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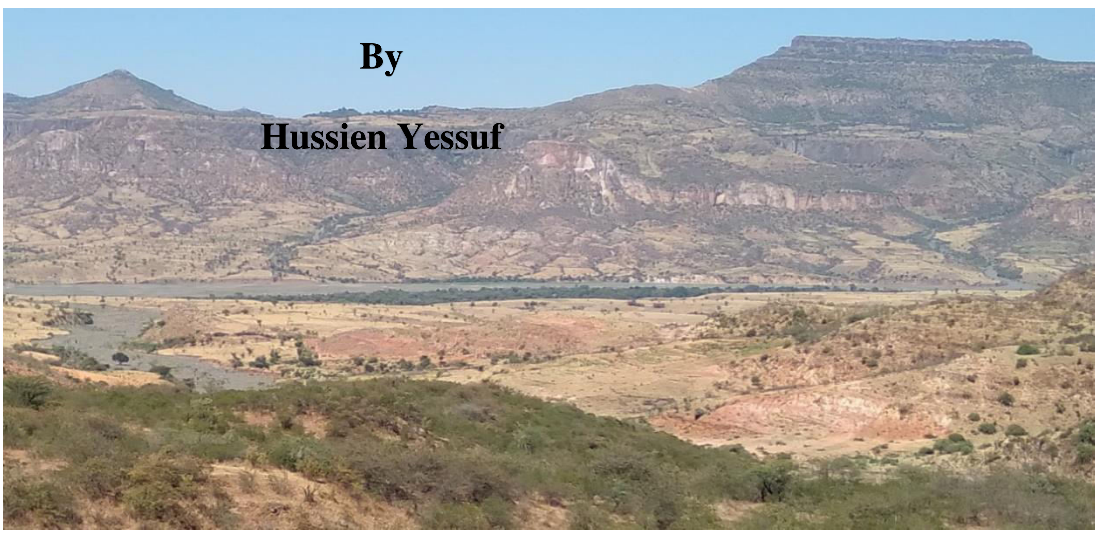
Addis Ababa University

School Of Earth Sciences

GEOLOGY, PHYSICOCHEMICAL CHARACTERIZATION AND POSSIBLE INDUSTRIAL APPLICATION OF TEGORA SILICA SAND OCCURRENCE IN THE ABAY BASIN, CENTRAL ETHIOPIA.



By

Hussien Yessuf

A thesis submitted to the School of Earth Sciences, Addis Ababa University in partial fulfillment of the requirements for the degree of Master of Sciences in Resource Geology (Mineral Deposits).

June, 2023

Addis Ababa, Ethiopia

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Advisor: Worash Getaneh (Prof.)

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APPROVAL PAGE

This is to certify that the research set by Hussien Yessuf, entitled "Geology, physicochemical characterizations, and possible industrial use of Tegora silica sand occurrence in the Abay basin, Central Ethiopia" is conducted under the supervision of Professor Worash G. and submitted in partial fulfillment of the requirements for the degree of Master of Science in Resource Geology (mineral deposits) prepared with the University's rules and regulations and it fulfills accepted requirements in terms of quality and originality.

Approved by the examining committee:

Prof. Worash Getaneh	________________	________________
Head, School of Earth Science	Signature	Date
Prof. Worash Getaneh	________________	________________
Advisor	Signature	Date
Dr. Balemwal Atnafu	________________	________________
Examiner	Signature	Date
Prof. Gezahegn Yirgu	________________	________________
Examiner	Signature	Date

DECLARATION OF ORIGINALITY

I hereby declare that this thesis work about geology, physicochemical characterizations, and possible industrial use of Tegora silica sand occurrence, which is my original degree of Master of Science under the supervision of Professor Worash G., School of Earth Sciences, and Addis Ababa University. I also declare that this study has not been presented or submitted to any other university or institution for the award of any degree or diploma. Almost all sources and materials used for the thesis have been properly referenced and acknowledged.

Hussien Yessuf (MSc candidate) ________________________ ________________

Signature Date

This is to witness that the above thesis declaration made by the candidate is correct to the best of my knowledge.

Prof. Worash Getaneh (advisor) ________________________ ________________

Signature Date

ABSTRACT

Silica sand is the second most dominant mineral in the earth's crust and the most often used technical term for sand or sandstone that easily disintegrates and contains a substantial amount of silicic acid (quartz grains). The Tegora silica sand occurrence is situated in the upper parts of the Abay basin, central Ethiopia, about 229 and 180 kilometers north of Addis Ababa and Debre Berhan respectively. Geologically, the deposit area is composed of Mesozoic age clastic to marine sedimentary successions that are unconformably overlain by thick Cenozoic volcanic rocks, such as limestone, mudstone, basalt, and sandstone in which silica sand is hosted. The main goal of the research is to investigate the geology, physicochemical characteristics, and possible industrial use of Tegora silica sand occurrence. To conduct this, field observation, and analytical investigation activities were applied. The Tegora industrial sand resource is dominantly found as light grey to white, poorly-consolidated sand layers interspersed with siltstone and conglomeratic beds, as the onsite investigation shows. Findings from the sieve analyses, the investigated quartz sand resource is described by the majority of sand-size grains (avg. 96.40%) with lesser amounts of gravel (avg.1.247%) and mud (avg.2.367%) size particles. The dominant sand grains reveal an angular to sub-angular and less spherical shape. Complete silicate analysis reveals that silicon dioxide (SiO2) forms the abundant metal oxide in the entire samples with an average quantity of 92.25%, followed by (Al_2O_3=6.45%), (Fe_2O_3 =0.63%), (K_2O=0.3%), (TiO_2= 0.17%), (Na_2O= 0.11%), (P_2O_5= 0.08%), (MgO=0.05%), and trace amounts of CaO, MnO, and Cr_2O_3. The mineralogical analyses on silica sand with the XRD method implied that quartz, kaolinite, feldspar, and tridymite show the most diffraction picks, and quartz (SiO2), which revealed a high phase average percentage proportion of above 80%, is the major crystalline component of the Tegora silica sand samples. Resource estimation and classification explained researched area has about 4.22 billion tons of quartz sand deposit in an indicated resource class. Based on Ethiopia's present yearly industrial sand consumption (84.5 million tons), it can continuously extract for 50 years. Geological and physicochemical characteristics analysis shows that the silica sand resource from the Tegora area can be used for filter media, abrasive, foundry, and cement industries. Furthermore, with the beneficiation of the deposit, the upgrade silica sand is utilized for high-grade glass and ceramic sectors.

Key Words: Industrial applications, Physicochemical characteristics, Silica sand, Tegora

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LIST OF ACRONYMS

AAS	Atomic Absorption Spectrometry
ACS	American Ceramic Society
ASTU	Adama Science and Technology University
a.s.l	Above Mean Sea level
CIM	Canadian Institute of Mining,
CSAE	Central Statistical Agency of Ethiopia
BS	British Standard
DEM	Digital Elevation Model
DLS	Debre Libanos Sandstone
FDRE MoM	Federal Democratic Republic of Ethiopia Ministry of Mines
GIS	Geographic Information System
GSE	Geological Survey of Ethiopia
IBM	Indian Bureau of Mines
IMR	Industrial Minerals and Rocks
IS	Indian Standard
LOI	Loss On Ignition
UTM	Universal Transfer Mercator
NW	North West
SE	South East
SEM	Scanning Electron Microscopy
XRD	X-ray Diffractometer
UNE	United Nations and Environment Programme

CHAPTER ONE

INTRODUCTION

1.1 Background of the study

Quartz sand is the most common technical term for easily disintegrating sand or sandstone with a very high content of silicic acid (quartz grains). It is found in sedimentary rocks, igneous and metamorphic rocks (Ketner, 1973; Bourne, 1994). Quartz sand may also be originated d from sandstones, quartzite, and poorly consolidated sand deposits (Press, 2001; Tsoar, 2004; Wilkinson, 2005). The silica, SiO_2, exists in different forms such as quartz (crystalline); chalcedony, agate, flint, and jasper (cryptocrystalline) and opal (hydrated form); sandstone (sedimentary deposit composed of small grains of quartz); quartzite (metamorphosed sandstone) and quartz sand (fragmented sandstone or quartzite enriched with silica). The composition of quartz sand varies greatly depending on rock sources and geological conditions. It is usually mined by surface mining (open pit) methods (Presse, 2001; Wilkinson, 2005). The extracted sand undergoes an intensive treatment to improve the silica content by reducing impurities. It is then dried and sorted to obtain the desired particle size distribution for the intended use (Langer, 2003; Dolley, 2004a). Industrial sand is the most versatile of non-metallic minerals. This is due to its wide distribution around the world, its specific physical properties such as durability, hardness, chemical resistance, strength, and heat, as well as its low unit price and high place value. Silica sand applications are depend on its physicochemical properties. It is mainly used as an essential raw material in glass, foundry, construction, ceramics, dyeing, chemical, and other industries (Shaffer, 2006; Edem et al., 2014; Platias et al., 2014). The occurrence of quartz sand resources in Ethiopia is widespread, from Precambrian basement rocks to Paleozoic and Mesozoic sedimentary formations and in various locations. For example, significant silica sand resources are found in the Abay basin (Muger Canyon, Jemma-Wonchit-Jara valleys, etc.) and Mekele basin (Jelene,1964;Assefa,1991b; Tadesse et al., 2003; Tadesse, 2009); Mohammedyasin and Wudie, 2019;Tessema,2012). Although the deposit is large, its production is relatively inadequate. One of the main factors is the lack of detailed data on the mining industry's contribution or the economically insufficient exploration of industrial sand deposit. Likewise, this area is not well studied and published in the form of scientific papers in terms of physicochemical properties and suitability for possible areas of industrial use of the raw material. Therefore, the objective of this research is to characterize the technological properties of silica sand resources through sampling, geological mapping at a scale of 1:15000, and laboratory analysis. Based on the results of laboratory analyses and geological field studies, the industrial character of the occurrence of quartz sand in this region was developed and its possible industrial applications were demonstrated.

1.2 Geographic settings of the study area

1.2.1 Location and accessibility

The proposed area is found in Central Ethiopia, Amhara National Regional State, North Shewa zone, Mida Woremo Woreda (Meranya), and around Tegora Kebele. A large amount of clastic to marine sedimentary successions that are unconformably overlaid by thick Cenozoic volcanic rock and overlie the mudstone unit defines the research area's geology. Geographically, it is bounded between 1124000 to 1132000 N latitude and 496000 to 507000 E longitudes in the Universal Transverse Mercator (UTM) (Fig.1.1). The study area covers around 88 km^2.

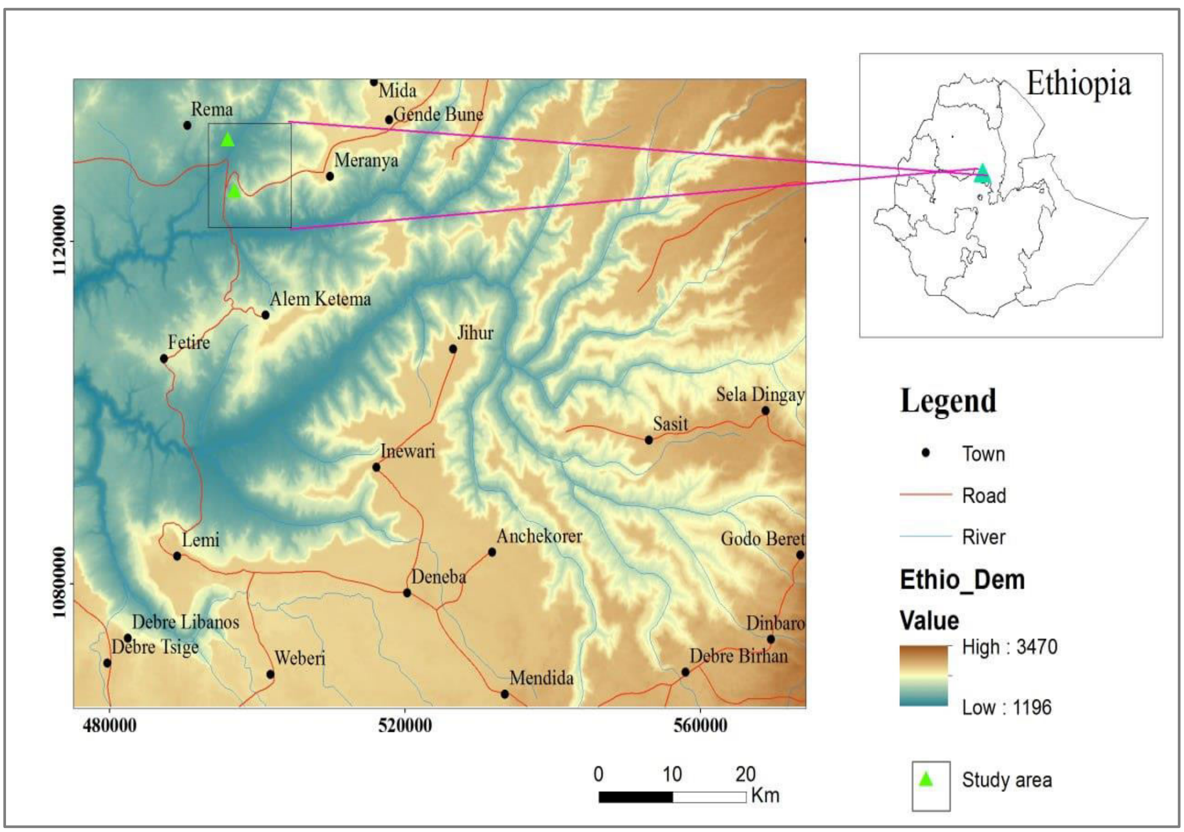


Figure 1.1: Location map of the study area

The project area can be accessed through an 85 Km asphalt road from Addis Ababa to Mukature and a 144 Km gravel road from Mukature to Meranya. Alternatively, the area can also be addressed through a 130 km asphalt road from Addis Ababa to Debre Berhan and a 180 Km gravel road from Debre Berhan to Merayna.

1.2.2 Physiography and drainage

As implied in the location map, the research area is set of the central Ethiopian highlands that are manifested by the canyon and river cuts by south to southwest and northwest flowing streams. The physiographic condition of the study area and its surrounding is defined by different topographic features of continental plateaus of flood lava flows, mountainous shield volcanoes, canyons, and the escarpment of the cliffs. These geographically useful physiographic features of the area are the results of episodically and deeply cutting of the Mesozoic sedimentary siliciclastic sediments and carbonate successions. The common physiographic attribute of the study area are indicated from the Digital Elevation Model (DEM) physiographic map below (Fig.1.2).

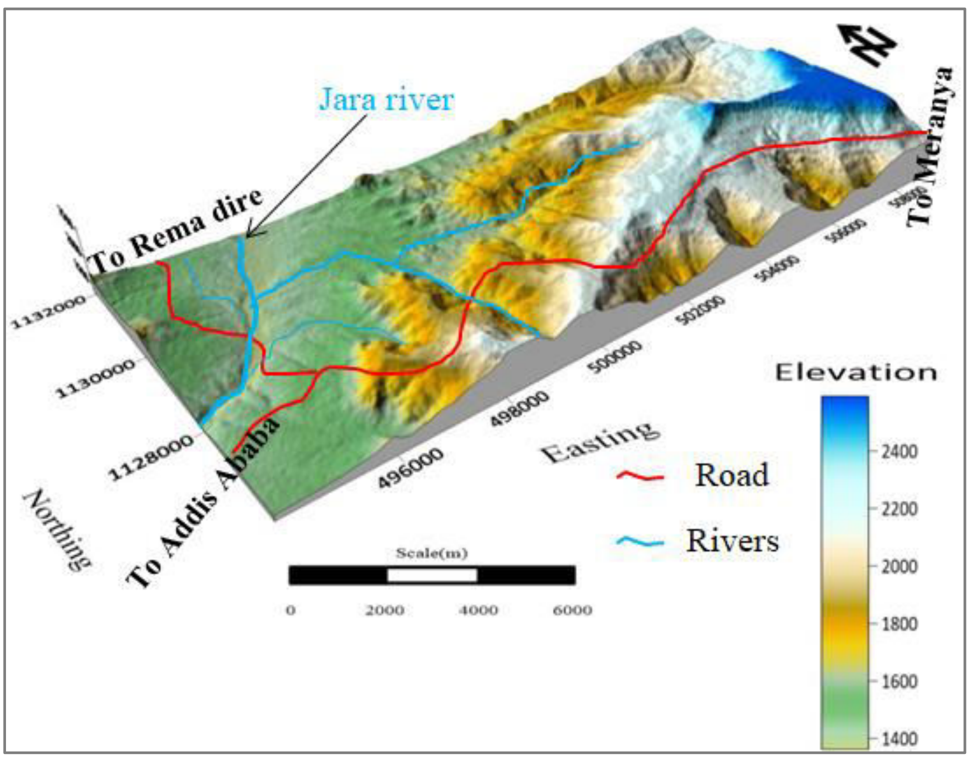


Figure 1.2: DEM physiographic map of the study area.

The drainage systems of the area are a dendritic pattern and flow towards the northwest and southwest direction from the plateaus and ridges to the lower elevated areas (Fig.1.3). The structures and topographic landforms are affect the flow orientation and distribution of the drainage patterns of the area. Most of the streams in the project area are represented by sediment accumulations in their channels as longitudinal and point bar bodies. According to the information obtained from the onsite observation and the local communities, these streams are intermittent.

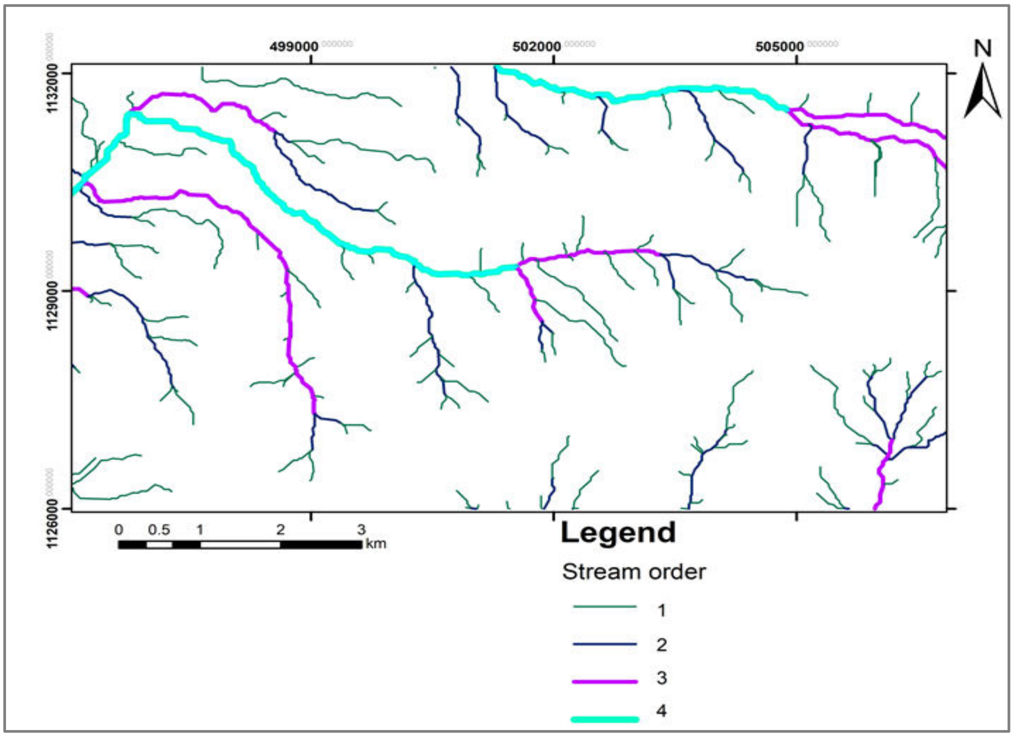


Figure 1.3: Drainage pattern of the study area

1.2.3 Climate

The climate in Mida Woremo Woreda is warm and temperate. This location is classified as subtropical highland oceanic climate (Cwb) by Köppen and Geiger (Kottek et al., 2006). It is dry and windy from September to June. The highest rainfall is during the summertime, while the winters have very little rainfall. In December, the least amount of rain falls. This month's average is 2 mm. The month of August receives the most precipitation; averaging 276 mm. May typically has the hottest weather, with an average temperature of 23.4 °C. The coldest month is August, with average highs of 18.1°C (Fig.1.4).

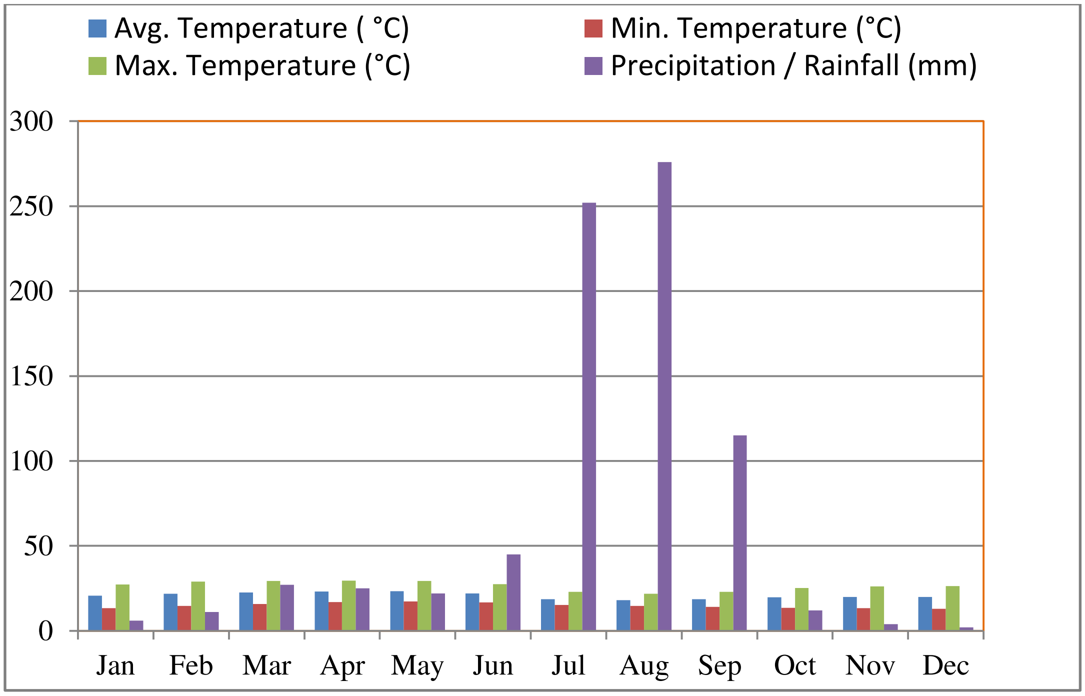


Figure1. 4: Weather and climate conditions of the study and surrounding area

1.2.4 Vegetation distribution

The vegetation distribution of the area is controlled by structures and topographic landscapes as well as localized streams. They are densely vegetated on flatlands surrounding stream channels whereas they are relatively distributed sparsely on sloppy landforms and places far from drainage courses in the study area. The main common plants found in the study area are Dedeho, Bissana, Bahirzaf, Warka, Kitkita, Tilem, Embis, Kinchib, Geba, Agam, and Warka by their local name. Additionally, fruits, grass, and crops are among the main vegetation of the area (Fig.1.5).

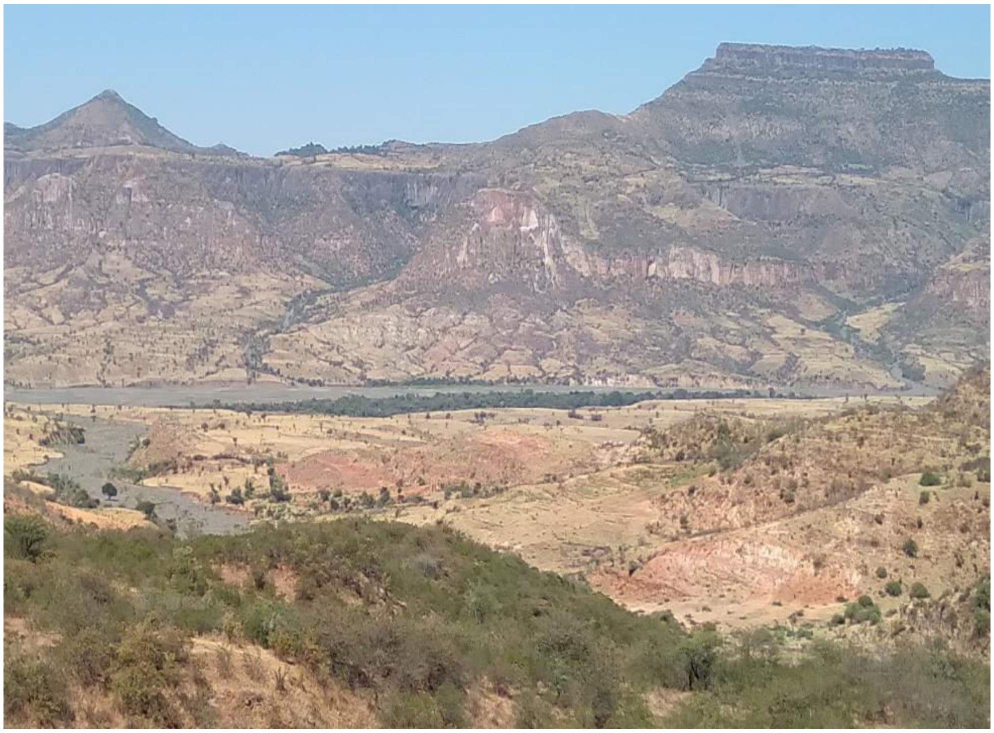


Figure 1.5: Panoramic view showing vegetation coverage and topography in central and northwestern part of the study area

1.2.5 Population and settlement

The Central Statistical Agency of Ethiopia (CSAE), which compiles national census statistics (2007), estimates that the Mida Woremo woreda has an entire population of 93,729, of which 47,074 are males and 46,655 are women. 92.48% of this population lives in rural areas, compared to 7.52% who live in urban areas. Despite occupying an area of 836.81 square kilometers, Mida Woremo has a population density of 112.01, which is lower than the area's average of 115.3 persons per square kilometer. The Amhara was the biggest recorded ethnic group in the area (99.79%), and 99.8% spoke Amharic as their mother tongue. 11.51 people identified as Muslims, while 88.41 people claimed to be Ethiopian Orthodox Christians, making up the bulk of the population. The inhabitants of the area are densely populated in the town and surrounding rural villages. Places apart from these are settling sparsely and they are used as farming fields. Agriculture (cereal crops such as Teff, wheat, maize, sorghum, chickpea, and animal herding), shopping, and other business activities are the primary economic sector of the place.

