 14 km away from the Haripur toward east. Previously, this fault mapped is a normal fault having contact with the Tanawal Formation and the Shekhai Formation (Calkin et al., 1975). Gudwalian fault is not distinctly visible in a line of zone but there is having enough positive indication of fault. The reason as the contact is very sharp and the veins (calcite and quartzite) are present in the Shekhai Formation are truncated by the Tanawal Formation in some places.

2.5.2 Baghdara Fault

Baghdara Fault of Gandghar Range is named after a village situated in the south of Gandghar area called Baghdara, which is few Km away from Pir area. Baghdara fault juxtaposed the Tanawal formation and the Shekhai Formation with the Manki Formation. In the hanging wall of Baghdara Fault the Manki Formation, while in the foot wall of Baghdara Fault the Tanawal and Shekhai Formation are present (Figure. 2.2). Drag fold in the fault zone shows reverse sense of slipping in this fault (Riaz et al., 1991).

2.5.3 Sirikot Fault

This fault named after a village Sirikot situated on the northwestern side of Haripur, about 19 km away from the Haripur. Sirikot Fault can also be seen on the Haripur road about 4 km east of Sirikot village.

2.5.4 Darrah Fault

Darrah fault is located in Darrah village to the northwest side of Gandghar ranges, about 14 km away from Sirikot. Darrah fault juxtaposed Tanawal formation (Basal conglomerate member) with Manki Formation. Drag fold in the strata below the fault shows reverse faulting. Slickensides on the both footwall and Hanging wall show dip-slip movement of back thrust fault (Riaz et al., 1991).

Figure 2.2 Showing Baghdara fault between the Shekhai Formation and the Manki Formation.

2.6 Stratigraphy of Study Area

The Stratigraphy of study area in Gandghar Ranges consist of thick basic argillaceous series of (Manki Formation) overlain by algal possessing limestone and also shale of Shahkot, the Shekhai, Utch Khattak Formations. A Proterozoic age suggested for this series (Talent and Mawson, 1979). Stratigraphic column was established in response to the absence of fossils and relation of the Manki Formation with the Hazara Formation (Figure. 2.4) The contact commonly gradational throughout the succession consist of basic igneous intrusion probable of Late Pennsylvanian-Early Permian age.

Initially, several names for bedrock units are used as Manki Slate, Shahkotbala Formation, Khattak Limestone, and Shakhai, names were given by Tahirkheli (1970). Later on, Tahirkheli (1971) named it Utch Khattak Formation, Shahkot Formation and Shekhai Formation in Attock Cherat Range.

2.6.1 Manki Formation

It comprises of oldest bedrocks unit having argillaceous rocks were initially named “Attock Slates” by Waagen and Wynne (1872), after its exposure at intersection closely to river Kabul and Indus, Marks and Ali (1961), named it Hazara Slate. The Manki Formation consist of an argillite, slates, and phyllite. On fresh surfaces color of rocks range from dark greenish grey to dark grey, on weathered surface olive grey, dark grey to reddish brown. Manki Formation having graded contact with the overlying Shahkot Formation. However, the basal contact of the Manki Formation with the basement rocks is less visible.

2.6.2 Shahkot Formation

The survey of Shahkot Formation originally performed by Tahirkheli (1970), comprised of a mainly limestone, shale and slate within the Attock-Cherat Ranges. Tahirkheli (1971), identified the Mohat Nawan Limestone in the Gandghar Range and connected to the Shahkotbala Formation of the Attock-Cherat Range. Shahkot Formation composed of limestone, argillite, and shale. Grain size from fine to medium-grained while the bedding is thin-to-medium-bedded, color is yellowish to grey on fresh surfaces and brownish grey on weathered surfaces. Map of Hussain (1984), indicate that the lower Manki Formation and the upper Shahkot Formation having up to 300-meter-thick comfortable contact in Attock Cherat Ranges. The Shahkot Formation Contact can be seen in (Figure. 2.4), overlain by the Utch Khattak Formation.

2.6.3 Utch Khattak Formation

The Utch Khattak Formation rocks are exposed close to footwall of Baghdara Fault in the southeast Gandghar Ranges. The argillites layers, shale, and a distinct form of limestone were named (Khattak Limestone) when they were originally examined across the Attock-Cherat Range (Tahirkheli, 1970). However, Tahirkheli (1971), during his research on Gandghar Range named one unit of limestone as Baghdara Limestone and corelated with Khattak Limestone, exposed in the Attock-Cherat Ranges. The name (Khattak Limestone) replaced with name of (Utch Khattak Formation) due to presence of other lithologies along with limestone (Hussan, 1984). The contacts of the Utch Khattak Formation conformable both with the underlying Shahkot Formation as well as with the above Shekhai Formation shown in (Figure. 2.4). The composition of the Utch Khattak Formation is limestone, layers of argillite, and shale. The grain size of Utch Khattak limestone is from fine to medium grained, thin bedded, color from bluish grey to dark grey. Stromatolites are highly developed in certain areas, although their initial orientation is unknown and the thickness of limestone range from 10 meter to 70 meters.

The Utch Khattak Formation is unfossiliferous and the existence of interformational conglomeratic clasts are belongs to the Manki Formation and Shahkot Formation. This indicate that the Utch Khattak Formation younger than both the Manki formation and Shahkot Formation and having graded contacts with the underlying Shahkot Formation. Therefore, the age of the Utch Khattak Formation is most likely Late Precambrian (Hussain, 1984).

Figure 2.3 Photograph showing Shahkot Formation in left Shekhai Formation on the right and in between is Utch Khattak Formation of Gandghar ranges.

2.6.4 Shekhai Formation

Tahirkheli (1970), initially mapped during in work and given name "Shakhai Limestone" to the Shekhai Formation in Attock-Cherat Ranges. The exposure of Shekhai Formation within the research region at the footwall of the Baghdara fault located at the north of Pirthan limestone can be seen in (Figure. 2.2). The Shekhai Formation is composed of limestone, marble and subordinate of argillite, shale and quartzite. Limestone of the Shekhai Formation is fine to medium grained, thin to medium bedded while the color is light grey, dark grey, light brown and pink. The

Shekhai Formation assigned a Precambrian age based on their conformable contact with underlying Utch khattak Formation and absence of fossils by Yeats and Hussain (1987).

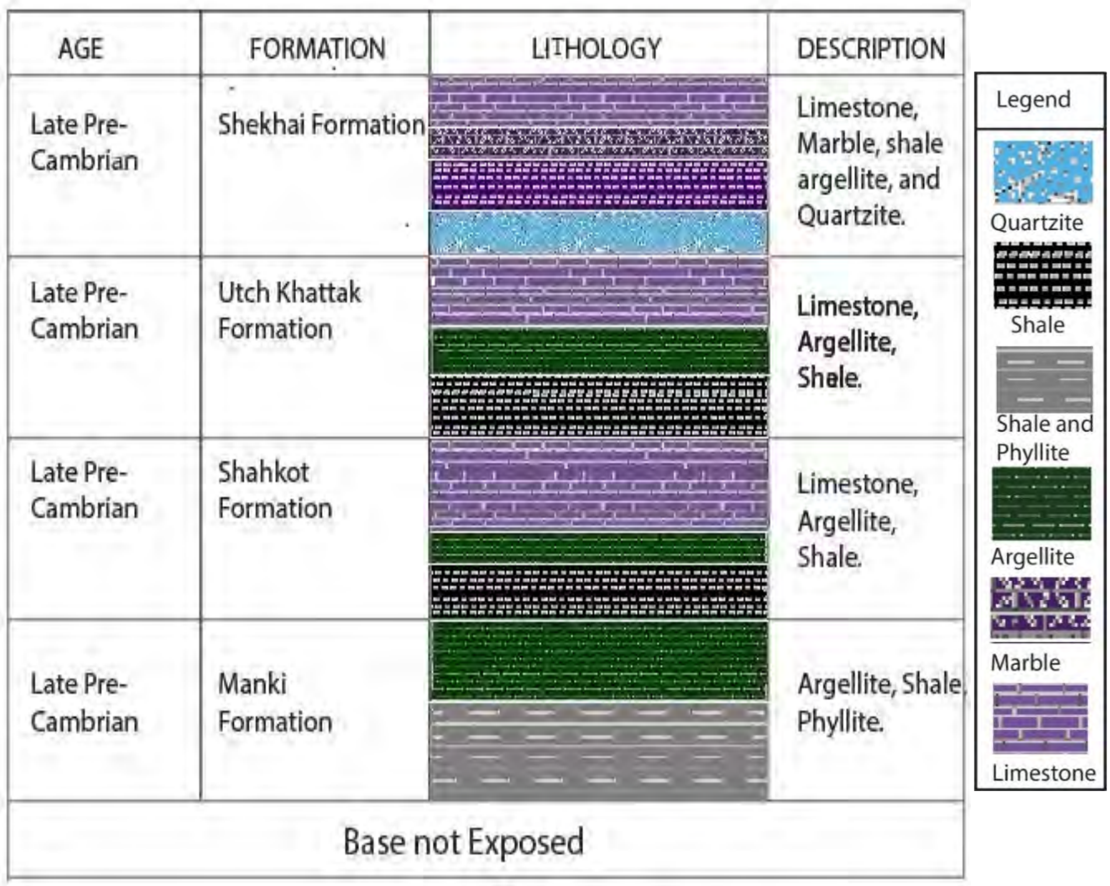

Figure 2.4 Generalized stratigraphic column of the study area adopted from (Hylland, 1990).

2.7 Intrusive Rocks

According to Riaz et al., (1991), Gandghar Range has fundamentally intruded by sills and dikes. The thickness of sills and dikes in the Gandghar Range from 2 meters to 5 meters but having great impact on the structure of country rock. The nature of these sills and dikes are diabasic. However, texture of the rocks is ophitic, contain augite and labradorite laths. Hussain, (1989), identified Same types of intrusion in the Attock-Cherate Range (Hussain,1984). Similarly, in Peshawar Basin (strata of Carboniferous age) similar nature of intrusion was observed, but the age of these intrusions is unknown (Pogue, 1993). According to Karim & Sufian, (1989) these intrusions are chemically thiolytic of continental flood basalt. Punjal volcanic has also same type of origin (Honegger et al., 1982).

CHAPTER 3

FIELD OBSERVATIONS AND METHODOLOGY

3.1 Introduction

A comprehensive field work was carried out in the research area, located near to Gudwalian Dam, in the Gudwalian village, District Haripur, Khyber Pakhtunkhwa, Pakistan. Detailed investigations were carried out of the Utch Khattak Formation of Gudwalian section, the marked section having E-W extension, approximate location 34^0 0' 48'' N latitude and 72^0 47' 48'' E longitude at the Gudwalian village in District Haripur. The bulk samples were collected based on the variation at the outcrop scale and different field features were observed. At the footwall of the Baghdara fault, the thickness of the Utch Khattak limestone is approximately 200 to 250 meter and possesses conformable contact to the underlying Shahkot Formation and the overlaying Shekhai Formation.

These Formation has a varied composition of several lithologies as seen in (Figure. 2.4). The Utch Khattak Formation consists of various lithofacies of limestone. The investigated limestone having bedding thin to medium bedded and grain size from fine to medium grained. The color of the Utch Khattak Formation is bluish grey to dark grey. The measured thickness of limestone in the Utch Khattak Formation range from about 10 meters to 70 meters, the bedding of shale is thin and light-grey to light brown in color. Utch Khattak limestone is unfossiliferous.

Figure 3.1 Photograph showing different Formations, the Utch Khattak Formation, Shahkot Formation and the Shekhai Formation.

