Rock Aggregate Potential of Cretaceous and Paleocene Carbonates Exposed in the Darsamand Anticline, District Hangu, Khyber Pakhtunkhwa, Pakistan

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DEDICATION

Dedicated to the Geological resources of my Motherland.

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ABSTRACT

Limestone is widely used in mega-construction projects and chemical companies all over the world. Pakistan is endowed with vast resources of carbonates, which are widely used in major engineering projects and infrastructure construction. Therefore, vast deposits of carbonates of Cretaceous Kawagarh Formation and Paleocene Lockhart Limestone are exposed in the vicinity of Darsamand Anticline, District Hangu are evaluated petrographically, geochemically, and physico-mechanically for assessing their suitability as an aggregate source in asphalt and concrete works. These carbonates are vastly exposed in the western parts of the Kohat Plateau, Khyber Pakhtunkhwa. The limestone from the Kawagarh Formation is comprised of micrite, bioclasts and planktonic foraminifera while that of the Lockhart Limestone is composed of bioclast, algae and micrite. The limestone from Kawagarh has a mudstone depositional fabric while that of the Lockhart Limestone has a wackestone texture. Diagenetic calcite veins and stylolites occur in both the studied rock units. No deleterious minerals were encountered in both these carbonate units. The physical properties of the Kawagarh Formation The physical properties of the Kawagarh Formation limestone units and Lockhart Limestone as aggregate materials (i.e., soundness, water absorption, Los Angles abrasion, specific gravity, and coating and striping) are in accordance with ASTM standards and can thus be used as aggregate sources in construction projects and Lockhart Limestone as aggregate materials (i.e., soundness, water absorption, Los Angles abrasion, specific gravity, and coating and striping) are in accordance with ASTM standards and can thus be used as aggregate sources in construction projects.

Moreover, the geotechnical parameters of these two carbonate units i.e Lockhart Limestone and Kawagarh Formation were correlated theoretically with the petrographic characteristic. If the carbonates having more CaO, less pore spaces, and less amount of bioclasts the more will be the strength, durability, and suitability of the limestone and vice versa. Similarly, if limestone having more SiO_2, Fe_2O_3, and K_2O can negatively influence the physical parameters of aggregate, and can cause failure of the structure. The amount of clay minerals within carbonates can negatively effects the strength of carbonates. However, from the petrographic, geochemical and geotechnical analysis show that the Lockhart Limestone and Kawagarh Formation of Darsamand Anticline is having no effects of oxides, cryptocrystalline and other deleterious on the geotechanical parameters of aggregate. Hence, Lockhart Limestone and Kawagarh Formation have the potential aggregate source to be used in large and small construction projects.

Chapter 1

Introduction

Limestone is a sedimentary rock that is largely made of calcite ($CaCO3$). Limestone originates either through the activity of animals or directly as a result of inorganic processes. Limestone can be produced and deposited mechanically, or it can be chemically or biochemically precipitated and generated in situ with current and growth bedding. Soft chalk to hard crystalline rock (Pettijohn, 1975) are the different types.

However, limestones can also be used as aggregate material in engineering projects and in construction of infrastructures such as, building of dams, bridges, buildings, and in various components of roads e.g sub grade ,sub base, and in asphalt depend upon the strength and durability of the aggregate. As the strength, quality, and durability of the aggregate closely associated with mineralogical composition and surficial characteristics present within the rock units i.e cracks, joints, micro fractures, and including hydro thermal activities within aggregate. In recent years, researchers have developed models for predicting mechanical behavior of rocks based on their physical index (Karakus et al. 2005; Chang et al. 2006; Sonmez et al. 2006; Yilmaz and Yuksek 2008; Sarkar et al. 2010; Yagiz et al. 2012; Majdi and Rezaei 2013; Yesiloglu-Gultekin et al. 2013; Ajalloeian and Mohammadi 2014; Diamantis et al. 2014). The appropriateness of aggregate is determined by several parameters, including texture, mineralogy, weathering, and chemical compositions (Irfan, 1996; Omar and Ismail, 2015). According to (Arif et al., 2019), who conducted his studies on the Ambela granitic complex, all types of physically competent minerals, mineral grains with irregular shape, fine grained minerals, and a wide grain size range lead to increased aggregate potential and suitability. The geological history of rock, as well as geological processes such as joints, fissures, micro fractures, and hydrothermal modifications, influence the quality, strength, and durability of aggregate. As a result, different geological processes influence the chemical and physical qualities of aggregate in terms of lithological description. The physical and mineralogical characteristics of sedimentary rocks have significant influence on their mechanical properties (Mosch and Siegesmund, 2007; Sabatakakis et al., 2008; Tandon and Gupta, 2013; Wang et al., 2019). Moreover, a number of recent studies have determined the effect of mineralogical composition on mechanical behavior of rock even some researchers around the world have established relationship between petrographic features and mechanical properties of the rocks (e.g. Dincer et al., 2008; Kilic and Teymen, 2008; Liu et al., 2005; Meng and Pan, 2007; Zorlu et al., 2008)

The relative abundance of the deleterious components e.g silica, chert, chalcedony, flint and all other cryptocrystalline minerals within the carbonates can affect the strength, durability, and suitability of the aggregate, and cause failure of the engineering structures by causing adverse chemical reaction e.g Alkali Carbonate Reaction (ACR) and Alkali Silica Reaction (ASR). However, within the Lockhart Limestone and Kawagarh Formation of Darsamand Anticline there is no such deleterious minerals which can influence the quality, strength, and durability of the aggregate. Researchers have carried out several studies on limestone and aggregate, and have investigated the mechanical properties of aggregate and then have proposed their use in mega engineering projects. Apart from silica, the relative abundance of pure calcite, Fe_2O_3, and MgO, K_2O also affect the quality and strength of carbonates. The presence of these oxides in carbonates can cause more consumption of water during its using in concrete, which ultimately leads to the formation of fissures within the concrete after the evaporation of water from concrete which make it unfeasible for use as a construction aggregate and in concrete designed projects. Adding to this, the clay minerals in carbonates can cause contraction and expansion which ultimately leads to swelling and produce cracks in the structures. However, within the carbonates of Lockhart Limestone and Kawagarh Formation of Darsamand Anticline the amount of deleterious materials is less than 2% which have no effect on strength, quality, and durability of aggregate.

The limestone deposits are extensively exposed in different parts of Pakistan which can readily be used in different construction projects. Different researchers have investigated different rocks of Pakistan in terms of geotechnical characterizations (e.g. Arif et al., 1999; Shah and Gohar, 2003; Bilqees and Shah, 2007; Jan et al., 2009; Sajid and Arif, 2015; Bilqees et al., 2012), however, no similar work has been done in the proposed research area. In Pakistan, due to good quality, strength, and suitability Margalla Hill Limestone is commonly and extensively use in mega engineering projects, apart from Margalla Hill Limestone other formations of limestones exposed in Pakistan are in use. A detail investigation of these limestone formations in terms of their aggregate suitability in different parts of the country would help the construction industry to use these promptly. However, as the need for massive engineering projects expands and the population grows, the already studied carbonates are on the edge of extinction. As a result, new aggregate sources should be investigated in order to meet the demand of the construction industry.

Hence, this project is thus designed to evaluate the rock aggregate potential of the Cretaceous and Paleocene limestone formations exposed in the surroundings of the Darsamand Anticline, District Hangu, Khyber Pakhtunkhwa, Pakistan.

1.1 Study Area

The Darsamand anticline is a part of Kohat Ranges which are exposed along Main boundary thrust (MBT). Darsamand anticline is situated with the link road of about 5 km toward North from Main Hangu Thall highway. The study area is situated at a distance of 270 km from Islamabad, and 156 km from Peshawar and 45km from District Hangu. The area is restricted between Latitude (N 33 °26′ 30″ to N33° 29′30) and Longitude (N 70 °39′ 0″ to E 70° 42′0) as shown in the below (Figure 1).

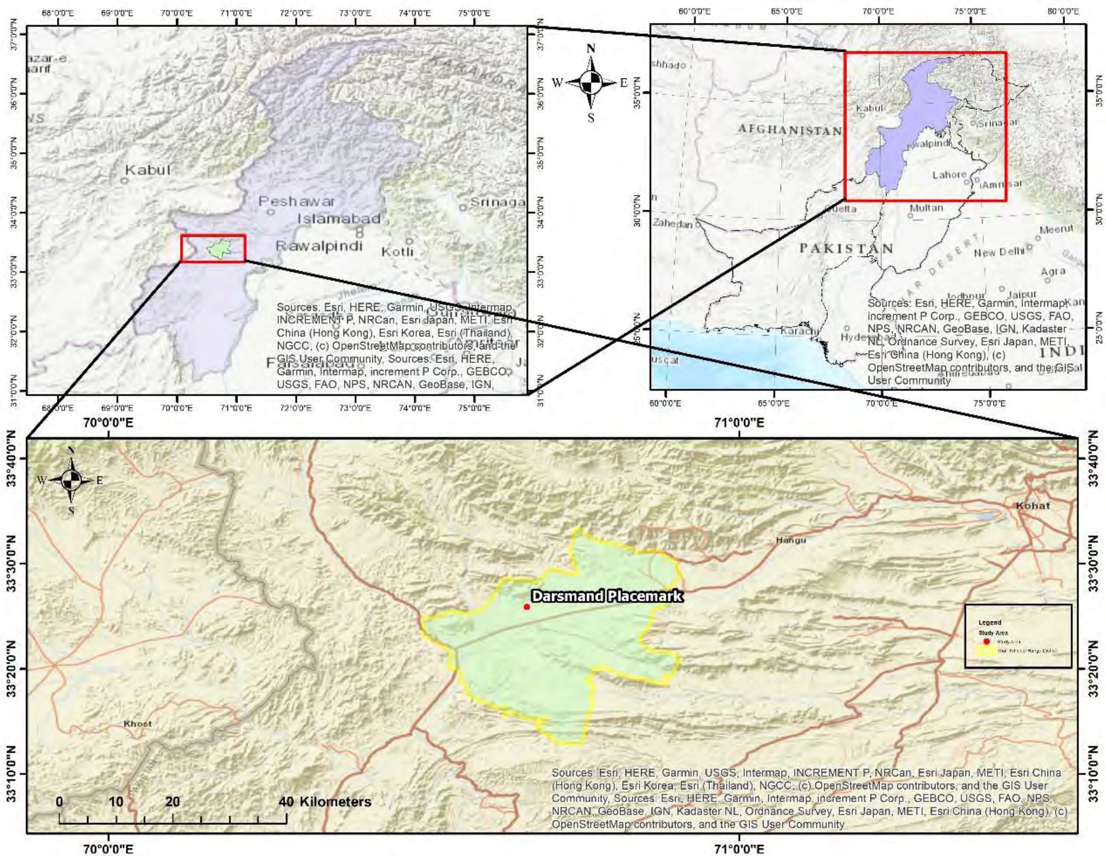

Figure 1.1 Landsat image showing Location of the study area

1.2 Research Aims

- The purpose of this research is to analyze the limestone of the Lockhart Limestone and Kawagarh Formation exposed near the Darsamand Anticline in terms of geochemistry, petrography, and physico-mechanical parameters, and to propose its suitability for use in the construction sector. The following objectives will be used to attain the goals. To carry out detailed petrographic and geochemical analysis in order to find out the mineralogical composition of the samples collected from Lockhart Limestone and Kawagarh Formation.

- The physical and mechanical parameters of rock aggregate from the Lockhart Limestone and Kawagarh Formation exposed in the Darsamand Anticline were determined.
- To develop a possible relationship between geochemical, petrographic, and geotechanical parameters.
- To establish a feasibility and suitability of the Lockhart Limestone and Kawagarh Formation for use in mega engineering projects.

1.3 Previous Work

Initially, different researchers have had carried out work on industrial utilizations of limestone. (Gillson, 1960) had discussed its chemical and physical properties and its uses. He discussed some of the common uses of limestone and dolomite. (Oats, 1998) has worked on the chemistry, technology, production and uses of the limestone. (Tucker and Wright, 1990) and (Scoffin, 1987) studied the geology of the carbonate sediments and rocks.

In Pakistan, (Hussain, 1977) conducted the first ever work on the limestone deposits in the Nizampur basin; in addition, other geo scientists worked and shown that diverse limestone deposits in Khyber Pakhtunkhwa are appropriate for cement industry. Later, (Bilqees and Shah, 2007), and (Bilqees et al., 2012) assessed the suitability of several limestone resources in Khyber Pakhtunkhwa for construction industries.

In Pakistan, researchers have conducted several studies on mineralogical composition of rock which directly influence the quality, durability, and suitability of aggregate, and have proposed it for construction.

Darsamand anticline carbonate rocks are well exposed which are of Jurassic (Samana Suk formation), Cretaceous (Kawagarh formation), and Paleocene (LockhartLimestone) age. No work exists on the aggregate potential of these carbonates in the vicinity of Darsamand anticline. So, this study is conducted to report the aggregate potential of these extensively exposed carbonate deposits.