1.3 Statement of the problem

According to the United Nations and the Department of Economic and Social Affairs (2019), the world population exceeds 7.884 billion and has been growing ever since. Around 54% of the world's population currently lives in cities, which is expected to rise to 66% by 2050 (UNDESA, 2014). Governments, companies, and other organizations will be under pressure to change the way they approach urban development as a consequence of both the ongoing global population expansion and the accelerating rate of urbanization. Due to the widespread usage of a commodity in the industry, there is a very high consumption for industrial mineral resources. For instance, concrete is the most frequently used material in the construction industry (Crow, J.M., 2008), and the demand for sand is rising as a result. To produce one ton of cement, about six to seven tons of sand and gravel are needed (United Nations and Environment Programme (UNEP), 2014). Sand demand is exploding.

According to the United States Geological Survey (USGS) minerals yearbook (2018), approximately 335 million metric tons (Mt) of industrial sand and gravel were produced globally in 2018, which is a 5% increase over 2017. The developed and civilized world industry uses silica sand resources as a leading raw material. The demand for silica sand is increasing globally due to urbanization and the growth of companies that use it (Shaffer, 2006; Rafi et al., 2018). Similarly to this, Ethiopia's demand for silica sand is gradually rising as a result of the nation's urbanization and human development. Currently, it is utilized in the production of glass, glass fiber, silicon carbide, sodium silicate, Portland cement, silicon alloys, and metals, as well as filter media for water treatment, paint, hydraulic fracturing, foundry, abrasives, chemicals, sandblasting, and a variety of other products used across the country. Ethiopia has been importing silica sand and processed products due to the country's limited supply of the mineral (Mengistu and Fentawu, 2003; FDRE MoM, 2011). The absence of specific data on the mining industry's contribution to the country's economic growth, particularly the local silica sand resource, is one of the key causes of this.

In addition, the silica sand potential of the study area is not well known and has not been studied so far. This makes constraints to understanding the detailed technological properties of the resource and its suitability for various industrial applications. In order to reduce this gap and minimize the country’s expenditure, integrated studies that conduct properties of the silica sand deposit could be conducted.

The present study is designed to determine the geological, geophysical, and geochemical characterization of silica sand occurrence, around the Tegora area, in central Ethiopia and to achieve their suitability for the possible industrial applications.

1.4 Objectives of the study

1.4.1 General objective

The main objective of this research work is to attain the geology, physicochemical characteristics, and possible industrial use of Tegora silica sand occurrence from Abay basin, Central Ethiopia.

1.4.2 Specific objectives

The following points are specific objectives of this research work:

- ✓ Sketch geological map and cross-section of the deposit at a scale of 1:15,000.
- ✓ Physicochemical characterization of Tegora silica sand deposit.
- ✓ Assess possible industrial application of Tegora silica sand deposit.

1.5 Research Questions

The main research questions in this study are:

1. What are the study area's physicochemical characteristics of silica sand deposits?
2. What are the possible industrial applications of Tegora silica sand?
3. What is the class of Tegora silica sand resource depending on the level of geological confidence?

1.6 Research methods and materials

In order to conduct the above objectives of this study, different types of technical works and materials were conducted. It includes field observation and analytical investigation activities. Geological, geophysical, and geochemical laboratory analyses are the main research methods applied for this research work.

1.6.1 Field study and geological mapping

The field work activity was conducted in January 2023. This part of the method is also termed as an on-site investigation under which the surface geology of the study area was studied and the representative samples were collected for laboratory analysis. During the field work the following activities were conducted.

- Detail observations, descriptions, and measurements of the geological unit/s along traverse lines.
- Fresh and representative sampling for physical tests, geochemical and mineralogical analysis were collected.
- Lithological variations in color, texture, and mineral composition, degree of weathering, fabric, and sedimentary structures were described.
- Geological mapping and cross-section at a scale of 1:15,000 were prepared.

The geological map of a region at a scale of 1:15,000 was created by transferring the lithological units identified to the base map. The geological cross-section of the research area was made using elevation data that was recorded during the field survey at the contacts of the lithological units. The area covered by the quartz sand deposit is shown on the geological map. On the other side, the geological cross-section offers a rough estimate of the deposit's thickness.

These data are used as inputs to calculate the silica sand deposit's tonnage. According to the variation in color, texture, and spacing, representative quartz sand samples with a mass of more than 1.5 kg each were taken from more exposed layers of sandstone units. After that, the samples were put in plastic bags with codes for shipping to the laboratory for preparation and evaluation.

1.6.2 Laboratory work

This method explains straightforward test procedures to establish industrial requirements and outlines the physicochemical characteristics of silica sand. The fieldwork is over, and the samples that were gathered are submitted to the laboratory for different tests. These analyses' main goal is to gather crucial data for the quantitative and qualitative assessment of the Tegora industrial sand deposit. These different analyzes include physical tests (grain size distribution, grain shape, and bulk density), geochemical analysis (major element concentration), and mineralogical analysis (relative mineralogical proportions).

1.6.2.1 Physical property test

The purpose of this test is to determine whether Tegora silica sand is appropriate for various industrial uses. Grain size, grain morphology, and bulk density are all put to the test. In this instance, 10 representative silica sand samples are chosen and delivered to the soil laboratory at Addis Ababa University (AAU) for grain size analysis. The ASTU soil and central laboratories examined the results of the grain shape tests on 5 chosen samples. In contrast, the central laboratory in Geological survey of Ethiopia examined the bulk density of two chosen Tegora silica sand samples.

a) Grain size test

Grain size distribution is one of the common textural properties of quartz sand, which determines its suitability for various industries. The sieve analysis technique was used. The percentages by weight of the sample retained on each sieve are measured after the particles are passed through a set of screens with progressively smaller mesh sizes. The percentage of the sample by weight is finer than that size.

In the current project, this analysis was performed at the Addis Ababa University (AAU) soil laboratory to demonstrate the grain size distribution, predominant size range and manner of grading of quartz sand samples collected from the study area. A dry sieve method was used to perform the analysis. Initially, 10 selected samples were coned and quartered separately to obtain a homogeneous and representative fraction. The quartered samples were then dried in an oven for 24 hours at a temperature of 105°C using 0.5 kilograms of each sample. After drying, the weight of each sample was measured and placed in a set of stacked sieves having aperture diameters of 4.75, 2, 0.6, 0.425, 0.3, 0.106 and 0.075 mm, respectively. The sieves were shaken for 15-20 minutes and computed percentages of particle size retention for each sample on each sieve (Sundararajan et al., 2009; Freestone, 2005). This data is processed to determine the grain size distribution, mean size (D50), inclusive graphical standard deviation (σi), coefficient of uniformity (Cu) and coefficient of curvature (Cc) values of the Tegora silica sand resource.

b) Grain morphology analysis

Grain shape analysis was used in the current work to identify the morphologies of the sand grains that compose the Tegora silica sand resource. This aids in determining the deposit's appropriateness for various industrial field of applications. The Scanning Electron Microscope (SEM) method was used to visualize the morphology of the silica sand particles' surfaces.

Five representative samples were prepared at Geological Survey of Ethiopia in Addis Ababa in order to conduct the analysis. There were three main stages to the preparation. First, grains from samples TSS-08, TSS-09, TSS-10, TSS-12, and TSS-17 that were passed on sieve 63 microns were obtained. They were then given a light wash to get rid of any adhesive dirt that would have concealed the grain surface characteristics. The samples were finally dried in an oven for 24 hours.

The prepared samples were sent to the Adama Science and Technology University (ASTU), soil and central laboratories found in Adama to visualize the sphericity and roundness of silica sand particles.

c) Bulk density test

Assessing the bulk density of silica sand samples is used as an input parameter for determining the tonnage of silica sand deposits located in the study area. The test is conducted on two samples at Geological Survey of Ethiopia in Addis Ababa. The immersion in water method was used to determine the test. By weighing a sample of unconsolidated or friable sediment in the air and then weighing the same sample suspended in water, and later apply the formula: Bulk density $= (\text{weight in the air})/(\text{weight in air} - \text{weight in water})$, this technique was used to determine the bulk density of the deposit under a controlled of procedures.

1.6.2.2 Geochemical analysis

In order to identify anomalous geochemical properties related to industrial fields of utilization, geochemistry entails measuring the chemistry of silica sand. The geochemical analysis is uniquely useful for confirming the sample's acceptability for various industries. To ascertain the deposit's suitability for various industrial sectors of uses, one of the primary aims of this investigation is to characterize the geochemistry of Tegora silica sand deposit.

For the current project work a total of twelve (12) representative silica sand samples were sent to the central geochemical laboratory in Geological Survey of Ethiopia for complete silicate analysis. The samples were prepared with 200 mesh (75 microns) to produce a suitable particle size. The complete silicate analysis of the collected representative samples was analyzed by LIBO2 fusion, HF attack, and Gravimetric, Colorimetric, and Atomic Absorption Spectroscopy

(AAS) methods. The detection limit and accuracy are crucial first criteria. As a result, the detection limit and accuracy values for the whole silicate analysis were set at 0.01% and ±1.5%, respectively.

50g of each sample was carefully measured using an analytical balance after being put into a clean crucible. To calculate the loss on ignition of Tegora silica sand, the weighted samples were then placed in an electric furnace and fired for one hour at 950°C (Edem, 2014).

1.6.2.3 Mineralogical analysis

Determining the mineralogical properties of the silica sand deposit in the research area is one of the main methods of the present study. These mineralogical characteristics, especially quantitative information of the minerals found in silica sand samples are determined by X-ray Diffractometer (XRD). It offers details on the sample's phase composition via qualitative and quantitative phase analyses as well as crystal structural analyses.

To conduct this, six representative silica sand samples collected during fieldwork were submitted to the mineralogical laboratory center of Geological Survey of Ethiopia for preparation. To conduct the preparation, three main phases are adopted. At the start, 6 selected representative samples were dried. Then after, 200gm of each sample is ground in a mortar. Lastly, it is permitted to pass through a filter measuring 63 microns in size until the necessary quantity of powdered silica sand is obtained. Before and after grinding and sifting individual samples, the precaution was always present throughout preparation by cleaning all the tools (mortar and sieve).

The powdered samples were sent to the Adama Science and Technology University (ASTU), Department of Materials Science and Engineering (MSE), mineralogical laboratory found in Adama to quantify and qualify the minerals present in the silica samples and the relative proportion of each mineral in the deposit.

1.6.3 Documentation, interpretation and presentation

In order to determine the technological properties of the silica sand samples collected from the research area and investigate the appropriateness of the deposit for significant industrial uses, the interpretation process began by assessing the data acquired using the aforementioned methodologies. Conclusions and suggestions concerning the silica sand deposit of the Tegora area are developed on the basis of data analysis and interpretation.

On-site geological data is evaluated in light of the location of the silica sand deposit in the research area. Additionally, this information displays the lithological properties of the unit, such as its thickness and area coverage. Inputs for determining the amount of silica sand deposit in the research region come from field geological data. By comparing laboratory results to well-known worldwide standards, it was possible to understand the physicochemical characteristics of the silica sand deposit and its significance as a natural resource. The acceptability of the deposit for a particular industrial sector is determined by how closely the quality criteria of the collected samples fit international standards. The results of the laboratory also assist in identifying the area's silica sands' suitability for beneficiation and in recommending methods to improve its quality for different industrial applications.

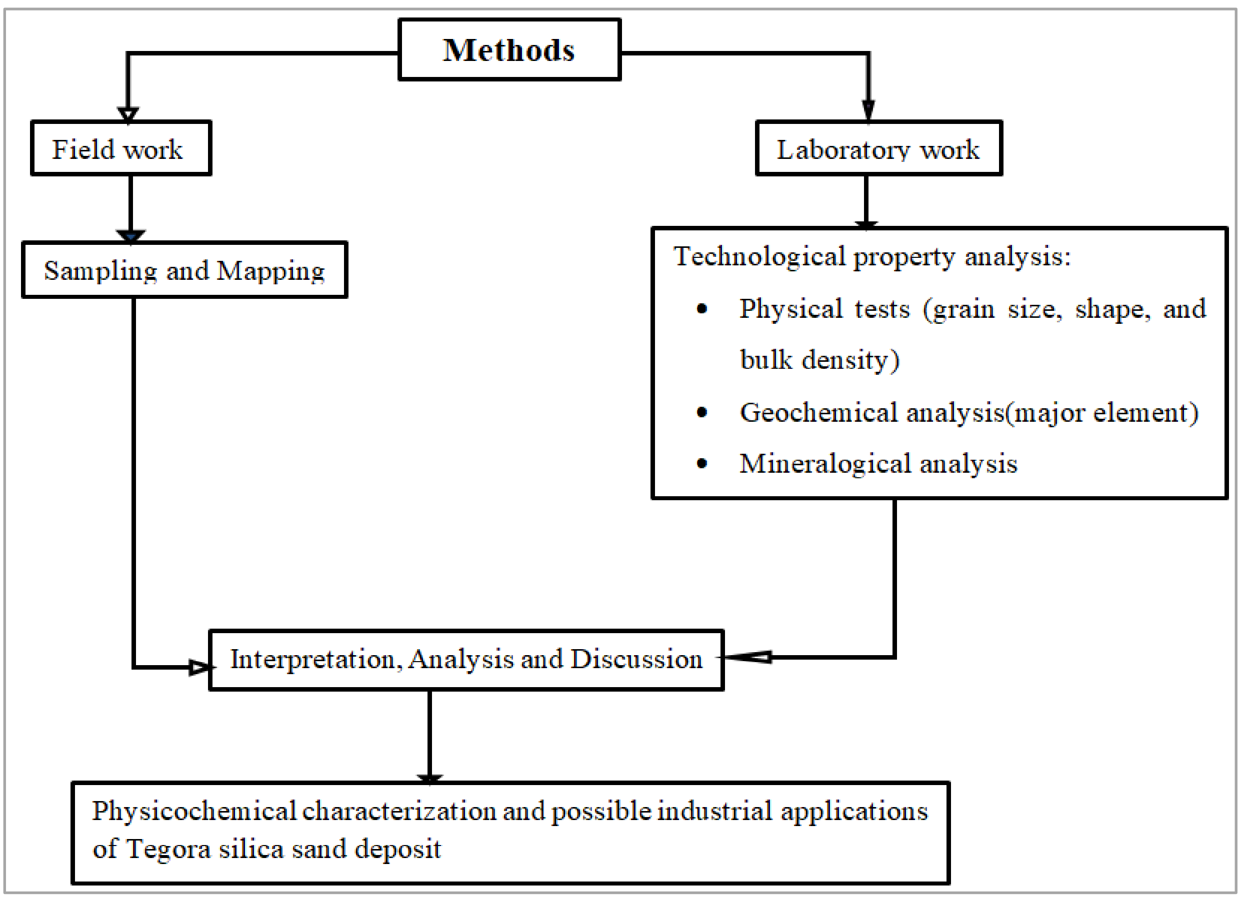


Figure1. 6: General flowchart of methods used in this research

1.7 Outcomes and significance of the study

Tegora Silica sand has not so far been studied with respect to technological characterization and possible industrial applications. Hence, this research work will intend the following outcomes and significances.

The outcomes of the research are:

- Complete delineation of silica sand occurrence of the target area.
- Determination of the geology of silica sand deposit occurrence in the area.
- Demonstration of physicochemical characteristics of the silica sand of the study area.
- Preparation of geological map the area at a scale of 1:15,000.
- Determine the classification of silica sand resources in the area based on the level of geological confidence.

Some of the significances of the research work:

- The Delineation of the quality and possible field of industrial applications of the Tegora silica sand deposit.
- Providing a guide for future scientific society and giving information for the mining companies, government as well as other geo communities, who are working on silica sand exploration and production.
- The researcher will get logical concepts and deep knowledge through reviewing field investigations and data processing.

1.8 Limitations of the study

Due to inadequate budget and limited time which clearly have significant effect on any research work activity; trace element composition analysis was not conducted in this study although it is important components of the study of silica sand characteristics.

1.9 Research overview

The research project for the present study is often divided into several main chapters and notable sub-chapters. The first chapter can include a general framework and details on the background, location, and accessibility of the study area, as well as its physiographic and climatic aspects.

This section of the study includes the main and specific objectives, applicable methodologies, the problem of the research statement, and the importance of the research. The second chapter of this work includes reviews of the literature on the geology and origin of silica sand, the occurrence of silica sand resources in Ethiopia, explorations, mining, processing, applications, and specifications, resource classification and estimation, and economic aspects of the silica sand resource. The regional geology and geodynamic evolution of Blue Nile sedimentary basin as well as volcanic trap of Ethiopia were emphasized in the third chapter. In chapter four, the geological units that define the study area were described and depicted. Following these chapters, chapter five presents the results from field mapping and laboratory analysis. The origin and depositional environment, quality, potential industrial applications, anticipated beneficiation methods and economic considerations of the Tegora silica sand deposit are all thoroughly discussed in chapter six. Finally, chapter seven summarizes the conclusions obtained from the various findings and provides some recommendations.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

According to Heinrich (2001), to a greater extent, "mineral resource" is becoming a household word. More and more, we have become aware of the significance of our mineral resources and some of the troubles relating to wise resource development, management, and use. Earth scientists broadly grouped resources into metallic and nonmetallic (industrial) mineral resources based on their end uses. The former category includes ore deposits that consists economically viable contents of metals whereas the latter one conducts mineral resources used as raw materials in manufacturing industries or consumed as bulk construction materials and dimension stones (Evans, 1993; Marshak, 2004; Christidis, 2011). Based on Evans, 1993; Kogel et al., 2006; Getaneh and Tadesse, 2015, from the two subclasses of mineral resources, industrial minerals, and rocks (IMR) are relatively most abundant and play a crucial role in diverse aspects of industrial applications. IMR are earth materials utilized as bulk because of their technological properties (physical and chemical characteristics) rather than their metal and energy content (Kuzvart 1984; Evans, 1993; Christidis, 2011).

Industrial sands contain a high proportion of silica in the form of quartz and are marketed for purposes other than for direct application in the construction industry. They are important raw materials for glass, foundry, ceramics, chemicals manufacture, water filtration media, sports and horticultural applications(No, 2004). The applications of industrial sand depend on its mineralogy, and technological properties. The chemical, mechanical and physical characteristics of silica sand deposits were studied by many authors for suitability of possible industrial applications in the world (e.g. Khalid, 1993; El-Bokle and Hassanein, 1993; El-Fawal, 1994; Fathi, 2002; Salopek et al., 2004; Madanat et al., 2006; Bayat et al., 2007; Howard, 2008; Sundarajam et al., 2009; Awadh, 2010; Mustafa et al., 2011; Odewale et al., 2013 and Ramadan, 2014). Similarly, in Ethiopia, a number of researchers were conducted on the technological properties of silica sand resources of the country; mainly in the Abay basin (Mugher, Jema, Wenchit,) and Mekelle basins. The Abay basin where the current study area is situated previously studied with respect to various geological and deposit aspects (Assefa, G. 1991 and Wolela, A., 2002; 2009) conducted a detailed description of the sandstone unit as Debre Libanos

Sandstone (DLS) and Mugher mudstone. Debre Libanos Sandstone unit of the area is the main host rock for silica sand occurrence.

2.2 Silica sand occurrence of Ethiopia

According to Tadesse et al. (2003), Ethiopia's industrial mineral and rock resources are extensively dispersed throughout a variety of geological scenarios, including Proterozoic basement rocks, Late Paleozoic to Mesozoic sediments, and Cenozoic volcanic and related sediments. In these geological environments, the nature of occurrence and the origin of the resource vary accordingly. Based on Assefa (1991b), Tadesse (2009), and FDRE MoM (2011), the silica resource of the country is found as quartz veins, quartzite layers, and as a component of pegmatite intrusions of the basement rocks. In the Phanerozoic geological environment, this resource of Ethiopia is found as sand deposits in the well cemented to poorly cemented sandstone units (Jelene, 1964; Kazmin, 1975; Leonid et al., 1989). Cretaceous sandstone occurrence at Muger canyon, Jemma-Wonchit-Jara valleys, and Gelemso- Kulubi areas are well-known resources (Fig2.1). It is the main source of silica in Ethiopia relative to the other occurrences. This silica sand is formed as deposits of quartz sand in the wider braided channels (Assefa, 1991b; Mohammedyasin and Wudie, 2019).

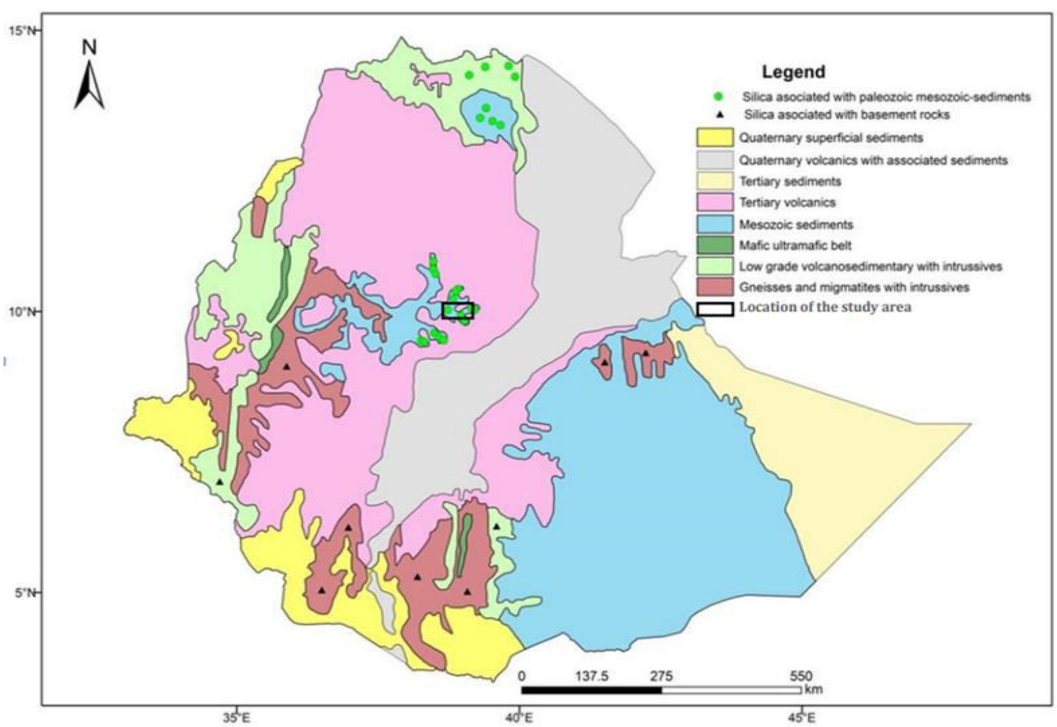


Figure 2.1: Distribution of silica sand resources in Ethiopia (Mengistu and Fentawu, 2003)

2.3 Exploration methods of silica sand deposit

Mineral exploration is a process of finding and demonstrating of new economical deposit in certain place. Rapid rise of silica sand demand in the country and throughout the world facilitate the exploration as well as beneficiation of sand. In order to accomplish sustainable demand and consumption of silica sand resource comprehensive exploration task is needed. For many industrial minerals, particularly those of high place value, the first important to be explored is a market research rather than a deposit (Harris, 1986). Knowing the demand for the potential, its accessibility, and distance to markets, and transportation routes allows a resource supplier to decide the viability of the project for further studies (Kogel et al., 2006). Similarly, silica sand deposits must be easily accessible, located near to the market, and availability of transport facilities to be considered as valuable raw material besides fulfilling physiochemical specifications (Lewis, 2001).

2.4 Mining and processing methods of silica sand

Mining industrial mineral is the extraction of those minerals from the earth. Surface and underground mining are applicable to the mining of industrial minerals. The most common method of mining for industrial minerals mainly for silica sand is quarrying mining methods. The first activity considered in surface mining is removing overburden using different machines and manpower based on the scale of mining. Once the overburden is removed the next step is lifting and transporting the silica sand to the processing site for further processing (GSE, 2021).

Correction of sand composition and gradation is the most critical factors for the suitability of various industrial applications of the silica sand deposit. Edem (2014), argues that while nature separates and purifies silica sand to have the highest concentration of silica, further treatment is required to get sand that is adequately pure for use in industries. Depending on the nature of the raw materials and the sand's intended application, the complexity of silica sand processing varies. Processing aims to improve the sand's physicochemical characteristics to meet user specifications (No, 2004). Sand's potential usage is significantly influenced by how easily contaminants (such as iron-bearing impurities and clay) can be removed as well as the degree of losses incurred in removing the oversize and undersized fractions from the sand (No, 2004). Nowadays, sand processing technology can enhance sand resources that are not naturally pure enough for modern applications. Chemical purity and particle size are the main significant parameters. The major impurities are iron (Fe_2O_3), alumina (Al_2O_3), and titanium dioxide (TiO_2), lime (CaO), soda (Na_2O) and potash (K_2O) (Andrew et al., 1989; Schurlz and Kohl, 1991; Zdunczyk, 1994). These contaminants in the silica sand will decrease its purity. Therefore, raw materials are should be processed to separate minerals that contain impurities (Goldman, 1994). Different processing methods are applied to enhance the purity, whiteness, and other commercial characteristics of the resource (Murray, 1997). The most common processing method of silica sand is washing with water, however, there are other methods like gravity separation to remove heavy minerals, desliming to remove small particles, Sizing to reduce the size, washing to remove undesired materials, especially fines, and Flotation methods can also avoid unacceptable minerals including micas (Kogel et al., 2006; Bulatovich, 2015; Raghavan et al., 2017) (Fig.2.2).

