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Petrographic and Mechanical Analysis of Grano-Diorite Deposits in the Qala Region, Dikundi Province, Afghanistan

Mohammad Sadiq Azimi
Lecturer at Engineering Geology and Mineral Exploration department, Ghazni Technical University, Afghanistan. Email: sadiqazimi744@gmail.com
Mohammad Fahim Weyaar*
Lecturer at Mining Engineering and Management department, Afghan International Islamic University, Afghanistan. Email: fahimweyaar@gmail.com
Mohammad Ullah Ahmadzai
Lecturer at Engineering Geology and Mineral Exploration department, Takhar University, Afghanistan. Email: mohammadullahahmadzai562@gmail.com

Abstract

This research paper offers a detailed investigation into the petrographic composition and physical-mechanical properties of granodiorites in the Qala area of Dikundi Province. It starts with a geological overview of the region. It examines macroscopic and microscopic petrographic characteristics, paragenetic mineral composition, and critical physical-mechanical properties such as bulk density, water absorption, and uniaxial compressive strength. XRF analysis was also employed for accuracy. The research approach is purely investigative, with samples collected from the Qala area and tests conducted by international standards. These granodiorites' uniaxial compressive strength was approximately 94.02 Mega Pascals, signifying their exceptional structural durability. Additionally, these granodiorites exhibit a specific gravity of 2.57, considered high, and a water absorption rate of about 0.29%, making them highly suitable for construction.

In summary, this academic research comprehensively analyses granodiorites within the Qala region, Dikundi Province. These findings are essential for evaluating the suitability of these granodiorites for various applications, particularly in the construction industry, contributing significantly to our understanding of this geological resource. The research recommends the need for government investment in the granodiorite mining sector, particularly in the Qala deposit. Detailed geological investigations are imperative to harness the full potential of this resource, generate employment opportunities, reduce dependency on stone imports, and explore international markets.

Keywords: Granodiorite, petrographic, composition, spectrometer.

1. Introduction

Afghanistan, characterized by its mountainous terrain, boasts abundant reserves of metallic, non-metallic, and construction materials. Geological surveys and mapping activities have been ongoing in the country for several years. The construction sector, mainly residential development, is rising, driving a pressing demand for construction materials and decorative stones. Additionally, as large-scale residential projects globally continue to flourish, the market for construction materials and decorative stones such as granodiorite, marble, and travertine remains robust. This presents an opportunity for economic growth and investment (England, 2012).

Granodiorite is an igneous rock that occupies a significant place in geology due to its intriguing geological characteristics and practical applications in various fields, particularly construction and engineering (Engidasew, 2014). This literature review aims to provide an overview of granodiorite's key aspects, including its formation, mineral composition, geological occurrences, and industrial uses.

Granodiorite is classified as a plutonic or intrusive igneous rock, forming deep beneath the Earth's surface through magma's slow cooling and crystallization. It belongs to the family of granitic rocks, sharing similarities with granite but exhibiting distinct mineralogical differences (Frost & Frost, 2019). The primary minerals in granodiorite include feldspars, quartz, biotite, and hornblende. This mineral composition imparts unique physical and mechanical properties to granodiorite, making it highly versatile for various applications (Bjorkman, 2017).

Granodiorite deposits can be found worldwide, occurring in various geological settings. They are associated with subduction zones, continental margins, and mountain-building processes (Frisch, Meschede, & Blakey, 2011) in some instances, granodiorite may intrude on existing rocks, leading to the creation of igneous complexes. Notable occurrences of granodiorite can be found in the Sierra Nevada Mountains of the United States, the Andes of South America, and the Himalayas (Day, Moores, & Tuminas, 1985).

Granodiorite exhibits several physical and mechanical properties that render it suitable for diverse applications. These properties include high compressive strength, low water absorption, excellent durability, and resistance to weathering (Alexander & Mindess, 2005). The specific gravity of granodiorite is relatively high, enhancing its suitability for structural and decorative purposes. These attributes make granodiorite preferred for construction materials, monuments, countertops, and sculptures (Khanlari, Heidari, & Momeni, 2012).

