ANTON DE KOM UNIVERSITY OF SURINAME

FACULTY OF TECHNOLOGICAL SCIENCES

MINERAL GEOSCIENCE

A petrographic survey to investigate the origin of high-grade metamorphic rocks in the Kwai-Kwai zone and their relationship with the Marowijne Greenstone belt, the Gran Rio Granites and the Sara's Lust Gneiss.

A thesis submitted in partial fulfillment of the requirements for the degree of **BACHELOR OF SCIENCE** in **GEOSCIENCES**

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June 6th 2022
Paramaribo, Suriname

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List of Abbreviations

Aln	Allanite
Bt	Biotite
Ep	Epidote
Hbl	Hornlende
Mc	Microcline
Ms	Muscovite
Opq	Opaque
Pl	Plagioclase
PPL	Plane Polarized Light
Qz	Quartz
Ser	Sericite
Ttn	Titanite
TTG	Tonalite- Trondhjemite- Granodiorite
XPL	Crossed Polarized Light

Abstract

The Sara's Lust Gneisses are a recently separately named formation adjacent to the Marowijne Greenstone Belt in the Guiana Shield, which borders the belt to the southwest and to the north. This area consists of the insufficiently investigated Kwai-Kwai zone, which therefor provided the apportunity and motivation for this research. This study aims to find the genetic relationship between the Marowijne greenstone belt to the north, the Gran Rio granite to the south as well as the northern outcrop of Sara's Lust Gneiss. This will be achieved by conducting a literature study and detailed petrographic analysis of the thin sections series JU1-19 and JU90-96 gathered and sampled in this area by the Geological Mining Department. The data obtained from this research indicates the occurrence of predominantly hornblende-biotite gneisses, biotite gneisses, amphibolites, trondhjemites and aplites in this area. The rapid alternation of biotite gneiss and amphibolites indicates a supracrustal origin and the protolith of the rocks are most likely to be sedimentary and volcanic rocks, which are similar to the Sara's Lust Gneiss and there is a gradual transition between the Marowijne Greenstone Belt, the Gran Rio Granites and the Sara's Lust Gneiss.

1 Introduction

The contact relationship of the Kwai-kwai zone with the greenstone belt in the north and the Gran Rio Granite in the south is not well understood. Moreover, it is unknown whether the Kwai-Kwai zone is just like the Sara's Lust Gneiss in the north or differs from it. This petrographic research focuses on the southwestern contact of the Marowijne Greenstone Belt at the transition zone into the older Gran Rio granites. The rock samples used in this research are the series JU1-19 which lies along the Suriname river, a few kilometers inwards and the series JU90-96 which lies uttermost at the western part of Sara's Lust gneiss. The data obtained from this research will give a better understanding on how the Marowijne Greenstonebelt, the Gran Rio granites and the Sara's Lust gneisses correspond to each other and moreover, the data may also contribute to the development of the geological map of Suriname showing a better picture of the regional distribution of rocks in this area.

As a result of new geochronological data obtained in Suriname and the adjacent countries, the sequential placement of the various rock units in the Proterozoic basement of Suriname, as described in the 1977 concept (Kroonenberg et al., 2016; GMD, 1977; Bosma et al., 1983) and adopted since then, had to be revised now. Based on the 1977 concept, all granites belonged to the Gran Rio Granite, a single igneous suite (IJzerman, 1931) but since more than 50 new U–Pb and Pb–Pb zircon ages and geochemical data have been obtained in Suriname after large parts of the basement were affected, the geological evolution of the basement has been revised (Kroonenberg et al., 2016). The revision has prompted several investigations to map the age and rock types from the Proterozoic basement of Suriname to understand and establish the new order of rock units (Kok, 2019; Goumans, 2019). The Proterozoic basement of Suriname includes the Marowijne Greenstone Belt and two high-grade metamorphic belts namely the Bakhuis Granulite Belt and the Coeroeni Gneiss Belt. According to the new U-Pb and Pb-Pb zircon geochronological data, the Sara's Lust Gneiss formation north of the greenstone belt has recently been separated from the high-grade rocks in the Coeroeni region because they differ in age by nearly 100 Ma (Kroonenberg et al., 2016). Several studies have been carried out to determine this newly separated formation on basis of the rock distribution in this region. However, the Kwai-kwai gneiss zone which represents the southwestern segment of the Sara's Lust Gneiss is still poorly investigated. Although gneisses from the northern flank (Goumans, 2019) and the southern contact of the Marowijne Greenstone Belt (Kok, 2019) have been investigated recently, there is still a lack of exploration of the high-grade metamorphic rocks in the Kwai-Kwai zone during transition from the Marowijne greenstone belt to the ancient Gran Rio granites in the western segment. The results of this research are compared with the rocks from the northern and southern flanks of the Sara's Lust gneiss to see if the rocks in the western segment correspond to the rocks from Gouman's and Kok's research.

1.1 Research questions and objectives

This study aims to determine the mineralogy of the high-grade metamorphic rocks in the Kwai-kwai zone along the transition from the Marowijne greenstone belt to the ancient Gran Rio granites. The petrographic analysis will help determine its protolith and indicate to which suite of rock unit these rocks belong to. The results will be compared with the work of Goumans (2019) and Kok (2019).

How can the high grade metamorphic rocks of the KwaiKwai zone be characterized and how are they related to the Marowijne Greenstone Belt, the Gran Rio Granite and the Sara's Lust gneiss?".

Two subquestions that will help solve the main question are:

1. is the Kwai-Kwai zone a transition zone between the greenstone belt and the Gran Rio granite or something else, and
2. considering the composition and origin, is the Kwai-Kwai zone comparable to the Sara's Lust zone in the north?

This research describes the rocks at the transition zone from the Greenstone Belt to the Gran Rio Granites through petrographic analysis and classifies the rocks in groups of most related types. This helps identify and understand the distribution of rocks in the Kwai-Kwai zone of the Sara's Lust gneiss, resulting in further development of the geologic map of Suriname in this region. During this research a fieldwork was conducted across the Suriname river for better understanding the occurrence of rocks in this area. However, this study only focusses on the thin section series JU1-19 and JU90-96 as shown in the figure below (Figure 1). The data obtained from the fieldwork is not included within this research, because it was not possible to obtain thin sections from the samples in time.

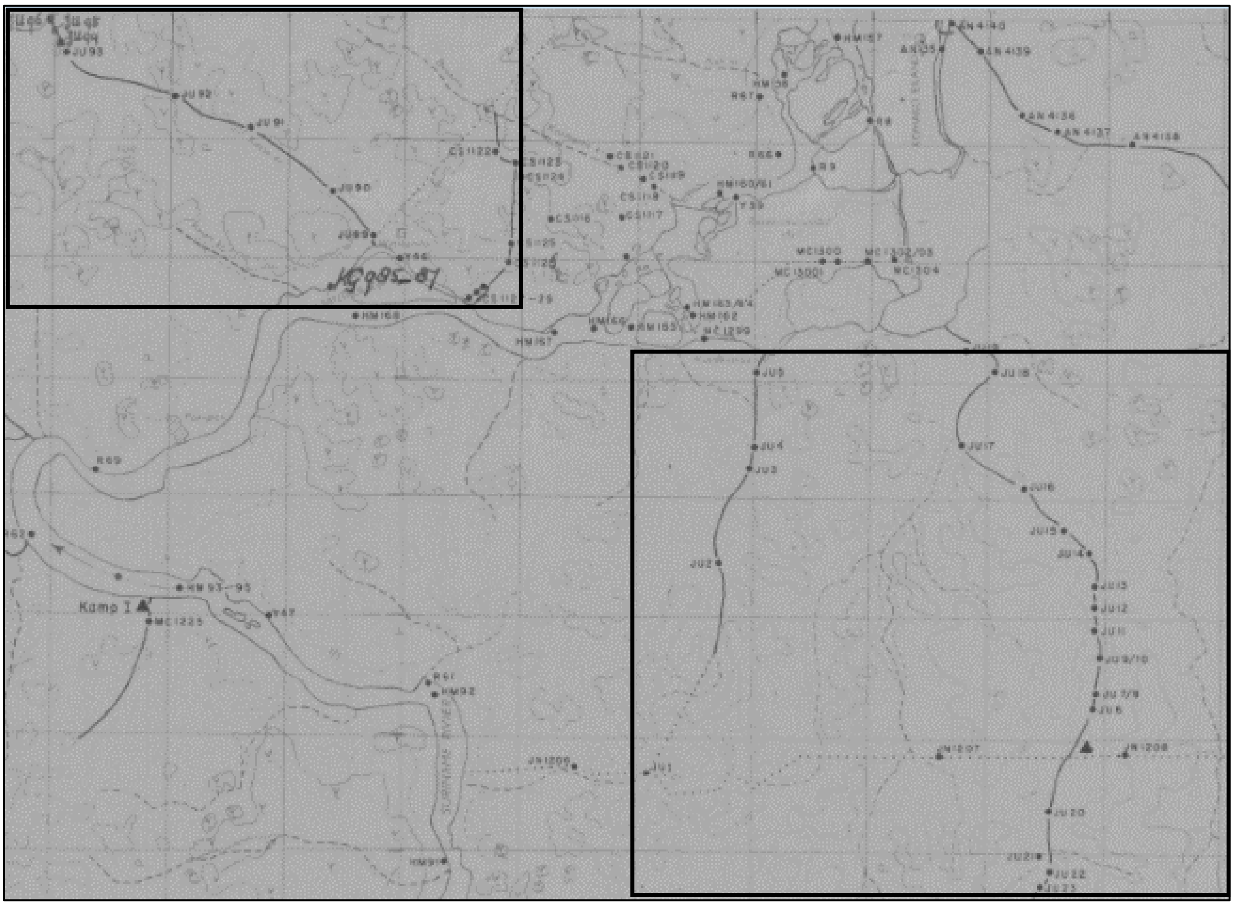


Figure 1 Location of thin sections analyzed within this research

1.2 Structure of the report

This report is written mostly according to the research cycle made available by (Universiteit Utrecht, n.d.) and is divided into different chapters starting with a brief introduction on the subject in chapter one and describing the problem along with a research plan. Chapter two gives all the relevant information on the research. In chapter three the research procedure and used equipment's and materials are discussed. Chapter four gives an overview of the results obtained and in chapter five each group of result is discussed separately. Finally, in chapter six based on results obtained and the discussion a conclusion is given which answers the problem statement and encloses this chapter with recommendations for further research. Appendix A gives a schematic display on the research design (P stands for final presentation).

2 Theory

The earth's crust consists of rocks and minerals. Rocks are a consolidated mixture of one or more minerals and are grouped into three main categories based on how they form, namely:

1. Igneous rocks
2. Sedimentary rocks
3. Metamorphic rocks

The composition and structure of the rocks are slowly but steadily being changed from one form to another, and the steps involved are shown in the rock cycle (Figure 2). Igneous rocks are formed by the cooling and crystallization of magma and can be divided into intrusive igneous rocks (cools slowly within the crust) and extrusive igneous rocks (erupts onto the earth's surface and cools quickly). Sedimentary rocks form when weathered segments of other rocks are buried, compressed, and cemented together and metamorphic rocks form by burial of sedimentary or igneous rocks due to heat and pressure (Earl, 2019). Considering the nature of this research the focus will mainly be on metamorphic and igneous rocks respectively. In addition, the geological setting of part of the Proterozoic basement will be discussed.

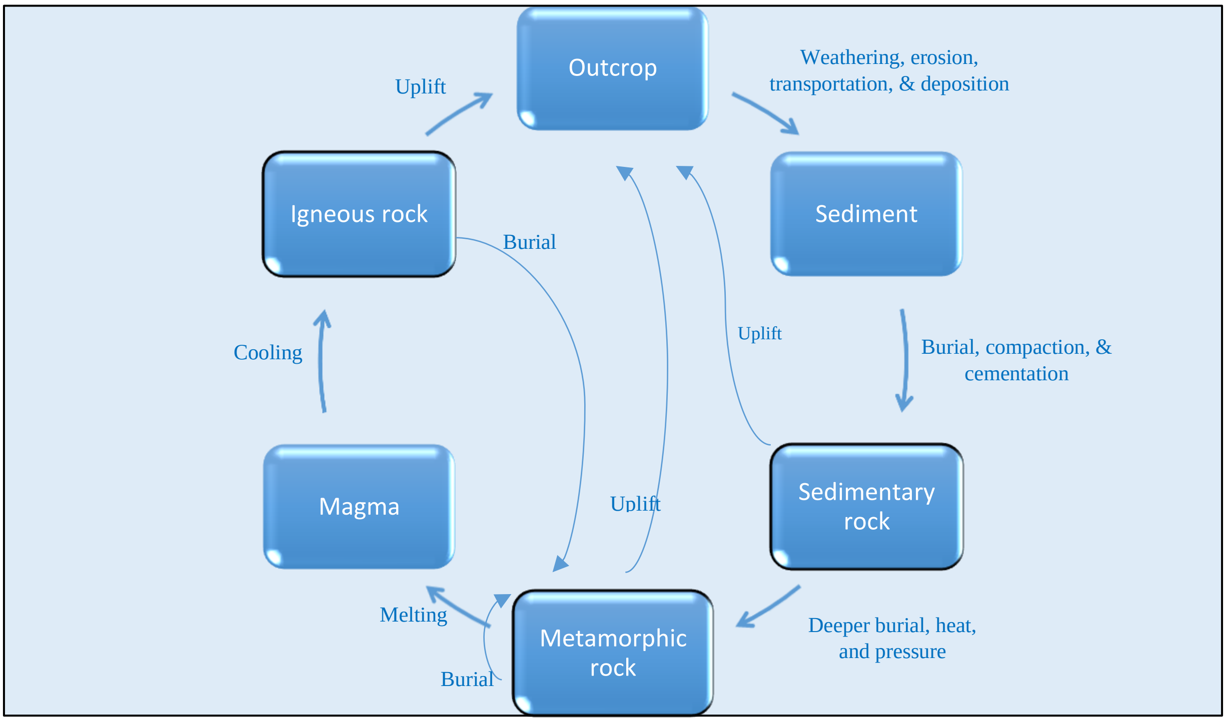


Figure 2 The rock cycle

2.1 Igneous rocks

Igneous rocks are formed by cooling of magmas that formed from partial melting of existing rocks. The minerals which consists in this magma crystallizes at different temperature forming an igneous rock. The sequence in which minerals crystallize from a magma (Figure 3) is known as the Bowen reaction series (Earl, 2019). Normally, olivine crystallizes first. While the temperature drops, if some silica remains in the magma, the olivine crystals will react with some of the silica to form pyroxene. If there is silica remaining and the speed of cooling is slow, this process continues down the discontinuous branch. At the stage where pyroxene begins to crystallize, plagioclase feldspar also begins to crystallize (Earl, 2019).

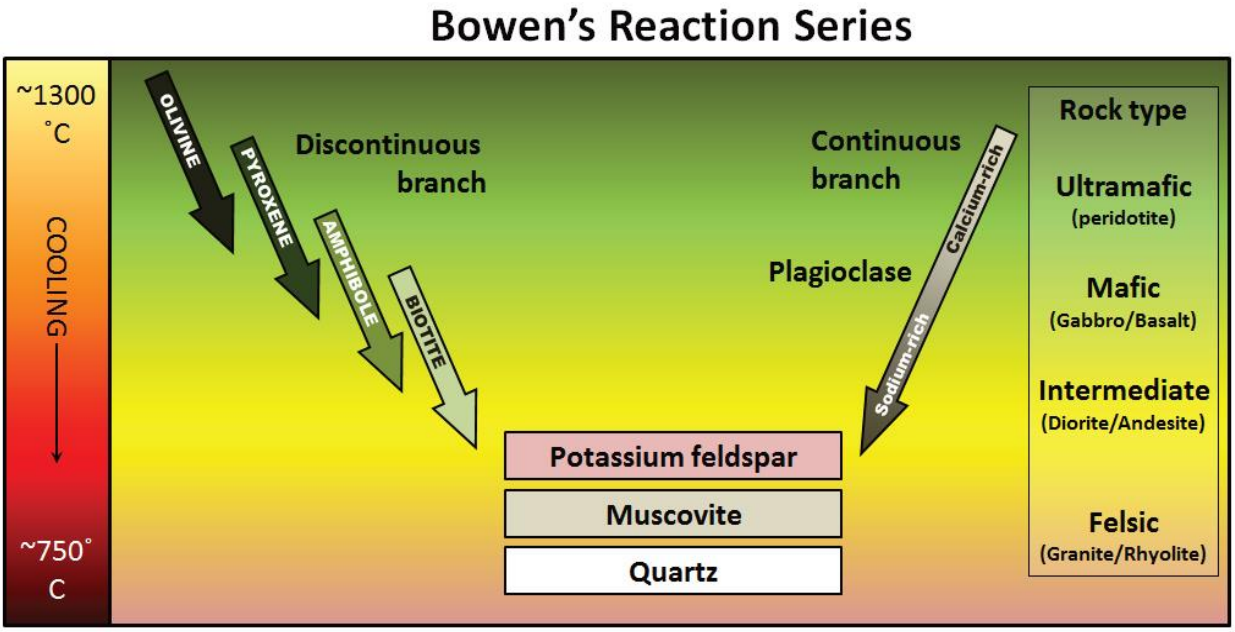


Figure 3 The Bowen's Reaction Series (Earl, 2019)

2.1.1 Classification of igneous rocks

2.1.1.1 Textures

Igneous rocks can also be classified based on their textures. When magma crystallizes beneath the earth’s surface, the crystals grow up to a few millimeters giving a crystalline structure. The crystals form an interlocking mass of approximately the same size and have no preferred direction or layering (Wong et al., 2017). These are plutonic rocks with a phaneritic structure. When magma solidifies halfway in a fault zone, a dyke is formed. These rocks have a phaneritic (crystals are large enough to distinguish from each other) or porphyritic (when crystals undergo two stages of cooling, slow and fast, large crystals forms into a matrix of smaller crystals) structure. Pegmatitic structures (very large crystals) are observed when crystal cooling was extremely slow or if water was present during cooling. Aphanitic (small crystals forming an interlocking mass of approximately the same size, sometimes crystalline structure and are hard to distinguish) structures are observed in volcanic rocks (Earl, 2019).

2.1.1.2 *Mineral compositions*

Igneous rocks can be classified into four categories, these are felsic, intermediate, mafic, and ultramafic. Earl shows a simplified classification diagram for igneous rocks based on their mineral compositions (Figure 4). The red line as shown in this figure separates the non-ferromagnesian silicates (silicates which do not contain iron or magnesium) in the lower left such as K-feldspar, plagioclase feldspar and quartz from the ferromagnesian silicates (silicates which contain iron or magnesium) in the upper right such as biotite, amphibole, pyroxene and olivine. In classifying intrusive igneous rocks, the first thing to consider is the percentage of ferromagnesian silicates. In most igneous rocks the ferromagnesian silicate minerals are clearly darker than the non-ferromagnesian silicate minerals (Earl, 2019).