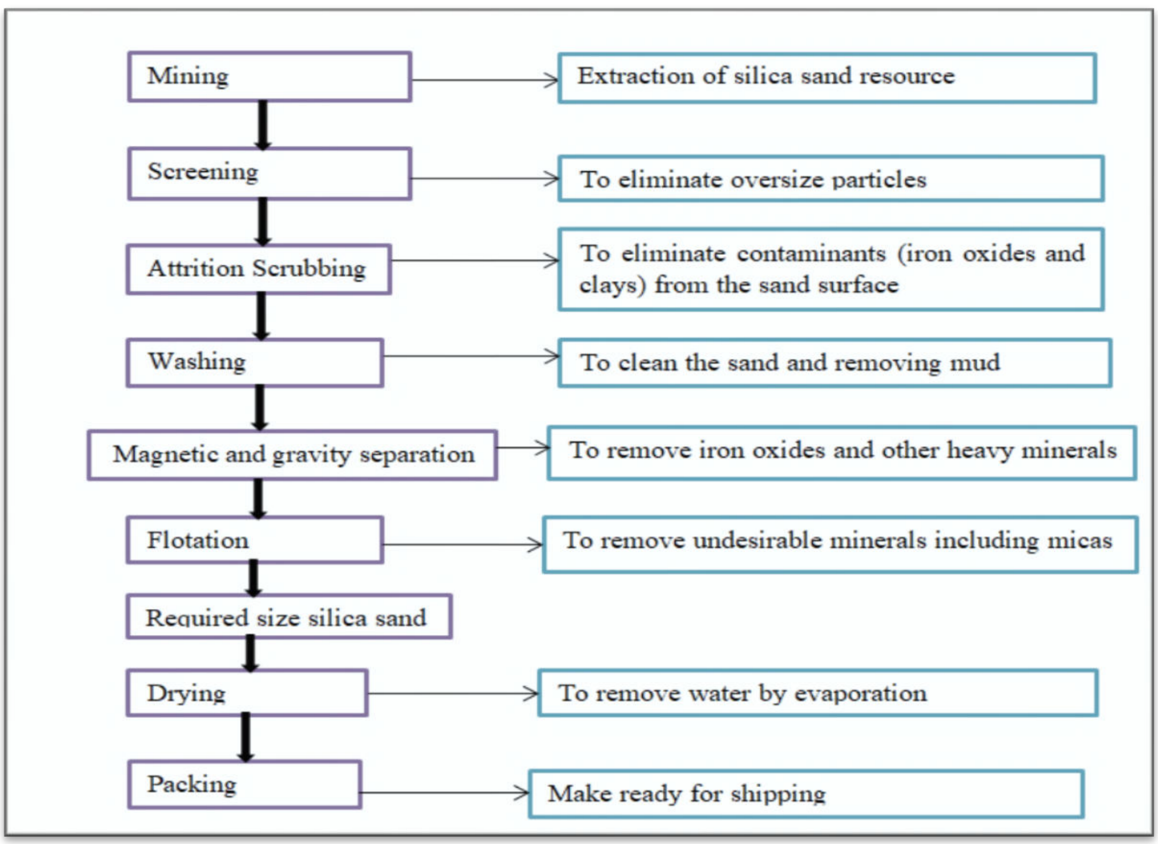


Figure 2.2: Flow chart showing processing steps for silica sand (Kogel et al., 2006).

2.5 Analysis of silica sand

Silica sands are valued depending on their physicochemical properties. These include high quartz content and, more importantly, low amount of deleterious impurities such as clay, iron oxides, and typically a narrow grain-size distribution (0.5 to 0.1 mm). The Common uses of industrial sands have to meet to very nearly defined specifications, and specific applications demand various combinations of characteristics (No, 2004). The suitability of silica sand for possible industrial applications is depending on the evaluation of quartz sand in terms of its technological characteristics (McLaws, 1971; Platias et al., 2014; Ismaiel et al., 2017).

The textures (grain size, grain morphology (roundness and sphericity), and fabric, bulk density, and composition are the main parameters conducted from silica sand to determine its physicochemical properties. The size and morphology are properties of individual silica sand grains; in contrast, the fabric is a characteristic of grain aggregate. Grain size is one of the most critical physical properties of silica sand that characterize its suitability in various industries. It affects the melting condition, permeability, and the mixing nature of the sand (McLaws, 1971; Heinrich, 2001). The distributions of different grain sizes determine the physical parameters of industrial sand. Grain size analysis provides the grain size distribution of the deposit. According to McLaws (1971) silica sand used for glass making should be passed through a 20-mesh sieve (0.83mm) and more than 95% retained on the 1000-mesh sieve. Based on GWP consultants (2010), coarse-grained silica sand deposits are used in a rapid sand filter system to treat drinking water whereas fine-grained silica sand is used in a slow sand filter system to treat used water (wastewater). According to McLaws (1971), grain size distribution also influences the permeability of foundry sand. Uniformly graded silica sand provides paramount permeability for degassing. Based on Indian Standard (1974-1987) high-quality silica sand should have narrow silica sand grading with 70% or more grains that shall retain only on three consecutive sieves. Alternately, a minimum of 95% of silica sand grains should be distributed only on four or five successive screens to give adequate permeability (Brown, 2000).

In terms of particle sphericity and roundness, particle morphology can be described. The general particle shape, or sphericity, is similar to a sphere. The term "roundness" refers to how sharp a particle's corner is (Rodriguez et al., 2013). The surface morphology of sand grains may be carefully examined using scanning electron microscopy (Dowdeswell, 1982). The most promising way for determining grain shape is to visually compare pictures from various microscopic investigations with charts from Krumbein and Sloss (1963) (Fig. 2.3) and Powers (1953) (Fig.2.4).

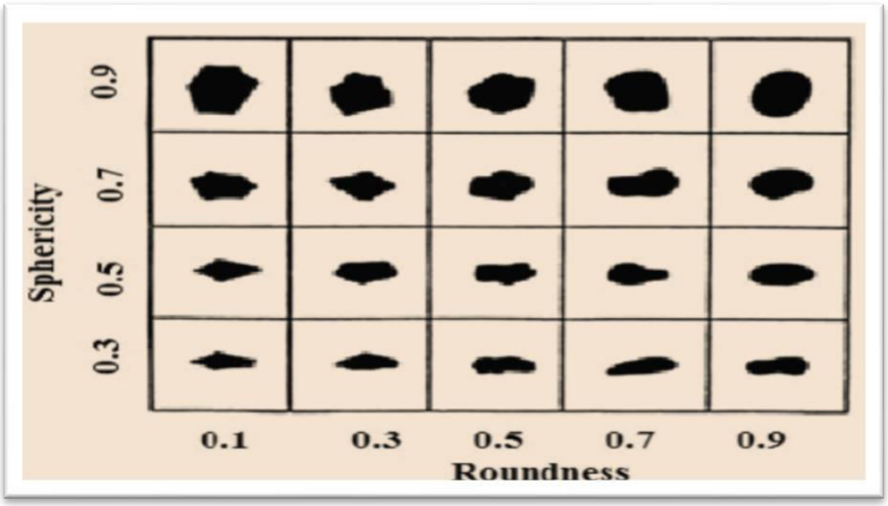


Figure 2.3: Visual roundness and sphericity chart (Krumbein and Sloss ,1963).

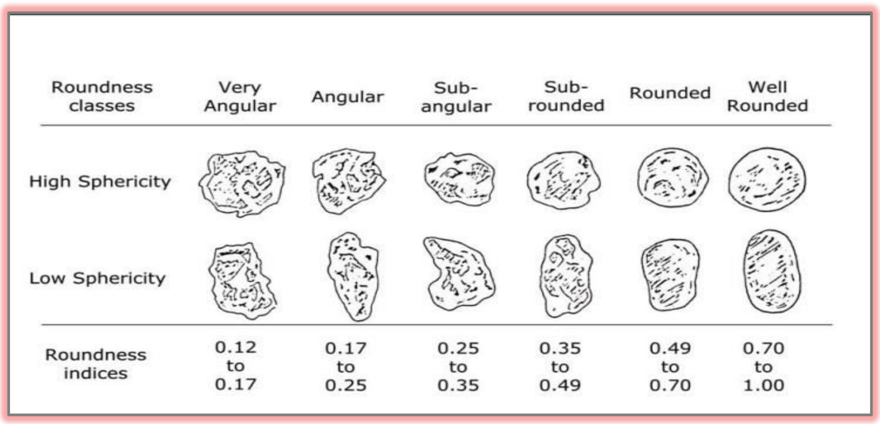


Figure 2.4: Roundness qualitative scale (Powers, 1953).

The morphology of the quartz particles is important as it affects the melting characteristics in glass making; the particles are too needle-like they will not melt uniformly (the ends of the needles melt first) whereas circular particles tend to melt uniformly (McLaws, 1971; Ismaiel et al., 2017). Rounded sand grains are ideal when the industry needs the permeability of the silica sand, while angular sand grains are chosen if the speed of silica sand melting is essential (Hamidullah et al., 1996; Kogel et al., 2006).

The presence of contaminating impurities including oxides (iron, titanium, aluminum, magnesium, chromium, and calcium oxides) and clays affect the purity of sand by influencing its color, melting temperature, transparency, viscosity permeability, and making it unsuitable for industrial applications. Iron oxide and titanium oxide affect the glass's color and transparency (Chatterjee, 2009; Valchev et al., 2011).

2.6 Applications and specifications of industrial sand deposit

Like many industrial minerals, the use of silica sand as a potential raw material is not merely dependent on its physical property alone as construction aggregates, fill, mortar, and concrete. Hence, it tends useful when a specification and standards of physicochemical and mineralogical properties are conducted (Norton, 1957; BS: 2975, 1988; Heinrich, 2001; Pohl, 2011). These technological and mineralogical properties include high silica content, low levels of contaminates particularly metallic oxides, and, narrow grain size range, suitable grain shape, and high resistance to temperatures (British Geological Survey [BGS], 2009; Dustman et al., 2011).

Glass manufacturing is the most consumer of silica sand (Shaffer, 2006; PRNewswire, 2012; Osseni et al., 2018). Industrial sand to be preferred for the glass manufacturing, it must contain a very high amount of silica and a very limited proportion of metallic oxides (Ramadan, 2014). The specifications and standards for glass sand products are based on the proportion of silica and metallic oxides including alumina, lime, magnesia, and iron oxides. As illustrated in Table 2.2 below, the glass industry requires a minimum of 95.0% of silica and other limited contents of metallic oxides.

To determine if silica sand is suitable for potential industrial use, mineralogical specifications are also essential. Particularly unfavorable are the heavy detrital accessory minerals (also known as "refractory heavy minerals") found in sandstones, such as kyanite, sillimanite, corundum, etc., which do not melt at glassmaking temperatures and instead persist as "stones" (Heinrich, 2001).

Table 2.1: Specifications for the chemical composition for different silica sand industries based on the American Ceramic Society (ACS) and National Bureau of Standards (Norton, 1957), IS: 488 (1980) and BS: 2975 (1988).

No.	Product quality	Chemical composition (wt. %)															
		SiO_2% (Min.)			Al_2O_3% (Max.)			Fe_2O_3% (Max.)			CaO+MgO% (Max.)			TiO2 %(Max.)			LOI (Max.)
		ACS	BS 2975	IS 488	ACS	BS 2975	IS 488	ACS	BS 2975	IS 488	ACS	BS 2975	IS 488	ACS	BS 2975	IS 488	IS 488
1	Optical glass	99.8	99.7	99.0	0.1	0.2	*	0.02	0.013	0.02	0.1	-	-	0.1	-	0.1	0.5
2	Flint containers and tableware	98.5	-	-	0.5	-	-	0.035	-	-	0.2	-	-	-		-	-
3	Flint glass	95.0	-	-	4.0	-	-	0.035	-	-	0.5	-	-	0	-	-	-
4	Sheet and plate glass	98.5			0.5		*	0.06	-	-	0.5	-	-	-	-	-	-
5	Sheet and plate glass	95.0			4.0		*	0.06	-	-	0.5	-	-	-	-	-	-
6	Green container and Windows glass	98.0			0.5		*	0.3			0.5			-			-
7	Green glass	95.0			4.0	-	*	0.3	-	-	0.5			-	-	-	-
8	Amber glass containers	98.0			0.5		*	1.0			0.5			-	-	-	-
9	Amber glass	95.0	-	-	4.0	-	*	1.0	-	-	0.5	-	-	-	-	-	-
10	Foundry	-	95.0	-	-	0.6	-		-		-	0.4(CaO)	-	-	-	-	-
11	Ceramic	-	97.5	-	-	1.9	-	-	0.25	-	-	0.3(CaO)	-	-	-	-	-
12	Water filtration		80	-	-	-	-	-	2	-	-	-	-	-	-	-	-
13	Cement		-	65	-			-	6	-	-	1.5(MgO)	-	-	-	-	-
14	Abrasives	78	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

* These requirements shall be as agreed to between the purchaser and the supplier.

Physically, silica sand is also required mainly to be well sorted, containing narrow grains size distribution ranges from coarse sand (0.1 mm) to fine sand (0.08 mm) for various possible industrial uses (Ramadan, 2014; Ismaiel et al., 2017). According to specifications of the BS: 2975(1988) and IS: 488-1980 (1980), different industrial applications have different specified size ranges of silica sand. For example, Glass making sand, Abrasive sand, Foundry sand, and Filter media sand demand 0.09mm to 0.5mm, 0.5mm to 2mm, 0.07mm to 0.9mm, and 0.4mm to 1mm respectively.

Glass-making silica sand has to pass through a 20-mesh sieve (0.83mm) and retain more than 95% of it on a 100-mesh sieve (0.15) (McLaws, 1971). According to specifications of the BS: 2975(1988) and IS: 488-1980 (1980), silica sand should contain the particle size distributions ranges from 0.5 to 0.09mm size and relatively homogenous grain shape parameters to be used for the production of all kinds of glass.

According to BS 2975 (1988), industrial sand must have a minimum of 80% SiO_2 and grains that are between 0.5 and 1 mm in size in order to be used in filter medium in the water treatment industry. According to silica sand works well as an abrasive substance to clean metal surfaces and create dimension stone for granite and marble walls (McLaws, 1971). The sand having 78% of SiO_2 and abundantly rounded with particles ranging in size from 2 mm to 0.5 mm is acceptable for use as an abrasive.

According to McLaws (1971), both round to angular Silica sand works well as a sand blasting substance to clean metal surfaces, removing rust, paint, cleaning tanks, and pipeline and create dimension stone for granite and marble walls. However, the silica content applicable for this purpose incudes 78-99% SiO_2 and it is free of cay, rock fragments, mica and coating of iron. This industry can employ sand that is substantially round, with grains ranging in size from 4.76 mm to 0.21 mm (Fig. 2.5). The morphology of sand grains affects the permeability and binder required of molding sands in addition to grain size and deleterious impurities (IBM, 1993). Greater permeability and reduced binder consumption are found in spherical and rounded grains as opposed to less spherical and angular sands (Sundeen, 2001b).

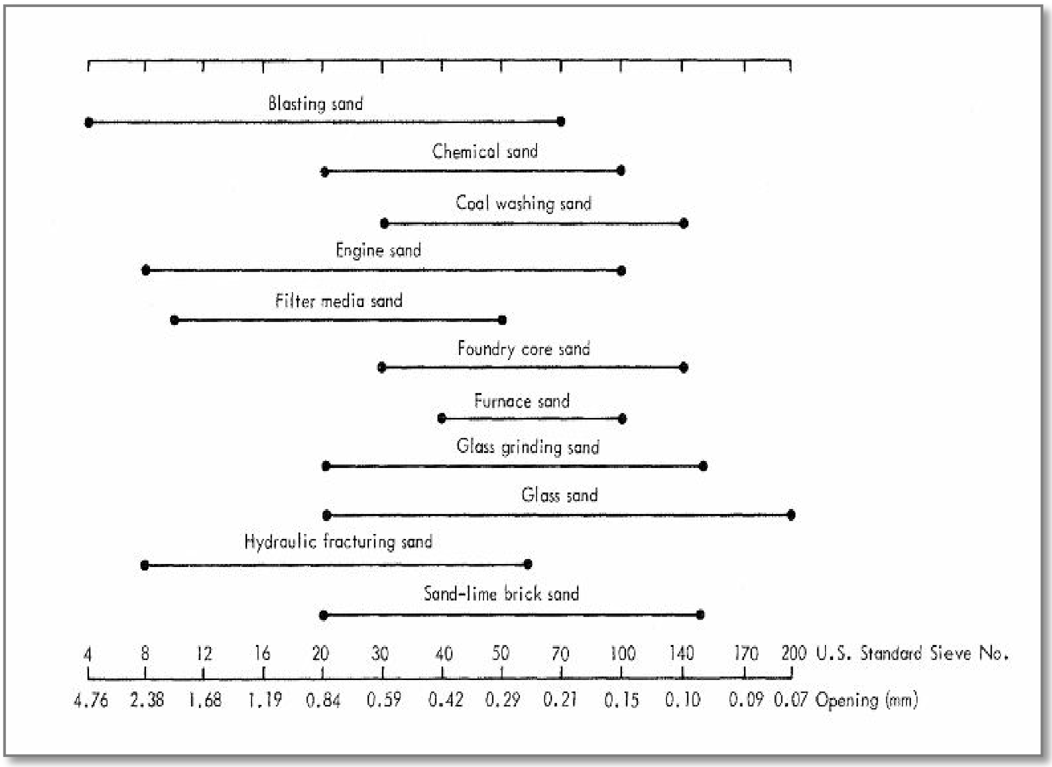


Figure 2.5: Common specified size ranges of silica sand (McLaws, 1971).

2.7 Resource classification and estimation

Classification and estimation of mineral resources are one of the important activities of this study. It demonstrates the deposit's potential for profitable exploitation. The Australasian Joint Ore Reserves Committee Code (JORC Code) seems to be gaining more acceptability as a standard despite the fact that there are other categorization systems in use across the world (Battalgazy & Madani, 2019). Mineral resources and reserves are divided into the following more specific sub-groups in accordance with the JORC code: A component of a resource whose tonnage, grade, and mineral composition can only be identified with a low level of geological certainty is an inferred mineral resource; A deposit is considered an indicated mineral resource if tonnage, density, form, physical properties, grade, and mineral amount can be reasonably estimated. A measurable mineral resource is also a component of a mineral resource that can be confidently assessed in terms of tonnage, density, shape, physical properties, grade, and mineral content (Battalgazy & Madani, 2019) (Fig.2.6).

The quantity and quality of mineralization in a deposit may be estimated using a number of different techniques. The techniques can be grouped into two categories: conventional techniques and geostatistical techniques. While section and plan maps are frequently used in conventional methods, geostatistical approaches utilize sophisticated, computer-driven 2-D and 3-D statistical algorithms to predict tonnage and grade (Moon et al., 2006). According to Moon et al. (2006), the equation used to compute resources by the conventional method is provided as given below; T = A * Th * BD. Where T is the tonnage of deposit, in tons; A is the area of influence on a map or section, in m^2 or km^2; Th is the thickness of the deposit in meters; and BD is the bulk density in g/cm^3.

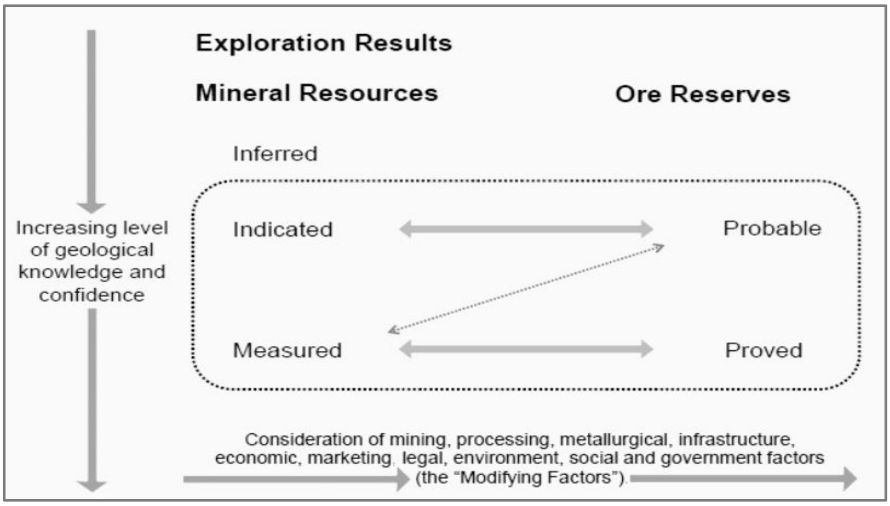


Figure 2.6: a general correlation between ore reserves, mineral resources, and exploration results (The JORC code, 2012).

2.8 Economic analysis

The various mine industries take into account a variety of significant economic aspects of sand deposits, including size of the deposit (sufficient silica sand reserve), accessibility, and transportation. Every potential location must have enough sand to support operations for a very long time in order to recover start-up costs (Sundeen, 2001a). Due to the direct impact, it has on the price of transporting sand from the mine to the market, accessibility is crucial. Even though this is a condensed view of the economic factors involved in sand mining, these economic characteristics are crucial in determining the economic viability of inland sand resources for the quartz sand industry (Robert Marrone, 2005, pers. Comm., Schrotenboer & Arbogast, 2010).

On the other side, one way to improve sand resources for potential industrial silica sand usage is to lower transportation costs. Industrial sand's final cost may increase noticeably when it is transported to a market. By the time sand reaches the industry, the price per ton may have more than doubled, depending on how far it must travel (Kogel et al., 2006). Therefore, to be regarded as a viable raw commodity, silica sand deposits must be close to markets and accessibility of transportation to be considered (Lewis, 2001).

CHAPTER THREE

REGIONAL GEOLOGIC SETTINGS

3.1 Introduction

According to Assefa (1991), the Blue Nile basin is one of the main East African sedimentary basins found in Ethiopian Plateau. It is located in the Northwestern Ethiopian Plateau and is demarcated to the E and SE by the tectonic escarpment of the uplifted western flank of the Main Ethiopian Rift and to the N and S by the Axum–Adigrat and Ambo lineaments, respectively (Gani et al., 2008). Similar to NW-orienting Mesozoic rifts that are present throughout northern and central Africa, the basin is thought to have originated during the Mesozoic break-up of Gondwana (Bosellini 1989; Russo et al. 1994). According to Gani et al. (2009), the Blue Nile basin has a portion of Mesozoic sedimentary rocks that is about 1400 m thick, unconformably underlain by Neoproterozoic basement rocks, and unconformably overlain by Cenozoic volcanic rocks. The regression of the Indian Ocean from the northern and central parts of Ethiopia started to deposit meandering and braided type of sediments within Blue Nile basin. The basin is endowed by its attractive industrial (example; limestone, sand stone, gypsum and clays) and energy (oil and gas) mineral resources (Wolela A., 2002). Economic minerals of the basin are exposed due to erosion and cross cuttings by rift system together with plateaus of Ethiopia (Mogessi et al., 2002). The proposed location, which is a section of the Abay basin in the Northwestern Ethiopian Plateau, is composed of Mesozoic sedimentary rocks and Cenozoic volcanic rocks.

3.2 Geodynamic evolution of Blue Nile sedimentary basin

The development of African basins during the Phanerozoic can be thought of as correlating to the poly phase break-up of Gondwana. From the late Carboniferous onward, rifting related to the breakdown of Gondwana was predominant, and basins formed as a consequence of this stretching both at the boundaries and inside the continental African plate. When East and West Gondwana split apart and the middle Atlantic Ocean started to expand, rifting started in the Early-Middle Jurassic (Bumby and Guiraud, 2005). Subsidence associated with rifting leads to the emergence of Karoo type basins at the margins and within the continental African plate and the starting of marine flooding in the region (Bumby and Guiraud, 2005; Catuneanu et al., 2005).

The Blue Nile basin is one of the main East African sedimentary basins found in Ethiopia in addition to Mekele, Ogaden, Gambela and Southern rift basins (Getaneh Assefa, 1991).

According to earlier research, the Blue Nile basin was created during the Permo-Carboniferous initial phase of the Karoo rifting and has undergone many tectonic phases and structural complexity (Wolela, 1997, 2008; Russo et al., 1994). The NNE trending faults that are connected to the Karoo phase, which occurred from the late Paleozoic to the Jurassic, were created by the NE-SW direction extensional movement associated with the break-up of Gondwana (Worku and Astin, 1992; Salman and Abdula, 1995; Wolela, 1997; Cannon et al., 1981). The NNE- SSW trending faults follow the Neoproterozoic basement regional fabric (Gani et al., 2009). The commencement of the breakup of Gondwana resulted in the formation of the Blue Nile basin along NW-trending faults that controlled the rift basin in the central and eastern regions of Africa (Gani et al., 2009). Gondwana was divided into different blocks as a result of the second phase of the Karoo rifting, which took place in the Early to Middle Jurassic (Wolela, 2008). The Abay basin, according to Jie et al. (2006), has undergone three major periods of evolution. These phases include (1) the sedimentation stage, which may have taken place during the Paleozoic age and involved the pre-rift peneplanation of the Neoproterozoic basement rocks. (2) The Cretaceous sedimentation phase, including; (a) fluvial sedimentation for lower sandstone deposition; (b) beginning of marine transgression for glauconitic sandy mudstone deposition; (c) deepening of the basin for lower limestone formation; (d) the basin's desiccation and the accumulation of gypsum in the Early-Middle Jurassic, (e) Middle-Late Jurassic marine transgression for upper limestone deposition; (f) Uplift and marine regression in the Mesozoic basin for the deposition of upper sandstone (3) Examples of the post-sedimentation period include the Oligocene eruption of lower tertiary volcanic rocks linked to the Afar mantle plume and the deposition of quaternary volcanic rocks. According to Wolela (2009) Abay basin was eventually dissected into western (Dejen-Gohatsihon) and eastern (Jemma and Muger) sub-basins due to NE-SW oriented Dera fault system. The Debre Libanos sandstone (DLS) units and the Mugher mudstone were distributed due to this fault system, which also regulated the occurrence of marine regression from the area. Following the deposition of Cretaceous continental sediments, the Oligocene period marked the greatest outpouring of the continental flood basalts (trap series) across the peneplain's land surface (Hofmann et al., 1997; Pik et al., 1998). Basaltic lava flows and pyroclastic tuff dominate the tertiary rock units are underlain by Mesozoic sedimentary rocks (GSE, 2015). They are divided into several tholeitic and alkaline units (Daniel Meshesha and Shino, 2007).

