ADDIS ABABA INSTITUTE OF TECHNOLOGY

CENTER FOR ETHIO-MINES DEVELOPMENT DEPARTMENT OF MINERAL ENGINEERING

Mineralogical characterization of Bikilal Iron ore of Western Wollega, Gimbi, Ethiopia

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Declaration

This is to certify that the thesis prepared by **Jebessa Mammo**, entitled: "**Mineralogical Characterization of Bikilal Iron ore, Western Wollega, Gimbi, Ethiopia** and submitted in partial fulfillment of the requirements for the degree of Master of Science in Mineral engineering complies with the regulations of the University and meets the accepted standards with respect to originality and quality.

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Abstract

The Bikilal Iron Deposit is located in Gimbi, West Wollega zone of Oromia National Regional State, 440 kilometers west of Addis Ababa and is found at 25 kilometers northeast of Gimbi town. Its iron ore deposit is a Kiruna-type magnetite – ilmenite deposit that consists of magnetite, ilmenite, hematite, sulphides, and apatite. The principal ore minerals are magnetite and ilmenite. Bikilal iron ore with 57 million tons of magmatic origin. Its iron ore accounts 23.3% magnetic iron content and with 41% total iron. The main objective of the project is to characterize the mineralogy of Bikilal iron ore so as to identify the main valuable minerals, gangue minerals, and their relationships, as well as the grain size in the various ore phases.To study the mineralogy of Bikilal Iron Ore secondary data were collected. Primary data were gained from laboratory analysis for thin section and polish section (One sample each) done at Ethiopian Geological Survey of Ethiopia, X-Ray Diffraction analysis done at Adama Science and Technology University Laboratory. The Polish section analysis indicates that mineral compositions were 10% Pyrite, 15% Ilmenite, 20% Magnetite and 1% Chalcopyrite with xenoblastic texture and 54% gangue. Thin section analysis also indicate that the description of the ore were dark gray in color and fine to coarse grained in texture and its mineral compositions were 62% plagioclase, 30% hornblende, 5% Opaque, and 3% Biotite.. Six Chemical composition analysis by atomic absorption Spectrophotometry (AAS) were taken from secondary data (Zewdneh Tassew, 1990) and (Debebe Tafesse, 1995) to analyze the major oxides present in the ore and their average results were 48.55% SiO_2*, 0.85%* TiO_2*, 9.47%* Fe_2O_3*, 17.08%* Al_2O_3*, 8.68% MgO, 10.53% CaO, 2.35%* Na_2O*, and 0.308%* P_2O_5*. Additionally, Seven X-ray florescence (XRF) results were taken from (tesfa Lemu, 2013) and the average results were 47.97%* SiO_2*, 0.91%*TiO_2*,17.52%*Al_2O*, 9.65%*Fe_2O_3*, 0.13%MnO, 8.58%MgO, 12.03%CaO, 2,52%*Na_2O*, 0.09%*K_2O*, and 0.312%*P_2O_5*. Three samples were analyzed by the X-ray diffraction (XRD) on the Bikilal iron Ore at Adama Science and Technology University Laboratory. The phases were identified as 52.2% Hornblende, 1.2%Biotite, 27.8% Actinolite, 6.3% Titanomagnetite, and 12.6% amphibole. The elemental composition of the XRD analysis were O, Si, Fe, Ca, Mg, Al, K,Ti with negligible amount of F and V.*

From analysis results above SiO_2*,* TiO_2*, and* Al_2O_3 *make up the majority of the gangue minerals in Bikilal iron ore, with an unacceptably high concentration of the harmful element phosphorus. One explanation for the indication of a decrement in the amount of the key mineral in the ore (*Fe_2O_3*) is the relatively high silica content of the Bikilal iron ore, even when compared to the iron mineral hematite. This indicates the amount of the gangue is very high that exceeds the amount of the important mineral present in the ore. Others impurities found in the ore include MgO, CaO,* Na_2O*,* K_2O*,* TiO_2 *and albeit in smaller amounts. The commercial ore should contain fewer than 6% and 4% of silica and alumina, respectively (Joan J. Kiptarus et al., 2015) but the Bikilal iron ore* SiO_2 *and* Al_2O_3 *average content are 36.2% and 6.4% respectively, that is very big difference in respect to gangue contents. Alumina is a particular target during the beneficiation of iron ore and is a representation of pollution in the steel-making process. As a result, the Bikilal iron ore deposit's average quality is below the needed requirement, which is less than 40%, and is not comparable to the top iron ore nations, leading to the low-grade ores. The deposit of the ore can be exploited for multiple sources of different valuable commodities in addition to iron ore like phosphorus, Gold, Aluminium and Titanium.*

***Key Words:* Mineralogical, valuable minerals, gangue minerals, Bikilal iron**

CHAPTER ONE

1. INTRODUCTION

1.1. Background of the study

With 35% of the earth's total mass, iron is the most abundant element by mass and the fourth most abundant element in the crust. The earth's layers differ substantially in their iron content.

It is extremely high in the deep core and very low at the outer crust.(Solomon Rebso, 2013). Iron ore makes up around 5% of the earth's crust. If the iron content is more than 65%, the ore is considered high-grade; if it is less than 58%, it is considered low-grade (Edwin Basson, 2022). The majority of industries depend on the supply and availability of iron ore, which is essential to modern industry. In the modern era, it is the metal most essential to the development of industry and technology. This implies that industries related to iron are critical to economic expansion and may even serve as a gauge of a country's wealth, influence, and power. This illustrates how much iron-producing countries take pleasure in their political hegemony and leadership in day- to-day affairs (Solomon Rebso, 2013). Because of its chemical activity, iron can be found in rocks and soils in combination with other elements. Iron is chemically bound to oxygen, water, carbon dioxide, or sulfur in many of its natural forms. After hematite ($Fe2O3$) and magnetite ($Fe3O4$), goethite ($Fe2O3.H2O$) is the most common iron ore.Composite minerals can occasionally have a high iron content, but other times they have a high impurity level and are therefore less valuable (Seeger et al, 2001). Ninety-five percent of the tons of metal produced worldwide are iron metal. It is the most used metal. The production of steel, which uses about 98% of the iron ores that are mined, is one of the greatest inventions and most practical materials ever made by humans. Iron makes up the majority of steel, an alloy with less than 2% carbon. Thus, iron ore is needed to produce steel, which is necessary to maintain a robust industrial base. About fifty countries, including Australia, Brazil, China, India, the United States, and Russia, mine the majority of the world's iron ore.

Together, Australia and Brazil export nearly one-third of the world's iron ore, dominating the market. More than 800 billion tonnes of crude ore are thought to be available worldwide, and that ore contains more than 230 billion tonnes of iron (Solomon Rebso, 2013).

Table 1: World Steel Productions (Edwin Basson, 2022)

Country	**Production**	**-exports**	**+imports**	**Consumption**
Austria	3.0	0.0	3.2	6.2
France	-	0.1	11.2	11.1
Germany	1.2	0.9	33.4	33.8
Italy	-	0.0	5.4	5.3
Netherlands	-	16.9	24.4	7.5
Slovakia	-	0.1	4.4	4.3
Spain	-	0.1	3.6	3.5
Sweden	29.2	27.1	0.0	2.2
Other EU	-	0.5	4.0	3.5
European Union(27)	33.4	45.6	101.9	89.6
Bosnia-Herzegovina	1.4	0.0	0.0	1.4
Norway	1.6	1.8	0.0	-0.2
Turkey	7.9	2.2	9.9	15.6
UK	-	0.0	7.1	7.1
Europe	44.2	49.7	120.3	114.9
Russia and others +Ukraine	203.1	86.1	8.2	125.2
Canada	58.8	55.1	7.1	10.7
Mexico	11.4	1.9	1.5	11.0
USA	38.6	10.4	5.2	33.3
USMCA	108.7	67.5	13.7	55.0
Brazil	391.0	342.6	0.2	48.6
Chile	15.0	17.0	0.2	-1.8
Peru	8.9	11.6	0.0	-2.8
Venezuela	1.5	0.8	-	0.7
Other Central and South America	0.3	0.6	5.1	4.8
Central and South America	416.6	372.6	5.5	49.5
Liberia	5.1	5.1	-	0.0
Mauritania	13.5	14.1	-	-0.6
South Africa	69.0	65.5	0.0	3.5
Other Africa	5.7	0.5	23.2	28.4
Africa	93.3	85.1	23.2	31.4
Middle East	53.6	10.4	25.1	68.3
China	270.5	15.6	1170.4	1425.2

India	203.8	52.0	0.7	152.5
Japan	-	0.0	99.4	99.4
South Korea	0.3	0.3	70.4	70.5
Other Asia	17.9	40.9	78.9	55.9
Asia	492.6	108.8	1419.8	1803.6
Australia	922.5	873.0	0.9	50.4
New Zealand and Other Oceania	3.8	2.9	0.00	0.9
World	2338.4	1656.1	1616.8	2299.1

Iron is a vital metal that is used for commercial purposes, but the process of extracting it from ores, processing it further, as well as purifying it involves several steps, all of which call for the material to be described in terms of its behavior physical, chemical, mineralogical characteristics. Certain characterization tests rely solely on physical measurements, but others also use chemical and optical data as a basis. Therefore, in order to predict how the ore will behave during processing activities and, ultimately, to optimize the process, it is imperative to fully understand its physical, chemical, textural, mineralogical, granulometric, and other features using these methodologies. Ore needs to be characterized in order to distinguish between undesirable coexisting elements and valuable minerals.

Because the ore's composition varies depending on its origin, a detailed characterization is required to ascertain its mineralogical, chemical, and elemental composition. This holds true regardless of whether low-grade iron ores are upgraded or high-grade ores are utilized directly for industrial purposes. The investigation of numerous criteria, such as the ore's grade, morphology, size distribution, constitution, and so on, constitutes the feature of ore characterization.

A comprehensive understanding of the ore's chemical composition through characterization studies not only facilitates the assessment of a given geological formation's quality but also aids in defining feasible mining methods and forecasting the behavior of the ore during further ore processing, such as direct reduction operations, thereby establishing the ore's suitability for such operations and providing a detailed description of the ore (Adedeji, F. A., and F. R. Sale.1984). The development of engineering and technology led to the adoption of various approaches that were connected and integrated, including the mineralogy of the raw material and the efficacy and efficiency of its processing and beneficiation, particularly when choosing the optimal processing technique. Consequently, mineralogy is the decisive element in choosing the process conditions to be used, such as floatation (the type and amount of reagents, time and other parameters to be applied) (Xiao et.al, 2020).

When considering Ethiopia's mineral resources, a wide variety of minerals are present in significant amounts. Nearly every known mineral, industrial, and rock found in Ethiopia, including gold, platinum, rare and uncommon minerals, nickel, copper, iron, chromium, kaolin, feldspar, clay, asbestos, talc, marble, limestone, and rock, is found in the Precambrian crystalline bedrock. Gold, platinum, tantalum, nickel, and iron are commodities that received exclusive attention due to Ethiopia's significant metallic mineral deposits. While some metallic mineral processing is currently underway, others are still undergoing analysis.

Lega Dembi is where precious metal gold is processed, and Kanticha is already processing tantalum from rare metals. Bikilal iron ore is the iron reserves that have been the subject of numerous studies and analyses by experts such as Zewdneh Tassew (1990), Debebe Tafesse (1995), Solomon Rebso (2013), and Tesfa Lemu (2013), as well as by other researchers. The analysis has advanced to the processing tip. Additionally, although the occurrences of amalgam metals (Cr, Mo, and Mn) and base metals (Zn, Pb, and Cu) are confirmed, their reserves are unknown, and as a result, their economic viability is not guaranteed. The metallic distributions found in major and minor quantities are located as below in the table (Solomon Tadesse et al., 2003).

