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TECHNICAL EVALUATION OF THE DARWAZA FORMATION IN ENGINEERING AND CHEMICAL INDUSTRIES, KHYBER PAKHTUNKHWA, PAKISTAN: INSIGHTS FROM PETROGRAPHY, GEOTECHNICAL, AND GEOCHEMICAL PROPERTIES

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Abstract

The objective of this research is to conduct a comprehensive geotechnical investigation of the Darwaza Formation at the study site, a Cambrian-aged geological unit predominantly composed of limestone. Petrography and a series of physio-mechanical, chemical, and analytical tests were conducted, including Los Angeles (LA) abrasion, impact strength, specific gravity, water absorption, soundness testing, scanning electron microscopy (SEM) with attached energy dispersive X-ray spectroscopy (EDX). Petrographic analysis of the Darwaza Limestone unit under polarized light microscopy reveals that the limestone is largely micritic to sparitic in texture, with varying degrees of recrystallization. The primary constituents include calcite, with minor occurrences of dolomite in some samples. The calcite in the Darwaza Limestone exhibits neomorphic textures, indicating diagenetic alteration of the original micritic material. Mineralogical characteristics and textural features were correlated with physio-mechanical properties to validate the laboratory results. The physio-mechanical properties (e.g., LA =20.9%, Soundness = 2.0%) and Impact value test = 12.1%), of the Darwaza Formation are found to fall within acceptable standard limits of ASTM. Based on these findings, it is proposed that the limestone of the Darwaza Formation is suitable for engineering applications and can be effectively used as construction aggregate. Beyond its suitability for the construction industry, the high calcium carbonate ($CaCO_3$) content–exceeding 95% also supports the potential use in paper, glass, sugar, ceramics, adhesives, food and pharmaceutical industries.

INTRODUCTION

General statement:

Limestone is a vital resource for the construction industry, owing to its abundant availability, durability, and versatility. In Pakistan, particularly in Khyber Pakhtunkhwa (KP), limestone deposits are both extensive and of high quality, playing a crucial role in the construction industry. These deposits not only support the local economy but also contribute significantly to the development of the region's infrastructure. The primary use of limestone in the construction industry is in the production of cement. Limestone is heated in a kiln to produce lime (CaO), which is then combined with clay and other minerals to produce cement. Crushed limestone is commonly used as an aggregate in concrete and asphalt. In the construction of highways and foundations, lime (produced from limestone) is used for soil stabilization. Lime helps improve the properties of the soil by reducing its plasticity and increasing its load-bearing capacity. In industrial applications, limestone is used in flue gas desulfurization (FGD) processes to reduce sulfur emissions from power plants.

As the demand for construction materials increases, it becomes essential to evaluate limestone's engineering properties to ensure its suitability for specific uses. Proper evaluation helps identify the most appropriate limestone deposits for various construction applications, ensuring that the material will perform well over time under various environmental and mechanical conditions. By assessing factors such as petrography, compressive strength, porosity, elasticity, durability, and chemical composition, Material Engineer can ensure that limestone is used effectively and safely in construction applications.

Considering the industrial significance of limestone, the deposits of the Darwaza Limestone exposed along the Khair Abad-Nizampur road is assessed for their suitability in construction and cement industries.

Location and Accessibility:

Darwaza Formation is well exposed along Khairaabd-Nizampur road section in the District Nowshera Khyber Pakhtoon khwa, Pakistan. The study area (33°53'42.2"N 72°13'43.9"E) is located about one and half hour drive at distance of 70 km from Peshawar and is easily accessible through a metaled roads connecting Peshawar-Islamabad throughout the year.

Regional Geotectonic Setting

The Himalayas, among the world's most striking mountain ranges, are located between the Eurasian plate to the north and the Indian plate to the south. In Pakistan, they extend in an east-west direction. Their formation is linked to global tectonic movements, which began when the Indo-Pakistan landmass broke away from Gondwana around 130 million years ago and began drifting northward. This movement led to the gradual closure of the Neo-Tethys Ocean that once lay between the Indian and Eurasian plates.

The subduction of the Neo-Tethys oceanic crust resulted in the formation of several island arcs, including the Kohistan-Ladakh, Nuristan, and Kandahar arcs. Over a span of about 40 million years, arc magmatism occurred, after which the Kohistan-Ladakh arc collided with the Eurasian plate, forming the Main Karakoram Thrust (MKT), a major geological boundary. The subsequent collision between the Indian plate and the Kohistan-Ladakh arc during the Eocene epoch created the Main Mantle Thrust (MMT), signaling the beginning of Himalayan mountain building (orogeny).