1.3.1 Research Gap

The quality of aggregate of Margalla Hill Limestone have enabled it to be widely used in construction projects. It is widely used in Pakistan in mega engineering projects, and now almost on the verge of extinction. Therefore, this research work is designed to explore the huge deposits of Lockhart Limestone and Kawagarh Formation of Darsamand anticline, Khyber Pakhtunkhwa, Pakistan as an alternate source of the Margalla Hill Limestone for construction aggregate. In present research study, not only the geotechanical aspect of Lockhart Limestone and Kawagarh Formation were studied, but also the detailed petrographic and geochemical analysis were also carried out. Adding to this, the suitability of Lockhart Limestone and Kawagarh Formation as a potential source for mega Engineering projects, mutual correlation between petrographic, geochemical, and geotechanical parameters were analyzed.

1.4 Objectives

Pakistan is swiftly switching towards urbanization in terms of mega engineering projects such as, China Pakistan Economic Corridor (CPEC) which is a mega project of the country with worth of 46 billion US dollars. It includes the construction of roads, industrial zones, power houses, and bridges at different locations of the country. The demand of mega projects is increasing day by day and already proposed and areas for the extraction of carbonates are on the verge of extinction. Apart from this, most of the carbonate formations in Pakistan are not according to international standard of construction aggregate. The Lockhart Limestone and Kawagarh Formation are situated at Darsamand anticline, Hangu, Khyber Pakhtunkhwa, Pakistan which is also linked to Punjab province via Kohat. The huge deposits of Lockhart Limestone and Kawagarh Formation of Darsamand Anticline needs to be explore as a source of aggregate for mega engineering projects, in order to meet the demands of construction material for both Khyber Pakhtunkhwa and Punjab province**.**

Chapter 2

REGIONAL GEOLOGY

The Himalayas, a mountain range spanning around 2,500 kilometers in length, originated from the convergence of the Eurasian Plate to the north and the Indian Plate to the south, occurring approximately 50-65 million years ago. The aforementioned geological phenomenon, commonly referred to as continent-continent collision, has resulted in the formation of a relatively recent and rather stationary entity (Gansser 1964; Lefort 1975; Molner and Tapponnier 1975; Fraser et al. 2001). The northward advance of the Indian plate from Gondwana commenced around 130 million years ago (Jonson et al., 1976), leading to the contraction of the Neo-Tethys located between the Indian and Eurasian plates (McKenzie and Sclater, 1976).The convergence between the Kohistan-Ladakh arc and the Eurasian plate approximately 70-100 million years ago led to the formation of a continental margin resembling the Andean-type. Consequently, this collision gave rise to a newly formed geological feature referred to be the Main Karakorum Trust (MKT). Based on [Powell, 1979] study conducted in 1979, it was found that the subduction process of Neo-Tethys beneath the KIA was uninterrupted and resulted in the complete consumption of the leading edge of the plate. This eventually led to a collision between the remnants of KIA and the subducted plate during the Eocene period. The collision occurred along the Main Mantle Thrust (MMT) between 50-65 million years ago, as indicated by the research conducted by (Smith et al. and Chamberlain 1994; and Zeitler, 1996). The southern limit of Himalayan deformation is demarcated by the Main Boundary Thrust (MBT), situated south of MMT. The Northern Deformed Fold and Thrust Belt serves as a geological boundary that separates MMT and MBT. According to (Ahmad, 2003), the Mesozoic and more recent strata of the Northern Deformed Fold and Thrust Belt have been displaced over Miocene mollase sediments by the MBT.

The Salt Range Thrust (SRT) is located south of the MBT. The geological feature in question is comparatively more recent than the Main Boundary Thrust (MBT) and is indicative of the southward continuation of the Himalayan tectonic deformation. The Seismic Reflection Transect (SRT) in Pakistan has been found to be laterally similar to the Himalayan Main Frontal Thrust (MFT) according to a study conducted by (Baker et al., 1988). The Southern Deformed Fold and Thrust Belt refers to the geographical region situated between the Main Boundary Thrust (MBT) and the Sub-Himalayan Ranges Thrust (SRT). The geographical area under consideration comprises the Kohat and Potwar plateaus within the Upper Indus Basin. The SRT has a tectonic setting where Eocene-Paleozoic rocks are subjected to thrusting over Pliocene-Recent sediments. According to (Ahmed, 2003), the Salt Range Thrust and the Trans-Indus Ranges Thrust are currently active deformational fronts situated on the Indo-Gangatic foredeep. These thrusts are responsible for the southern displacement of Cambrian to Paleocene rocks.

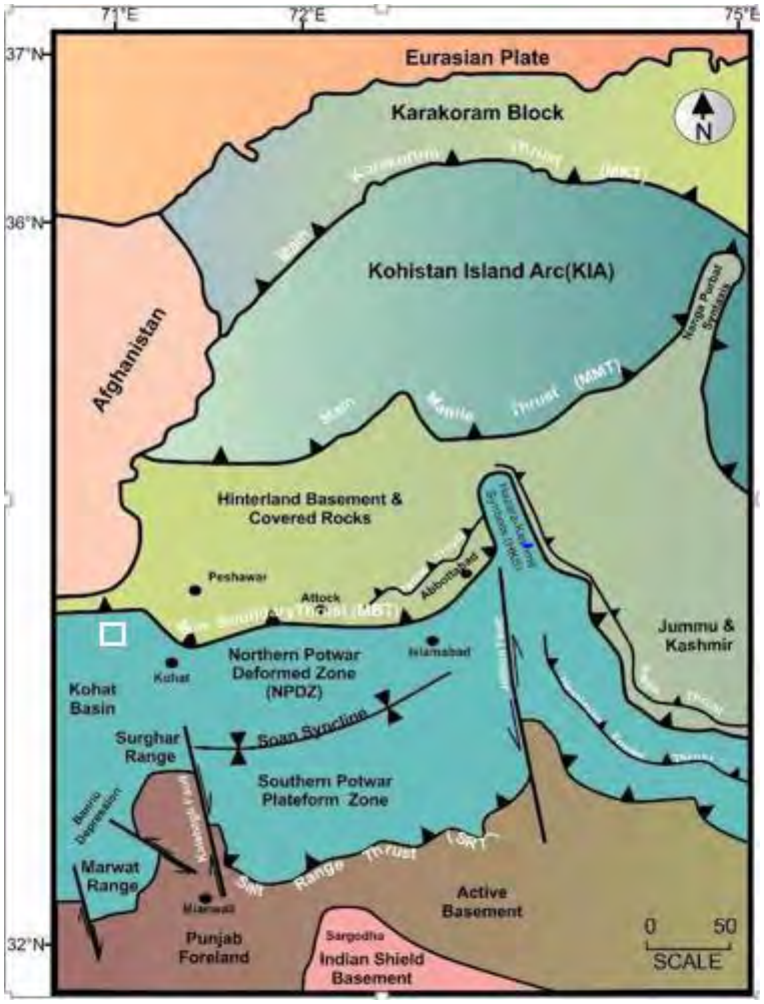

Figure 1.1 Tectonic Map of Pakistan showing major structural boundaries and Location of research area (white box) (After Kazmi and Rana, 1982).

2.1 Local Geology

The Darsamand anticline is a significant anticlinal structure evident along the Main Boundary Thrust (MBT). To the north, it is limited by Cretaceous Kurram group rocks. The Kohat Foreland Basin is located in the Lesser Himalayas in north Pakistan, to the south of the Darsamand anticline. The Darsamand Anticline is an East-West trending fold structure that separates the Kurram Group rocks to the north (southwest) from the Kohat Plateau Eocene-Miocene rocks to the south (southeast).

This fold is quite large, with a half wavelength of 0.5 km and a striking length of over 20 km. This fold's tendency is east-west, parallel to the broader structural trend of the Kohat belt. This structural trend is comparable to the Samana Anticline, which is thought to represent a fault propagation fold severed at the Jurassic rock level (Ahmad et al., 2003). The Kurram Fault connects severely deformed Mesozoic rock from Samana, Darsamand, Thall, and North Waziristan Agency with Kohat Plateau deposits from the Eocene to Miocene (Ahmad et al., 2003). The basin's geographic and geological boundaries with Orakzai Agency to the west are marked by a succession of an echelon anticline trends such as Khadimak, Darsamand, and Samana Anticline (Samana Range). These formations revealed a Jurassic to Paleocene rock succession consisting of limestone, shale, and sandstone that was 1000 meters thick. (Ahmad et al., 2003)

2.2 Stratigraphy of the Area

The Jurassic to Paleocene rocks is exposed in the Darsamand anticline (Figure, 2.2). The Jurassic unit is comprised of Samana Suk Formation which is a limestone dominated unit and at places is dolomitized. The Samana Suk Formation is unconformably overlain the Cretaceous Chichali Formation which is dominantly composed of glauconitic Sandstone. Then Lumshiwal Formation overlies the ChichaliFormation is composed of Sandstone. The micritic limestone dominated unit late Cretaceous Kawagarh Formation has a sharp lower contact with the Lumshiwal Formation. The Kawagarh Formation is overlain by the Paleocene sandstone dominated Hangu Formation which in turn is overlain by the late Paleocene Lockhart Limestone.Green shales and dirty brownish sandstone bearing patala Formation shale is exposed at the limbs of the anticline. The detailed stratigraphic column of Darsamand anticline is given below (Figure 2.2).

2.2.1Paleocene Sequence

In Darsamand Anticline, Lockhart Limestone and Hangu Formation sandstone are extensively exposed, while Patala Formation only few meters in length is exposed at the limbs of the anticline.

2.2.1.1 Patala Formation

The "Patala shale" of (Davis and Pinfold, 1937) was renamed "Patala Formation" by the Pakistan Stratigraphy Committee. The type locality of Patala formation is in salt range by the name of Patala Nala. In Darsamand Anticline Patala Formation is exposed along the flanks of Anticline which is only 3-4 meters in length. In Darsamand Anticline Patala Formation composed of brown fossiliferouse brown shales. Patala Formation makes an upper contact with Lockhart Formation.

2.2.1.2 Lockhart Limestone

The Stratigraphic Committee of Pakistan has applied the label "Lockhart Limestone" to similar Paleocene limestone strata in other parts of the Kohat-Potwar region (Davies, 1930). The unit's type locality is the Samana Range near Fort Lockhart (Lat. 33° 26' N: Long. 70° 30' E).

The large, rubbly, rubble-like, medium to thick-bedded, grey to medium grey Lockhart Limestone in Kohat is brecciated in some places (Figure 2.3). The flaggy base of this limestone unit is dark grey to bluish grey. This formation is conformable to the Paleocene Hangu Formation below and Patala Formation above.

The Kohat-Potwar Province has good Lockhart Limestone development. It is 40 m thick at Thal on the northwest Kohat Plateau, 60 m at the type locality, and 36 m in Darsamand.

2.2.1.3 Hangu Formation

The Hangu Formation was designated by the Pakistan Stratigraphy Committee; previously, it was known as Hangu Shale or Hangu Sandstone. The Hangu Formation's type locality is in the Kohat basin. The Hangu Formation is exposed in various areas of Pakistan with varying lithological features. The Hangu Formation exposed Darsamand Anticline is 75 meter in length. Hangu formation of Darsamand Anticline composed of coarse, and pure quartzose white sandstone having porosity and permeability than other sandstone.

2.2.2 Cretaceous Sequence

Cretaceous sequence of Darsamand Anticline comprises of Chichali Formation, Lumshiwal Formation, and Kawagarh Formation. Kawagarh Formation is extensively exposed within the Darsamand Anticline, while Chichali and Lumshiwal Formation is exposed but vegetated.

2.2.2.1 Kawagarh Formation

Kawagarh Formation was proposed by (Fatmi, 1977). Its type locality is in the Attock Distt, which lies north of the major Kala Chitta Range.

This Formation is extensively exposed in Darsamand anticline and is also named as “Darsamand Limestone” in the western Kohat. The formation is divisible intotwo members.

The lower Chalor Silli member and the higher Tsukhail Tsuk limestone component. The Tsukhail Tsuk peak, located north of Darsamand (latitude 33°, 26, 25] N, longitude 70°, 38', 9"), and the Chalor Silli village, located in the Samana Ranges (latitude 33°, 26, 25] N, longitude 70°, 38', 9") are the names of the two members in western Kohat.

Western Kohat generally contains the Kawagarh Formation, a thick-bedded sub-lithostratigraphic limestone unit, in the top part of the Tsukhail Tusk limestone member and in the lower portion of the Chalor Silli member (Figure, 2.3). The thickness in western Kohat ranges from 120 m in the Darsamand area to 110 m in the Samana Ranges.

This Formation is in disconformable contact with the underlying Lumshiwal Formation, which is primarily early Cretaceous in age, and the Paleocene-aged Hangu Formation that it overlies. Kawagarh Formation having a smaller number of larger fossils except from Darsamand Anticline where ammonites. This Formation is poor in mega fossils except in Darsamand area which has some ammonites in the basal part of the Kawagarh Formation. The Kawagarh Formation has been assigned a late Cretaceous age (Shah, 2009).

2.2.2.2 Lumshiwal Formation

The "Lumshiwal Sandstone" by (Gee, 1945) was renamed "Lumshiwal Formation" by the Pakistan stratigraphic committee. At Darsamand Anticline Lumshiwal formation is exposed across the Anticline. The upper section of the Lumshiwal Formation at Darsamand Anticline is comprised mainly of sandstone with red marl interbeds. The Lumshiwal Formation's lowest section is dark grey with gluconitic shale. A significant portion of the Darsamand Anticline Lumshiwal Formation is vegetated.