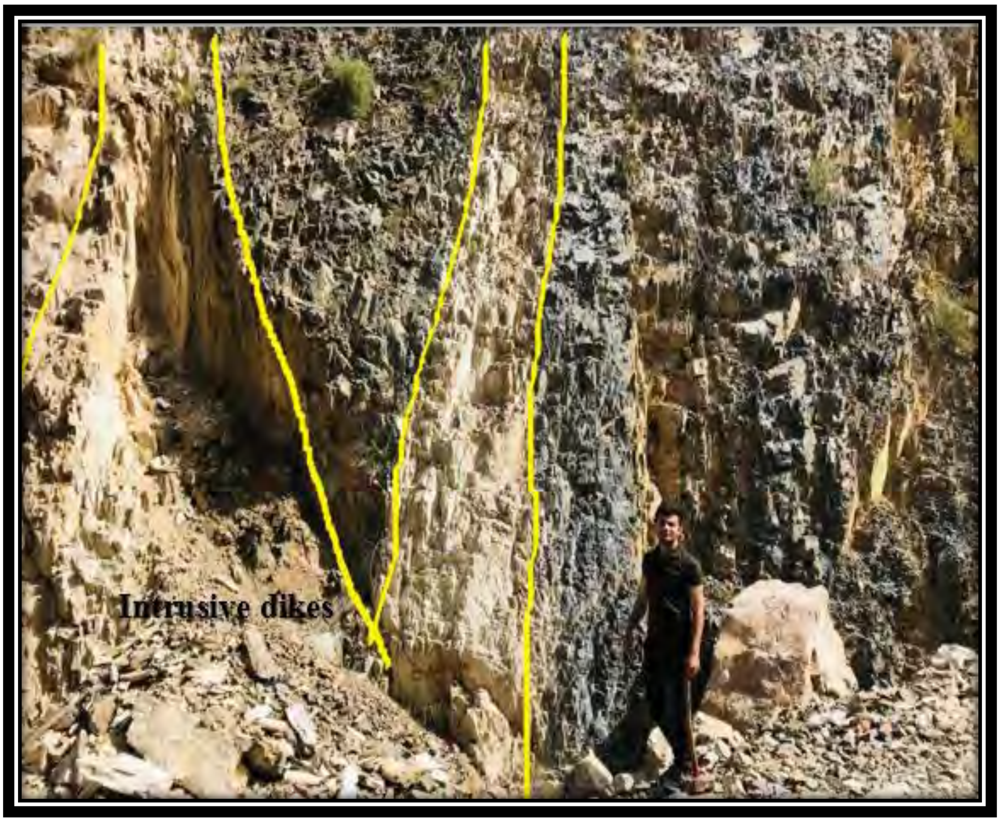

Figure 3.2 Photograph showing intrusion in theUtch khattak Formation.

3.2 Observed field Features

The most important features we observed during field work were Dikes, faults and folds. The Dikes are basic igneous in nature which intruded along the bedding of limestone in different intervals. These sills/Dikes are structurally deformed and less than 2-meter in thickness, shown in the (Figure. 3.2). In research area consist of three types of faults normal, thrust and reverse faults. However, during field work we have marked a reverse fault such as Baghdara fault between Manki Formation and underlain Shekhai Formation indicated in (Figure. 2.2).

Figure 3.3 Photograph of sample extracted area in the Utch Khattak

Figure 3.4 Photograph showing bedding of the Utch Khattak Formation.

3.3 Methodology

A comprehensive Geotechnical investigation were carried out, comprised of field work and laboratory analysis to study the rock strength and their suitability for the different Geological and Geotechnical projects. The investigations performed on the Utch Khattak Limestone near Gudwalian Dam, located in the Gudwalian Village; District Haripur, Khyber Pakhtunkhwa, Pakistan. The selected area as mentioned earlier (Utch Khattak Limestone) is well exposed in the Gandghar Ranges. For detailed Geological investigation a field was arranged to collect samples and observe the field features of the Utch Khattak Formation. A flow chart summarizing the details of followed methodology given in the (Figure. 3.5).

3.4 Field instruments

Different types of field instruments were used during out crop study in the field. Geological Hammer used for sampling to break outcrop rocks. Measuring tape for to measure the thickness of strata. Similarly, Brunton compass used to calculate the orientation of respective formation encountered. Global positioning system device (GPS device) was used to locate and record the coordinates of the study area. For fine details of rocks units, a Hand lens was used.

3.5 Sampling

A total 10 bulk samples were collected based on lithological and bed thickness variation after division of formation into different zones. Samples collection performed systematically at equal interval by using conventional method and tools of Geological field work. Upper and lower contacts of the respective formation marked and scaled photographs were taken, lithological log was prepared for the whole section and outcrops features like grain size, color, bedding pattern, lateral extension, fauna was observed to determine geological suitability, workability and economic potential of the Formation. A proper orientation of the formation was recorded. The exposed thickness of the formation observed visually and thickness also measured through measuring tape. A large hammer and lever were used to breakdown a bulk sample from outcrop. The bulk samples numbered from UK 1(Utch Khattak) to UK 10. Field photographs have been taken of any intrusion, lithological variation;

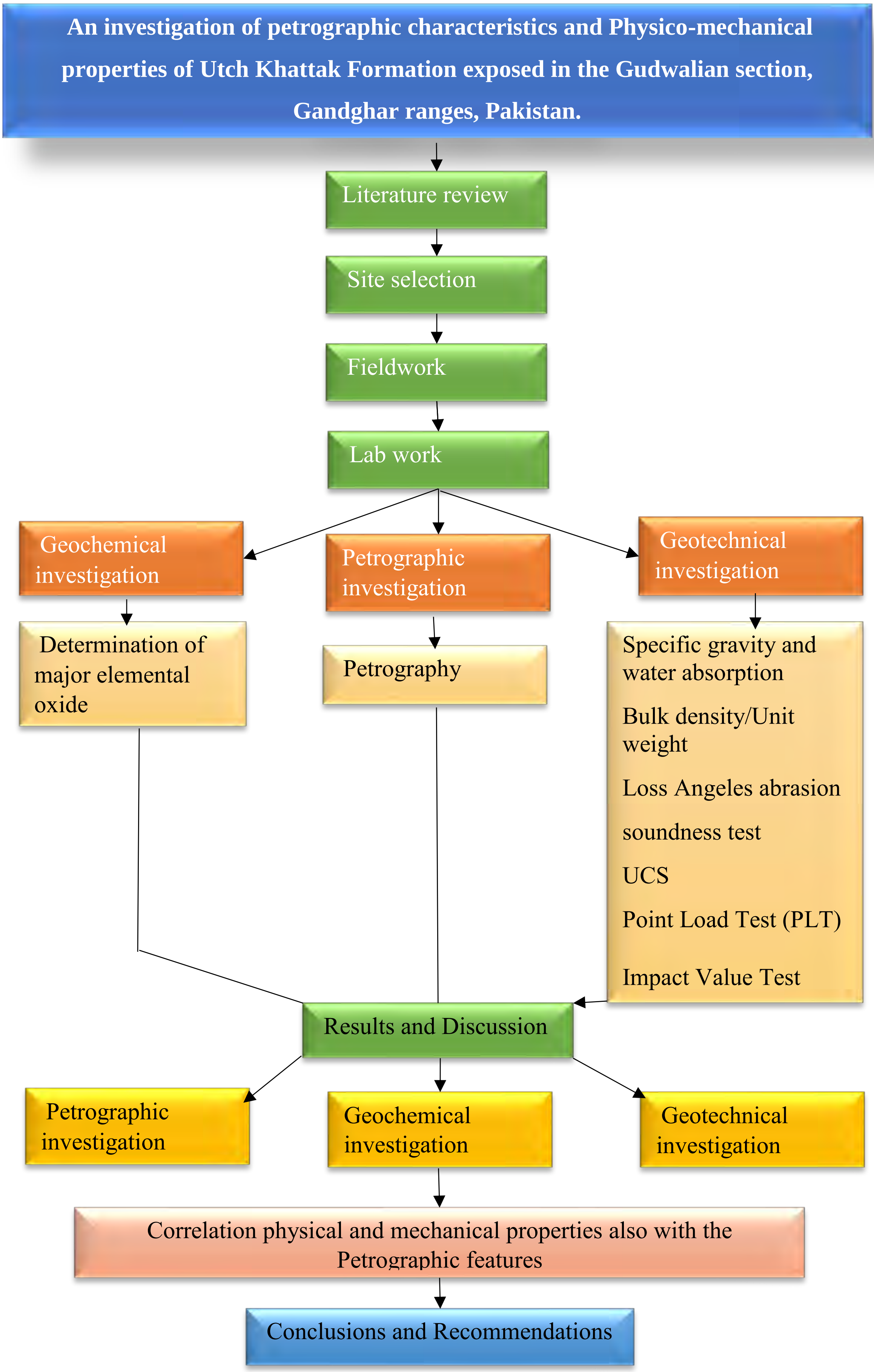

Figure 3.5 Chart reflecting followed methodology in this research.

and any encountered discontinuity. Azad Jammu and Kashmir University (AJK) and (NCEG Peshawar) National Centre of Excellence in Geology, received the transported samples and processed for geotechnical testing. Geochemical analysis was also carried out at the (NCEG).

3.6 Coring

Bulk samples transported to an Utron Engineering-Pvt Ltd (Main Boulevard Gulberg Greens Islamabad) to drill cores for Geotechnical tests. Almost 10 cores were drilled, Unconfined compressive stress (UCS) and point load test (PLT) were determined using two samples from each bulk sample. The remaining samples were transferred to the Pakistan Council of Science and Industrial Research (PCSIR) in Peshawar to crush the rocks in order to obtain aggregates, and the crushed samples were then sent to the (AJK) and (NCEG Peshawar).

3.7 Laboratory Analysis

3.7.1 Thin Section Preparation

For petrographic analysis a total of 20 thin section prepared two from each sample in the departmental lab of Earth Science, Quaid-i-Azam university, Islamabad. The collected samples cut and grinded in the rock cutting lab, after grinding the cutting samples were placed on the hot plates, the reason as not to cause bubbles during attachment by removing the moisture content. Polished thin grading samples attached with the help epoxy resin to the slide. Finally, the samples again thinned and polished to a standard size.

3.7.2 Petrographic Microscopy

The microscopy of thin section for petrography was carried out in the Petrographic Lab at Quaid-i-Azam University's Department of Earth Sciences in Islamabad. Microscope Leica with attached camera wse used with different resolution powers of 200um and 100um.

3.7.3 Physico-Mechanical Tests

Physico-mechanical tests were carried out in line with the international standards in order to check the aggregate usage and toughness of the Utch Khattak Formation as proposed for the construction industry. Coarse aggregate was evaluated in accordance with (ASTM C 33-13). The results of Los Angeles and Abrasion Value, Water Absorption, Sulphate Soundness, Specific Gravity, point Load

Test (PLT), Impact Values, and Unite Weight Tests were examined. In compliance with ASTM D 2938-2000 and ASTM D5731-16, For the UCS and (PLT) tests, two cores having a diameter of 1.95 inch were extracted from every single bulk sample. The section follows an explanation of the coarse grain Physico-mechanical investigations.

Table 3.1 list of tests performed on Utch Khattak limestone

	Type of tests performed	Standards followed	No. of samples tested
1	Unconfined compressive strength test	ASTM D 2938-2000	Total 10 cores from bulk samples
2	Specific gravity and water absorption	ASTM C 127-12	5 bulk samples
3	Loss Angeles abrasion test/ Resistance todegradation	ASTM C 131-06	5 bulk samples
4	Sulphate Soundness test	ASTM C 88-13	4 bulk samples
5	Point Load test	ASTM D5731-16	5 core samples
6	Aggregate impact value	BS 812-112	5 bulk samples
7	Unit weight test	ASTM C 29-09	5 bulk samples

a) Sulphate Soundness Test

Weathering have significant impact on aggregate quality, Low degree of change in aggregates pores volume during soaking, freezing, drying, and thawing such an aggregate is recommended for use during construction. According to (Abdelhedi et al., 2020) the Soundness test for less effective aggregates display negative impacts such as map cracking and D-line, or pop out. All through, in the test aggregates were soaked in Na_2SO_4 or $MgSO_4$ solutions and dried multiple times. The soundness of an aggregates was confirmed using the ASTM C88-13 test technique.