Table 2: Metallic ores distribution in Ethiopia (Solomon Tadesse et al., 2003)

Metallic ores	**Major deposits**	**Minor deposits**
Au, Ag (±Cu, Zn, Pb, As, Sb, Bi)	Lega Dembi, Megado, Sakaro Main	Ogo, Dul, Haramsam, Hasamte, Oda-Godere, Adi Zeresenay
Au, Ag	Adola Belt, Bore	Bedakessa, Lege Dima, Demi Denissa, Akobo, Sirkole
Au, Ag (As, BM)		Abetselo, Kata, Azale-Akendeyu
Au, Ag (As)		Gedemsa, Corbetti, Tendaho
Be, Li		Bissidimo valley (Mo-Be), Gubda valley (Be), Kenticha (Ta, Be, Li)
Cu		Chercher, Galetti valley
Cu		
Cu		Adi Dairo-Indallilo 1 (Au–Cu), Ashashire (Au–Cu–Pb–Zn), Bomo (Au–Cu), Digati (Au–Cu–Pb)
Cu		Enticho (Cu), Fawly
Cu		Abetselo, Kata, Azale-Akendeyu, Galeti
Cu		Soka (Pb–Cu), Ijabuna (Pb–Cu)
Fe, Ti (P)	Bikilal	Melka Arba
Fe		Beliga 2, Chago, Gordana, Koree
Fe (Mn)	Melka Sedi, Gammalucho, Garo	Adua, Entichio; Adi Berbere, Chilachikin, Dimma, Gato (Mai Guda)
Mn		Enkafela
Mn		Adi Berbere, Melka Sedi
Mo		Fakusho
Mo		Bissidimo valley, Chiltu
Ni, Co (Cr)	Adola Belt:- Tulla, Ula Ulo, Kilta	Big Dubicha, Monissa, Burjiji, Lolotu
Pb		Affratu, Gara Ua, Mariam Adi Desta, Soka
Pb, Zn, BM		
Pb, Zn, BM		Chamuk, Haramsam (+Au), Ashashire (Au–Cu–Pb–Zn)
Pt, Pltd (Au)	Yubdo	Tulu Dimtu

Pt, Pltd (Au)		Soddu, Yubdo, Tulu Dimtu
Ta,Nb, Ce	Kenticha (Ta)	Meleka (Ta–Nb), Kilkile, Agere Maryam (Ta)
Tiilm, TiRt, Zr		Aflata (TiRt, Tiilm, Zr); Bedessa Tega, Sacco River, Zembala Woha
U, Th		Harar (U–Th)
W		Kata (+Mo)
W		Digati(+Au–Pb–Zn–Cu–Ni–As), East Sakaro (+Au–As–Ag), Korkoro(+Au–Pb–Ag), Mestefinfin (Azenge) (+Au–Cu)

The major reserves and status of iron ore deposits are known and identified at various locations, despite the fact that iron ore is found in many different places.

Major iron ore deposits like Bikilal, Gammalucho, Garo, and Melka Sedi are estimated to have reserves (in tons), while minor deposits include Yubdo, Dha, Worakalu, Katta Valley, Mai Gudo, belowtuist, dombova, Aduwa, Melka arba, axum and Enticho, and others. ((Solomon Tadesse et al., 2003) & (Solomon Rebso, 2013)). Although the reserves of their deposits are unclear, numerous iron ore deposits have been found at Billa, Bissidimo, Galeti, Kunni, Beliga, Dembi Dollo, Gambo, and other locations. (Solomon Rebso, 2013).

The famous and most important iron ore in Ethiopia was recently discovered at Bikilal in Wollega. Precambrian meta-sedimentary rocks (feldspar–amphibolite schist, quartz–amphibole schist, quartz feldspar and amphibole schist, and marble) that were invaded by basic–ultrabasic rocks and granitoids made the deposit possible. Magmatic isolation forms create the Fe–Ti–P (apatite) sort from ultra-basic magma (Solomon Tadesse et al., 2003). Bikilal is one of the areas where iron ore mineral was found, taken into consideration, and designated as the essential location for raising project by the Ethio-Korean Iron Investigation team. It contains fifty-seven million tons of iron ore with magmatic origin, carrying 23.3% magnetic iron and totaling 41% iron with penetrating, drilling, and trenching. It is situated in the Western Wollega zone of Gimbi, Oromia National Regional State, 440 kilometers west of Addis Ababa. The Addis Ababa-Burayu-Ambo-Sire-Nekemte-

Gimbi highways link the 33 square kilometers of the total area. (Solomon Rebso, 2013).

The mineralogical characteristics of the Bikilal iron ore have not yet been examined, despite the fact that it has been the focus of multiple exploration studies, such as the Ethio-Korean iron ore exploration project. An in-depth knowledge of the mineralogical characteristics of iron ore is necessary to maximize its use in the production of iron and steel. In order to determine whether the iron ore from the Bikilal iron ore deposits is suitable for use in the production of steel, the goal of this study is to characterize it from a mineralogical standpoint. Knowing the compositions and comprehending the mineralogy are the first crucial steps that must be completed before processing. This aids in choosing the right technology for extraction as well as determining whether the commodity is suitable for exploitation. Additionally, increase the required profit and make the investor decision at the lowest possible cost.

1.2. Location of the Study Area

The Bikilal iron deposit is situated 440 kilometers west of Addis Ababa in Gimbi, West Location of the Oromia National Regional State's Wollega zone study area. It is located 25 kilometers northeast of Ghimbi town and is included in Ethiopian Mapping Agency topo sheet No. 0935 D2. Its eastern and northern limits are 35052'26" to 35055'23" and 9015'15" to 9020"6" respectively. The size of this deposit area is 33 square kilometers. The route from Addis Ababa to the study area, which is Ambo-Boku-Sire-Nekemte-and Ghimbi, has a number of detours. The gravel road between Ghimbi Town and Bikilal, which is 24 km long, is being built. Furthermore, Bikilal's center is connected to the Gelel River in the west and the Soti River in the east by walkways (Solomon rebso, 2013).

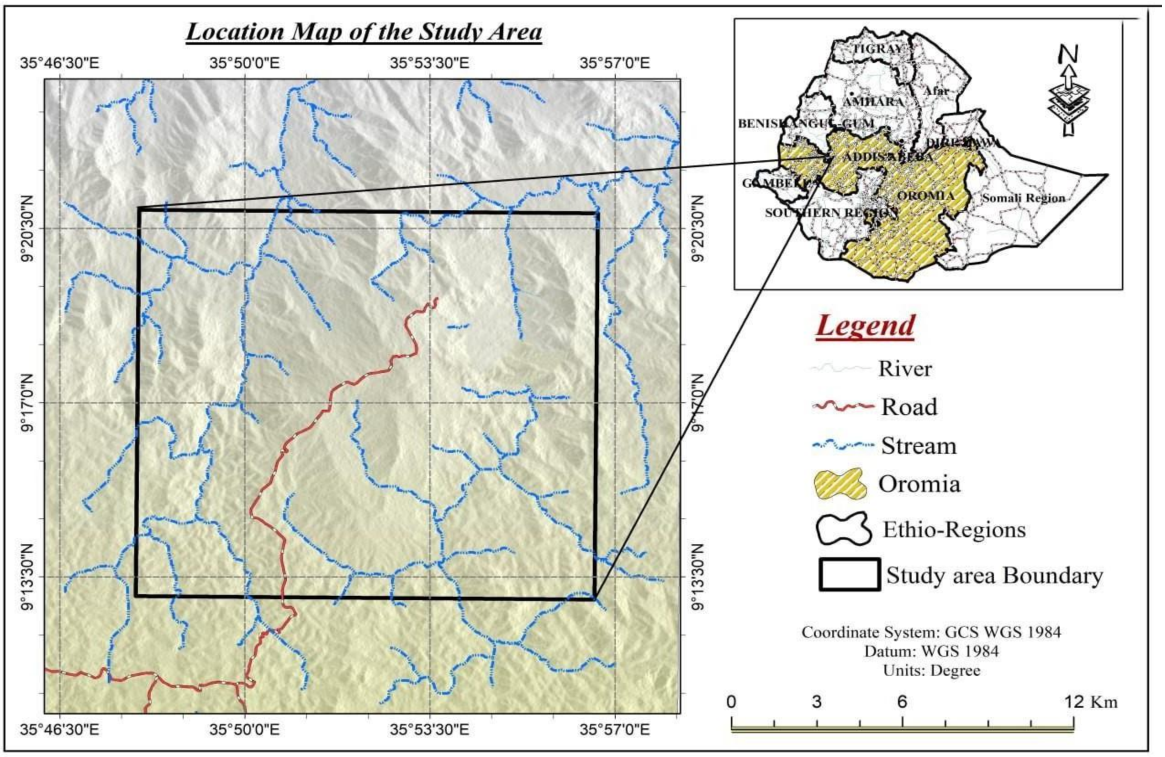


Figure 1: Location map of the study area

1.3. Physiography

The current study location is located within the physiographic unit at the Western Ethiopian level. Bikilal might be a very difficult and hilly area. In the Jejeba waterway bowl, the highest recorded rise is 2216 meters, while the lowest is 919 meters. The area under consideration is situated between the Bikilal Mountains and the Jejeba waterway bowl, which is made up of valleys and edges. Numerous erratic and perennial streams split off Bikilal before merging into the Gelel and Soti streams. There are four main streams that encircle Gimbi. They are Birbir, Dabus, Didesa, and Abay. The two biggest tributaries of Abay are Dabus and Didesa. Waterways that are tributaries of Didesa, such as the Jejeba, Sayi, Soti, and Gelel, are included in the second arrangement. Most of the streams and rivers take after the N-S, NW -SE, NE-SW and seldom E-W patterns. These trends are associated with Northeast Africa's territorial structural frameworks (Solomon Rebso, 2013).

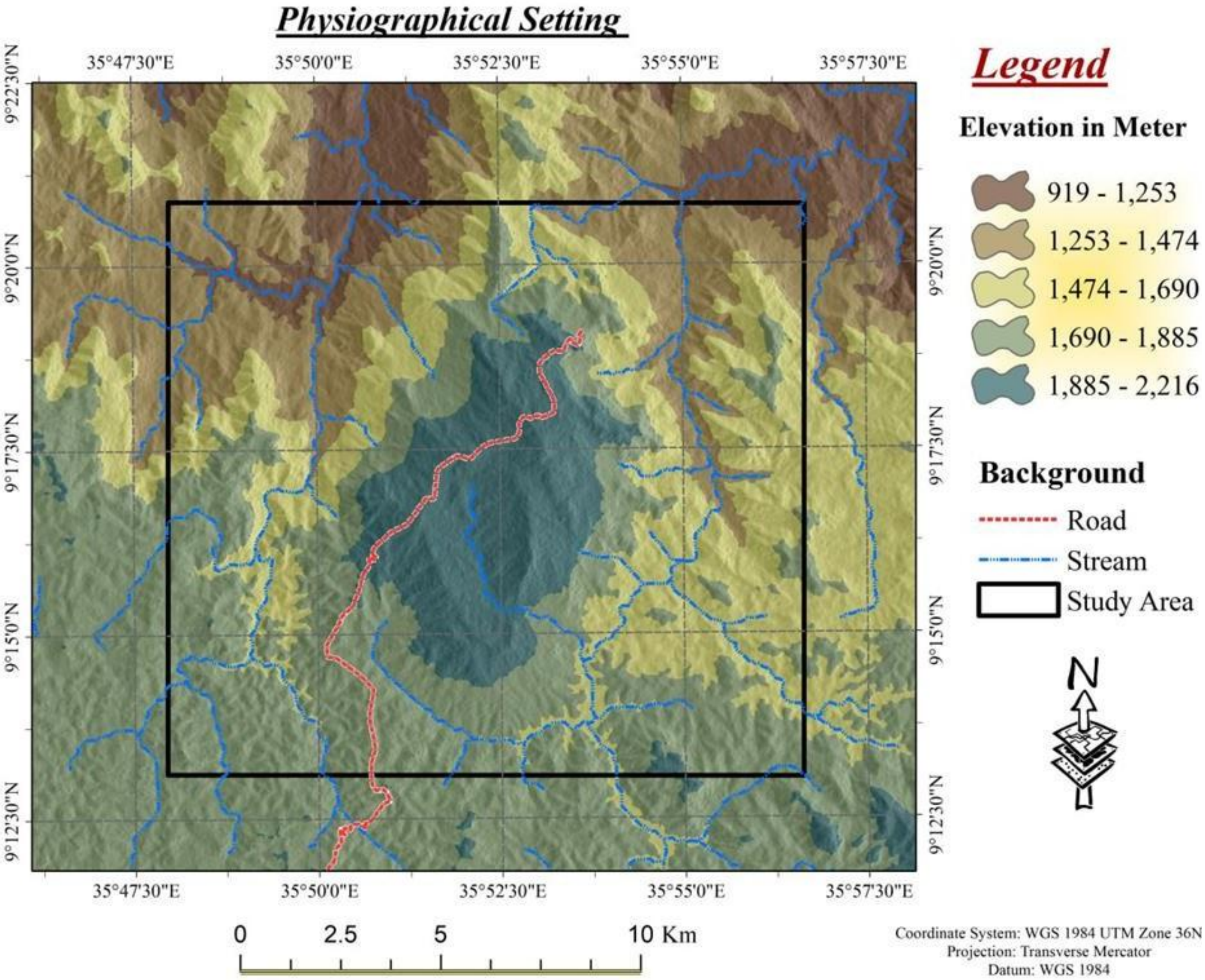


Figure 2: The Physiographical setting of Bikilal Area

1.4. Genesis of Bikilal Iron Ore

According to a research study, Bikilal iron ore deposits were formed from basic magma through magmatic isolation processes, followed by late magmatic types ore bodies.

