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Investigation of Serpentinized Ultramafic Rocks and Chromite Mineralization in the Ada Area, Deh-Yak District, Ghazni, Afghanistan

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Abstract

This study aims to assess ultramafic rocks in the Ada area, Deh-Yak district, Ghazni province, Afghanistan, which are considered potential sources of chromite. The objective is to evaluate the petrographic characteristics, geochemical composition, and possible presence of chromite minerals in the rocks of the study area. After data collection and field surveying, thin-section laboratory analyses of field samples were conducted using a petrographic microscope and an XRF (X-ray fluorescence) instrument. Petrographic analysis of the samples shows that the rocks in the area studied are predominantly olivine, clinopyroxene, and orthopyroxene, which have been extensively altered to serpentinite by severe hydrothermal and metamorphic processes. The rock's lithology, as examined, is classified as dunite, pyroxenite, and serpentinite, with a massive texture and granular to farinaceous structure. This Study of these thin sections shows that the chromite occurs as an accessory mineral and is retained as the primary phase despite extensive serpentinization. In addition, XRF analysis supports the petrographic investigation. It shows increases in iron (Fe) and chromium (Cr), as well as significant levels of nickel (Ni) and cobalt (Co), which are typical of the presence of chromite minerals. Geochemical analysis on whole-rock powders and genetic association of ultramafic rock and chromite minerals confirm the presence of these minerals of interest in the study area. To sum up, these findings show that the study area has a high chromite mineral potential.

Keywords: Chromite Mineralization, Dunite, Petrography, Serpentinite, Serpentinization, Ultramafic Rocks, X-ray Fluorescence (XRF).

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1. Introduction

Ultramafic rocks are an essential component of the Earth's lithosphere and play a major role in the primary processes of the mantle, tectonic evolution, and the formation of economically valuable minerals. Among these, chromite is the main economic mineral, rarely found as a pure double oxide and belonging to the spinel group, which crystallizes in the isometric system with the general formula $R^{2+}O \cdot R^{3+}{}_2O_3$. In natural systems, chromite is more accurately found as (Mg, Fe) O·(Cr, Al, Fe)$_2$O$_3$, reflecting extensive substitution among Mg, Fe^{2+}, Fe^{3+}, Cr, and Al [21].

This exchange results in the formation of several types of chromite, including chrompicotite, chromium hersinite, and magnesio-chromite, often associated with magnetite and magnesio-ferrarite. Chromite is a highly valued element because of its wide use in the metallurgical, refractory, and chemical industries. Its sediments are typically hosted by ultramafic mantle-derived rocks such as donites and peridotites, or their serpentinite-like equivalents. The study of these complexes is of interest for understanding regional geodynamic trends and potential for other rare mineral exploration [18].

The Kabul Block, located in the south-eastern part of Afghanistan, is a major tectonic unit of the Alpine-Himalayan. The geological history of this block indicates multiple magmatic, deformative, metamorphic, and tectonic events that are related to the Indian and Eurasian plates. Ultramafic bodies in the Kabul block, such as in the Logar and Ghazni provinces, are considered to be lithospheric fragments originating from the mantle processes and affected by regional and hydrothermal metamorphism later [1, 10].

Previous studies reveal the occurrence of ultramafic rocks containing chromite and their metallogenic significance in the Logar province, Afghanistan. However, no similar work has been done on Ghazni, especially in the Deh-Yak area. The field work observations reveal the presence of dune, pyroxenite, and serpentinite in the Deh-Yak district, especially in the Ada area, which indicates that these rocks are mostly serpentinized, which is the result of hydration of primary olivine and pyroxene at metamorphic conditions of hydrothermal and low grade [4, 9]. Serpentinite alteration changes mineralogical and textural properties and may redistribute economically important elements such as Cr, Ni, and Co. For Nickle it means that during the serpentinization process, olivine and pyroxene are altered by hydrothermal fluids, releasing the (Ni^{2+}) originally present inside the olivine by replacing magnesium (Mg^{2+}). Mobilility of Nickle during the serpentinization process occurs primarily because Ni^{2+} is released from olivine during hydrothermal alteration and can be transported in aqueous fluids even at relatively low temperatures, and combines with serpentine minerals or secondary sulfides [16]. This process leads to local redistribution or enrichment of Ni in serpentinites relative to their ultramafic protoliths. Chromite, due to its chemical stability, typically survives transformation and is a reliable indicator of ultramafic protoliths and chromite mineralization. [2, 8].

Petrographic analysis of the thin sections is essential to determine the mineral composition, texture, alteration features, and metamorphic overprints of the ultramafic rock. Combined with the entire rock geochemical data, particularly X-ray fluorescent (XRF) analysis, petrography provides a reliable framework for lithological classification,

petrogenetic reconstruction, and metallogenetic assessment. The main components of chromite, bivalent iron and magnesium, and trivalent chromium, aluminum, and iron are predominantly found in ultramafic rocks. Therefore, integrated petrographic and geochemical surveys are essential to assess the potential for exploration of chromite in unexplored areas [17].

2. Literature Review

2.1. Geological Framework of the Kabul Block and Ghazni Province

The study area is located in the Ada area of Deh Yak District, Ghazni Province, Central Afghanistan, in the Kabul Block, which is one of the main tectonostratigraphic units in south-eastern Afghanistan and part of the eastern segment of the Mediterranean-Himalayan Orogenic System. The Kabul Plateau is a relatively stable crystalline basement terrane that has experienced complex polyphase tectonic, magmatic, and metamorphic evolution from the Proterozoic to the Cenozoic, largely associated with the convergence and collision of the Indian and Eurasian plates (Figure 1) [3]. The geological environment of the area is characterized by high-grade metamorphic rocks, intruded by mafic to ultramafic rocks and ultramafic complexes, such as dunites and harzburgites, which are locally exposed in serpentinite of the Ada area. These geological compartments provide favorable conditions for the mineralization of chromite [9, 14].

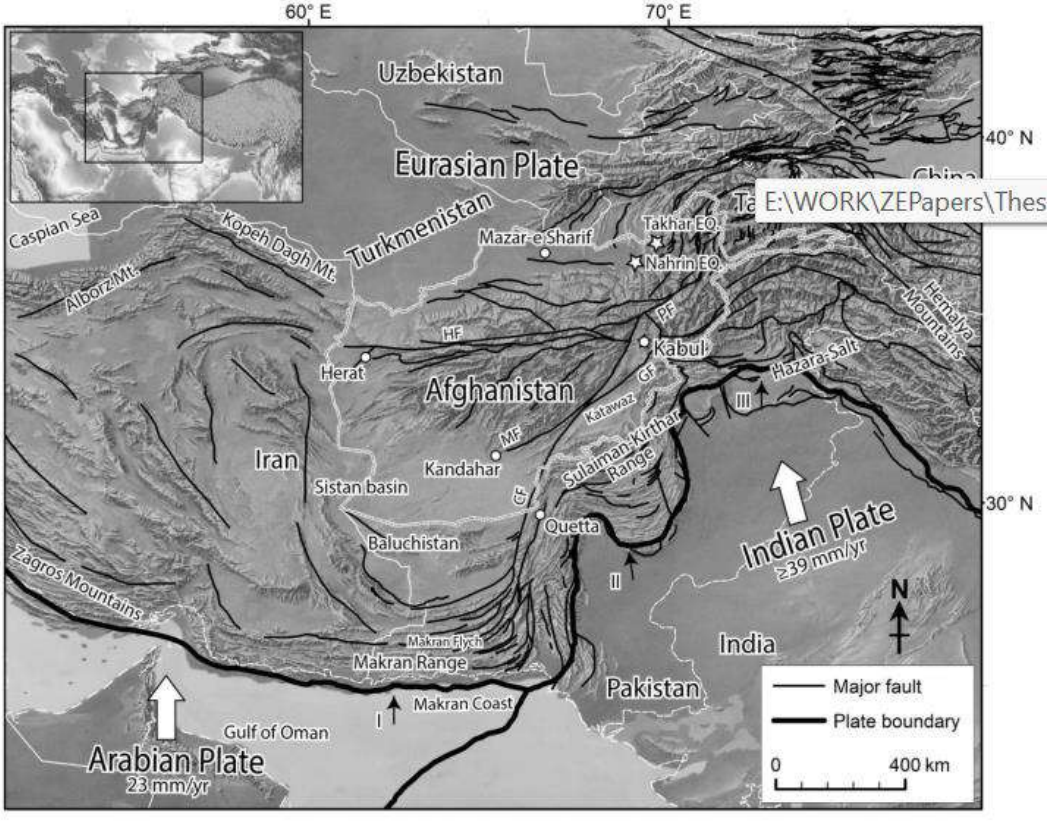


Fig. 1. Tectonic setting of Afghanistan and surrounding regions [14]

The regional structure of the Kabul bloc is further dominated by large-scale lithospheric fault systems, including the Chaman-Moqor, Altimor, and Sarobi fault zones, which play a key role in deformation, magmatic emplacement, metamorphism, and mineralization. Despite the established regional geological framework, till now, no detailed petrographic and geochemical studies have been conducted in the Ada area of Ghazni province, which highlights the importance of this research work (Figure 2) [9].