Table 3.2 Sample weight and sieve size for soundness test

Coarse aggregate			Sieve used after five cycles of soundness
Passing sieve in inches (mm)	Retain sieve in inches (mm)	Weight in grams	
3/8 (9.5)	# 4 (4.75)	300 ± 5	# 5 (4 mm)
¾ (19)	3/8 (9.5)	1000 ± 10	5/16 (8mm)
½ (12.5)	3/8 (9.5)	330 ± 5	5/16 (8mm)
¾ (19)	½ (12.5)	670 ± 10	5/16 (8mm)
1 ½ (37.5)	¾ (19)	1500 ± 50	5/8 (16mm)
1 (25)	¾ (19)	500 ± 30	5/8 (16mm)
1 ½ (37.5)	1 (25)	1000 ± 50	5/8 (16mm)
2 ½ (63)	1 ½ (37.5)	5000 ± 300	1¼ (31.5mm)
2 (50)	1 ½ (37.5)	2000 ± 50	1¼ (31.5mm)
2 ½ (63)	2 (50)	3000 ± 300	¼ (31.5mm)

b) Los Angeles and Abrasion Values Test

According to the (Khanna and Justo, 1990) the test is carried out to measure the toughness or wear ability of aggregates which result of friction with steel ball. The powder produced from rocks samples was tested for abrasion resistance shown in (Figure. 3.10). Moreover, stronger aggregates have lower Los Angeles abrasion values proposed by Smith and Collis (2001). The Los Angeles abrasion value was derived using the ASTM C 131 to check suitability of concrete aggregate, wear resistance. If not, it may collapse as a result of vehicle pressure.

c) Aggregate Impact Test

The relative resistance of an aggregate to a sudden shock indicating by (AIV) test. However stronger aggregates are supposed to be able to endure any unexpected impact without breaking down itself. The aggregate impact value of a rock will be lower if it is resistant to breakdown as well as granulation (Smith and Collis, 2001). Durability of aggregates can be determined through this test.

d) Specific Gravity and Water Absorption (S.g & W.a)

Specific gravity is the weight of a particular amount of aggregates divided by an equivalent weight of water. The water absorption strength of a rock is determined by its capacity to absorb water. A rise in the value of water absorption causes the concrete to deteriorate owing to enlargement. likewise, less water absorption values suggest that the rock is unaffected by breakdown and deterioration. ASTM C-127 standard was used to determine aggregate specific gravity and water absorption.

e) Unconfined Compressive Strength (UCS)

The rock values for strength were determined using (ASTM C170/C170M-17). The greatest stress that a rock can sustain in the axial direction in termed as its unconfined compressive strength (UCS) (Bell, 2007). The values of UCS work as a rock index characteristic to find out the best excavation tactics on time (Ceryan et al., 2013).

f) Point Load Test

Point load geotechnical tests are normally used to measure the rock strength and mechanical characteristics for concrete. This test is important for determining the quality of the rock, calculating the strength of its compression, and determining whether it's suitable for various technical uses. Point load tests aid in the characterization and evaluation of rock masses. They may be used to locate weaker zones, joint planes, and bedding planes in a rock mass. Point load test performed according to (ASTM D5731-16).

g) Unit Weight Test

As per ASTM C29/C29M-09 Unit weight or bulk density define as a rocks aggregate weight of material essential to completely fill a specific unit volume container**.** Higher unit weight aggregates are more tightly packed resulting in a lesser void percentage and give high strength. The percentage of void in aggregates increases with angularity and decreases with well-sorting, and also change with change in size, shape, gradation, roughness of the surface, specific gravity (a rise in specific gravity resulted in raises bulk density).

3.8 Geochemical Analysis

Geochemical study performed at (NCEG) National Centre of Excellence in Geology University of Peshawar using X-ray fluorescence to analyze major elemental oxide composition.

3.8.1 Determination of major Oxides

Analysis of major oxide performed on X-Ray Fluorescence spectroscopy.

X- Ray Florescence

XRF spectrometric analysis is a quantitative analysis for principle elements. five limestone samples analyzed to determine major element composition such as CaO, SiO_2, Fe_2O_3, K_2O, Al_2O_3, TiO_2. The key objectives of geochemistry are following.

a) To observe the impurities in the rocks.
b) Major elemental composition.

Processing

Limestone samples were first pulverized, after which glass beds were made for the complete rocks. A PANalytical with a rhodium anode X-ray tube of PW4400/24 spectrometer was used. Moisture in samples was eliminated by heating up to 110 C^o prior to testing. Each of 0.7-gram rocks samples with the lithium tetraborate ($Li_2B_4O_7$) combination, 7 gm of lithium metaborate (LiBO2) was added. The mixture obtained by adding two to three drops of lithium iodide. The resultant sample-flux was fused at 1100 C^o for 5 to 10 minutes in a platinum having (95%) gold and (5%) crucible. The crucible was regularly swirled over a stove during this period to eliminate gas bubbles and to make sure the melt was properly blended and uniform. The melt had been placed in a 30 mm diameter platinum mold. Fe2O3, CaO, K2O, K_2O, Al_2O_3, TiO_2 and SiO2 levels were analyzed in each bead. International values, specifically WROXI-1, WROXI-2, WROXI-3, DT-N, SDC-1, and PG-1 G-2, were processed in parallel with every set of five samples to identify the machine's precision and accuracy; the minimal detection limits for the essential components are as follows: CaO, (.0040%), Fe_2O_3 (.008%), K_2O (.0033%), SiO_2 (.0034%), Al_2O_3 (0.004%), K_2O (0.0033 %).

3.9 Loss on Ignition (LOI)

Loss on Ignition is the weight reduction in percentage as a result of ignition. In this procedure, a certain quantity of the sample is burnt at thousands of Celsius degrees. Evaporation of free water, hydrated water, carbon dioxide, Sulphur dioxide, vaporous and naturally occurring components, all these components contribute to the decrease in substance quantity. Following the passage of 2 mg of sample over a 100-mesh size filter, after that then 0.1 milligram of sample added into a beaker and covered for 30 minutes, at 400° Celsius, within muffled furnace to borne the sample. At 1000 ± 20° C, a constant value of mass was attained. Before being weighed, the sample was kept and cool in a desiccator. The sample's initial and final weight difference was utilized to compute the loss on ignition.

Figure 3.6 Powdering of rock samples in the tungsten carbide ball mill machine.

Figure 3.7 Photograph taken during performing Impact value test.

Figure 3.8 Coring of bulk samples in Progress.

Figure 3.9 Photograph reflecting UCS test in progress.

Figure 3.10 Showing Los Angeles and Abrasion test in Progress.

Figure 3.11 Photograph showing extracted cores samples.

CHAPTER 4
RESULTS AND DISCUSSION

4.1 General Statement

Calcium carbonate is the major component of calcareous rocks usually present in the form of aragonite or calcite. The most common calcareous rocks include limestone, marble, dolomitic limestone. All these are normally utilized in the construction industry across the world with the exception of chalk, coquina and tufa. The Utch Khattak Limestone of the Gandghar Ranges was studied to investigate its suitability for different mega construction projects.

4.2 Petrographical Analysis

Petrography describes the systematic analysis and division of rocks, accomplished mostly by microscopic examination of the thin sections. Microscopic investigation that defines the aggregate material in terms of harmful alkali aggregate reaction (Lopez-Buendia et al., 2006). Thus, the research area's Utch Khattak Limestone examined petrographically for deleterious components and presence of such components can cause failure of the structure.

Gandghar Ranges, Utch Khattak Limestone having cracks, microcracks, veins and stylolites filled with calcite cements. The color is ranging from dark grey on fresh surface and yellowish grey to bluish grey on weathered surface. According to the petrographic studies of the Utch Khattak Limestone dominantly consist of calcite and less concentration of dolomite in the form of fine-grained ground material while quartz is present in trace amount as illustrated in (Figure. 4.2,4.4,4.5). Stylolites are also present filled by fine-grained calcite and ferrous minerals.

The studied rock samples having fine to medium grained with sparite as shown in (Figure. 4.1,4.5). The modal mineralogy of the examined rock samples is displayed in Table 4.1. The amount of calcite in sample is up to 98%. Observation also show that medium grained spar calcite (sparite) found in some places, for instance UK7. However, there is a predominance of fine-grained micritic groundmass (Figure. 4.7). Additionally, it was found that sample like UK1, UK 4, UK9, and UK10 had a few microfractures shown in (Figure. 4.3,4.4 and 4.5) filled with Ferrous minerals and sample UK5, UK6 & UK 7 had calcite veins (Figure. 4.4). Altered microfossils observed in certain samples, like UK 1, UK3, UK4 UK7, they account very rare in the overall samples. The micrite, which is composed of fine-grained calcite, serves both as a cement and a ground mass. Calcite make up the fossilized traces (Figure. 4.7). Iron leaching (Pyrite, limonite, hematite) also visible in some samples is a discoloration along the (fracture and veins) (Figure. 4.2, 4.4) Petrographically, the rock has high concentration of $CaCO_3$ and mostly consists of carbonate-filled fractures (Figure. 4.6). From the investigation it is believed that Utch Khattak limestone from the Gandghar ranges has no harmful minerals that might cause alkali carbonate reaction (ACR) and alkali silica reaction (ASR) in rocks materials. However, the high concentration of $CaCO_3$ more than (80%) and negligible amounts of microfossils and quartz indicate that the investigated Formation is suitable to use as an aggregate. Although, stylolite, quartz, microfractures which is observed in some samples have negative effects on the strength of rocks. Moreover, bio clasts which had negative effects on the strength of rocks have not been observed in the investigated samples which is good for the studied rocks.

Table 4.1 Petrographic analysis of Utch Khattak Formation.

S.No	Dunham Classification	Micrite %	Sparite %	Totel Calcite %	Quartz %	Dolomite %	Bioclast %	Fracture/ Stylolytes
UK1	Mudstone	90%	8%	98%	0.50%	1.50%	Altered and dissolved	calcite filled micfractures
UK2	Mudstone	95%	3%	98%	0.80%	1.20%	0%	N/A
UK3	Mudstone	81%	14%	95%	0.70%	4%	Altered	fractures with stylolites
UK4	Mudstone	78%	10%	88%	1.00%	2.3%	Altered	calcite filled micfractures
UK5	Mudstone	70%	12%	82%	1.9%	4.5%	0%	fractures with stylolites filled by Ferrous materials
UK6	Mudstone	75%	23%	97%	2%	1%	recrystallization	fractures with stylolites filled by Ferrous materials
UK7	Mudstone	81%	16%	97%	0.50%	2.5%	Altered and dissolved	fractures with stylolites filled by Ferrous materials
UK8	Mudstone	73%	16%	90%	0.80%	0.20%	Altered	N/A
UK9	Mudstone	74%	18%	94%	2.5%	5%	0%	Calcite filled microfractures
UK10	Mudstone	79%	15%	94%	2%	4%	0%	Calcite filled microfractures

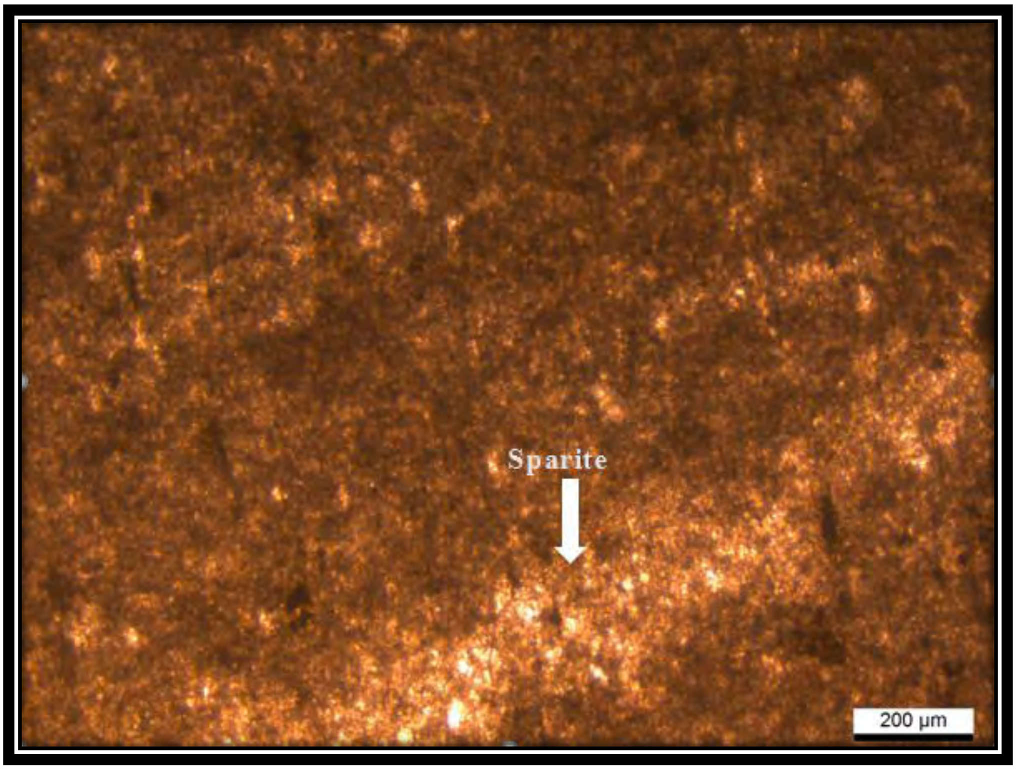

Figure 4.1 Photo micrograph showing Sparite in a vein.