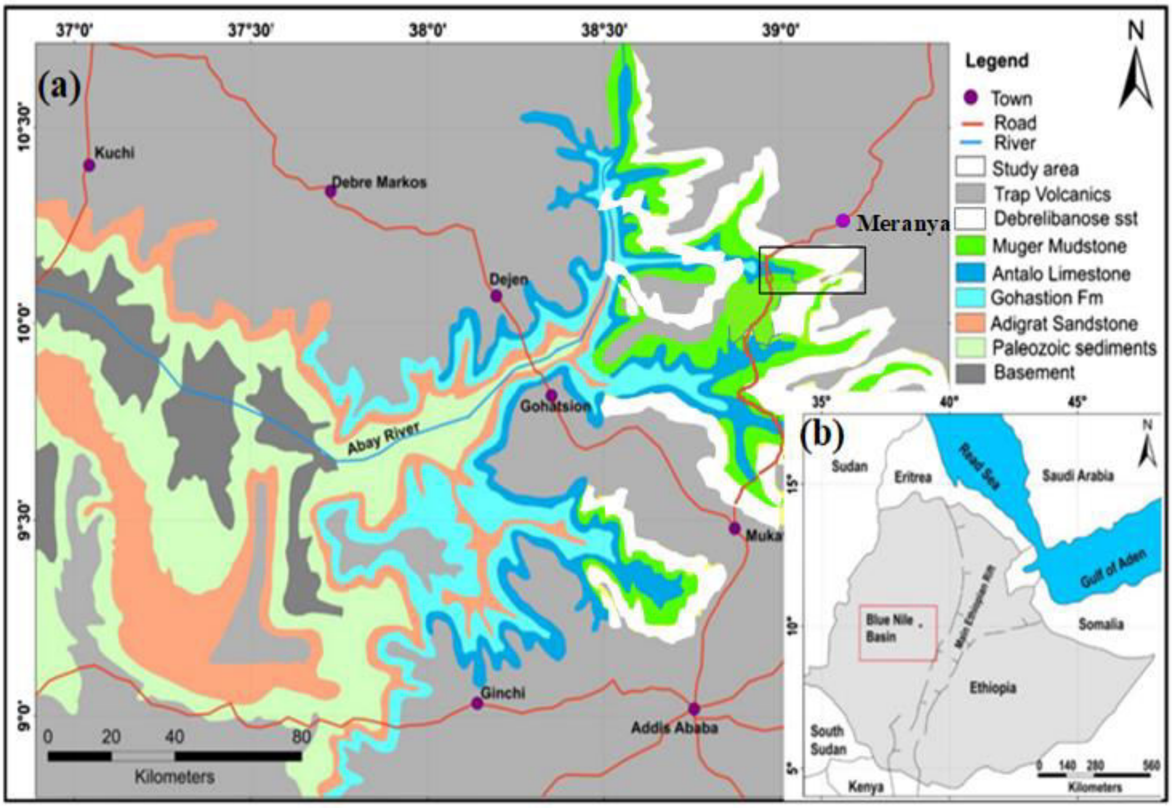


Figure 3.1: The Geological map of the Blue Nile basin and location of the study area (a)(modified after Kazmin, 1972; Mohammedyasin & Wudie, 2019), and Geographic location of the Blue Nile basin within Ethiopia and East Africa (b) (Mogessie et al., 2002).

3.3 Stratigraphy of Blue Nile sedimentary basin

The stratigraphy of the Abay sedimentary basin is classified into five distinct formations. These includes from the base to the upper as the Adigrat Sandstone unit, Gohatsion Formation, Antalo Limestone Formation, Muger mudstone, and Debre Libanos Sandstone (Getaneh, 1991) (Fig. 3.2).

3.3.1 Basement rocks

Basement rocks of a thickness of ~900 -1500 m are revealed within the rough terrain of the Abay basin (Jie et al., 2006). According to U-Pb and Rb-Sr geochronologic studies, the age of the units is thought to be Neoproterozoic and ranges from 850 to 550 Ma (Ayalew et al., 1990). This rock unit is overlain unconformably by Adigrat sandstones. The basement unit consists of variably metamorphosed quartz feldspathic schist and gneisses, migmatites, and plutonic rock (Jie et al., 2006).

3.3.2 Adigrat Sandstone Formation

The Adigrat Sandstone is distributed to a large extent in the Abay basin (wolela, 1991). The unit is unconformably positioned above Neoproterozoic basement rocks, which are then overlain by Oligocene volcanic rocks, according to Jie et al. (2006). According to the finding of Worash (2002), the geochemical and provenance studies explain that the source rock for this unit is adjacent silicic to intermediate basement rocks through severe weathering. It is mainly characterized by texturally and compositionally sub-matures to mature sandstone. In the basin, the unit was probably deposited in delta, meandering, and lacustrine depositional environments during Triassic to Early Jurassic time (Beyth, 1972 and Wolela, 2008). Adigrat Sandstone Formation is composed of conglomerates, coarse to medium-grained sandstones, and very fine-grained cross-bedded clastic rocks (Wolela A., 2008).

3.3.3 Gohatsion Formation

Gohatsion Formation is underlain by a lower sandstone unit and overlain by a Middle-Late Jurassic Antalo Limestone Formation (Getaneh, 1991). The unit is made up of upper limestone and gypsum strata that alternate with lower, thinly bedded limestone (Jie et al., 2006). Gohatsion formation is attained 450 m thick and it consists of mudstone, limestone, dolostone, shale, and gypsum units (Assefa, 1981).

3.3.4 Antalo Limestone Formation

Antalo Limestone Formation is believed to be deposited in the middle to late Jurassic due to the main transgression event that flooded the entire East Africa which leads to the deposition of about 420 m thick carbonate succession in the Abay basin and the other sedimentary basins of Ethiopia. This unit conformably overlies the Gohatsion Formation and is overlain by the late Jurassic – early Cretaceous Upper Sandstone unit (Bosellin, 1989; Russo et al., 1994; wolela, 1997). According to Mogessie et al., (2002), the Antalo Limestone unit has three features, includes the lower part consists of fossiliferous and burrowed mudstone and oolitic limestone; the middle part is characterized by silty limestone with very thin marl unit, and massive limestone in the upper part.

3.3.5 Muger Mudstone Formation

According to Getaneh, (1991) a 260m thick Muger Mudstone Formation is exposed through the withdrawal of the sea from the east African Craton during the Late Jurassic. This unit is absent in the Dejen- Gohatsion section, but exposed in the valleys of Mugher, Dersena, Ega, Wodem, Berresa, Adabai, Zhema, Jema-Wenchit-Jara, and Chennli rivers. Muger Mudstone

Formation has two main features, includes the lower part consists of alternating gypsum, dolomite, and shales, and the upper part is represented by mudstone and fine to medium-grained siltstone (Mogessie et al., 2002). Based on the sedimentary facies, the unit was deposited from continental to supratidal and lagoonal environments.

3.3.6 Debre Libanos Sandstone

Sandstone unit was formed during the early Cretaceous, by depositing regressive continental sediments over the Ethiopian region. The Debre Libanos Sandstone was exposed regionally in different regions of the country such as the Lemi area, Muger, and Jema-Wonchit-Jara Rivers (Getaneh Assefa, 1991). The thickness of the unit varies from zero (near Gohatsion and Fincha valley) and 280m (near Lemi area) (Mogessie et al., 2002). Debre Libanos Sandstone of Abay basin is represented by upward fining in texture with lenses of conglomerate resulting from meandering river sedimentation (Wolela, A., 2009). Horizontally bedded, massive beds, laminated shale, mud and siltstones, and fine to medium-grained sandstones are the common features of upper sandstone (Wolela, A., 2002; 2009). The Debre Libanos Sandstone unit conformably overlies the Muger Mudstone and is unconformably overlain by the Cenozoic volcanic rocks (Assefa, 1991a; Wolela, 2009).

3.3.7 Trap volcanics

Trap volcanic rock series rest unconformably on the upper sandstone unit (Jie et al., 2006). The trap volcanic sequence of Ethiopia was emplaced with the opening of the EAR during the Oligocene, about 30 million years ago (Ayalew, D and Yirgu, G., 2003). These volcanic rocks, which are mostly made up of basalt and are typically referred to as trap succession, are estimated to have had a pre-erosion area coverage of greater than 750,000 km^2 and a volume of 350,000 km^3 (Mohr, 1983). The teritiary-quaternary trap volcanic rocks of Ethiopia are classified into trap series and aden series (Tefera et al., 1996). According to Mohr and Zanettin (1988), and Tefera et al.(1996), the term "trap series" refers to the entire mass of the tertiary flood basalt sequence with intercalation of felsic lava and pyroclastic rocks that create the northwestern and southeastern plateaus and reach a total volume of 300,000km3. The Aden series has been used for Middle Miocene to Quaternary volcanic rocks of the Main Ethiopian Rift, Afar depression, and some parts of Ethiopian plateaus. Traditionally, the Cenozoic volcanism of the northwestern Ethiopian Plateau has been subdivided into four formations, including the lower basaltic Ashangi and Aiba units and the middle ignimbrites Alaji unit, and the upper basaltic Termaber formation (Berhe et al., 1987). The volcanic emplacement of ash and coarse pyroclastic fragment products form the trap segments composed of basalts to siliceous verities (Kazmin, 1975). This flood basalt has 600,000km^2 containing the youngest Quaternary sediments of conglomerate, sand, and clays exposed in Afar and the northern margin of the Rift (Kazmin, 1975; Kieffer et al., 2004).

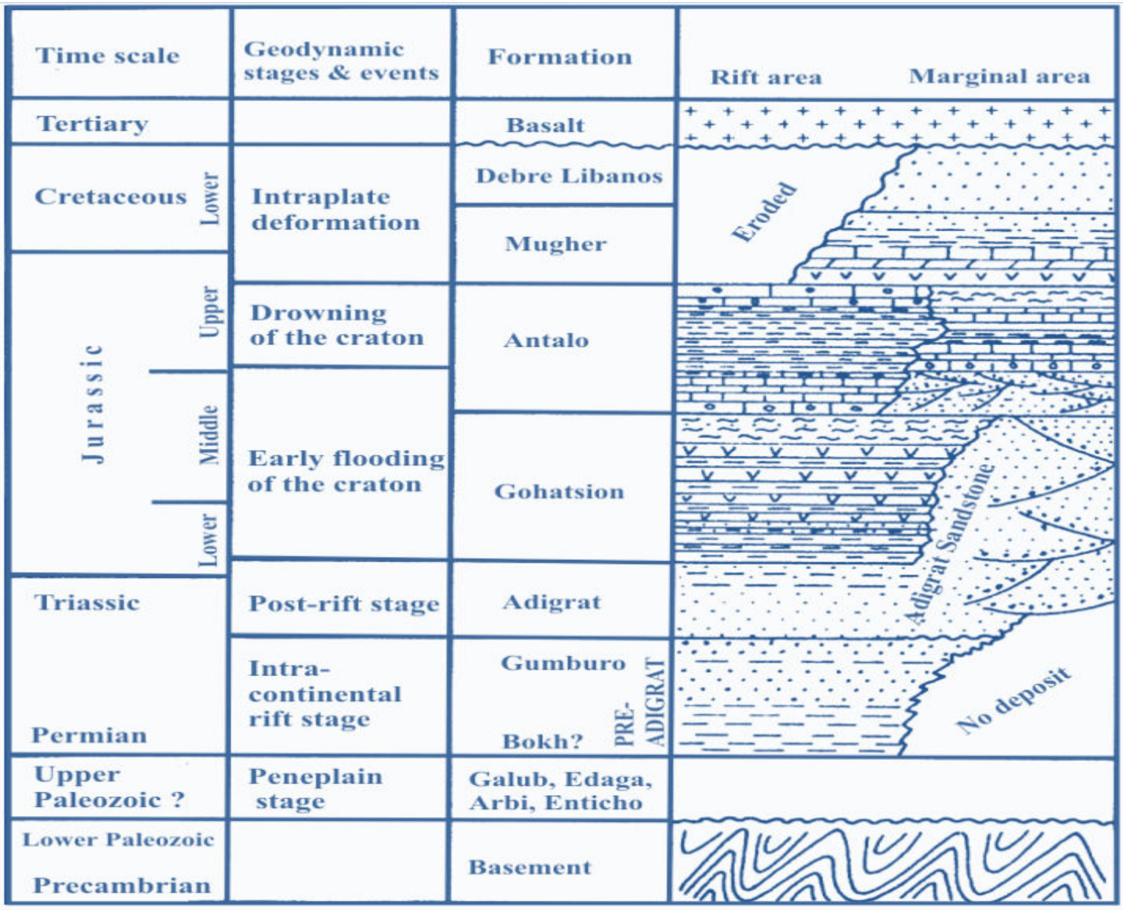


Figure 3.2: Chronostratigraphy, major geodynamic events and lithostratigraphy of Abay basin (Russo et al., 1994).

CHAPTER FOUR

GEOLOGY OF TEGORA AREA

4.1 Introduction

Mesozoic sedimentary and Cenozoic volcanic rock units predominate in the research area. The Tegora area is a component of the Abay's upper sub-basin. North and Southwest of Meranya town, which is covered by a thick plateau of flood basaltic topography, is where the current study area is located. Basalt, limestone, sand, and other industrial minerals are frequently found in the area and are mostly used in constructions and other industrial purposes. The research area is located in the Debre Libanos Sandstone of the Mesozoic sedimentary sequence. Mesozoic sedimentary successions are prevalent in the Tegora area, and they are unconformably covered with thick trap volcanoes.

Antalo Limestone, Muger Mudstone, Debre Libanos Sandstone, and flood basalt are the common unit strata successions that are found in the research area. Depend on their horizontal contact connection, they were characterized and mapped. On the geological map, which has a scale of 1:15,000, the areal distribution of these lithological units is shown (Fig.4.1 A). Additionally, the vertical stratigraphic successions of the units are also shown by the geological cross-section (Fig.4.1 B). The following is a thorough description of each rock unit based on its geologic sequence (bottom to top).

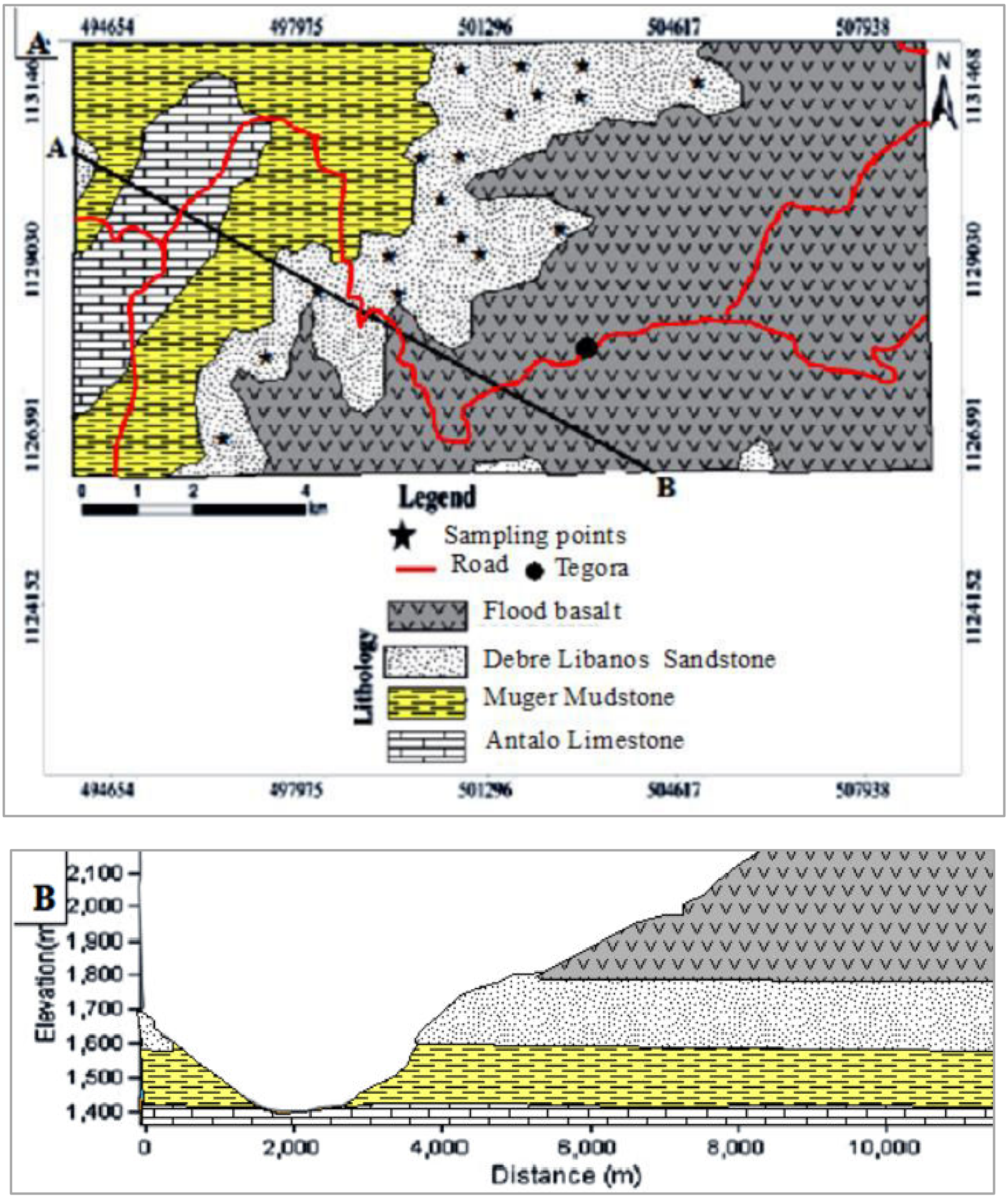


Figure 4.1: Geological and sampling map of the study area (A) and geological cross section along A to B (B).

4.2 Description of Lithological units

4.2.1 Antalo Limestone

From the basin river valley, the limestone of the Abay basin extends to the upper sub-basin on the Tegora area. From the river cut to the mudstone upper succession, which has an average thickness of around 81m, this unit is exposed. The steep cliff-former carbonate rock next to the river cut is the research area's Antalo Limestone unit. Antalo Limestone contributes for the least amount of the study area; only 5.11 % with an aerial exposure of 4.5 km^2. It has pale, yellowish, brownish, gray color (Fig.4.2). At an altitude of around 1450 m above sea level, it is separated from the mudstone underneath it by an intercalated contact. The limestone outcrop is mostly spread in the south and north western parts of the study area. The thickness of limestone's successive beddings ranges from 0.1m to 1 m. The different sorts of this unit found in the research region are packstone and micritic limestone. Bivalve and brachiopod shells are the fossilized components observed in the packstone (Fig 4.2 B). The deposition mechanisms of this unit vary from well-compacted and lithified to friable fine sediments of clay and carbonate materials.

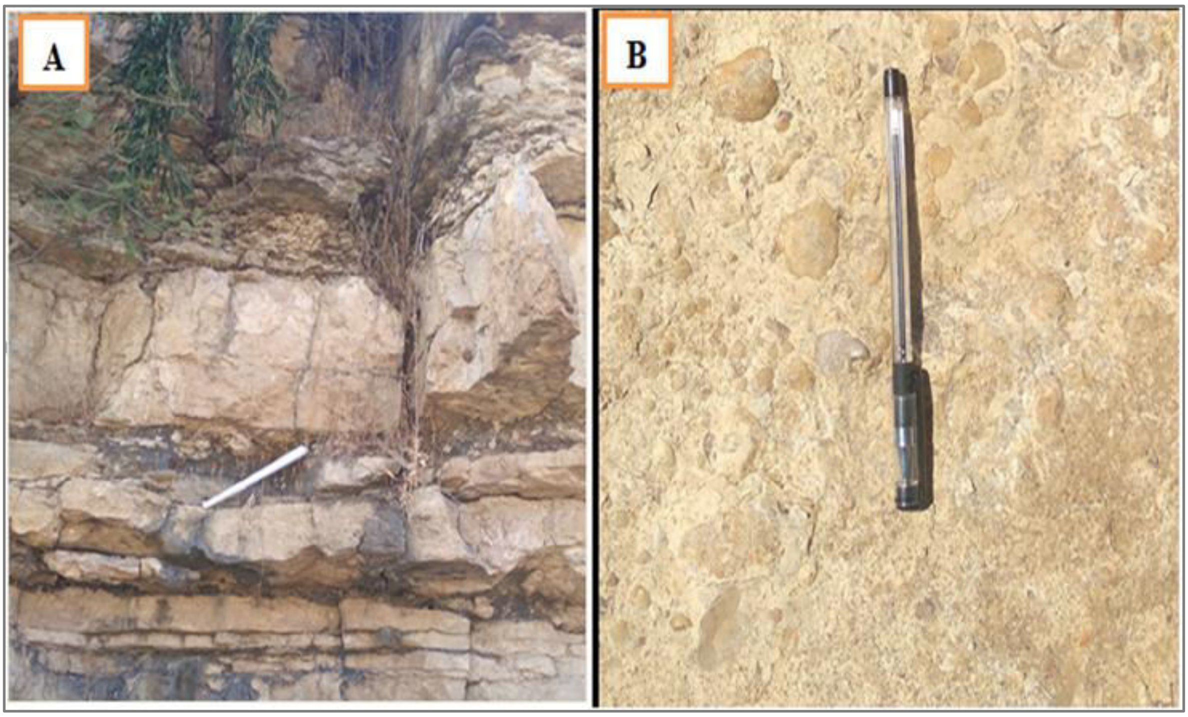


Figure 4.2: An outcrop of non-fossiliferous (A) and fossiliferous (B) limestone in the northwestern part of the study area.

4.2.2 Muger Mudstone

Any indurated sediment comprised of silt and/or clay is referred to as mudstone in general (Boggs, 2014). Below an elevation of 1600 m a.s.l in the research area, Muger Mudstone conformably overlies the Antalo Limestone layer and lies under the Debre Libanos Sandstone unit. The unit is represented by an unconsolidated and massive nature. It creates gently sloped farm lands with thick soil coverage. The total average thickness of the unit reaches up 150 m. With an aerial extent of 19.15 Km^2, Muger Mudstone covers 21.76% of the entire mapped area. It is characterized by yellowish, red, brownish to light grey layers with a thickness of

5cm to 30cm (Fig.4.3). The outcrop of this unit predominantly covers the central and northwestern parts of the study area. In these regions, it is observed at the side of the main roads and along the stream channels. The unit examined by Assefa (1991) has an average composition of 58% mudstone, 34% sandstone, 3% gypsum, and 5% dolomite. Hence, the unit is called mudstone because mudstone predominates in the area. Either Debre-Libanos Sandstone or Tertiary basalt conformably or disconformably overlies the unit respectively.

Figure 4.3: Thin to medium-layered light gray to red mudstone layers in northeastern part of the study area.

4.2.3 Debre Libanos Sandstone

The Debre Libanos Sandstone unit which is found beneath the flood basaltic unit is the major source of silica sand in the study area. The study area's sandstone unit is unconformably overlain by flood basalt and conformably overlies Muger Mudstone. 19.23% of the mapped area is covered with Debre Libanos Sandstone, with an aerial extent of 16.92 km^2. There is extensive silica sand deposit in the area which is silty, sandy to gravely size, and has whitish, brownish grey, reddish to light yellowish in color (Fig.4.4 & 4.5A). The DLS unit of the area is the main target of this study. The total average thickness of the unit attains 141.04 m. The silica sand of the area is hosted within this unit as a continuous horizontal bed. A silica sand deposit makes up around an average of 137 m thick of the unit's vertical section. The remaining host rock is composed of non-silica sand layers including conglomerate, siltstone, and mud rock was makes up an average of 4.04m thick (3%) of the deposit. The unit is mainly cropped out along the sides of main roads, cliffs, intermittent river sections, and stream channels. Lithofacies of this unit shows the alternating sequence of mudstones and fine-grained sandstones at the base that change into a cliff forming coarse-grained sandstone beds towards the top (Russo et al., 1994). While the top contact of the unit is unconformable and abrupt against the Tertiary volcanic, the contact with the underlying Muger Mudstone Formation is gradational and conformable. Based on the comparisons in lithological characters and stratigraphic position, the sandstone of the research area correlated with the regional upper sandstone or Debre Libanos Sandstone unit. The most top part of the unit is covered by soils derived from weathering of overlaying flood volcanic, while the lower portion of the sandstone has gradational contact with the Muger Mudstone of the area. This sandstone's bedding is characterized by gradational patterns with upward grain variations.

In various sections of the research sites, there are more than a hundred meter thick silica sand deposits. The deposit's thickest block may be located close to Debay (~ 149m thick) and Genet (~ 119m thick) and Aferbayine (~125m thick) areas. The upper portions of the deposit are gray-whitish and substantially coarser than the lower portions of the deposit, and it forms cliff-forming topography.