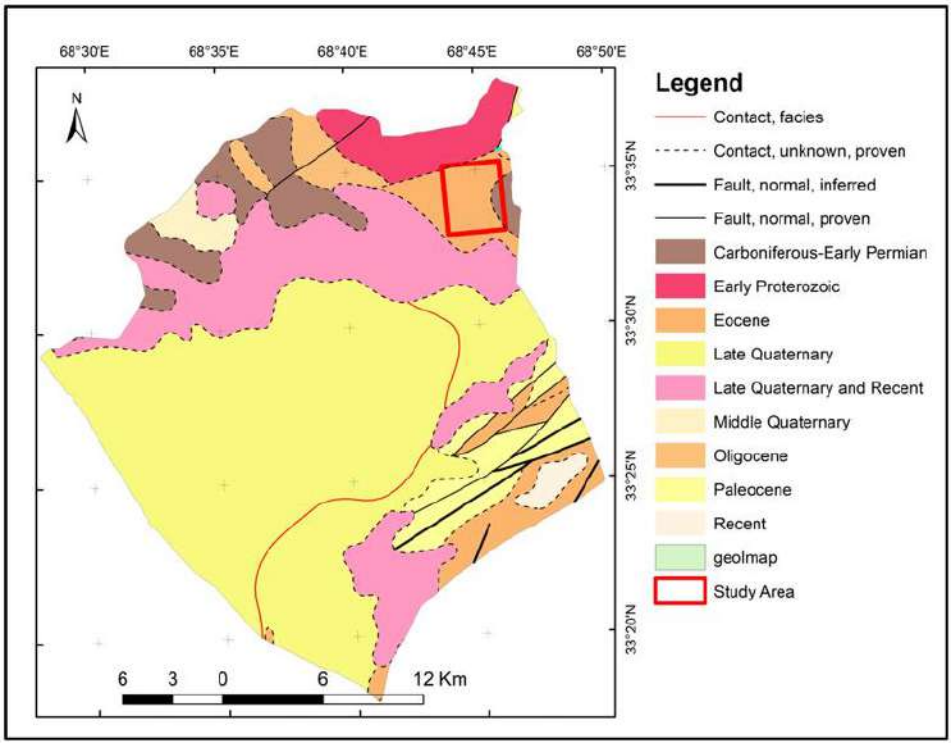


Fig. 2. Geological map of the study area, Ada area, Ghazni, Afghanistan

The topography of the Ada area is generally rugged and mountainous, typical of Central Afghanistan, and is dominated by lithology, tectonics, and erosion. The landscape is composed of steep hills, ridges, and narrow valleys, with steep gradients that vary considerably over short distances. Ultramafic and serpentinite rocks typically form resistant ridges and rocky outcrops, while more weathered and deformed rocks occur on lower slopes and at the lower parts of the valleys. The drainage is mainly seasonal, and the limited soil cover reveals the underlying rock over a large area, making geological mapping easier and easing the observation of lithological units and the chromite-bearing strata on the surface (Figure 3).

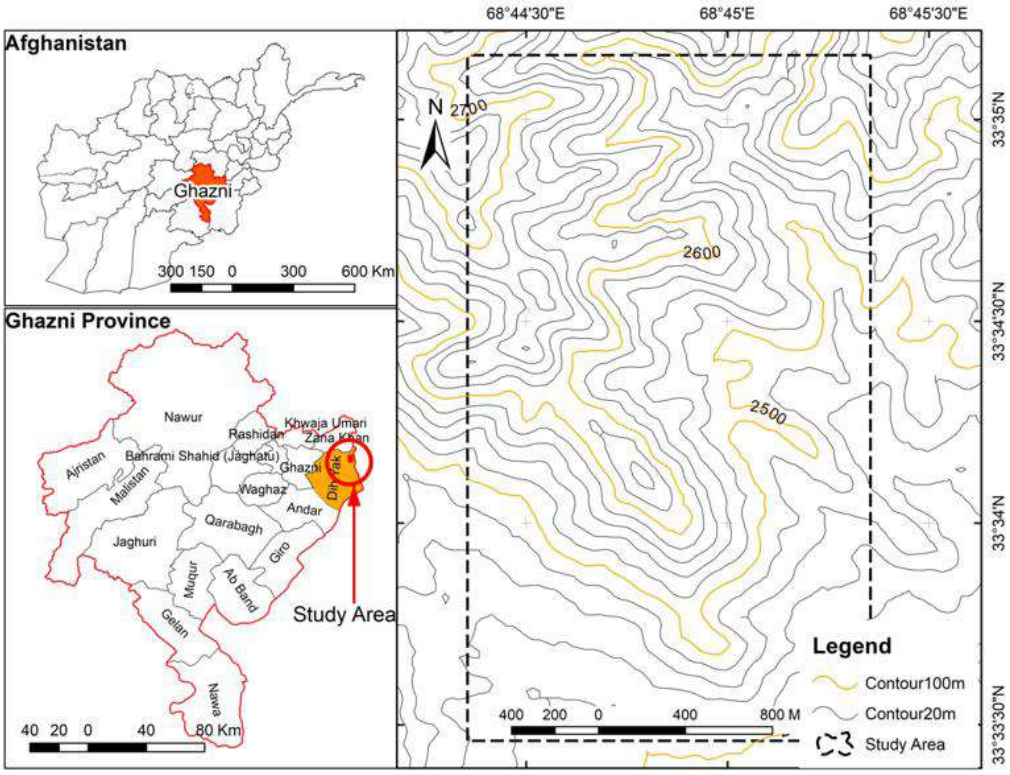


Fig. 3. Topographic map of the study area, Ghazni, Afghanistan

2.2. Ultramafic Rocks, Metamorphism, and Serpentinization

The lithological composition of the Kabul block is dominated by high-grade metamorphic rocks, including gneisses, amphibolites, schists, quartzites, and marbles, which are intruded by mafic to ultramafic rocks [19]. Ultramafic complexes exposed in Logar, Deh Yak, and the surrounding areas are generally composed of peridotitic rocks such as dunite, harzburgite, and pyroxenite, along with minor lherzolite and serpentinite, in accordance with the IUGS classification of ultramafic rocks [9]. In parts of the Logar ophiolite complex, the main ultramafic terrane of the Kabul block, these lithologies occur as a lower ultramafic sequence, overlaid by gabbro, dolerite-complexes, and later volcanic rocks, reflecting a more complete ophiolitic succession, with a thickness of 2,000 to 2,800 m. Dunite and harzburgite are both variably serpentinized, and their spatial relationships indicate their intra-oceanic origin associated with Himalayan orogeny processes (Figure 4) [14].

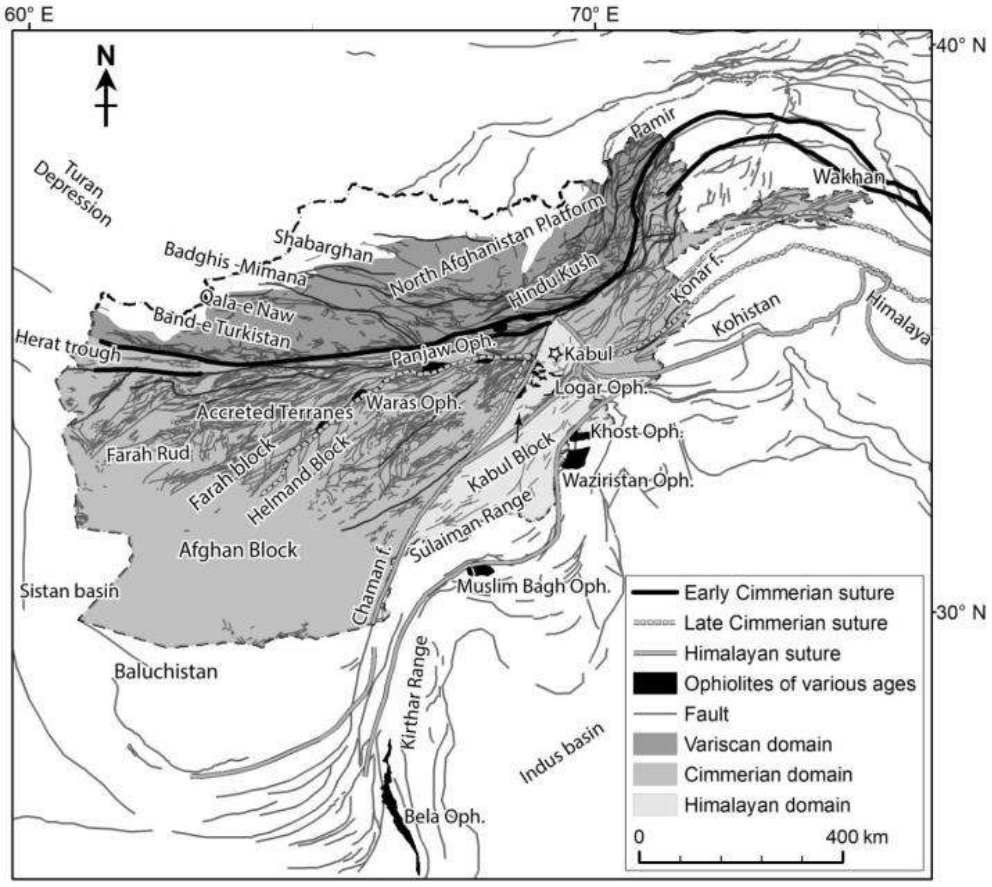


Fig. 4. Map show the location of the Kabul block in the tectonic sketch map of the Afghanistan orogenic segments [14]