2.2.2.3 Chichali Formation

Previously, it is known as “Beleminte Bed” but later on it was changed by (Danilchik and shah, 1967) to Chichali Formation. The type locality is Chichali Pass in Surghar Range of District Mianwali. According to (Shah, 2009), this formation contains fossilized belemnites, brachiopodes, and ammonoids in glauconitic sandstone and brownish-gray sandy glauconitic shale. At the Samana Anticline, the Chichali Formation of the Drasamand Anticline is entirely exposed and covered in vegetation.

2.2.3 Jurassic Sequence

In Darsamand Anticline, Samana Suk Formation of Jurassic sequence is exposed.

2.2.3.1 Samana Suk Formation

The limestone is known as Samana suk (Davis, 1930) and is located in the western side of the Samana Range, to the north-east of Shinawri settlement. The grey-colored Samana suk Formation is extensively exposed and immensely bedded at the Darsamand Anticline.

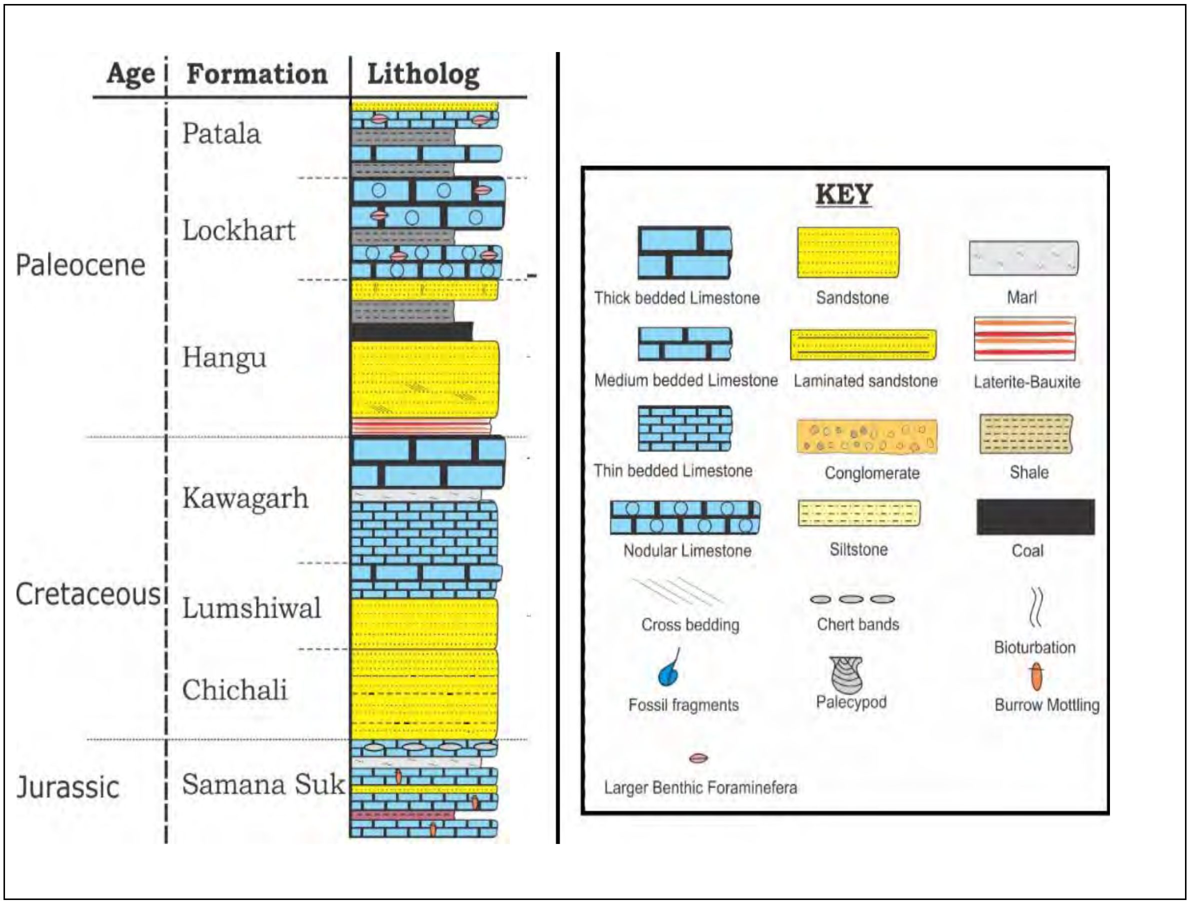

Figure 2.2 Stratigraphic column of different lithologies of Darsamand Anticline

Figure 2.3 Photograph showing outcrop of Lockhart Formation

Figure 2.4 Photograph showing the outcrop of Kawagarh Formation

CHAPTER 3

METHODLOGY

Introduction

The representative bulk samples were collected from the Lockhart Limestone and Kawagarh Formation exposed along the flanks of the Darsamand Anticline. A total of 16 limestone samples (8 each) were collected from the outcrops of Lockhart Limestone and Kawagarh Formation at Darsamand anticline for detail assessment of geotechanical parameters. The bulk samples of Lockhart Limestone and Kawagarh Formation were crushed according to the standard size of (ASTM) and (AASHTO) at Pakistan Council of Scientific and Industrial Research (PCSIR).

Specific gravity (S.G), water absorption (Wa), aggregate impact value (AIV), soundness, flakiness, and elongation index (IE), Loss Angeles abrasion values (LAV), and coating and striping were performed on aggregate samples from the Lockhart Limestone and Kawagarh Formation in the Geotechnical Laboratory of the National Centre of Excellence in Geology (NCEG), University of Peshawar.

3.1 Field Observation

Three days detailed field was carried out across the Darsamand Anticline which is exposed along the main boundary thrust. Darsamand anticline is a double plunging anticline and is a huge anticlinal structure, 0.5 km wide and more than 20 km in strike length. The trend of this fold is east-west which is parallel to the trend of Kohat belt. The strata's within Darsamand anticline are well exposed except the Patala Formation which is exposed at the flanks of the anticline only 2-3 meters in length.

The carbonates e.g Lockhart Limestone and Kawagarh Formation of Darsamand Anticline are well exposed across the anticline. During the field detailed investigations of Lockhart Limestone and Kawagarh Formation were carried out. During the field observations the Kawagarh Formation of Darsamand Anticline are medium to thick bedded, grey to pale yellow in color, fractured, having small to large stylolites filled with calcite cements, small to large calcite veins mostly in cross cutting relationship with each other, dissolution phenomena (cavernous dissolution) taken place because of rain water, microscopic marine fauna had been observed within the Kawagarh formation of Darsamand anticline as shown in (Figure 3.1 and 3.2). The upper contact of the Kawagarh Formation is with the Lumshiwal Formation, and the lower contact is with the Lockhart Limestone, as seen in (Figure 3.3, C).

The Lockhart Limestone of Darsamand Anticline are massively bedded, grey in color, less fractured, calcite veins filled with calcite cements, less dissolution phenomena, medium to large nodularity, small marine micro fossils apart from this Gastropods are well preserved within the Lockhart Formation of Darsamand Anticline as shown in (Figure 3.3 and 3.4). The lower contact of Lockhart Limestone of Darsamand Anticline are with Patala Formation which is exposed along the limbs of anticline only few meters in length as shown in (Figure 3.4, B), while the upper contact of Lockhart Formation is with the Hangu Formation as shown in (Figure 3.3, D).

Figure 3.1 Field photographs showing (A) stylolites and weathered surface (B) stylolites and veins (C) outcrop of the Kawagarh Formation and contact of Lumshiwal Formation with Kawagarh Formation

Figure 3.2 Field photographs showing (A) weathered surface (B) stylolites and veins (C) Fractures of the Kawagarh Formation

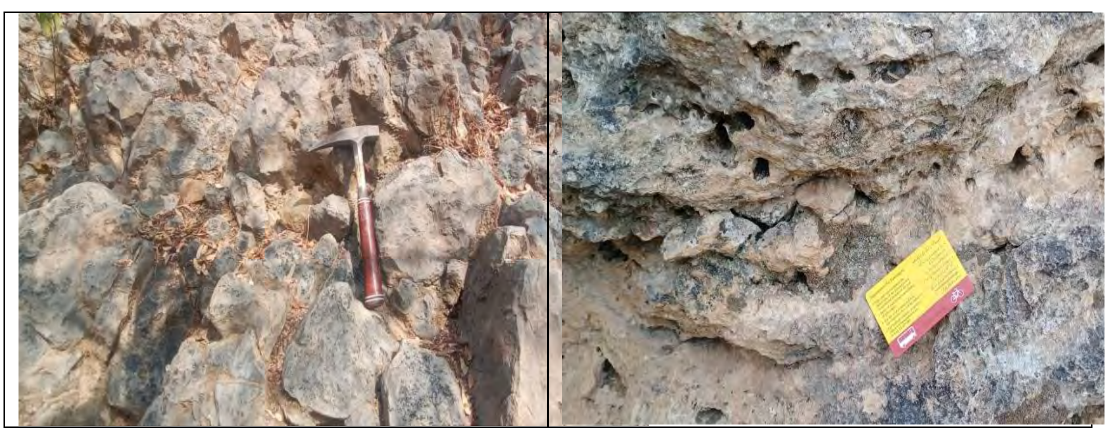

Figure 3.3 Field photographs showing(A) Nodularity (B) weathered surface and nodularity (C and D) contact between Hangu formation and Lockhart Formation

Figure 3.4 Field photographs showing (A) bulky and nodular unit (B) contact between Lockhart Formation and Patala Formation (C) weathered surface and dissolution activities within Lockhart Limestone

3.2 Thin Section Preparation

Thin sections of Lockhart Limestone and Kawagarh Formation rock samples were processed at the Quaid-I-Azam University, at thin section laboratory according to ASTM C 295-12. With the use of a diamond rock cutter, thin sections were cut to size (Thickness = 1 inch, Width = 1 inch, Length = 2 inches). The rock chips were then polished and adhered to the glass by 18 canada balsam to obtain the standard thin sections for petrographic analysis, it was ground and polished by means of mesh No.120, 240,300, 400, 600, and 1000 corundum powder. After, obtaining the standard size of the thin sections it was analyzed then at Microscope Lab at the same department.

3.3 Physical Properties

Carbonates rock and usually occurs in thick beds which are structurally simple and easy to quarry. . The physical and mechanical qualities of limestone must always be considered when evaluating it for multipurpose applications. Strength and durability, as well as specific gravity and water absorption, are essential factors in determining its suitability for usage as an aggregate source. A detail account of the various standard aggregate tests conducted over the aggregate samples from Lockhart Limestone and Kawagarh Formation is given as under.

3.3.1 Los Angeles Test

Procedure

As a gauge for the caliber and competency of the aggregate samples, the Los Angeles test (ASTM C 131-89) is implemented. The test is highly helpful for determining the aggregate's quality and identifying its characteristics for a certain purpose. The purpose of the test is to determine the percentage wear produced on the aggregate by the relative rubbing action of the steel balls used as an abrasion charge (Lea, 1976). Insufficiently resilient and abrasion-resistant aggregates might give rise to problems during construction. Depending on the nature of class A aggregate, ASTM recommends one of four classes for this test. Class aggregating of aggregates was utilized in determining the Los Angeles abrasion value of limestones, and the resulting results were then compared to the ASTM-specified limits. The percentage of weight loss in the aggregate is the result of this test's value. As a result, the rock is more competent the lower the value. The ASTM-recommended acceptable range is 0-40%, as illustrated in (Figure 3.5).

3.3.2 Soundness

Procedure

The soundness test is used to measure the soundness of aggregates in concrete or in other applications when exposed to weathering conditions, and it provides a preliminary estimate of aggregate resistance to weathering. The method involves repeated immersions of aggregate in saturated solutions of sodium sulphate, followed by oven drying to dehydrate the salt precipitated in permeable pore spaces. The rehydration of the aggregates stimulates internal expansion of water on freezing. The soundness of aggregates from the studied limestone Formations of district Hangu was determined in accordance to (ASTM method C 88-90). Qualitative examination of the samples after the test performed showed results below. The values obtained by this testrepresent the percent loss in weight. The permissible range of values recommended byASTM is 0-12.

3.3.3 Specific Gravity

Procedure

The specific gravity for the course aggregate was calculated by taking ratio between weight of aggregate in air and the water. The test sample was oven dried over-night in order to get moist free sample. Then the test sample was weighted in air by using electronic balance. Afterward, the sample is weighted in the deionized water. Thus, the ratio of sample weight in air in water will give us its specific gravity by using the below given formula;

Specific gravity = (weight in air) / (weight in air-weight in water)

3.3.4 Water Absorption

Procedure

For determination of water absorption of the aggregate, 2000 gm of oven dried ½ sieve passing material was immersed in the deionized water, for 24 hours. After the completion of immersion period, sample was removed form water in the thin film of water present on the aggregate was roll off by an absorbent cloth. The percentage in theweight gain is calculated as water absorption as follows;

$$\text{Water absorption (\%)} = \frac{100(\text{final weight- initial weight})}{(\text{Initial weight})}$$

3.3.5 Impact Value

Procedure

The aggregates undergo fragmentation into smaller particles due to the impact resulting from vehicular traffic on the road (ASTM C125). Consequently, it is imperative that the aggregates exhibit resilience in order to withstand impact-induced disintegration. The evaluation of this feature is conducted through the utilization of the effect value test. The ability to withstand sudden impact or shock is assessed by the aggregate impact value, which can vary from the ability to withstand gradually applied compressive stress.