Granodiorite's versatility has made it a valuable resource in various industrial sectors. It is frequently employed for building facades, pavements, and structural components in construction due to its strength and aesthetic appeal. Its low water absorption rate ensures its longevity in outdoor applications. In the dimension stone industry, granodiorite is sought after for its ability to be polished to a high sheen, making it a favoured material for countertops and decorative surfaces. Additionally, its durability and resistance to wear make it suitable for heavy traffic areas such as flooring.

Granodiorite is an igneous rock of geological significance and practical importance. Its formation, mineral composition, global occurrences, and advantageous physical-mechanical properties contribute to its wide range of applications, from construction to artistry. Understanding the characteristics of granodiorite is fundamental for harnessing its potential in various industries and appreciating its role in Earth's geological history. As further research and exploration continue, granodiorite's prominence in geological and industrial domains will likely persist.

Furthermore, the declining prices of construction materials and decorative stones in industrialized and developing countries have attracted the attention of local and global private sectors to invest in Afghanistan (Hale & Ali, 2023, pp. SP526-2022). Among the countries, Afghanistan stands out with its abundant, untouched reserves of construction materials and decorative stones, ranking it among the world's resource-rich nations (Barker, 2006) (Ballentine & Sherman, 2003). Given these factors, the development of the construction materials sector has captured the attention of the country's economic market, and substantial investment in these resources becomes a fundamental cornerstone for national economic growth.

While numerous geological studies have been conducted in various fields in Afghanistan, these studies are often inaccessible to local geology students, and many of the reports still need to be explored. Moreover, research has been minimal or nonexistent in several geological sectors, leaving a dearth of detailed documentation in these areas.

1.1. Research Objectives:

Primary Objectives:

1. To examine the geological features of granodiorites.
2. To ascertain the physical and mechanical properties of the granodiorites above.

Secondary Objectives:

1. Can the granodiorites from the Qala area in Dikundi Province be effectively employed as construction materials?

2. What are the benefits associated with the utilization of these granodiorites?

2. Research Methodology:

The research employs a multifaceted approach, combining library research, fieldwork, and laboratory analysis methodologies, to comprehensively investigate the geological and physical-mechanical properties of granodiorite rocks in the Qala area of Dikundi Province, Afghanistan.

2.1. Literature Review and Data Compilation:

The study commences with an extensive review of existing literature and geological data. This phase aims to establish a robust foundation by gaining insights into the geological characteristics and historical context of granodiorite formations in the Qala area. This information serves as a critical backdrop for subsequent research activities.

2.2. Fieldwork:

Fieldwork constitutes a pivotal component of this research endeavor. It entails on-site visits to the Qala area within Dikundi Province to procure representative samples of granodiorite rocks. These field-collected samples are indispensable for conducting various physical-mechanical tests and making direct geological observations.

2.3. Laboratory Analysis:

The collected granodiorite samples undergo a comprehensive battery of physical and mechanical tests within a controlled laboratory setting. These tests include, but are not limited to:

Specific Gravity Measurement: Determining the density of the granodiorite samples.

Water Absorption Assessment: Evaluating the ability of the rocks to resist water infiltration.

Compressive Strength Testing: Assessing the rocks' resistance to axial loads.

Impact Resistance Analysis: Evaluating the rocks' durability in the face of impact.

In addition to these physical tests, an X-ray Fluorescence (XRF) analysis is conducted to ascertain the chemical composition of the granodiorite samples. This analysis provides crucial insights into the elemental composition, further enhancing our understanding of the rock's properties.

By synergizing library research, fieldwork, and laboratory analysis, this research methodology offers a comprehensive approach to unraveling the geological and physical-mechanical characteristics of granodiorite rocks in the Qala area. This holistic investigation equips us with valuable data essential for assessing the suitability of these rocks for various construction applications.

3. Research Subject:

This research focuses on analysing the petrographic composition and investigating the physical-mechanical properties of granodiorites found in the Qala area of Dikundi Province, Afghanistan. The research topic includes the study of mineral composition and paragenetic minerals, physical properties such as specific gravity and water absorption, and mechanical properties including compressive strength and impact resistance.