During intrusion, various pieces of amphibolite and amphibole schist were mixed with the basic magma. A decrease in temperature and the production of more acidic magma were caused by the recurrence of pieces within the edge zone. Over time, the magma splits into two magmas. One stable (olivine gabbro) and one unstable (gabbro) are found in the inner and outer zones of intrusion, respectively. The gabbro zone was simultaneously complicated by the deterioration of the more acidic rocks. Because of this, separation occurs rapidly in this zone, and different types of magmas have already separated from one another at a depth. Similar to a heterogeneous liquid flowing down a pipe divider, a few isolated magmas formed limit layers that were oriented parallel to the shape of the intrusive. Furthermore, while gabbro magma formed transitive forms of gabbro close to the temperature of crystallization, ultra basic ore mineral magma produced ore through ore mineral crystallization during the late magmatism period when the silicates crystallized. At that time, the essential plagioclase was replaced by more acidic- shaped horneblonde, actnolite, tremolite, epidote, chlorite, and phlogopite due to alkali-autometasomatism, both recently and after the oxides crystallized. Additionally, olivine, pyroclastic, and infrequently amphibole were replaced. Thus, olivine pyroxenite and/or ultrabasic rocks replaced the gabbro with meta-gabbro, meta-horneblondite with pyroxenite or horneblondite, and ore-rich actinolite-containing rocks replaced the gabbro. Chlorite rich in ore Near (and inside) the mineral deposits, meta-horneblondite replaced little to medium review ore- rich pyroxenite or horneblondite (Tebebe Tafesse, 1995).

The regional geological map and the location of the ore body of Bikilal Area is kept below:

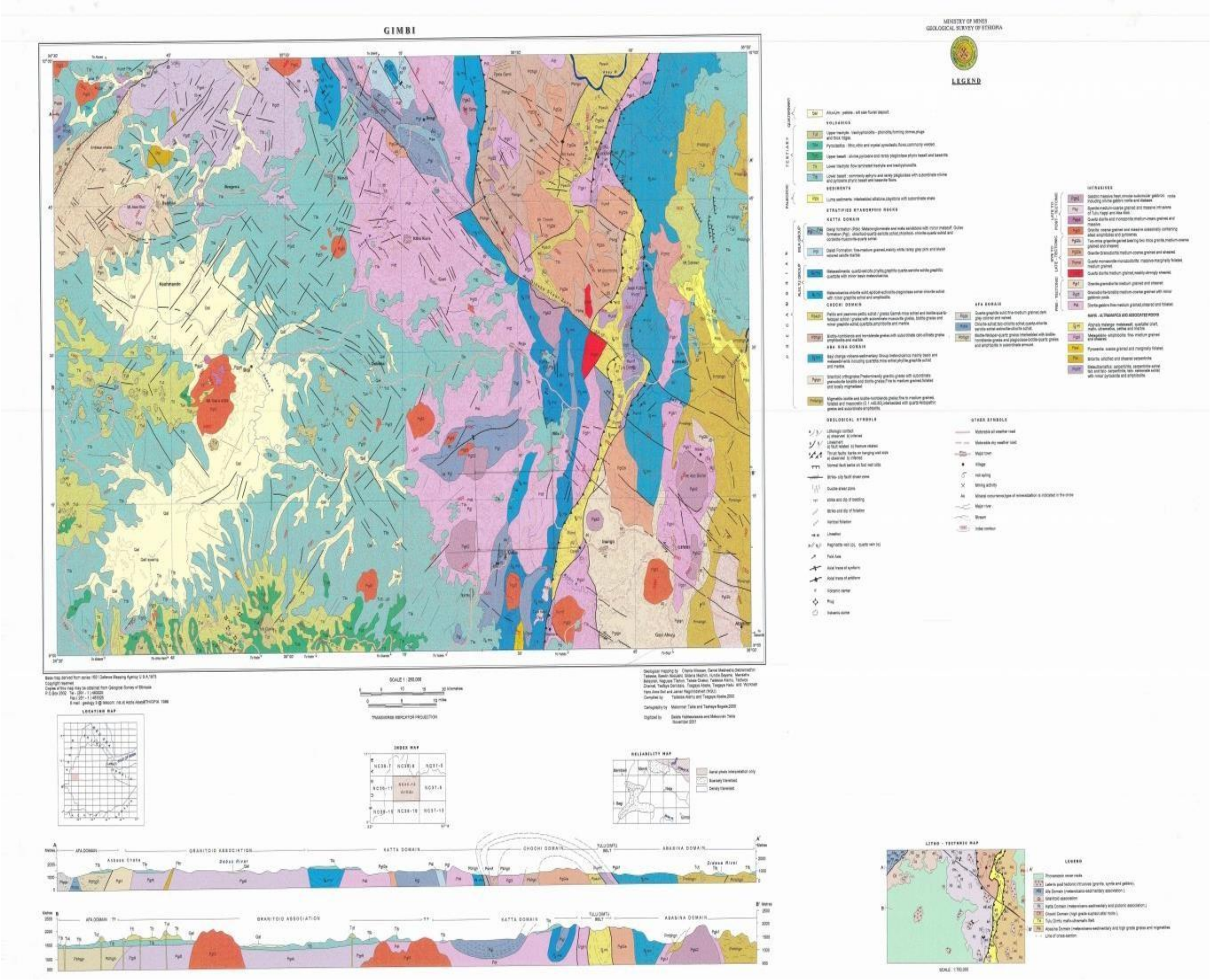


Figure 3: The regional geological map and the location of the ore body

1.5. Statement of the Problem

The intrusive magnetite-ilmenite complex that made up the Bikilal iron ore deposits was part of a syn-post tectonic gabbroic complex. Like the Kiruna deposit, these deposits are created when magma cools and solidifies inside the Earth's crust. Different elements combine to form different minerals as the magma cools. These minerals include ilmenite and magnetite, the main sources of titanium and iron in the deposits, respectively. Smaller amounts of other minerals are also found, including apatite, sulfides, gold, and hematite, another iron mineral. The ability to produce iron, a valuable metal for a variety of industries, makes the iron ore deposits significant. They must first undergo a procedure known as beneficiation, which separates the valuable minerals from the undesirable ones, before they can be put to use. The physical and chemical characteristics of the minerals determine this process. Understanding the ore body's properties as thoroughly as possible before mining starts has become increasingly important.

There are numerous iron ore resources in Ethiopia spread across the nation. One of the most notable iron ore deposits is the Bikilal deposit in Western Wollega, which can be exploited with careful selection of the right concentration techniques.

Former geologists Solomon Rebso, Tebebe Tafesse, Solomon Tadesse, and others only made detailed geological maps of the region and performed petrological characterizations pertaining to the ore genesis or the nature of ore formations, despite the fact that the Bikilal iron ore deposit is recognized as a significant source of iron-bearing minerals. This suggests that information on a thorough chemical and mineralogical characterization is lacking, and even if it were present, it would not be sufficient for additional processing in the separation of iron ore minerals from related gangue minerals. Mineralogical identification, chemical composition analysis, grain size distribution analysis, and textural analysis will be used to fill in the information gaps in this proposed study, which aims to perform a thorough chemical and mineralogical characterization of an ore deposit with regard to the implications on beneficiation of iron ore mineral from its associated gangues.

The physical and chemical characteristics of the minerals determine this process. Understanding the ore body's properties as thoroughly as possible before mining starts has become increasingly important. Understanding the ore body's variability and identifying problematic minerals that may affect grinding, flotation, and/or leaching are two important functions of mineralogy. Identification of hazardous mineral species is necessary to minimize issues during the remediation phase. This strategy is motivated by the need to lower risk and expenses as well as the growing complexity and lower-grade nature of ore bodies. The mineralogy of the feed must be understood in order to properly design a plant, and specific mineralogical data like texture (grain size and grain boundary relationships) is crucial to comprehending how challenging it would be to separate valuable minerals from gangue and assessing the feasibility of a project. Grain size and grain boundaries of the valuable minerals with gangue, as well as the impact on grinding, are examples of mineral properties that are recommended in relation to textural relationships. Additional thorough quantitative analysis of specific mineral phases can reveal the existence of elements that could pose a challenge to the ore's processing, which would result in penalties, and that might contain hazardous components. Because of the growing demand and production of iron metal, steadily rising iron ore prices are also driving up the need for iron ore process mineralogy. Therefore, it is worthwhile to carry out a more thorough mineralogical characterization of the Bikilal iron ore deposits and determine the most effective techniques for their beneficiation in order to close this knowledge gap. The majority of the time, not all of the resources' constituents are valuable minerals; instead, some of them are hazardous and unusable. We therefore look for methods to exploit and process the minerals for development after characterizing and comprehending them.

1.6. Objectives

1.6.1. General objectives

The main objective of the study is to investigate mineralogical characterization of Bikilal iron ore.

1.6.2. Specific objectives

- ✓ To identify the ore minerals and gangue minerals in the iron ore.
- ✓ Identify the textural relationship of the valuable minerals with gangue.
- ✓ To determine liberation size of valuable mineral (iron) and gangue minerals

1.7. Significance of the study

With the growing demand for premium raw materials and mineral products, mineral characterization is essential for competitiveness. More thorough and in-depth analyses of the mineralogical makeup of iron deposits are now possible thanks to advancements in micro- analytical technology, which can help choose the most effective extraction techniques. In addition to offering a strong basis for feasibility studies and processing projects of iron ore companies and firms, this study has important practical implications for improving the utilization of Biklal iron resources. This study was conducted for a variety of reasons related to industrial minerals. The first is the acknowledged growing need for raw material and product specifications to satisfy market demands, the ongoing need to optimize mineral processing, and the drive to maximize the financial gain from resource exploitation. In summary, a thorough mineral characterization of a deposit is a crucial benefit that can direct deposit exploitation for optimal financial gain. By enabling recovery optimization or, for instance, by identifying issues of an environmental or marketing nature that cannot be determined solely by chemical analysis, the necessary investment to conduct such a study can easily pay for itself. The proper application of technical and financial criteria to enhance operating plans and evaluate the deposit's commercial viability will be made possible by ore characterization. As previous works considered mineral investigation, reserve assessment, and beneficiations to economically use the asset, I came to understand the importance of logical inquiry into the origin, beginning, and mineralogy of Bikilal-iron mineral. By addressing information gaps regarding mineralogical assessments, such as mineral identification, grain size distribution analysis, compositional analysis, and determination of the liberation size of the target ore mineral, this study will generally be of great importance to the scientific community. This is especially helpful to the scientific community that wants to carry out more research on iron ore mineralogical characterization for beneficiation from its ore deposit in the Bikilal area. Additionally, by acting as a feasibility study or marketing document to draw in foreign investment firms, this proposed research will either directly or indirectly affect the Ethiopian mining industry.

1.8. The scope of the study

The project aims to achieve its target through a series of specific objectives, including identifying the presence of iron and gangue minerals in the Bikilal iron ore, identifying their textural relationship of the valuable minerals and gangue minerals, and determine the liberation size of iron mineral and gangue minerals. Therefore, the results of this project could provide valuable insights into the potential of Bikilal iron ore for mineralogical characterization of the ore. This could inform future research and development efforts to aim at improving the efficiency and effectiveness of characterization technique for the Bikilal iron ore**.**

1.9. Expected Output

In general, this study offers information to people and organizations who must study for academic purposes as well as to investors who wish to take advantage of the deposits. This partially bridges the knowledge and understanding gap regarding the deposits, particularly Bikilal iron ore, and provides information for those who wish to study other deposits of iron ore found at various locations. Despite the fact that Ethiopia has a large number of iron resources, there is a dearth of information regarding their chemical and mineralogical characterization and guidance for the feasibility and feasibility study to add values to those deposits. Particle size distribution analysis with sizing curves, mineral identification of gangue and valuable minerals, textural analysis (type of grain interlocking, type of associated gangue minerals, degree of mineral liberation, etc.), and suggestions for the best concentration method are all included in the detailed chemical and mineralogical characterization results.