To calculate road pavement aggregate impact value. Assess their suitability for road layers (base and surface) based on effect value.

A 45–60 kg testing equipment having a metal base and a plane bottom surface with a minimum diameter of 30 cm. An at least 45 cm thick level and flat concrete floor supports it. The base should also have mechanisms for fixing the machine's base. 102 mm internal diameter, 50 mm depth, and 6.3 mm minimum thickness describe a cylindrical steel cup. Sieve material with 12.5mm and 10.0mm IS sieves. The test material is 12.5 mm sieved aggregates. The aggregate is subsequently poured into the measurement cylinder, filling only one-third of its whole depth. The material should be compacted within the cylindrical mould by applying 25 gentle blows using the rounded end of the tamping rod. Two additional layers are arranged in a like manner in order to occupy the entirety of the cylindrical space. Eliminate the surplus accumulations. Calculate the precise net weight (W1) of the aggregates, rounded to the nearest gram. Position the impact machine onto the level plate, block, or floor in a manner that ensures rigidity and vertical alignment of the hammer guide columns, without the need of wedging or packing materials.

Next, position the hammer at a height of 380 mm above the aggregate surface within the cup, and allow it to descend without any external force upon the sample of aggregate. The individual is exposed to a series of 15 strikes, with a one-second interval between each strike.

The crushed aggregate should be extracted from the cup and subjected to filtration using 2.36 mm IS sieves for a duration of one minute, or until there is no further significant amount passing through. Measure the weight of the fraction that successfully passes through the sieve with a precision of 1 gram (W2). As depicted in Figure 3.6, the percentage of material that remains in the sieve is assigned a weight..

3.3.6 Flakiness and Elongation

The percentage of elongated and flay minerals found in aggregate particles distinguishes their shape. The presence of more flaky and elongated minerals is considered unfavorable for the building of concrete types because elongated and flaky minerals produce weakness with the possibility of shattering under significant applied stress. As a result, evaluating particle form in terms of elongation and flakiness is essential.

The aggregate flakiness index refers to the ratio of particles, based on weight, that have a lowest dimension (thickness) less than three-fifths (0.6 times) of their average size. According to the information presented in Figure 3.6, the flakiness test is suitable for particles with diameters below 6.3 mm.

The term "aggregate flakiness index" denotes the proportion of particles, measured by weight, whose minimum dimension (thickness) is less than three-fifths (0.6 times) of their average size. Based on the data provided in Figure 3.6, it can be inferred that the flakiness test is applicable to particles with diameters smaller than 6.3 mm.

Procedure

The sample should be passed through the IS sieves in order to separate and classify its particles. Collect a minimum of 200 samples of rock aggregate for each fraction that will undergo testing, and proceed to measure their weight. In order to achieve the separation of flaky particles, it is necessary to calibrate each fraction with respect to its thickness using a thickness gauge. The width of the aperture utilized should align with the specified measurements for the corresponding particle dimension. This analysis assesses the reliability of the brittle substances that successfully meet the calibration criteria, exhibiting a precision level of less than 0.1% in relation to the samples under examination. The process of calibrating individual fractions for length using a length gauge is essential for the separation of elongated minerals. The selection of the slot thickness should align with the required dimensions that correspond to the suitable particle size. Assess the elongated materials held on the gauge with a precision of 0.1 percent of the evaluated samples.

3.3.7 Crushing Value

The procedure of conducting the aggregate crushing value test on coarse aggregates allows for a comparative evaluation of the ability of an aggregate to withstand crushing when subjected to a gradually increasing compressive load. The coarse aggregate crushing value refers to the proportion, expressed as a percentage by weight, of crushed material obtained when test aggregates are subjected to a specific load under predetermined conditions.

Procedure

Place the cylinder on the base plate in this position and weigh it (W). After sorting the samples into three heaps, each pile is subjected to a load of 25 strikes with a tamping rod. In case of fragile behavior of the material maintenance of the particles is important in order to prevent it from breakage and weight it (W). Flat the upper layer of the aggregate with carefulness and embed the plunger so that it can lies transversely on the upper layer. Carefulness is important to assure that the plunger does not tie- up in the cylindroid. Put the cylindroid with plunger on the drop-off location of the compressing testing machine. The load should be introduce at the homogenous pattern as such that the total force of 40T is introduced in ten (10) minutes. Remove the load and collect the material from the cylindroid. Carefulness is important while sieving the material with 2.36 mm IS sieve in order to prevent the loss material. Weight the smaller fine fragments moving through the sieve (W2). In each test, the proportion of finer particles produced to total sample weight should be shown as a proportion, with the results recorded to the first decimal fraction.

Aggregate crushing value = (W2 x 100) / (W1-W2)

W2 =Weight of fraction passing through the appropriate sieve

W1-W =Weight of surface dry sample.

3.3.8 Coating and Stripping Value (AASHTO-182)

The coating and stripping values of the source aggregates are distinguished by a proportion of the exposed area observed with naked eyes to the total area of aggregates.

Procedure

200 grams of dry, clean aggregates that pass through a 20mm filter and are held on a 12.5mm sieve should be heated to 1500 C. Take 5% of the bitumen binder by weight and heat it to 1600 C. The aggregates and binder should be thoroughly combined before being transferred to a 400 ml beaker and allowed to cool at room temperature for about two hours. The coated aggregates should be submerged in distilled water. Cover the beaker and keep in a water bath maintained at 400 C taking care that the level of water in the water bath is at least half the height of the beaker. Bitumen coated Aggregates kept outside, and kept in distilled water for observation of stripping of bitumen coating. After 24hours take the beaker out, cool at room temperature and estimate the extent of stripping visually while the specimen is still under the water as shown in (Figure 3.9 and 3.10).

3.4 Geochemistry

To find out the major oxides within the carbonates of Darsamand Anticline i.e Lockhart Limestone and Kawagarh Formation geochemical analysis were carried out at XRF Lab with PXRF at the National Centre of Excellence in Geology (NCEG).

3.4.1 Sample Preparation

In total four bulked samples 2 from Lockhart Limestone, and 2 from Kawagarh Formation of Darsamand Anticline were collected for geochemical analysis. Geochemical analysis were conducted through potable x-ray Fluorescence Spectrometry (PXRF) for finding out major oxides within the carbonates of Lockhart Limestone and Kawagarh Formation. In order to remove the surface adulterant whole rock samples were washed away with distilled water and scrub brush to make it feasible for geochemical analysis. Whole samples of rock were cleaned with towel and dry it compressed air. The dry rock samples were then marmalize and amalgamate by hands using agate mortar and pestle. From the rocks powder pressed powder pellets were prepared. The powders were pressed unchangeably to obtain consolidated powder pellets.

Figure 3.5 showing Los Angeles and abrasion equipment housed in Geotechanical Lab of NCEG

Figure 3.6 showing Impact value equipment housed at Geotechanical Lab of NCEG

Figure 3.7 Showing Flakiness test sieve housed at Geotechnical Lab of NCEG

Figure 3.8 Showing Elongation sieve housed at Geotechanical Lab of NCEG

Figure 3.9 Showing Coating and Stripping test of Lockhart Limestone

Conducted at Geotechanical Lab of National Engineering Services Pakistan

(NESPAK)

Figure 3.10 Showing Coating and striping test of Kawagarh Formation conducted at Geotechanical Lab of National Engineering Services of Pakistan (NESPAK)

CHAPTER 4

RESULTS AND DISCUSSION

Introduction

The various physio-mechanical analysis of the studied limestone of Kawagarh Formation and Lockhart Limestone such as Los Angeles Abrasion, Soundness, Crushing Value, Coating and Striping, Flakiness and Elongation, Impact Value, Water Absorption, Specific Gravity have been determined as shown in the below (Table 4.1). The values of various physico-mechanical tests for the analyzed limestones of the Kawagarh Formation and Lockhart Limestone are markedly different as shown in the (Table 4.1). The values of LAA, soundness is much high for Kawagarh Formation than that of the Lockhart Limestone while those of the impact value, crushing value, flakiness and elongation and specific gravity are lower than Lockhart Limestone. And, also more amount of calcium oxides in limestone of Lockhart Limestone as compared to Kawagarh formation which further influence its strength and potential as an aggregate source. While in Kawagarh Formation the recrystallization of calcite cements in cracks, bioclasts and in fractures is negligible as compared to Lockhart Limestone and also the amount of calcium oxides is less than that of Lockhart Limestone. This marked contrast difference in the physical properties can be solely attributed to the textural differences between the two studied limestone units' e.g the relative abundance of pure calcite, silica and oxides can reduce the potential of the aggregate. Moreover, the Kawagarh Formation being lithographic, porcelaneous and micritic is much weaker than the granular limestone of the Lockhart Limestone. However, according to the standards of engineering parameters both limestones can be use in mega engineering projects.

4.1 Comparison between Physical Properties of Kawagarh Formation and Lockhart Limestone

The difference between the physical properties of carbonates of Darsamand Anticline is attributed to the textural characteristics of Kawagarh Formation and Lockhart Limestone. The increase in values of physical parameters of Lockhart Limestone is due to the recrystallization of calcite cements in microstructures of Lockhart Limestone as compared to Kawagarh Formation which ultimately increase the potential of aggregate as a source in mega engineering projects. However, values of geotechanical parameters of Kawagarh Formation and Lockhart Limestone are according to the standards of ASTM and are feasible for use as an aggregate source and on concrete designed projects. The values of physico-mechanical properties of Kawagarh Formation and Lockhart Limestone are given below in (Table 4.1).

Table 4.1 showing the marked difference between the geotechanical parameters of Lockhart Limestone and Kawagarh Formation of Darsamand Anticline

Tests	**Kawagarh Formation**	**Lockhart Limestone**
Loss Angeles	30.1%	26.7%
Soundness	3.5%	2.6%
Specific gravity	2.694 SSD 2.682 Oven dry 2.715 Apparent	2.687 SSD 2.681 Oven dry 2.697 Apparent
Water absorption	0.45%	0.23%
Flakiness and elongation	6.13%	6.41%
Impact value	22.9%	18.3%
Crushing value	25.3%	22.6%

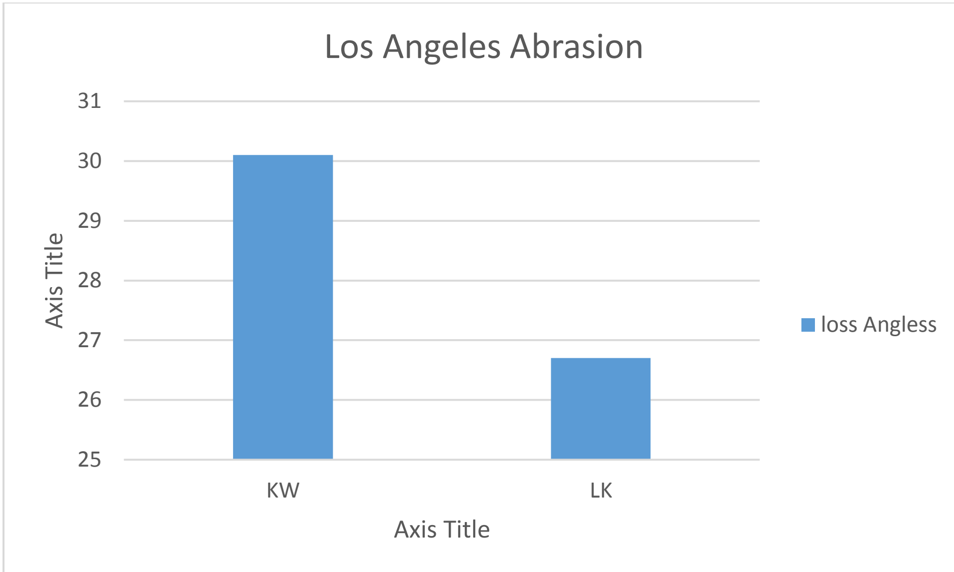

Figure 4.1 Graphical representation of Los Angeles and Abrasion of Lockhart Limestone (LK) and Kawagarh Formation (KW)