To accomplish this, multiple samples have been collected from the mines in this area during fieldwork, and their petrographic and physical-mechanical characteristics have been studied in the Ministry of Mines and Petroleum and Kabul Polytechnic University laboratories.

In essence, this research aims to provide a comprehensive understanding of these granodiorites' qualitative and quantitative aspects, including their geological composition and suitability for various applications.

4. Geology of the Region:

Based on previous studies conducted by local and international experts between 1977 and 1987, geological mapping at scales of 1:250,000 and 1:500,000 has been completed in the Helmand tectonic zone (Abdullah et al., 1977), including the Dikundi Province. The rocks studied are part of the Helmand tectonic zone, considered part of the old or pre-Alpine folded zone, and directly border the young Baluchistan-Himalayan collision region. These rocks, consisting of granodiorite, granite, and granitic gneiss, form batholiths in the Qala area and its surroundings. According to previous studies, these rocks are attributed to the Tertiary period, and a portion of these rocks, covering approximately 8.3325 square kilometres, have been mapped, contoured, and studied during the project.

The plutonic rocks in the study area in Qala village have a medium grain size, while in the Ghoochk area, they have a coarse grain size, easily visible to the naked eye. The primary minerals observed in these rocks include plagioclase, biotite, hornblende, orthoclase-type alkali feldspar, pyroxene, and quartz. Sillimanite mineral is secondary in the rock's composition, and the rocks have a granular structure with a hypidiomorphic texture. This composition bears similarities to granodiorites due to the mineral combination.

Natural fractures are visible in these rocks, formed due to various factors, especially contraction and expansion during cooling. Both natural factors and the physical-chemical effects of infiltrating waters play a role in forming these fractures.

These fractures divide the rock mass into irregular polyhedral pieces due to the cooling of the molten rock and the tectonic forces acting on the solidified rock.

5. Petrographic Analysis

Description of Slide W-001:

This slide shows that the granodiorite sample comprises a rich and diverse range of minerals. Here are descriptions of the types of minerals observed in this sample and their respective sizes:

1. Sodium and Potassium Feldspars (Plagioclase and Alkali Feldspars): The slide predominantly contains sodium and potassium feldspars. The size of these minerals varies, with sodium and potassium feldspars ranging from 0.06 to 1.68 mm.
2. Plagioclase: Plagioclase feldspar is present in the sample, with sizes ranging from 0.26 to 3 mm.
3. Quartz (Quartz Crystals with Irregular Shapes): Quartz grains, characterized by irregular shapes, are observed in the sample, with sizes ranging from 0.3 to 0.56 mm.
4. Biotite: Biotite minerals are present in the sample, ranging from 0.04 to 1.94 mm.
5. Hornblende (Amphibole): Hornblende minerals are also seen in the sample, ranging from 0.06 to 1.34 mm.

Accessory minerals in this slide include sphene, zircon, and apatite. Given the mineral composition and textural characteristics, the studied sample can be classified as a plutonic igneous rock, specifically a biotite-bearing granodiorite, due to these minerals' presence and grain sizes. Representation of this sample PPL (Plane polarized light) and XPL (Cross polarized light) is presented in Figure 1.

Fig 1: Slide W-001: Zoom in of 4X.

Table 1: The macroscopic properties of the sample Number W-001.