Wider regional studies have identified extensive mafic, ultramafic, and volcanic units in southern Afghanistan, including the Helmand Block, suggesting a wide distribution of igneous and ultramafic rocks beyond the Kabul region [1]. These ultramafic bodies were emplaced during tectonic accretion and then altered by regional and hydrothermal metamorphism. Serpentinization is the dominant alteration process, which involves the hydration of primary olivine and pyroxene to form serpentinite minerals (chrysotile and antigorite), commonly accompanied by the formation of magnetite and talc [3]. Petrographic studies throughout the Kabul Basin indicate extensive deformation, recrystallisation, and retrograde metamorphosis under conditions of greenschist- to lower amphibolite-facies conditions. The accessory minerals, especially chromite, are usually retained during serpentinization because of their high chemical stability. The presence of chromite serves as a reliable indicator for ultramafic protoliths and is particularly important for the study of ore geology. Serpentinite and hydrothermal alteration may also change the bulk chemical composition, in particular the concentrations of SiO_2 and Al_2O_3, which are usually reflected in the geochemical analysis of the entire rock [8, 21].

2.3. Geochemical Characteristics and Application of XRF Analysis

Whole rock geochemical characterization using X-ray fluorescence (XRF) analysis is the standard and generally accepted method of examining ultramafic and metamorphic rocks. XRF analysis provides reliable data on major and minor elements, which are essential for lithological classification, mineralogical interpretation, and the assessment of the metallogenic potential of ultramafic complexes. The main oxide compositions of ultramafic rocks are typically Al_2O_3, Fe_2O_3, MnO, MgO, CaO, Na_2O, K_2O, and P_2O_5. Chromite is commonly associated with ultramafic rocks and belongs to the spinel group of minerals that crystallize in an isometric system and have a general formula $R^{2+}O \cdot R^{3+}{}_2O_3$. In natural systems, chromite is more precisely expressed as (Mg, Fe) O· (Cr, Al, Fe)2O3, reflecting the large substitution of divalent and trivalent cations in the solution of the solid [11, 17].

Replacement of FeO by MgO and Cr_2O_3 by Al_2O_3 and/or Fe_2O_3 results in various compositions and the production of several types of chromite, including chromium. Chromite rarely has a fixed formula and is usually found as a mixture of different types, with magnetite and magnesite usually contributing to its chemical composition [7, 13]. Chromite composition variability is normally represented by end-member compositions including ferrochromite ($FeO \cdot Cr_2O_3$), magnesiochromite ($MgO \cdot Cr_2O_3$), spinel ($MgO \cdot Al_2O_3$), hercynite ($FeO \cdot Al_2O_3$), magnesioferrite ($MgO \cdot Fe_2O_3$), and magnetite ($FeO \cdot Fe_2O_3$). These end members define the corners of the triangular prism of composition, in which most natural chromites lie along the major isomorphic zone extending from magnesio-chromite–spinel compositions to the magnetite [11, 15].

This framework provides a solid basis for the interpretation of chromite chemistry results from XRF and associated analytical methods. Mineralogical studies of chromite ores of chemical grade show that variations in chromite composition, phase purity, and related minerals of the spinel group strongly influence the efficiency of extraction of chromium during industrial processing. Techniques such as XRF, XRD, SEM, EPMA, and AAS are necessary to characterise these characteristics and optimise the treatment to reduce loss of chromium in the soda ash [20,16].

Previous geological studies of ultramafic complexes in the Kabul Block have reported a steady increase in concentrations of FeO, MgO, Cr, Ni, and Co, reflecting their source in the mantle and the mineral composition of the chromite-bearing assemblages. Comparable geochemical properties are reported for ophiolite and mantle-hosted chromites worldwide, where chromite composition records both the primary magmatic trend and subsequent sub-sulfide or metamorphic alteration [6, 7].

Variations in the content of SiO_2 and Al_2O_3 are usually attributed to secondary processes such as serpentinization, silicification, and metamorphic recrystallization, rather than primary magmatic differentiation. The integration of petrographic observations with XRF-derived rock-wide geochemical data thus provides a reliable framework for lithological classification, protolithic reconstruction, and metallogenetic evaluation. In the hyperbasite complex at Logar, these integrated studies show a close genetic link between chromite mineralization and the formation of dunite and serpentinite [13, 16].

2.4. Chromite Mineralization and Ore Geological Context

Chromite mineralization is a characteristic feature of the Kabul block ultramafic rocks and is usually found in disseminated, schiolene-type, or lens-shaped bodies hosted by dunites and serpentinite [13]. Chromite is a member of the spinel group and rarely occurs as a pure double oxide. Its main source is ultramafic rocks, and in nature, its chemical composition is always changing. The reason for its chemical alteration is that different metal ions can replace each other in the crystal structure. Among them, Mg, Fe^{3+}, and Al can be mentioned, which can replace Fe^{2+} or Cr. In addition, this composition can contain other spinel groups such as magnetite (Fe_3O_4) and magnesioferrite ($MgFe_2O_4$) [5, 12].

Large-scale chromites generally retain their original magmatic composition; however, metamorphosed chromite, like dunites and harzburgites, shows an altered composition reflecting postmagmatic transformation.

In other words, ophiolite-bearing chromite occurs as podiform bodies in the mantle and as stratiform layers in supra-Moho sequences with different melt compositions and tectonic settings. Shear zones, thrust contacts, and tectonic boundaries are the most common controlling structures of the Earth's crust for locating and maintaining chromite mineralization. In general, the presence of accessory chromite in serpentinized ultramafic rocks is also considered suitable for its exploration. Although the metallurgical potential of the Kabul block is well known, to date, no study has been carried out on the chromite deposits in the Ada area of Ghazni province, especially regarding [15, 18, 21].

2.5. Research Gap

Despite extensive study of the Kabul block ultramafic complexes in Ghazni Province, particularly in the Ada area, no petrographic and site-specific geochemical investigations have been done yet to present comprehensive information on the available chromite mineralization. It means no study has been carried out to determine mineralogical properties, alteration history, and chromite mineralization potential of the ultramafic rocks in this area, yet. However, such field work and investigations have already been carried out in Logar province, Afghanistan. In addition, a lack of petrographic and XRF-based geochemical investigations to understand mineralogical properties, alteration history, and chromite mineralization potential limits efficient exploration in this area.

3. Research Objectives

The main objectives of this study are:

- To determine the overall rock geochemical composition of the studied rocks using X-ray fluorescence (XRF) analysis, with particular emphasis on Cr, Ni, and Co in the Ada area of the Deh-Yak district, Ghazni, Afghanistan.
- To assess the history of alteration, petrogenesis, and potential for mineralization of chromite. To characterize the mineralogical composition, texture, and structure of ultramafic rocks by detailed petrographic analysis of thin sections.
- To evaluate the nature and extent of deformation processes, in particular serpentinization, that affect the ultramafic lithologies.

4. Significance of the Study

The ultramafic rocks in the study area are of scientific and economic interest because they host many other precious minerals, like nickel, chromite, platinum group elements, talc, gemstones, and magnetite. Detailed geological analysis of these rocks is very important to understand the condition of their formation, the history of alteration, and finally, to successfully carry out the development of the exploration and exploitation process. Moreover, the results of this research will contribute to the regional palaeogeological framework of southeastern Afghanistan.

5. Research Questions

1. What is the mineralogical composition of ultramafic rocks in the Ada area, Deh-Yak district, Ghazni, Afghanistan?
2. Besides chromite, what other precious elements or minerals are present in these rocks?
3. Whether the rocks contain enough precious minerals to justify their profitable extraction.

6. Research Limitation

Previous geological investigations in the Ada area, Deh-Yak, Afghanistan, are very limited, and no comprehensive studies of ultramafic rocks have been published. Therefore, this study was conducted with minimal references to previous site-related data, which limits direct comparison of this study to previous works. However, the findings presented here will provide a reliable basis for future studies in the field of geological and mineral exploration in this area.

7. Research Methodology

7.1. Library-Based Method

The library-based method was used to collect background information and establish the theoretical framework of this study. Relevant textbooks, scientific articles, and academic resources related to geology, petrography, and geochemical analysis were reviewed, especially books and master's theses of the Department of Geology, Engineering and Exploration of Mines, Kabul Polytechnic University. In addition, reputable online scientific sources were consulted, particularly for methodological references.