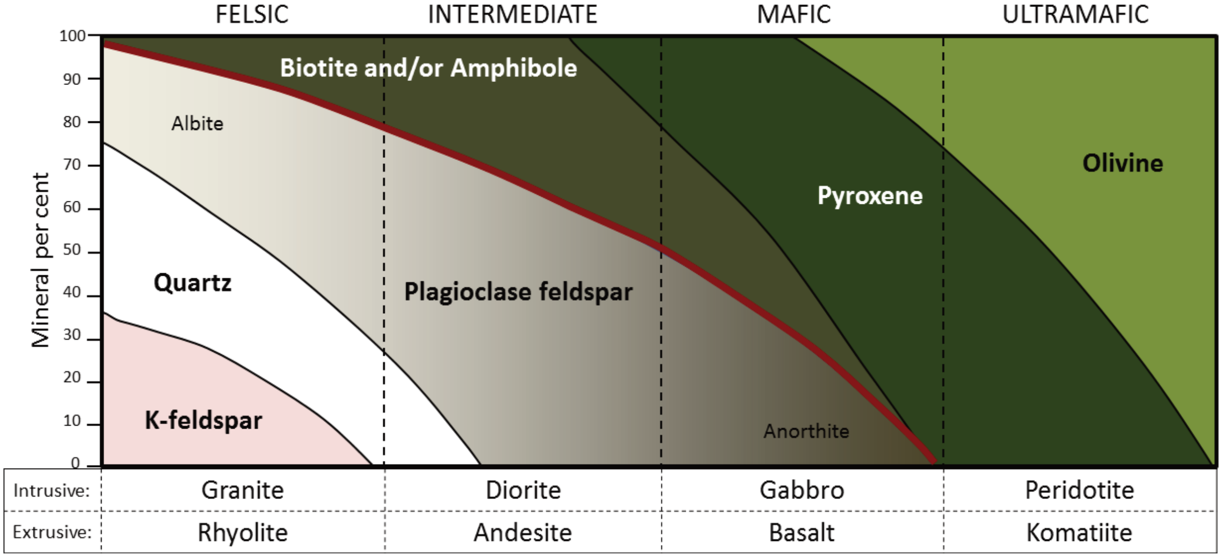


Figure 4 A simplified classification diagram for igneous rocks based on their mineral compositions (Earl, 2019)

2.2 Metamorphic rocks

Temperature and pressure are two main mechanisms for forming metamorphic rocks. Metamorphic rocks form through burial of either Igneous, sedimentary, or pre-existing metamorphic rocks (Figure 2). After burial the temperature and pressure on the rock increases which changes the structure of the rock and some minerals become instable and tend to react with each other and forming new minerals. However, the overall chemical composition in the rock stays the same. Based on temperature and pressure some minerals crystallize into different polymorphs (Earl, 2019) that is the crystalline structure differs but the chemical composition stays the same. Figure 5 shows the stability fields of three polymorphs of Al_2SIO_5. Kyanite, Andalusite and Sillimanite are stable at different pressures and temperatures and form a key indicator of these two variables that existed during metamorphism (Earl, 2019).

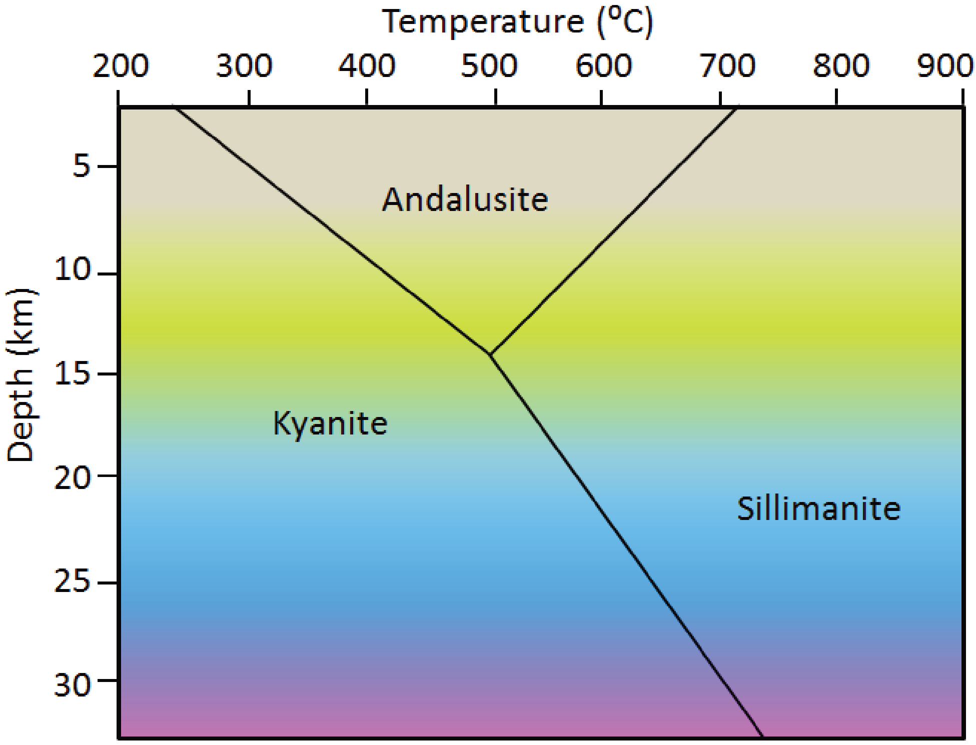


Figure 5 The temperature and pressure stability fields of three polymorphs of Al2SiO5 (Earl, 2019)

2.2.1 Types of metamorphism

There are three types of metamorphism which forms metamorphic rocks. *Regional metamorphism* (most common type of metamorphism) occurs in fold mountain belts or cratonic areas. The metamorphic rocks arise by the combined action of heat, burial pressure, differential stress, strain, and fluids on pre-existing rocks. *Contact metamorphism* occurs at shallow depth where bodies of hot magma increase the temperature of the surrounding rocks which causes metamorphism. *Dynamic metamorphism* takes place in narrow zones adjacent to faults and thrusts. The high shear stresses associated with faults and thrusts compresses the adjacent rocks (Earl, 2019). Figure 6 shows the metamorphic facies based on temperature and depth. In every stage there are characterictic minerals to identify the metamorphic facies.

Greenschist facies: Greenschist is a fine- to medium-grained foliated metamorphic rock dominated by chlorite, actinolite and epidote, with or without albite, quartz and calcite. The greenschist phase is determined by the particular temperature and pressure conditions required to metamorphose basalt to form the typical greenschist facies minerals chlorite, actinolite, and albite.

Amphibolite facies: Amphibolites define a particular set of temperature and pressure conditions known as the amphibolite facies, with temperature of 500 to 750 °C and pressures of 8-7 kbar (Strekeisen, 2006). Changes in mineralogy depends very much on protolith, however, production of abundant garnet and hornblende are most characteristic (Strekeisen, 2006).

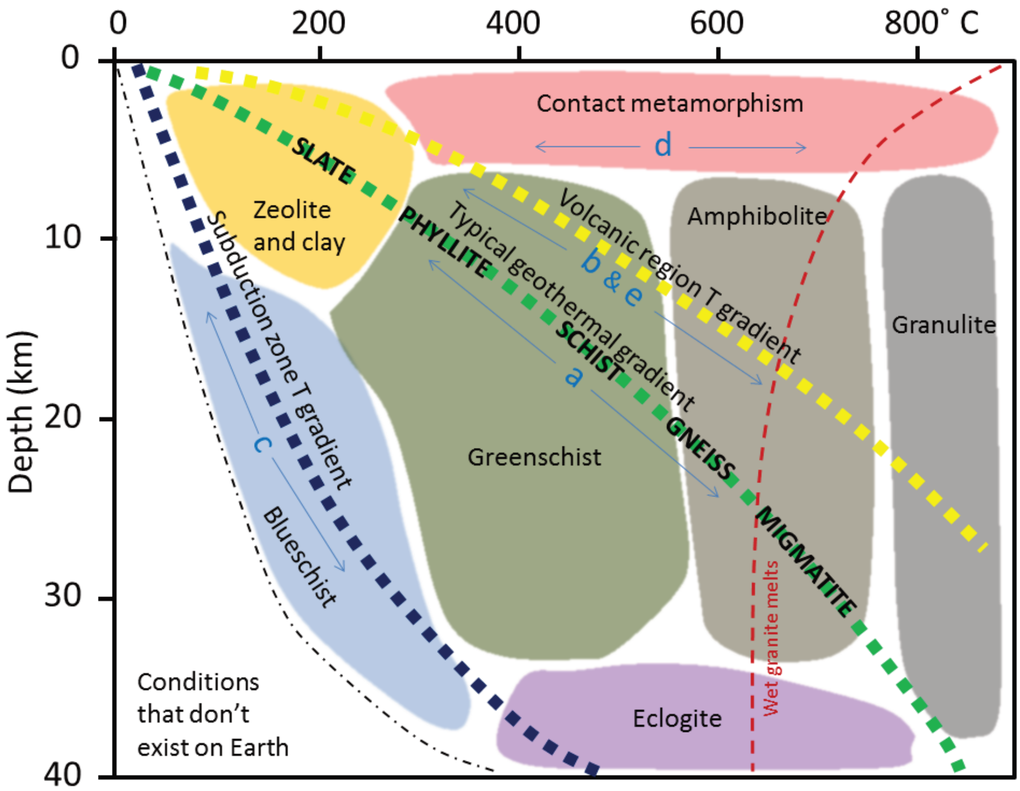


Figure 6 Types of metamorphism shown in the context of depth and temperature under different conditions (Earl, 2019

Metamorphic rocks become foliated due to increasing pressure. This occurs mainly through regional metamorphism. During metamorphosis, mineral grains from pre-existing rocks are oriented parallel to each other or organized into distinctive bands. The various types of foliated metamorphic rocks, described in order of the grade of metamorphism and the type of foliation (Earl, 2019) are:

Slaty: rocks with a slaty texture are fine-grained (too small to see with the naked eye), they have dull surfaces, typically planar, and spilt apart easily.

Phyllitic: rocks with a phyllitic texture occur at a higher metamorphosed grade than those with a slaty texture. The grains are small and shiny, they have crinkled surfaces, wavy layers, and they also split apart easily.

Schistose: rocks with a schistose texture have visible grains. They are commonly made up of platy minerals. These textures occur at a higher metamorphosed grade than those with a phyllitic texture.

Gneissic: rocks with a gneissic texture have distinct banding, which is apparent in hand specimen or on a microscopic scale. Gneiss usually is distinguished from schist by its foliation and schistosity; gneiss displays a well-developed foliation and a poorly developed schistosity and cleavage (Strekeisen, 2006). Most of the mineral grains of gneissose rocks are visible to the naked eye. Banding in this rock is a result of mineral segregation into separate, typically light- and dark-colored layers; light-colored layers are usually composed of feldspars and quartz and dark-colored layers are usually composed of hornblende and biotite (Strekeisen, 2006). These too have a higher metamorphosed grade than rocks with a schistose texture.

Migmatite: rocks with a migmatitic structure are found in medium and high-grade metamorphic areas that can be heterogeneous at the microscopic to macroscopic scale and consists of two or more, petrographically different parts (Sawyer, 2008). One of these parts must have formed by partial melting and contain rocks that are petrogenetically related to each other, (called the neosome) and to their protolith through partial melting or segregation of the melt from the solid fraction (Sawyer, 2008). The partially melted part typically contains pale-colored rocks that are quartzofeldspathic or feldspathic in composition, and dark-colored rocks that are enriched in ferromagnesian minerals (Sawyer, 2008). Table 1 shows the types of metamorphic rocks which arises during different stages as the temperature of the rock increases.

Table 1 A rough guide to the types of metamorphic rocks that form from different parent rocks at different grades of regional metamorphism (Earl, 2019)

Parent rock	**Very low grade (150-300 °C)**	**Low grade (300-450 °C)**	**Medium grade (450-550 °C)**	**High grade (> 550°C)**
Mudrock	Slate	Phyllite	Schist	Gneiss
Granite	No change	No change	Almost no change	Granite gneiss
Basalt	Chlorite schist	Chlorite schist	Amphibolite	Amphibolite
Sandstone	No change	Little change	Quartzite	Quartzite
Limestone	Little change	Marble	Marble	Marble

Metamorphic rocks with non-foliated texture often arise under either low-pressure conditions or just confining pressure through contact metamorphism. These rocks are classified primarily based on their mineral composition. Non-foliated metamorphic rocks appear massive or granular, they can form whether there is directed pressure or not and these rocks do not typically display the characteristic of parallel aligned minerals (The Australian Museum, 2018; Earl, 2019).

2.2.1.1 Mineral composition

Another way of classifying metamorphic rocks is to look at the mineral composition of the rock. Specific minerals within these rocks are indicative of different grades of metamorphism. These minerals are known as index minerals (Earl, 2019). The grade of metamorphism increases as the temperature and pressure on the rocks increases. Index minerals include chlorite, epidote, muscovite, biotite, garnet, andalusite, kyanite and sillimanite. Figure 7 shows some of these index minerals, arranged in order of the temperature range over which they tend to be stable (Earl, 2019).

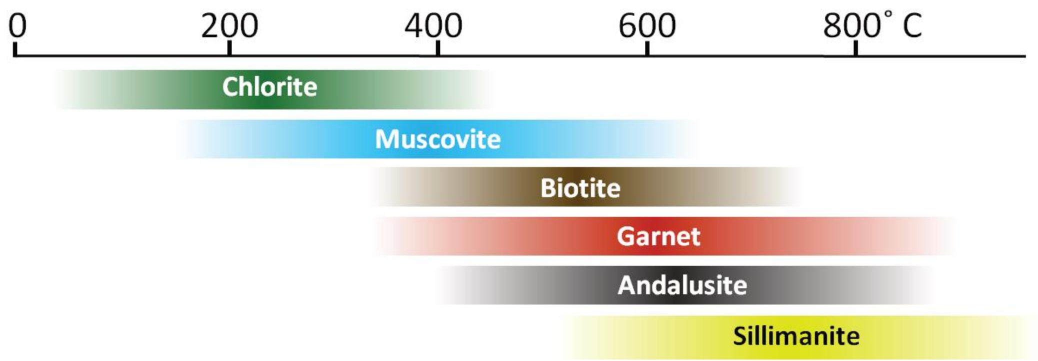


Figure 7 Metamorphic index minerals and their approximate temperature ranges (2019,Earl)

2.3 Geological setting

2.3.1 Regional geology

Suriname lies in the north-eastern part of South America, and it is part of the Guiana shield. The Guiana Shield in the north is separated from the Central Brazilian Shield in the southern part by the Amazon– Solimões basin (Figure 8). Together these two shields form the Amazonian Craton (Kroonenberg et al., 2016). The Guiana Shield covers approximately 90% of the southern part of the country Suriname, forming the Proterozoic basement, including a greenstone–tonalite–trondhjemite–granodiorite belt in the northeast of the country, the Marowijne Greenstone Belt. The basement also contains two high-grade belts namely the high-grade Bakhuis Granulite Belt in the northwest and Coeroeni Gneiss Belt in the southwest, respectively, and a large granitoid–felsic volcanic terrain in the central part of the country which is being interrupted by numerous gabbroic intrusions. The sequence of formation of the three belts according to the older concept (GMD, 1977) was as follows: first the emplacement of the Bakhuis Granulite Belt in the northwest took place, in the Archean age, making this rock unit the oldest one. Secondary Coeroeni Gneiss Belt in the southwest was formed followed by the Marowijne Greenstone Belt in the northeast of the country, thus making the last rock unit the youngest one (Kroonenberg et al., 2016).

Figure 8 The Amazonian Craton divided by the Amazon– Solimões basin into the Guiana Shield and the Brazilian Shield (Kroonenberg, et al., 2016).

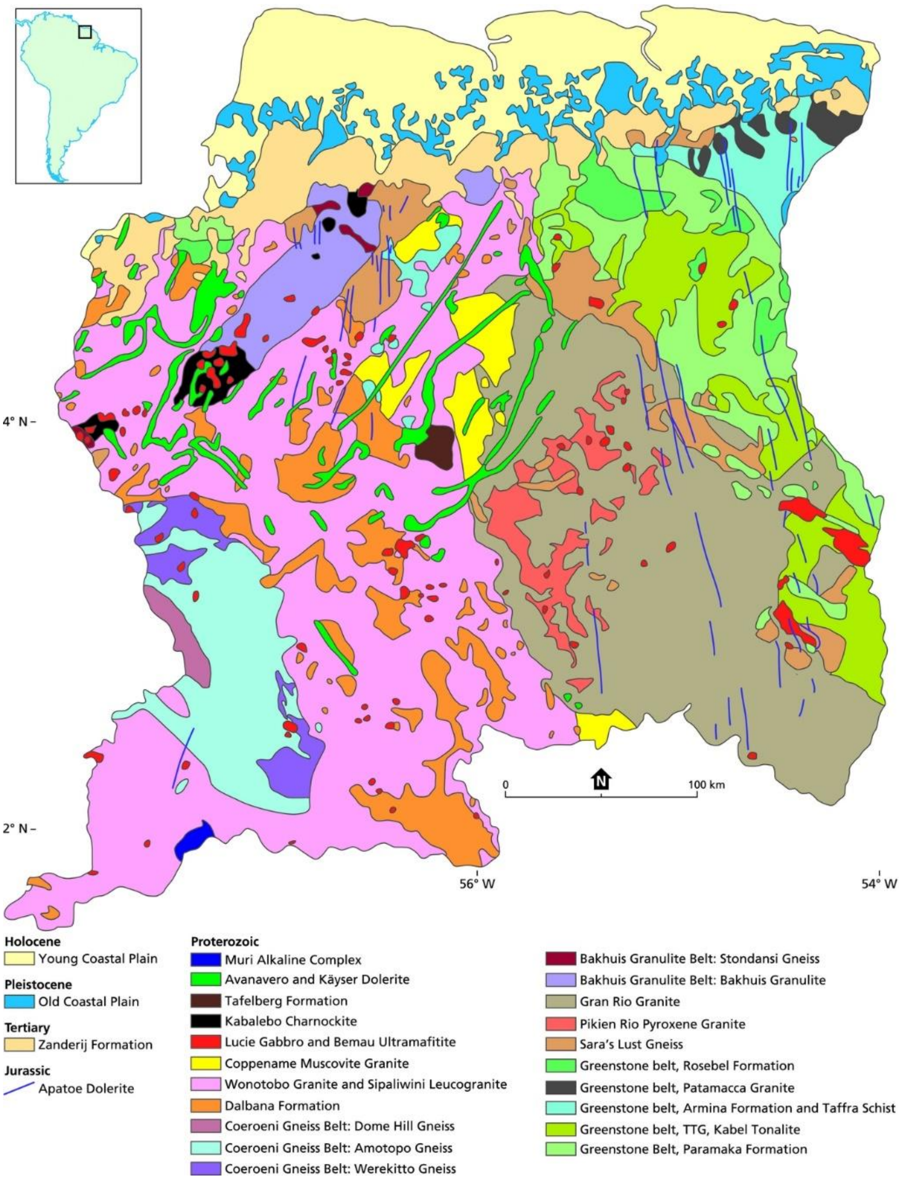


Figure 9 Simplified geological map of Suriname, according to modern data (Kroonenberg et al., 2016).

2.3.2 The Marowijne Greenstone Belt

The Marowijne Greenstone Belt is estimated to be part of a nearly continuous E-W to SE-NW striking greenstone belt which lies along the northeastern margin of the Guiana shield, stretching all along western Africa (Bosma et al., 1983) and consisting of the Paramaka, Armina and Rosebel formation. The stratigraphic sequence of the formation of The Marowijne Greenstone belt is based on a variety of rock units. According to (Bosma et al., 1983) the emplacement of the Paramaka formation took place, which was also considered to be te oldest rock unit. This formation mainly contains tholeiitic ocean-floor metabasalts, island arc meta-andesites and are intruded by TTG bodies. The area is overlain by metaturbidites of the Armina Formation and is intruded by two-mica granites. The Rosebel formation containing low-grade-metamorphosed fluvial sandstones and conglomerates lies unconformably all over the Paramaka and Armina formation and forming the youngest formation of the Marowijne Greenstone Belt. This whole area is intruded by small volcanic plutons (Naipal et al., 2020). The geological structure observed within this belt is tight to isoclinal foliation with horizontal to steeply dipping fold axes (Kroonenberg et al., 2016).

2.3.2.1 Paramaka Formation

The rocks which form the Paramaka formation, mainly volcaniclastic sediments, has undergone metamorphism up to greenschist facies and it is surrounded by tonalite–trondhjemite–granodiorite intrusions from the Kabel Tonalites. Furthermore, metabasalts with pillow structures are observed (Kroonenberg et al., 2016).