Sample Number W-001	
Macroscopic properties	
Colour	Gray
Weathering	Average
Porosity	Missing
Specific gravity	2.57
Reaction against acid (HCl)	Missing

Table 2: Geological properties of the sample number W-001

Geological properties	
Sample name	Grano-diorite
Petrographic class	Plutonic igneous rock
Geological formation	Granotoidi Dikundi

Description of Slide W-002:

In this slide, the granodiorite sample primarily consists of various minerals, including sodium and potassium feldspars, plagioclase, quartz, biotite, and hornblende. Here are descriptions of the types of minerals observed in this sample and their respective sizes:

1. Sodium and Potassium Feldspars (Plagioclase and Alkali Feldspars): The slide contains sodium and potassium feldspars, ranging from 0.12 to 1.32 mm.
2. Plagioclase: Plagioclase feldspar is present in the sample, with sizes ranging from 0.16 to 2 mm.
3. Quartz (Quartz Crystals with Irregular Shapes): Quartz grains are observed, characterized by irregular shapes, with sizes ranging from 0.44 to 1.34 mm.
4. Biotite: Biotite minerals are present in the sample, ranging from 0.04 to 1.8 mm.
5. Hornblende (Amphibole): Hornblende minerals range from 0.1 to 1.26 mm in the sample.

Accessory minerals in this slide include zircon. Given the mineral composition and textural characteristics, the studied sample can be classified as a plutonic igneous rock, specifically a biotite-bearing granodiorite, due to these minerals' presence and grain sizes. Representation of this sample PPL (Plane polarized light) and XPL (Cross polarized light) is presented in Figure 2.

Fig 2: Slide W-002: Zoom in of 4X.

Table 3: The macroscopic properties of the sample Number W-002.

Sample Number W-002	
Macroscopic properties	
Colour	Gray
Weathering	Average
Porosity	Missing
Specific gravity	2.57
Reaction against acid (HCl)	Missing

Table 4: Geological properties of the sample number W-002

Geological properties	
Sample name	Grano-diorite
Petrographic class	Plutonic igneous rock
Geological formation	Granotoidi Dikundi

6. Geochemical Analysis:

Geochemistry concerns the Earth's crust's distribution, formation, and abundance of chemical elements. Various analytical techniques and instruments determine the elemental composition and percentage in geological samples. A spectrometer collected four samples from the respective area for geochemical analysis. The results are presented in Table 5.

Elements %	Sample numbers			
	W-002	W-005	W-009	W-0011
Si	17.24	16.98	17.82	25.4
Ca	3.22	4.65	5.19	2.49

Al	2.20	3.33	2.24	2.6
Fe	5.3	4.95	3.91	2.45
K	0.22	1.7	1.71	2.82
Ti	0.5	0.32	0.39	0.26
Mn (ppm)	756	678	748	482
Ba (ppm)	467	231	325	480
S	832	0.12	-	-

7. Physical and Mechanical Tests:

Stones, like soil, often contain pores that can become filled with water under certain conditions, leading to weathering and disintegration of the stones. Additionally, the presence of pores can reduce the compressive and tensile strength of the stones, directly affecting their mechanical properties and quality. Therefore, it is essential to conduct a set of mechanical tests to assess the mechanical properties of stones.

The physical and mechanical properties of the granodiorites from the central area of Dikundi province have been examined in the laboratory of the Ministry of Mines and Petroleum of Afghanistan. The following properties have been determined:

1. Specific Weight (Density): The specific weight of the granodiorite is 2.57, indicating its relatively high density.
2. Water Absorption: The water absorption of the granodiorite is 0.29%, which is considered suitable for granite and granodiorite rocks as it suggests low porosity.
3. Compressive Strength: The granodiorite has a compressive strength of 94.02 MPa, indicating excellent resistance to compression. This makes it suitable for use as a construction material and in infrastructure projects.

A series of mechanical tests have been conducted according to international and ASTM (American Society for Testing and Materials) standards to evaluate the physical and mechanical properties and the suitability of these granodiorites for construction materials and infrastructure. These tests are outlined in Table 6.