7.2. Field Method

Fieldwork was conducted in the Ada village of Deh-Yak District, located in the southeastern part of Ghazni province. The study area is characterized by well-exposed ultrabasic rock units, which occur extensively in the region. Geological field observations included the identification of rock types, measurement of structural and positional elements, and documentation of geological features. Standard field equipment, including a GPS device, geological compass, geological hammer, hand lens, measuring tape, camera, and field notebooks, was used. Rock samples were systematically collected along a geological profile to ensure representative sampling. The collected samples were

labeled and transported to the Ministry of Mines and Petroleum for further laboratory analysis (Figure 5).



Fig. 5. Photograph taken during the collection of the sample at the observation point L54-1

7.3. Laboratory Methods

Laboratory investigations consisted of petrographic analysis and geochemical analysis using X-ray Fluorescence (XRF).

7.3.1. Petrographic Analysis

Petrographic analysis was performed using thin sections examined under a polarizing microscope to determine the mineralogical composition, texture, and structure of the rock samples. Thin sections were prepared following standard geological procedures, including cutting, grinding, polishing, mounting of thin sections, and thinning to approximately 30 μm.

7.3.2. X-Ray Fluorescence (XRF) Analysis

The study area's metamorphic and related lithologies were analyzed using a Thermo Scientific XRF instrument at the Ministry of Mines and Petroleum of Afghanistan, on seven representative samples, to find out the composition of their elements. In addition, the rocks' chemical composition was also ascertained using this method. The samples were dried in an electric furnace and then powdered to 30 μm. Following their identification and placement in designated containers, the powder samples were put into the XRF device and examined. The time required to analyze each sample was around 120 sec. Parts per million (ppm) and percentage (%) measurements of the elemental concentration were made, and the corresponding computerized results were obtained (Fig 6).

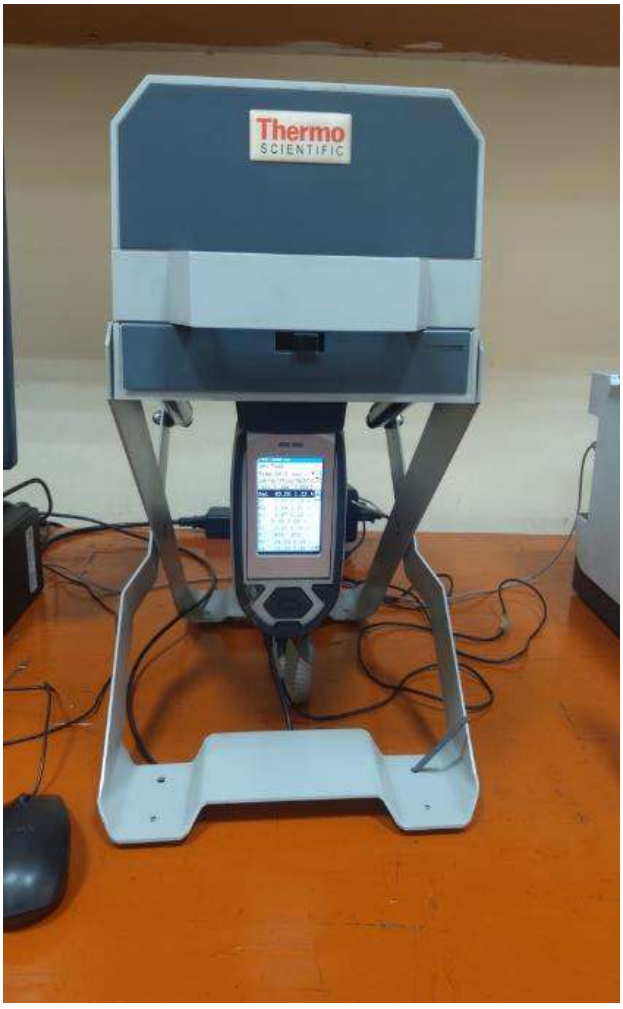


Fig. 6. XRF machine in the process of determining element concentrations

8. Discussion

8.1. Petrographic Microscopic Analysis of Thin Sections

Petrographic examination of thin sections No. L1-2, L54-1, L54-3, L54-4, L54-27, L54-29, L54-30, were conducted using a polarizing microscope, and the following results were obtained for each thin section accordingly.

8.1.1. Thin Section No. L54-1

Mineralogical Composition: The rock is composed predominantly of olivine and pyroxene, with extensive serpentinization of pyroxene, along with chromite, which is present as a significant subordinate mineral.

- Essential (rock-forming) minerals: Olivine constitutes approximately 30–70 vol.%, while pyroxene accounts for about 25–30 vol.%. The pyroxene is largely altered to serpentinite.
- Minor minerals: 2 – 4 vol.% chromite.
- Accessory minerals: 0.5 vol.% of the total rock.

Grain Size: The grain size of the constituent minerals is generally fine-grained.

- Olivine: 0.01 to 0.05 mm
- Pyroxene: 0.02 to 0.04 mm
- Serpentinite: 0.01 to 0.02 mm

Overall, the grain size of the rock-forming minerals ranges from 0.01 to 0.05 mm.
Texture and Structure: It has a massive, allotriomorphic texture with allotriomorphic granular structure. (Fig. 1.4).

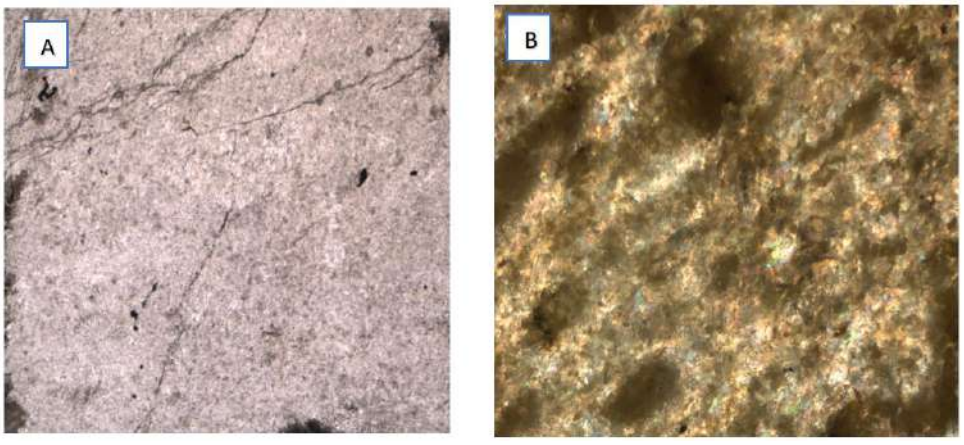


Fig. 7. Thin-section image of sample L54-1 under a polarized light. Fig. A: Thin section studied under crossed-polarized light (using two Nicol prisms). Fig. B: Thin section studied under plane-polarized light (using one Nicol prism)
Microscopic Details:
Field of view: 5 mm × 5 mm
Objective magnification: 40×
Texture: Massive
Grain shape/structure: Allotriomorphic (anhedral)
Rock name: Serpentinite

8.1.2. Thin Section No. L54-2

Petrographic Examination: Petrographic analysis of thin section L1-2 was conducted using a polarized light microscope, and the following observations were made.
Mineralogical Composition:
The rock is composed predominantly of olivine and serpentinite, with subordinate pyroxene, chromite, and minor accessory minerals.

- Essential (rock-forming) minerals: Olivine constitutes approximately 90 vol.% of the rock, while pyroxene accounts for 4–10 vol.%.
- Minor minerals: Chromite, 1–4 vol.% of the rock.
- Accessory minerals: Minor accessory minerals make up 0.1–0.3 vol.% of the total rock.

Grain Size: The grain size of the constituent minerals is generally fine- to very fine-grained:

- Olivine: 0.2–0.5 mm
- Serpentinite: 0.1–0.2 mm
- Chromite: 0.001–0.01 mm

- Accessory minerals: 0.001–0.002 mm

Overall, the grain size of the rock-forming minerals ranges from 0.002 mm to 0.5 mm. Texture and Structure: The rock exhibits a massive texture, with all mineral grains being anhedral. The primary granular structure is microcrystalline. Olivine is heavily replaced by serpentinite, accompanied by secondary alteration. Chromite remains largely unaltered. Based on the degree of olivine alteration, this is a metamorphosed ultramafic intrusive rock. Due to the presence of chromite, the rock is classified as dunite.