CHAPTER TWO

2. LITERATURE REVIEW

Mineralogical characterization of iron ore identifies the main valuable minerals, gangue minerals and their relationships, and the grain sizes of the various ore phases. Microscopic analysis is performed using a microscope to learn more about the mineral assemblage of the deposit. For mineral release studies, identifying the major minerals present in the ore body and the particle size of each component is required (Bachmann et.al, 2017)**.** Around the world, studies have done on the chemical, physical and Mineralogical characterization of iron ores and some of the examples are showed below:

Characterization and analysis of Dilband iron ore deposit in Balochistan, Pakistan was done by chemical composition analysis by XRF, AAS elemental analysis, and quantitative mineralogical analysis. Then textural analysis for thin section by petrographic microscopy was done and showed that Dilband iron ore was revealed to be mainly composed of iron ore 46.27% hematite, 17.41%quartz, 14.47% calcite, 9.24% chlinochlore, 10.5% kaolinite and 1.75% fluoropatite minerals. Atomic absorption spectrometry of different size fractions from -600 µm to -38 µm shows that Dilband iron ore contains an average of 40.18% Fe, 18.34% SiO_2, and 5.32%Ca, 2.262% Al. Then Average analysis of different size fractions with XRF revealed 44.3%Fe, 20.4% SiO_2, 8.8% CaO, 6.35% Al_2O_3, 1.08% P_2O_5, and 0.065% SO_3 (Abro et.al, 2008).

Additionally, studies on the characterization and processing of silicate iron ore deposits were carried out, and emission sizes were determined by chemical or elemental analysis using atomic absorption spectrometry/AAS (Dwari et.al, 2013).

Furthermore, the investigation was carried out using quantitative electron microscopy (QEM) for the mineralogical characterization of the iron ore residue used in the desilting stage. The analysis showed that the main mineral components were hematite and quartz and was found to contain smaller proportions of goethite, kaolinite, and gibbsite. The types of mineralogical occurrences related to the degree of release are as follows: 88.13% of grains are completely free of hematite/magnetite, 0.53% are associated with quartz, and 6.77% are associated with goethite (Souza, et.al, 2021)**.**

They also performed mineralogical characterization of iron ore sinter using optical microscopy, X-ray diffraction (XRD) and X-ray fluorescence (XRF) methods. Optical point counting (OIA) characterization was performed based on color, reflectance, and morphology of each phase using a reflective optical microscope with a step stage.

Moreover, studies comparing the mineralogy of iron ore sinter have been carried out using optical image analysis and point counting(PC), XRD, and two different electron microscopy systems (quantitative evaluation of the material by scanning electron microscopy(QEMSCAN) and TESCAN integrated mineral analyzer(TIMA) (Donskoi et.al, (2021)).

Nowdays Iron metal is becoming the necessary metal for technological and industrial development. Due to this supply and availability of iron ore with the required specification is the necessary issue to produce Iron metal of the better quality. From the produced iron ore produced worldwide, 98% is consumed to produce steel which is the greatest technology and most useful commodity that ever created by human being. Of all metals, iron is the most commonly used, accounting for 95% of the total amount of metal produced worldwide. China, Australia, Brazil, India, Russia, Ukraine, South Africa, Iran, Canada, the United States, Kazakhstan, Sweden, Venezuela, and Mauritania are the world's largest iron ore producers annually. The high-grade ore at Kiruna in northern Sweden is the most famous and productive iron ore deposit in the world and is the result of magma segregation (Solomon Rebso, 2013).

The three most common iron ore minerals magnetite, hematite, and goethite, account for more than 99% of all iron minerals. Chemical information is often used in mining facilities to classify iron ore. Although chemical standards are widely used, they do not provide information about mineral composition, especially the relative proportions of mineral phases in ores. The ratio of the iron-containing ore magnetite (Fe_3O_4, 72.4 wt% Fe), hematite (Fe_2O_3, 69.9 wt% Fe), and goethite ($FeO(OH)$, 59.9 wt% Fe) decides the iron content of the ore (Clout, J. M. F., and J. R. Manuel., 2015).

Goethite is the most contaminated and water-containing material; as it sinters, water is released, increasing the porosity of the sinter. (De Andrade, (2016)).

Magnetite (Fe3O4) is a common iron ore mineral found in metasedimentary and magmatic iron ore deposits. Its structure is inverse spinel, and in near-surface conditions, it partially transforms into hematite or kenomagnetite. Hematite is generally believed to form from the oxidation of magnetite in the near-surface environment, although it has been demonstrated that the transformation of magnetite to hematite or vice versa can also be accomplished via a pH shift without a redox reaction (Clout, J. M. F., and J. R. Manuel. 2015).

Goethite, an iron oxyhydroxide (-FeOOH), is thought to be the most common iron ore mineral in sedimentary and near-surface altered metasedimentary iron ore deposits. Although maghemite is more commonly found in alluvial deposits, which are typically iron-rich conglomerates and gravels, it can partially replace magnetite in weathered iron ores (Clout, J. M. F., and J. R. Manuel. 2015).

Also siderite and pyrite, are iron-bearing minerals that can occasionally be used to extract iron, they are not considered economically viable iron ore minerals because of the unacceptable levels of SOx and CO2 that are produced during their subsequent agglomeration and high- temperature processing. Additionally, clays (kaolinite and gibbsite) predominate in weathered supergene altered and near-surface exposures of ore deposits, minnesotaite and stilpnomelane are the most common silicate minerals in unweathered iron formation deposits. Overall, quartz is the most prevalent mineral found in iron ore gangue. Iron ore deposits are associated with a wide range of other major to minor gangue minerals, including numerous silicates (like amphiboles and chlorites), carbonates (like siderite and ankerite), sul- fides (like pyrite), and oxides (like pyrolusite).Variations in the chemistry, texture, mineralogy, and physical characteristics of iron ore are closely linked to the types of iron deposits. (Clout, J. M. F., and J. R. Manuel. 2015).

Thus, it is essential to first acquire a comprehensive understanding of ore, more especially of gangue minerals and ore minerals. Processing technology, which is largely based on the process of mineral separation and liberation, is used to separate and obtain ore minerals from gangue in a commercially and technologically feasible manner. Because of the rising demand for ore, processing technology is now required. Prior to processing iron ore, mineralogical characterization is a crucial and crucial step that must be completed (Nayak Bibhuranjan, 2007). Some of the main characterization tests used in the processing of iron ore include SEM (Scanning Electron Microscopy), XRD (X-ray Diffraction), and FTIR (Fourier Transform Infrared Spectroscopy). These tests are important for analyzing various properties like elemental composition, porosity, mineral association, and liberation, among others. There is also an introduction to new and additional methods utilized in iron ore processing operations and mineralogical assays. Characterization tests are available that can be applied to high-grade iron ores as well as low-grade waste products like tailings and fines. Other methods, such as XRD, FTIR, and others, are useful for comprehensive chemical studies and physical characterization, while optical microscopy and SEM are useful for micro-morphological examinations. It may be believed that combining these approaches is the best way to fully understand ore properties. (Clout, J. M. F., and J. R. Manuel. 2015).

For the purpose of using mineral resources for industrial purposes, this type of research is essential because specifications are important for raw materials and mineral products that will compete in the market. Additionally, findings from mineralogical characterization may help identify the most effective ways to process minerals, which will increase profit and minimize cost (Cook and Nigel J. 2000).

The production of iron ores and other types of metalliferous deposits, where iron ore is produced as a by-product, has historically relied on a wide variety of iron ore deposits. The majority of the world's current iron ore production and resources come from deposits hosted by iron formations. Important channel iron deposits (CIDs) that filled Tertiary river channels, Kiruna-type iron oxide-apatite ores, and specific varieties of Cu-Fe skarn (e.g. g. Daye, People's Republic of China (PRC); Hapugoda et al., Apurimac-Cusco porphyry-skarn belt. 2009) and deposits of rare earth elements (Bayan Obo, PRC). Ninety-five percent of iron ore deposits, according to experts, are sedimentary in origin, meaning they started as chemical precipitates from ocean water. Terrestrial detrital iron deposits, marine placer deposits, oolitic goethite deposits, and contact metamorphic ores are some additional sources of iron (Clout, J. M. F., and J. R. Manuel.2015).

High-grade iron ore with consistent chemical, mineralogical, and metallurgical grades is in high demand from steel companies. Iron ore must be geometallurgically characterized in order to meet this demand. The location and distribution of silicon, aluminum, and phosphorus in the ore can be determined with the aid of microscale mineralogy and chemistry. The production of steel and its metallurgical characteristics are negatively impacted by phosphorus, particularly when it is mixed with other alloying elements like manganese and chromium. Silicon and aluminum also affect the toughness and ductility of cast and deformed steels. Therefore, when creating methods for handling and processing high-grade iron ore, it is essential to understand and interpret the mineralogical associations of the hazardous elements (Ramanaidou and Brick. 2008).

In Ethiopia, iron ore deposits have been found in a number of locations, including Gordoma, Chago, Worakalu, Dimma, Billa, and Tulu Bolale in Wollega, Mai Gudo, GwmmaIucho, Kurkue, Garo, Dombowa, and Melka Sedi in the Kaffa, and aduwa and enticho in Tigrai. Additional locations suspected of having iron ore deposits are also identified. Through the use of drilling and trenching, the Ethio-Korean Exploration Project's assessment revealed that the Bikilal iron ore deposit was the primary one, with an estimated total ore reserve of 57 million tons of magmatic origin at average grades of 23.3% magnetic iron and 41% total iron. However, the results obtained since the early 1960s have not been assessed or put to the test for the local development of cottage industries until now. The current research region is located in the physiographic unit of the North Western Ethiopian Plateau. Bikilal is a very rocky and mountainous area. The highest point in the Jejeba river basin is 2222 meters, while the lowest point is 1200 meters. The study area is situated between the Bikilal Mountains and the ridges and valleys of the Jejeba River basin. Bikilal is crossed by a multitude of intermittent and perennial streams that eventually empty into the main Gelel and soti rivers. Bikilal magnetite- ilmenite deposits found in Western Wollega, Ethiopia, are the source of kiruna-type iron ore. The intrusive gabbroic complex, which is composed of hornblendite and homblende gabbro, is surrounded by Precambarian gneiss. Minor lithological units include migmatite, anorthosite, pegmatite, and granite. All lithological units have a dipping angle ranging from 350 to 750 degrees to the southwest. The structural trends in the study area are northwest to southeast depending on regional lineament and so according drillhole data collected in the area, the rocks are stratified and exhibit magnetite-ilmenite and apatite mineralization in homblend gabbro and homblendites with anorthosite. At Addis Abeba University's School of Earth Sciences, the identification of minerals in the ore and their textural relationships were also investigated using a transmitted light microscope (Solomon Rebso, 2013)

1.4. 2.1. Local Geological Setting of Bikilal Iron Ore

Bikilal gabbroic intrusion comprises olivine gabbro in the center, hornblende gabbro and hornblendite as dominant rock at the periphery of the intrusive as well as pegmatite, granite, migmatite, and anorthosite found as a minor lithology.