2.3.2.2 Armina Formation

The rocks from the Armina formation form a regular sequence of alternating low-grade volcaniclastic metagreywacke and phyllite which are recognized as metaturbitites. This sequence starts with coarse grained metagreywacke beds, which are being topped by fine-grained metasiltstones or phyllite. The metagreywackes consist mainly of quartz, altered plagioclase and fragments of intermediate metavolcanic rock (Kroonenberg et al., 2016; Bosma et al., 1983).

2.3.2.3 Rosebel Formation

The rocks from the Rosebel Formation are recognized as metasedimentary rocks. This formation overlies the Paramaka- and Armina formation unconformably and consists of meta-arenites and metaconglomerates (Kroonenberg et al., 2016). This rock unit underwent metamorphism up to greenschist-facies. The metasandstones are medium- to coarse grained lithic meta-arenites, grading into arenitic greywackes. They show well-preserved sedimentary structures, predominantly micro- and mega-ripple cross-bedding (Bosma et al., 1983).

2.3.3 Sara's Lust gneiss

The Sara's Lust gneisses were initially considered to be part of the high-grade Coeroeni Gneiss Belt in the southwestern part of Suriname (GMD, 1977), but recent geochemical data shows that these rocks are probably over 100 Ma older. The Sara's Lust gneisses from the northern flank were investigated by Goumans in 2019. He divided the rocks from this area into three suits namely: a felsic suite, an intermediate to mafic suite and a sedimentary suit (Goumans, 2019). The felsic suit is identified as granitoids which probably originated through partial melting and the mafic suit is comparable to the Paramaka formation suggesting that these rocks are from the same unit (Goumans, 2019). The Paramaka formation contains volcaniclastic sediments and tonalite–trondhjemite–granodiorite intrusions up to amphibolite facies (Kroonenberg et al., 2016).

Furthermore, the rocks from the northern flank of the Sara's Lust gneisses are thoroughly described by Kroonenberg S. indicating that this area contains predominantly migmatitic hornblende–biotite gneisses, biotite–plagioclase gneisses, garnet–biotite gneisses and quartzofeldspathic gneisses, with minor amphibolites, locally with garnet or clinopyroxene, and furthermore pelitic sillimanite–biotite–muscovite gneisses and calcsilicate rocks, clearly of supracrustal origin (Kroonenberg et al., 2016). The southern flank of the Sara's Lust gneisses, a rock known as Kwai-Kwai gneiss was investigated by Kok in 2019. He conducted a petrographic analysis on the rock called the Kwai-Kwai gneiss and based on obtained data from his research he concluded that this rock was a tonalite (Kok, 2019). According to Kroonenberg S. this segment contains andalusite–cordierite sillimanite schists, garnet-biotite gneiss and pyroxene gneisses (Kroonenberg et al., 2016).

During the fieldtrip some of these rocks were observed as shown in Figure 10; (a) Primary sedimentary stratification enhanced by migmatization. The picture shows alternation of hornblende and biotite-rich layers, (b) Amphibolites surrounded by partial melting of felsic minerals causing the amphibolite units to drift apart, in addition pegmatite veins are cutting through this rock unit, (c) High-grade metamorphosed biotite gneisses, migmatitic texture and folds indicate partial melting of the rock, (d) Close-up biotite gneisses showing migmatitic texture.

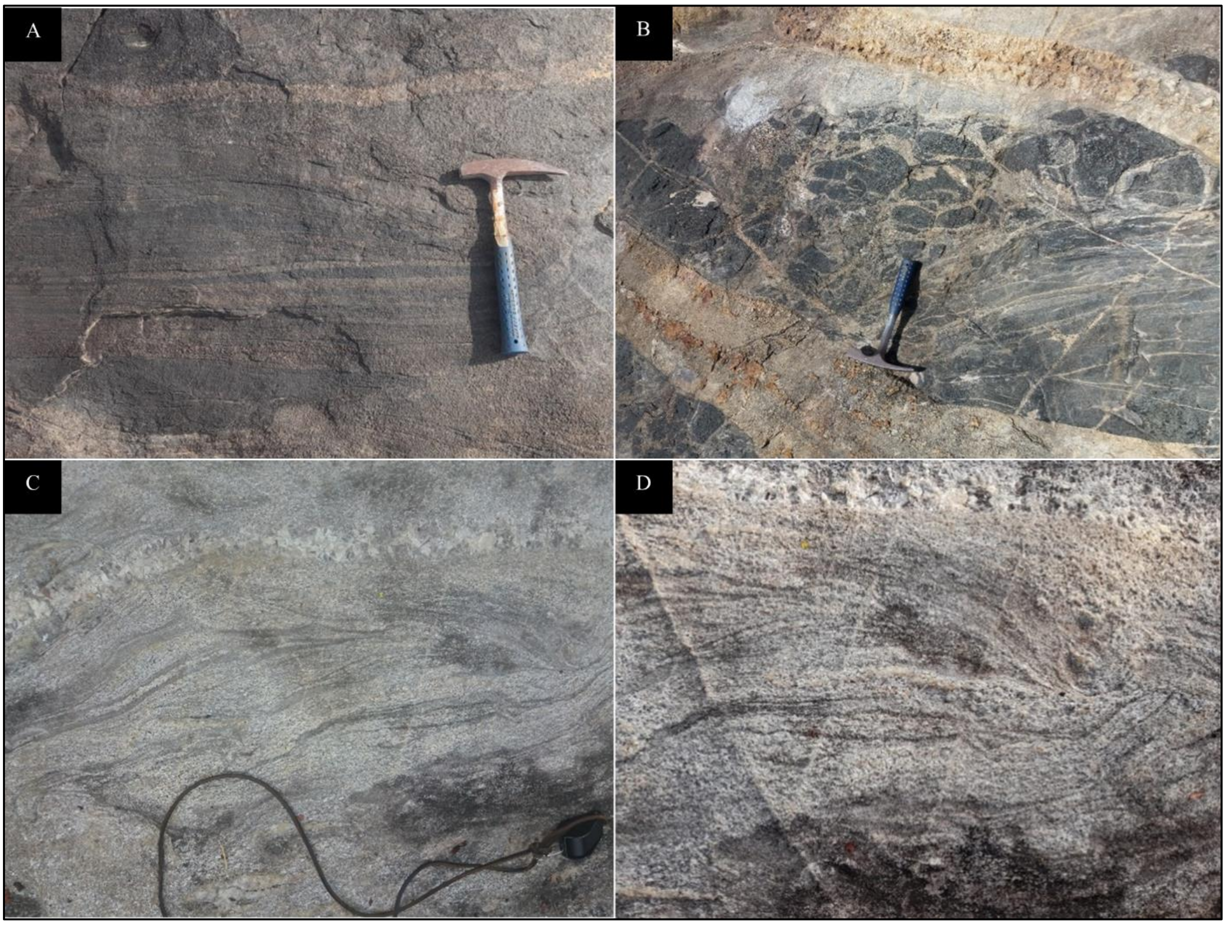


Figure 10 Rocks from the Sara's Lust gneiss (a) alteration of hornblende and biotite-rich layers (b) amphibolites & pegmatite vein (c) biotite gneiss (d) close-up biotite gneiss showing migmatitic structures.

2.3.4 Gran Rio Granite

The igneous rocks in Suriname are distinguished into four groups; (1) deep-level granites, (2) shallow-level granites, (3) Dalbana formation and (4) De Goeje Gabbro. The Gran Rio Granite was discerned by (IJzerman, 1931) containing the first group of igneous rock, the deep-level granites, with migmatitic aspects (Bosma et al., 1983). The Gran Rio Granite is a rock unit which crops out along the Gran Rio River and the Tapanahony River and it consists of medium- to coarse grained biotite granite and hornblende- biotite granite (Kroonenberg et al., 2016). These rocks are quite inhomogeneous and consists of quartz, kalifeldspar, plagioclase, biotite and somewhat hornblende as mafic minerals (Wong et al., 2017). They may also have low banded appearance and migmatitic structures (Kroonenberg et al., 2016) and they encloses enclaves and large tracts of high-grade quartzofeldspathic gneisses, locally showing vague banding and schlieren (Bosma et al., 1983).

3 Methodology

3.1 Materials & Equipment

To conduct the research the following materials & equipment were used:

1. Thin sections series JU 1-19 collected a few kilometers inward, along the Suriname river by the Geological Mining Department (GMD).
2. Thin sections series JU 90-96 collected uttermost at the western part of Sara's Lust gneiss by the Geological Mining Department (GMD).
3. Petrographic microscope at the Geological Mining Department (GMD).
4. Leica DM 750P petrographic microscope at the Anton De Kom University of Suriname.
5. HP Laptop & LAS EZ 3.4 DVD 272 software.

3.2 Research design & procedure

This research was initiated with a literature study to provide information on the geology of the research area. Also, comparable previous studies were consulted to get a better understanding of the regional spreading of rocks in this area which gave a clearer outlook on what to expect from this research.

Finally, the investigation started according to a procedure as described below:

At first the thin sections were grouped according to their percentage dark and light minerals by macroscopic observation. Each group was then taken, and all the thin sections of each group were described in full detail separately. The thin sections were placed one by one on a polarized microscope at the Geological Mining Department (GMD) and all the characteristics observed were noted. The observation was made based on different characteristics of the thin sections, namely:

1. The actual percentage of light and dark minerals within the thin section were observed and estimated.
2. The grain-sizes were determined.
3. The overall structure of the thin section based on the alignment of the minerals contained in it was noted.
4. The minerals occurring in each thin section were identified.
5. Finally, based on all the observed characteristics each thin section was allocated into groups of their own rock origin.

After all the thin sections were examined the Leica DM 750P petrographic microscope at the Anton De Kom University of Suriname was used along with a laptop and the LAS EZ 3.4 DVD 272 software to photograph each thin section and scale them correctly. Finally, all the obtained data were edited and included in this report under chapter four.

4 Results

4.1 Results from petrographic analysis

In this research a petrographic analysis was made of the thin sections JU 1-19 and JU 90-96. Initially, the thin sections were grouped based on the percentage of light and dark minerals observed in the thin sections through a polarized microscope (Table 2). The percentages given in the table are estimated values. After thoroughly studying the different thin sections, mapping the various characteristics, and determining a possible name for each thin section, the series were regrouped based on the types of rocks. Table 3 shows a summary of the various rocks found within the corresponding thin sections. In the following different paragraphs, a comprehensive description of each thin section is given and according to their mineral composition and textures are classified into different rock types.

Table 2 Thin section classification based on percentage light and dark minerals

Group	Thin section classification	Estimated percentage Ferromagnesian silicates	Thin sections
1st	Felsic	1 - 20%	JU 2, 3, 7, 9, 12, 13, 14, 15, 17, 18, 93, 94
2nd	Intermediate	20 - 50%	JU 4, 5, 11, 16, 19, 91
3rd	Mafic	50 - 90%	JU 8, 10, 90, 92, 95, 96
4th	Ultramafic	90 – 100%	JU 95

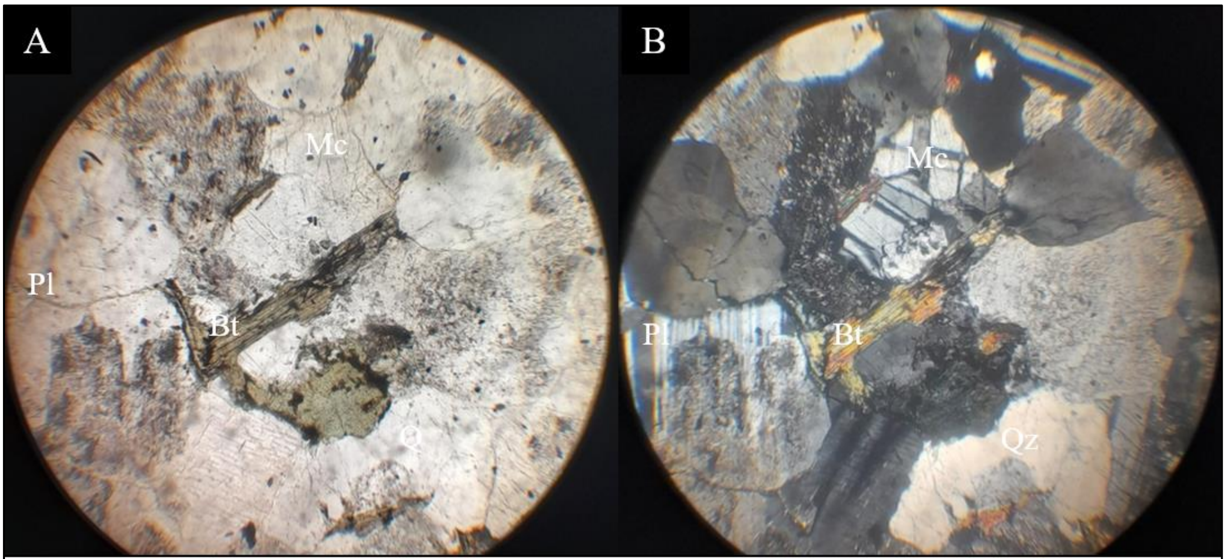
Table 3 Summary of thin section classification after petrographic analysis

Rock type	Rock name	Thin section
Igneous rocks	Aplite	JU 2, 9, 15
	Granite	JU 13, 18
	Pegmatite	JU 7
	Trondhjemite	JU 3, 12, 14, 93
Metamorphic rocks	Amphibolite	JU 8, 90, 92
	Biotite gneiss	JU 17, 94
	Hornblende biotite gneiss	JU 4, 5, 10, 16, 19, 91, 96
	Hornblendite	JU 95
	Metagreywacke	JU 11

4.1.1 Aplite

Table 4 Schematic summary of the Aplites

Nr.	Minerals	Felsic-mafic minerals	Grain size
JU2	Biotite, Plagioclase, Quartz, Microcline	90 – 10 %	Medium
JU9	Biotite, Plagioclase, Quartz, Microcline	95 – 5 %	Medium
JU15	Biotite, Plagioclase, Quartz, Microcline	80 – 20 %	Medium



Magnification=6x/0.18 Pol. | A=PPL, B=XPL.

Figure 11 Petrographic image of JU 2

Figure 11 (JU2) is a petrographic image of a medium-grained rock. The shape of the crystals is anhedral to subhedral. The grains have no subangular or subrounded boundaries. . The minerals show no preferred orientation. It is probably an igneous rock. This rock consists of approximately 90% felsic- and 10 % mafic minerals. Under ppl some minerals show moderate to high relief, the shape of these crystals are anhedral, and they have a brownish color. The crystals are non-pleochroic. Under xpl they show third order orange to greenish interference colors, and they have a parallel extinction. These are crystals of biotite. Some minerals are colorless, they have extremely low relief and anhedral shape. They show no pleochroism as the stage is rotated. They show little traces of cleavage under ppl. Under xpl they show first order grey to white interference colors, and they have inclined extinction as the stage is rotated. The crystals show typical twinning and are identified as plagioclase. Under ppl some of these colorless minerals show no traces of cleavage, and under xpl they have a wavy extinction and first order grey to white interference colors. These are crystals of quartz. Some of the colorless minerals show a cross-hatched twin pattern under xpl, they also have first order grey to white interference colors and are identified as microcline. The crystals in this rock form an interlocking mass of approximately the same size. This rock is an Aplite. Abbreviations from (Donna & Bernard, 2010).

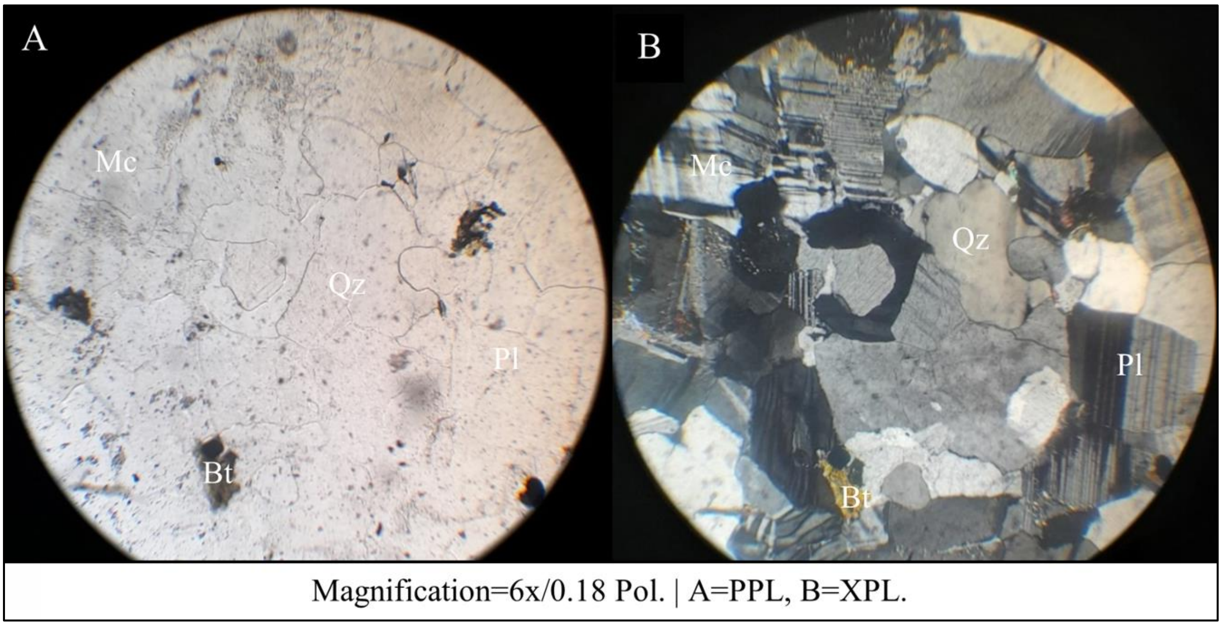


Figure 12 Petrographic image of JU 9

Figure 12 (JU9) is a petrographic image of a medium-grained rock. The shape of the crystals is anhedral to subhedral. The grains have no subangular or subrounded boundaries.The minerals show no preferred orientation.It is probably an igneous rock. The rock consists of approximately 95% felsic- and 5% mafic minerals. Under ppl some minerals show moderate to high relief, the shape of these crystals is anhedral, and they have a brown color. The crystals are weakly pleochroic. Under xpl they show third order orange interference colors, and they have parallel extinction. These are crystals of biotite. Some minerals are colorless, they have extremely low relief and anhedral shape. They show no pleochroism as the stage is rotated. They show little traces of cleavage. Under xpl they show first order grey to white interference colors, and they have an inclined extinction as the stage is rotated. The crystals show typical twinning and are identified as plagioclase. Some of these colorless minerals show no traces of cleavage under ppl, they have a wavy extinction and first order grey interference colors under xpl. These are crystals of quartz. Some of the colorless minerals show a cross-hatched twin pattern under xpl, they also have first order grey to white interference colors and are identified as microcline. The crystals in this rock form an interlocking mass of approximately the same size. This rock is an Aplite vein. Abbreviations from (Donna & Bernard, 2010).