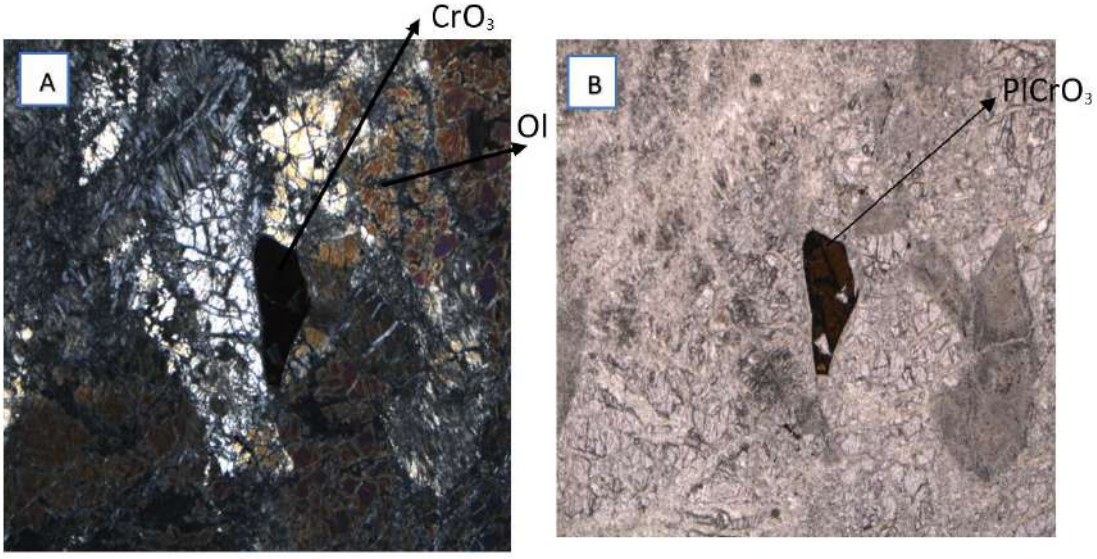


Fig. 8. Thin-section image of sample L1-2 under a polarized light microscope. Fig. A: Thin section studied under crossed-polarized light (using two Nicol prisms). Fig. B: Thin section studied under plane-polarized light (using one Nicol prism)

Microscopic Details:
Field of view: 5 mm × 5 mm
Objective magnification: 40×
Texture: Massive
Grain shape/structure: Allotriomorphic (anhedral)
Rock name: Dunite

8.1.3. Thin Section No. L54-3

Mineralogical Composition:

The rock is composed predominantly of olivine and pyroxene, with minor accessory minerals and small amounts of chromite.

- Essential (rock-forming) minerals: Olivine and pyroxene are the main rock-forming minerals. Both olivine and clinopyroxene show extensive serpentinization and secondary alteration.
- Minor minerals: Chromite occurs as an accessory mineral. Other minor accessory minerals are present in trace amounts.

Grain Size:

The grain size of the constituent minerals is generally fine- to very fine-grained:

- Olivine: 0.1–0.2 mm
- Clinopyroxene: 0.1–0.2 mm

- Chromite: 0.001–0.01 mm
- Accessory minerals: 0.0001–0.001 mm

Overall, the grain size of the rock-forming minerals ranges from 0.0001 mm to 0.2 mm.
Texture and Structure:
The rock exhibits a granular, massive texture, characterized by a porphyroblastic structure. Olivine and pyroxene have been largely altered to serpentinite and are classified as serpentinite.

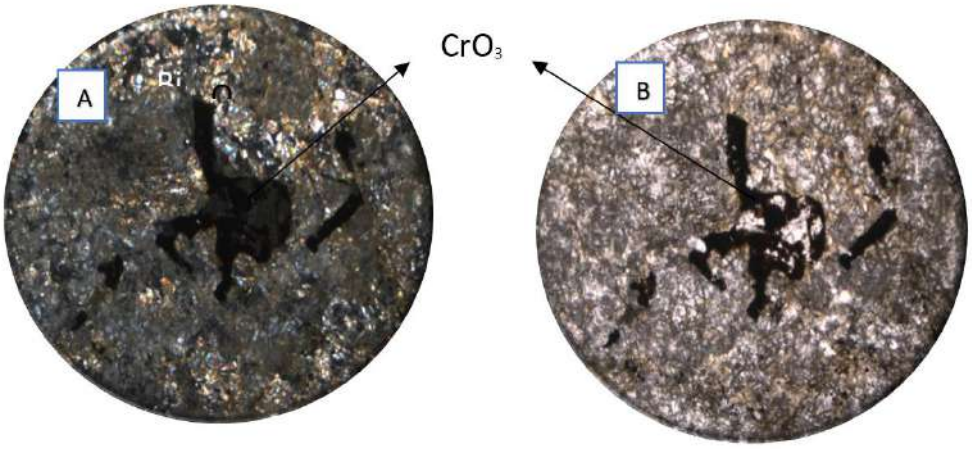


Fig. 9. Thin-section image of sample L54-3 under a polarized light microscope. Fig. A: Thin section studied under crossed-polarized light (using two Nicol prisms). Fig. B: Thin section studied under plane-polarized light (using one Nicol prism)

Microscopic Details:
Field of view: 5 mm × 5 mm
Objective magnification: 40×
Texture: Massive
Grain shape/structure: Porphyroblastic
Rock name: Serpentinite

8.1.4. Thin Section No. L54-4

Mineralogical Composition:
The rock is composed predominantly of olivine and pyroxene, with minor chromite.

- Essential (rock-forming) minerals:
- Olivine constitutes approximately 93 vol.% of the rock and has been largely altered to serpentinite.
- Minor minerals:
- Pyroxene occurs as 1–5 vol.% of the rock.
- Accessory minerals:
- Chromite is present in minor amounts, approximately 0.2–1 vol.%.

Grain Size: The grain size of the rock-forming minerals is generally not clearly visible under the microscope, reflecting a massive texture.
Texture and Structure: This rock has undergone extensive secondary alteration, during which the primary minerals were replaced by serpentinite through alteration (hydrothermal) metamorphism, resulting in the formation of serpentinite.

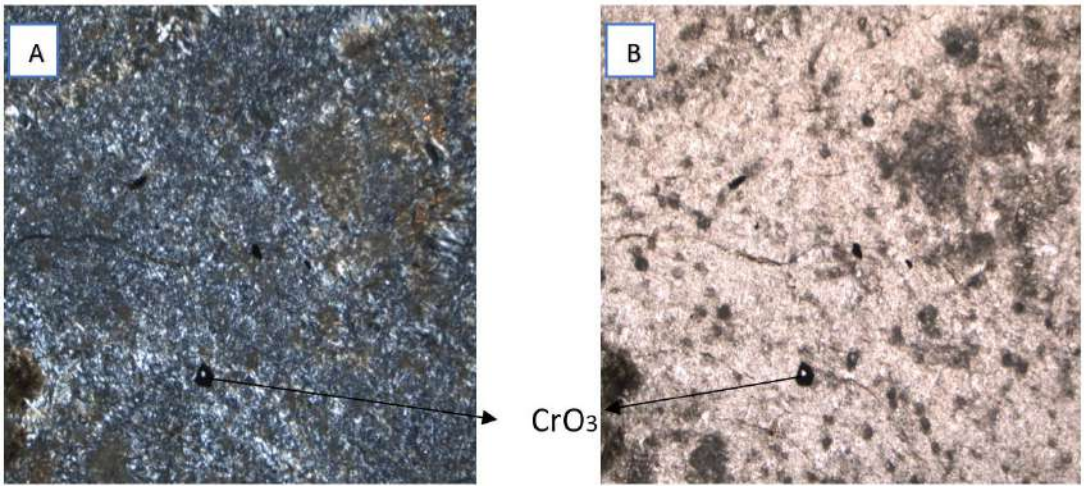


Fig. 10. Thin-section image of sample R2-4 under a polarized light microscope. Fig. A: Thin section studied under crossed-polarized light (using two Nicol prisms). Fig. B: Thin section studied under plane-polarized light (using one Nicol prism)

Microscopic Details:
Field of view: 5 mm × 5 mm
Objective magnification: 40×
Texture: Massive
Structure: Fibroblastic
Rock name: Serpentinite

8.1.5. Thin Section No. L54-27

Mineralogical Composition: The rock is composed predominantly of olivine and pyroxene, with minor accessory minerals.

- Essential (rock-forming) minerals: Olivine constitutes approximately 95 vol.% of the rock. The remaining mineral content is clinopyroxene, which has been largely altered to serpentinite.
- Minor minerals: Pyroxene occurs as 1–5 vol.% of the rock.
- Accessory minerals: Chromite is present as 0.1–1 vol.%.

Grain Size: The grain size of the rock-forming minerals is generally not clearly discernible under the microscope, due to secondary alteration. Olivine and pyroxene have been extensively replaced by serpentinite. The primary fabric of rocks is evident as talcose, indicating that the serpentinite has been further altered to talc by hydrothermal metamorphism.

Texture and Structure: The rock exhibits a massive texture and a fibroblastic structure, which is classified as serpentinite.