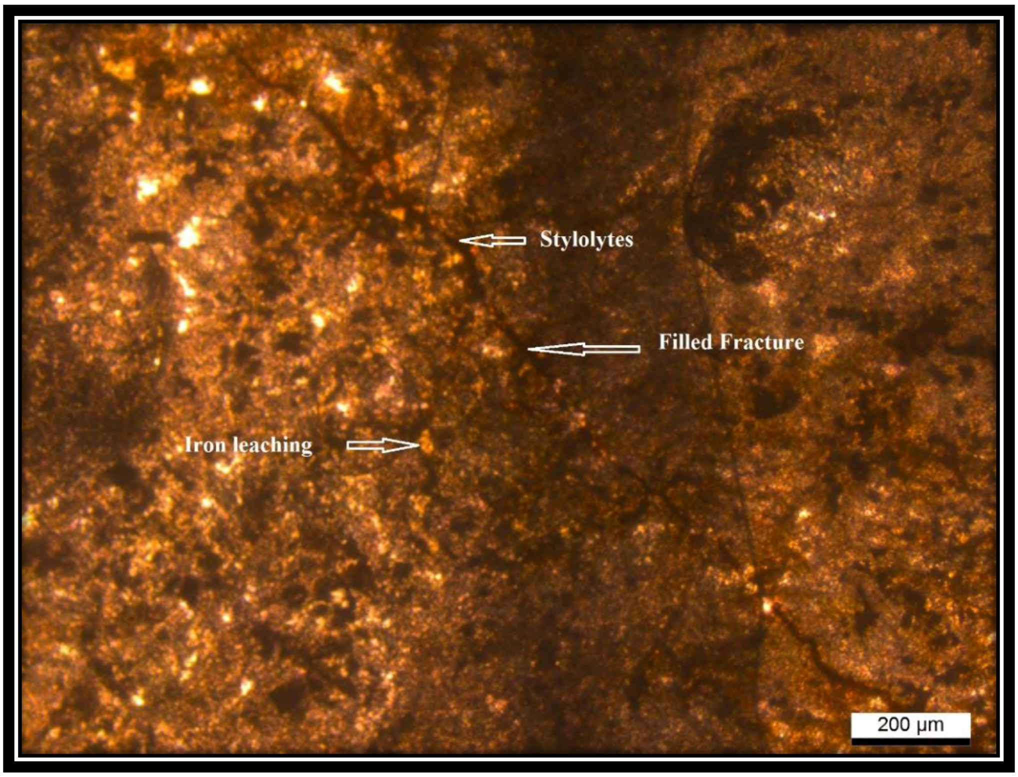

Figure 4.2 Photo micrograph showing Iron leaching and filled stylolite.

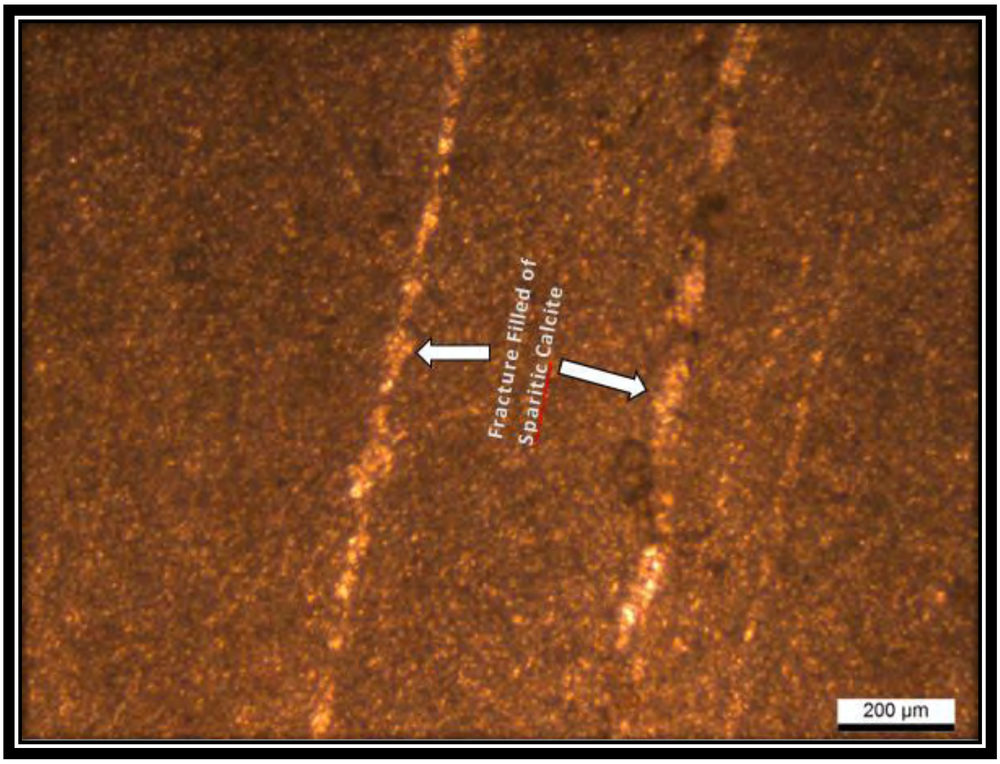

Figure 4.3 Photo micrography showing sparitic calcite filled fracture.

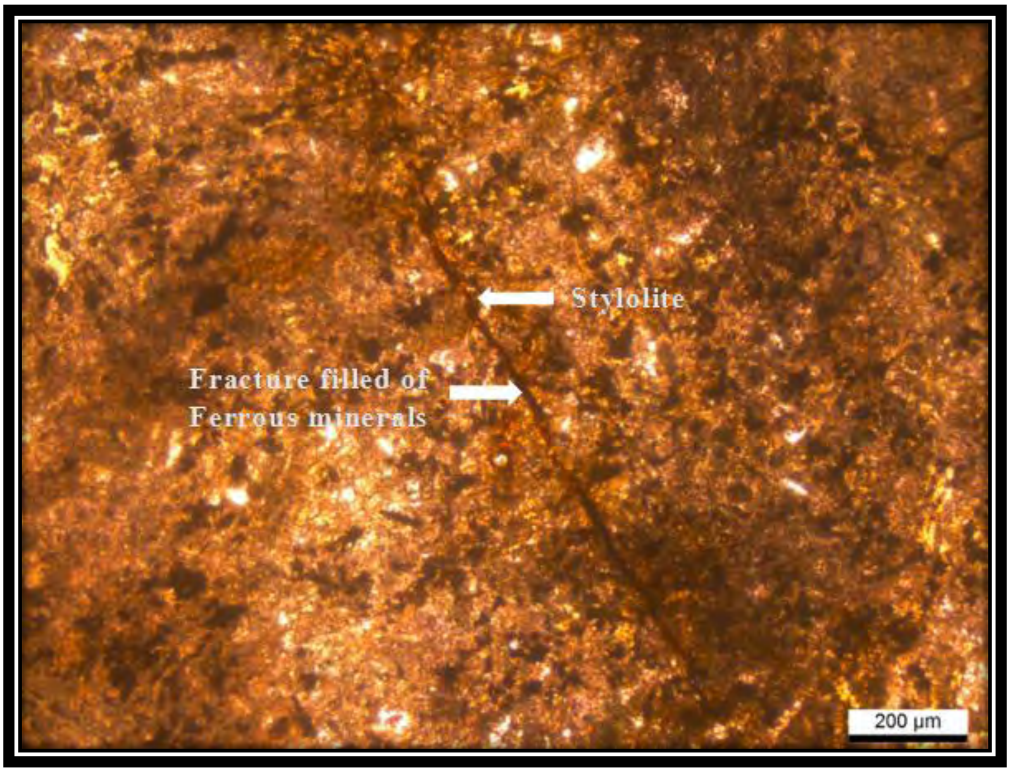

Figure 4.4 Photo micrograph showing stylolite and Fracture filled by ferrous minerals.

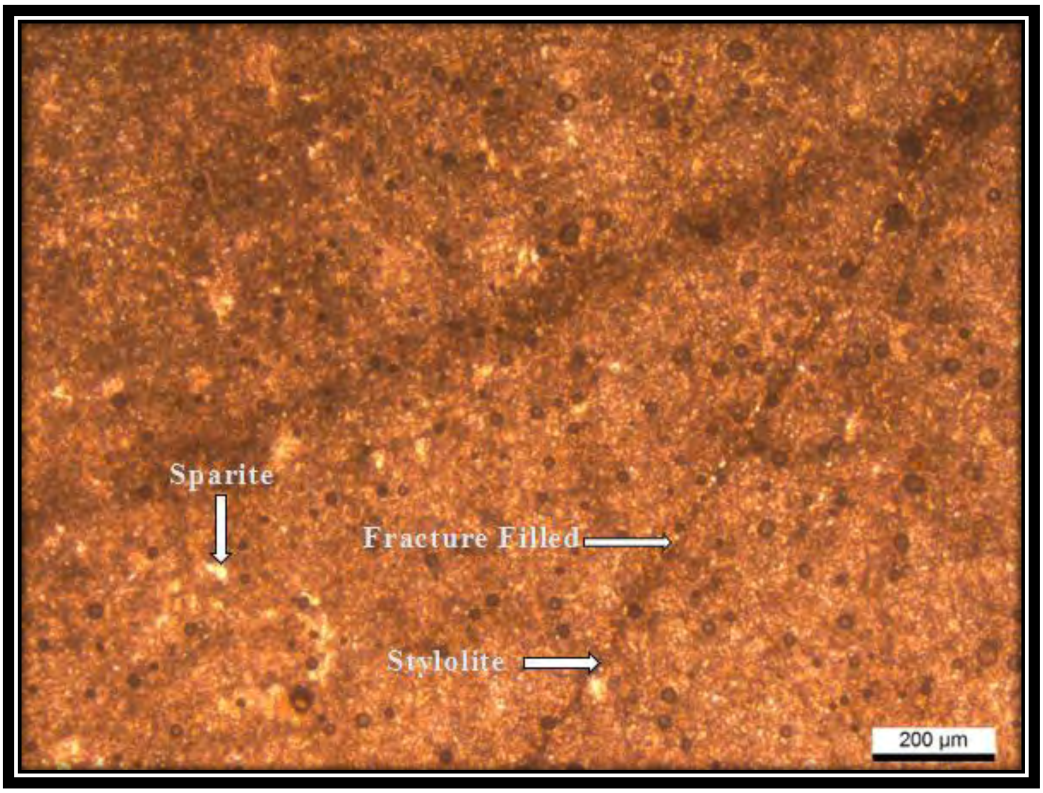

Figure 4.5 Sparite and calcite filled vein shown in photo micrograph.