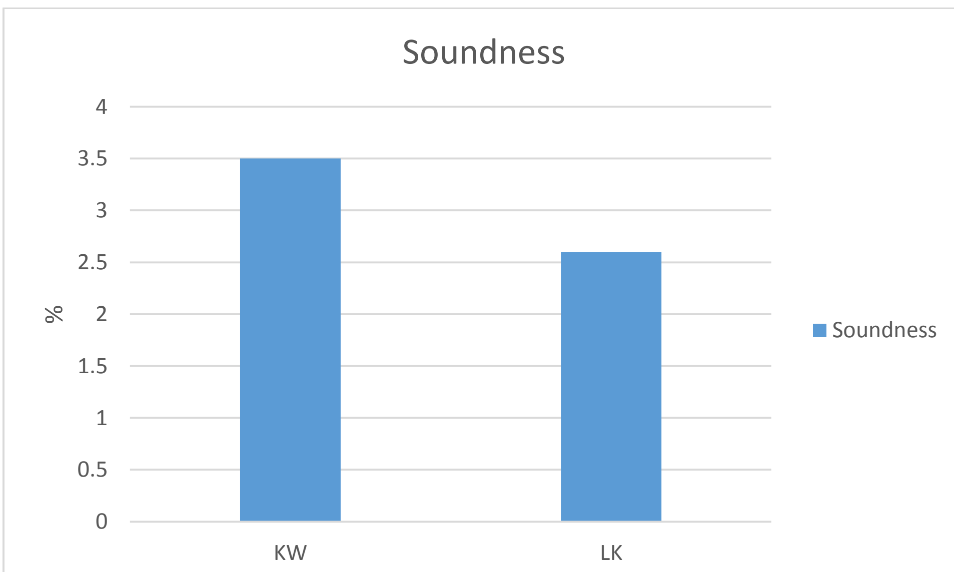

Figure 4.2 Graphical representation of Soundness of Lockhart Limestone (LK) and Kawagarh Formation (KW)

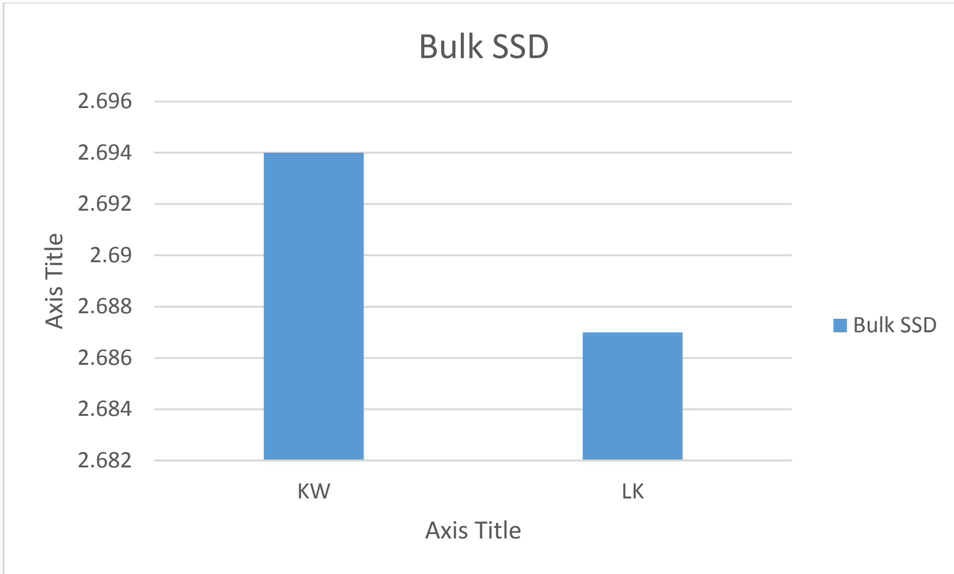

Figure 4.3 Graphical representation of Bulk SSD of Lockhart Limestone (LK) and Kawagarh Formation (KW)

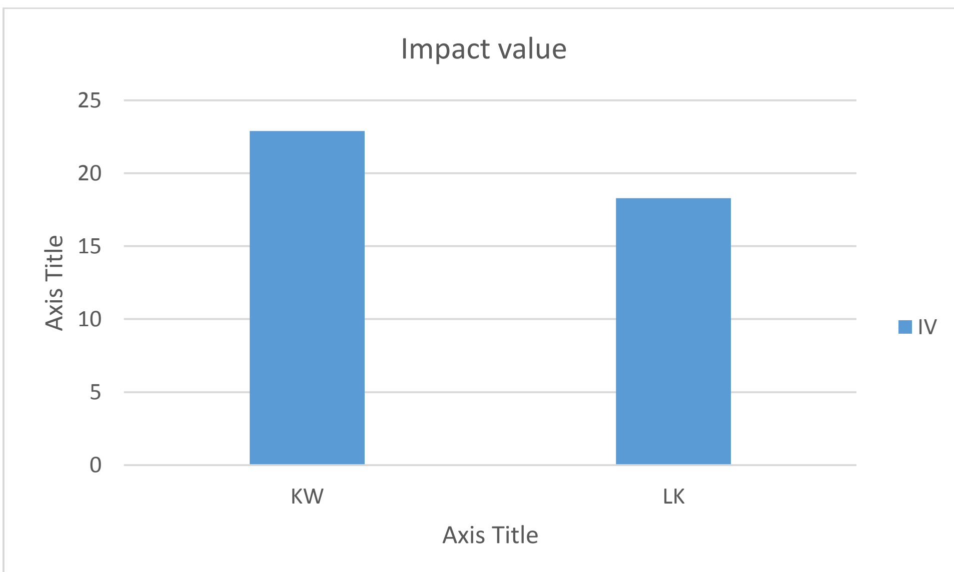

Figure 4.4 Graphical representation of Impact value of Lockhart Limestone (LK) and Kawagarh Formation (KW)

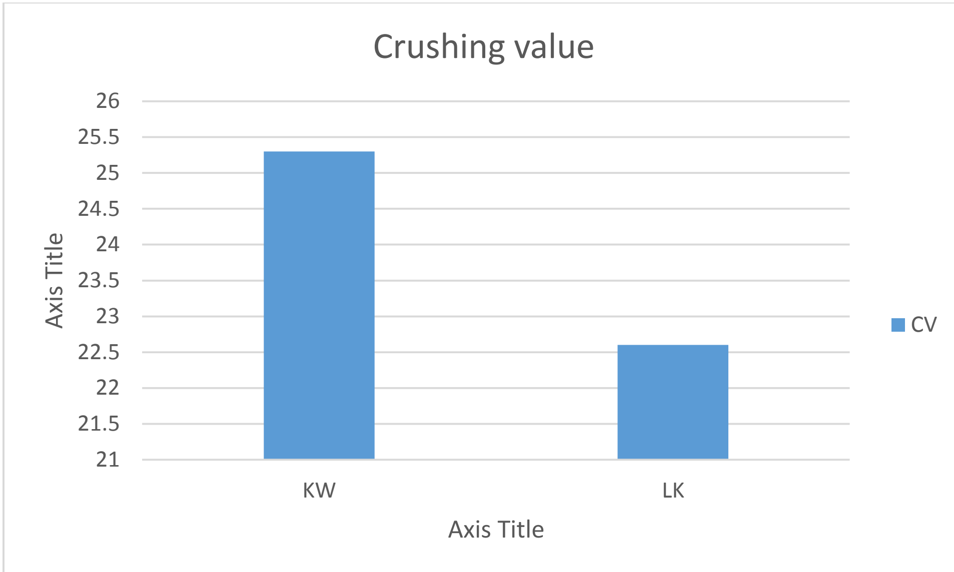

Figure 4.5 Graphical representation of Crushing value of Lockhart Limestone (LK) and Kawagarh Formation (KW)

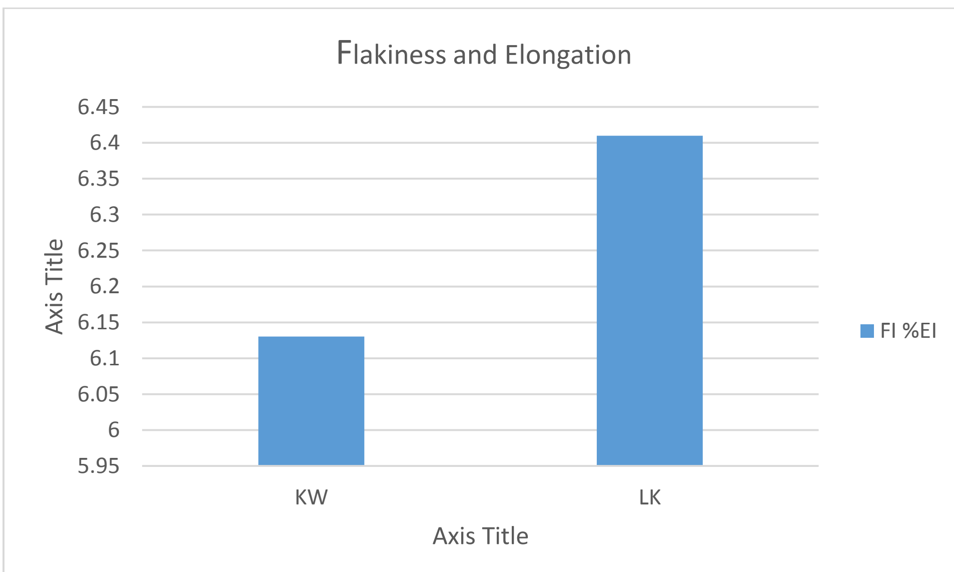

Figure 4.6 Graphical representation of Flakiness and Elongation of Lockhart Limestone (LK) and Kawagarh Formation (KW)

4.2 Comparison between Geochemistry of Kawagarh Formation and Lockhart Formation

Geochemically, the relative abundance of pure calcite and oxides and other deleterious minerals such as silica, chalcedony, and flint can reduce the strength, and durability of the carbonates by causing adverse chemical reactions, however, within Lockhart Limestone of Darsamand Anticline the average abundance of calcium oxides (CaO) is greater than that of Kawagarh formation of Darsamand Anticline, adding to the above, the iron oxides Fe_2O_3 and silica of Lockhart Limestone is also less than that of the Kawagarh Formation of Darsamand Anticline as shown in the below(Table 4.2).

Table 4.2 showing the difference between major oxides of Lockhart Limestone and Kawagarh Formation

S.no	CaO%	SiO_2%	Fe_2O_3%	TiO_2%	K_2O %
KW 1	50.78	1.70	1.03	1.15	0.21
KW 2	51.49	3.25	1.45	1.50	0.20
LK1	54.00	2.76	0.64	1.45	0.06
LK2	52	2.35	0.54	1.65	0.05
Average for KW	51.13	2.48	1.24	1.32	0.20
Average for LK	53.00	2.56	0.59	1.55	0.06

4.3 Comparison between Petrography of Kawagarh Formation and Lockhart Limestone

The difference between the petrographic characteristics which further increase the suitability of aggregate of Lockhart Limestone as compared to Kawagarh Formation of Darsamand Anticline. This marked difference between Lockhart Limestone and Kawagarh Formation is due to the recrystallization of calcite cements within the veins, stylolites, bioclasts, and in fractures which increase the strength and quality of aggregate of Lockhart Limestone as shown in the above. (Table 4.3) showing the marked difference between the petrographic characteristics of Kawagarh Formation and Lockhart Limestone of Darsamand Anticline.

Table 4.3 showing the average petrographic percentage of Kawagarh Formation and Lockhart Limestone

Sample No.	Micrite	Bioclast	Calcite vein	Stylolites	Pyrite leaching	Fracture
KW Avg.	56%	18.8%	9.4%	11.5%	9.6%	13.5%
And LK Avg.	24%	21%	48%	-	10.3%	-

The physical attributes determined for the studied limestone units are compared with those of the other commonly used as rock aggregates limestone units in the Khyber Pakhtunkhwa and are found suitable for use in construction projects.

4.4 Comparative chart of Physical Properties of Limestones of Pakistan

The physical properties of the examined limestone units are compared to those of other commonly used as rock aggregates limestone units in Khyber Pakhtunkhwa and are found suitable for usage in construction projects, as shown in (Table 4.4).

Table 4.4 showing the difference between the physical parameters of different Limestone units that are extensively exposed in Pakistan, and currently are in use in mega engineering projects and for the construction of infrastructures

Tests	Margala hill Limestone (Abbottabad)	Khyber Limestone	Samana Suk Formation (Abbottabad)	Kawagarh Formation	Lockhart Limestone	Standards(limits)for aggregates
Loss Angeles	22.8%	26.6%	15.1%	30.1 %	26.7%	ASTM C-131(less than 40%)
Soundness	4%	2.5%	3%	3.5 %	2.6%	
Specific gravity	2.6%	2.7%	2.6%	2.7%	2.6%	ASTM 127 (min. 2.6)
Water absorption	0.96%	0.68%	1%	0.45%	0.23%	ASTM 127 (less than 2.5%)
Flakiness and elongation	13-15%	16-25%	17-25 %	6.13%	6.41%	Bs 112 p_105,882 and 812:105.2
Impact value	15-16%	-----	11 %	22.9	18.3	ASTM C 125 Max (30%)
Crushing value	------	-----	------	25.3	22.6	ASTM C131(less than 30%)

4.5 Geochemistry

In carbonate rocks, the presence of different types of deleterious minerals can affect the strength and durability of the aggregate. In carbonates, the higher amount of pure calcite (Ca), Fe_2O_3, and alkalis can cause mechanical failure, and expansion and popping out of the structures. In aggregate of the carbonates, if it contains certain deleterious minerals, can cause Alkali Silica Reaction (ASR), and Alkali Carbonate Reaction (ACR) which cause expansion and considerably reduce the strength, and durability of the civil structures. While on the other hand, the abundance of CaO increase the purity of the carbonates thereby increase the strength of the aggregate. The collected samples 2 from each, Lockhart Limestone and Kawagarh Formation of Darsamand Anticline were analyzed through XRF analysis. The (Table 4.5) shows the consolidation of main oxides as well as the graphical parameters with reasonable limitations of oxides of the Kawagarh Formation and Lockhart Limestone.