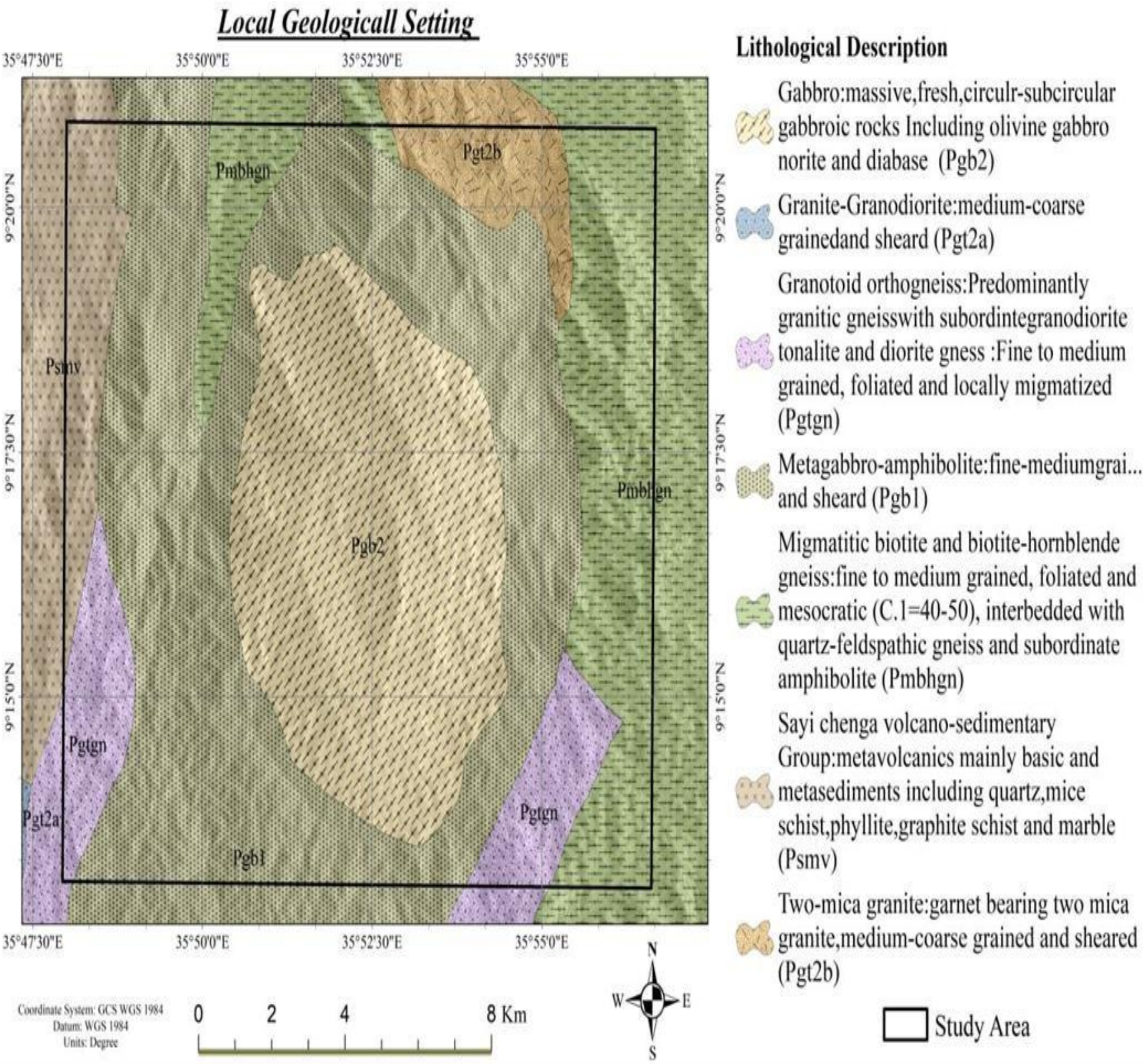


Figure 4: Local Geological Setting of Bikilal Iron ore

CHAPTER THREE

3. METHODOLOGY OF THE STUDY

3.1. Secondary Data Collection

To have a thorough grasp of the mineralogy of the rock under examination, a variety of literatures, journals, published and unpublished papers, and articles have been gathered from various sources and studied. Previous research on the geology, mineralogy, and provenance of the ore deposit should be included. This will lead to a better knowledge of the kinds of minerals found in the ore and the mineralization processes that created the deposit. Any ambiguities or knowledge gaps that must be filled during the laboratory investigation should also be noted in the reviewing of the secondary sources. This entails gathering information about the Bikilal iron ore deposit from geological maps and earlier research on the nature of the deposit's ore. It is important to document the deposit's location, dimensions, and shape in addition to any details regarding its minerals and geology. The mineralogical data obtained from the Atomic Absorption Spectroscopy (AAS) and X-Ray Fluorescence (XRF) secondary data.

3.2. Desk study

To obtain representative samples of the ore, sampling deposit is required. The samples should be collected using the appropriate sampling techniques in order to minimize bias and guarantee representative samples. Samples of low-quality iron ore, primarily magnetite (23.3%), ilmenite, and hematite ore, with a total iron grade of 41%, were obtained from the laboratory store of the Ethiopian Geological Institute that were transported there from the Bikilal iron deposit location in Wollega, Western Ethiopia. Improved comprehension of the physiography of the Bikilal iron ore and knowledge acquisition through the collection and analysis of rock samples, as well as the search for uncommon minerals and rocks for the study, are the goals of the field study. To prevent contamination, the gathered samples must be clearly labeled with non-metallic ink and describe the sample size. For the sampling process to produce quality results, it must be methodical.

3.3 Laboratory investigation

3.3.1. Sample preparation

The collected samples need to be crushed and ground into a fine powder for laboratory analysis. Care must be taken during sample preparation to avoid contamination and preserve the mineralogy of the samples.

3.3.2. Mineralogical and geochemical analysis

X-ray diffraction (XRD) analysis should be used to ascertain the mineralogy of the ore samples. In the XRD analysis, X-rays are used to determine the samples' crystal structure and mineral content. An analysis using X-ray fluorescence (XRF) should be used to quantify the elemental composition of the ore as well. This will show how much iron and other elemental content there is in the ore. In order to analyze the oxides in the ore, atomic absorption spectrometry, or AAS, will also be used for chemical analysis on the samples.

3.3.2.1. Atomic absorption Spectroscopy (AAS) analysis procedure

The preparation of laboratory sample from growth samples and then taking analyte sample is the first stage in the analysis of any sample. Zirconium or Platinum fusion crucible used and lithium tetraborate and analyte sample will be mixed thoroughly by glass rod. Or if Lithuim tetraborate not available potassium hydroxide pellets added to sample and then shaked. Heating of the mixture to 700^0c for 20 to 30 minutes for fusion and taking out and cover by lead glass and cooling. We use lead glass because of its resistance to chemicals and heat. Hydrochloric acid added to neutralize the Potassium hydroxide pellets and transferring to 400ml Teflon beaker by rinsing thoroughly. Heating at low temperature for 3 to 5 minutes to remove chloride and to neutralize the solution and transferring the solution to 500ml volumetric flask level to the mark with the distilled water and then shaking. The content will be settled overnight and atomic absorption spectroscopy reading will be done. For Atomic absorption spectroscopy calibration, standard have to be prepared from stock solution 1000ml bottle.

3.3.2.2. X-ray diffraction analysis procedure

The prepared sample's structural and phase identification was completed using XRD equipment, enabling a thorough analysis of every sample. The XRD equipment that will be used for this project uses Cu-K radiation and the DIFFRAC+EVA computer program. In addition, a computer would record the results of the test and enable easy configuration of the apparatus. XRD equipment is available at the Adama university, where this characterisation is carried out. The short list of instructions for using the XRD equipment is provided below:

- Prepare the crystalline sample in different tubes.
- The X-ray tube is stationary, the sample moves by angle θ, and the detector moves simultaneously by angle 2θ. The sample holder, detector arm, and associated gearing are composed of two types of assemblies. One of them is the θ: 2θ assembly. The second one is the θ:θ assembly, where the detector and X-ray tube move simultaneously over the angular range θ while the sample remains stationary in the horizontal position. In this work, two assemblies are used.
- The sample tubes placed on the sample holder properly
- The XRD equipment configured with the computer.
- The X-ray tube held stationary.
- The sample holder moves by some specified angle θ, and the detector simultaneously moves by angle 2θ.
- The final diffraction pattern result of each sample captured from the computer

3.3.3. Microscopic analysis

An optical microscope should be used to examine the mineral textures and elemental compositions of the ore. The mineralogy and mineral relationships of the ore samples can be precisely determined through microscopic analysis. This can help identify any shifts in the mineralogy of the deposits.

3.4. Flowchart Methodology

Table 3: Flowchart methodology

Preliminary	▪ Determining where the project must be done ▪ (commodity, Location, and then the Title) ▪ Submitting the permission for the project ▪ Determining the problem formulation and objectives of the project
Data Collection	**1. Primary Data** ▪ Collecting the samples ▪ Doing the analysis (Polish section, thin section, and X-ray diffraction) **2. Secondary Data** ▪ Data from Secondary sources on related topics (Articles and journals)
Data Processing and Analysis	▪ Interpreting the data ▪ Discussion ▪ Conclusion ▪ Recommendation

CHAPTER FOUR

4. RESULTS AND DISCUSSIONS

4.1. Results

4.1.1. Introduction

High Fe and low impurity element levels are ideal for iron ores in order to warrant the expenditure of the exploration work. There are certain generalizations that can be made about the most significant elements found in ores in this area of practice, but no minimum requirements have been established for the percentages of iron, silica, alumina, calcium, and magnesium in commercial iron ores. In raw iron ores, the most significant components have a generalized content of greater than 65%. High-grade ore with a gangue content of less than 5%, or 62%–64%, has a Fe content.

Medium-grade iron ore contains 5%–7% gangue, while low-grade iron ore with less than 57% Fe content has more than 12% gangue content and contains hazardous elements ranging from 0.04% to 0.065% phosphorus (Kotta et al (2018)).

4.1.2. Petrography

Petrographic investigation on selected representative rock sample have been conducted in to understand the mineral types, association, texture, deformation, alteration and Metamorphism.(Solomon Rebso, 2013).

At the Geological Survey of Ethiopia Central Laboratory, One thin section and one polished section was created for examination under a microscope.

4.1.3. Thin Section

At Geological survey of Ethiopia central laboratory one thin section was done for analysis and description indicates that the ore were dark gray in color and fine to coarse grained in texture. From the laboratory analysis mineral composition of the ore were plagioclase, hornblende, Opaque, and Biotite. Their compositions were kept in the table below.

Table 4: petrographic analysis result for thin section

Mineral	Modal (%)	Texture
Plagioclase	62	Anhedral
Hornblende	30	Anhedral
Opaque	5	Anhedral
Biotite	3	Flaky

From the analysis results above in the table 3, the texture of the ore was granular and ground mass mainly composed of 62% plagioclase, 30% hornblende, 5% Opaque, and and 3% biotite. The the rock was Diorite. The analysis also revealed that they were composed primarily of anhedral textures.

The predominant phase in this unit is hornblende minerals, which have grains that range in size from 1.5 to 4.5mm. Inside the hornblende, opaque grains can be found as a xenoblast or occasionally arranged beside. This unit's hornblende and plagioclase grains exhibit schistose alignment along a particular direction of deformation as a result of the intrusion's shearing against the nearby Precambrian gneiss. (Solomon Rebso, 2013).

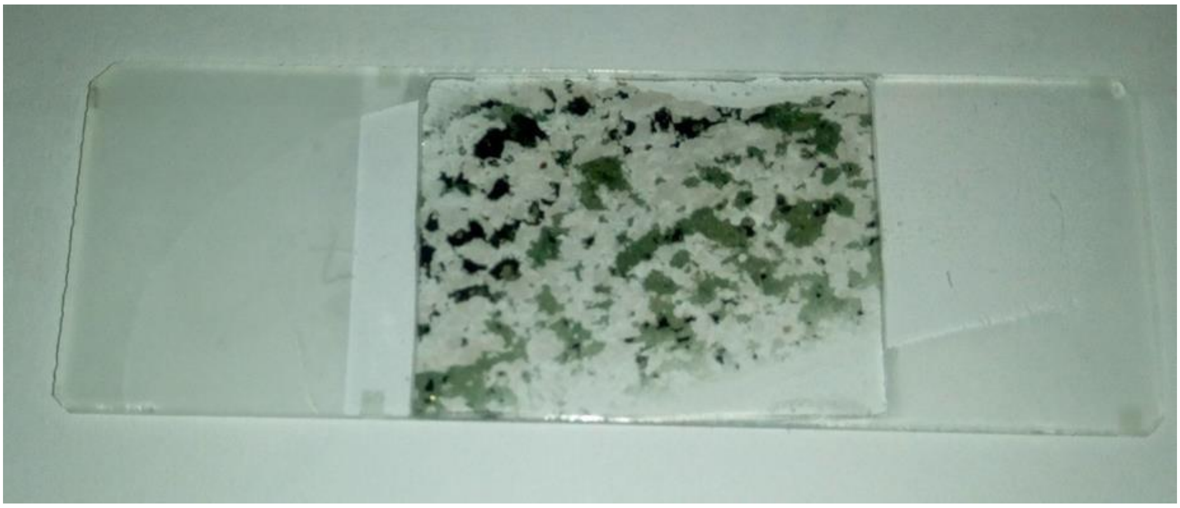


Figure 5: Microphotograph of Thin Section

4.1.4. Polished Section

From the Laboratory result done at Ethiopian Geological survey Laboratory, the Mineral compositions of the ore was Pyrite, Ilmenite, Magnetite and Chalcopyrite with Xenoblastic texture and gangue**.**

Table 5: Petrographic analysis for polished section

Mineral	**Modal (%)**	**Texture**
Pyrite	10	Xenoblastic
Ilmenite	15	Xenoblastic
Gangue	54	-
Magnetite	20	Xenoblatic
Chalcopyrite	1	Xenoblastic

According to investigations on the microscopic structure of the ore by polish section analysis, the average composition of the ore mineral assemblages is 15% ilmenite, 20% magnetite, 10% Pyrite, 54% Gangue and 1%bChalcopyrite.