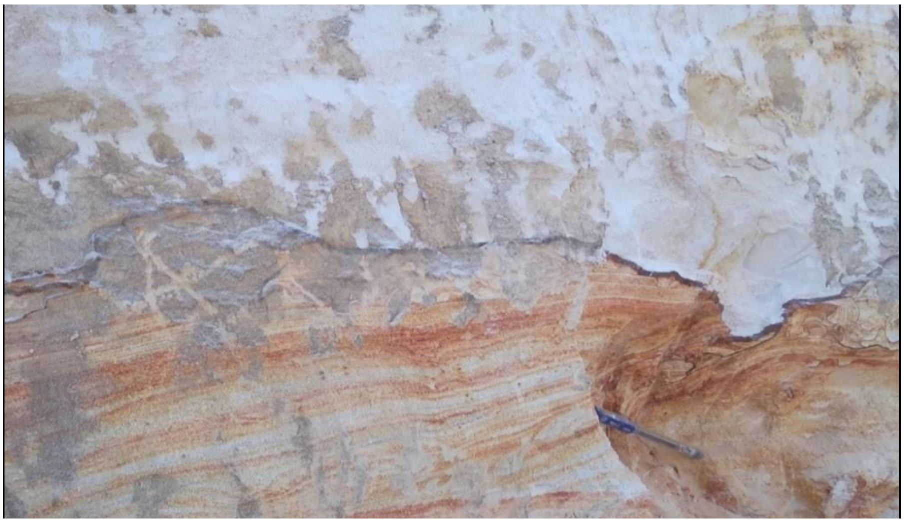
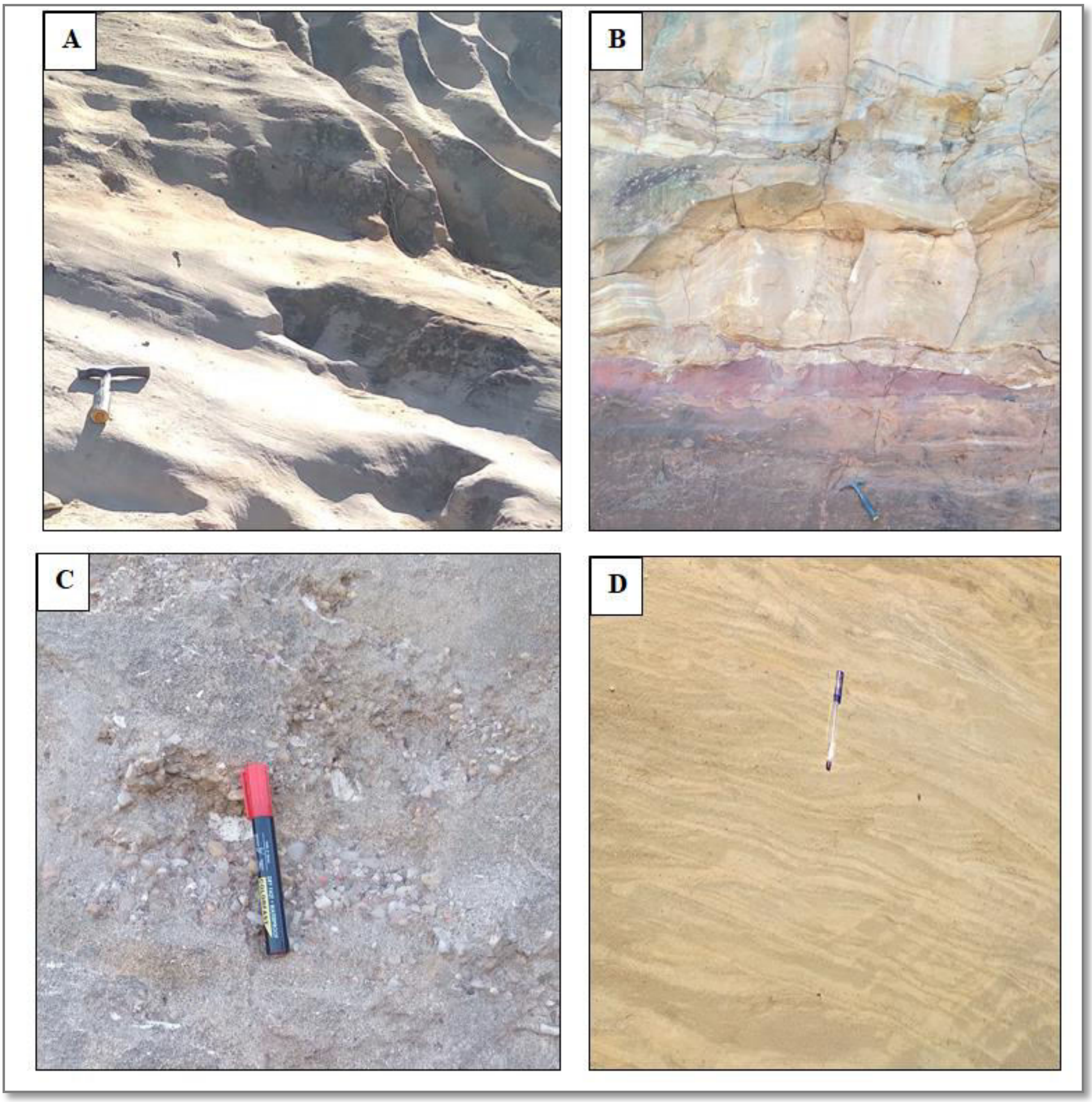


Figure 4.4: Road cut exposure of silica sand deposit in the central part of the study area

With lenses of conglomerated quartz pebbles, the fine cemented silt to clay portion and medium to coarse-grained sand and gravel are coarsening upward. The morphology of the quartz conglomerated lenses ranges from rounded to sub-rounded grains. They are 90 cm to 1.5 cm thick and usually embedded in coarse-grained sandstone (Fig.4.5 C). Sandstone and mud rock are intercalated at some stratigraphic sections. The hue of this bed ranges from brownish-red to mottled color (Fig. 4.5B). Mud rock can range in thickness from tiny cm-sized lamellas to as much as 15 meters in area. Planar-tabular and asymmetrical trough cross-beds, flat beds, channel surfaces, and massive beds are the main sedimentary features in these sandstone deposits (Fig.4.5 D).



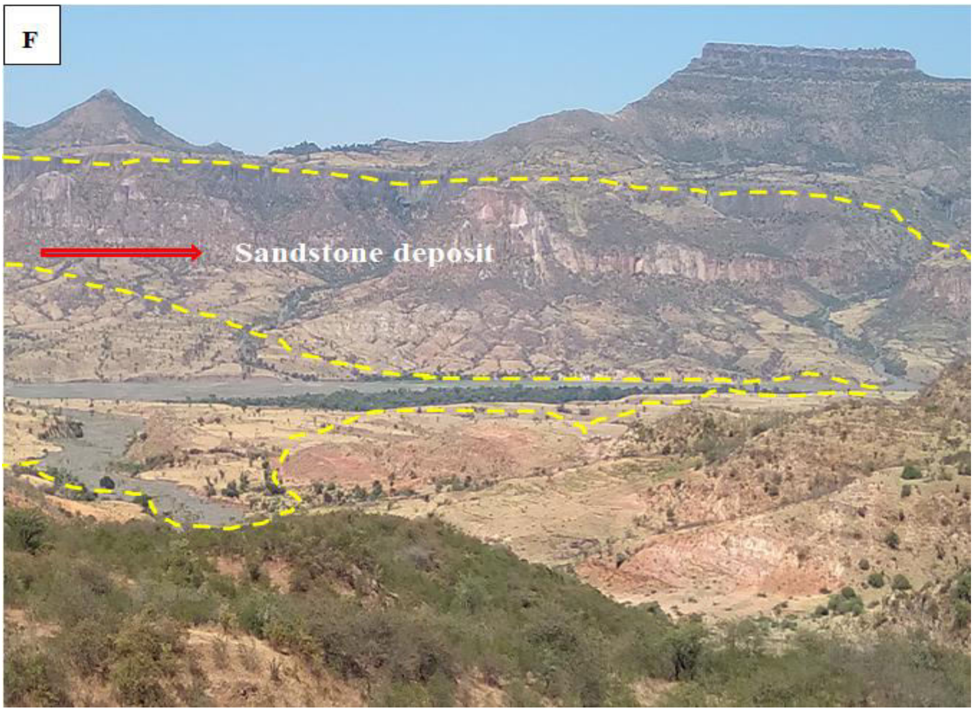


Figure 4.5: Debre Libanos Sand stone in the study area: surface exposure of silica sand (A), mud rock (B), conglomerate lenses embedded with in coarse sandstone (C) and cross-bedded sandstone (D), and panoramic view(F).

According to Gani et al. (2009), the depositional environment for the unit is continental alluvial to fluvial. Regionally, the unit is correlable with the Mekele basin's Amba Aradom sandstone (Dawit, 2010).

4.2.4 Flood basalt

In the research area flood basalt is one of the most common igneous rocks which are overlain and underlain on the Debre Libanos Sand stone unit. Aphanite to porphyritic texture basaltic units is found in various parts of the study areas. All parts of area above the sedimentary succession are covered by approximately 700m thick Cenozoic basaltic rock unit and cover an area of 47.42 km^2. The flood basaltic unit found at Tegora area is aphanite texture and it is thick succession and shows joints and columns. There are closely spaced fractures on the flood basaltic lithological units. A set of column that are straight and regular are called colonnade and this are formed due to stressing during lava cooling. Contraction joints or fractures occur as a thick lava flow cools, and the extensive fracture network that forms causes columns to appear. (Fig.4.6). In hand specimen the fresh parts of this lithological unit shows dark gray color , while the weathered part of it shows reddish brownish to light yellowish.

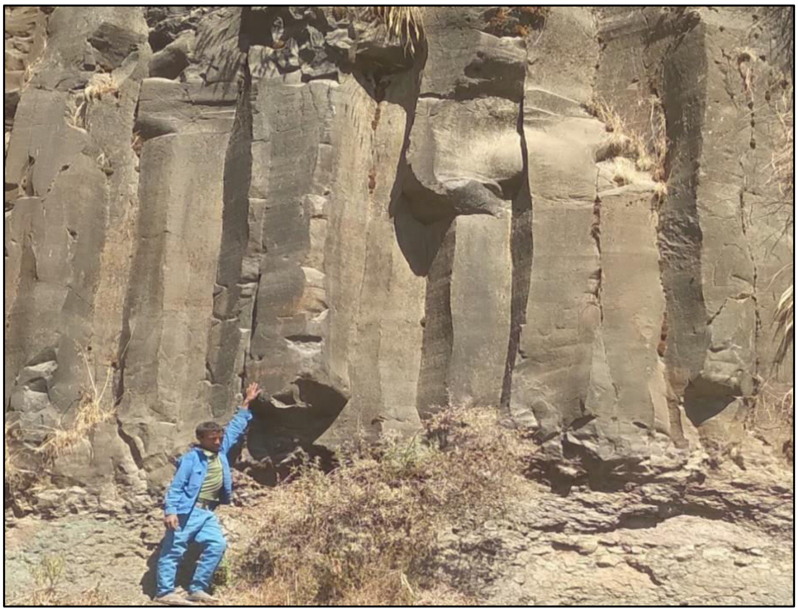


Figure 4.6: The group of columnar basalt in the southeastern section of the study area.

4.3 Sedimentary structures

Beddings, cross-lamination, trough cross-beds, and planar cross-beds are some of the sedimentary features that have been observed. Low energy currents deposited the sediments, forming the trough and flat cross beds. More coarse sediments are often deposited by high-energy currents than by low-energy currents. Layering inside a stratum that is perpendicular to the main bedding plane is known as cross-bedding. The somewhat horizontal units comprised of inclined strata may form sedimentary structures (Fig. 4.7).

Figure 4.7: Cross bedding of sand stone in the northeastern part of the study area

CHAPTER FIVE

RESULTS

5.1 Introduction

Results from the different analytical techniques are reported in this chapter. They are divided into three sections for ease of presentation. Geology of the industrial sand deposit is presented in the first part. It provides explanations of the deposit's geology. The physicochemical and mineralogical analysis's findings are illustrated next to this section. The chapter's last section, addresses, the resource classification and tonnage estimation.

5.2 Geology of the deposit

5.2.1 General information on silica sand

Silica sand is an industrial mineral derived from sandstone and other silica-containing rocks. Unconsolidated sediment including clay, silt, silica, and various accessory minerals is what general silica sand is. Fine sediments such as clay and silt are eliminated from the sediment during weathering and transportation, and the residual resistant minerals like quartz produce silica sand deposits. The presence of fine sediment minerals and other resistant minerals determines the quality of silica sand deposits. Iron and titanium are the most resistant minerals found in silica sand and other sedimentary deposits. Those minerals have influenced the deposit's quality by altering the color, strength, and smoothness of the end products.

In Ethiopia, the principal source of silica sand is Cretaceous sandstone. The sandstone unit which is found beneath the basaltic unit is the main source of silica sand in the area. The mechanical and chemical weathering of quartz-bearing igneous and metamorphic rocks, such as granites and certain gneiss, is the main source of silica sand. Less susceptible minerals, like quartz and zircon, are liberated whereas less stable minerals, especially feldspars, are ruined by erosion and chemical weathering. The mineral particles that are stable are transported and deposited in water. Wave and stream activity may further change the deposits by filtering and washing them until only a relatively pure silica sand deposit remains.

5.2.2 Geology of Tegora silica sand deposit

The Tegora silica sand deposit is situated between 1127000 to 1132000 N latitude and 495000 to 509000 E longitude in the Universal Transverse Mercator (UTM), about 229 kilometers north of Addis Abeba. The area is found in the upper Abay basin. The Debre Libanos Sandstone (DLS) and Mugher Mudstone Formation are present in the Blue Nile's upper sub basin. Tegora silica sand deposits are located in the Debre libanos Sandstone Formation's sandstone strata. It is known as the silica sand deposit of the Shewa province, according to Jelenc (1964). The host rock has an average thickness of approximately 141 m. A silica sand deposit makes up around an average of 137m thick of the unit's vertical section. The remaining host rock is composed of non-silica sand a layer including conglomerate, siltstone, and mud rock was comprised of 3% of the deposit. The distribution of industrial sand in the Tegora area is mostly located in the central, northern, northwestern, southern, south western and western edges. The deposit is exposed at sporadic streams, cliffs, and roads. It is located between the 150 m thick Muger Mudstone Formation and the 700 m thick Trap volcanic rock. It is made up of layers moderately to weakly cemented, friable, white to light grey and occasionally yellowish-colored sand. These strata are constituted of quartz grains, according to field observations on hand specimens. The sand occasionally has a white clay matrix. The yellowish layers differ from the gray and white variants in that they have finer grain sizes.

5.3 Physical properties of Tegora silica sand deposit

The principal physical characteristics used to assess the technological properties of silica sand are grain size, morphology, and bulk density. The following is a thorough explanation of each physical parameters based on its laboratorial analysis.

5.3.1 Grain size distribution

One of the typical textural characteristics of quartz sand that governs its appropriateness for different sectors is the grain size distribution. In the present study, this analysis was conducted by a standard set of sieves used for the grain-size examination to ascertain the percentage ideal fraction of the silica sand samples.

In Table 5.1, the Tegora silica sand sample average grain size percent of mass retained analysis (%) is shown. According to the findings, the relative silica sand mean grain size distribution ranges from 3.84% to 32.792%. Following that, 1.247% and 2.367% of the deposit were composed of gravel and mud-size particles, respectively.

According to sieves with set intervals, the average amount of grain retained is 4.75 mm (0.091%), 2 mm (1.156%), 0.6 mm (14.574%), 0.425 mm (19.832%),0.3 mm (25.346%), 0.106 mm (32.792%), 0.075 mm (3.84%), and pan (2.367%), respectively. As a result, the middle four sieves retained the majority of the sand grains (92.544%). These are sieves of 0.6 mm, 0.425 mm, 0.3 mm, and 0.106 mm openings (Fig.5.1).

Table 5.1: Percentage of weight retained of silica sand samples from Tegora area (%).

Sample code	Sieve size (mm)								
	4.75	2	0.6	0.425	0.3	0.106	0.075	Pan	Total
TSS-08	0	0.53	8.99	22.8	33.9	25.88	5.1	2.8	100
TSS-09	0	0.22	11.23	15.32	28.45	36.9	4.88	3	100
TSS-10	0.55	2.24	25.46	33.95	23.7	12.65	0.79	0.66	100
TSS-12	0	2.08	10.57	11.44	22.12	50.2	1.98	1.6	99.99
TSS-14	0.13	0.65	15.41	18.9	27.7	28.93	4.95	3.33	100
TSS-15	0	0.57	20.22	14.4	17.36	40.13	5.33	1.99	100
TSS-16	0	1.32	11.56	18.25	16.9	42.07	3.9	6	100
TSS-17	0.23	1.73	15.03	20	29.16	31.11	0.78	1.95	99.99
TSS-18	0	1.53	12.1	23.28	34.43	25.95	1.71	1	100
TSS-19	0	0.69	15.17	19.98	19.74	34.1	8.98	1.34	100
Average	0.091	1.156	14.574	19.832	25.346	32.792	3.84	2.367	99.998

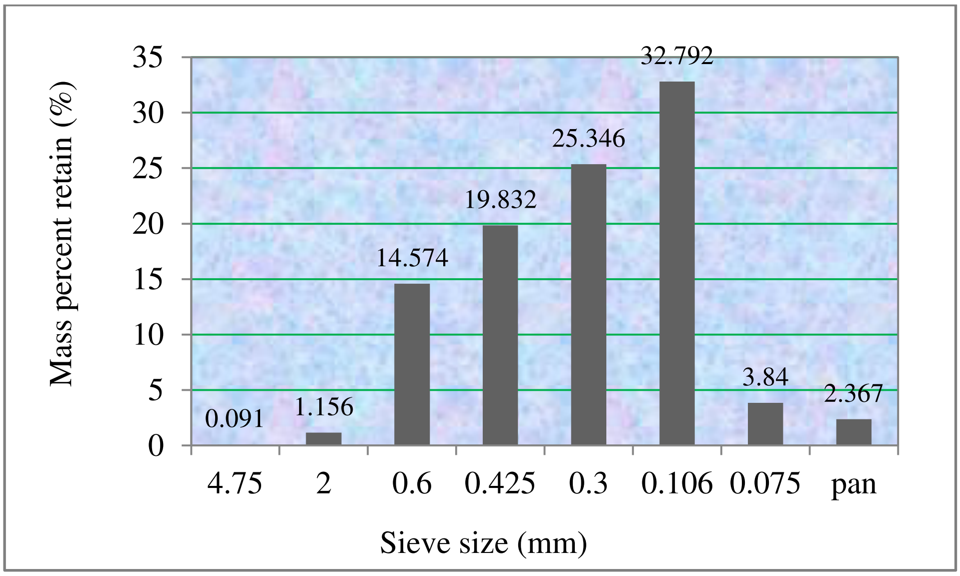
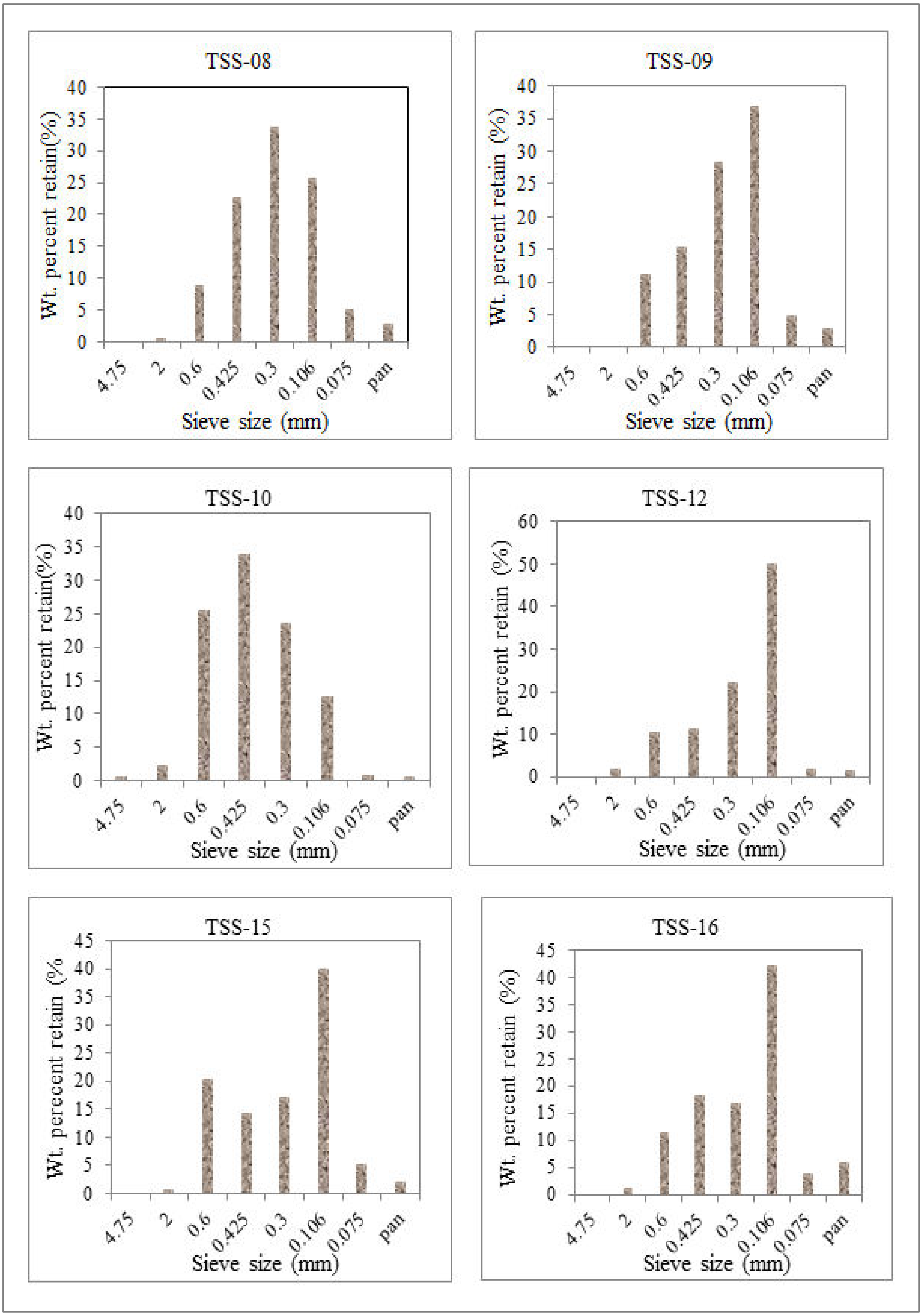


Figure 5.1: The average percentage of grains retained on sieve size 4.75 mm to pan for Tegora silica sand samples.

Figure 5.2 shows the grain size distribution of 10 samples of Tegora silica sand. Almost all, the collected studied silica sand samples have retained the majority of sand grains on sieves of 0.3mm and 0.106mm diameters. In contrast, relatively minor grain size distributions on screens of 4.75 mm and 0.075mm openings and pan.


TSS-08
Wt. percent retain(%)
40 35 30 25 20 15 10 5 0
4.75 2 0.6 0.425 0.3 0.106 0.075 pan
Sieve size (mm)
TSS-09
Wt. percent retain (%)
40 35 30 25 20 15 10 5 0
4.75 2 0.6 0.425 0.3 0.106 0.075 pan
Sieve size (mm)
TSS-10
Wt. percent retain(%)
40 35 30 25 20 15 10 5 0
4.75 2 0.6 0.425 0.3 0.106 0.075 pan
Sieve size (mm)
TSS-12
Wt. percent retain (%)
60 50 40 30 20 10 0
4.75 2 0.6 0.425 0.3 0.106 0.075 pan
Sieve size (mm)
TSS-15
Wt. perecent retain (%
45 40 35 30 25 20 15 10 5 0
4.75 2 0.6 0.425 0.3 0.106 0.075 pan
Sieve size (mm)
TSS-16
Wt. percent retain (%)
45 40 35 30 25 20 15 10 5 0
4.75 2 0.6 0.425 0.3 0.106 0.075 pan
Sieve size (mm)

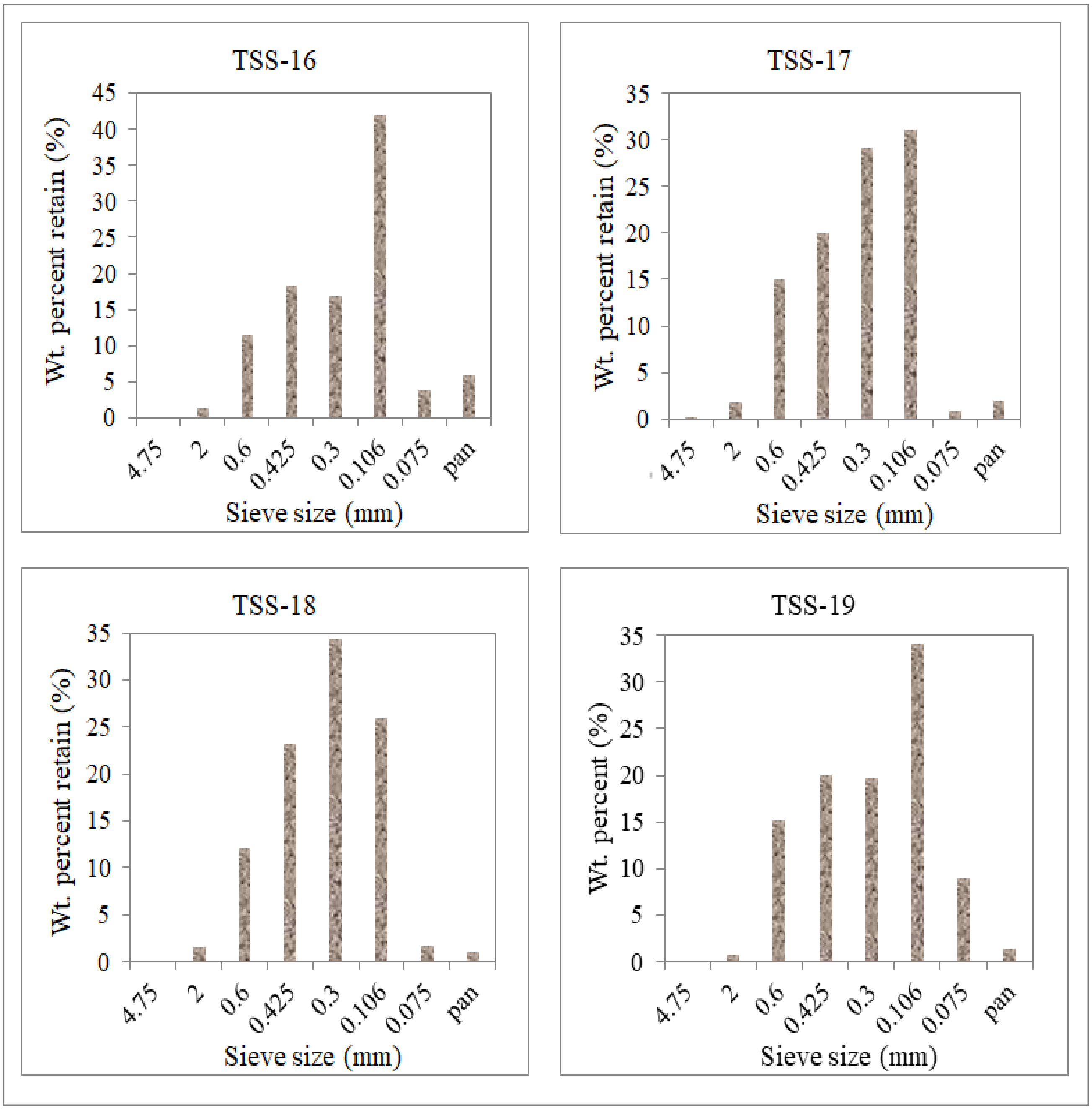


Figure 5.2: Grain size distribution of 10 collected Tegora silica sand samples.