The concentration of main oxides of Lockhart Limestone and Kawagarh Formation is depicted graphically in (Figures 5.1, 5.2, 5.3, 5.4, 5.5). The chemistry of the studied carbonates is highly variable as shown in the (Table 4.1). According to the (Table 4.5) the oxides of the Kawagarh Formation ranging CaO from 50.78 to 51.49 wt% , SiO_2 from 1.70 to 3.25 wt%, Fe_2O_3 from 1.03 to 1.45 wt%, TiO_2 from 1.15 to 1.50 wt%, K_2O from 0.21 to 0.20 wt%.

Moreover, the oxides of Lockhart Formation ranging, CaO from 44 to 52 wt%, SiO_2 from 2.76 to 2.35 wt%, Fe_2O_3 from 0.64 to0.54 wt %, TiO_2 from 0.06 to 0.05 wt%, K_2 O from 0.06 to 0.05 wt% as shown in the (Table 5.1).

In carbonates, silica occur in different forms, such as, chert, chalcedony, flint, and holohyaline which can cause adverse chemical reaction with alkalis due their strong surface energy and weak internal structure. A silica gel is formed when the silica of the aggregate react with the alkalis of the cement which directly affect the strength, durability, and serviceability of the aggregate. However, the impurities present within the carbonates of Lockhart Limestone, and Kawagarh Formation are less than 2% which does not affect the potential of the aggregate. Besides, the concentration of the CaO in the Lockhart Limestone and Kawagarh Formation are greater than the 50% which portray that Lockhart Limestone and Kawagarh Formation of Darsamand Anticline are pure carbonates, and can be used as a source of aggregate in different construction projects.

Comparative graphical geo chemical analysis of carbonates of Darsamand Anticline are given below in the form (Table 4.5), and (4.1, 4.2, 4.3, 4.4, 4.5) which shows that, the concentration of CaO in the Lockhart Limestone is greater than that of Kawagarh Formation of s Darsamand Anticline. There is marked difference between the relative abundance of CaO, SiO_2, and Fe_2O_3 of Lockhart Limestone and Kawagarh Formation of Darsamand Anticline. The above (Table 4.1) shows that, Lockhart Limestone having greater amount of CaO and less amount of deleterious minerals such as silica, and other harmful oxides which increase the strength and suitability of aggregate of Lockhart Limestone as compared to Kawagarh Formation of Darsamand Anticline.

However, both carbonate units Darsamand Anticline fall according to the standard engineering parameters and are feasible for use in mega engineering projects.

Table 4.5 showing geochemical analysis of samples of Lockhart Limestone and Kawagarh Formation

S.no	**CaO%**	**SiO_2%**	**Fe_2O_3%**	**TiO_2%**	**K_2O%**
KW 1	50.78	1.70	1.03	1.15	0.21
KW 2	51.49	3.25	1.45	1.50	0.20
LK1	54.00	2.76	0.64	1.45	0.06
LK2	52	2.35	0.54	1.65	0.05
Average for KW	51.13	2.48	1.24	1.32	0.20
Average for LK	53.00	2.56	0.59	1.55	0.06

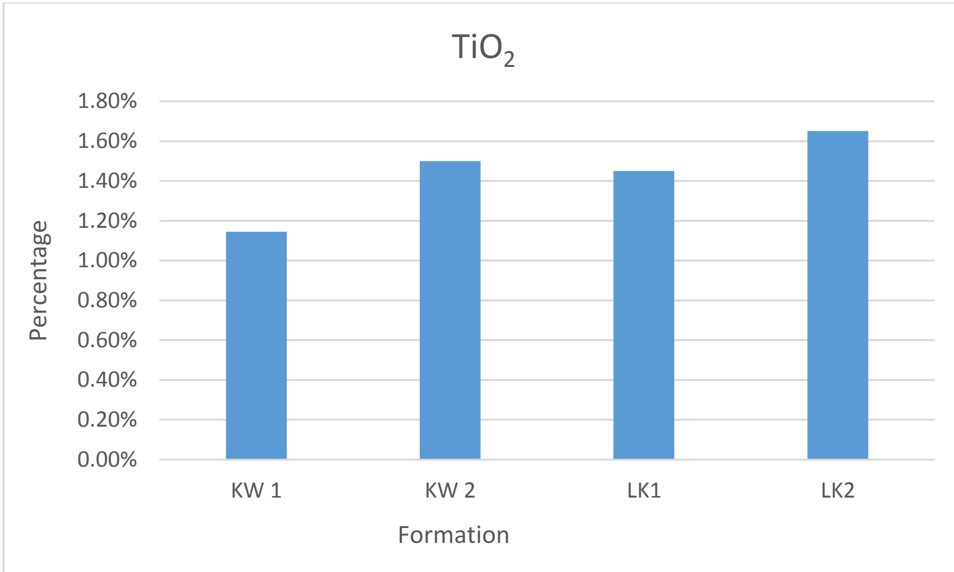

Figure 4.7 Graphical representation of TiO_2 of a collected samples of Lockhart Limestone and Kawagarh Formation

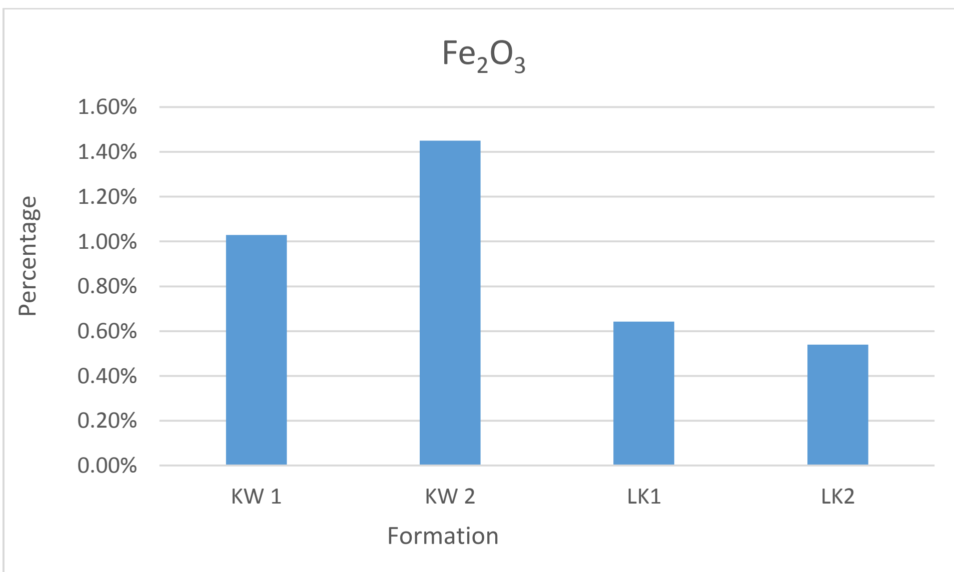

Figure 4.8 Graphical representation of Fe_2O_3 of a collected samples of Lockhart Limestone and Kawagarh Formation

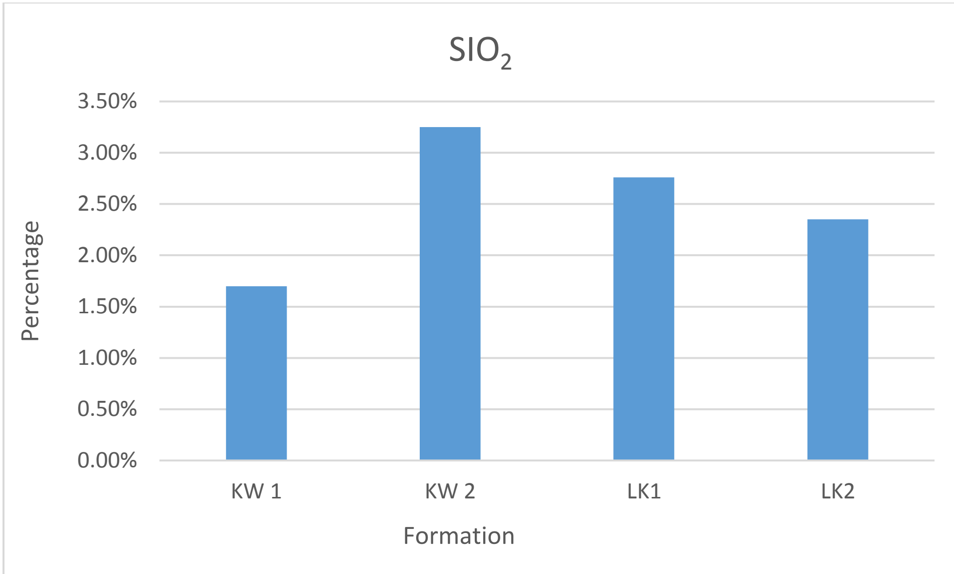

Figure 4.9 Graphical representation of SiO_2 of a collected samples of Lockhart Limestone and Kawagarh Formation

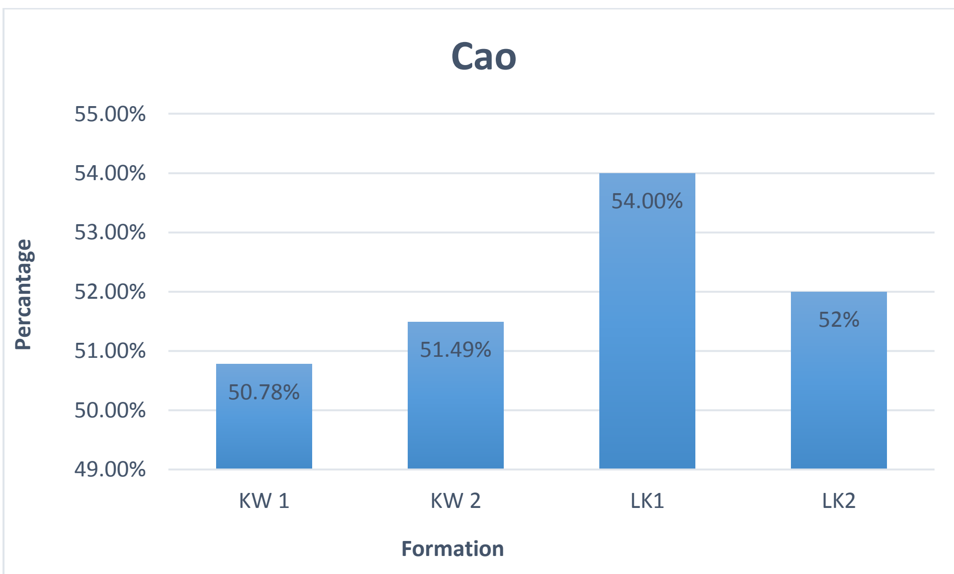

Figure 4.10 Graphical representation of CaO of a collected samples of Lockhart Limestone and Kawagarh Formation

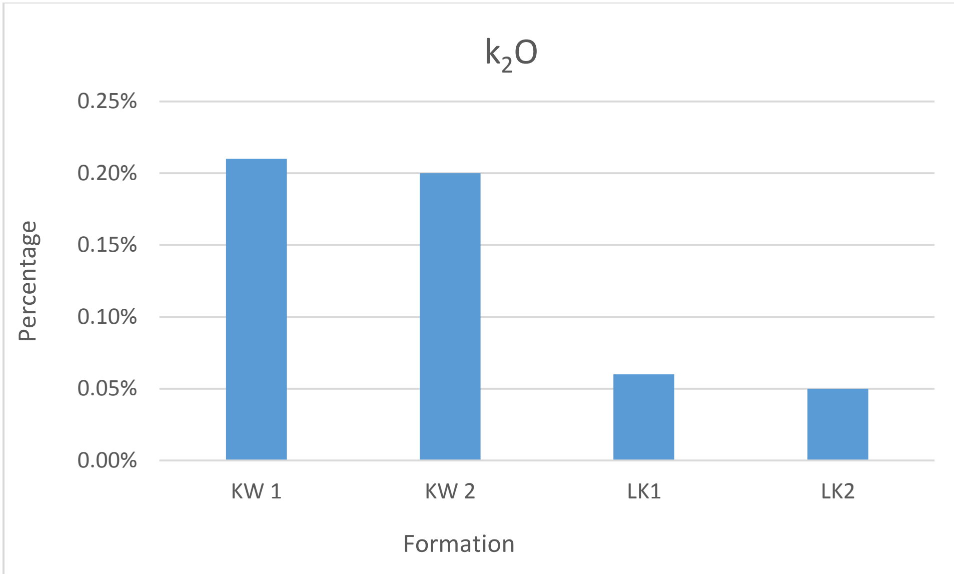

Figure 4.11 Graphical representation of K_2O of a collected samples of Lockhart Limestone and Kawagarh Formation

4.6 Physical Properties

The Limestone is a common rock and usually occurs in thick beds which are structurallysimple and easy to quarry. Besides these, limestone are excessively use in mega engineering projects as aggregate and in concrete. According to the (Omer and Ismial, 2015), 70% volume of concrete is comprise of aggregate, physical and mechanical properties of aggregate can influence the strength and suitability of concrete that is why our focus is physical and mechanical parameters of aggregate used in mega engineering projects. An evaluation of the limestone for multipurpose applications must always consider its certain physical and mechanical properties. Strength and durability together with specific gravity and water absorption are important in its assessment for use as aggregate source. Besides petrography and geo chemical analysis, the bulk samples were crushed and standard aggregate tests conducted over the aggregate samples from Lockhart Limestone and Kawagarh Formation is given as under.