Magnetite, ilmenite, pyrite, and chalcopyrite were clearly visible over the gangue minerals and the texture of the rock was Xenoblastic.

Figure 6: The Microphotograph of the Polish section

4.1.5. Chemical Composition of the Bikilal Iron Ore

According to Report done in 1990 by Ethiopian institute of geological survey on subsurface exploration and Reserve calculation of Bikilal iron ore Deposit (Zewdneh Tassew,1990) and final report on phase 1 of the Bikilal iron ore project (Debebe Tafesse,1995) the following result extracted and used as table below:

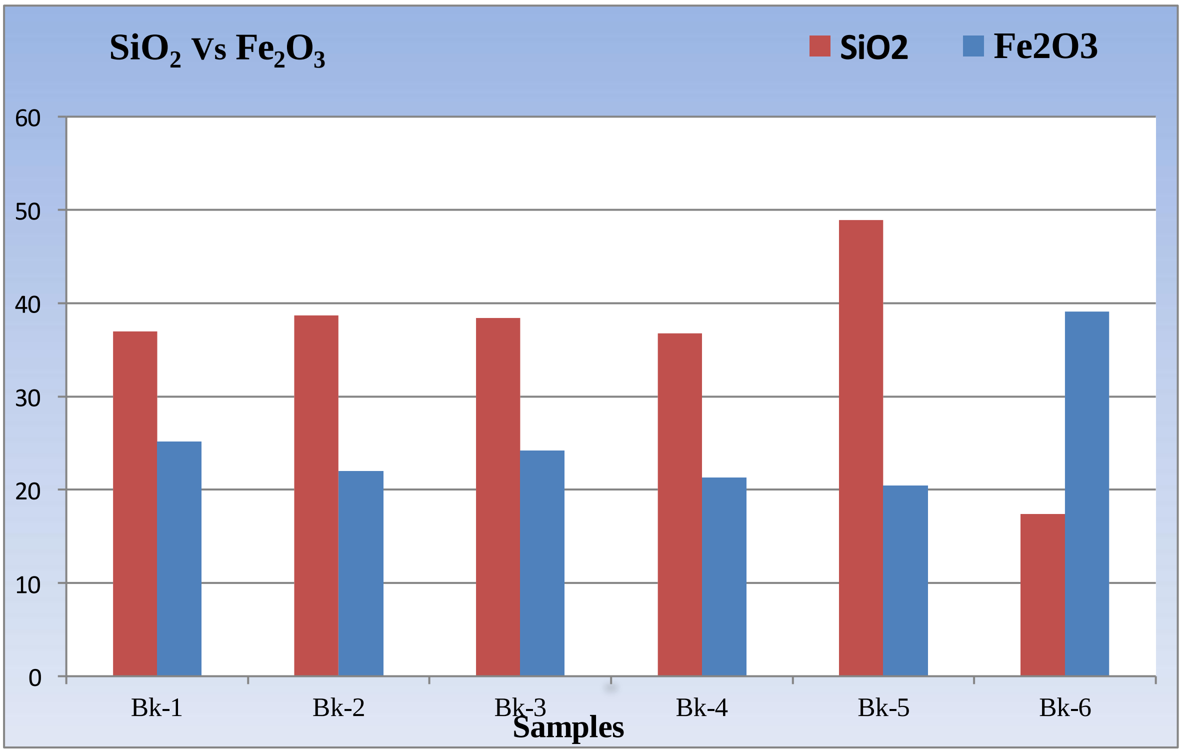
Table 6: The extracted laboratory report results of AAS Analysis (Zewdneh Tassew, 1990 and (Dr.Debebe Tafesse, 1995)

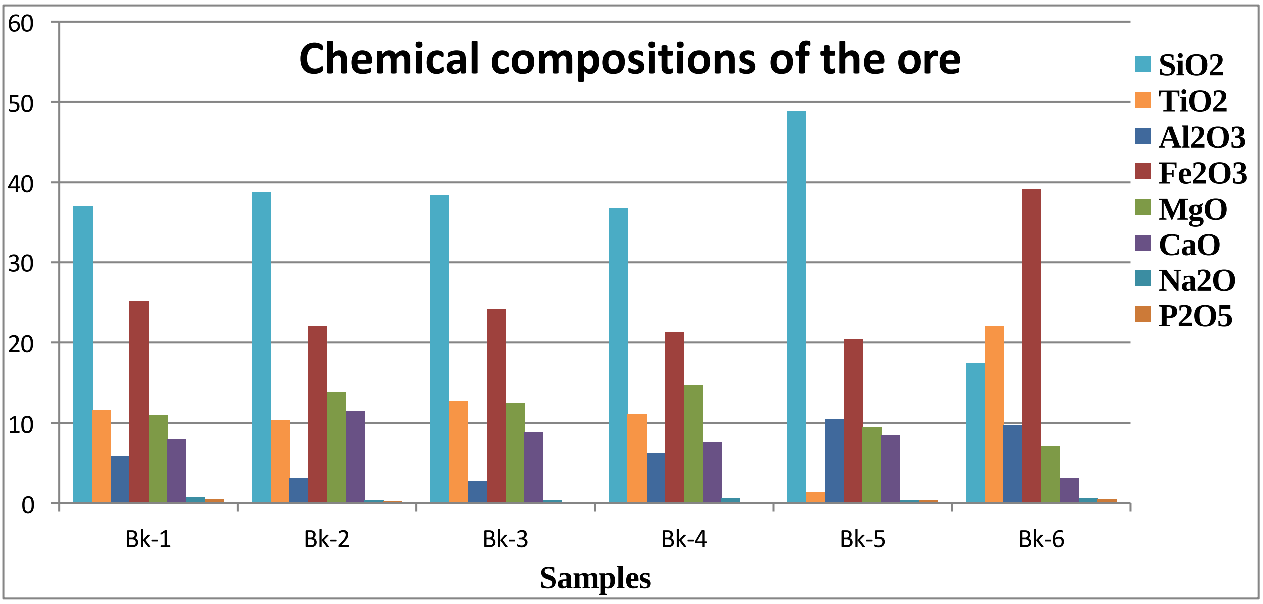
CHEMICAL COMPOSITIONS (MASS %)									
Sample	**SiO_2**	**TiO_2**	**Al_2O_3**	**Fe_2O_3**	**Fe**	**MgO**	**CaO**	**Na_2O**	**P_2O_5**
Bk-1	47	0.8	17.2	7.84	17.58	9.5	7.98	2.4	0.57
Bk-2	47	2.0	15.2	17.37	15.38	8.5	11.45	2.3	0.23
Bk-3	48.3	0.9	16.3	5.18	16.92	8.5	10.5	2.5	0.11
Bk-4	47.5	0.7	17.6	7.83	14.91	7.1	11.5	1.9	0.15
Bk-5	50	0.5	16.9	12.11	14.29	9.5	11.8	2.2	0.31
Bk-6	51.5	0.2	19.3	6.5	27.34	9.0	10	2.8	0.48
Average%	**48.55**	**0.85**	**17.08**	**9.47**	**17.76**	**8.68**	**10.53**	**2.35**	**0.308**
Min.	**47**	**0.2**	**15.2**	**5.18**	**14.29**	**7.1**	**7.98**	**1.9**	**0.11**
Max	**51.5**	**2.0**	**19.3**	**17.37**	**27.34**	**9.5**	**11.8**	**2.8**	**0.57**

According to the atomic absorption spectrometry or AAS results above in the table 2, the average chemical composition of the Bikilal iron ore were 48.55%SiO_2, 0.85% TiO_2, 17.08%Al_2O_3, 9.47%Fe_2O_3, 8.68%MgO, 10.53%CaO, 2.35%Na_2O, and 0.308%P_2O_5.

Even this single gangue mineral i.e SiO_2 ranges from **47**% to 51.5% by mass and the iron mineral, Fe_2O_3, ranges from 5.18% to 17.37% by mass in the iron ore.

The major Gangue Minerals Vs the Iron Oxide





According to the chemical composition study, silicate, ilmenite, and alumina make up the majority of the gangue minerals in iron ore, with a minor quantity of phosphorus—apatite—a harmful element. In general, the Bikilal iron ore has higher gangue contents than the iron ore itself when all the different kinds of gangues combine to form the low-grade ore. Other impurities found in the ore include MgO, CaO, Na2O, K2O, and TiO2, albeit in smaller amounts.

4.1.6. Elemental Analysis of Bikilal Iron Ores

Since there is no facility to do X-ray flouresence (XRF) analysis in our country these days, the results of X-ray flouresence analysis of Bikilal iron ore from 7 samples was taken from secondary data by extracting from (Tesfa Lemu, 2013).

Table 7: Elemental Analysis of Bikilal Iron Ore (Tesfa Lemu, 2013)

	SiO_2	**TiO_2**	**Al_2O_3**	**Fe_2O_3**	**MnO**	**MgO**	**CaO**	**Na_2O**	**K_2O**	**P_2O_5**
Bk-1	47.66	0.7	16.79	9.73	0.14	9.59	12.5	2.22	0.06	0.21
Bk-2	46.07	2.07	18.55	12.94	0.14	6.03	10.11	3.25	0.17	0.13
Bk-3	47.23	0.87	16.35	10.68	0.15	10.3	11.95	2.26	0.05	0.21
Bk-4	48.2	0.38	17.65	8.25	0.12	10.09	12.96	2.1	0.04	0.31
Bk-5	47.68	0.38	17.54	8.74	0.12	10.54	12.7	1.89	0.04	0.41
Bk-6	45.74	1.36	16.34	12.14	0.16	9.61	11.56	2.25	0.09	0.52
Bk-7	52.99	0.65	19.43	5.09	0.11	3.92	12.49	3.7	0.19	0.27
Average	**47.94**	**0.91**	**17.52**	**9.65**	**0.13**	**8.58**	**12.03**	**2.52**	**0.09**	**0.312**

The average composition of the Bikilal iron ore were 47.94% SiO_2, 0.91%TiO_2, 17.52%Al_2O, 9.65%Fe_2O_3, 0.13%MnO, 8.58%MgO, 12.03%CaO, 2,52%Na_2O, 0.09%K_2O, and 0.022%P_2O_5.

The gangue minerals present in the ore SiO_2 and Al_2O_3 were 47.94% and 17.52% respectively and indicate the high gangue content of the ore more than half of the ore composition and with low Fe_2O_3 content 9.65% and low deleterious component P_2O_5.

4.1.7. Mineralogical Analysis of Bikilal Iron Ore

The phases that iron and other mineral phases—particularly silicas—presented were shown, and the XRD technique was utilized to quantify each phase. The typical results of X-ray diffraction analysis of the Bikilal iron ore samples are shown in Figures: 4, 5, and 6 respectively.