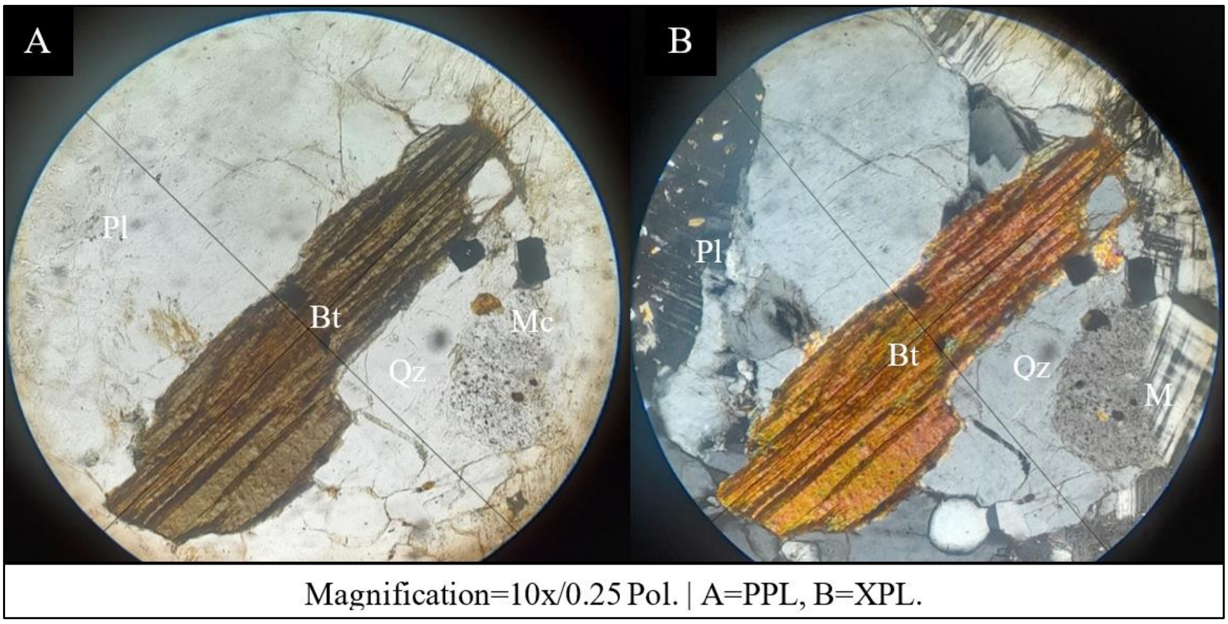


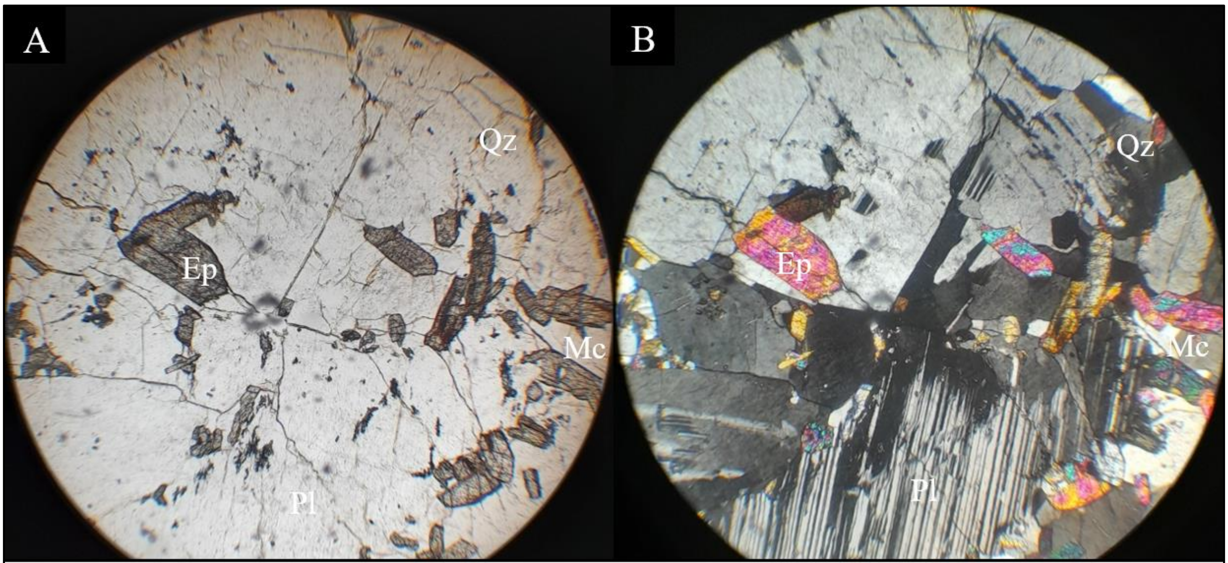
Figure 13 Petrographic image of JU 15

Figure 13 (JU15) is a petrographic image of a medium-grained rock. The shape of the crystals is anhedral. The grains have no subangular or subrounded boundaries. The minerals show no preferred orientation.. It is probably an igneous rock. The rock consists of approximately 80% felsic- and 20% mafic minerals. Under ppl some minerals show moderate to high relief, the shape of these crystals is anhedral, they have a brown color, and are weakly pleochroic. Under xpl these crystals show third order orange to pinkish interference colors, and they have parallel extinction. These are crystals of biotite. FFUnder ppl some minerals are colorless, they have extremely low relief and anhedral shape. They show no pleochroism as the stage is rotated. They show little traces of cleavage. Under xpl they show first order grey to white interference colors, and they have inclined extinction as the stage is rotated. The crystals show typical twinning and are identified as plagioclase. Some of these colorless minerals show no traces of cleavage, under xpl they have a wavy extinction and first order grey interference colors. These are crystals of quartz. Some of the colorless minerals show a cross-hatched twin pattern, under xpl they also have first order grey to white interference colors and are identified as microcline. The crystals in this rock form an interlocking mass of approximately the same size. This rock is an Aplite. Abbreviations from (Donna & Bernard, 2010).

4.1.2 Granite

Table 5 Schematic summary of the Granites

Nr.	Minerals	Felsic-mafic minerals	Grain size
JU13	Epidote, plagioclase, microcline, quartz	80 – 20 %	Coarse
JU18	Biotite , microcline, plagioclase, quartz	80 – 20 %	Coarse



Magnification=6x/0.18 Pol. | A=PPL, B=XPL.

Figure 14 Petrographic image of JU 13

Figure 14 (JU13) is a petrographic image of a coarse-grained rock. The shape of the crystals is anhedral to subhedral. The grains have no subangular or subrounded boundaries. The minerals show no preferred orientation.It is probably an igneous rock. The rock consists of approximately 80% felsic- and 20% mafic minerals. Under ppl some minerals show extremely high relief, subhedral shape and they have a brownish color. They show weak yellow to green pleochroism as the stage is rotated. Under xpl these crystals show bright yellow to pink second order interference colors and they have parallel extinction. These crystals are identified as epidotes. The epidotes are surrounded by large colorless crystals. These crystals have an anhedral shape and show no pleochroism as the stage is rotated. Under xpl they show first order grey to white interference colors, and they have an inclined extinction. These are crystals of plagioclase. Some of the plagioclase crystals have typical lamellar twinning, they have grey to black first order interference colors and they show parallel extinction. This feature is observed as the perthite structure of feldspar. Under ppl some of the colorless minerals show no traces of cleavage and are non-pleochroic, under xpl they have a wavy extinction and first order grey interference colors. These are crystals of quartz. Some of the colorless minerals show a cross-hatched twin pattern, under xpl they also have first order grey to white interference colors and are identified as microcline. The crystals in this rock form an interlocking mass of various sizes. This rock is a Granite. Abbreviations from (Donna & Bernard, 2010).

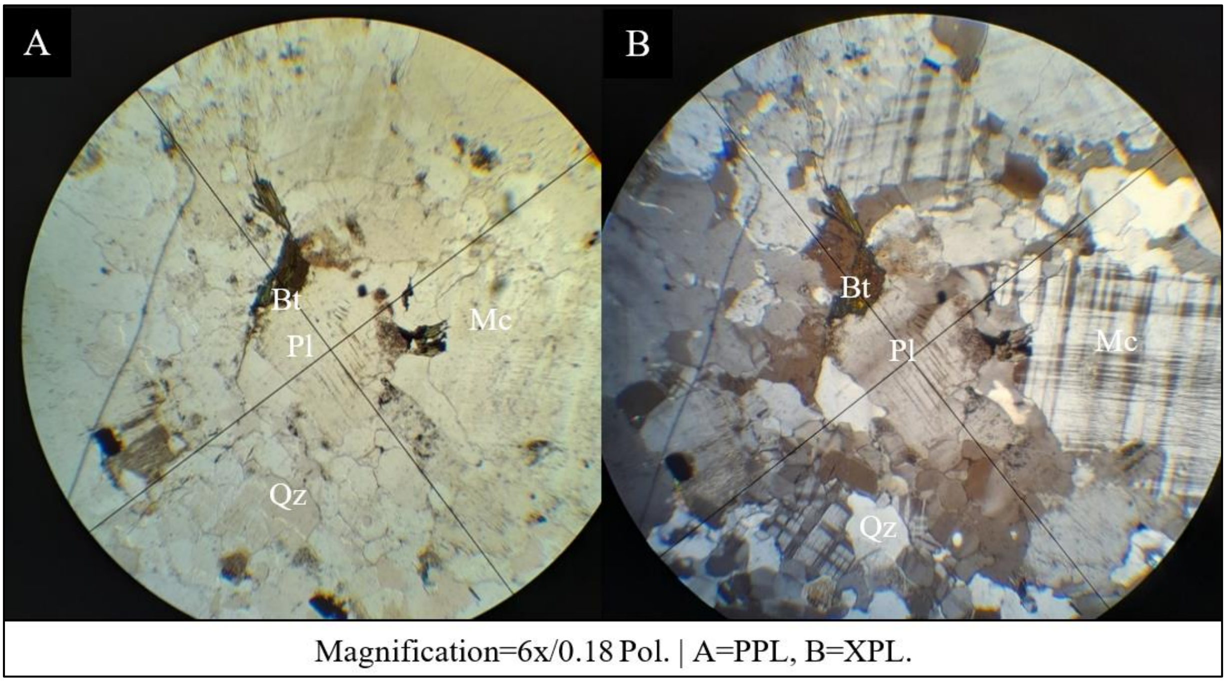


Figure 15 Petrographic image of JU 18

Figure 15 (JU18) is a petrographic image of a coarse-grained rock. The shape of the crystals is anhedral. The grains have no subangular or subrounded boundaries. The minerals show no preferred orientation. It is probably an igneous rock. This rock consists of approximately 80% of felsic- and 20% mafic minerals. Under ppl low amount of minerals with moderate to high relief are observed, the shape of these crystals are anhedral, and they have a brown color. These crystals are strongly pleochroic, they turn darker as the stage is rotated. Under xpl the interference colors of these crystals are mostly masked by the strong mineral color. Low traces of the color are observed which show third order interference colors and they have parallel extinction. These are crystals of biotite. Some minerals are colorless, they are anhedral and have very low relief. These crystals show low traces of cleavage and are non-pleochroic. Under xpl these crystals show low first order grey interference colors, they have an inclined extinction and are identified as plagioclase. Under xpl some of the colorless minerals show typical cross-hatched twin pattern and have first order white to grey interference colors. These crystals show an inclined extinction as the stage is rotated. These are crystals of Microcline. Some of the colorless minerals show absolutely no traces of cleavage and under xpl these crystals show low first order grey interference colors and have a wavy extinction. These crystals are of quartz. The crystals in this rock form an interlocking mass of various sizes. This rock is a Granite. Abbreviations from (Donna & Bernard, 2010).

4.1.3 Pegmatite

Table 6 Schematic summary of the Pegmatites

Nr.	Minerals	Felsic-mafic minerals	Grain size
JU7	Plagioclase, quartz, epidote, muscovite	90 – 10 %	Coarse

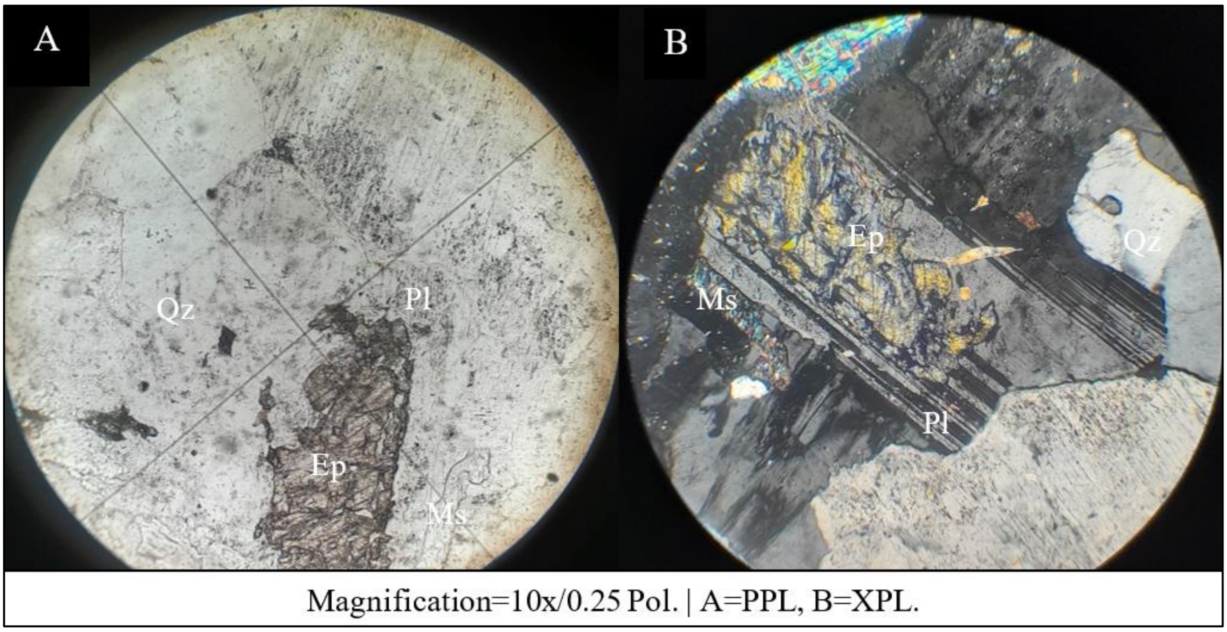


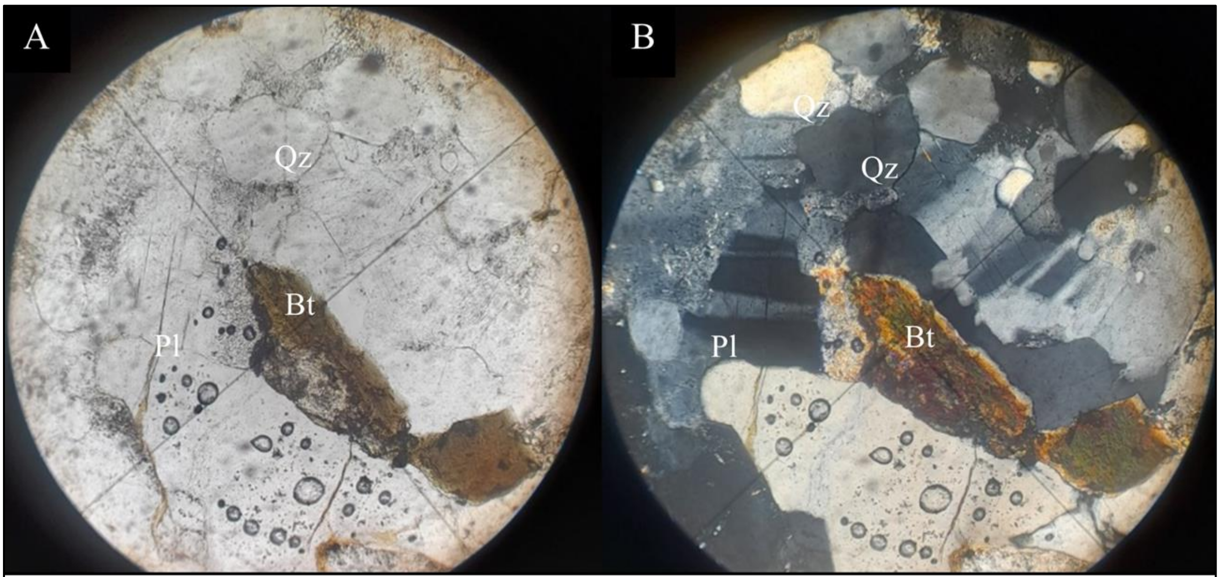
Figure 16 Petrographic image of JU 7

Figure 16 (JU7) is a petrographic image of a coarse-grained rock. The shape of the crystals are anhedral to subhedral. The grains have no subangular or subrounded boundaries. The minerals show no preferred orientation. It is probably an igneous rock. The rock consists of approximately 90% felsic- and 10% mafic minerals. Under ppl some minerals have extremely high relief; they have a brownish color and subhedral shape. These crystals show no pleochroism as the stage is rotated. Under xpl these crystals show third order yellow interference colors and are partially masked by the mineral color itself, and they show parallel extinction. These are crystals of epidotes. The epidotes are surrounded by large colorless crystals. They have an anhedral shape and show no pleochroism. Under xpl they show first order grey to black interference colors, and they show inclined extinction. These crystals have typical Carlsbad-albite twinning and are identified as plagioclase. Some of the colorless minerals show no traces of cleavage. Under xpl they show first order grey to white interference colors and show a wavy extinction. These are quartz crystals. Under ppl some crystals have extremely low relief, a prismatic shape and are non-pleochroic. Under xpl they show bright second order blueish interference colors and they show parallel extinction as the stage is rotated. These are crystals of muscovite. The crystals in this rock form an interlocking mass of various sizes. This rock is probably a pegmatite. Abbreviations from (Donna & Bernard, 2010).

4.1.4 Trondhjemite

Table 7 Schematic summary of the Trondhjemites

Nr.	Minerals	Felsic-mafic minerals	Grain size
JU3	Biotite, plagioclase, quartz	90 – 10 %	Fine
JU12	Biotite, epidotes, plagioclase, microcline, quartz	80 – 20 %	Coarse
JU14	Biotite, plagioclase, quartz	90 – 10 %	Fine
JU93	Biotite, plagioclase, quartz	80 – 20 %	Coarse



Magnification=10x/0.25 Pol. | A=PPL, B=XPL.

Figure 17 Petrographic image of JU 3

Figure 17 (JU3) is a petrographic image of a fine-grained rock. The shape of the crystals are anhedral. The grains have no subangular or subrounded boundaries. The minerals show no preferred orientation.It is probably an igneous rock. The rock consists of approximately 90% felsic- and 10% mafic minerals. Under ppl some minerals show a very high relief, the shape is anhedral, and they have a brown color. They show weak pleochroism as the stage is rotated. Under xpl these crystals show third order brownish interference colors and parallel extinction as the stage is rotated. These are crystals of biotite. Some minerals are colorless, they have an anhedral shape and show no pleochroism as the stage is rotated. They show traces of cleavage. Under xpl these crystals show first order white to grey interference colors, and they show inclined extinction. These are crystals of plagioclase. Some of these crystals show no traces of cleavage. Under xpl these they have first order grey interference colors, and they show wavy extinction. These are crystals of quartz. The crystals in this rock form an interlocking mass of approximately the same size. There is no hornblende found within this rock, thus it is probably a Trondhjemite. Abbreviations from (Donna & Bernard, 2010).