Water absorption is most important parameter which determine all other geotechanical parameters of the aggregate. This parameter determined the ability of carbonates to store water in pores and fractures, greater number of pores, or greater capacity to absorb water can reduce the strength and durability of aggregate. Additionally, it establishes a connection between the bitumen and aggregate sources as asphalt percolates via pore spaces to create a stiffened and firmed relationship. The value for water absorption should not be greater than 2.5 %. The measured water absorption values for the Kawagarh Formation is (0.45%) and for Lockhart Limestone is (0.23%) as shown in the (Table 4.6).

According to the (Khan, et al., 2000) higher specific gravity is related to the mineral arrangement and its compacted pattern. While in contrast, the aggregate having low specific gravity are more fragile than those with high specific gravity. The apparent specific gravity of Kawagarh formation is 2.715 and that for Lockhart limestone is 2.697 (Table 4.6). The specific gravity of a rock determines its strength, potential, and durability. As specific gravity increases, the links between the mineralogical components become more tightly bound, requiring more force to break them. Whether rocks with a specific gravity lower than 2.55 are appropriate for use in large-scale construction projects.

Table 4.6 showing Specific gravity and Water absorption of Kawagarh Formation and Lockhart Formation

Sample Name	Kawagarh Formation	LockhartL imestone
S.S.D Weight	1227.64	1188.92
Weight in Water	771.96	746.43
Oven Dry Weight	1222.19	1186.17
Absorption	5.45	2.75
% Absorption	0.45	0.23
Apparent Specific Gravity	2.715	2.697
Bulk Oven Dry Specific Gravity	2.682	2.681
.S.D Specific Gravity	2.694	2.687

The quality, strength, durability and resistance offered by the aggregate to the weathering and erosion can be find out through soundness test. Through soundness we can know the failure of the aggregate to natural weathering. According to ASTM C 88-05, the average value for sodium sulfate aggregate soundness is 12%. The soundness value for Kawagarh Formation limestone is (3.5%), while for Lockhart Limestone is (2.6%), as stated in the tables below (4.7 and 4.8).

Table 4.7 showing Gradation of aggregates and their weights for Soundness test of Kawagarh Formation

Passing through Sieve	Retained on Sieve	% Original Gradation	Wt of Fraction Before Test (gm)	Wt of Fraction After Test (gm)	Loss in wt	% Loss	Actual Loss
		A	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	0.0
1 1/2"	3/4"	49.6	1500	1452	48	3.2	1.6
3/4"	3/8"	33.9	1000	973	27	2.7	0.9
3/8"	# 4	16.5	300	281	19	6.3	1.0
Total		100					**3.5**

Table 4.8 showing Gradation of aggregates and their weights for Soundness test of LockhartLimestone

Passing through Sieve	Retained on Sieve	% Original Gradation	Wt of Fraction Before Test (gm)	Wt of Fraction After Test (gm)	Loss in wt	% Loss	Actual Loss
		A	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	0.0
1 1/2"	3/4"	59.7	1500	1461	39	2.6	1.6
3/4"	3/8"	27	1000	979	21	2.1	0.6
3/8"	# 4	13.3	300	290	10	3.3	0.4
Total		100					**2.6**

Flakiness and elongation test determined the flaky and elongated minerals within the carbonates. Flaky and elongated minerals can offer lesser resistance as compared to the rounded, sub rounded, and angular grains within the rocks. Moreover, the flaky and elongated minerals are liable to the resistance The Flakiness and Elongation tests for the aggregate from Kawagarh Formation is (6.13%) and that for Lockhart Limestone is (6.41%) as mentioned in the below (Table 4.9 and 4.10).

Table 4.9 showing Flakiness test values for the aggregate sample of Kawagarh Formation

Size of Aggregate		**Original Gradation**	**Weight of Test Fraction**	**Weight of thin And Elongated Particles**	**Thin and Elongated Particles in %**	**Corrected Avg. Weight %**
Passing through sieve	**Retained on sieve**					
1-1/2"	1"	25.4	3000.0	126	4.2	1.07
1"	3/4"	24.2	2000.0	147	7.35	1.78
3/4"	1/2"	24.8	1500.0	89	5.9	1.47
1/2"	3/8"	9.1	1000.0	72	7.2	0.66
3/8"	1/4"	16.5	500.0	35	7.0	1.16
Total		100.0				6.13

Table 4.10 showing Elongation test results for the aggregate samples of Lockhart Limestone

Size of Aggregate		**Original Gradation**	**Weight of Test Fraction**	**Weight of thin And Elongated Particles**	**Thin and Elongated Particles in %**	**Corrected Avg.Weight %**
Passing through sieve	**Retained on sieve**					
1-1/2"	1"	30.4	3000.0	146	4.9	1.48
1"	3/4"	29.4	2000.0	164	8.2	2.41
3/4"	1/2"	21.6	1500.0	92	6.1	1.32
1/2"	3/8"	5.4	1000.0	70	7	0.38
3/8"	1/4"	13.2	500.0	31	6.2	0.82
Total		100.0				6.41

The hardness and toughness of aggregate when the aggregate suddenly introduce to the load can be determined through impact value. As per ASTM D 5874-16, the impact value has a 30% upper limit. The Aggregate impact value of Kawagarh Formation is (22.9%) and for Lockhart

Limestone is (18.3%) as shown in the below (Table 4.11).

Table 4.11 showing Impact value test results for the limestone samples from the Kawagarh Formation and Lockhart Limestone

Sample Name	**Kawagarh Formation**		**Lockhart Limestone**	
Weight of aggregate before test W1	345.59	352.62	326.59	330.27
Weight of aggregate passing 2.36 mm sieve W2	79.59	80.52	59.59	60.45
% Impact value = W2/W1*100	23.0	22.8	18.2	18.3
Average=	22.9		18.3	

The hardness and toughness of aggregate when the load is gradually introduced on the aggregate can be determined through the crushing value of the aggregate. While aggregate crushing value of the limestone aggregate from Kawagarh Formation is (25.3%) and that from Lockhart Limestone is (22.6%) and the maximum allowed limit is (30%) as shown in the below mentioned (Table 4.12 and 4.13).

Table 4.12 showing Crushing Value test for the aggregate of Lockhart Limestones

Sample Name	**S1**	**S2**	**S3**
Weight of aggregate before test W1	1197	1185	1190
Weight of aggregate passing 2.36 mm sieve W2	276	265	268
% Crushing Value = W2/W1*100	23.1	22.4	22.5
Average=	22.6		

Table 4.13 showing Crushing Value for the aggregate of Kawagarh Formation

Sample Name	**S1**	**S2**	**S3**
Weight of aggregate before test W1	1195	1190	1198
Weight of aggregate passing 2.36 mm sieve W2	303	297	307
% Crushing Value = W2/W1*100	25.4	25.0	25.6
Average=	25.3		

The wearing, tearing and crushing of the aggregate can be find out through Los anglese and abrasion test. Los angles and abrasion, the more harder and resistant the material for abrasion can be used as a construction material. Because hardness is a crucial quality of a good aggregate, if it is not sufficiently firmed and stiffened, it may disintegrate or fracture when subjected to weight or pressure. For this purpose, Los Angeles abrasion (LAA) test is conducted over the aggregate samples of the Kawagarh Formation and Lockhart Limestone and its value is 29.9% and 26.7%respectively (Table 4.14). The maximum value of LAA for a suitable aggregate is 40% (ASTM C 131-89). The LAA value for both the analyzed samples falls in the permissible range however the value for Kawagarh Formation is lower than that of theLockhart Limestone.

Table 4. 14 showing Los Angeles Abrasion test of Kawagarh Formation and Lockhart Limestone

Sample	Total weight (W1)	Weight retainedon sieve (W2	% Los $\frac{W1 - W2}{W1} \times 100$
Kawagarh Formation	5000g	3505g	29.9%
Lockhart Limestone	5000g	3666g	26.7%

The coating and striping of bitumen to asphalt determined the linkage amount of pores within the carbonates. The stripping value of aggregates is determined as the ratio of the uncovered area observed visually to the total area of aggregates, expressed as a percentage. The estimated coated area for the limestone aggregate from Kawagarh Formation is (90%) and that from Lockhart Limestone is (97%) as shown in the below (Table 4.15 and 4.16).

Table 4.15 showing Coating and Striping test for the aggregate of Kawagarh Formation

Bitumen Aggregate Mixture • Size of Aggregate • Weight of Aggregate • Weight of Bitumen	 9.5/6.3 mm200 gm 5 %
Heating and Mixing • Container and Aggregate Oven • Asphalt C • Maxing with warm spatula result • Cooling temp	 135-149 C for 1 hour inHeat separately to 135/149for 2-3 minutes till the Allow the mix to cool at room
Curing in Distilled Water • Quantity of Water • Temperature • Duration	 400 ml 25 C 16-18 hrs
Description	1
Weight of material	200 gm
Bitumen rade (60-70)	10%
Water immersion at 25 c	18 hrs
Visual inspection coated area	91%
Specification	Estimated coated area (Above 90%)

Table 4.16 showing Coating and Striping test for the aggregate of Lockhart Limestone

Bitumen Aggregate Mixture • Size of Aggregate • Weight of Aggregate • Weight of Bitumen	 9.5/6.3 mm200 gm 5 %
Heating and Mixing • Container and Aggregate • Asphalt • Maxing with warm spatula • Cooling	 135-149 C for 1 hour in Oven Heat separately to 135/149 C for 2-3 minutes till the result Allow the mix to cool at room temp
Curing in Distilled Water • Quantity of Water • Temperature • Duration	 400 ml 25 C 16-18 hrs
Description	1
Weight of material	200 gm
Bitumen rade (60-70)	10%
Water immersion at 25 c	18 hrs
Visual inspection coated area	98%
Specification	Estimated coated area (Above 97%)

4.7 Petrography

Introduction

The inspection of thin slices with a polarizing microscope provides valuable information about the fabrics, textural characteristics, and mineralogy composition of the rock under assessment. Rock identification and categorization are based on information gleaned through petrographic research. Moreover, petrographic investigations at microscopic scale of rock aggregates helps indetermining the presence and amount of reactive constituents such as silica, chalcedony, and tridymite that may cause adverse chemical reaction with alkali of cement in the presence of water and cause failure of the structures (Be rube and Fournier, 1993). Similarly, the presence of clay minerals such as smectite, illite, and kaolinite in carbonates cause contraction and expansion, due this property the form pop-up structures. Therefore, petrographic analyses of aggregates are extremely vital for prognosis of various reactions before using them in concrete and asphalt works.

However, the most important tool for carrying out petrography is the polarizing petrographic microscope. Most important observations include lithologies, benthic and planktonic fossils, grains texture, and structures such as, cracks, fractures, stylolites, veins, and cements within these micro structures of carbonates. In this study the limestones from the Kawagarh Formation and Lockhart Limestone have been subjected to detailed petrographic analysis as shown in the below (Table 4.17 and 4.18).

4.7.1 Kawagarh Formation

The Kawagarh formation limestone in hand specimen is light grey to dark grey on fresh and yellowish to greyish on weathered surface. It is fine-grained, medium to thick bedded, hard and compact limestone. Petrographic study of the Kawagarh Formation reveal that, it is dominantly composed of micrite ranging from (49%- 62%) bioclasts (14%-32%), stylolites(9%-14%), fractures(10%-17%), and having pyrite leeching ranging from (5%-14%) as shown in the below (Table 4.17), and these veins, cracks, and micro fractures including bioclasts of Kawagarh Formation are filled with calcite cements as shown in the below (Figure 4.12). The studied limestones can be classified as “Mudstone” according to Dunham (1962) classification scheme.

4.7.2 Lockhart Limestone

In hand samples, Lockhart Limestone in the research area is medium grey to grey, thick to massively bedded, brecciated, and rubbly. Under the petrographic microscope the Lockhart Limestone is dominantly composed of micrite ranging from (16%-35%), bioclasts (14%-32%), calcite (32%-69%), and pyrite leeching ranging from (5% to 19%) as shown in the below (Table 4.18). Along with this fragments of planktonic foraminifera, fractures, and veins are filled with recrystallized blocky calcite cements as shown in the below (Figure 4.13). The depositional texture can be assigned as “wackestone to Packstone” according to Dunham’s (1962) classification of carbonate rocks.

Petrographically, the carbonates of Darsamand Anticline i.e Kawagarh Formation is dominantly composed micrite, veins, stylolites, and fractures which are filled with calcite cements, while in contrast the Lockhart Limestone is composed of veins, bioclasts, and micrite while fragments of bioclasts and veins are filled with recrystallized blocky calcite cements which increases its durability and strength. However, there is no deleterious components within the carbonates of Darsamand Anticline which decrease the potential of limestone units as an aggregate.