In Pakistan, the Himalayas are divided into tectonic zones based on thrust types and metamorphic grades. According to Gansser (1964), they are classified into the Higher, Lesser, and Sub-Himalayas. The Higher and Lesser Himalayas form the internal zones, bordered to the north by the MMT (or Indus Suture) and to the south by the Main Boundary Thrust (MBT). South of the MBT lies the external zone, which includes the foreland thrust and fold belt.

The MBT marks the boundary where older rocks from the northern belt are thrust over younger molasse sediments. South of the MBT lies the Salt Range Thrust (SRT), defining the Southern Deformed Fold and Thrust Belt, which includes the Kohat and Potwar plateaus of the Upper Indus Basin. The study area lies between MMT in the north and MBT in the south and known as Attock Cherate Range (Hussain et al.,1987).

Geology of the study area

The tectonic setting of the basin is transitional, with a sedimentary fold and thrust belt to the south and a metamorphic terrain to the north (DiPetro et al., 1999). The degree of deformation and metamorphism gradually increases from south to north across the Peshawar basin.

The Attock Cherat Range is composed of multiply deformed sedimentary and meta-sedimentary sequences. Rocks older than the Cenozoic are metamorphosed to the north of the Khairabad fault (Pogue et al., 1999). The region consists of three east-west trending, thrust-bounded blocks that generally dip to the north and named as Northern, Central and Southern blocks. These blocks are folded into several anticlines and synclines, typically vergent to the south. The area's structural style is dominated by three major faults: the Khairabad thrust, the Cherat thrust, and the Hisartang thrust (Tahirkheli, 1970; Pervez, 1987).

The Northern Block of the Attock-Cherat Range consists of four Precambrian formations: Manki, Shahkot, Uch Khattak, and Shekhai. These formations primarily feature limestone, slate, phyllite, shale, and quartzite, with occasional dolerite.

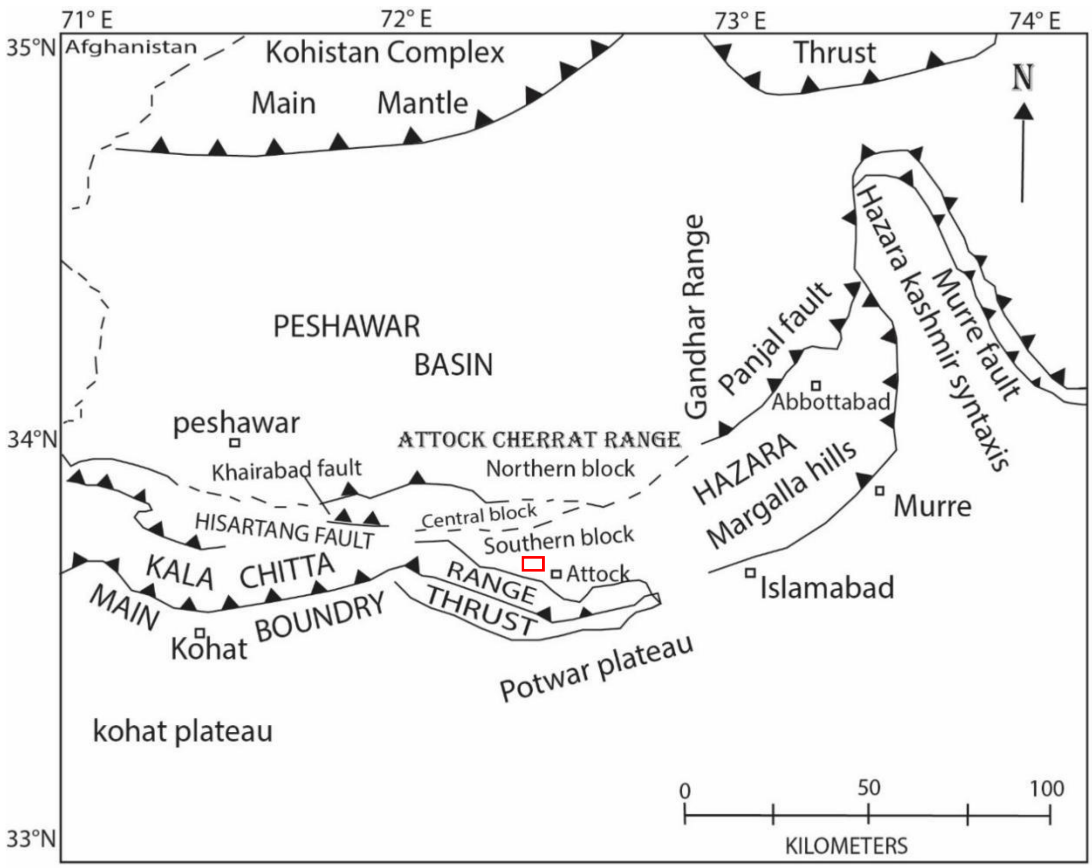

Figure 1 : Tectonic map showing major structural boundaries and study area (rectangular inset) (Yeats and Hussain, 1987).