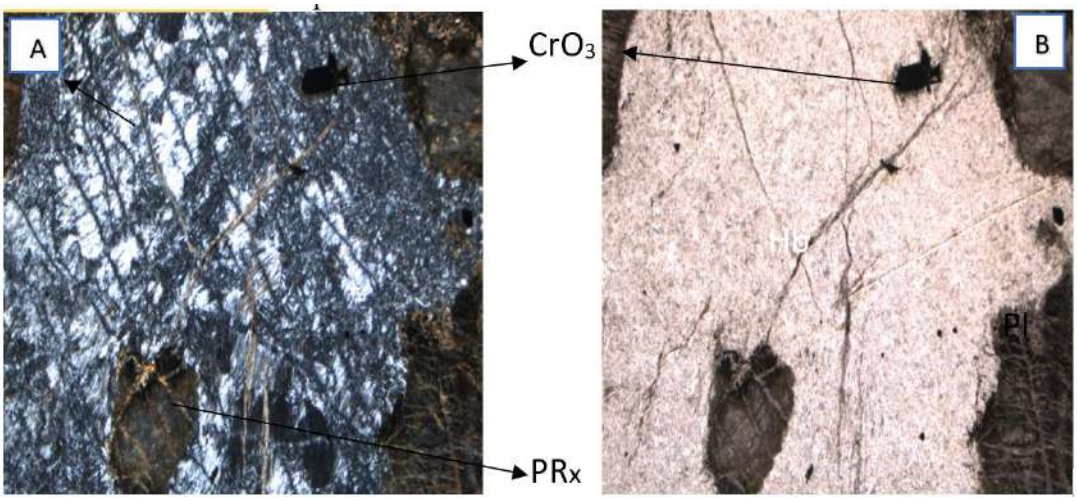


Fig. 11. Thin-section image of sample L54-27 under a polarized light microscope. Fig. A: Thin section studied under crossed-polarized light (using two Nicol prisms). Fig. B: Thin section studied under plane-polarized light (using one Nicol prism)

Microscopic Details:
view: 5 mm × 5 mm
Objective magnification: 40×
Texture: Massive
Structure: Fibroblastic
Rock name: Serpentinite

8.1.6. Thin Section No. L54-29

Mineralogical Composition: The rock is composed predominantly of olivine and pyroxene, with minor accessory minerals.

- Essential (rock-forming) minerals: Olivine constitutes approximately 95 vol.% of the rock, while pyroxene accounts for 4–5 vol.%.
- Minor minerals: None observed in a significant amount.
- Accessory minerals: Chromite occurs in trace amounts, approximately 0.01–0.2 vol.%.

Grain Size: The grain size of the rock-forming minerals is very fine-grained and not clearly visible under the microscope:

- Olivine: 0.1–0.3 mm
- Pyroxene: 0.1–0.2 mm
- Accessory / minor minerals: 0.01–0.1 mm

Olivine dominates the composition, while the remainder consists of pyroxene and accessory minerals. Olivine and pyroxene have been extensively altered to serpentinite. The alteration is intense, reflecting a primary dunite that has been almost completely converted to serpentinite through intense serpentinization.

Texture and Structure: The rock exhibits a massive texture and an allotriomorphic (anhedral) granular structure. The rock is also classified as serpentinite.

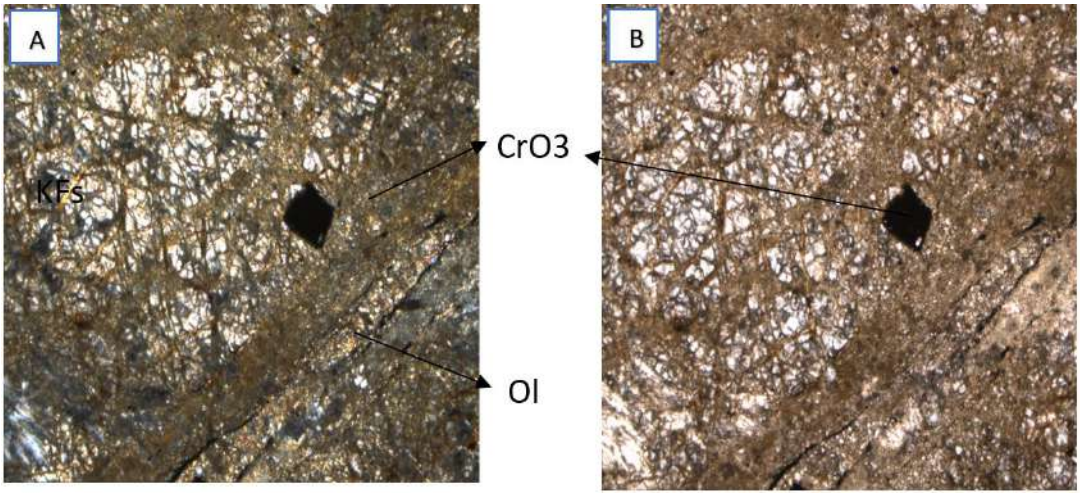


Fig. 12. Thin-section image of L54-29 under a polarized light microscope. Fig. A: Crossed-polarized light (using two Nicol prisms). Fig. B: Plane-polarized light (using one Nicol prism)

Microscopic Observations:

A

Field of view: 2 mm × 2 mm

Objective magnification: 40×

Texture: Massive

Structure: Allotriomorphic granular (anhedral)

Rock name: Serpentinite

B

Field of view: 2 mm × 2 mm

Objective magnification: 10×

Texture: Massive

Structure: Porphyroblastic

Rock name: Orthoschist

8.1.7. Thin Section No. L54-30

Mineralogical Composition: The rock is composed predominantly of olivine and pyroxene, with minor accessory minerals.

- Essential (rock-forming) minerals: Olivine constitutes approximately 95 vol.% of the rock, while the remaining mineral content is clinopyroxene.
- Minor minerals: None observed in a significant amount.
- Accessory minerals: Chromite is present in minor amounts.

Grain Size: The grain size of the rock-forming minerals is generally fine and ranges as follows:

- Olivine: 0.06–3.5 mm
- Clinopyroxene: 0.04–3 mm
- Minor accessory minerals: 0.2–1.3 mm

The rock is a metamorphosed ultramafic, resulting from hydrothermal metamorphism (serpentinization), and it corresponds to dunite.

Texture and Structure: The rock exhibits a massive texture and an allotriomorphic granular structure.

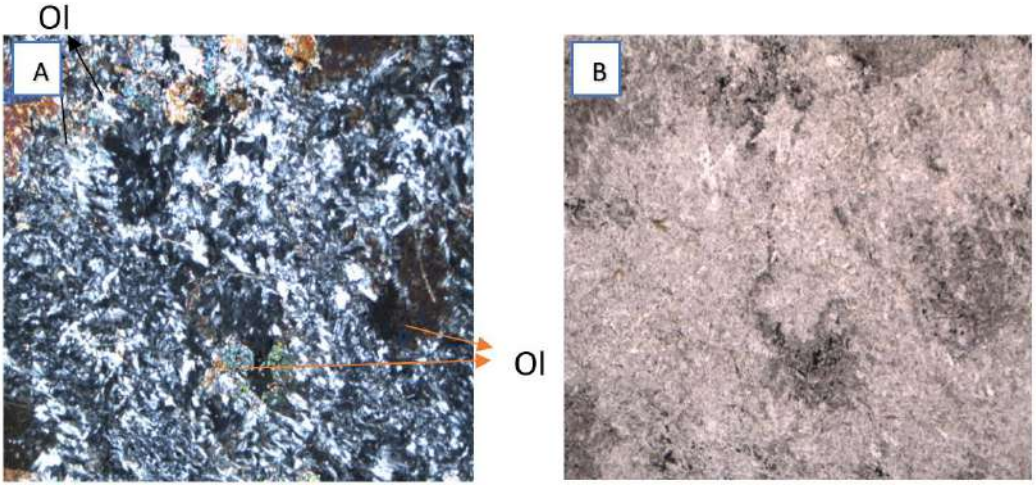


Fig. 13. Thin-section image of sample L54-30 under a polarized light microscope. Fig. A: Crossed-polarized light (using two Nicol prisms). Fig. B: Plane-polarized light (using one Nicol prism)

Microscopic Observations:
Field of view: 5 mm × 5 mm
Objective magnification: 40×
Texture: massive
Structure: Allotriomorphic (anhedral)
Rock name: Dunite

Additional Thin-Section Observations:
Field of view: 2 mm × 2 mm
Objective magnification: 10×
Texture: Massive
Structure: Porphyroblastic
Primary granular structure: Cataclastic
Rock name: Orthoschist

Field of view: 2 mm × 2 mm
Objective magnification: 10×
Texture: Massive
Structure: Porphyroblastic
Primary granular structure: Cataclastic
Rock name: Orthoschist

Petrographic investigations of the thin sections indicate that, in sample L54-1, olivine and pyroxene are the principal rock-forming minerals, while minor minerals occur as subordinate phases; accessory minerals are also present. In this sample, olivine has been replaced by serpentinite as a result of secondary alteration processes and is more abundant than pyroxene. Olivine occurs as porphyritic grains in this sample. The rock exhibits a massive texture, with all mineral grains having an allotriomorphic granular structure. Accordingly, the rock is classified as serpentinite.