Table 4.17 showing the petrographic analysis of Kawagarh Formation

Sample No.	Micrite	Bioclast	Calcite vein	Stylolites	Pyrite leaching	Fracture
KW1	55%	19%	16%	-	10%	-
KW2	57%	22%	21%	-	-	-
KW3	49%	10%	10%	9%	5%	17%
KW4	57%	19%	-	14%	-	10%
KW5	62%	24%	-	-	14%	-
KW Avg.	56%	18.8%	9.4%	11.5%	9.6%	13.5%

Table 4.18 showing the petrographic analysis of Lockhart Limestone

Sample No.	Micrite	Bioclast	Calcite	Pyrite leaching
LK1	28%	32%	33%	5%
LK 2	23%	19%	49%	9
LK 3	16%	14%	69%	-
LK 4	18%	24%	50%	11
LK 5	35%	17%	42%	16%
LK Avg.	24%	21%	48%	10.3%

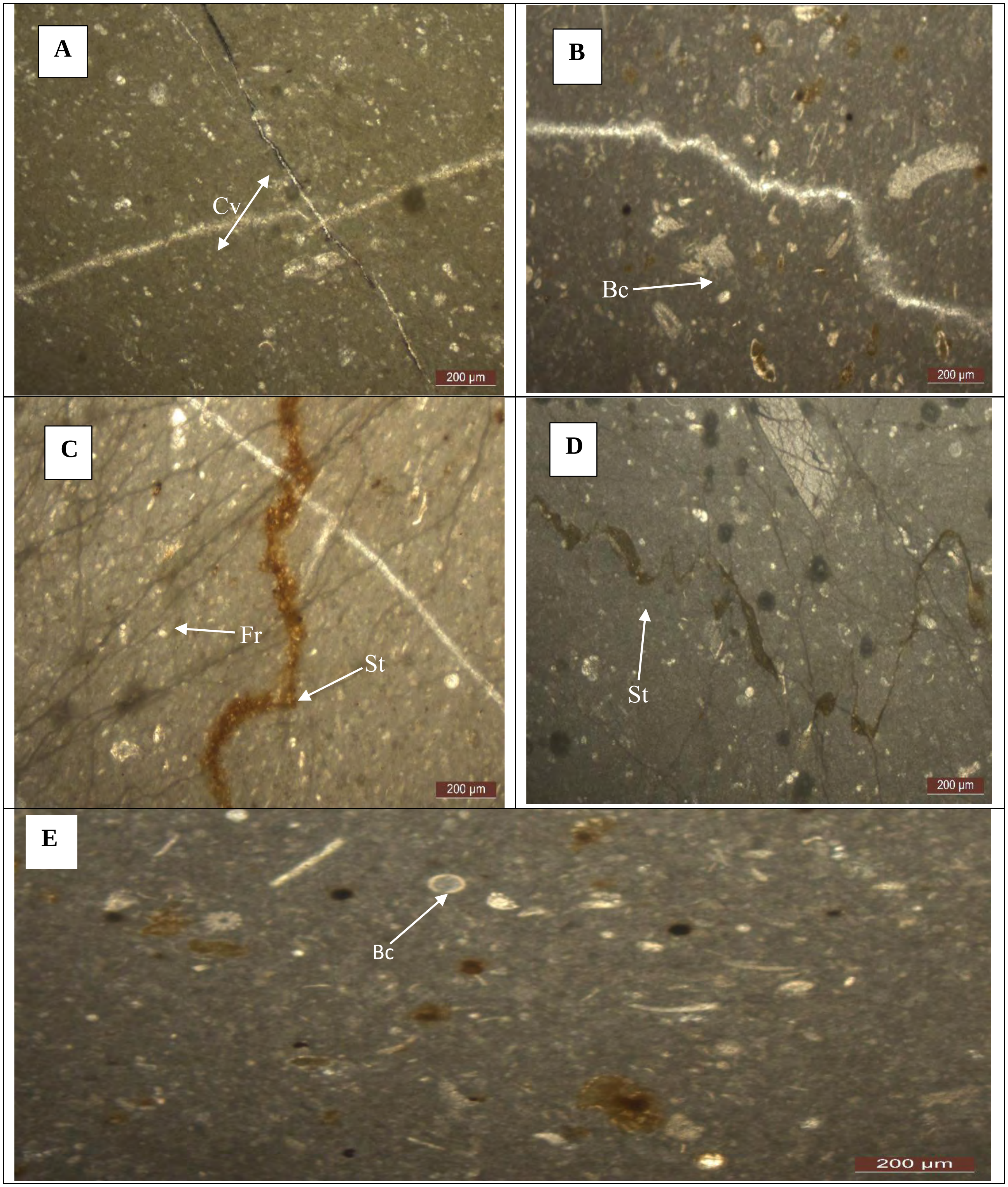

Figure 4.12 showing (A) Calcite vein (CV), (B) showing bioclasts (Bc), (C) Fractures (Fr) and stylolite (St), (D) long amplitude stylolites (St), and (E) showing fragments of bioclasts (Bc).

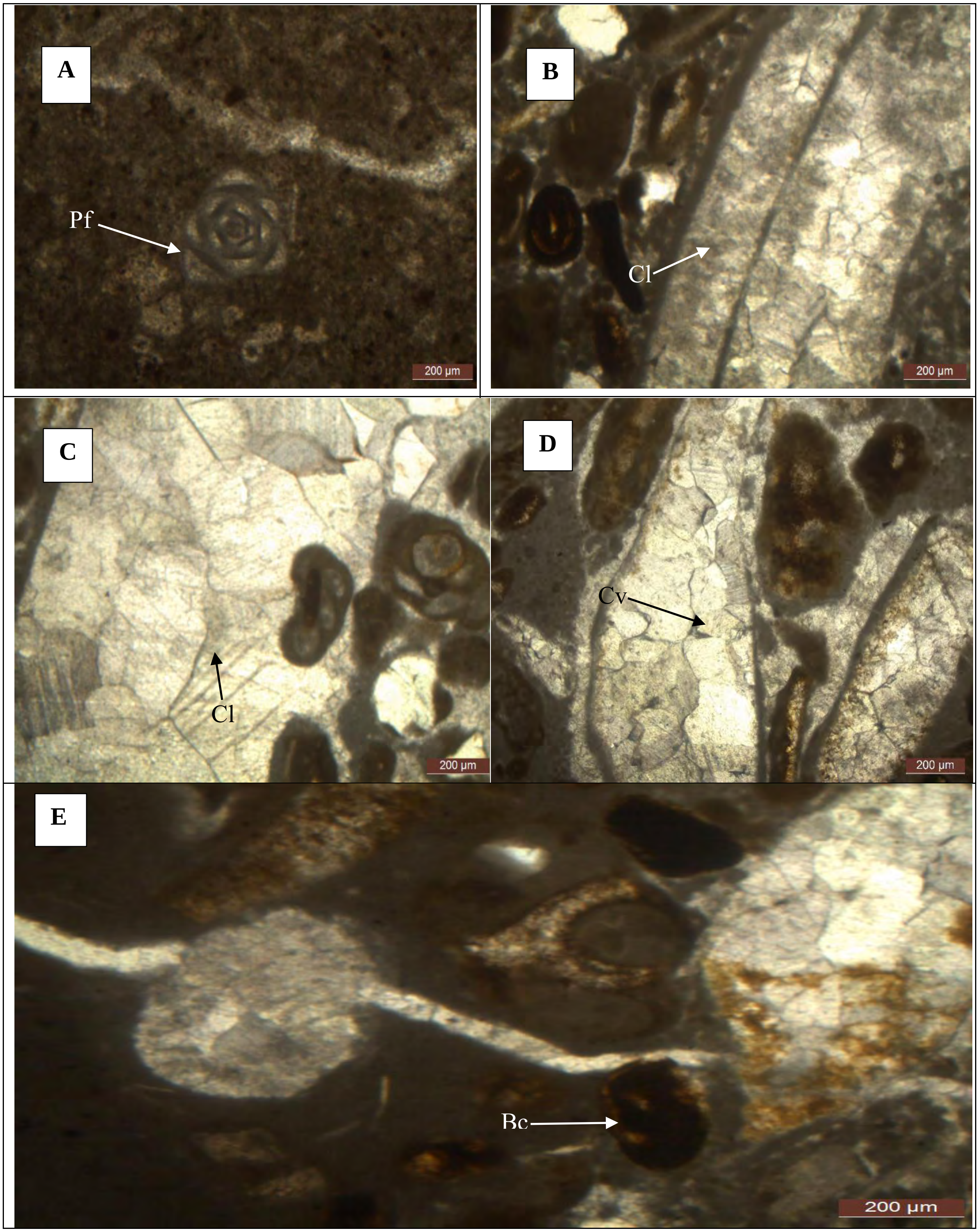

Figure 4.13 showing (A) Planktonic foraminifera (Pf), (B) showing calcite vein (CV) filled with blocky calcite (C) Calcite (Cl), and (D) showing bioclasts (Bc)

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

The Lockhart Limestone and Kawagarh Formation of the Darsamand Anticline were petrographically, geochemically, and geotechanically elevated to determine their feasibility as a possible source of aggregate in mega engineering projects and infrastructure construction. The petrographic studies were conducted in accordance with ASTM C 295-12, and it was determined that Lockhart Limestone of Darsamand Anticline is primarily composed of veins, stylolites filled with calcite cements, bio clasts, planktonic foraminifers, iron leeching, and other clay minerals in negligible amounts, and Lockhart Limestone of Darsamand Anticline is classified as a wackestone to packstone. The recrystallization of calcite cements in veins, cracks, and in cracks of fragments of bioclats within the Lockhart Limestone increases its strength and durability as a construction aggregate as shown in the above (Figure 4.13). Hence, no deleterious minerals were found which cause an adverse chemical reaction and cause failure of the infrastructures. The geochemical analysis was performed which indicates that CaO is the major component of Lockhart Limestone and along with this other oxides were also present in trace amount such as Fe_2O_3, SiO_2 , $Fe_2 O_3$, TiO_2, K_2O.

Kawagarh Formation comprises of veins, long amplitude stylolites filled with calcite cements along with this it also contains iron leeching, minor amount of bioclasts, and fine grained ground mass. The phenomena of recrystallization within the fractures, veins and in bioclasts of Kawagarh Formation is less than that of Lockhart Limestone. Kawagarh Formation is classified as a mudstone as shown in the above (Figure 4.12). No deleterious minerals were observed within the carbonates of Kawagarh Formation of Darsamand Anticline. Carbonates of Kawagarh Formation is also elevated geochemically and found that CaO is the major component, along with CaO other oxides are also present in trace amount such as Fe_2O_3, SiO_2, TiO_2, and K_2O.

Apart from that, minerals such as smectite, illite, and kaolinite have the property of compression and extension, which can induce the creation of pop-up structures and cracks within the structures, however there are no clay minerals inside the limestone units of the Darsamand Anticline.

Based on the petrographic and geochemical investigations it is confirmed that the carbonates of Kawagarh Formation and Lockhart Limestone of Darsamand Anticline can be use in mega engineering projects.

Apart from the petrographic and geochemical analysis, geotechanical studies were also carried for Lockhart Limestone and Kawagarh Formation for feasibility as a construction aggregate. The selected aggregate test were carried out on carbonates of Lockhart Limestone and Kawagarh Formation which includes Los Angeles and abrasion, soundness, impact value, crushing value, flakiness and elongation, specific gravity, and water absorption.

The values of various standard aggregate tests for the studied limestone of Kawagarh Formation like Specific gravity (2.7%), Water absorption (0.4%), Impact value (22.9%), Crushing value (25.3%), Soundness (3.5%), Los Angeles and abrasion (29.9%), and Flakiness and Elongation (6.13%). Are under the permissible range of standard specifications. Likewise the values of physical parameters for Lockhart Limestone are Specific gravity (2.6%), Water absorption (0.23%), Impact value (18.3%), Crushing value (22.6%), Soundness (2.6%), Los Angeles and abrasion (26.7%), and Flakiness and Elongation (6.41%).

The geotechanical parameters were also correlated with the petrographic features of the Lockhart Limestone and Kawagarh Formation theoretically. The positive correlation of geotechanical parameters with calcite cements and negative correlation with bioclasts and porosity indicates the potential, feasibility, and durability of carbonate units are directly associated to the amount of calcite cements and inversely linked with the bioclasts and porosity.

The results, which include petrographic, geochemical, and physical data, suggest these limestones can be exploited as an aggregate source in concrete and asphalt. As a result, the massive carbonate deposits of the Darsamand Anticline are suitable for utilization for massive engineering projects.

5.1 Recommendations

• The Darsamand Anticline is located 273 kilometers from Islamabad, 156 kilometers from Peshawar, and approximately 50 kilometers from Hangu city, where grinding plants should be developed to provide a relatively inexpensive source of construction material for both provinces, Khyber Pakhtunkhwa and Punjab.

• The carbonates of the Lockhart Limestone and Kawagarh Formation in the research region should be explored for use in diverse industries such as paint, fertilizer, and cement in accordance with international criteria.

• The feasibility study should be carried out based on a discontinuity survey and extensive geological mapping in order to figure out a strategy for mining the Lockhart Limestone and the Kawagarh Formation of the Darsamand Anticline.

• The Lockhart Limestone and Kawagarh Formation can also be utilised in asphalt and concrete constructions.

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