Within the Southern block: The Darwaza Formation consists of limestone, dolomite, and maroon shale; the Hisartang Formation is composed of fine-grained quartzite and dark-grey to black argillite; and the Inziri Limestone is made up of finely crystalline limestone with black weathered laminations and manganese dendrites.

Methodology

The research methodology comprises two main components: **Field Work** and **Laboratory Work**.

1. Field Work

Fieldwork involved the collection of representative limestone samples based on textural variations for petrographic and geotechnical analysis. This enabled the assessment of macroscopic properties and proper sampling from the study area.

2. Laboratory Work

Laboratory analysis focused on two key aspects:

2.1. Petrographic analysis

Samples were collected from various locations along a road-cut section of the Darwaza Limestone. Selection was based on lithological variations. The samples were then cut and prepared as thin sections for microscopic analysis using standard laboratory techniques. Modal analysis was conducted to determine the framework mineral composition and to study the textural properties.

2.2 Geotechnical Tests

These tests assessed the physical strength and durability of the limestone. The remaining material after thin section preperation was then processed to produce coarse aggregate for the Los Angeles abrasion test. The Los Angeles Abrasion test (ASTM C131-03) was performed to evaluate the wear resistance of the coarse aggregate derived from the limestone. In addition, tests for specific gravity (ASTM C127-88), impact value (IRC, 2000), ASTM C 127 and soundness (ASTM C88-99) were determined

2.3 Geochemical Analysis

These analysis are aimed at determining the chemical suitability of limestone for industrial use. Tests included: EDX and AAS for elemental composition, LOI for water, organic matter and CO_2 contents and SEM imaging for analyzing grain shape and porosity.

PETROGRAPHIC DETAILS

General statement:

A thorough understanding of modal mineralogy, micro-textures, and textural relationships is essential for the proper evaluation of sedimentary rocks for aggregate and other industrial applications. These characteristics are most effectively analyzed through petrographic studies, which include both field observations and detailed microscopic examination. In this study, the petrography of the Darwaza Limestone has been carried out to assess its suitability for use as construction aggregate and for various industrial purposes.

a) Petrography:

The limestone of the Darwaza Formation is thin- to thick-bedded, hard, and compact, with a light grey to cream color (Figure 2). Under the petrographic microscope, it is predominantly composed of micrite, making up approximately 90–95% of the rock, with no fossil content observed (Figure 3). Neomorphosed calcite grains are present but constitute only about 1–3% of the limestone unit (Figure A; Table 1). In addition to neomorphism, other diagenetic features such as microfractures and well-developed stylolites are observed (Figure 3D), with iron-rich residues commonly occurring along the stylolites. Petrographic analysis reveals that quartz occurs as monocrystalline grains and ranges from traces up to 1% whereas the dolomite concentration occurs up to 4%.

The mineralogical make-up, therefore, reveals that concentrations of quartz and dolomite lies within the suitable/innocuous ranges (ASTM C 295) and hence the aggregate will neither cause alkali silica reactivity (ASR) nor alkali carbonate reactivity (ACR) if used as aggregate with with ordinary portland cement (OPC). The aggregate is also declared suitable for asphalt work.