No	test	description	percentage
1	Specific gravity and water absorption	Water absorption	0.29%
		Specific gravity	2.57

	according to the (ASTM D-6473)		
2	Compressive strength according to the (ASTM D-6431)	Point load index	94.02 MPs

8. Results and Suggestions:

After analysing and comparing the results of petrographic analysis, XRF analysis, and spectrometry, the following results can be drawn:

1. Petrographic Analysis: The examined rock primarily consists of silicate minerals, mostly feldspars, quartz, biotite, and hornblende. These minerals are typical components of silicic rocks.
2. XRF Analysis: The XRF analysis confirms the high silicon (Si) concentration in the samples, a fundamental component of silicate minerals. Silicon constitutes approximately 16-25% of the analysed elements, further validating the accuracy of XRF analysis and its agreement with petrographic studies. The presence of iron (Fe) in the range of 2.31-5.5% suggests the presence of minerals such as biotite and hornblende in the rocks. Potassium (K) is also detected in the samples, indicating its association with sodium and potassium feldspar minerals. Potassium levels range from 0.22-2.8%.
3. Mechanical Testing: Uniaxial compressive strength testing of the granodiorite samples from the Qala Mountains area yielded a value of approximately 94.02 mega Pascals (MPa). This indicates excellent compressive strength, as it falls within the range of (60-160) MPa, typically associated with granite and granodiorite. Therefore, these granodiorites exhibit high mechanical resistance, making them suitable for various construction and infrastructure applications.
4. Physical Properties: The granodiorites' specific gravity (density) measured at 2.57, which is relatively high and desirable for granite and granodiorite materials. Water absorption is around 0.29%, considered low and favorable for granite and granodiorite, indicating their resistance to water infiltration.

9. Suggestions:

1. The granodiorite mine in Qala, Dikundi Province, is among Afghanistan's best and highest-quality granodiorite deposits. Therefore, the government should seriously consider investing in this sector.
2. Since detailed geological studies have yet to be conducted at this mine, the government must prioritize and allocate resources for comprehensive geological investigations. This will enable us to utilize our resources effectively.
3. The Qala area's granodiorites and all the Dikundi Province's granite mines are considered high-quality and visually appealing. Significant investment in these resources will create numerous job opportunities within the country, reduce the import of low-quality stones from neighbouring countries, and potentially become a valuable export item if marketed globally. It is recommended that the government pays serious attention to this sector.
4. Considering the current capacity and conditions of the country, the Afghan government should focus on small and medium-sized mines, with a particular emphasis on granite and granodiorite deposits. These rocks are easily extractable, do not require complex beneficiation processes, and have a strong market demand. Prioritizing such resources can add to Afghan engineers' experience and expertise while benefiting the national economy.

In summary, investing in the granite and granodiorite mining sector, including the Qala deposit, can significantly contribute to the country's economy, create jobs, reduce imports of low-quality stones, and enhance the skills of Afghan engineers. Therefore, the government needs to give due consideration to this sector.

10. Conclusion:

In conclusion, the comprehensive analysis of the granodiorite samples from the Qala Mountains area provides valuable insights into this resource's geological and economic potential. The convergence of data from petrographic analysis, XRF analysis, mechanical testing, and evaluation of physical properties underscores the significance of the granodiorite deposit in Dikundi Province, Afghanistan.

Petrographic analysis revealed the predominant presence of silicate minerals, characteristic of silicic rocks, while XRF analysis confirmed the high silicon content, aligning with the petrographic findings. The presence of iron and potassium further supported the mineral composition identified through petrographic analysis.

Mechanical testing demonstrated the excellent uniaxial compressive strength of the granodiorite samples, rendering them suitable for a range of construction and infrastructure applications. The high specific gravity and low water absorption values enhance the desirability of these granodiorites for various engineering purposes.

The recommendations highlight the need for government investment in the granodiorite mining sector, particularly in the Qala deposit. Detailed geological investigations are imperative to harness the full potential of this resource, generate employment opportunities, reduce dependency on stone imports, and explore international markets.

Furthermore, focusing on small and medium-sized mines, with a specific emphasis on granite and granodiorite deposits, is a strategic approach. These resources are easily extractable, require less complex processing, and align with market demand. Prioritizing such endeavors benefits the national economy and contributes to the skill development of Afghan engineers.

In summary, spotlighting the Qala deposit, the granite and granodiorite mining sector holds promise for Afghanistan's economic growth, employment generation, and self-sufficiency in stone resources. The government's attention and investment in this sector are crucial steps toward realizing these potential benefits and securing a prosperous future for the country.

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