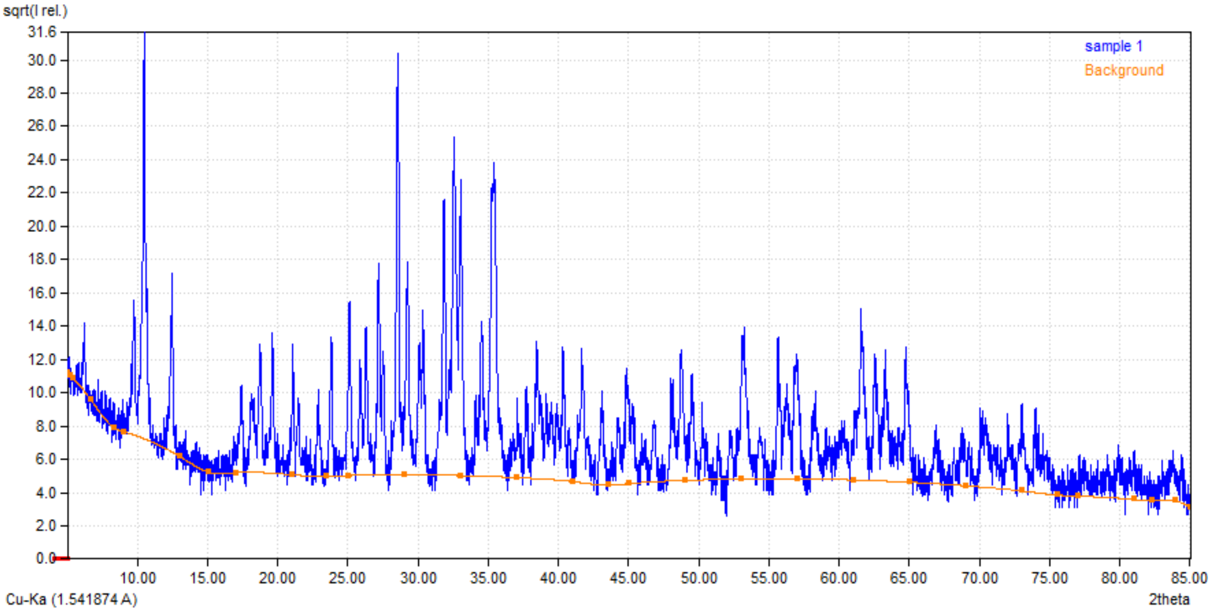


Figure 7: Sample 1 results of X-ray diffraction analysis of the Bikilal iron ore

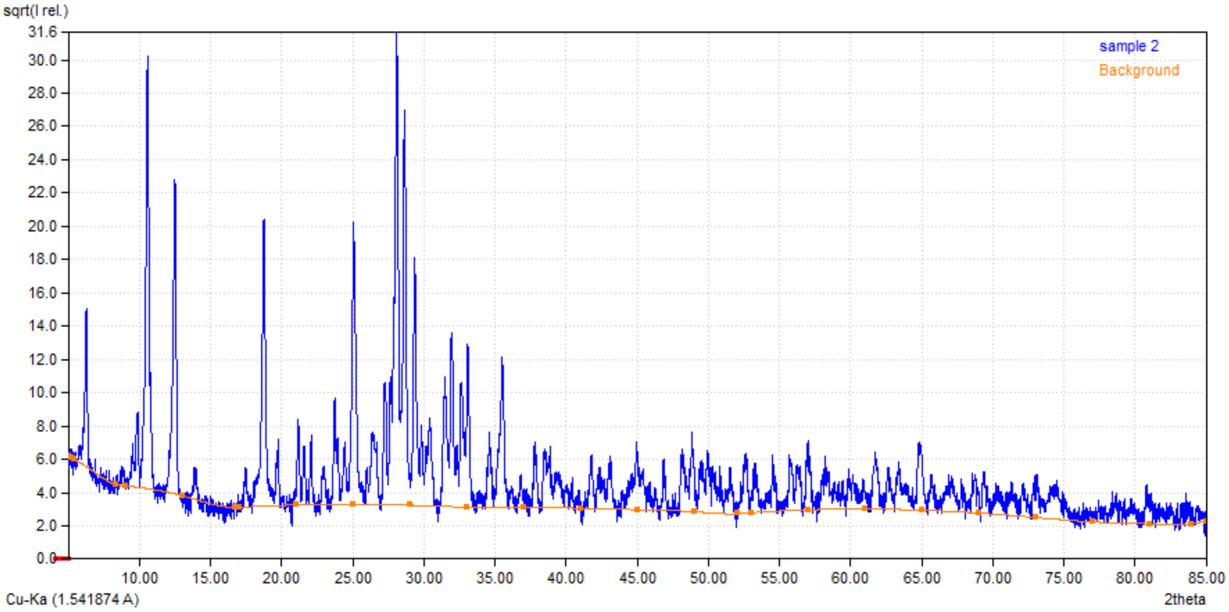


Figure 10: Sample 2 results of X-ray diffraction analysis of the Bikilal iron ore

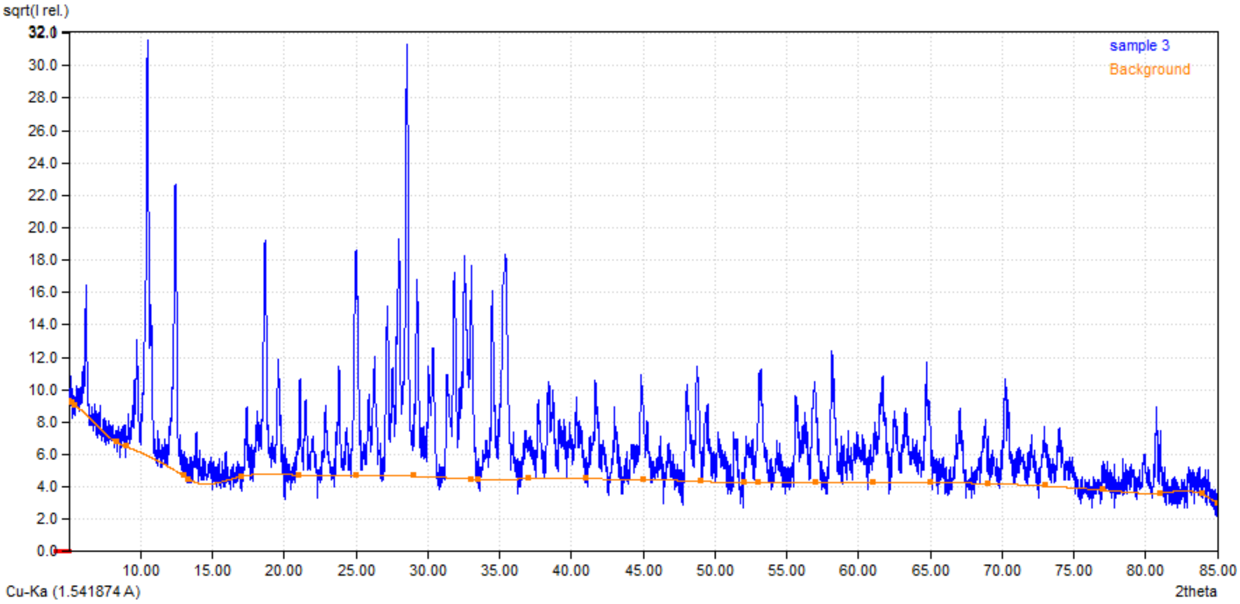


Figure 11: Sample 3 results of X-ray diffraction analysis of the Bikilal iron ore

From the X-ray diffraction analysis, the Phases and elemental composition was identified (by using match software) and the following results were analyzed from the spectrum. The phases were Hornblende, Biotite, Actinolite, Titanomagnetite, and amphibole with 52.2%, 1.2%, 27.8%, 6.3%, and 12.6% respectively.

The elemental composition were O, Si, Fe, Ca, Mg, Al, K, Ti and others with negligible amounts (F, V) , with 41.5%, 19.9%, 11%, 5.5%, 5.3%, 4.8%, 4.4%, 1.1%, 6.0% respectively.

4.2. Discussions

In raw iron ores, the most significant components have a generalized content of greater than 65%. High-grade ore with a gangue content of less than 5%, or 62%–64%, has a Fe content. Medium-grade iron ore contains 5%–7% gangue, while low-grade iron ore with less than 57% Fe content has more than 12% gangue content and contains hazardous elements ranging from 0.04% to 0.065% phosphorus (Kotta et al (2018)).

From petrological analysis, the Bikilal layered complex consists of hornblende, Plagioclase, opaque minerals includes ilmenite, magnetite, and apatite (Solomon Rebso, 2013).

Plagioclase and hornblende exhibit a relict to granoblastic texture, with accessory ilmenite, apatite, and chlorite.The examination shows that the hornblende gabbro is Composed of 45- 55% hornblende, 6-10% (opaque) ilmenite + magnetite + sulphides, 20-25% plagioclase, 3- 6% apatite, and 3-4 sphene with a dominant subhedral – anhedral texture. There are documented coarser and finer variations of the unit; the grain size is typically medium, ranging from 3 to 4 mm on average. It is made up of uncommon apatite grains, plagioclase, hornblende, varying proportions of ilmenite and sulphides, and leucocratic to melanocratic variants. Given that the unit is the outermost one, numerous diorite, migmatite, and amphibolite inclusions as well as microgranite and pegmatite vein dikes are visible., with 50–70% plagioclase, 25–40% hornblende, and 5–10% opaque minerals (magnetite + ilmenite). (Tesfa Lemu, 2013).

From Polished section, minerals like magnetite, ilmenite, hematite, sulphides, apatite, and gold can be found in the Bikilal iron ore deposit. Ilmenite and magnetite are the main ore minerals that come from the ore. Ilmenite is the second most common iron ore mineral found in the Bikilal iron ore deposit. The two most widespread sulfide phases are pyrite and chalcopyrite, which can be found as tiny inclusions in silicates or as composite grains that have mostly fractured and changed to goethite. Both magnetite and ilmenite frequently undergo hematization and meritization in this ore deposit. Calcite, sphene, rutile, and goethite are minor gangue minerals, whereas quartz, K-feldspar, biotite, and chlorite are the primary gangue minerals (Solomon Rebso, 2013).

According to the chemical composition (AAS) , SiO2, TiO2, and Al2O3 make up the majority of the gangue minerals in iron ore, with an unacceptably high concentration of the harmful element phosphorus. One explanation for the indication of a decrement in the amount of the key mineral in the ore (Fe2O3) is the relatively high silica content of the Bikilal iron ore, even when compared to the iron mineral hematite in the above table (Table 4).Even this single gangue mineral i.e SiO_2 ranges from **47**% to 51.5% by mass and the iron mineral, Fe_2O_3, ranges from 5.18% to 17.37% by mass in the iron ore. Therefore, the amount of the gangue is very high that exceeds the amount of the important mineral present in the ore.

In general, the Bikilal iron ore has higher gangue contents than the iron ore itself when all the different kinds of gangues combine to form the low-grade ore. Other impurities found in the ore include MgO, CaO, Na2O, K2O, and TiO2, albeit in smaller amounts. The commercial ore should contain fewer than 6% and 4% of silica and alumina, respectively. (Joan J. Kiptarus et al) but the Bikilal iron ore SiO_2 and Al_2O_3 average content are 48.55% and 17.08% respectively, that is very big difference in respect to gangue contents. Alumina is a particular target during the beneficiation of iron ore and is a representation of pollution in the steel-making process. Most iron ores that are exported worldwide have a total iron concentration of between 62 and 64%. As a result, the Bikilal iron ore deposit's average quality of iron ores is below the needed requirement, which is less than 40%, and is not comparable to the top iron ore nations, leading to the low-grade ores. Additionally from XRF results the gangue minerals present in the ore SiO_2 and Al_2O_3 were 47.94% and 17.52% respectively and indicate the high gangue content of the ore more than half of the ore composition and with low Fe_2O_3 content 9.65% and 0.312% deleterious component P_2O_5.

Finally, the XRD results indicate that the Si and O_2 content of the ore is high exceed the Fe present. The rock forming elements also low in their respective amount and not comparable with gangue minerals amount and therefore the iron content of the ore is less and if the ore have to be processed the amount of deposits present will be very high to further processing by investing or the other options have to be implemented like if other additional commodity available to process in parallel with iron ore. The Phosphorus content of the ore not indicated in the composition this may be the phosphorus present is the form of amorphous and therefore not displayed composition analysis.

CHAPTER FIVE

5. CONCLUSION AND RECOMMENDATIONS

5.1. Conclusions

Bikilal iron ore, a high-phosphorus iron ore, has been characterized using a variety of analysis techniques in an attempt to unravel the presentation and distribution of phosphorus in the iron ore (between the iron-rich phase and the gangue mineral(s) which will be very useful in planning effective beneficiation and phosphorus removal strategies). From the results of this study, the presence of phosphorus is confirmed, its concentration in the sample studied is determined to be 0.3-0.57 wt% P, and its spatial distribution in the ore is demonstrated to be in both the iron-rich phase and the gangue minerals. However, the actual presentation of phosphorus in the ore could not be determined as the XRD results did not show the presence of any phosphorus containing crystalline phases (minerals). This might be indicative of the plausible presence of phosphorus in Bikilal iron ore as an amorphous phase, and/or as interstitials in the iron oxide/hydroxide structure, and probably also in the structure of the aluminosilicates of the gangue mineral(s).The contents of the gangue minerals in the ore also very high Specially SiO_2 and Al_2O_3. The high aluminum content iron ore is considered as inferior quality ore. It is well known that from different literature as Aluminum content of ore increased more than 3% the melting point and Viscosity of the slag increased and put burden on blast furnace and therefore drop the yield of the furnace. Consequently, knowing the Separation Mechanism Al-Fe is the essential step in successful usage of the ore. And then because of its low iron grade and high impurities content the compositions of the ore have the negative effect during the processing and have to be removed and/ or to be minimized to boost the quality of the iron ore.