Grain size gradation (distribution) curve in Tegora silica sand samples is presented graphically in figure 5.3 A and B below. The graph implies that poorly graded (uniformly graded) samples include those that have a high percentage of particles of the same (sand) size.

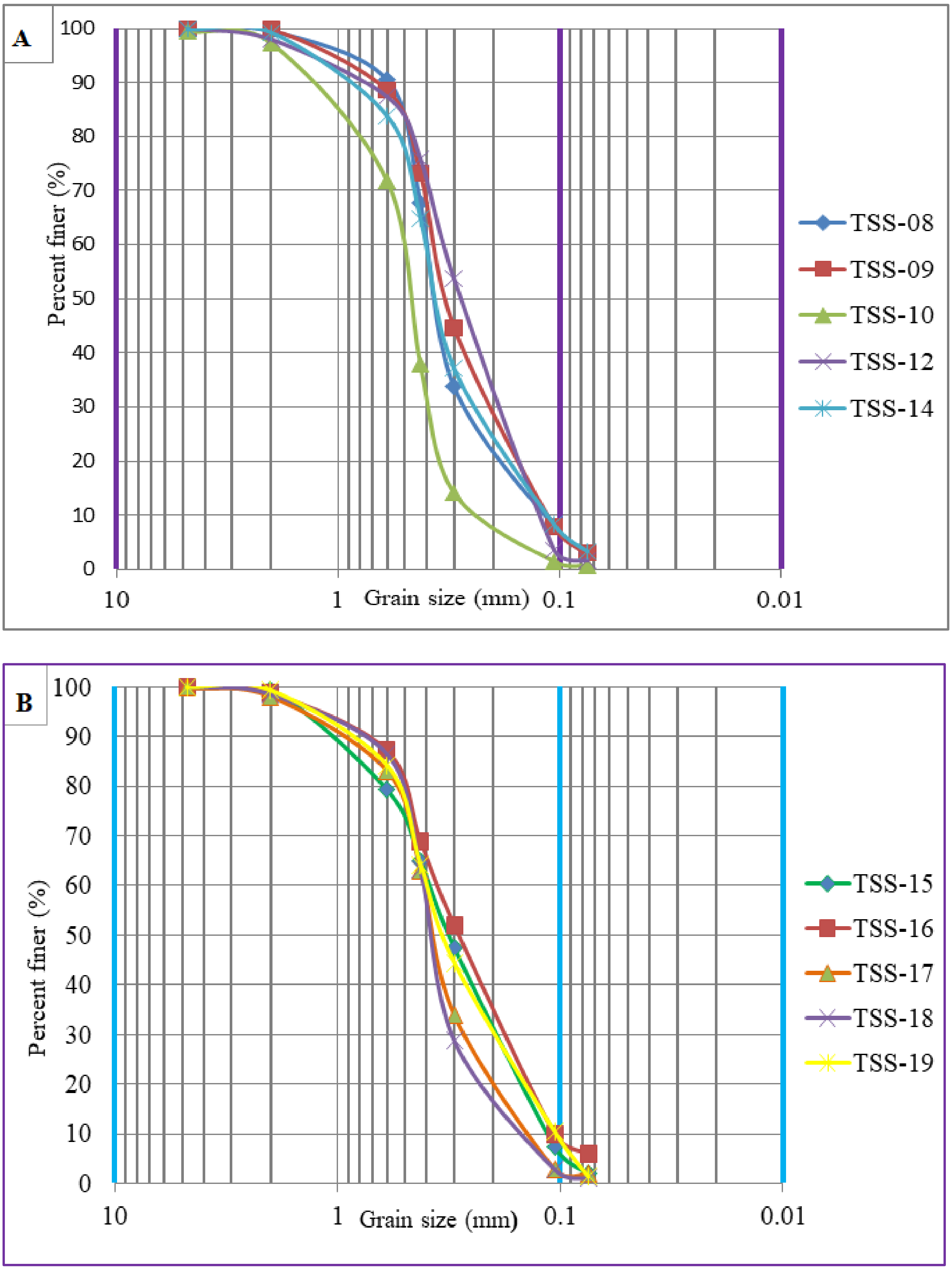


Figure 5.3: Grain size distribution curves of Tegora silica sand samples.

Other grain size parameters, such as the coefficient of uniformity (Cu) and coefficient of curvature (Cc), reveal the range of grain sizes distribution (nature of grading curve) in a particular soil sample. Coefficient of curvature (Cc) must be between 1 and 3, and coefficient of uniformity (Cu) must also be larger than 4 for gravels and greater than 6 for sands in order to be considered well-graded. Otherwise, it is poorly (uniformly) graded (Das, 2002 and Kalinski, 2011).

The coefficient of uniformity and coefficient of curvature values for 10 Tegora silica sand samples are determined and shown in Table 5.2 to show this peculiarity of the Tegora silica sand deposit. Kalinski (2011) provides the equations that were used to compute them, which are listed below; Cu = $\frac{D60}{D10}$, and Cc = $\frac{D^{2}30}{D60 * D10}$ .Where, Cu= coefficient of uniformity, Cc= coefficient of curvature, D60, D30, and D10 are the diameters corresponding to percent finer of 60%, 30%, and 10% respectively. The median size (D50) of Tegora silica sand samples ranges from 0.29mm to 0.49mm, which implies that the studied quartz sand samples are commonly medium-grained size.

Table5.2: Grain size nature of grading of Tegora sand samples

Sample	Parameters					Gradation
	D60	D30	D10	Cu	Cc	
TSS-08	0.4	0.27	0.12	3.33	1.52	Poorly graded
TSS-09	0.37	0.22	0.12	3.08	1.09	Poorly graded
TSS-10	0.54	0.38	0.24	2.25	1.11	Poorly graded
TSS-12	0.34	0.21	0.13	2.62	1	Poorly graded
TSS-14	0.4	0.25	0.12	3.33	1.3	Poorly graded
TSS-15	0.39	0.22	0.12	3.25	1.03	Poorly graded
TSS-16	0.36	0.2	0.11	3.27	1.01	Poorly graded
TSS-17	0.41	0.28	0.15	2.73	1.28	Poorly graded
TSS-18	0.41	0.31	0.16	2.56	1.47	Poorly graded
TSS-19	0.4	0.22	0.11	3.64	1.1	Poorly graded

Inclusive graphic standard deviation is additional physical parameters that indicate the nature of sorting of sediments. A sediment sample is regarded as very well-sorted if its standard deviation value is less than 0.35 and considered to be well-sorted if it has an inclusive graphic standard deviation value of 0.35 to 0.50. If the sample's standard deviations value is more than 1, the sample is said to be poorly sorted (Folk and Ward, 1957). Table 5.3 shows the computed and displayed inclusive graphic standard deviation values for 10 silica sand samples. The formulae required to calculate them are provided by Folk and Ward (1957) and are stated below;

$$\sigma_i = \frac{\phi^{84} - \phi^{16}}{4} + \frac{\phi^{95} - \phi^{5}}{6 \cdot 6}$$

Where, σi= inclusive graphic standard deviation, 95, 84, 16, and 5 are the diameters corresponding to percent finer of 95%, 84%, 16%, and 5% respectively.

Table 5.3: Grain size sorting of 10 Tegora silica sand samples.

Sample	Parameters					
	ϕ95	ϕ84	ϕ16	ϕ5	σi	degree of sorting
TSS-08	1.31	0.55	0.17	0.09	0.28	Very well sorted
TSS-09	1.31	0.55	0.15	0.09	0.29	Very well sorted
TSS-10	1.88	1.27	0.31	0.16	0.5	Well sorted
TSS-12	1.61	0.55	0.15	0.11	0.33	Very well sorted
TSS-14	1.62	0.62	0.16	0.09	0.35	Very well sorted
TSS-15	1.69	0.93	0.15	0.09	0.44	Well sorted
TSS-16	1.55	0.57	0.13	0.08	0.33	Very well sorted
TSS-17	1.72	0.69	0.19	0.12	0.37	Well sorted
TSS-18	1.6	0.58	0.21	0.12	0.32	Very well sorted
TSS-19	1.6	0.59	0.14	0.09	0.34	Very well sorted

5.3.2 Grain morphology

One of the crucial textural aspects in assessing sand for various industrial applications is the morphological analysis of silica sand. The Scanning Electron Micrograph (SEM) method was employed to determine the grain shape of sand grains that make up the Tegora silica sand deposit. SEM analysis was conducted on five chosen Tegora sand samples (TSS-08, TSS-09, TSS-10, TSS-12, and TSS-17).

As demonstrated in the literature review portion of the study, the roundness and sphericity values for each sand particle were obtained by visually comparing their micrographs with the accepted Krumbein and Sloss comparison chart (1963) for roundness and sphericity. Based on the roundness qualitative scale of Powers (1953) and the particle morphology class limit of Russell & Taylor (1937), the findings are interpreted. The silica sand samples' grain shapes were angular to rounded and less spherical (Fig.5.4). The angular to sub-angular and less spherical grain shape categories contain the majority of the observed sand grains (Table 5.4). A comparison of the obtained images with roundness and sphericity quantitative chart of Powers (1953) reveals all the samples grains possess lower sphericity.

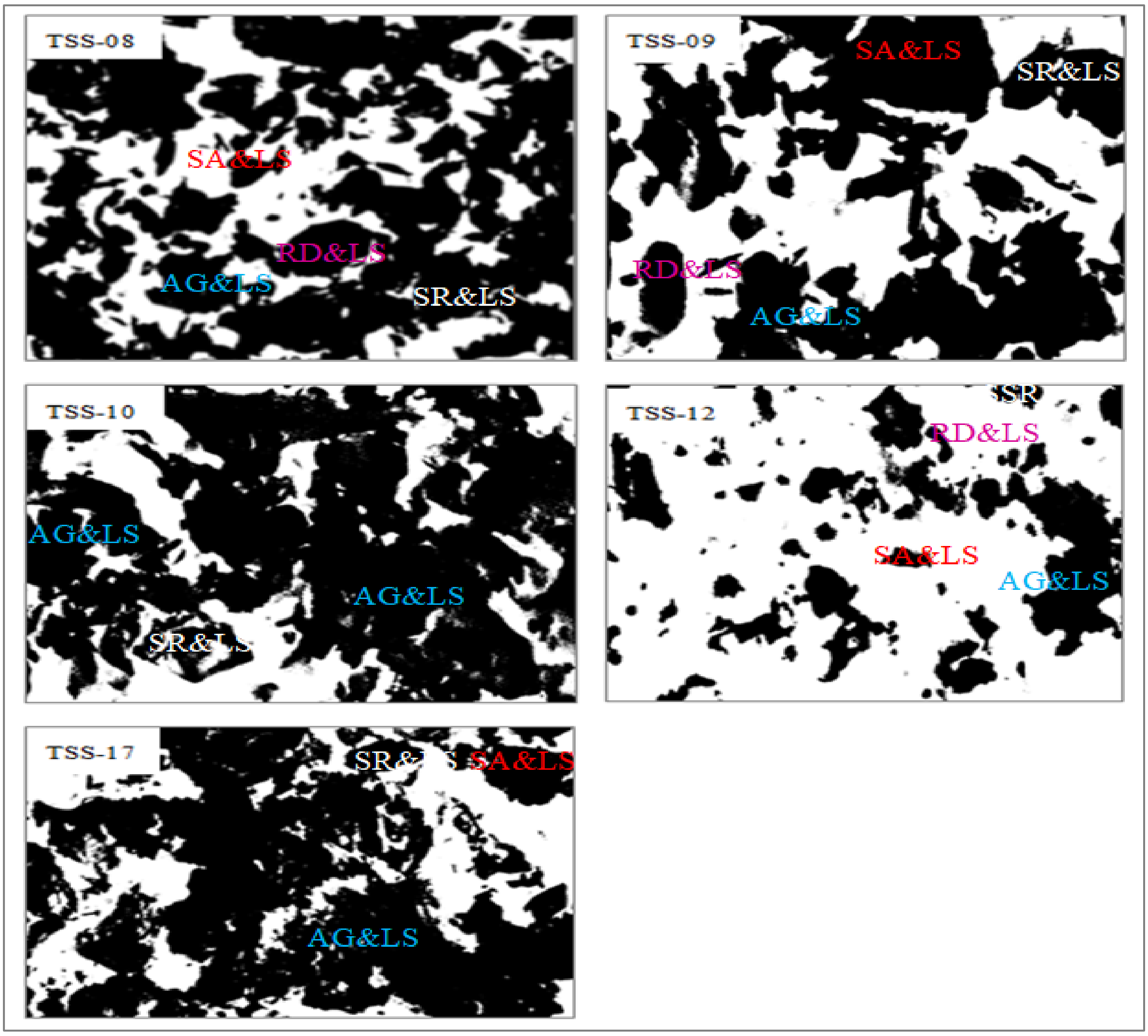


Figure 5.4: SEM photos of sand grains in Tegora silica sand samples(AG=Angular, SA=Sub angular, SR=Sub rounded, RD=Rounded and LS=Less sphericity).

Table 5.4: Numerical presentation of 5 Tegora silica sand grain morphology analysis result

Sample	Size fraction(mm)	Roundness in (%) Angular &sub angular	Sub rounded	Rounded	Well rounded	Sphericity in (%) Highly spherical	Less spherical
TSS-08	0.63	70	16.67	13.33	0.0	0.0	100
TSS-09	0.63	76.67	13.33	10.0	0.0	0.0	100
TSS-10	0.63	91.30	8.70	0.0	0.0	0.0	100
TSS-12	0.63	86.36	9.10	4.55	0.0	0.0	100
TSS-17	0.63	92.00	8.00	0.0	0.0	0.0	100

The high proportion of angular to sub angular (avg.83.27%) and less sphericity (avg.100%) sand grains is the parametric feature of Tegora silica sand occurrence. Similarly, 11.16% and

5.58% of the deposit were composed of sub rounded and rounded grain shape particles, respectively (Fig. 5.5).

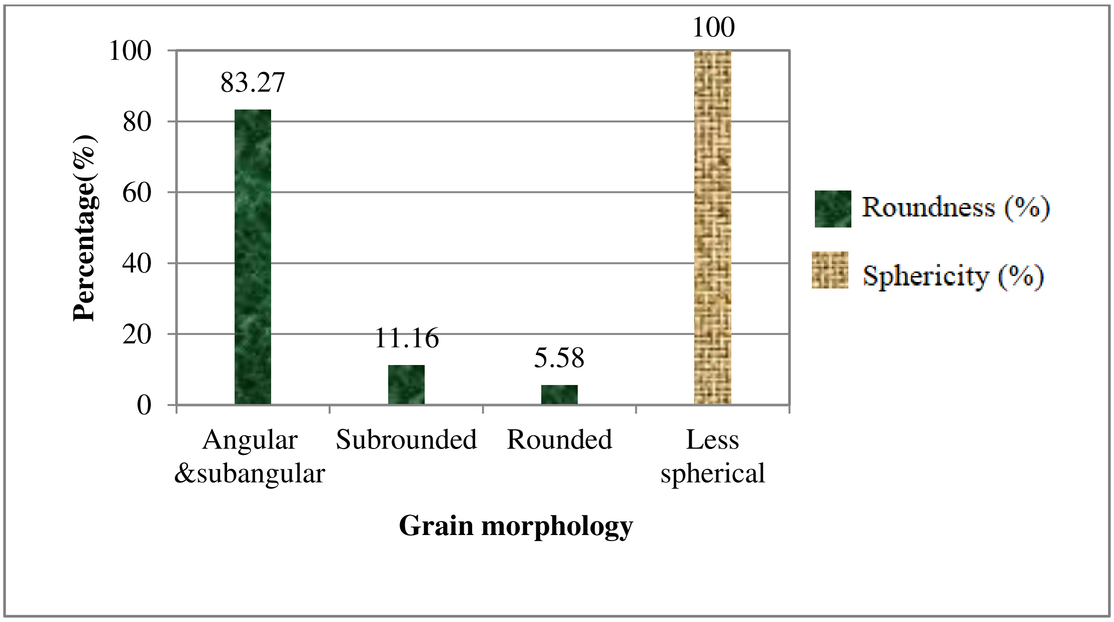


Figure 5.5: Graphical representation of roundness and sphericity of sand grains comprise Tegora silica sand occurrence

5.3.3 Bulk density

Assessing the bulk density of silica sand samples is used as an input parameter for determining the tonnage of industrial sand deposits located in the study area. This was conducted by using immersion in water method. By weighing a sample of unconsolidated or friable sediment in the air and then weighing the same sample suspended in water, and later apply the formula: Bulk density = $(\text{weight in the air})/(\text{weight in air} - \text{weight in water})$, this technique was used to compute the bulk density of the deposit under a controlled of procedures. According to the analysis, the average amount of bulk density of Tegora industrial sand deposit is 1.79 g/cm^3.

5.4 Geochemical analysis

Complete silicate element composition is among the most critical geochemical characteristics of industrial sand that determines its suitability to various industries. These properties are important to find out purity level of the deposit by revealing the concentration of silica and impurities present in the resource.

To verify the major and minor element percentage concentration of the industrial potentials of silica sand obtained from the Tegora area, analytical methods including LIBO2 fusion, HF attack, Gravimetric, Colorimetric, and Atomic Absorption Spectroscopy (AAS) were conducted. According to the geochemical analysis of the sandstone in the studied area, the major component elements in varying concentrations include SiO_2, Al_2O_3, Fe_2O_3, CaO, MgO, Na_2O, K_2O, MnO, TiO_2, Cr_2O_3, and P_2O_5 .

The result of the complete silicate analysis is shown in Table 5.5. The findings of the analyses demonstrate that silicon dioxide (SiO2), which has an average percentage concentration of 92.25, is the predominant metal oxide in the entire sample of silica sand, followed by (Al2O3=6.45), (Fe2O3 =0.63), (K2O= 0.3),(TiO2= 0.17), (Na2O= 0.11), (P2O5= 0.08), (MgO=0.05), (CaO <0.01), (MnO <0.01), and (Cr2O3 <0.01). Sample TSS-10 has the highest concentration of SiO2 (98.42%), whereas sample TSS-19 has the lowest concentration (83.62%). The proportion of SiO2 varies somewhat amongst the Tegora silica sand samples, as can be shown in figure 5.6.

Table 5.5: Major element composition for 12 Tegora silica sand samples (wt. %).

Sample	Major element composition (wt. %)											
	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O	MnO	P_2O_5	TiO_2	Cr_2O_3	H_2O	LOI
TSS-08	97.12	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.09	0.15	<0.01	0.5	2.07
TSS-09	96.08	<0.01	0.64	<0.01	<0.01	<0.01	<0.01	<0.01	0.09	0.17	<0.01	0.73	1.46
TSS-10	98.42	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.01	0.11	<0.01	0.17	1.2
TSS-11	93.22	4.6	<0.01	<0.01	0.04	<0.01	<0.01	<0.01	0.05	0.17	<0.01	0.51	2.47
TSS-12	94.52	3.17	<0.01	<0.01	0.04	0.04	<0.01	<0.01	0.09	0.15	<0.01	0.36	0.99
TSS-13	91.98	5.44	0.18	<0.01	0.08	0.16	<0.01	<0.01	0.07	0.14	<0.01	0.34	1.9
TSS-14	87.24	9.7	0.15	<0.01	<0.01	<0.01	<0.01	<0.01	0.1	0.19	<0.01	0.18	2.88
TSS-15	86.72	7.9	1.26	<0.01	0.01	0.12	0.3	<0.01	0.1	0.2	<0.01	0.25	2.89
TSS-16	86.96	9.29	1.18	<0.01	0.08	0.1	<0.01	<0.01	0.08	0.21	<0.01	0.34	2.4
TSS-17	96.24	3.17	0.36	<0.01	<0.01	<0.01	<0.01	<0.01	0.05	0.17	<0.01	0.19	<0.01
TSS-18	94.88	4.09	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.11	0.12	0.04	<0.01	1.23
TSS-19	83.62	10.73	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.12	0.3	<0.01	0.26	4.19
Average	92.25	6.45	0.63	<0.01	0.05	0.11	0.3	<0.01	0.08	0.17	<0.01	0.35	2.15

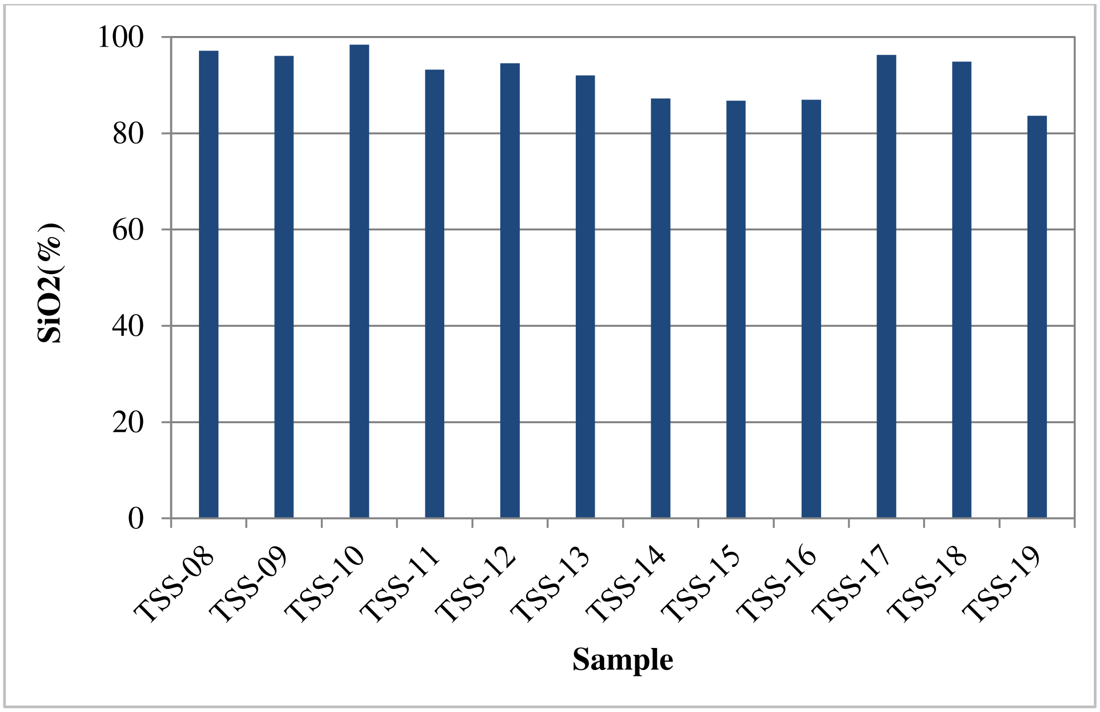


Figure 5.6: Distributions of silica sand in the studied area

Al2O3 is the second most prevalent metal oxide in the Tegora silica sand deposit, with an average concentration of 6.45%. The highest percentage of Al2O3 is found in sample TSS-19 (10.73%), while the lowest percentages are identified in samples TSS-08, TSS-09, and TSS-10 (<0.01%) (Fig.5.7).

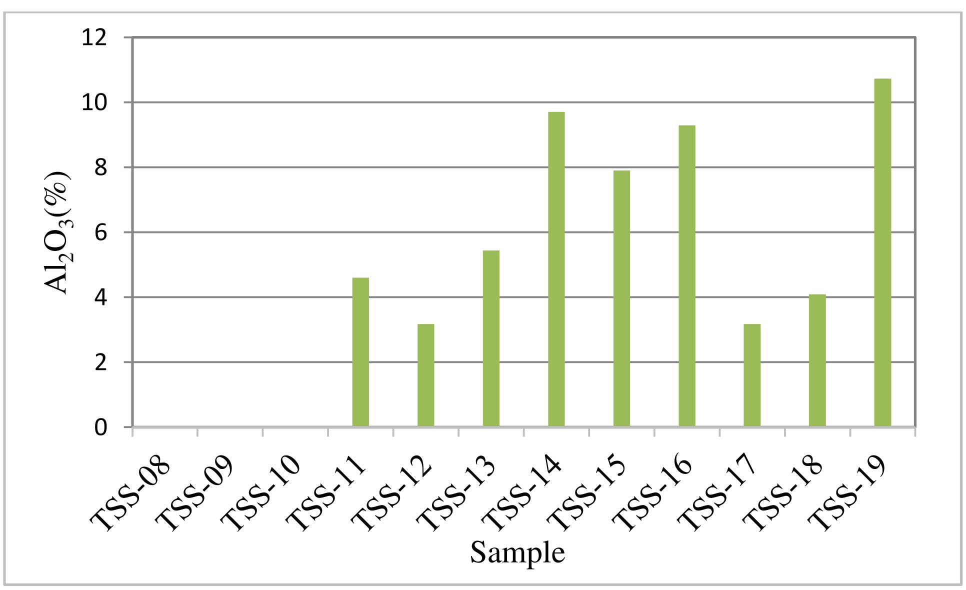


Figure 5.7: The distribution of aluminium oxide (Al2O3) in Tegora silica sand samples

Iron oxide (Fe2O3) is the third primary oxide found in the quartz sand resource of the studied area, after SiO2 and Al2O3. 0.01% to 1.26% is its percentage range (Fig.5.8). Iron oxide is present at a mean percentage of 0.63%.