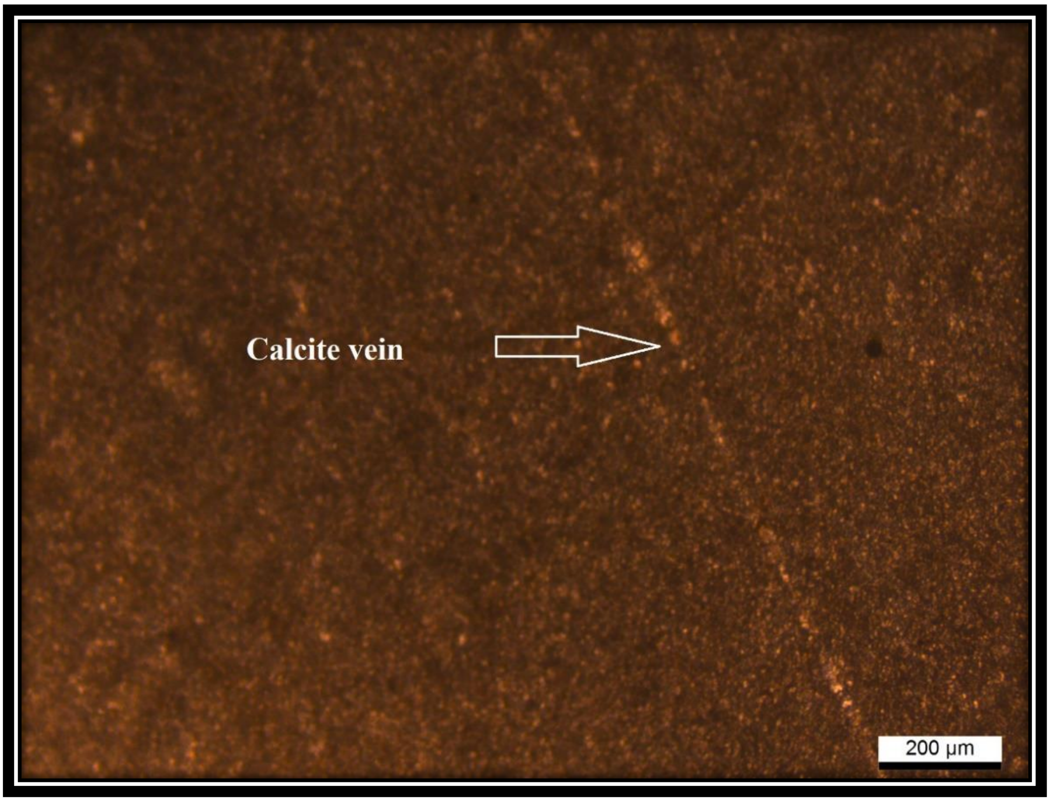

Figure 4.6 Photo micrograph showing calcite filled vein.

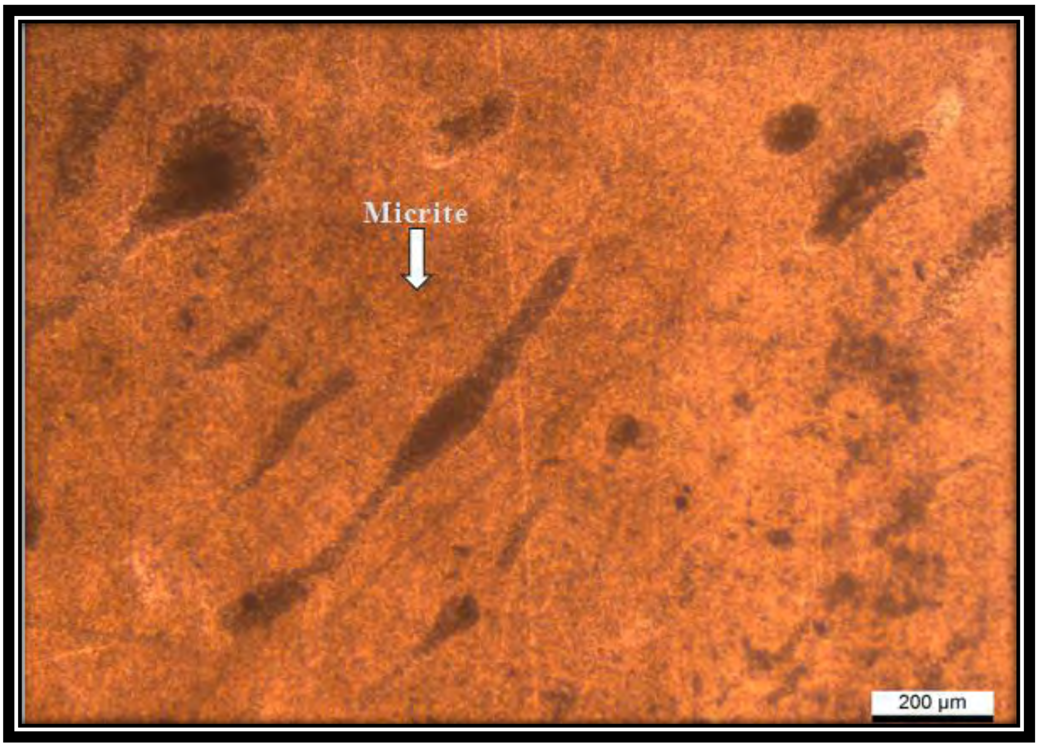

Figure 4.7 Photo micrograph of micrite (ground mass).

4.3 Geochemistry

The strength and durability of aggregate may vary and depend on the existence of elemental Oxides percentage in carbonate rocks and may have positive or negative effects on the physical parameters. For instance, the strength of limestone rises with the rise in concentration of (CaO) while, SiO_2 can cause the most harmful reactions such as Alkali-Carbonate Reaction (ACR) and the Alkali-Silica Reaction (ASR). Correspondingly, the higher quantities of Fe_2O_3, Al_2O_3, and alkaline minerals cause expansion and rupture in concert (Yaghoobi, et, all., 1990.). Similarly, a higher CaO content promotes limestone purity, which in turn increases aggregate strength and durability. Primarily carbonates composed of CaO and CO_2 with impurities such as Alumina, silica, sulfides and iron oxides. Hence, for identification of principal elements chemistry we used X-ray Fluorescence spectroscopy (XRF) on 5 rock samples from the Utch Khattak Formation. Table 4.2 provides the concentration of various oxides in Utch Khattak Limestone together with statistical data, maximum, minimum, and average limits of certain oxides.

The concentration of different oxide shown graphically in (Figure. 4.8, 4.9, 4.10,4.11, 4.12). According to given Table 4.2, the silica percentage is very low, less than 3%, favoring less Alkali Silica Reaction. Thus, it has good impact on concrete and strength of rock. Additionally, water evaporation is the result of fissures in compacted concrete which is mainly depend on Aluminum concentration in carbonates, greater the concentration of Aluminum greater will be the evaporation of water. In the investigated rock, Al_2O_3 is present in small amounts average value is 0.708 %, which have very good impact on the durability of rocks. The presence of trace amounts of impurities such as Fe_2O_3, TiO_2 and K_2O, K_2O have no effect on the durability and strength of source rocks.

Table 4.2 Geochemical analysis of various samples of Utch Khattak limestone

S. no	CaO%	SiO2 %	Fe2 O3 %	TiO2 %	Al2 O3 %	K2 O %	L. O. I	Total%
UK1	49.295	2.56	0.621	1.292	0.95	0.38	42.14	97.238
UK3	48.295	1.95	0.22	0.06	0.49	0.86	40.95	92.825
UK4	53.67	1.67	0.3	0.05	0.76	0.33	42.01	98.79
UK6	51.34	2.1	0.5	0.2	0.54	0.22	40.15	95.05
UK8	50.62	1.21	0.66	0.22	0.8	0.91	41.61	96.03
Minimum	48.295	1.21	0.22	0.05	0.49	0.22	40.15	92.825
Maximum	53.67	2.56	0.66	1.292	0.95	0.91	42.14	
Average	50.644	1.898	0.4602	0.364	0.708	0.54	41.37	