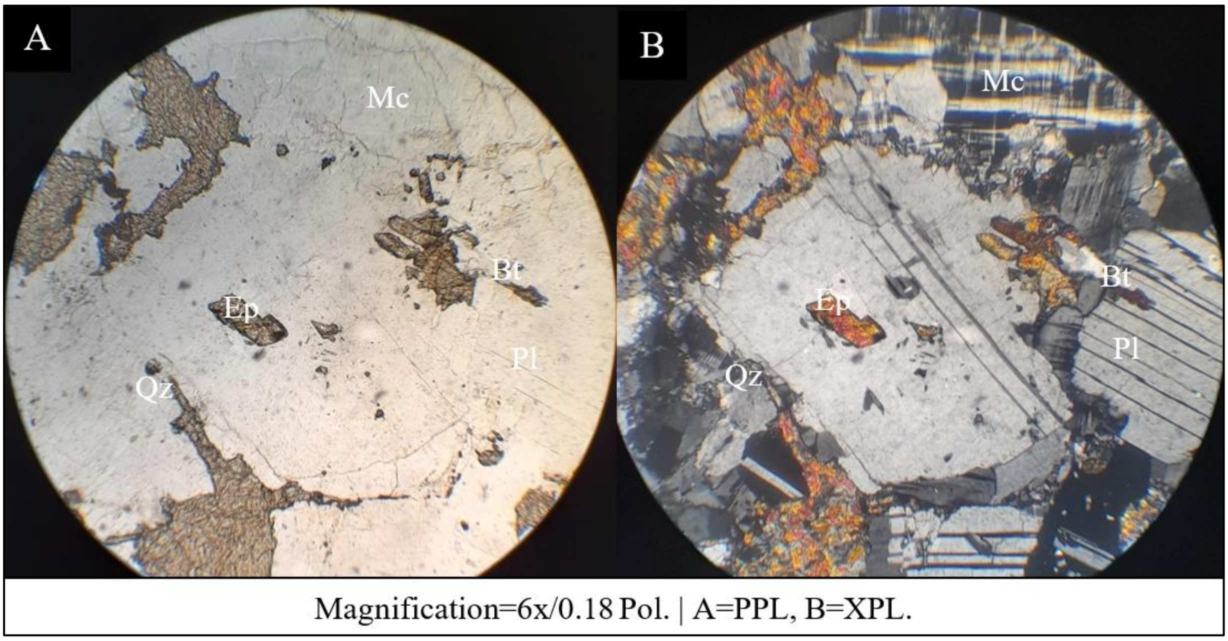


Figure 18 Petrographic image of JU 12

Figure 18 (JU12) is a petrographic image of a coarse-grained rock. The shape of the crystals is subhedral. The grains have no subangular or subrounded boundaries. The minerals show no preferred orientation. It is probably an igneous rock. The rock consists of approximately 80% felsic- and 20% mafic minerals. Under ppl some minerals show a very high relief, the shape is subhedral, and they have a greenish color. They show weak pleochroism as the stage is rotated. Under xpl these crystals show third order brownish interference colors and parallel extinction as the stage is rotated. These are crystals of biotite. Under ppl some of the crystals show extreme high relief. The shape is anhedral to subhedral, and they have a brownish color. These crystals show no Pleochroism as the stage is rotated. Under xpl these crystals show third order orange to pink interference colors, they have an inclined extinction and are identified as epidotes. Some minerals have very low relief under ppl, they are colorless and show no pleochroism. The mineral shape cannot be identified due to the extremely low relief these crystals have. Under xpl these minerals show first order grey to white interference colors. This mineral has no cleavage, and it has a wavy extinction. This mineral is quartz. Another mineral can be distinguished from the thin section which is also colorless but do show traces of cleavage. The shape is difficult to identify because of extreme low relief and it shows no pleochroism. Under xpl these crystals show first-order grey interference colors, and they show multiple or lamellar twinning and so can be identified as plagioclase feldspar. Some of these grains show clear cross-hatched twin patterns under xpl. They have first order grey to white interference colors and are identified as microcline. The crystals in this rock form an interlocking mass of various sizes. This rock is probably a Trondhjemite. Abbreviations from (Donna & Bernard, 2010).

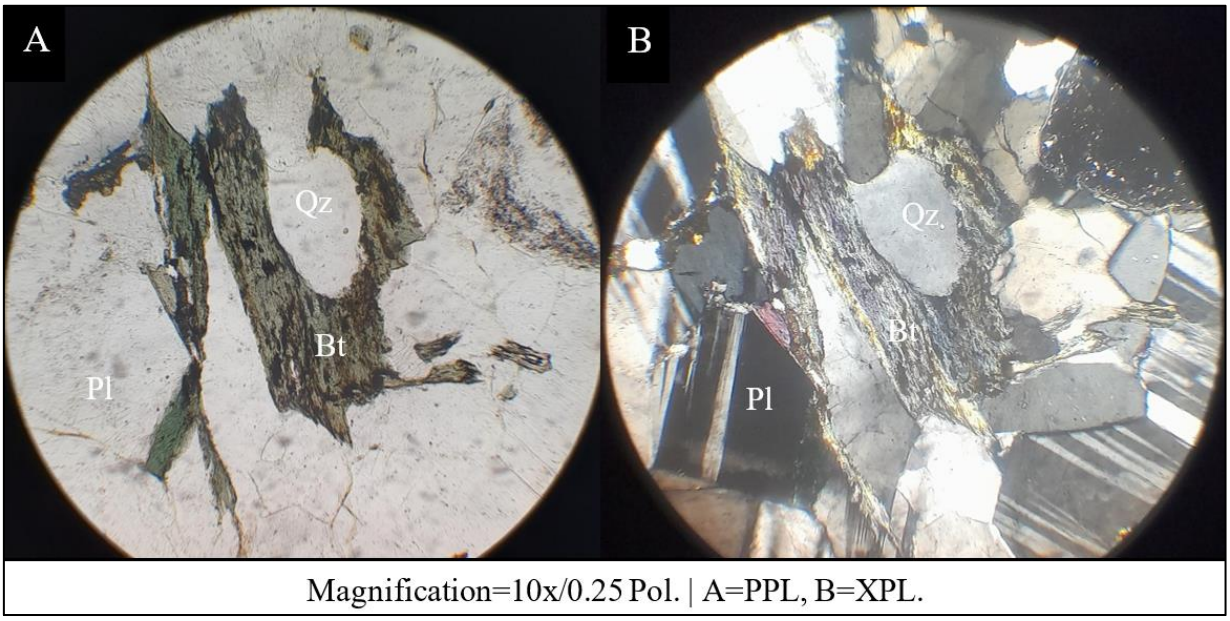
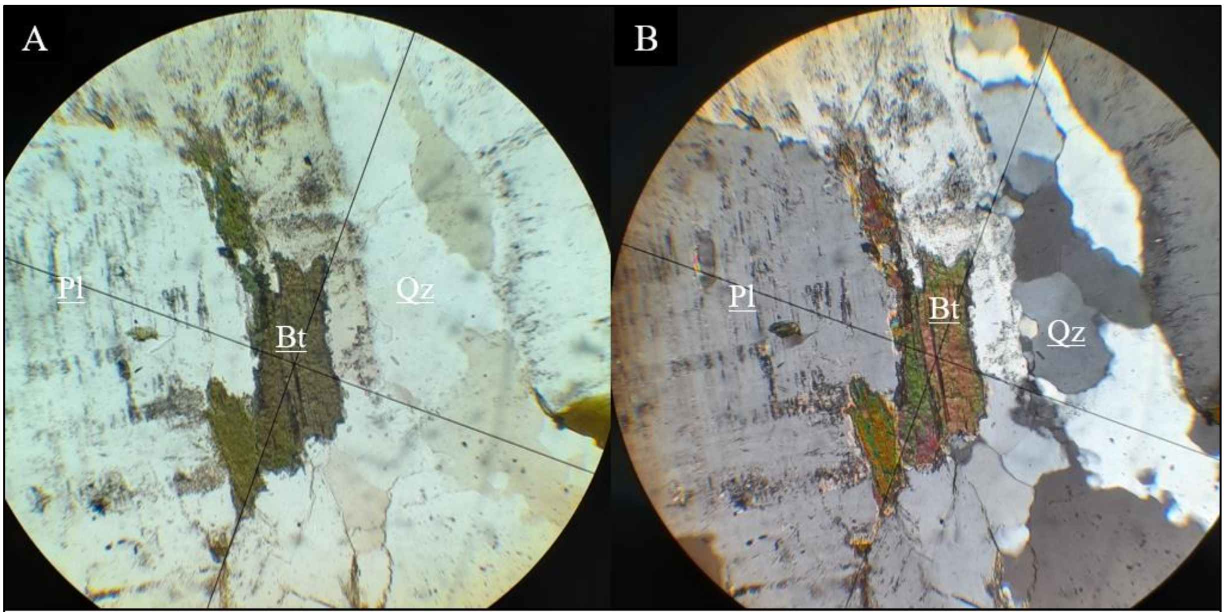


Figure 19 Petrographic image of JU 14

Figure 19 (JU14) is a petrographic image of a fine-grained rock. The shape of the crystals is anhedral. The grains have no subangular or subrounded boundaries. The minerals show no preferred orientation.It is probably an igneous rock. The rock consists of approximately 90% felsic- and 10% mafic minerals. Under ppl some minerals show moderate to high relief, the shape of these crystals are anhedral, and they have a greenish color. The crystals show weak brown to greenish pleochroism as the stage is rotated. Under xpl these crystals show third order blueish interference colors and have parallel extinction and are identified as biotite. Under ppl some minerals are colorless, they have extremely low relief and anhedral shape. They show no pleochroism as the stage is rotated. They show little traces of cleavage. Under xpl they show first order grey to white interference colors, and they have inclined extinction as the stage is rotated. The crystals show typical twinning and are identified as plagioclase. Some of these colorless minerals show no traces of cleavage, under xpl they have a cloudy appearance and show wavy extinction. The crystals have first order grey interference colors and are crystals of quartz. There is a little foliation observed within the rock. The crystals form an interlocking mass of approximately the same size. This rock is Trondhjemite. Abbreviations from (Donna & Bernard, 2010).



Magnification=10x/0.25 Pol. | A=PPL, B=XPL.

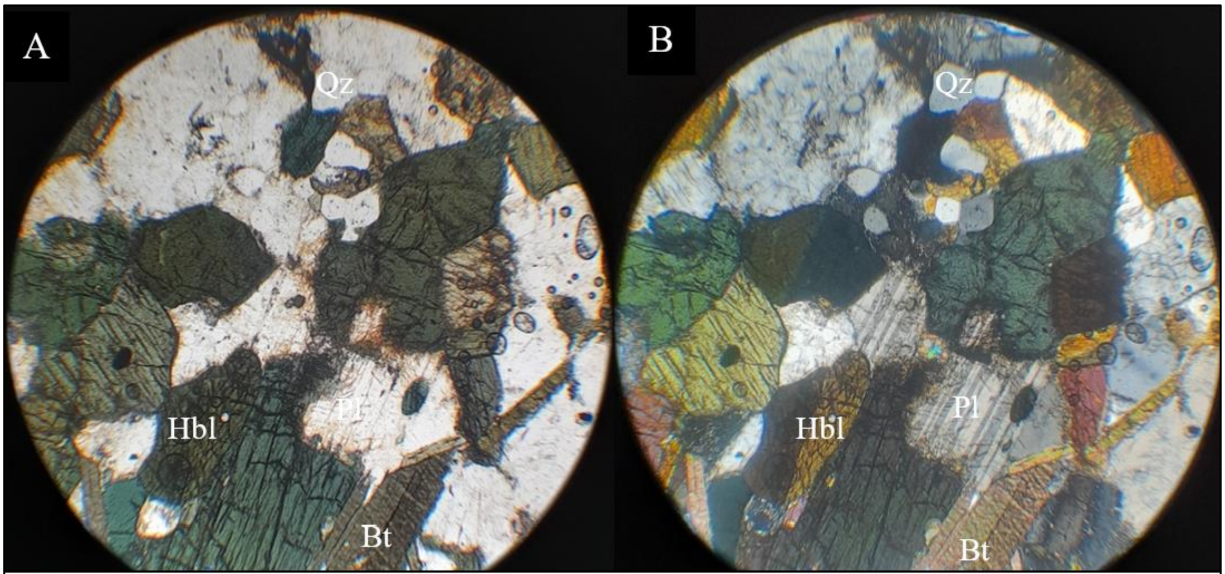
Figure 20 Petrographic image of JU 93

Figure 20 (JU93) is a petrographic image of a coarse-grained rock. The shape of the crystals are anhedral. The grains have no subangular or subrounded boundaries. The minerals show no preferred orientation. It is probably an igneous rock. The rock consists of approximately 80% felsic- and 20% mafic minerals. Under ppl some minerals show moderate to high relief, the shape of these crystals is anhedral, and they have a brown color. The crystals show brown to dark grey pleochroism as the stage is rotated. Under xpl these crystals show third order pinkish interference colors, they have parallel extinction and are identified as biotite. Under ppl some minerals are colorless, they have extremely low relief and anhedral shape. They show no pleochroism as the stage is rotated. They show little traces of cleavage. Under xpl they show first order grey interference colors, and they have inclined extinction as the stage is rotated. The crystals are identified as plagioclase. Some of these colorless minerals show no traces of cleavage, under xpl they have a wavy extinction and first order grey interference colors. These are crystals of quartz. The crystals in this rock form an interlocking mass of various sizes. This rock is a Trondhjemite. Abbreviations from (Donna & Bernard, 2010).

4.1.5 Amphibolite

Table 8 Schematic summary of the Amphibolites

Nr.	Minerals	Felsic-mafic minerals	Grain size
JU8	Biotite, hornblende, plagioclase, quartz	20 – 80 %	Coarse
JU90	Hornblende, biotite, quartz, plagioclase	20 – 80 %	Medium
JU92	Hornblende, plagioclase, Quartz	20 – 80 %	Medium



Magnification=6x/0.18 Pol. | A=PPL, B=XPL.

Figure 21 Petrographic image of JU 8

Figure 21 (JU8) is a petrographic image of a coarse-grained rock. The shape of the crystals is anhedral to subhedral and most of the crystals are perfectly aligned which gives the rock a banded appearance. This is a metamorphic rock. The rock consists of approximately 80% mafic- and 20% felsic minerals. Under ppl some minerals show moderate to high relief, the shape of these crystals is subhedral, and they have a brown color. The crystals show weak brown to greyish brown pleochroism as the stage is rotated. Under ppl these crystals show low third order interference colors and have a parallel extinction as the stage is rotated. These are crystals biotite. Some minerals with high relief, brown color and subhedral shape show perfect 60/120° cleavage which is a typical amphibole cleavage. They show brown to green pleochroism as the stage is rotated. Under xpl these crystals show bright high second order orange interference colors and they have a parallel extinction. These crystals also show parallel twinning and are identified as hornblende. Some minerals are colorless, they have extremely low relief and anhedral shape. They show no pleochroism as the stage is rotated. They show little traces of cleavage. Under ppl they show first order grey to white interference colors, and they have inclined extinction as the stage is rotated. The crystals show typical twinning and are identified as plagioclase. Some of these crystals show absolutely no traces of cleavage and they have a wavy extinction. These crystals are identified as quartz. The crystals in this rock form an interlocking mass of approximately the same size. This rock is an Amphibolite. Abbreviations from (Donna & Bernard, 2010).

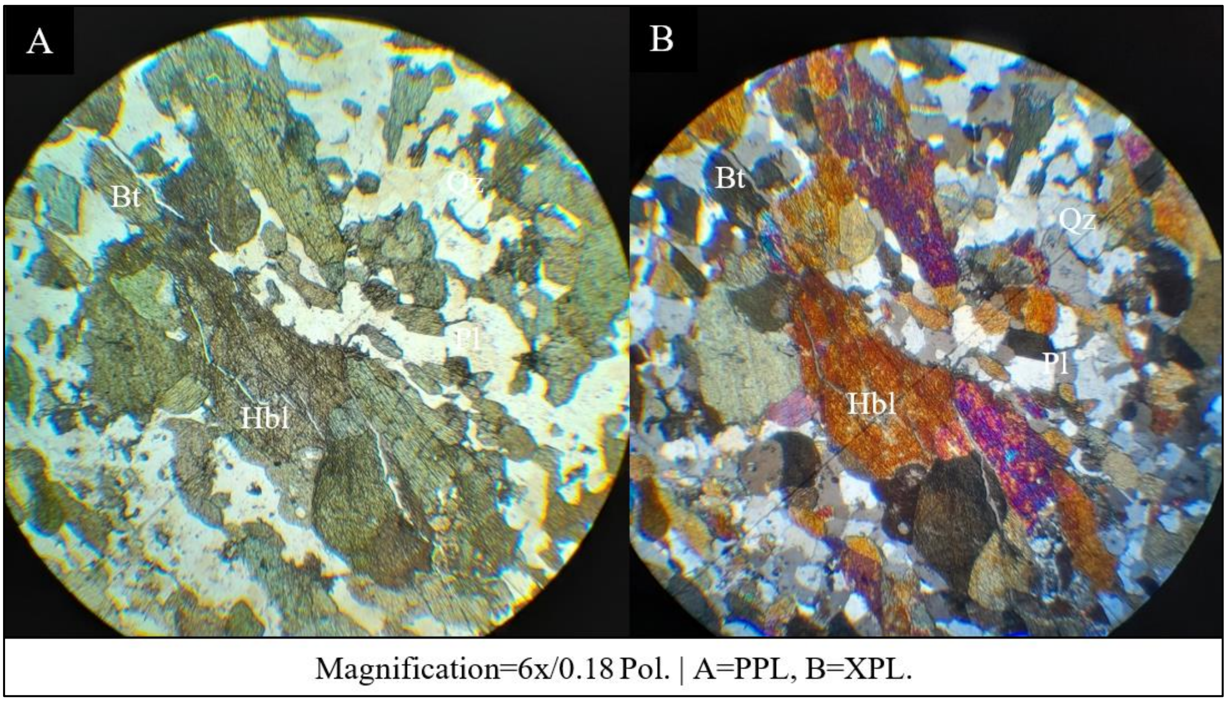


Figure 22 Petrographic image of JU 90

Figure 22 (JU90) is a petrographic image of a medium grained rock. The shape of the crystals is anhedral to subhedral, and they are perfectly aligned which gives the rock a banded appearance. The rock has a schistosity texture, and it is a metamorphic rock. The rock consists of approximately 20% felsic- and 80% mafic minerals. Under ppl some minerals show very high relief, green color and anhedral to subhedral shape. These crystals show pleochroism, they change colors from brown to green as the stage is rotated. Most of these crystals show perfect 60/120° cleavage which is a typical amphibole cleavage. Under xpl these crystals show bright second order high interference colors and are identified as hornblende. These crystals cover almost 80% of the rock and they are all aligned the same way. Some minerals show moderate to high relief, the shape of these crystals is subhedral, and they have a brown color. The crystals show weak brown to greyish brown pleochroism as the stage is rotated. Under xpl these crystals show low third order interference colors and have parallel extinction. These are crystals of biotite. Some of the minerals are colorless and show low relief. They show no pleochroism as the stage is rotated and under xpl, they show first order grey to white interference colors. This mineral has no cleavage, it has a wavy extinction, and it is identified as quartz. Some of these minerals have very low cleavage, these minerals can be identified as plagioclase. The crystals in this rock form an interlocking mass of various sizes. The quartz and plagioclase grains are much smaller than the hornblende grains. This rock is an amphibolite. Abbreviations from (Donna & Bernard, 2010).