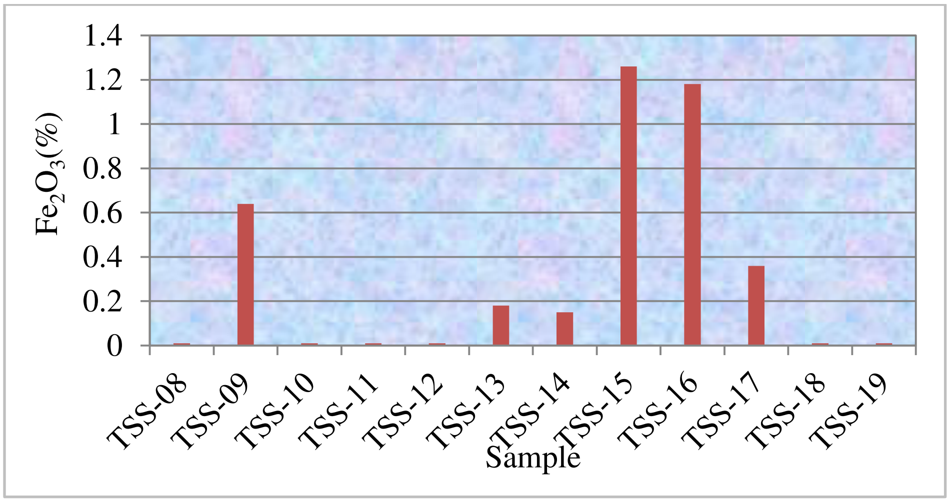


Figure 5.8: The distribution of iron oxide (Fe2O3) in Tegora silica sand samples

In most samples, there is an inverse relation between SiO2 concentrations and an Al2O3 and Fe3O4 percentage which implies that as the values of SiO2 increases that of Al2O3 and Fe2O3 Fig. 5.9).

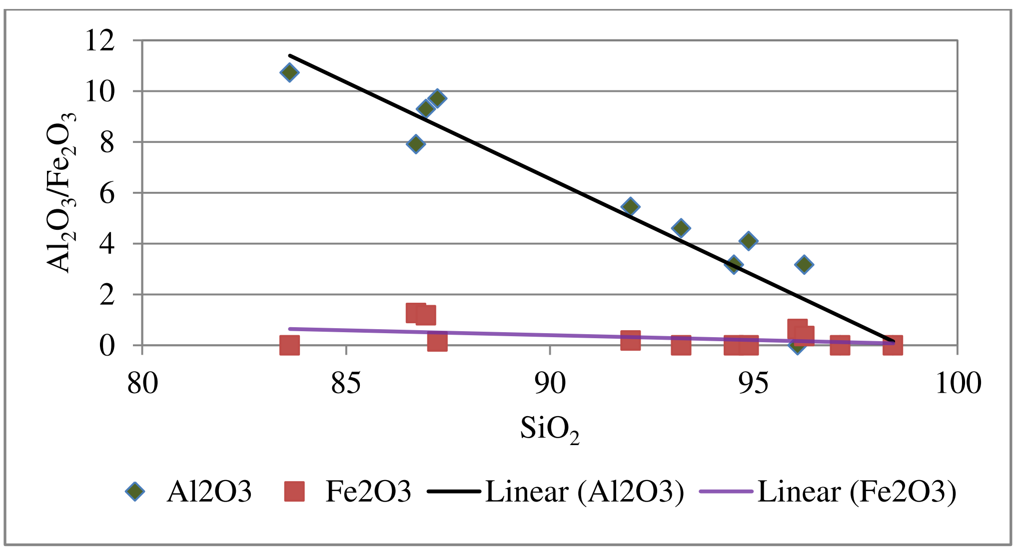


Figure 5.9: The relationship between SiO2 with A2O3 and Fe2O3 in Tegora silica sand samples

The sample also includes K2O (avg. 0.3%), TiO2 (avg. 0.17%), Na2O (avg. 0.11%), P2O5 (avg. 0.08%), MgO (avg. 0.05%), and trace amounts of CaO, MnO, and Cr2O3 in addition to the aforementioned metal oxides. Tegora silica samples have an average LOI value of 2.15%. The combined loss of volatile materials, such as combined structural water ($H2O^+$) and carbon dioxide from carbonates, is known as a loss on ignition (LOI). As a quality check is frequently done on substantial mineral deposits to measure the amount of volatile matter lost when a sample is heated to 950 °C or 1000 °C (Pulsation & Technology, 2015).

5.4.1 Geochemical classification of Tegora silica sand resource

According to Herron (1988), the geochemical classification schemes were conducted to determine the class of the Tegora silica sands. On these plots most of the sand samples are plotted in quartz arenite section and few are located in the Fe-sand, litharenite and sub-litharenite fields (Fig.5.10). According to geochemical analysis, the investigated silica sand deposit has an average SiO2 content of 92.25% and fewer than 8% of undesired metal oxides like Al2O3, Fe2O3, K2O, TiO2 and Na2O.

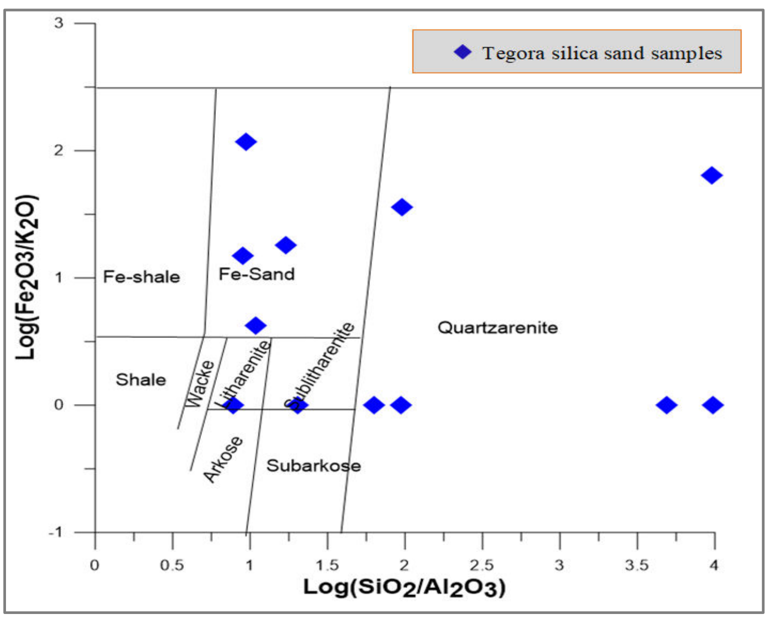


Figure 5.10 Geochemical classification diagram of the studied Tegora silica sand based on: log (SiO_2/Al_2O_3 versus log (Fe_2O_3/K_2O) (Herron, 1988).

Potter (1978) and Noori et al. (2014) argue that the high SiO2 concentration and high SiO2/Al2O3 ratio, which is larger than ten (10), respectively, represent the sandstone's quartz-rich composition and chemical maturity index. As a result, the currently under-study silica sand has high SiO2 contents (on average 92.25%) and an above 10 SiO2/Al2O3 ratio (on average

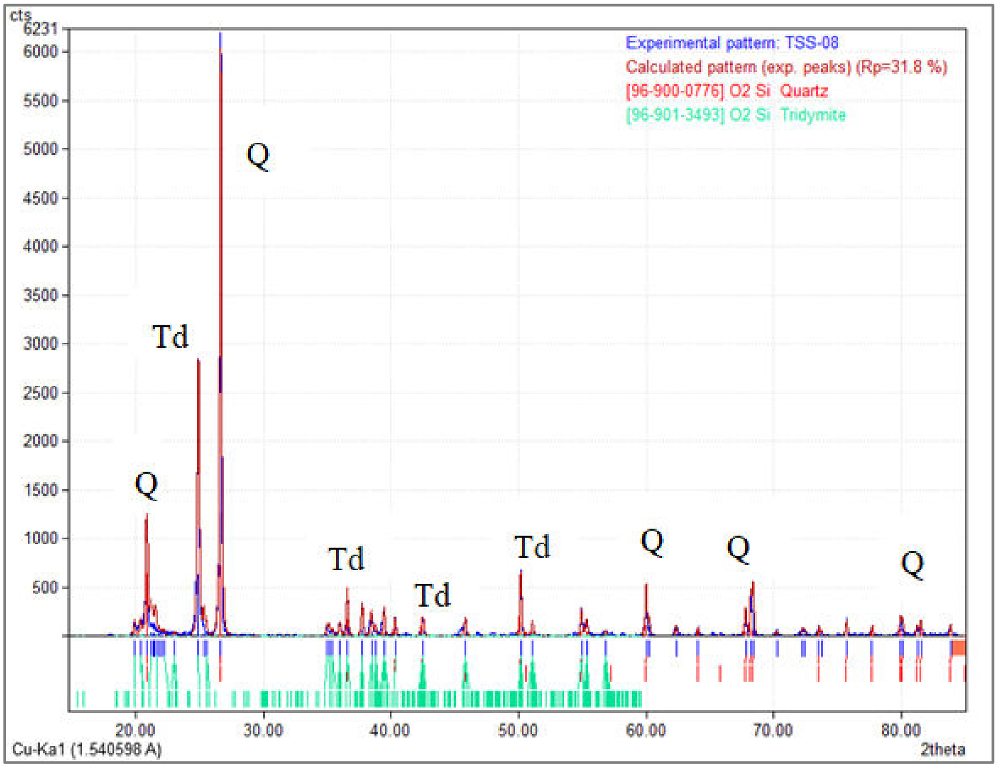
14.30%). This SiO_2/Al_2O_3 ratio result reveals that the silica sand under investigation is rich in quartz composition and matures chemically.

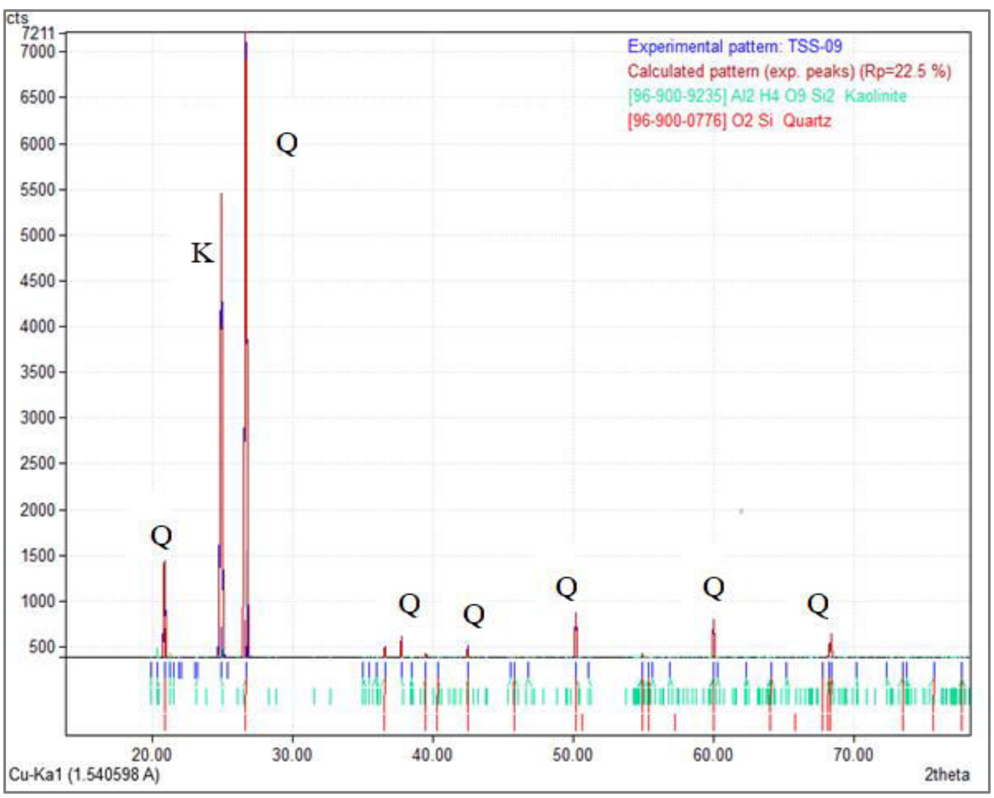
5.5 Mineralogical analysis

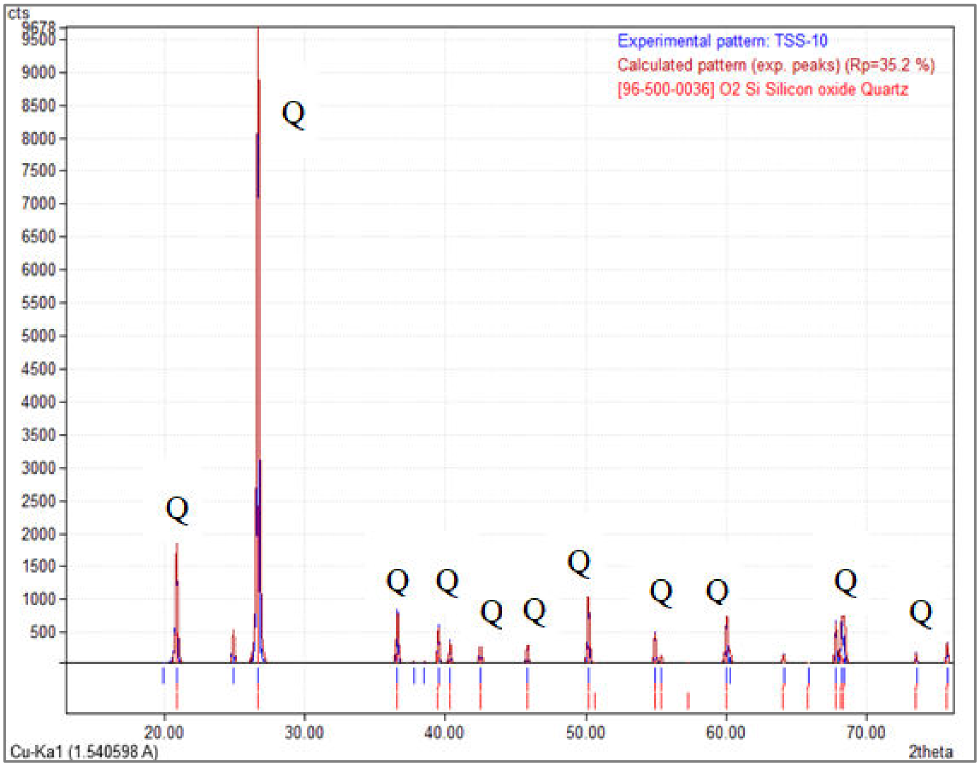
Determining the mineralogical composition of Tegora silica sand deposit is one of the main targets of the current study. This analysis is important to determine qualitative and semi quantitative information of the minerals found in silica sand samples.

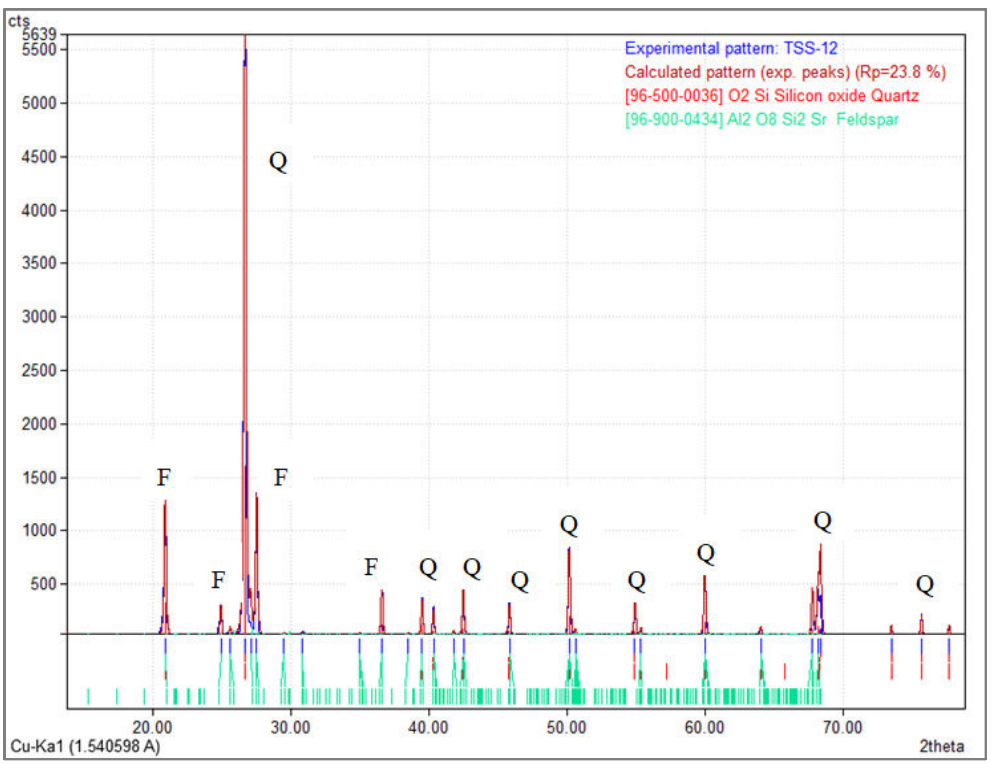
Using the X-Ray Diffraction method, the mineralogical analysis is determined by the qualitative and semi quantitative identification of mineralogical phases within crystalline materials. After the analysis of the diffractograms generated by the Shimadzu model XRD-7000 X-ray diffractometer, the entire mineralogy of selected sample of Tegora silica sand was conducted. Using “match! 3” data processing software, the major mineralogical phases were identified, and the semi-quantitative estimates were based on maximum intensity values on X-ray diagrams (Nasri et al., 2021).

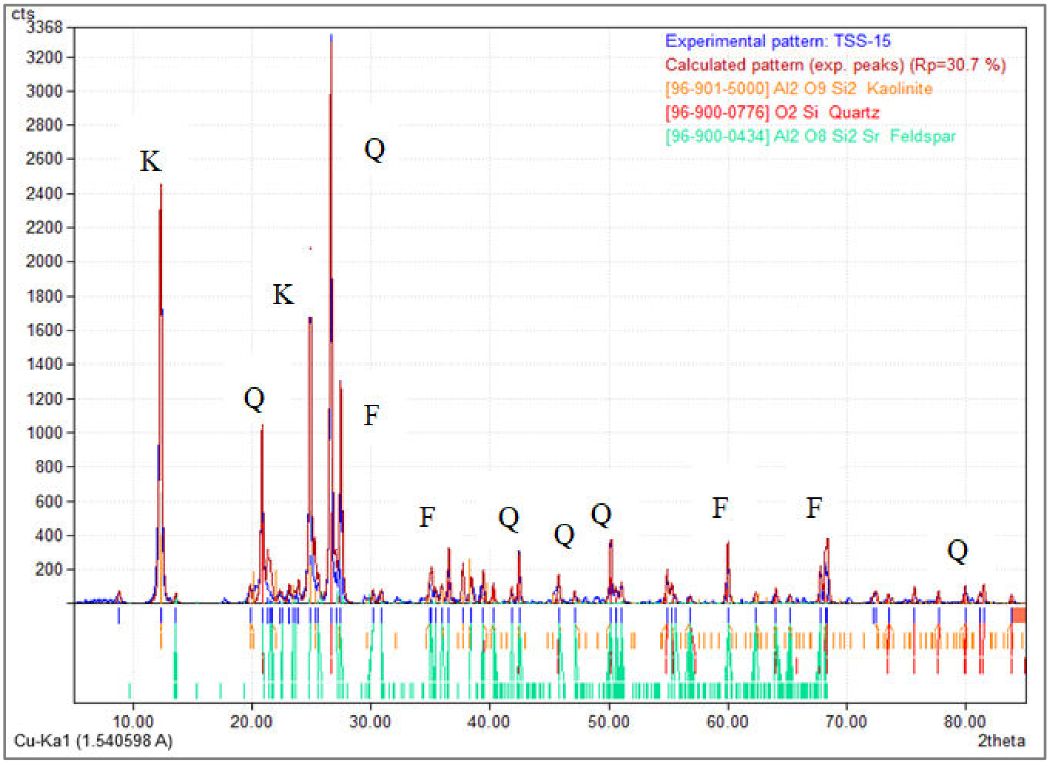
The X-ray diffractograms of an examined sample are displayed in Figure 5.11. The mineral phases identified include quartz, tridymite, kaolinite, and feldspar. The XRD major picks occur at the maximum intensity of the diffracted beam in counts (Fig 5.11). The picks values are developed at specific crystallized minerals that correspond to the 2theta values. The pattern of the picks is determined by the intensity beams of quartz, tridymite, kaolinite, and feldspar. The crystalline structures of minerals are identified from the diffracted beam energy. Quartz, kaolinite, and feldspar show the most diffraction picks. These highest diffraction beams reveal to us the most abundant mineral phase of the studied Tegora quartz sand samples.


cts
Experimental pattern: TSS-08
Calculated pattern (exp. peaks) (Rp=31.8 %)
[96-900-0776] O2 Si Quartz
[96-901-3493] O2 Si Tridymite
Q
Td
Q
Td
Td
Td
Q
Q
Q
Cu-Ka1 (1.540598 A)
2theta


cts
Experimental pattern: TSS-09
Calculated pattern (exp. peaks) (Rp=22.5 %)
[96-900-9235] Al2 H4 O9 Si2 Kaolinite
[96-900-0776] O2 Si Quartz
Q
K
Q
Q
Q
Q
Q
Q
Cu-Ka1 (1.540598 A)
2theta


cts
Experimental pattern: TSS-10
Calculated pattern (exp. peaks) (Rp=35.2 %)
[96-500-0036] O2 Si Silicon oxide Quartz
Q
Cu-Ka1 (1.540598 A)
2theta


cts
Experimental pattern: TSS-12
Calculated pattern (exp. peaks) (Rp=23.8 %)
[96-500-0036] O2 Si Silicon oxide Quartz
[96-900-0434] Al2 O8 Si2 Sr Feldspar
Q
F
Cu-Ka1 (1.540598 A)
2theta



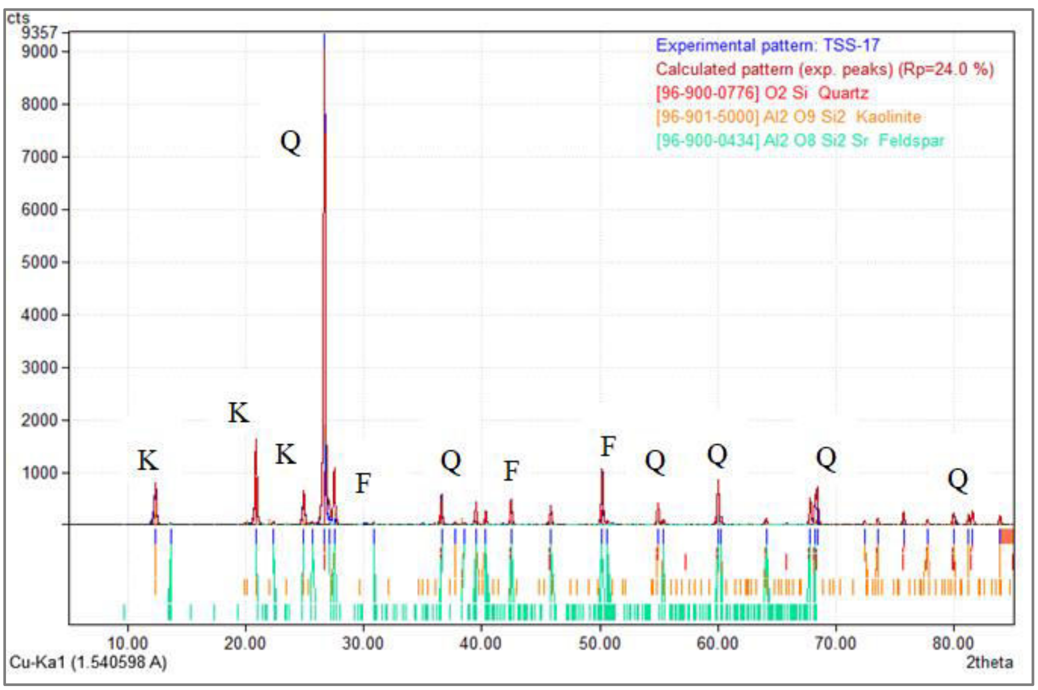


Figure 5.11: X-ray diffraction pattern of 6 selected silica sand samples from Tegora area (Q=Quartz, K=Kaolinite, Td= Tridymite, and F=Feldspar).

Table 5.6 illustrates the semi-quantitative estimate of the samples' mineralogical phases. Sample TSS-10 has the highest quantity of quartz (100%), whereas sample TSS-15 has the lowest level (59%). In Table 5.6, we also note the presence of the lowest proportions of minerals such as feldspar and kaolinite with a percentage of 6.2%, and 24.3 % for samples TSS-17 and TSS-09 respectively. In contrast, samples TSS-12 and TSS-15 have the highest contents of feldspar and kaolinite with a percentage of 14.5% and 30.4% successively.

Table 5.6: Semi quantitative XRD mineralogical Analysis of 6 Tegora silica sand samples

	Relative mineralogical composition (%)			
Sample	Quartz	Feldspar	Kaolinite	Tridymite
TSS-08	92.9	-	-	7.10
TSS-09	75.7	-	24.3	-
TSS-10	100	-	-	-
TSS-12	85.0	14.5	-	-
TSS-15	59.0	10.6	30.4	-
TSS-17	67.1	6.2	26.8	-

The result of the XRD mineralogical findings is shown in figure 5.12. The finding of analyses shows that the Tegora silica samples had substantial quantities of quartz, with average percentages proportion of 80%, followed by (kaolinite= 13.58%), (feldspar=5.22%), and (tridymite=1.18%).