In sample L54-2, olivine is present in very high abundance and has been replaced by serpentinite due to intense secondary alteration, whereas pyroxene occurs in relatively minor amounts. This sample's protolith was an igneous rock that later deformed and

became the metamorphic rock dunite. Furthermore, chromite is an accessory mineral that is a primary mineral that has not undergone secondary alteration. It is challenging to ascertain the orientation, grain size, and modal proportions of the minerals because of the severity of alteration. The rock exhibits an allotriomorphic granular structure and a massive texture. These petrographic features allow for the identification of the rock as dunite. In addition, olivine is once more prevalent than pyroxene in sample L54-3. Alteration metamorphism has caused serpentinite to significantly replace both olivine and pyroxene, while chromite has stayed stable in its primary state. A new metamorphic rock was created as a result of this stage of alteration. The rock exhibits a fibroblastic structure and a massive texture. It is categorized as serpentinite based on petrographic data. Also, sample L54-4's mineralogical makeup is not substantially different from the samples that have already been described. Pyroxene is less common than olivine, and hydrothermal processes have caused serpentinite to significantly replace both minerals. The rock has a fibroblastic structure and a massive texture. This rock is also identified as serpentinite based on petrographic data. Like the other samples, the main minerals in sample L54-27 are olivine and pyroxene, which have both undergone significant hydrothermal or alteration metamorphism and been replaced by serpentinite. Under a microscope, a fibrous structure is easily discernible, signifying the presence of talc. This implies that talc was later formed from serpentinite, and the presence of talc is a characteristic that can be used to identify this rock. Microscopic and petrographic observations reveal a fibroblastic structure and a massive texture. Chromite has not experienced secondary alteration and is still stable as a primary mineral. Serpentine is the classification given to this rock. Next, pyroxene and olivine are the main minerals found in sample L54-29, while dunite was the protolith. Both olivine and pyroxene were replaced by serpentinite after intense hydrothermal metamorphism, and pyroxene is no longer found. According to laboratory and petrographic data, the rock exhibits a massive texture and an allotriomorphic granular structure. Accordingly, the rock is identified as serpentinite. Moreover, in sample L54-29, the principal minerals are olivine and pyroxene, and the protolith was dunite. Following intense hydrothermal metamorphism, both olivine and pyroxene were replaced by serpentine serpentinite, and pyroxene is no longer observed. Based on petrographic and laboratory data, the rock displays a massive texture and an allotriomorphic granular structure. Accordingly, the rock is identified as serpentinite. Finally, in sample L54-30, the main minerals are olivine and pyroxene, which have been replaced by serpentinite as a result of intense hydrothermal or alteration metamorphism, leading to the formation of a new metamorphic rock. Petrographic and laboratory data indicate a massive texture and a granular structure. The rock is classified as dunite.

9. XRF Analysis of Rock Samples

The following points are obtained from the XRF analysis of the rock samples and are summarized as follows:

1. Among the seven samples mentioned above, four samples contain almost negligible amounts of Magnesium (Mg), which may be removed, redistributed, or replaced by iron (Fe) and other cations within the mineral structure, especially when the serpentinite has undergone advanced metamorphic modification.

2. The chromium (Cr) content in the samples is low (915–1772 ppm), whereas the iron (Fe) content is several times higher than that of chromium (36,274–57,899 ppm). For this reason, chromite is not the principal mineral phase in the samples. In addition, iron oxides that contain chromium as a minor constituent may also be present. Chromite typically consists of approximately 68% chromium (Cr) and the remaining 32% iron (Fe).
3. The concentrations of Ti, V, Mn, and Co are very low (negligible) in all samples. The nickel (Ni) content is approximately equal to the chromium (Cr) content.

A clear representation and explanation of the above-mentioned elements is also provided in the table below.

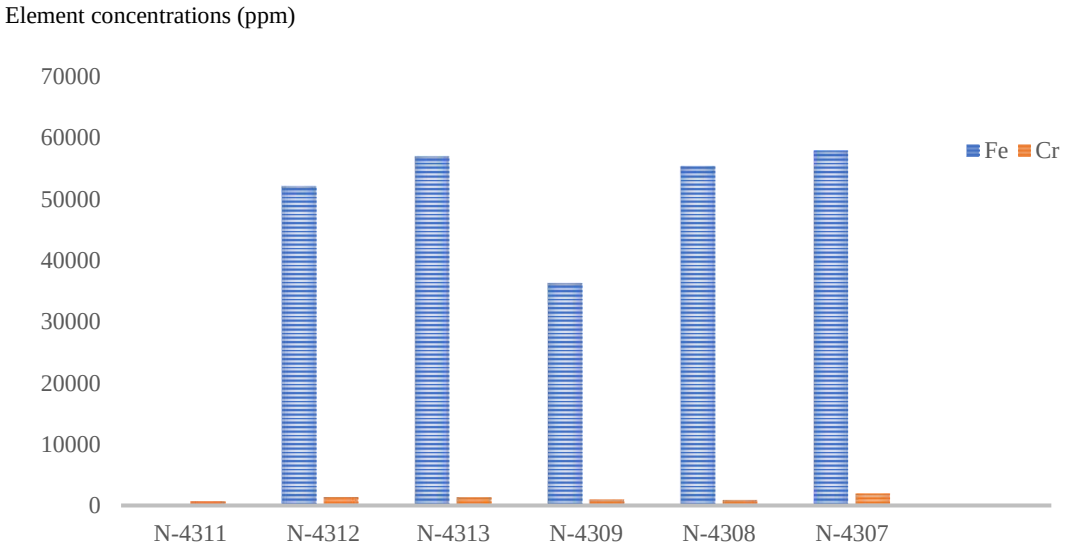


Fig. 14. Concentrations of Iron (Fe) and Chromium (Cr) Elements in Chromite within the Rock Composition

Table 1. Major, Minor, and Accessory Rock-Forming Minerals

No.	Sample ID	Olivine (%)	Pyroxene (%)	Chromite (%)	Ore Minerals (%)
1	L54-1	80–90	4–10	2–4	0.01–0.05
2	L54-2	80–90	4–10	1–4	0.01–0.03
3	L54-3	85–95	1–5	0.1–1	0.00–0.02
4	L54-4	85–93	1–7	0.2–1	0.01–0.02
5	L54-27	90–95	1–5	0.1–1	–
6	L54-29	90–95	4–5	0.01–0.2	–
7	L54-30	90–95	1–5	0.01–0.2	–

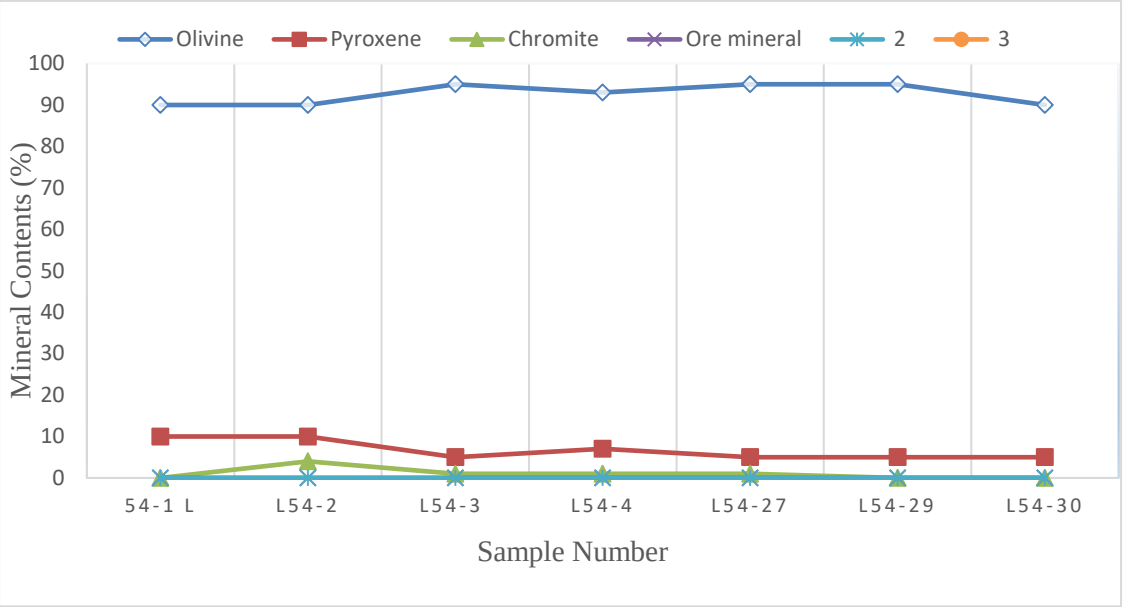


Fig. 15. Graph of the Mineralogical Composition of Ultramafic Rocks from the Ada Area, Deh Yak District, Ghazni Province