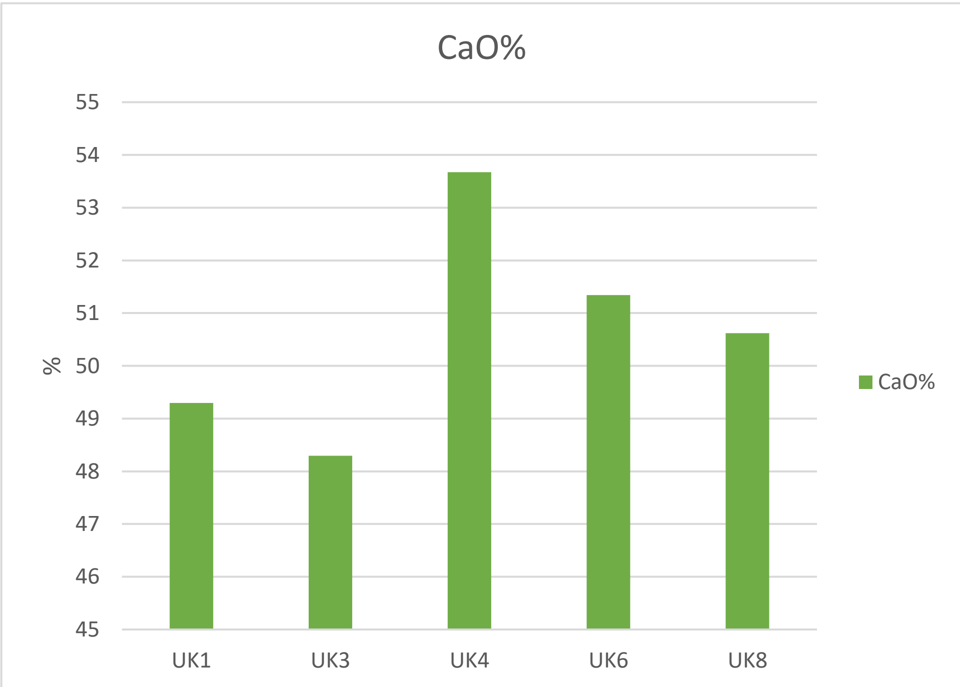

Figure 4.8 Comparative analysis chart of CaO% of different sample

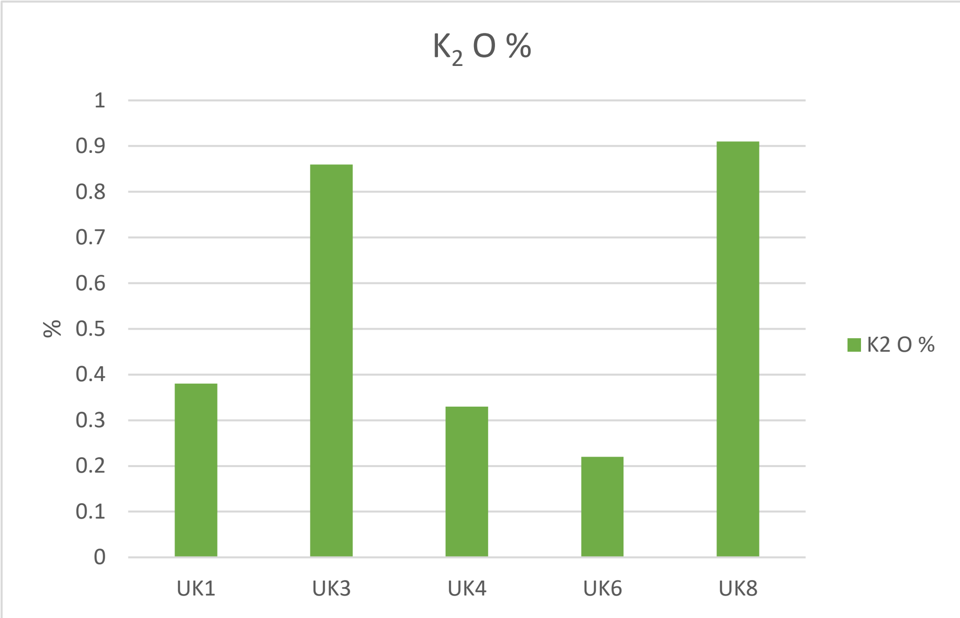

Figure 4.9 Comparative analysis chart of K_2 O% of different samples

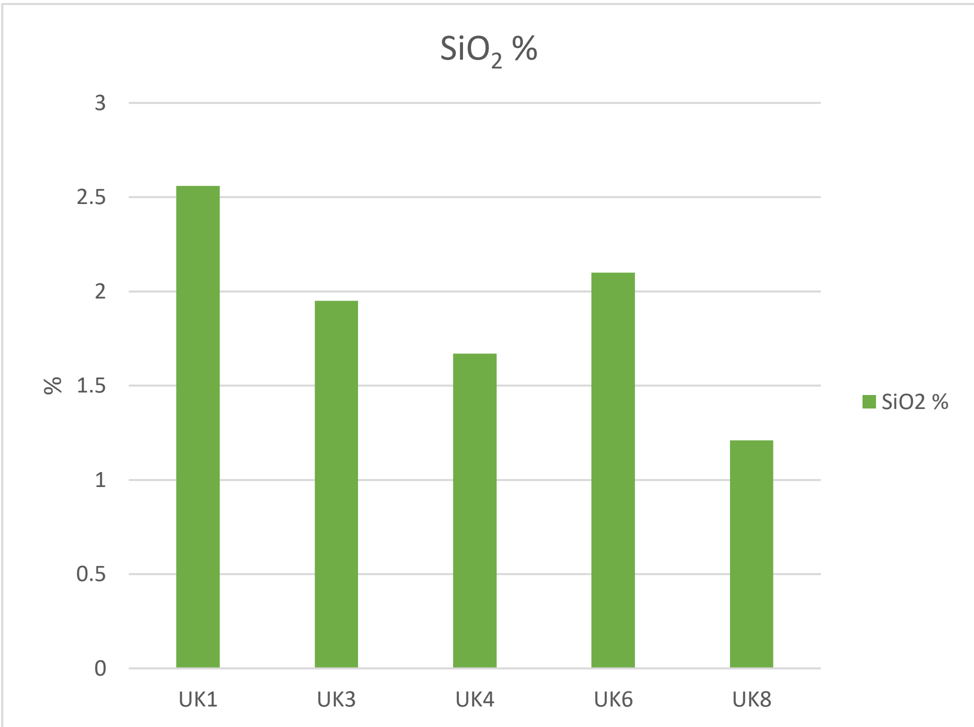

Figure 4.10 Comparative analysis chart of SiO_2% of different samples

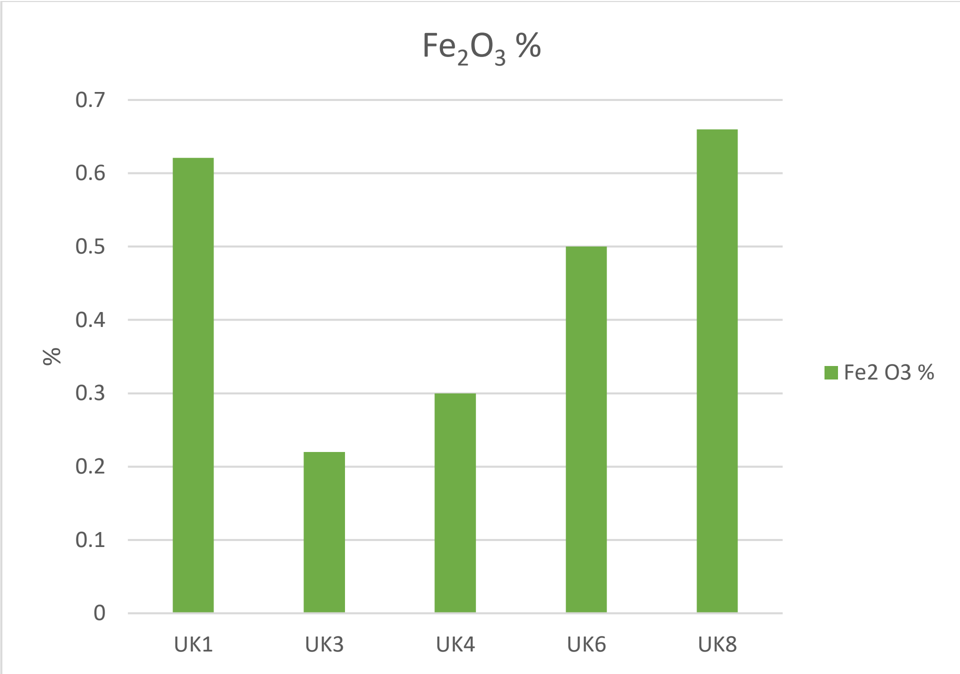

Figure 4.11 Comparative analysis chart of Fe_2O_3 % of different samples

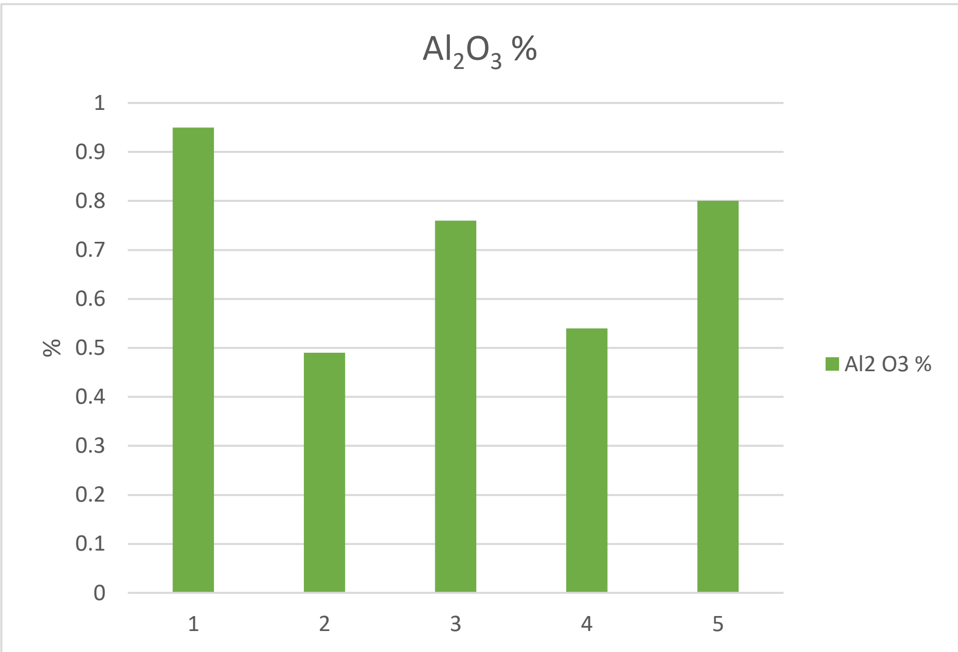

Figure 4.12 Comparative analysis chart of Al_2O_3% of different samples

4.4 Physico-mechanical properties

The Physico-mechanical characteristics of limestone must be considered in a limestone analysis for multidimensional engineering applications. Hence, limestone is crushed for the purpose to use in the construction sector as a concrete and road aggregate. Concrete is a composite material created artificially by human from cement, water, coarse and fine aggregate. Concrete consist of approximately 70 percent by volume of an aggregates, and their mechanical and physical characteristics have a great impact on the concrete's Physico-mechanical characteristics. Therefore, in large-scale engineering projects main focus is given to the mechanical and physical characteristics of rock (Omer and Ismail, 2015).

After petrographic and geochemical investigations, Physico-mechanical characteristics of the Utch Khattak Formation also evaluates in this research. the core specimens were drilled from five bulk samples such as (UK1, UK3, UK4, UK6, & UK8,) for the strength of investigated rocks. Unconfined compressive strength and Point Load test were performed on core specimens from the Utch khattak Formation. The remaining bulk samples were crushed and put through a variety of Physico-mechanical tests such as Soundness, Los Angeles Abrasion Value, Water Absorption and Specific Gravity percentage, Unit Weight, and Impact Value.

Specific gravity values of the examined samples are ranging from 2.66% to 2.72% presented in Table 4.3. Blyth and De Freitas (1974) stated that for construction projects the value of specific gravity must be greater than or equal to 2.55%. Tested limestone samples for water absorption has average value is 0.40% sown in Table 4.3. According to ASTM C 127-12, the rocks having water absorption capacity less than 2% are within the permissible limit.

Table 4.3 Specific gravity and water absorption of various rock sample

Sample No.	**Weight in air in gram**	**S.S.D weight in gram**	**weight in water in gram**	**oven dry weight in gram**	**Absorption in gram**	**Absorption %**	**Apparent Specific gravity**	**Bulk oven dry Specific gravity**	**Bulk SSD Specific gravity**
UK1	1500	1502.1	950	1497	3	0.34	2.73	2.71	2.72
UK3	1500	1503	948	1496.5	3.5	0.43	2.86	2.69	2.7
UK4	1500	1504.5	938.3	1498.1	1,9	0.42	2.67	2.643	2.66
UK6	1500	1502	946	1497.5	2.5	0.3	2.71	2.69	2.7
UK8	1500	1503.5	940	1495.7	4.3	0.52	2.69	2.65	2.66
Minimum value						0.3	2.67	2.643	2.66
Maximum value						0.52	2.86	2.71	2.72
Average value						0.402	2.732	2.6766	2.688

Bulk unit weight defines as aggregate mass in the given volume. Normally, the standard values of unit weight of concrete varied from 1.20 to 1.75 g cm-3. According to (Mehta & Monteiro, 1993), well-graded, tightly packed aggregate has a higher density value. (According to ASTM C 29-09) Table 4.4 shows that the bulk unit weight of Utch Khattak Limestone, average value is 1.62 gm/cm3 which conform the allowed range.

Table 4.4 Bulk unit weight tests of Utch Khattak Limestone.

Sample No	Wt. of mold (gm)	Volume of mold (cm)	Wt. of mold+ aggregate (gm)	Wt. of aggregate gram	Bulk unit wt. (g/cm^3)
UK1	5560 gm	3115 cc	10,645	4985	1.63
UK3	5560 gm	3115 cc	10,640	4990	1.63
UK4	5560 gm	3115 cc	10,630	4980	1.62
UK6	5560 gm	3115 cc	10,635	4975	1.62
UK8	5560 gm	3115 cc	10,620	4985	1.62
Minimum value					1.62
Maximum value					1.63
Average value					1.624

A soundness test can be used to evaluate an aggregate's durability and resistance to weathering. The maximum limit of sodium sulphate soundness for aggregate allowed by ASTM C 88-13 is 16%. Soundness test result of Utch khattak Limestone presented in Table 4.5, ranged from 3.08% to 4.54%, with an average value of 4.09%. The results show that the rocks have enough resistance to freezing and thaw action. However, all results fall inside the precise ASTM C 88-13 limit.

Table 4.5 Soundness test results of Utch Khattak Formation.

Sample No.	Passing through Sieve	Retained on Sieve	% Original Gradation A	Wt. of Fraction Before Test (gm)	Wt. of Fraction After Test (gm)	The loss of wt.	% Loss	Actual Loss
				B	C	d=b-c	e=d/b*100	f=a*e/100
	2 1/2"	1 1/2"	0	0	0	0	0	0
	1 1/2"	3/4"	48	1500±5	1470	30	2	0.91
UK1	3/4"	3/8"	38	1000±5	969	31	3.1	1.17
	3/8"	# 4	14	300±5	281	19	6	2
Total			100%	Total actual loss				4.08
	2 1/2"	1 1/2"	0	0	0	0	0	0
	1 1/2"	3/4"	38	1500±5	1461	39	2.6	0.98
UK3	3/4"	3/8"	49	1000±5	966	34	3.4	1.66
	3/8"	# 4	13	300±5	276	24	8	1.04
Total			100%	Total actual loss				3.68
	2 1/2"	1 1/2"	0	0	0	0	0	0
	1 1/2"	3/4"	40	1500±5	1465	35	2.3	0.92
UK6	3/4"	3/8"	37	1000±5	962	38	3.8	1.4
	3/8"	# 4	25	300±5	279	21	7	1.75
Total			100%	Total actual loss				4.07

Continuous ……...								
	2 1/2"	1 1/2"	0	0	0	0	0	0
	1 1/2"	3/4"	44	1500±5	1460	40	2.66	1.17
UK8	3/4"	3/8"	38	1000±5	959	41	4.1	1.55
	3/8"	# 4	22	300±5	275	25	8.3	1.82
Total			100%	Total actual loss				4.54
Minimum								3.68
Maximum								4.54
Average								4.0925

The aggregates resistance measure to breaking down, wear, and tear measure through Los Angeles test. According to (ASTM C 131-06) the test's upper standard limit is 40%. The results of Los Angeles abrasion values are presented in Table 4.6 and range from 24% to 27% with an average score of 25 %. The Los Angles value of Utch Khattak Limestone within range shows that the investigated rocks are durable for construction.