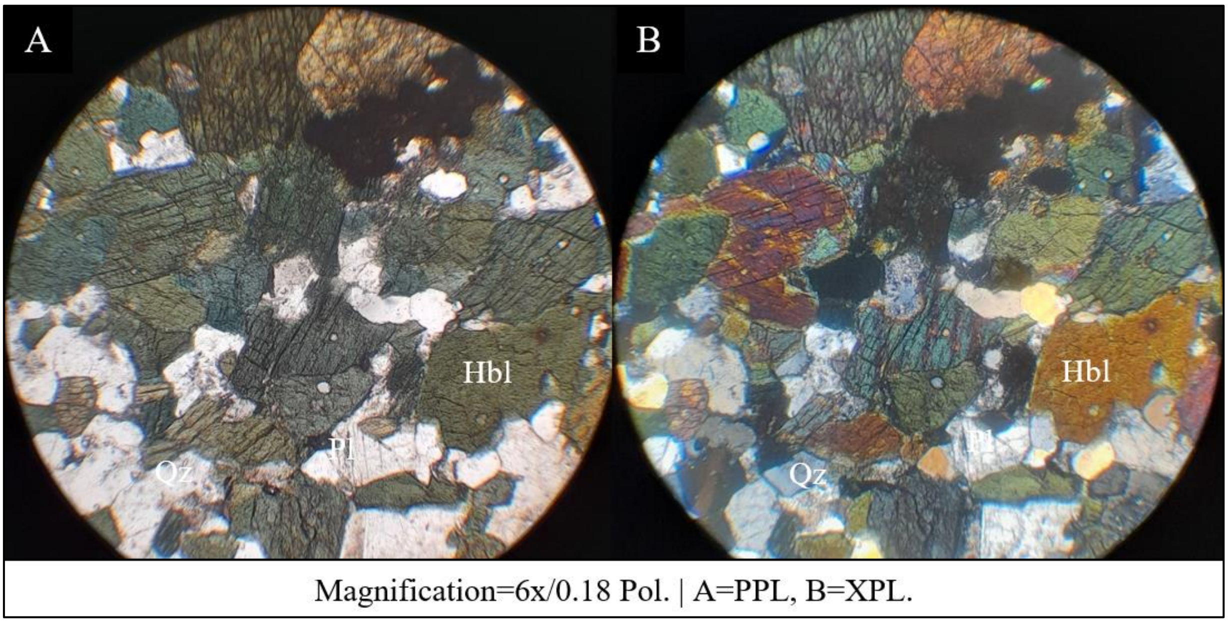


Figure 23 Petrographic image of JU 92

Figure 23 (JU92) is a petrographic image of a medium grained rock. The shape of the crystals is anhedral to subhedral, and they are perfectly aligned which gives the rock a banded appearance. This is a metamorphic rock. The rock consists of approximately 20% felsic- and 80% mafic minerals. Under ppl most of the minerals show a very high relief, and the color of these crystals is brown. These crystals are strongly pleochroic, they change color from brown to dark green as the stage is rotated. Most of these crystals show perfect 60/120° cleavage which is a typical amphibole cleavage. Most of these crystals are aligned the same way. The rock has been cut perpendicular to lineation. Under xpl these crystals show bright second order blueish to orange interference colors, they have a parallel extinction and are identified as Hornblend. Under ppl some minerals have low relief, they are colorless and show some traces of cleavage. These crystals are non-pleochroic, that is they show no change in color as the stage is rotated. Under xpl these crystals show low first order grey interference colors and they have an inclined extinction. These grains are crystals of plagioclase. Some of these crystals have no traces of cleavage, under xpl they show a wavy extinction and are identified as quartz. The crystals in this rock form an interlocking mass of approximately the same size. This rock is an amphibolite. Abbreviations from (Donna & Bernard, 2010).

4.1.6 Biotite gneiss

Table 9 Schematic summary of the Biotite gneisses

Nr.	Minerals	Felsic-mafic minerals	Grain size
JU17	Biotite, plagioclase, epidote, quartz	80 – 20 %	Medium
JU94	Biotite, plagioclase, epidote, quartz	80 – 20 %	Medium

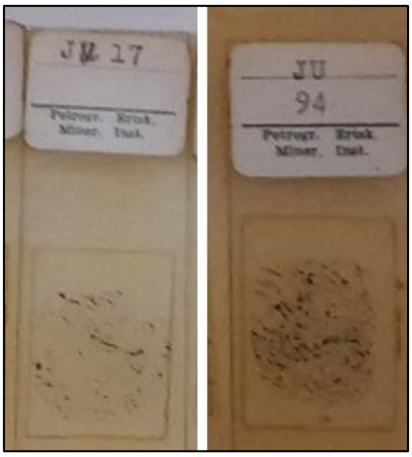


Figure 24 Biotite gneiss samples showing clear banding in thin section on macroscopic scale

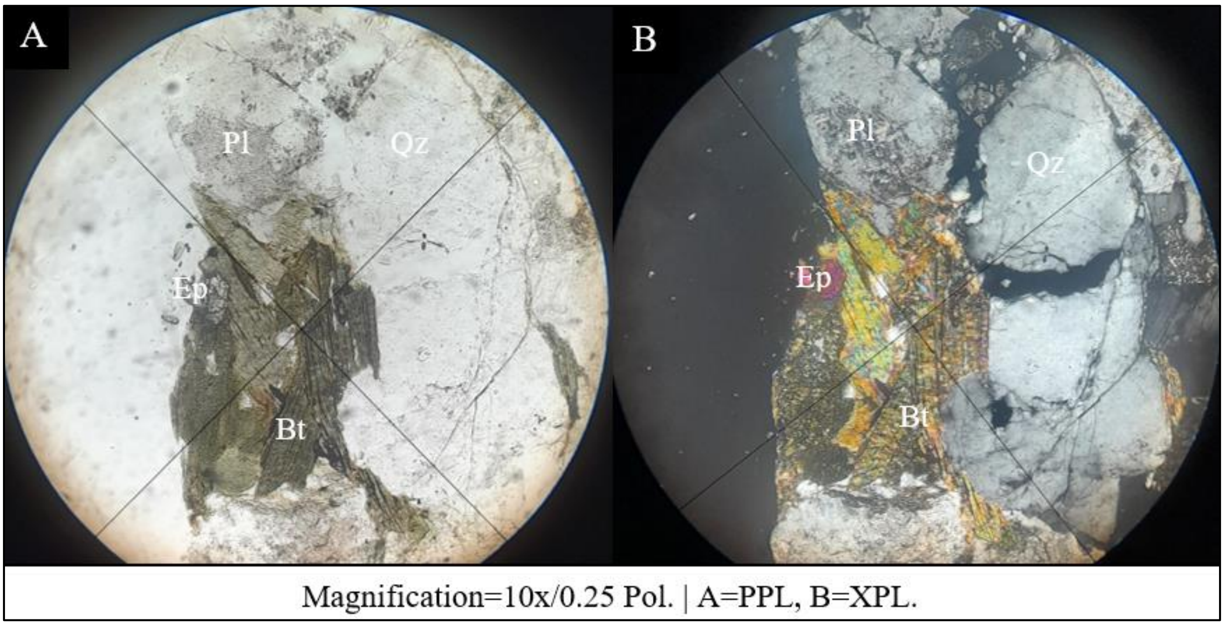
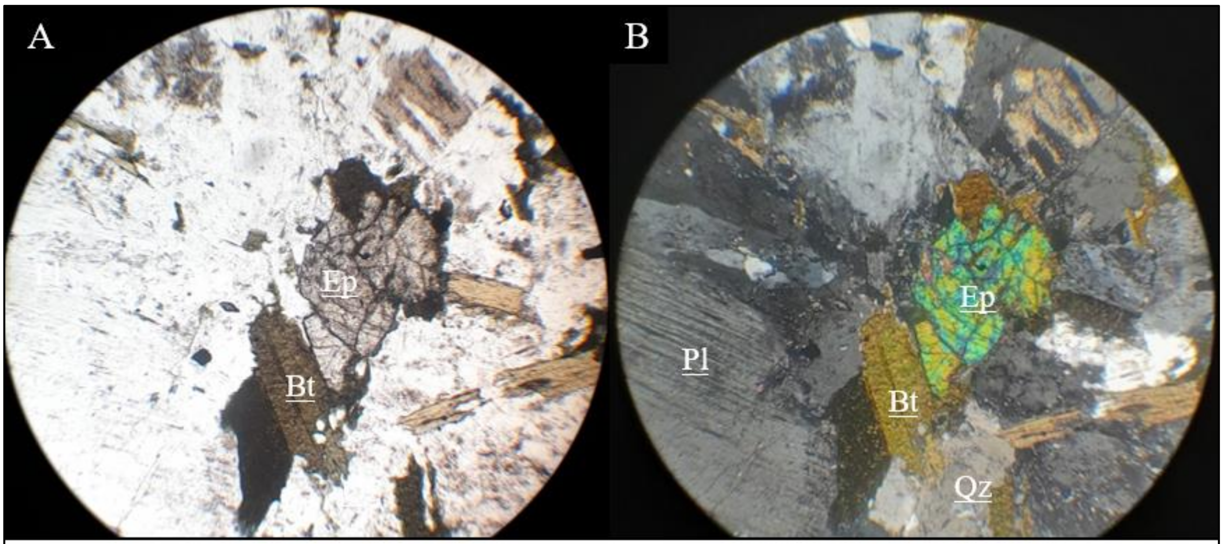


Figure 25 Petrographic image of JU 17

Figure 25 (JU17) is a petrographic image of a coarse-grained rock. The shape of the crystals is anhedral to subhedral, and they are perfectly aligned which gives the rock a banded appearance. This is a metamorphic rock. The rock consists of approximately 80% felsic- and 20% mafic minerals. Under ppl some minerals show moderate to high relief, the shape of these crystals is subhedral, and they have a brown color. The crystals turn darker as the stage is rotated, so they are strongly pleochroic. Under xpl these crystals show third order interference colors and have parallel extinction as the stage is rotated. These are crystals of biotite. Under ppl another mineral with high relief and subhedral shape can be distinguished from the thin section. It is colorless and show no pleochroism as the stage is rotated. Under xpl this mineral shows third order pink interference colors and has a parallel extinction as the stage is rotated. This mineral is epidote. Some minerals are colorless under ppl, they have extremely low relief and anhedral shape. They show no pleochroism as the stage is rotated. Under xpl they show first order grey-white interference colors, and they show inclined extinction. These are crystals of plagioclase. Some of these minerals show no traces of cleavage and have a wavy extinction under xpl as the stage is rotated. These crystals are identified as quartz. The crystals in this rock form an interlocking mass of various sizes. This rock is a Biotite gneiss. Abbreviations from (Donna & Bernard, 2010).



Magnification=6x/0.18 Pol. | A=PPL, B=XPL.

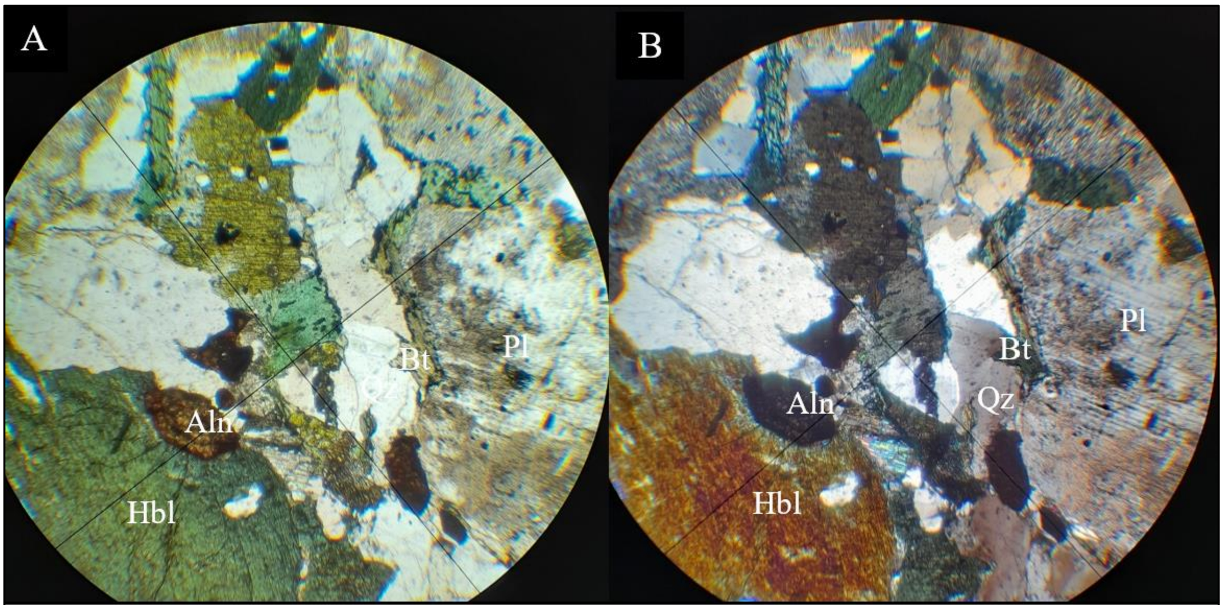
Figure 26 Petrographic image of JU 94

Figure 26 (JU94) is a petrographic image of a medium-grained rock. The shape of the crystals is anhedral to subhedral and most of the crystals are perfectly aligned which gives the rock a banded appearance. This is a metamorphic rock. The rock consists of approximately 80% of felsic- and 20% mafic minerals. Under ppl some minerals show moderate to high relief, the shape of these crystals is subhedral, and they have a brown color. The crystals show weak brown to grey pleochroism as the stage is rotated. Under xpl these crystals show parallel extinction and have low third order pinkish interference colors. These are crystals of biotite. Some minerals show extremely high relief, they have a subhedral shape and a brownish color. These crystals show pink pleochroism as the stage is rotated. Under xpl these crystals show bright third order high yellow to green interference colors, and they show parallel extinction and are identified as epidotes. Some crystals are colorless, they have an anhedral shape and very low relief. They show no pleochroism as the stage is rotated. Under xpl these crystals show low first order grey interference colors and have an inclined extinction. These crystals are plagioclase. Some of these minerals show no traces of cleavage and show a wavy extinction as the stage is rotated. These are identified as quartz. The crystals in this rock form an interlocking mass of approximately the same size. This rock is a Biotite gneiss. Abbreviations from (Donna & Bernard, 2010).

4.1.7 Hornblende biotite gneiss

Table 10 Schematic summary of the Hornblende biotite gneisses

Nr.	Minerals	Felsic-mafic minerals	Grain size
JU4	Hoornblende, biotite, allanite, quartz, plagioclase	60 – 40 %	Coarse
JU5	Biotite, hornblende, titanite, allanite, plagioclase, quartz	55 – 45 %	Coarse
JU10	Hornblende, biotite alteration to chlorite, plagioclase, quartz.	40 – 60 %	Medium
JU16	Hornblende, Biotite, Titanite, Plagioclase	55 – 45 %	Coarse
JU19	Plagioclase, biotite, hornblende, epidote, quartz	55 – 45 %	Coarse
JU91	Hoornblende, biotiet, epidote, quartz	70 – 30 %	Fine
JU96	Hornblende, biotite, plagioclase, opaque	40 – 60 %	Fine



Magnification=6x/0.18 Pol. | A=PPL, B=XPL.

Figure 27 Petrographic image of JU 4

Figure 27 (JU4) is a petrographic image of a coarse-grained rock. The shape of the crystals is anhedral to subhedral, and they are perfectly aligned which gives the rock a banded appearance. The rock is a metamorphic rock. The rock consists of approximately 60% felsic- and 40% mafic minerals. Under ppl some grains show low to moderate relief, anhedral shape and have a green color. These crystals show brown to green pleochroism as the stage is rotated. Under xpl these crystals show orange up to second order interference colors and are identified as hornblende. Some minerals show moderate to high relief, the shape of these crystals is anhedral, and they have a brown color. The crystals are weakly pleochroic. Under xpl they show low third order greenish interference colors and they have a parallel extinction. These are crystals of biotite. Under ppl another mineral with high relief can be distinguished, the shape is subhedral, the color is red-brown, and the mineral is non-pleochroic. This crystal is masked by their mineral color under xpl and can be identified as allanite. Some minerals have very low relief, are colorless and show no pleochroism under ppl. Some of these crystals show traces of cleavage and under xpl they show low first order grey interference colors and have an inclined extinction. These crystals are identified as plagioclase. Some of these colorless minerals show absolutely no traces of cleavage and under xpl they also show low first order grey interference colors. They have a wavy extinction and are identified as quartz. The rock is made up of interlocking crystals of approximately the same size. This rock is a Hornblende biotite gneiss. Abbreviations from (Donna & Bernard, 2010).

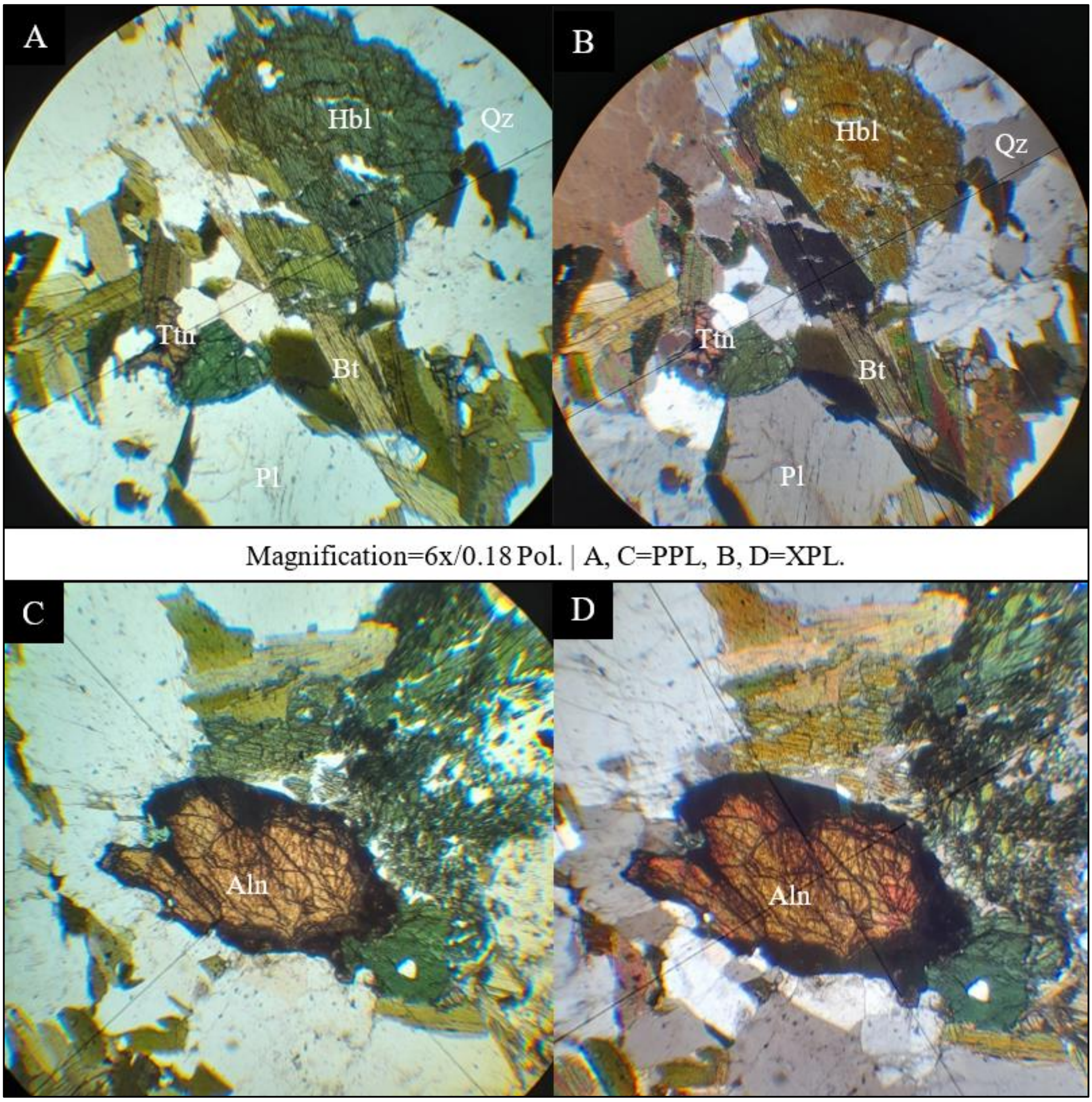
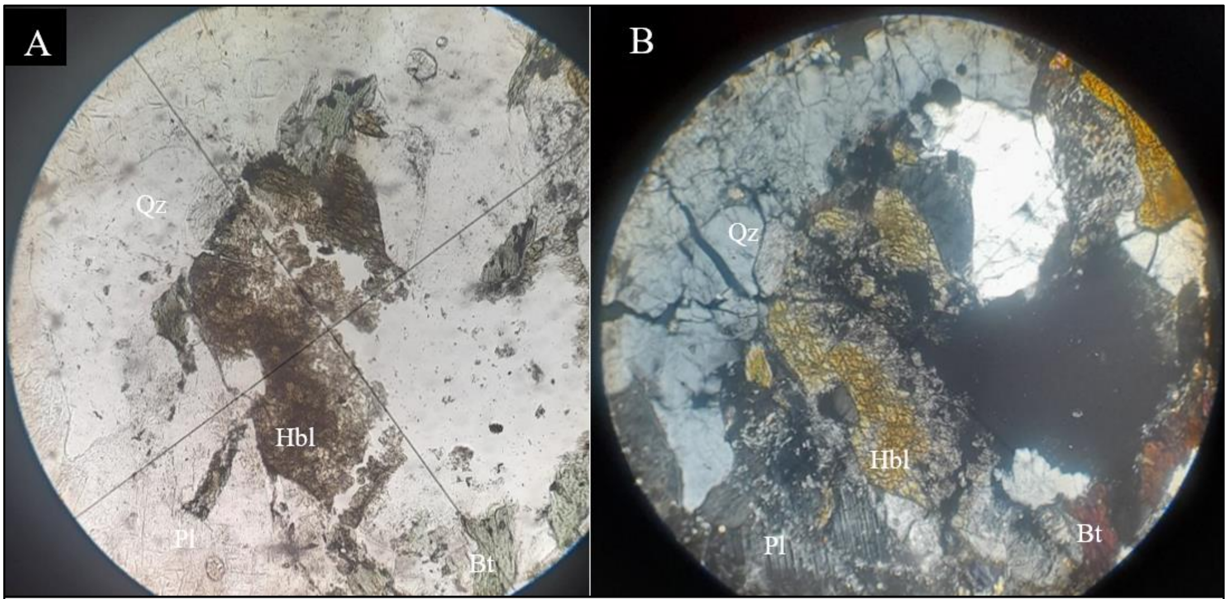