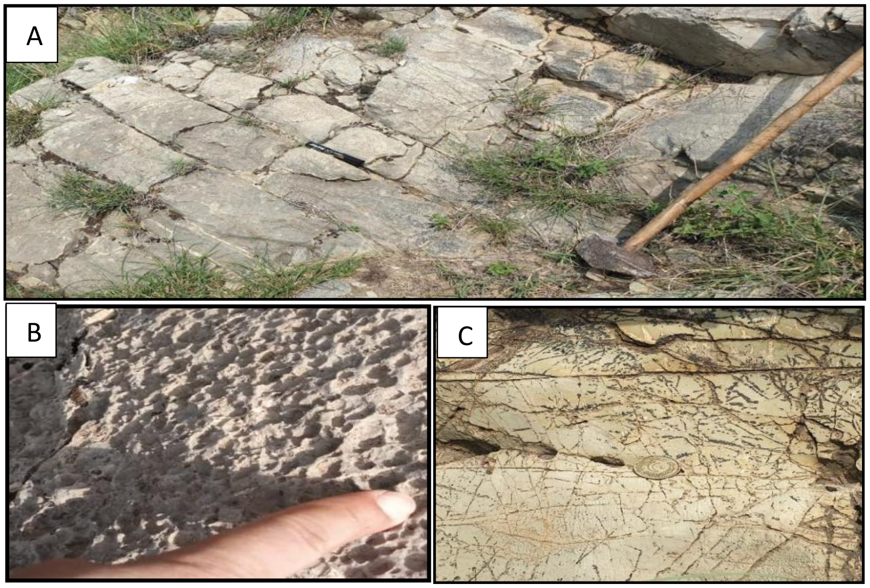

Figure 2. Field photographs of the Darwaza Formation exposed along Khairabad-Nizampur road; A) medium bedded limestone in Darwaza Limestone; B) Honeycomb texture, C) butcher chop weathering;

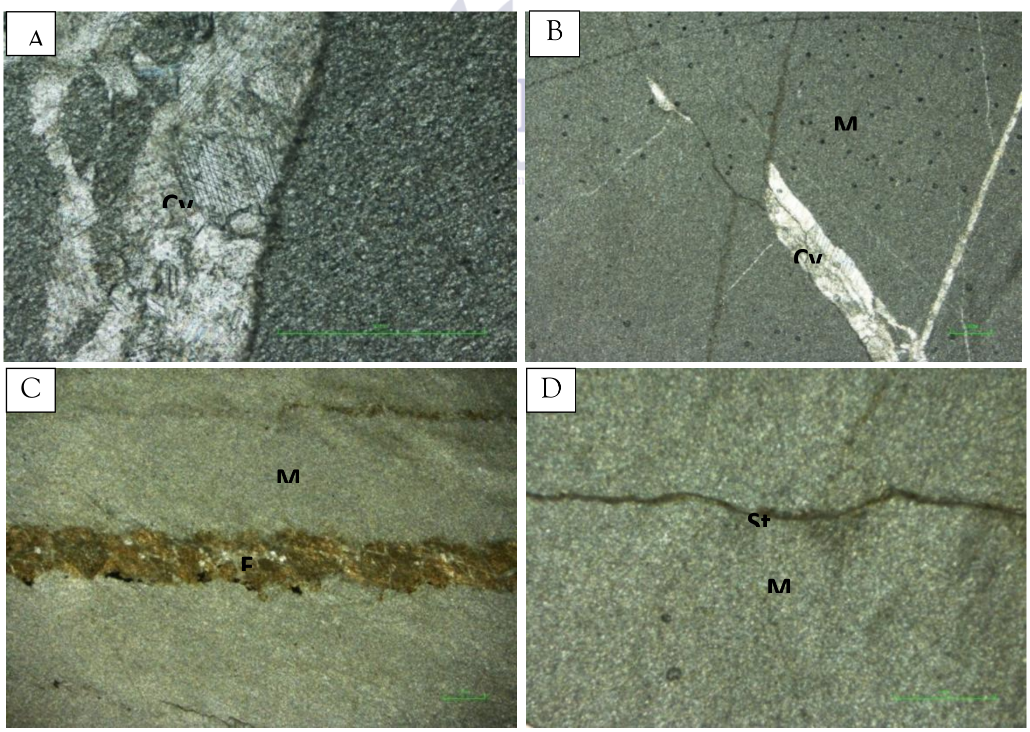

Figure 3. Photomicrographs (XPL) of the studied limestone unit of the Darwaza Formation (A) showing calcite vein (Cv) and micrite (M) and dolomite (Dl); (B) Weakly developed stylolite (St) and calcite vein (Cv); (C) Ferruginous material (F) and micrite (M); (D) A well-developed stylolite **(St).**

Table 1. A Summary Of The Petrographic Details Of The Limestone Unit Of The Darwaza Formation.