Table 2. Results of Rock Analysis Using XRF Instrument

No.	Date	Laboratory Sample ID	Field Observation Point	Element	Element Concentration (%)	Instrument Error (%)	Location
1	31-08-2021	4311	L1-1	Bal	93.8496	0.0309	Mineral composition of ultramafic rocks, Ada area, Deh Yak District, Ghazni Province
				Al	3.0675	0.0438	
				Si	0.1049	0.0699	
				P	0.3990	0.0146	
				S	0.0170	0.0080	
				Cl	0.5468	0.0044	
				Ca	1.887	0.0150	
				Cr	0.0073	0.0036	
				Mn	0.0243	0.0038	
				Fe	0.1267	0.0223	
				Co	0.1207	0.0062	
				Ni	2.5051	0.0033	
2	31-08-2021	4311	L54-2	Bal	89.4006	0.0577	
				Al	0.15056	0.0568	
				Si	2.8791	0.0754	
				Mg	0.747	0.2859	
				S	0.52	0.0090	
				Cl	2.03	0.0050	
				Ca	2.11	0.0511	
				V	0.0056	0.0028	
				Cr	0.1314	0.0054	
				Mn	0.0768	0.0066	
				Fe	5.2147	0.0387	
				Co	0.0395	0.0115	
				Ni	0.1772	0.0047	

				Cu	0.0028	0.0013	
				Zn	0.0044	0.0006	
				Sr	0.0005	0.0001	
				Ba	0.0164	0.0047	
3	31-08-2021	4313	L54-3	Bal	88.7734	0.0602	
				Mg	0.6709	0.2859	
				Si	3.1348	0.0784	
				P	0.0297	0.0167	
				S	0.0436	0.0090	
				Cl	0.0626	0.0050	
				Pb	0.0005	0.0003	
				Ca	1.1643	0.0550	
				V	0.0058	0.0028	
				Cr	0.1424	0.0055	
				Mn	0.1034	0.0072	
				Fe	5.6948	0.0409	
				Co	0.0480	0.0123	
				Ni	0.1835	0.0047	
				Zn	0.0041	0.0006	
				Sr	0.0014	0.0001	
				Ba	0.1858	0.0048	
4	31-08-2021	4314	L54-4	Bal	90.6604	0.0503	
				Si	3.1610	0.0759	
				P	0.0340	0.0159	
				S	0.0400	0.0086	
				Cl	0.0598	0.0048	
				Ca	0.2899	0.0287	
				V	0.0050	0.0028	
				Cr	0.1773	0.0057	
				Mn	0.0810	0.0069	
				Fe	5.2769	0.0387	
				Co	0.0286	0.0114	
				Ni	0.1677	0.0045	
				Cu	0.0021	0.0012	
				Zn	0.0029	0.0006	
				Sr	0.0003	0.0001	
				Ba	0.0123	0.0045	
5	31-08-2021	4307	L54-27	Bal	86.4666	0.0731	
				Al	0.2046	0.0610	
				Mg	1.7764	0.3428	
				Si	4.1796	0.0881	
				S	0.0475	0.0090	
				Cl	0.0628	0.0049	
				Ca	0.9183	0.0474	
				Ti	0.0090	0.0041	
				V	0.0071	0.0027	
				Cr	0.1960	0.0055	
				Mn	0.0876	0.0072	
				Fe	5.7891	0.0413	
				Co	0.0445	0.0124	

				Ni	0.1880	0.0053	
				Cu	0.0034	0.0013	
				Zn	0.0033	0.0006	
				Ba	0.0003	0.0048	
				Sr	0.1530	0.0001	
6	31-08-2021	4308	L54-29	Bal	91.1453	0.0452	
				Al	0.1978	0.0582	
				P	0.0310	0.0166	
				S	0.0150	0.0095	
				Cl	0.0628	0.0052	
				Pb	0.0005	0.0002	
				Ca	0.1690	0.0221	
				Cr	0.0915	0.0048	
				Mn	0.1025	0.0070	
				Fe	5.5353	0.0390	
				Co	0.0435	0.0117	
				Cu	0.0024	0.0013	
				Zn	0.0040	0.0006	
				Sr	0.0003	0.0001	
				Si	2.3127	0.0685	
				Ni	0.2501	0.0059	
7	31-08-2021	4309	L54-30	Bal	93.2669	0.0507	
				Al	0.1939	0.0957	
				Si	2.0404	0.0918	
				S	0.0901	0.0182	
				Cl	0.1315	0.0098	
				Ca	0.3967	0.0312	
				V	0.0045	0.0028	
				Cr	0.10001	0.0050	
				Mn	0.0304	0.0092	
				Fe	3.6292	0.0409	
				Ni	0.1006	0.0057	
				Ba	0.0153	0.0075	

The XRF analysis of seven ultramafic rock samples from the Ada area, Deh Yak District, Ghazni Province, revealed that silicon (Si) constitutes 2.97% of these rocks. Following silicon, the elements with the highest concentrations are aluminum (Al, 13%), chromium (Cr, 0.73%), calcium (Ca, 0.57%), iron (Fe, 4.8%), titanium (Ti), and magnesium (Mg, 0.45%).

It is noteworthy that, on average, 90.5% of the elemental content in these rock samples was unidentified. The remaining approximately 9.5% of elements are present in minor amounts, including barium (Ba), strontium (Sr), zirconium (Zr), phosphorus (P), and sulfur (S). Since oxygen-bearing minerals dominate the mineralogical composition of these rocks, it can be inferred that a significant portion of the unidentified elements measured by the instrument corresponds to oxygen.

The integrated interpretation of lithological investigations and XRF analyses, mentioned above, indicates that there is a significant correlation between mineralogical characteristics and geochemical compositions of the investigated rocks in the study area.

Petrographic investigations show that almost all the analyzed samples are composed of olivine and pyroxene, with olivine forming a majority (about 90%) and pyroxene forming a minority. The evidence also shows that chromite is consistently present in all thin sections as an accessory mineral.

Moreover, the study of these samples revealed that olivine and pyroxene grains were extensively replaced by serpentinite, while chromite remained stable. Therefore, it can be concluded that the early ultramafic rocks were subjected to intense hydrothermal deformation. And also, the stones generally show massive texture.

Results obtained by XRF analyses further support petrographic observations. Geochemical data show that iron (Fe) is present in high concentrations in all samples, followed by silicon (Si) as the next most abundant element. Other elements, including chromium (Cr), aluminum (Al), potassium (K), calcium (Ca), manganese (Mn), zinc (Zn), strontium (Sr), vanadium (V), nickel (Ni), barium (Ba), and cobalt (Co), occur in relatively low concentrations. The presence of chromium in small quantities is consistent with the petrographic identification of chromite as an accessory mineral. In addition, the increased iron content is in line with the abundance of iron-bearing minerals and iron-rich strata as determined microscopically.

Overall, the close concordance between the petrographic and XRF results confirms that the rock's elemental composition is closely related to the mineralogical composition and the mineralogical proportions of the minerals forming the rock. The integrated data set shows that the study rocks were originally formed as ultramafic magmatic rocks, supported by geochemical discrimination criteria such as elevated Mg and Fe concentrations, the presence of Cr and other trace elements characteristic of mantle-derived ultramafic magmas, and major element proportions (Si, Al, Ca) consistent with ultramafic silicate minerals.

10. Results

1. Petrographic studies show that the main constituent minerals of the meta-alkaline rocks of the Ada village of Deh-Yak district of Ghazni province are olivine, clinopyroxene, and orthopyroxene, which have been transformed into serpentine as a result of secondary deformation.
2. From the study of the thin sections, it is seen that chromite is present as a mineral in these meta-alkaline rocks, which may have economic value as a result of recent studies.
3. The results of the XRF method reveal that the meta-alkaline rocks of the Ada area of the Deh-Yak district contain Ni and Co in addition to chromium, which should be taken into consideration in future studies.
4. It is worth noting that the composition of the metamorphic rocks of the Deh Yak district includes dunite, pyroxenite, and serpentinite, and is associated with chromite mineralization, which should be used as a reference for exploration in other places.
5. The results of the petrographic studies are confirmed by the results obtained from the XRF method, which helps to confirm the presence of chromite deposits, and there may be a large chromite deposit here.

11. Recommendations

- Given the geological significance of the ultramafic rocks in the Ada area, Deh-Yak District, Ghazni Province, detailed geological mapping at a scale of 1:25,000 is recommended to better delineate lithological boundaries, structural controls, and the spatial distribution of ultramafic units and associated chromite-bearing zones.
- To improve understanding of subsurface geometry and mineralization continuity, future studies should include exploratory drilling and systematic subsurface sampling. Such investigations would enable assessment of vertical variability, chromite distribution patterns, and mineralogical continuity beyond surface exposures.
- Considering the limited availability of prior geological studies in the region, further multidisciplinary investigations are recommended to evaluate the physical and mechanical properties of ultramafic rocks in the area. This study would provide a scientific basis for assessing the potential suitability for use as a dimensional or construction stone under appropriate technical and environmental guidelines.

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