From different literatures the average grade of iron ore for large deposits has to be more than 25%Fe. For small deposits even have to be more than25%. The Average grade of Bikilal iron ore is less than this and also the deposits reserve estimation is not mineable as large-scale industry and can process by small scale.

According to Samuel Getaneh, 2023 (Reverse flotation potential of Bikilal Iron ore Deposit) three samples each were taken for 75micron and 63micron to investigate the Optimum Liberation size and then the average grade of iron were 60.2% for 75micron and 62.2% for 63micron. This indicates that less than 63micron is better to obtain good result.

5.2. Recommendations

A conceptual mine planning should be done in order to assess the investment choices, operating costs and also the costs of the whole operation for mining of iron and doing market study on the TiO_2 slag as one target for production that could boost the attraction of the of investment on the deposits/reserves that is necessary to collect sufficient knowledge of the possibility of selling produced product and their long term prices. In order to improve the economy of the product it is important to mobilize all valuable minerals at the Bikilal iron ore as different production options. Apatite should be additional options to regard as integrated part of Bikilal deposits and testing the possibility of producing saleable apatite concentrate.

The companies or individuals who have willing to do on Bikilal iron ore have to do economic feasibility thoroughly which consider the current economic condition of the country. In doing so the real and actual data have be used by studying as a new than using the old data and informations to get the real result that lead the companies or individuals to the correct direction that save them from loss or lead them to prosperity.

On other way complex utilization of the resource is recommendable because different companies and researchers did their study on this commodity and confirmed that different precious and useful metals presence like gold, vanadium, titanium and even aluminium in the ore that have to be studied thoroughly their viability, economically and technologically.

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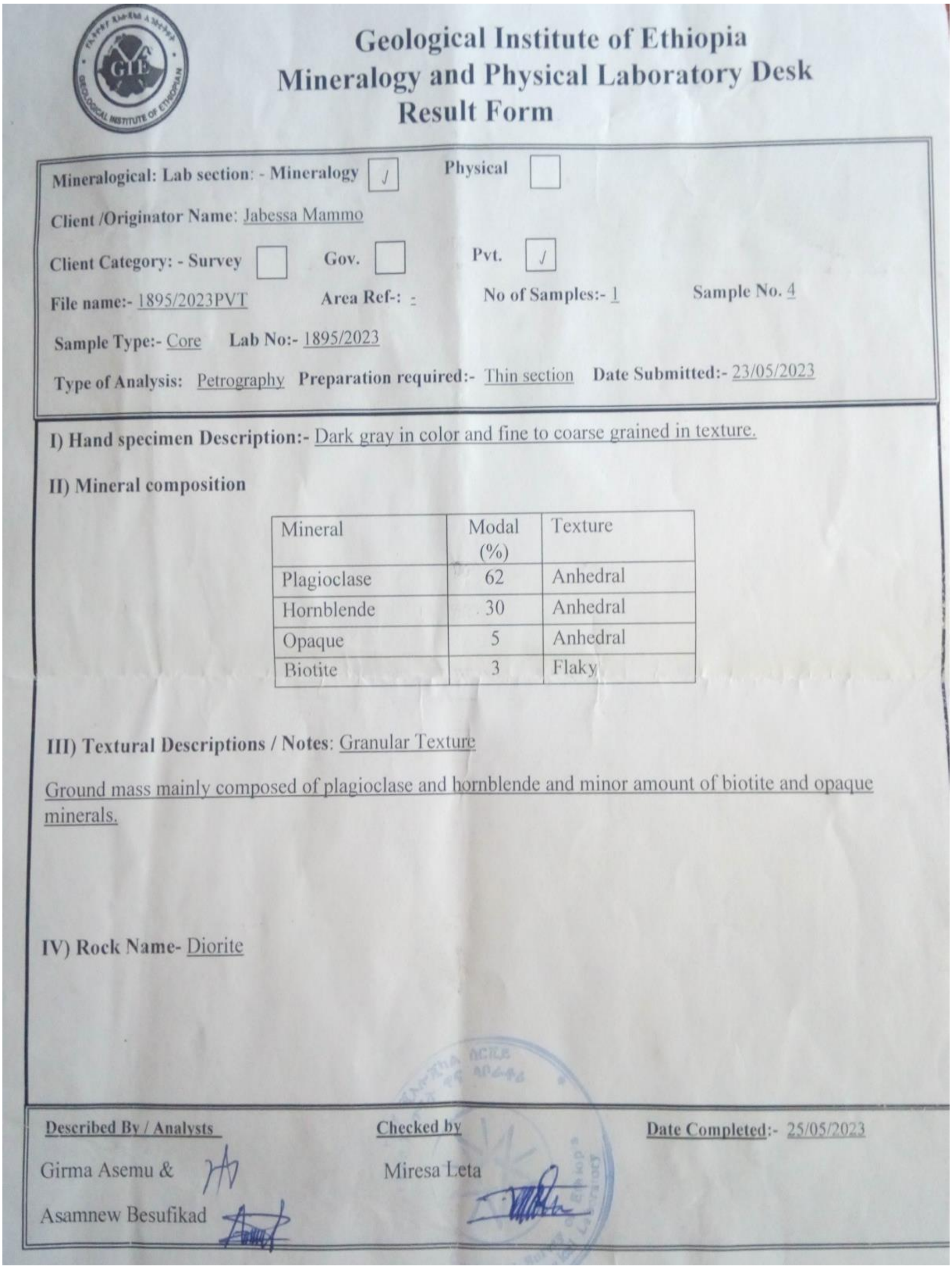
APPENDICES

Appendix I



Geological Institute of Ethiopia
Mineralogy and Physical Laboratory Desk
Result Form

Mineralogical: Lab section: - Mineralogy ☑ **Physical** ☐

Client /Originator Name: Jabessa Mammo

Client Category: - Survey ☐ **Gov.** ☐ **Pvt.** ☑

File name:- 1895/2023PVT **Area Ref-:** - **No of Samples:-** 1 **Sample No.** 4

Sample Type:- Core **Lab No:-** 1895/2023

Type of Analysis: Petrography **Preparation required:-** Thin section **Date Submitted:-** 23/05/2023

I) Hand specimen Description:- Dark gray in color and fine to coarse grained in texture.

II) Mineral composition

Mineral	Modal (%)	Texture
Plagioclase	62	Anhedral
Hornblende	30	Anhedral
Opaque	5	Anhedral
Biotite	3	Flaky

III) Textural Descriptions / Notes: Granular Texture

Ground mass mainly composed of plagioclase and hornblende and minor amount of biotite and opaque minerals.

IV) Rock Name- Diorite

Described By / Analysts

Girma Asemu &

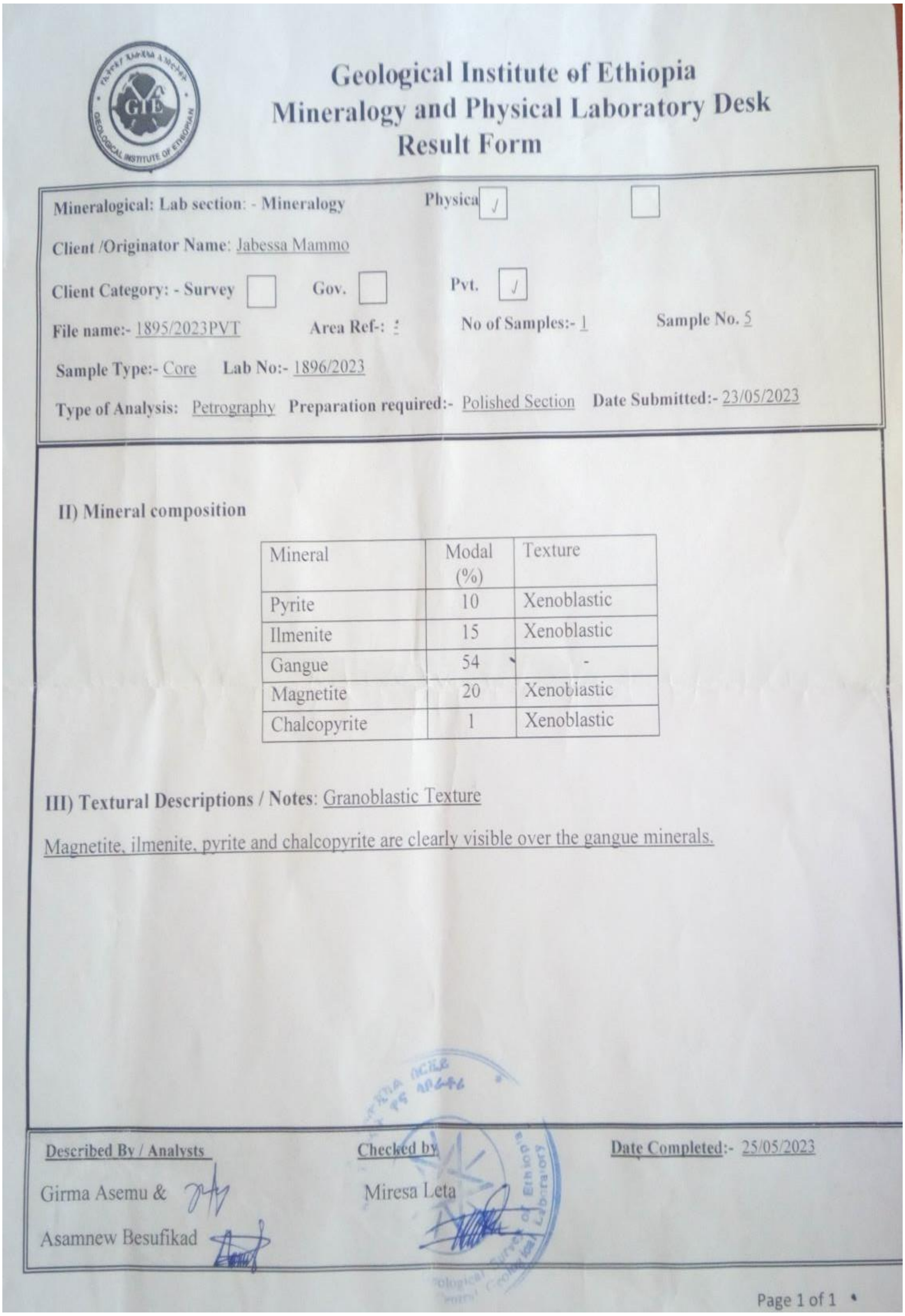
Asamnew Besufikad

Checked by

Miresa Leta

Date Completed:- 25/05/2023

Appendix II



Geological Institute of Ethiopia
Mineralogy and Physical Laboratory Desk
Result Form

Mineralogical: Lab section: - **Mineralogy** **Physica** ☑ ☐

Client /Originator Name: Jabessa Mammo

Client Category: - Survey ☐ **Gov.** ☐ **Pvt.** ☑

File name:- 1895/2023PVT **Area Ref-:** - **No of Samples:-** 1 **Sample No.** 5

Sample Type:- Core **Lab No:-** 1896/2023

Type of Analysis: Petrography **Preparation required:-** Polished Section **Date Submitted:-** 23/05/2023

II) Mineral composition

Mineral	Modal (%)	Texture
Pyrite	10	Xenoblastic
Ilmenite	15	Xenoblastic
Gangue	54	-
Magnetite	20	Xenoblastic
Chalcopyrite	1	Xenoblastic

III) Textural Descriptions / Notes: Granoblastic Texture

Magnetite, ilmenite, pyrite and chalcopyrite are clearly visible over the gangue minerals.

Described By / Analysts	Checked by	Date Completed:- 25/05/2023
Girma Asemu & Asamnew Besufikad	Miresa Leta	

Page 1 of 1