Sample	Micrite	Neomorphosed calcite Grains	Grain: Matrix	Classification Folk Dunham	
D-1	99	1	1:9	Micrite	Mudstone
D-2	98	2	1:9	Micrite	Mudstone
D-3	99	1	1:9	Micrite	Mudstone
D-4	98	2	1:9	Micrite	Mudstone
D-5	99	1	1:9	Micrite	Mudstone
D-6	99	1	1:9	Micrite	Mudstone
D-7	99	1	1:9	Micrite	Mudstone
D-8	99	1	1:9	Micrite	Mudstone
D-9	97	3	1:9	Micrite	Mudstone
D-10	97	3	1:9	Micrite	Mudstone
D-11	98	2	1:9	Micrite	Mudstone
D-12	99	1	1:9	Micrite	Mudstone
D-13	99	1	1:9	Micrite	Mudstone
D-14	98	2	1:9	Micrite	Mudstone

GEOMECHANICAL AND GEOCHEMICAL PROPERTIES

Table 2 presents the physio-mechanical properties of the limestone unit from the Darwaza Formation, situated in the Attock-Cherat Range. The results demonstrate that the tested samples exhibit generally consistent results with those found else where (cf. Anjum et al., 2019). The water absorption of the aggregate is measured at 0.26%, with a specific gravity of 2.72. The soundness test yields a value of 2.0%, while the aggregate impact value is recorded at 12.1%. The Los Angeles Abrasion resistance value of the aggregate is 20.9%. All these values lies within the permissible ranges of the recommended standards shown in Table 2.

Geochmical data is shown in the Table 3: The composition analysis reveals that Calcium Oxide (CaO) is the dominant component, with a high concentration ranging between approximately 57.65% and 59.02%. Silicon Dioxide (SiO_2) is present in small amounts, around 1.1% to 1.5%, while Aluminum Oxide (Al_2O_3) appears as a minor component, ranging from 0.36% to 0.76%. Iron Oxide (Fe_2O_3) was not detected in two of the samples but was present at 0.44% in one. CO_2 ranges between 46.61–51.08%. Magnesium Oxide (MgO) is found in very low amounts, between 0.2% and 0.3%. Additionally, the Loss on Ignition (LIO) values are high, ranging from 38.19% to 38.85%, indicating a significant presence of volatile compounds or carbonates.

The geochmeical data **(Table 3)** suggests that the analyzed rock is suitable for use in different industries including as paper, glass, sugar, ceramics, adhesives, and pharmaceuticals (Boynton 1980, Harben 1995, Emefurieta and Ekuajemi 1995, Gaied 1996 Umeshwar 2003, BGS 2011).

TABLE 2: ENGINEERING PROPERTIES OF LIMESTONE UNIT OF DARWAZA FORMATION

Test Category	Test Performed	Method/Standard	Results	Permissible Range
Geotechnical	LA Abrasion	AASHTO T 96	20.9%	40%
Geotechnical	Water Absorption	ASTM C33 / C33M	0.26%	0.1 to 2.0%
Geotechnical	Specific Gravity	ASTM C 127	2.72	2.5 to 3.0
Geotechnical	Impact Value	IRC 2000	12.1%	1 to 30%
Geotechnical	Soundness	C88,1999	2.0%	18 to 20%

Table 3. Displaying The Concentration (Wt.%) Of Major Oxides Present In The Analyzed Samples

Oxide/Sample	D1	D-4	D-14	Comments
CaO	58.93	57.65	59.02	
SiO_2	1.3	1.5	1.1	
Al_2O_3	0.68	0.36	0.76	
Fe_2O_3	n.d	n.d	0.44%	n.d = not determined
MgO	0.3	0.2	0.2	
LOI	38.19	38.85	38.29	loss on ignition

CONCLUSION:

The limestone of the Darwaza Formation, exposed along the Attock-Nizampur section, has been evaluated for its use as aggregate and industrial rock using petrographic, geochemical, and standard aggregate tests.

Petrographic analysis classifies the limestone as micritic limestone and mudstone based on Folk's and Dunham's classifications, respectively. It comprises over 90% micrite and neomorphosed calcite grains, with no evidence of fossils or other allochems.

Reactive minerals associated with Alkali-Silica Reaction (ASR) or Alkali-Carbonate Reaction (ACR) lies within the innocuous range.

Standard aggregate test results — Los Angeles Abrasion (20.9%), Soundness (2.0%), Specific Gravity (2.72), Water Absorption (0.26%), and Impact Value (12.1%) — fall within acceptable limits, indicating suitability for use in concrete and asphalt applications.

Geochemical analysis shows high CaO (57.65–59.02%) and CO_2 (46.61–51.08%) content, with relatively low SiO_2 (5.43–16.04%), suggesting its potential for use in chemical industries such as paper, glass, sugar, ceramics, adhesives, and pharmaceuticals.

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