Figure 28 Petrographic image of JU 5

Figure 28 (JU5) is a petrographic image of a coarse-grained rock. The shape of the crystals are anhedral to subhedral, and they are perfectly aligned which gives the rock a banded appearance. This is a metamorphic rock. The rock consists of approximately 55% felsic- and 45% mafic minerals. Under ppl some minerals are strongly colored and have a moderate relief. The shape of these crystals is subhedral, they show perfect cleavage, and the color is brown, and they show strong brown to dark grey pleochroism as the stage is rotated. Under xpl they show low third order brownish interference colors and have parallel extinction. These crystals are biotites. Some other minerals with moderate relief, anhedral shape and dark green color are also observed in ppl. They show perfect 60/120° cleavage and have strong pleochroism. The color changes from brown to dark green as the stage is rotated. Under xpl they show second order orange interference colors and have a parallel extinction. These crystals are of hornblende. Under ppl some crystals have very high relief, they have an anhedral shape and a pale brown color. These crystals are weakly pleochroic as the stage is rotated , under xpl they show third order beige interference colors and are identified as titanite. A rounded to irregular-shaped crystal is also present in the rock. It has a very high relief and a brown color. This crystal is non-pleochroic and under xpl the interference colors are masked by the strong mineral color. This crystal can be identified as allanite. Minerals with low relief are also distinguished from the thin section, they are colorless and show some traces of cleavage. Under xpl these crystals show low first order grey interference colors and they have an inclined extinction. These are crystals of plagioclase. Some of these crystals have no traces of cleavage and show a wavy extinction. These are identified as quartz. The rock is made up of interlocking crystals of approximately the same size. This rock is a Hornblende Biotite gneiss. Abbreviations from (Donna & Bernard, 2010).



Magnification=10x/0.25 Pol. | A=PPL, B=XPL.

Figure 29 Petrographic image of JU 10

Figure 29 (JU10) is a petrographic image of a medium-grained rock. The shape of the crystals is anhedral and most of the crystals are perfectly aligned which gives the rock a banded appearance. Preferred orientation is clear. This is a metamorphic rock. The rock consists of approximately 40% felsic- and 60% mafic minerals and a lot of inclusions of these felsic minerals are observed within this rock. Under ppl some minerals show moderate to high relief, the shape of these crystals is anhedral, and they have a green color. The crystals show brown to green pleochroism as the stage is rotated. Under xpl these crystals show third order interference colors and have parallel extinction as the stage is rotated. These are crystals of chloritized biotite. Under ppl crystals with high relief are also observed, they are anhedral and have a brown color. The crystals show brown to dark green pleochroism as the stage is rotated. Most of these crystals show perfect 60/120° cleavage which is a typical amphibole cleavage. Under xpl these crystals show bright second order yellow interference colors and are identified as hornblende which are all aligned the same way. Some minerals are colorless, they have extremely low relief and anhedral shape. They show no pleochroism as the stage is rotated. They show little traces of cleavage. Under xpl they show first order grey-white interference colors, and they have inclined extinction as the stage is rotated. These are crystals of plagioclase. Some of the colorless crystals have no traces of cleavage. Under xpl they show first order grey interference colors, and they have a wavy extinction. These are crystals of quartz. The crystals in this rock form an interlocking mass of various sizes. This rock is a Hornblende biotite gneiss. Abbreviations from (Donna & Bernard, 2010).

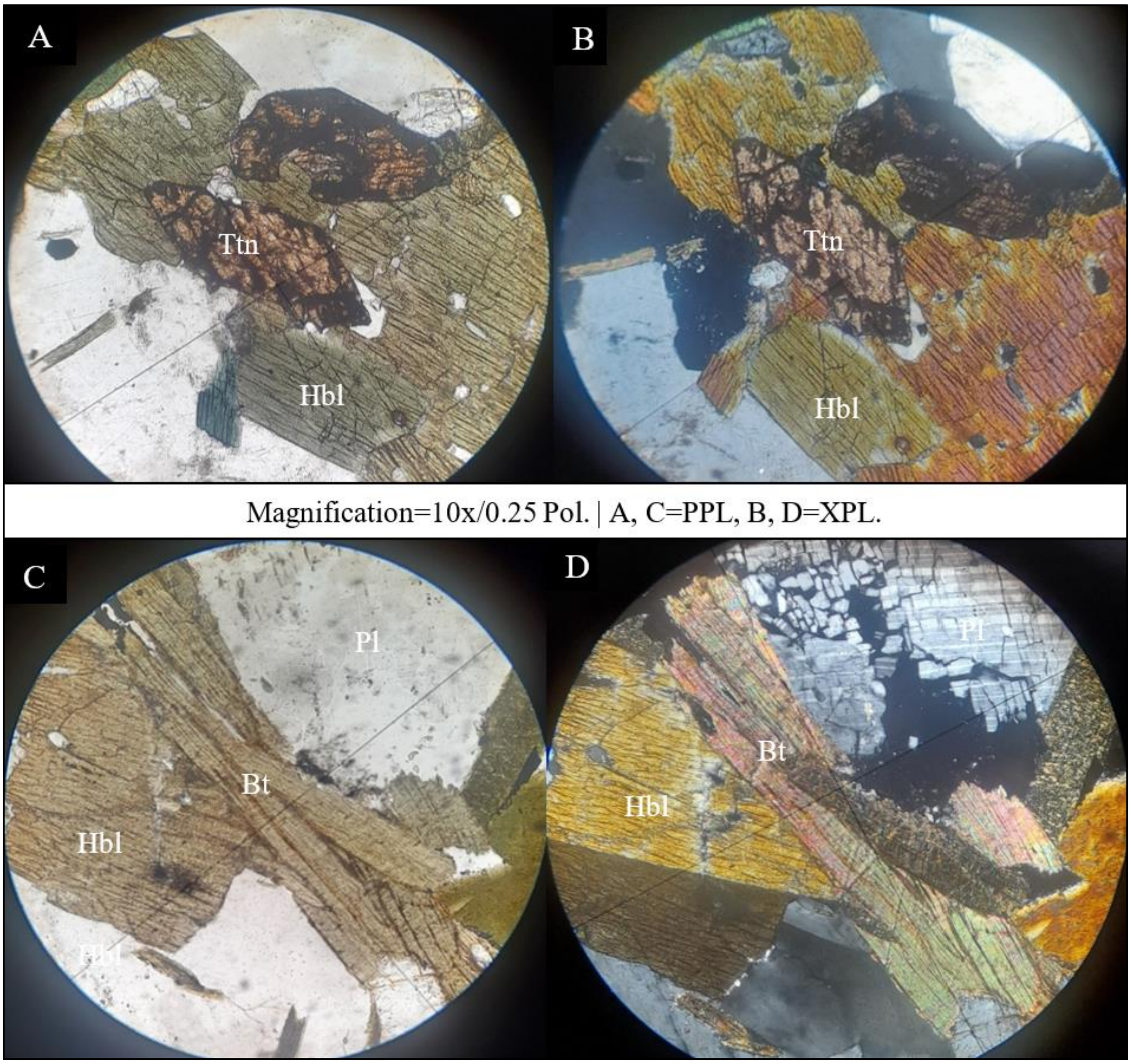
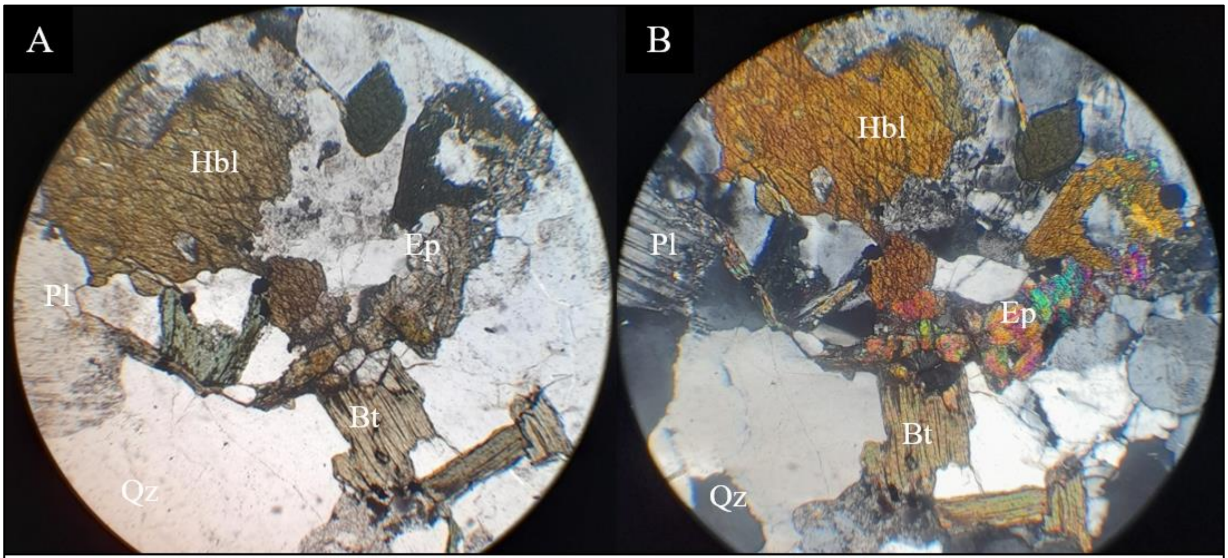


Figure 30 Petrographic image of JU 16

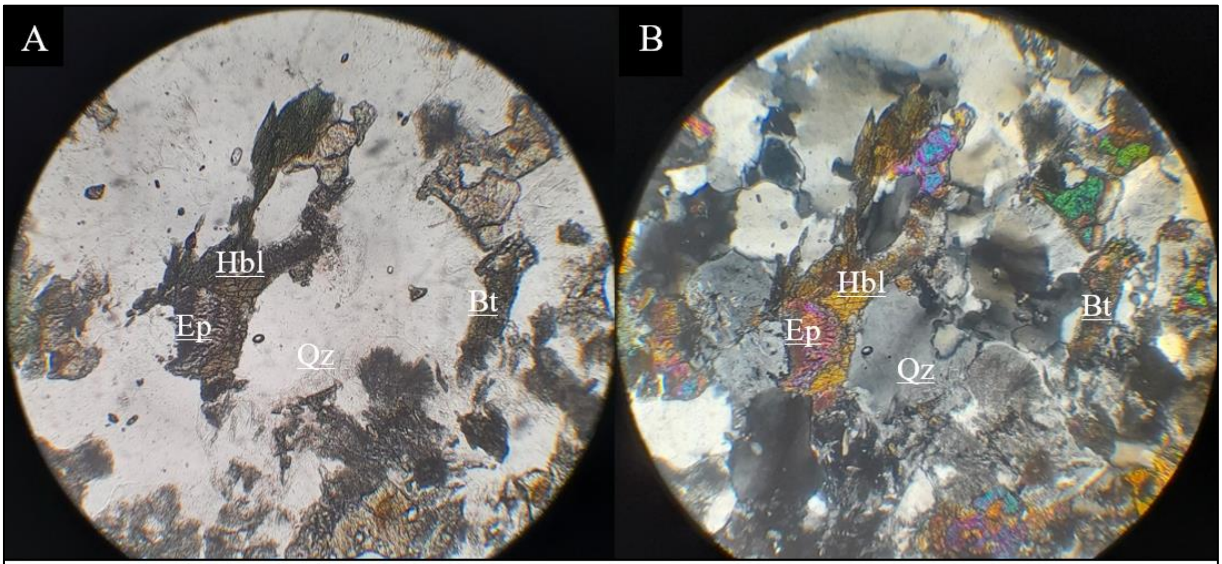
Figure 30 (JU16) is a petrographic image of a coarse-grained rock. The shape of the crystals is subhedral to euhedral and most of the crystals are perfectly aligned which gives the rock a banded appearance. This is a metamorphic rock. The rock consists of approximately 55% felsic- and 45% mafic minerals. Under ppl some minerals show moderate to high relief, the shape of these crystals is subhedral, and they have a brown color. The crystals show weak brown to greyish brown pleochroism as the stage is rotated. Under xpl these crystals show third order interference colors and have parallel extinction as the stage is rotated. These are crystals of chloritized biotite. Some minerals with high relief, brown color and subhedral shape show perfect 60/120° cleavage which is a typical amphibole cleavage. They show brown to green pleochroism as the stage is rotated. Under xpl they show bright second order orange interference colors. These are crystals of hornblende. A mineral with extremely high relief, wedge-shaped and brown color is observed in this rock. This mineral is weakly pleochroic. Under xpl the interference colors of this mineral are masked by the mineral color itself. These crystals are identified as titanite. Some minerals are colorless, they have extremely low relief and anhedral shape. They show no pleochroism as the stage is rotated. They show little traces of cleavage. Under ppl they show first order grey to white interference colors, and they have inclined extinction as the stage is rotated. The crystals show typical twinning and are identified as plagioclase. The crystals in this rock form an interlocking mass of approximately the same size. This rock is a Hornblende biotite gneiss. Abbreviations from (Donna & Bernard, 2010).



Magnification=6x/0.18 Pol. | A=PPL, B=XPL.

Figure 31 Petrographic image of JU 19

Figure 31 (JU19) is a petrographic image of a coarse-grained rock. The shape of the crystals is anhedral to subhedral, and they are perfectly aligned which gives the rock a banded appearance. The rock has a schistosity texture, and it is a metamorphic rock. The rock consists of approximately 55% felsic- and 45% mafic minerals. Under ppl some minerals show moderate to high relief, the shape of these crystals is subhedral, and they have a brown color. The crystals show weak brown to greyish brown pleochroism as the stage is rotated. Under xpl these crystals show low third order interference colors and have parallel extinction as the stage is rotated. These are crystals of biotite. Some of these biotite crystals show a greenish color, these are chloritized biotite. Some minerals with high relief, brown color and subhedral shape show perfect 60/120° cleavage which is a typical amphibole cleavage. They show brown to green pleochroism under ppl as the stage is rotated. Under xpl they show bright high second order orange interference colors and they have a parallel extinction. These are crystals of hornblende. Minerals with high relief, anhedral shape and a brown color are also distinguished from the thin section. These crystals show no pleochroism as the stage is rotated and under xpl they show bright high third order pinkish yellow to blue-green interference colors. These crystals are identified as epidotes. Some minerals are colorless, they have extremely low relief and anhedral shape. They show no pleochroism as the stage is rotated. They show little traces of cleavage. Under xpl they show first order grey to white interference colors, and they have inclined extinction as the stage is rotated. The crystals show typical twinning and are identified as plagioclase. Some of these colorless crystals show absolutely no traces of cleavage, under xpl they show first order grey to black interference colors and are identified as quartz. The crystals in this rock form an interlocking mass of various sizes. This rock is Hornblende biotite gneiss. Abbreviations from (Donna & Bernard, 2010).



Magnification=10x/0.25 Pol. | A=PPL, B=XPL.

Figure 32 Petrographic image of JU 91

Figure 32 (JU91) is a petrographic image of a very fine-grained rock. The shape of the crystals is anhedral and most of the crystals are perfectly aligned which gives the rock a banded appearance. This is a metamorphic rock. The rock consists of approximately 70% felsic- and 30% mafic minerals. Under ppl some minerals show moderate to high relief, the shape of these crystals is anhedral, and they have a brown color. The crystals show weak brown to light green pleochroism as the stage is rotated. Under xpl these crystals show low third order pinkish interference colors and they are partially masked by their mineral color. These crystals have parallel extinction and are identified as biotite. Some minerals with high relief, brown color and anhedral shape show perfect 60/120° cleavage which is a typical amphibole cleavage. They show brown to green pleochroism as the stage is rotated. Under xpl they show high second order orange interference colors and are identified as hornblende. Minerals with extremely high relief, anhedral shape and a brown color can also be distinguished within the thin section, these crystals are non-pleochroic. Under xpl they show bright third order pink and green interference colors and they have a parallel extinction. These crystals are epidotes. Some minerals are colorless, they have an anhedral shape and show no pleochroism. Under xpl these minerals show first order grey to white interference colors, and they have a wavy extinction. These crystals are identified as quartz. The crystals in this rock form an interlocking mass of approximately the same size. This rock is a Hornblende biotite gneiss. Abbreviations from (Donna & Bernard, 2010).