Table 4.6 Loss angles and abrasion test results

Sieve Size (mm)		**Allowable Weights in Each Grading (gm)**				**Aggregate weight used (gm)**					
						Sample No.					
Passing	Retained	A	B	C	D	UK1	UK3	UK4	UK6	UK8	Ave.
37.5(1.5")	25.0 (1")	1250±25				1250	1250	1250	1250	1250	
25.0 (1")	19.0(3/4")	1250±25				1250	1250	1250	1250	1250	
19.0(3/4")	12.3(1/2")	1250±10	2500±10			1250	1250	1250	1250	1250	
12.3(1/2")	9.5(3/8")	1250±10	2500±10	2500±10		1250	1250	1250	1250	1250	
9.5(3/8")	4.75(#4)			2500±10							
4.75(#4)	2.36(#8)				5000±10						
Total Wt. (X)		5000±10	5000±10	5000±10	5000±10	5000	5000	5000	5000	5000	
Total Agg. Wt. Coarser than No. 12 Sieve after 500 Revolutions (Y)						3800	3790	3725	3700	3650	
Loss Wt. Between the Origi. Mass and the Final Mass of Agg. Z=(X-Y)						1200	1210	1250	1300	1350	
Percentage Loss by Abrasion (%) (Z/X) *100						24	24.2	25.5	26	27	25.53%
Max. Allowable Percentage Loss (%)											40.00%

Table 4.7 Results of Impact value of different Formation

Sample No.	**UK1**	**UK3**	**UK4**	**UK6**	**UK8**	
Weight of agg regate before test W1	322.15	344.98	340.58	330.01	314.62	Average value
Weight of aggregate passing 2.36 mm sieve W2	41.69	47.36	50.06	55.34	58.48	
% Impact value (Wf) = W2/W1*100	12.94%	13.72%	14.68%	16.76%	18.58%	15.33%

Table 4.8 Unconfined compressive strength result of Utch Khattak Formation

Sample No.	Length (in)	Diameter (in)	Area (in)	Load (lbf)	UCS (Psi)	UCS (MPa)
UK1	4	1.95	3	32010	10670	73
UK3	4	1.95	3	31680	10560	72
UK4	4	1.95	3	30800	10266	70
UK6	4	1.95	3	29150	9716	66.98
UK8	4	1.95	3	28250	9416	64
Minimum						64
Maximum						73
Average						69.196

Aggregate impact test investigates the aggregate resistance to quick shock or impact and disintegration. The BS 812-112 specifies a 30% upper limit for impact value. According to the results in Table 4.7, the Utch Khattak Limestone falls within an acceptable range, with a minimum value of 13.56% and a high value of 17.95%, and average value is 15.34%.

The value of UCS was achieved according to ASTM D 2938-2000. Table 4.8 show the UCS value of core samples of the Utch Khattak Formation range from 64 MPa to 73 MPa. The investigated results of a samples show a medium strength of Utch Khattak Formation. However, Strength of UCS values depends manly upon the calcite and bioclastic contents and tectonic related processes with in investigated rocks such as faults, folds, dikes greatly affect the UCS properties.

The point load test is a mechanical test used to assess the durability of rock or concrete materials. It is a rapid, easy test that reveals important details regarding the strength and mechanical characteristics of the substance. Numerous characteristics, including strength index of the point load test (Is (50)) and estimation of UCS based on (Is (50) can be find through PLT. However, there is no reliable relationship can be predicted but approximate values can be found which range from 60.42 MPa to 72.5 MPa and Is MPa 2.68 to 3.22 value, this value show the medium strength of investigated rocks.

Table 4.9 Point load test and UCS estimated results of the Utch Khattak Formation.

Core Samples	Dimensions			Dimension checks	Parameters derived					
	L(mm)	D (mm)	De²(mm²)	L/D (>0.5)	P (KN)	Is(MPa)	F	Is50	Generalized value C	UCS(Mpa)
UK1	33	49.53	2453	0.66	7.9	3.22	0.99	3.18	22.8	72.5
UK3	35	49.54	2454	0.7	7.7	3.13	0.99	3.09	22.8	70.45
UK4	38	49.55	2455	0.76	7.3	2.97	0.99	2.94	22.8	67.03
UK6	32	49.57	2457	0.64	6.9	2.87	0.99	2.84	22.8	64.75
UK8	37	49.56	2456	0.74	6.6	2.68	0.99	2.65	22.8	60.42
Minimum					6.6					60.42
Maximum					7.9					72.5
Average					7.28					67.03

4.5 Relation between Mechanical and Petrographic analysis

Petrographic characteristics of rocks have considerable impact on its Physico-mechanical characteristics. According to Bell (1978), petrographic characteristics such as bioclasts and mineral constituents indirectly related to strength properties (Dobereiner and De Freitas (1986); Bonelli (1991); Yates (1992); Ulusay et al., 1994). Petrographic investigation reveals that Utch Khattak Limestone of the Gandghar ranges is mostly composed of calcite, with minor amount of dolomite and almost no fossils. According to Dunham's categorization, it is classified as mudstone as indicated in (Table 4.1). Calcite and bio clasts have had a significant impact on the rock's strength. Table 4.1, show the percentage of calcite varies from 88% to 98%. However, there is negligible amount of bioclastic in the utch khattak Formation.

By utilizing regression analysis of UCS and PLT with calcite, the value of the regression coefficient (R^2) was determined. Calcite concentration and UCS have a linearly positive connection with R^2 = 0.0211 (Fig. 4.13) and PLT having R2 = 0.2925 presented in (Figure. 4.14). These values indicate that strength of rocks increases with increase of calcite contents.

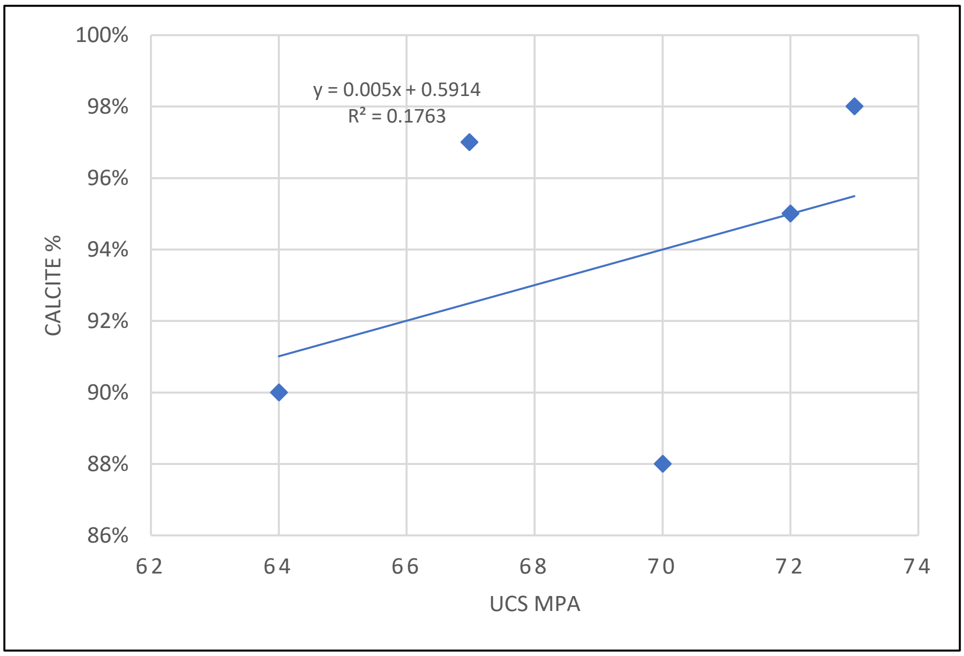

Figure 4.13 The regression analysis of Calcite contents with the UCS of Utch khattak limestone.

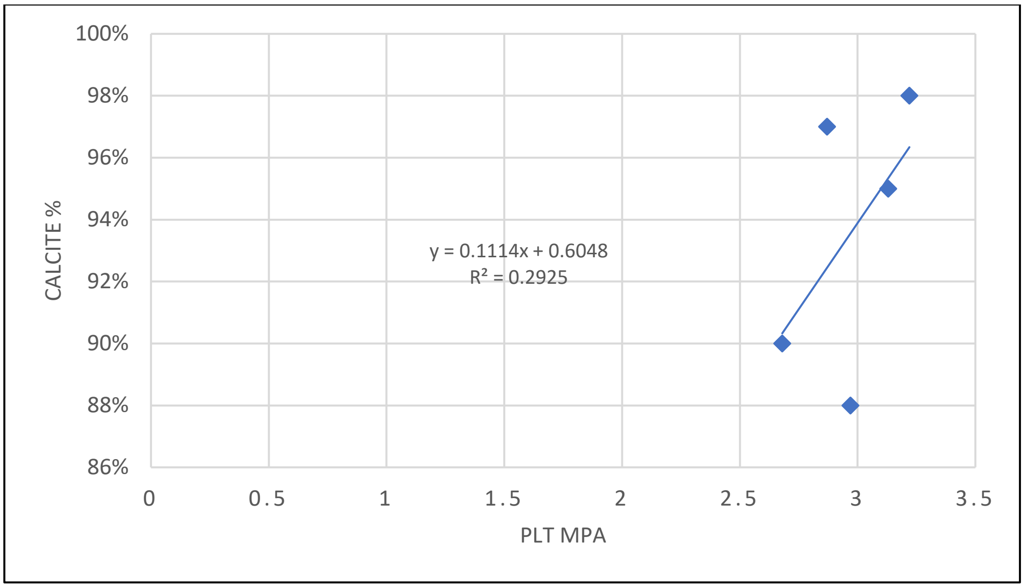

Figure 4.14 Regression analysis of Calcite versus PLT of Utch Khattak Formation

However, there is negligible amount of bio clasts in the investigated rocks. Therefore, there is no proper regression correlation exist.

4.6 Relationship between Physico-mechanical Properties

The intergranular fracture plays a vital role in defining the rock's strength, increase in deformation result in to decrease in rocks strength. In certain circumstances, grain size also has an impact on the strength of rocks, increase in grain size result to decrease in strength (Bell, 2007). According to ISRM (1981), the durability of the rock will decrease as the void volume increases. Weathering component may also have an impact on the mechanical characteristics (Torgal & Castro, 2006).

There is a substantial inverse relation between the Los Angeles Abrasion value (LAAV) and Unconfined Compressive Strength (UCS) and with the Point Load Test (PLT) for the Utch Khattak limestone shown in (Figure. 4.15). The exact same results as those predicted by Ballivy and Dayre (1984) have been observed in this investigation. Empty spaces with in the grain of rock samples have a great effect on the mechanical characteristics of the rock and also have strong relation with the Los Angeles Abrasion value and Unconfined Compressive Strength.

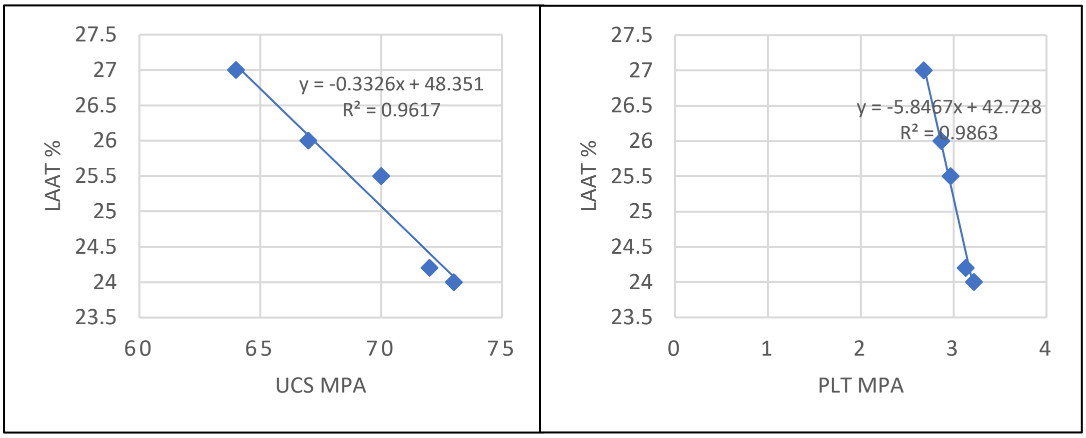

Figure 4.15 a) Indicate the relation between Los Angeles Abrasion (LAAT) and (UCS) unconfined compressive strength. b) show the (LAAT) and (PLT) point load test.

The strong inverse connection between the UCS and LAAV is seen in (Figure. 4.15 a), with a value of R^2=0.9617 there is a drop in the Abrasion values with an increase in Compressive Strength values. (Figure. 4.15 b), show similar strong inversely relation between Los Angeles Abrasion value (LAAV) and Point Load Test (PLT) with R^2=0.9863.