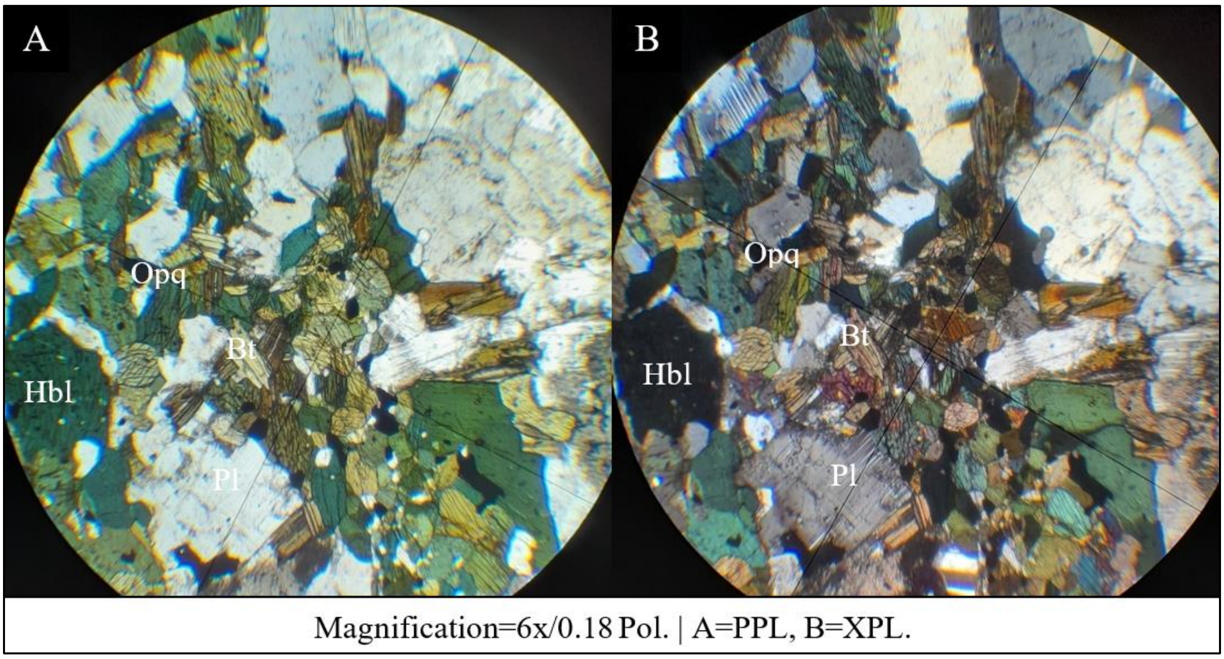


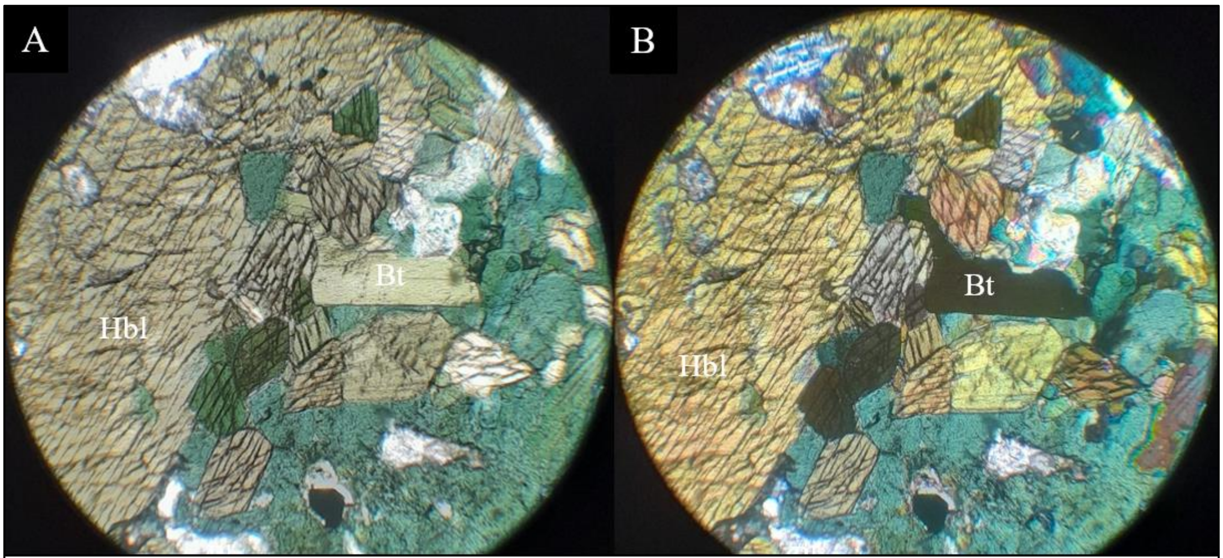
Figure 33 Petrographic image of JU 96

Figure 33 (JU96) is a petrographic image of a very fine-grained rock. The shape of the crystals is anhedral to subhedral, and they are perfectly aligned which gives the rock a banded appearance. This is a metamorphic rock. The rock consists of approximately 40% felsic- and 60% mafic minerals. Under ppl some minerals have a moderate to high relief. The shape of these crystals is subhedral, they show perfect parallel cleavage, and the color is brown. These crystals show weak brown to darkish brown pleochroism as the stage is rotated. Under xpl they show low third order pinkish interference colors and have a parallel extinction. These crystals are biotites. Some minerals have very high relief, they are anhedral and have a brown color. They show perfect 60/120° cleavage and show strong pleochroism. The color changes from brown to dark green as the stage is rotated. Under xpl they show second order orange to greenish interference colors and has parallel extinction. These crystals are of hornblende. Opaque minerals are also observed within the thin section, these crystals appear black in both ppl and xpl. Minerals with low relief are also distinguished from the thin section, they are colorless and show traces of cleavage. Under xpl these crystals show low first order grey interference colors and they have an inclined extinction. These crystals also show typical parallel twinning as the stage is rotated and are identified as plagioclase. The rock is made up of interlocking crystals of approximately the same size. This rock is a Hornblende biotite gneiss. Abbreviations from (Donna & Bernard, 2010).

4.1.8 Hornblendite

Table 11 Schematic summary of the Hornblendites

Nr.	Minerals	Felsic-mafic minerals	Grain size
JU95	Hornblende, biotite, muscovite, plagioclase	10 – 90 %	Fine



Magnification=6x/0.18 Pol. | A=PPL, B=XPL.

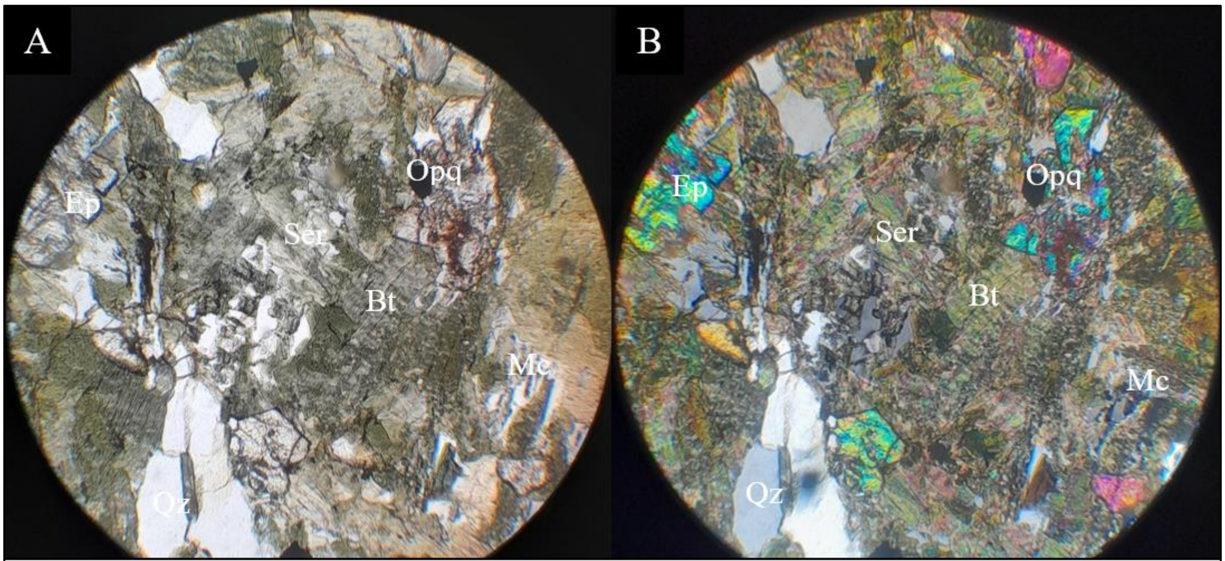
Figure 34 Petrographic image of JU 95

Figure 34 (JU95) is a petrographic image of a fine-grained rock. The shape of the crystals is anhedral to subhedral, and they are perfectly aligned which gives the rock a banded appearance. This is a metamorphic rock. The rock consists of approximately 10% felsic- and 90% mafic minerals. Under ppl some minerals have very high relief, they are anhedral and have a brown color. They show perfect 60/120° cleavage and show strong brown to dark green pleochroism as the stage is rotated. Under xpl these crystals show second order orange to greenish interference colors and has parallel extinction. These crystals are of hornblende. Some crystals have a moderate to high relief. The shape of these crystals is subhedral and the color is brown. These crystals show weak brown to darkish brown pleochroism as the stage is rotated. Under xpl these crystals show low third order pinkish interference colors and have parallel extinction. These crystals are biotite. Under ppl some crystals have moderate relief, a prismatic shape, they show perfect cleavage and are non-pleochroic. Under xpl they show bright second order blueish interference colors and they show parallel extinction as the stage is rotated. These are crystals of muscovite. Some crystals are colorless, they have an anhedral shape and show to pleochroism. They show some traces of cleavage. Under xpl these crystals show first order grey to white interference colors. These are crystals plagioclase. The rock is made up of interlocking crystals of various sizes. This rock is a Hornblendite. Abbreviations from (Donna & Bernard, 2010).

4.1.9 Metagreywacke

Table 12 Schematic summary of the Metagreywackes

Nr.	Minerals	Felsic-mafic minerals	Grain size
JU11	Biotite, quartz, sericite, opaque, microcline, epidote	70 – 30 %	Fine



Magnification=10x/0.25 Pol. | A=PPL, B=XPL.

Figure 35 Petrographic image of JU 11

Figure 35 (JU11) is a petrographic image of a fine-grained rock. The shape of the crystals is anhedral, and they are perfectly aligned which gives the rock a banded appearance. The rock has a schistosity texture, and it is a metamorphic rock. The rock consists of approximately 55% felsic- and 45% mafic minerals. Some minerals show moderate to high relief, the shape of these crystals is anhedral, and they have a brownish color. The crystals show weak brown to green pleochroism as the stage is rotated. Under xpl they show third order pinkish interference colors and are identified as biotite. Some of the crystals show extreme high relief. The shape is anhedral, and they have a brownish color. These crystals show no pleochroism as the stage is rotated and under xpl they show second order bright blue and green interference colors and have parallel extinction. These crystals are identified as epidotes. Some of the crystals show low to moderate relief, they are colorless and have an anhedral shape. These crystals have no pleochroism as the stage is rotated and under xpl they show third order low interference colors, they have a parallel extinction and, are identified as sericite. Some minerals have very low relief, they are colorless and show no pleochroism. The mineral shape is anhedral. Under xpl these minerals show first order grey to white interference colors. This mineral has no cleavage, and it has a wavy extinction. This mineral is quartz. Some of the colorless minerals show a cross-hatched twin pattern under xpl, they also have first order grey to white interference colors and are identified as microcline. Some opaque minerals are also distinguished within the thin section, these minerals are black colored under either ppl and xpl. The crystals in this rock form an interlocking mass of approximately the same size. This rock is probably a Metagraywacke. Abbreviations from (Donna & Bernard, 2010).

5 Discussion

The data from this research indicate the occurrence of predominantly high-grade metamorphic rocks and some felsic igneous rocks at the transition from the southwestern contact of the Marowijne Greenstone Belt into the older Gran Rio granites. The major group of rocks constitute Hornblende biotite gneisses followed by Trondhjemites.

Metamorphic rocks

According to the results obtained from this research the high-grade metamorphic rocks in this segment are Hornblende biotite gneisses, amphibolites and biotite gneisses. A hornblendite and Metagreywacke is also observed. Almost all the minerals within these rocks are pretty much aligned the same way giving the rocks a banded appearance. The metamorphic rocks contains amphiboles (hornblende) and plagioclase, which indicates that these rocks are metamorphosed up to amphibolite facies (Strekeisen, 2006). Biotites, quartz, epidotes and also allanites, titanites, chlorite and opaque minerals are observed within the metamorphic rocks.

Igneous rocks

Furthermore, some felsic igneous rocks are identified in this area. The main felsic igneous rocks in this segment are Trondhjemites and Aplites. Some granites and a pegmatite is also observed. The shape of the crystals within these rocks are mostly anhedral and they have no subangular or subrounded boundaries. They also have a random orientation. The most common minerals observed within these rocks are biotites, plagioclase, quartz followed by some microclines, epidotes and muscovite.

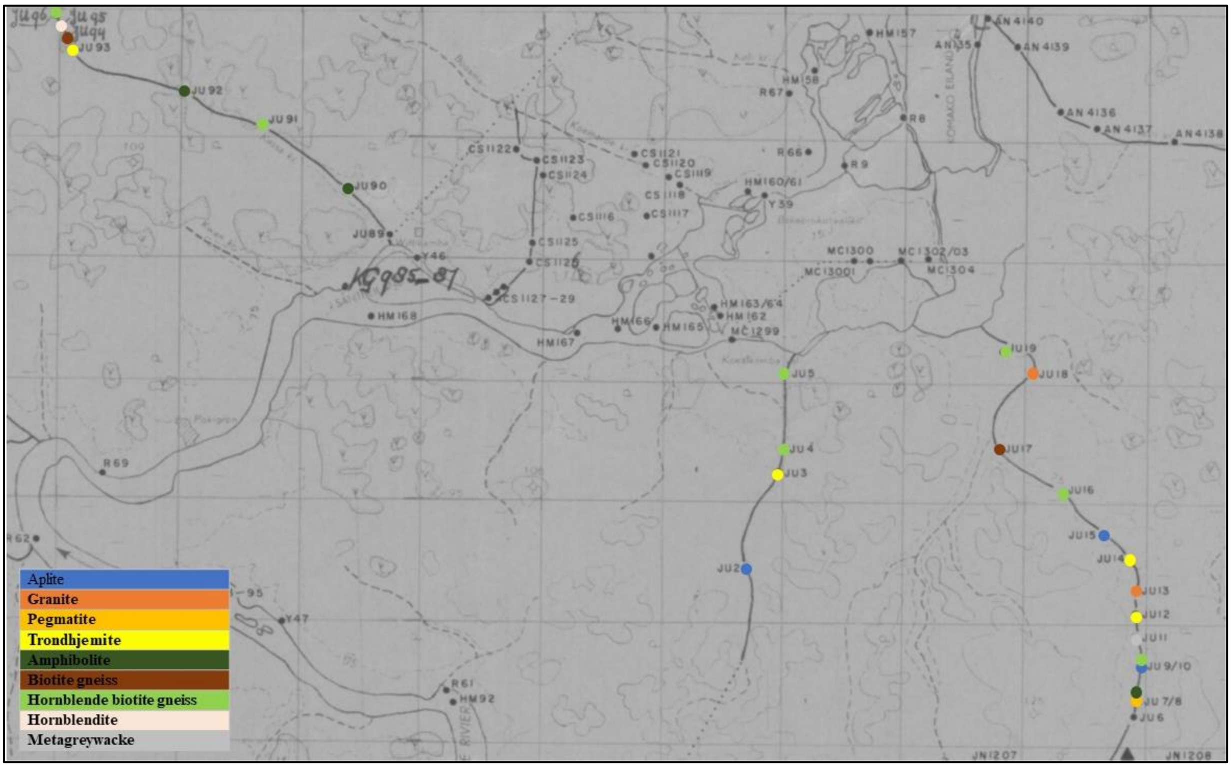


Figure 36 Rock mapping based on obtained results

5.1 Protolith determination

There are some sedimentary structures observed within the rocks. The biotite gneisses show clear banding, on macroscopic scale (Figure 24), which indicates remnants of the original sedimentary stratification. Since the rocks underwent high-grade metamorphism and so recrystallization, most of the sedimentary structures are no longer visible. Furthermore, the rapid alternation of biotite gneiss and amphibolites indicates a supracrustal origin, that is the protolith of the rocks are most likely to be sedimentary and volcanic rocks. Titanite is a common accessory mineral in igneous rocks and allanite is a characteristic accessory mineral in many granites (Strekeisen, 2006). Titanite and allanite are observed within the Hornblende biotite gneisses and have an igneous origin. These rocks probably belong to the Tonalites. This is also atested in field observations along the Suriname river.

5.2 Comparison with the Sara's Lust Gneisses

The samples from this research have a felsic to mafic character and hence are compared with the rocks from the felsic and intermediate to mafic suit from the research of Goumans (2019). Considering the occurrence of similar rocks in the Sara's Lust gneisses it is likely to say that the rocks found within this research correspond to the northern segment of the Sara's Lust gneisses. The migmatitic rocks are hornblende-biotite gneisses and biotite gneisses of supracrustal origin. These rocks are also most likely to be metamorphosed up to amphibolite facies considering the occurrence of amphiboles, plagioclase and often epidotes within these rocks. Also minor amphibolites are found in this area.

5.3 Comparison with the Marowijne Greenstone Belt

The Marowijne Greenstone Belt contains the Paramaka, Armina and Rosebel formation. As described earlier in chapter two the Paramaka formation contains volcaniclastic sediments which has been metamorphosed up to greenschist facies and it is also surrounded by tonalite–trondhjemite–granodiorite intrusions of the Kabel Tonalites (Kroonenberg, et al., 2016) and we also saw that this rock unit corresponds to the northern flank of the Sara's Lust gneisses. As described earlier the rocks from this research are likely to be the same as the rocks from the northern segment of the Sara's Lust gneiss and as Gouman's described, this suite is also likely to be the same as the Paramaka formation (Goumans, 2019). Taking into account this concept it is likely to say that the rocks from this research also correspond to the Paramaka formation. Furthermore, some trondhjemites are also identified which can be compared to the TTG intrusions. The Armina formation contains low-grade volcaniclastic metagreywackes and phyllites which are recognized as metaturbitites (Kroonenberg et al., 2016). Also the rocks from Rosebel Formation are recognized as metasedimentary rocks. This formation contains meta-arenites and metaconglomerates (Kroonenberg et al., 2016) and these rocks from the Armina- and Rosebel formation do not correspond to the results obtained from this research.

5.4 Comparison with the Gran Rio Granites

The Gran Rio Granite consists of medium- to coarse grained biotite granite and hornblende-biotite granite. They may have low banded appearance and migmatitic structures (Kroonenberg et al., 2016) and they encloses enclaves and large tracts of high-grade quartzofeldspathic gneisses, locally showing vague banding and schlieren (Bosma et al., 1983). The Gran Rio Granites are likely to correspond to the granite rocks from this research, as the granites show corresponding minerals such as quartz, kalifeldspar, plagioclase and biotite. However, the rocks from this research may have gone through a higher stage of metamorphism (up to amphibolite facies) comparing to the Gran Rio Granites resulting in migmatitic hornblende-biotite gneisses and biotite gneisses.

5.5 Tectonic setting

As a result of ultimate collision between the Amazonian Craton and the West African craton, the Marowijne Greenstone Belt developed (Kroonenberg, et al., 2016). One of the proposed theories from the research of Goumans is that the Sara's Lust Gneisses and the Marowijne Greenstone Belt have a tectonic relationship, in which the belt thrusted onto the Sara's Lust Gneiss which then led to higher-grade metamorphism in the Sara's Lust Gneiss (Goumans, 2019). The results obtained from this research indicate that the high-grade metamorphic rocks correspond to the northern segment of the Sara's Lust gneisses. The occurrence of Thronjemites can be an indication to be part of the TTG intrusions. Furthermore, the rocks from the Gran Rio Granite are most likely to correspond to the granites from this research although this segment has undergone a much lower stage of metamorphism compared to the rocks from this research. According to the distribution of rocks in this area, the results are not likely to contribute to the above, by Goumans mentioned, concept about the relationship between the Marowijne Greenstone Belt and the Sara's Lust gneiss. This indicates a gradual transition from the Marowijne Greenstone Belt to the Sara's Lust gneisses and the Gran Rio Granites.

6 Conclusion and Recommendations

6.1 Conclusion

The high-grade metamorphic rocks in the Kwai-Kwai zone at the transition from the Marowijne Greenstone Belt to the Sara's Lust gneisses are predominantly hornblende-biotite gneisses, biotite gneisses, amphibolites, trondhjemites and aplites. These rocks seem to have a supracrustal origin. The Hornblende-biotite gneisses have an igneous origin and probably belong to the Tonalites. Based on the obtained data it is likely to say that there is a gradual transition between the Marowijne Greenstone Belt to the Sara's Lust gneisses and the Gran Rio Granites, where the high-grade metamorphic rocks are probably younger than the Marowijne Greenstone Belt.

6.2 Recommendations

The concept theory of the relationship between the Marowijne Greenstone belt and the Sara's Lust gneisses is based on a limited amount of data which is only used within this research. To confirm this theory further study will be needed on the absolute age (age dating) of the high-grade metamorphic rocks from the Kwa-Kwai zone.

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Appendix A | Research Design Cycle