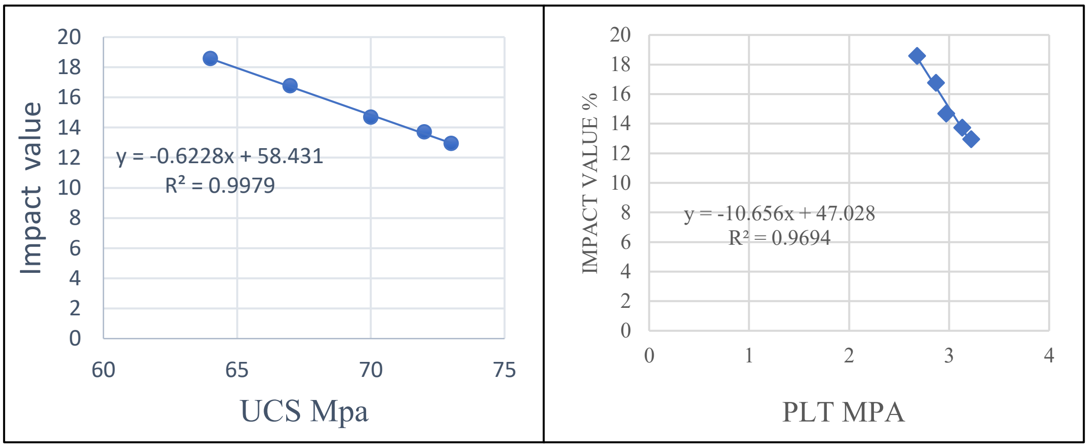

Figure 4.16 a) Unconfined Compressive Strength (UCS) against impact aggregate value. b) Point load test (PLT) Vs Impact value test.

The UCS and AIV have a significant inverse relation, as shown in Figure. 4.16 (a). With R^2=0.9979, a rise in UCS values reveals a decline in AIV values. (Figure 4.16) b) show that PLT and AIV also have an inverse relation with R^2=0.9694, a rise in PLT values reveals a decline in AIV values.

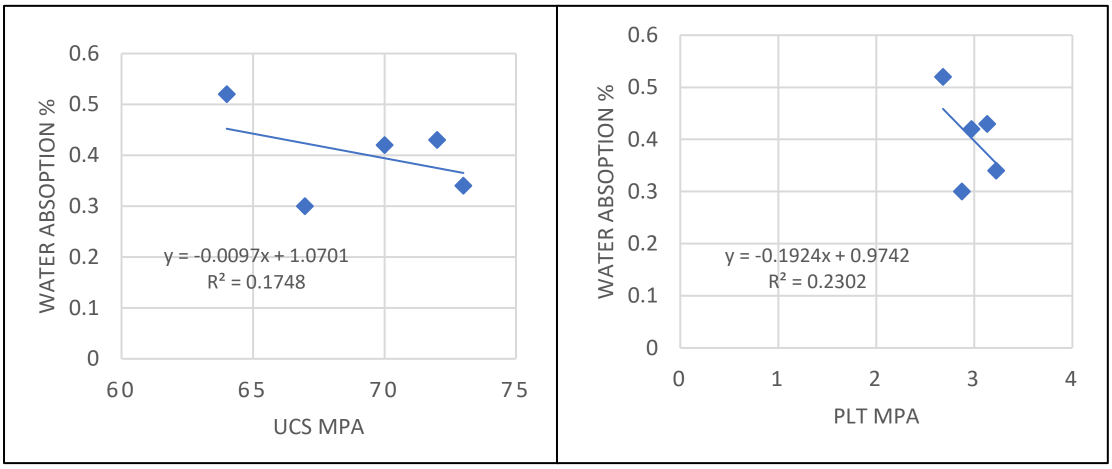

Figure 4.17 (a) Water Absorption value Vs UCS and b) Water Absorption Vs PLT.

There is an inverse relation between water absorption and Unconfined compressive strength (UCS) with $R^2 = 0.1748$ shown in Figure 4.17 a). While, b) have similar inverse relation between water absorption and Point load test (PLT).

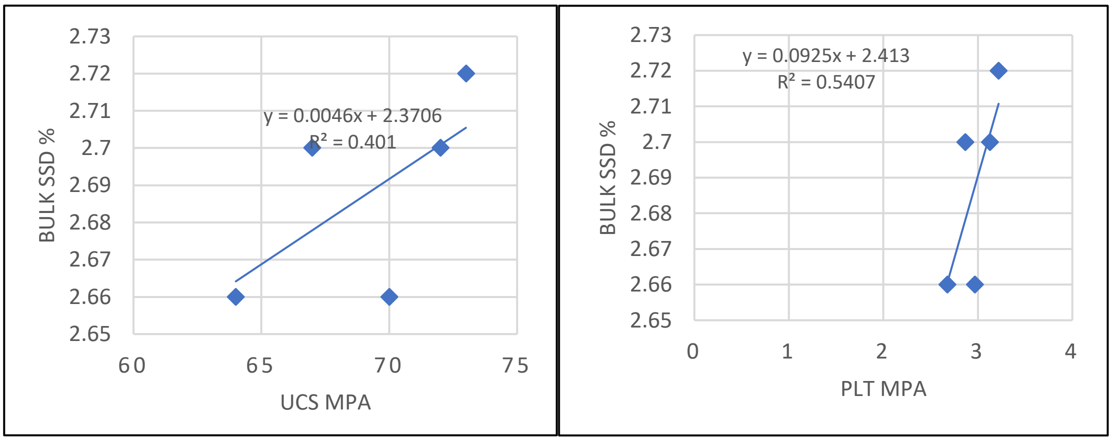

Figure 4.18 a) Bulk USSD Vs UCS value and b) Bulk USSD Vs PLT.

Figure 4.18 a) show strong positive relationship between Bulk SSD and UCS with r^2 = 0.401. However, in Figure 4.18 b) Bulk SSD Vs PLT also show strong direct relationship with $r^2 = 0.5407$.

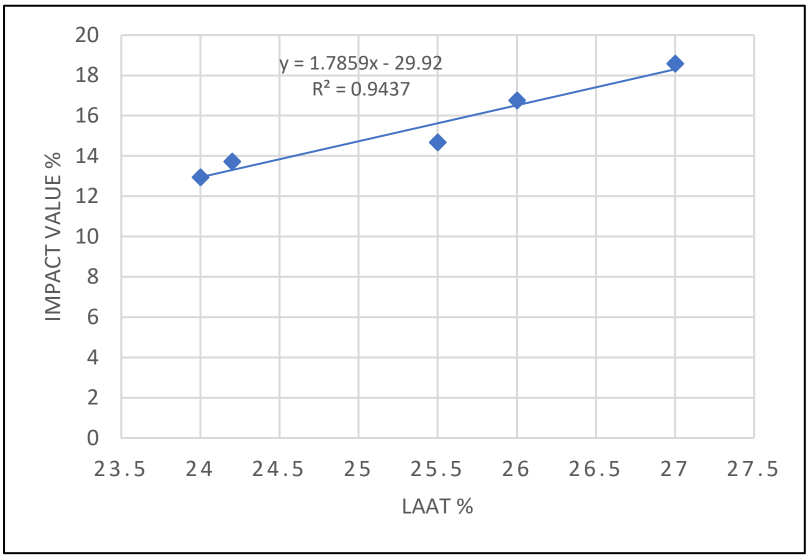

Figure 4.19 Show regression analysis of Los Angeles Abrasion value (LAAT) vs. Aggregate Impact value (AIV).

The direct and positive link between AIV and LAAV is seen in (Figure. 4.19) with R^2 = 0.9437, a rise in the LAAV level corresponds to a rise in the AIV value.

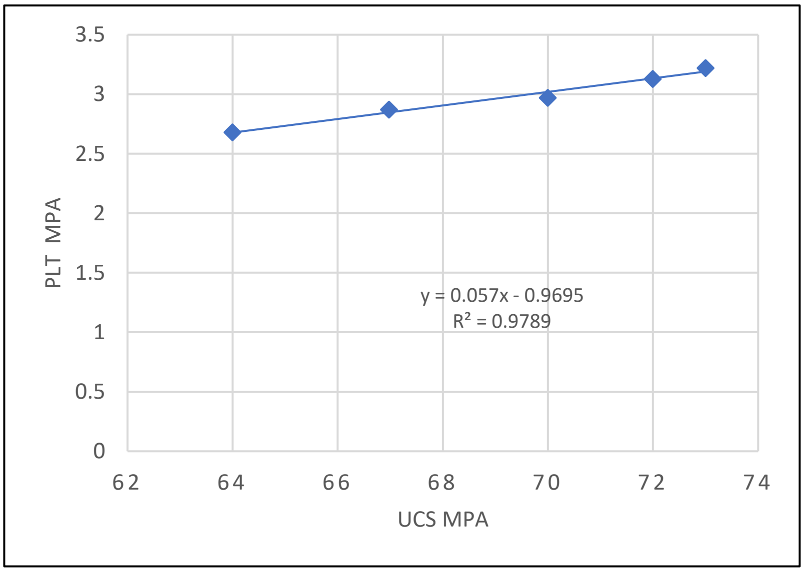

Figure 4.20 Regression analysis of UCS Vs PLA of Utch khattak Formation

Additionally, there is also a positive correlation between UCS and PLT having R^2 = 0.9789 (Figure. 4.20), indicating that UCS is directly related to PLA in terms of the strength of the Utch Khattak Limestone.

CHAPTER 5
CONCLUSION AND RECOMMENDATIONS

5.1 CONCLUSION

The Utch Khattak Formation of Gudwalian section in the Gandghar Range has investigated petrographically, geochemically and physico-mechanically. Petrographic investigation was carried out according to the ASTM C 129 and graded the rocks as a Mudstone according to Dunham (1962). Limestone of the Utch Khattak Formation contain calcite as a main component, quartz and dolomite found in minor amounts in the form of ground mass. Moreover, there is no adequate grains of reactive minerals and harmful elements were detected. Hence, the limestone is declared to be non-deleterious. A considerable concentration of CaO is also found in the geochemical research, along with traces of, SiO_2, Fe_2O_3, Al_2O_3, TiO_2 and K_2O. The petrographic and geochemical analysis along with physical parameters of the Utch Khattak Limestone from the research area is feasible for usage as a construction aggregate.

In addition to petrographic and geochemical study, Utch Khattak Limestone of the research area was Physico-mechanically evaluated for the suitability as a construction aggregate. The rock was evaluated using Unconfined Compressive Strength (UCS), Point Load Test (PLT), Specific Gravity, Water Absorption, Bulk Unit Weight, Soundness Test, Los Angeles Abrasion test, and Impact Value Test. The apparent Specific Gravity average value is 2.73, bulk saturated surface Dry Specific Gravity is 2.68, bulk oven dry specific gravity is 1.62 g/cm3, and the water absorption is 0.40%. while the average value of soundness is 4.09%. similarly, average values of Los Angeles and Abrasion test is 25.53%, Impact Value Test is 15.33%, Point Load Test is 7.28 KN and average value of Unconfined Compressive Test is 69.196 MPa. These all values are under specifications of ASTM for a source aggregate.

The Physico-mechanical characteristics of the Utch Khattak Limestone, such as UCS and PLT, were statistically related to petrographic features using linear regression analysis. Thus, UCS and PLT having direct propensity with calcite contents. While with increase in contents i.e., bioclasts and pores spaces decreases the potential, durability, and suitability of aggregate and may result in failure of the structures. However, the amount of bioclasts and pores spaces is less within the Utch Khattak Formation of Gudwalian section which depicts its suitability in construction of infrastructure. Physico-mechanical tests were compared through linear regression analysis for further confirmation of limestone strength and suitability as a source rock aggregate.

5.2 RECOMMENDATIONS

- The Gandghar region is located 2 km away from main road (Haripur-Sirikot) where, crushing plants should be established and supply a low-cost source of construction materials for both Khyber Pakhtunkhwa and federal regions.
- The geotechnical investigation for the Utch Khattak Formation is limited to mechanical characteristics. Therefore, before beginning large quarries at various stations, the results of various tests should be achieved from the rocks must undergo shear strength, young modulus, flex modulus, shear modulus, resistance to electricity, secondary wave, poison's ratio, modulus rupture, mix for concrete design, several asphalt tests and asphalt mix design test.
- Following worldwide standards, the study area's Utch Khattak Limestone should be investigated for the purpose to use in various sectors such as paint, fertilizer, leather, and cement.

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