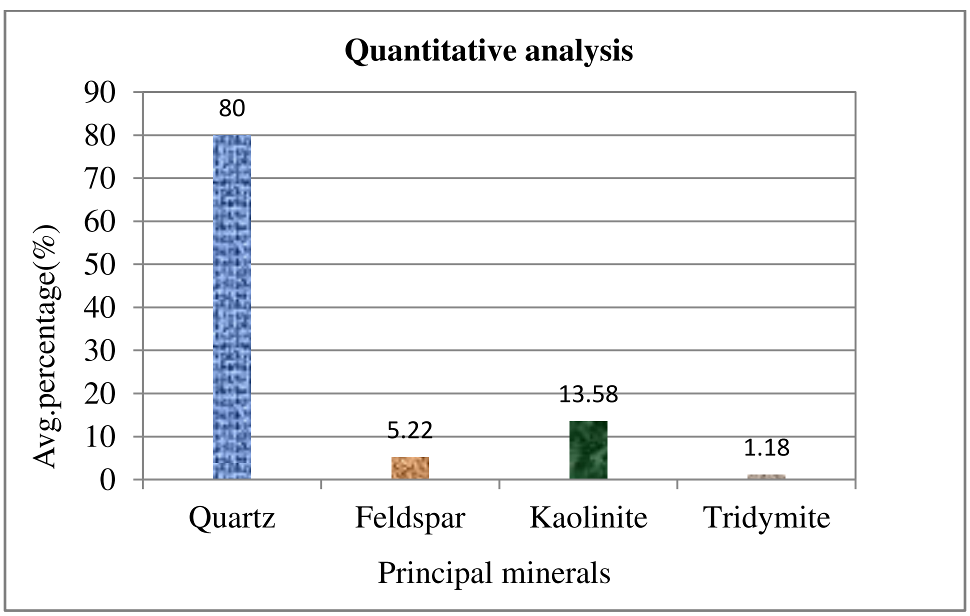


Figure 5.12: Graphical presentation of principal minerals of Tegora silica sand deposit

5.6 Deposit estimation and classification

As stated in the literature review section of the study, estimation, and classification of the mineral resources are one of the main important activities of this study. It demonstrates the deposit's potential for profitable exploitation (Kogel et al., 2006). The resource estimation method for the present project work was conducted by the conventional approach using the geological map of the study area, field survey, and laboratory data. Based on site investigation (thickness measurement of the deposit using GPS tool), in various sections of the research sites, there are a hundred meter thick sand deposit with some variations. The deposit's thickest block was located close to Debay (~ avg. 149 m thick) and Genet (~avg. 119 m thick) and Aferbayine (~ avg. 125 m thick) areas. Accordingly, the host rock has an average thickness of approximately 141 m. A silica sand deposit covers around an average of 137 m thick of the unit's vertical section. The remaining non-silica sand layers including conglomerate, siltstone, and mud rock was makes up an average of 4.04m thick (3%) of the deposit. Since the thickness of the deposit is not constant, the resource estimation considers this variation and weighted average thickness of the deposit is used. Additionally, the study area is further divided in to three blocks (Debay, Genet and Aferbaynie) considering thickness variations (Table 5.7).

According to Moon et al. (2006), the equation used to estimate resources (tonnage) by the conventional method is provided as given below; T = A * Th * BD. Where T is the tonnage of deposit, in tons; A: areal extent computed from the geological map of the study area using Arc Map 10.8 tool, m^2; Th: average thickness of the deposit (in m) obtained from the field investigation of the study area; and BD: is the bulk density of sand from laboratory result (g/cm^3).

Hence, based on Table 5.7 below, the total estimated tonnage (T) of the silica sand deposit within the mapped area only is: T = t1 +t2+t3, where t is tonnage of silica sand in each block (in tone).

T = 2.744 Bt +0.933 Bt+0.539 Bt

= 4.22 billion tones (Bt). This deposit estimation considers Tegora silica sand resource within the mapped area only.

Table5. 7: Estimated resource of Tegora silica sand deposit

Name of the blocks		A (m^2)		Th (m)		BD (g/cm^3)	Tonnage of silica sand of each block	Amount of non-silica sand layer of each block	Total tonnage of silica sand of each block	Total tonnage of silica sand of the area	Total amount of non-silica sand layer of the area
		silica sand deposit	non silica sand layer	silica sand deposit	non silica sand layer						
Debay	D1	3453071	26929	202	7.0	1.79	1.25Bt	0.34 Mt	2.744Bt	4.22Bt	0.804Mt
	D2	2931053	15947	146.5	3.5	1.79	0.77Bt	0.099Mt			
	D3	1992971	20029	123.75	5.25	1.79	0.442Bt	0.188Mt			
	D4	1470650	9350	107	1.5	1.79	0.282Bt	0.025Mt			
Genet	G	4489249	10751	116	3.0	1.79	0.933Bt	0.058Mt	0.933Bt		
Aferbaynie	A	2486909	13091	121	4.0	1.79	0.539Bt	0.094Mt	0.539Bt		

A = Area, Th =Thickness, BD= Bulk density, Bt= billion ton, Mt= million tone

This resource is categorized as an indicated mineral resource because of the increasing level of geological understanding and confidence (JORC code, 2012). This is due to the study's emphasis only on field data, geological maps, and technological properties tests, which cannot be used to validate the deposit's geological and quality continuity. According to the JORC code (2012), this resource might be transformed to a measurable level(reserve level) with the addition of detail sampling closely spaced drilling and borehole data and consideration of other modifying factors such as degree of geological, geochemical, geophysical, remote sensing studies and other non-geological factors (Fig.2.7).

CHAPTER SIX

DISCUSSION

6.1 Introduction

Silica sand, one of the most common minerals, can be found in a number of forms, such as quartz crystals, quartz sand, silica sands, and so on. It is used as a crucial industrial component in many different sectors (Rafi et al., 2018). The major markets for silica sand are glass, hydraulic fracturing, foundries, construction materials, and chemicals; along with a few minor ones (Mohammad, 2015). These silica sand applications depend on technological (physicochemical) properties (Shaffer, 2006; Edem et al., 2014; Platias et al., 2014). Hence, it is better to determine physicochemical characteristics analysis to demonstrate its suitability for various industrial applications.

The technological characteristics of the Tegora silica sand deposit were examined in the current study by field observation and laboratory analysis. The findings of the derived physicochemical analyses are assessed and discussed in this chapter to determine potential industrial uses of the deposit.

6.2 Quality of Silica sand

The conditions of sedimentation, mineralogical, chemical composition, and depositional environment all affect the grade and quality of silica sand deposit (Edem, 2014; Shaffer, 2006). The findings of the mineralogy, chemical and physical tests are used to evaluate the grade, quality, and its suitability for possible industrial applications of Tegora silica sand.

6.2.1 Physical properties

The primary textural parameter that indicates the physical quality of a silica sand deposit, according to Shafer ((2006), is the grain size destribution. The investigated silica sand deposit's grain size parameters are in accordance with various industry demands to variable degrees. According to Fig. 6.1 (A) and (B), 78%(0.5-0.09mm) of the grains fall within the acceptable range for glass-making sand, while an average of 61% (2-0.29mm) of the grains meet the requirements for filter media sand. 92.54 %(0.9-0.08mm) of the grains in the examined silica sand deposit fall within the range of foundry sand, and 15.73% (2-0.5mm) are within the suitable range for abrasive sand. Additionally, 59.75% (0.84-0.15mm) and 60.90 %(2.38-0.27mm) of the grains satisfy the specifications for chemical and hydraulic fracturing sand, respectively.

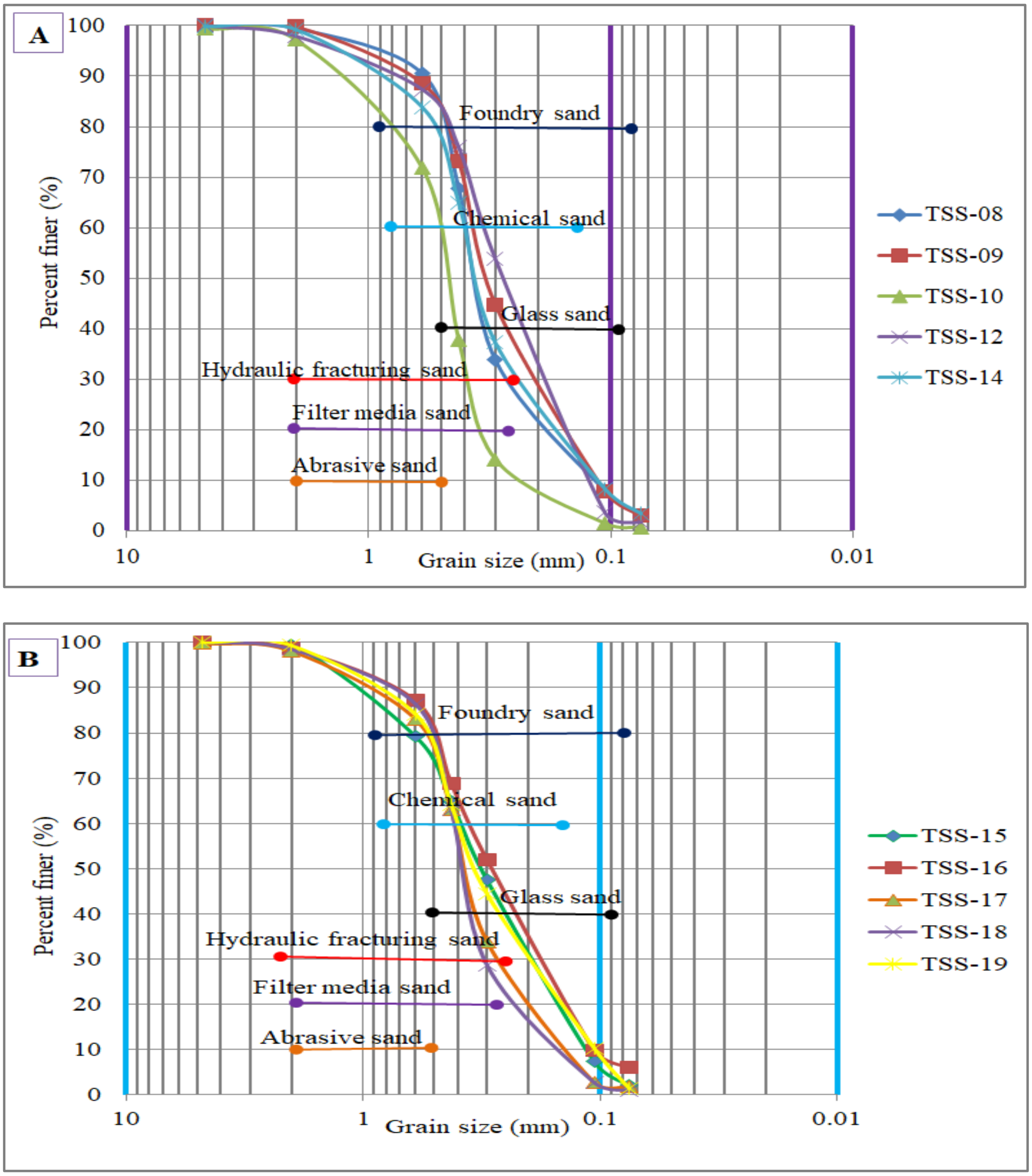


Figure 6.1: (A) and (B): Tegora silica sand grain size distribution curves and regularly used size ranges for applications in a variety of industries (McLaws, 1971; Ismaiel et al., 2017).

The computed findings of coefficient of curvature (avg.1.19) and coefficient of uniformity (avg.3.01) value show that the Tegora silica sand sample is poorly (uniformly) graded, despite the slight fluctuation in values (Kalinski, 2011). The deposit is representing to be mainly composed of a specific range of grain (sand) sizes.

The limit for very well-sorted and well-sorted sediments, which is not greater than 0.35 and 0.35 to 0.50 respectively, is determined while comparing the average standard deviation value of the Tegora silica sand deposit (0.32 and 0.44) with Folk and Ward's (1957) sorting verbal scale. This suggests that sediments with a limited range of particle size variation make up the silica sand deposit under the study. The Tegora silica sand samples' median size (D50), which ranges from 0.29 to 0.49 mm, reveals that the examined silica sand samples are typically medium-grained in size.

The morphology of the quartz sand particles is determined by the interaction between lithology, particle size, mechanism and duration of movement, the energy of the transporting medium, type, and degree of post-depositional weathering, and the history of sediment transport and deposition (Franzi, 2003). It is also other physical parameters that indicate the quality of quartz sand resource. Depending on the application industry, this parameter's requisite characteristics vary. The shape of the quartz particles is crucial because it determines how they melt while manufacturing glass; if the particles are too needle-like, they won't melt uniformly (the ends of the needles melt first), whereas circular particles tend to melt evenly (McLaws, 1971; Ismaiel et al., 2017). The most desirable sand particle morphology parameter to fulfill the requirements of glassmaking sand is homogenous (Ismaiel et al., 2017). Rounded sand grains are suitable when the silica sand's permeability is required for the industry; on the other hand, angular sand grains are desired when the silica sand's rate of melting is essential (Kogel et al., 2006). Tegora silica sand is represented by an abundance of angular to sub angular (avg.83.27%) and less spherical (avg.100%) sand grains, as demonstrated in the result section 5.3. 2 (Fig. 5.5). Accordingly, in the glass, and cement industries the aforementioned grain shape is most preferred (McLaws, 1971).

6.2.2 Chemical properties

The silica sand deposit's purity level is determined by its chemical composition. According to Kogel et al. (2006), pure sand has a high silica concentration and relatively few contaminating oxides. Accordingly, the Tegora silica sand deposit under investigation has an average SiO_2 concentration of 92.25% and less than 8% of undesirable metal oxides such as Al_2O_3, Fe_2O_3,

K_2O, TiO_2, and Na_2O. As stated in section 5.5, abundant Tegora sand samples were located in the quartz arenite part of clastic deposits using geochemical classification techniques, although some are found in the Fe-sand, lith arenite, and sub-lith arenite sections (Fig.5.8) (Herron,1988). This confirms the silica sand deposit under study is high chemical purity. According to Potter (1978) and Noori et al. (2014), the sandstone's quartz-rich composition and chemical maturity index is represented by the sandstone's high SiO2 concentration and high SiO_2/Al_2O_3 ratio, which are more than ten. As a result, the silica sand that is the subject of the current study contains high SiO2 contents (on average 92.25%) and a SiO2/Al2O3 ratio above 10 (on average 14.30%). This result also implies the high chemical maturity of the investigated silica sand deposit.

6.2.3 Mineralogy

Based on the XRD analyses of the Tegora silica sand deposit, quartz, kaolinite, feldspar, and tridymite show the most diffraction picks. From the analysis of the findings that quartz (SiO2), which revealed a high phase average percentage of above 80%, is the major crystalline component of the Tegora silica sand samples. As presented in section 5.5 (Fig. 5.11), the X-ray diffraction pattern shows the existence of all the peaks associated with the presence of quartz in a sample of Tegora silica sand, thus confirming the abundance of crystallinity. The physicochemical characteristics and these results are entirely consistent (with excellent agreement).

6.3 Specifications and possible industrial applications

The essential characteristics studied from silica sand deposits to evaluate their appropriateness for possible industrial fields of use are physical and chemical parameters (McLaws, 1971; Platias et al., 2014). The majority of the standard requirements are related to high-purity silica sand, which is essential for making glass, silicon carbide, and soluble silicates for the chemical sector, as well as molding sand, hydraulic fracturing sand, ceramic, and filter sand. Less pure sands used in specialized applications like sandblasting, abrasives, and construction materials are subject to additional standards (McLaws, 1971).

6.3.1 Glass sand

Chemical makeup, grain size, and grain shape are the primary characteristics investigated from the Tegora silica sand deposit to assess its appropriateness for the glass industry. Chemical compositions control the color, melting temperature, transparency, viscosity and permeability of glass sand. According to British standard: 2975 (1988) and Norton (1957, silica sand should have a maximum range of 0.013% to 0.3% of Fe_2O_3, 0.5% to 3.0% of Al_2O_3, 0.1% to 0.2% of LOI, and 2.5% of total alkalis whereas the minimum quantity of SiO_2 (94.5% to 99.8%) is required to be the studied sand deposit used for glass manufacturing (Table 6.1). The samples from the Tegora area fall within the appropriate class of the standard for their average concentration of total alkalis (avg. 0.47%). The average amount of SiO_2 (92.25%), Al_2O_3 (6.45%), and Fe_2O_3 (0.63%), on the contrast, does not meet the standards. Although perhaps more than 50% of the samples (TSS-08, TSS-09, TSS-10, TSS-12, TSS-17, and TSS-18) have a higher concentration, the average amount of SiO_2 is slightly below the standard specifications. Al_2O_3 and Fe_2O_3 on the other hand located at a higher amount than the standard. These explanations demonstrated that the Tegora area's silica sand deposit is not directly suited for the glass manufacturing. The deposit might be a potential supply of glass sand, if it can successfully execute certain beneficiation procedures and its SiO_2, Al_2O_3, Fe_2O_3, and LOI amount meet the requirements of the standard.

The melting properties of Tegora sand grains are determined by the grain size distribution. In order to be employed in the glass industry, its grain size distribution should lie between the ranges of 0.5 mm to 0.09 mm (Ismaiel et al. 2017). Since the larger grains may melt more slowly than smaller ones or they may not melt at all, resulting in "stones" in the finished product, whereas the finer grain is more likely to include iron oxide. According to the study that has been done here so far, 78% of the grains on average from the Tegora area fall within the required size range of 0.5 mm to 0.09 mm screen size. These characteristics demonstrate the deposit's appropriateness for the production of glass sand.

While producing glass, the melting properties of sand grains are influenced by their morphology. The grain shape or morphology must be angular and spherical rather than rounded, according to (Tate, 2015). These characteristics explain why the Tegora silica sand deposit's majority of sand grains have an angular shape. These characteristics improve the deposit's suitability for manufacturing glass (Table 6.1).

Table 6.1: Suitability of Tegora silica sand deposit for glass manufacturing based on Norton (1957), and BS: 2975 (1988) Standards.

<table>
<tr><td colspan="6">Chemical compositions (wt. %)</td><td rowspan="3">Suitability of the examined silica sand deposit for glass industries</td></tr>
<tr><td>Product (glass)</td><td>SiO_2 (min)</td><td>Al_2O_3 (max)</td><td>Fe_2O_3 (max)</td><td>CaO+MgO (max)</td><td>LOI (max</td></tr>
<tr><td>Optical glass</td><td>99.8</td><td>0.1</td><td>0.02</td><td>0.1</td><td>0.2</td></tr>
<tr><td>Green glass</td><td>95</td><td>4</td><td>0.3</td><td>0.5</td><td>-</td><td rowspan="7">It require certain beneficiation to meet the specification</td></tr>
<tr><td>Fiber glass</td><td>94.5</td><td>3</td><td>0.3</td><td>-</td><td>0.5</td></tr>
<tr><td>Flint glass</td><td>95</td><td>4</td><td>0.035</td><td>0.5</td><td>0.2</td></tr>
<tr><td>Amber glass</td><td>95</td><td>4</td><td>1</td><td>0.5</td><td>-</td></tr>
<tr><td>Borosilicate glass</td><td>99.8</td><td>0.2</td><td>0.01</td><td>-</td><td>0.1</td></tr>
<tr><td>This study</td><td>92.25</td><td>6.45</td><td>0.63</td><td>0.06</td><td>2.15</td></tr>
<tr><td colspan="6">Physical properties</td></tr>
<tr><td colspan="6"></td><td>Suitability of the examined silica sand deposit for glass industries</td></tr>
<tr><td>Product (glass)</td><td colspan="2">Gain size</td><td colspan="2">Gradation (uniformity)</td><td>Grain shape</td><td rowspan="8">Suitable for glass manufacturing with a given physical parameters</td></tr>
<tr><td>Optical glass</td><td colspan="2" rowspan="6">Dominant retention between 0.5mm and 0.09mm size</td><td colspan="2" rowspan="6">Uniformly graded</td><td rowspan="6">Angular, sub angular and rounded</td></tr>
<tr><td>Green glass</td></tr>
<tr><td>Fiber glass</td></tr>
<tr><td>Flint glass</td></tr>
<tr><td>Amber glass</td></tr>
<tr><td>Borosilicate glass</td></tr>
<tr><td>This study</td><td colspan="2">>78% of grains retain on size range of 0.09 to 0.5 mm</td><td colspan="2">Uniformly graded</td><td>Dominantly angular to sub angular</td></tr>
</table>

6.3.2 Foundry sand

In the iron and steel industries, the Tegora silica sand resource can be utilized as foundry material. The Indian Standard IS: (1987-1974) specifies that silica sand should contain at least 90% SiO_2 and at most 5% Al_2O_3, 1.5% Fe_2O_3, 1.5% $NaO+K_2O$, and 2% $CaO+MgO$ for use as foundry material (Table 6.2).). The study of the Tegora silica sand deposit's chemical properties for the foundry industry using standards revealed that most of the deposit (71.43%) has a high potential for producing high-quality foundry sand.

The grain size distribution is one of the basic physical properties of silica sand that determines w hether it is suitable for the foundry industries. According to Brown (2000), a minimum of 95% of the sand grains should only be distributed through four or five consecutive sieves to provide suitable foundry sand. Moreover, the foundry uses high silica sand must have a narrow grading and only 70% or more of the raw grains should be retained on the three successive sieves (Table 6.2) (IS: 1987-1974). In this way, 96.4% of the Tegora silica sand grains are retained on five successive screens, such as 0.6 mm (14.574%), 0.425 mm (19.832%), 0.3 mm (25.346%), 0.106 mm (32.792%), and 0.075 mm (3.84%), or 78% of the sand grains are restrained on three successive screens, which included 0.425 mm (19.832%), 0.3 mm (25.346%), and 0.106 mm (32.792%). This guarantees that the Tegora industrial sand deposit is within a range that is appropriate for foundries.

Angular to sub-angular silica sand grains are not suitable for producing molds and cores since they consume a high amount of binder and provide higher permeability (IBM, 1993). Samples collected from the research area were examined using scanning electron microscopy, which revealed that the bulk of the sand grains have angular to sub-angular grain shapes. Tegora silica sand grains are determined to have an undesired limit of roundedness and sphericity to be employed in the foundry sector.

Table 6.2: Chemical and physical specifications for using Tegora silica sand in foundry industries (IS: 1987-1974, and Brown, 2000).

Chemical compositions (wt. %)						Suitability of Tegora silica with a given standard for foundry application
IS (1987-1974)				Brown (2000)	**This study**	
	Grade 'A'	Grade 'B'	Grade 'C'			
SiO_2 (min	98	95-98	90-95	95	92.3	Suitable for grade: ' C' foundry
Al_2O_3 (max)	1	1.5	5	-	6.45	improvement is required
Fe_2O_3 (max)	1	1	1.5	0.3	0.63	Suitable for all grade foundry
CaO (max)	-	-	-	0.2	0.01	Suitable for making foundry
CaO+MgO(max)	1	1	2	-	0.06	Suitable for all grade foundry
$NaO+K_2O$ (max	0.5	0.5	0.5	1.5	0.41	Suitable for all grade foundry
LOI (max)	-	-	-	0.5	2.15	Improvement is required

Physical properties				Suitability of Tegora silica with a given standard for foundry application
IS (1987-1974)		Brown (2000)	**This study**	
Grain size distributions	70% on 3 consecutive sieves	95% on 4 or 5 consecutive sieves	78% on 3 sieves or 96% on 5 sieves	Suitable for foundry industry
Grain roundness	Sub angular to rounded	Rounded	Dominantly angular to sub angular	Improvement is required
Grain sphericity	-	medium to high	Dominantly less sphericity	Improvement is required
Fineness amount (<0.075mm)	4% (max)	2% (max)	2.40%	Suitable for foundry industry

6.3.3 Abrasive sand

Tegora silica sand resource can be used as a scouring agent to clean the surface of metals, glass, and dimension stones. Chemical composition determines the amount of dust generated during using the sand whereas grain size and grain shape control the application area of abrasive sand (IBM, 1993). According to McLaws (1971), the chemical specification for selecting a silica sand deposit as an abrasive commodity is given as a minimum of 78% SiO2 content. Accordingly, the chemical makeup of the investigated silica sand (avg. 92.25%) is within the desirable range for the abrasive industry.

Based on grain size distribution, McLaws (1971) divided silica sand and gravel used as abrasives into four grades (grades 1, 2, 3, and 4) (Table 6.3). Grade 1 includes finer sands whereas the subsequent grades (grades 2, 3, and 4), include coarser sands and gravels. As presented in Table 6.3, most of sand grains (avg. 34.41%) constituting Tegora silica sand deposit located in the range of grade 1 abrasive sand whereas the rest of the grade contains an averages grains of 15.73% grade2, 1.16% grade3, and 0.091% grade4. The dominant existence of angular sand grains in Tegora silica sand deposits is used when an incredibly smooth finish is not a key concern, such as in the steel industries. The specified physicochemical requirements were met by the Tegora silica sand deposit. As a result, it may be a suitable resource for obtaining good-quality abrasive sand.

Table 6.3: Grain size distribution of Tegora silica sand deposit with the corresponding grades of silica sand and gravel used as abrasive sand (McLaws (1971).

Grain size range(mm)	Grade	Grains in Tegora silica sand deposit (wt. %)
0.84-0.42	1	34.41
2.0 -0.59	2	15.73
2.0-3.0	3	1.16
4.75-2.36	4	0.091

6.3.4 Ceramic industry

British Standard: 2975 (1988) for utilizing high silica sand in making ceramic products specified a minimum of 97.5% of SiO2 and a maximum of 0.25% of Fe2O3, 1.9 Al2O3, and 0.3 of CaO. Accordingly, the abundances of SiO2 (avg. 92.25%), Al2O3 (avg. 6.45%), and Fe2O3 (avg. 0.63%) in the sample from the study area do not meet the requirements. Conversely, the average percentage of CaO (0.01%) is found in the suitable class of the specification. This explanation indicates that the Tegora area's silica sand deposit is not acceptable for producing ceramic industries directly. So far, the deposit has the potential to be a source of ceramic sand if it can successfully complete certain beneficiation procedures because the quantity of SiO2, Al2O3, and Fe2O3 satisfies the standard requirements.

6.3.5 Water filtration and treatment sand

To assess Tegora silica sand deposit's suitability for use in water filtration and treatment applications, the critical features must be considered: grain size distribution, grain shape and chemical composition.

GWP Consultants (2010) states that silica sand's grain size distribution controls how quickly water should be purified. The medium-sized sand grains are suitable for use as filtration media (Chatterjee, 2009). The coarser sands offer faster filtration but produce poor quality water whereas finer sands offer slower filtration rates but are more efficient at producing high-quality water. The Tegora silica sand deposit is represented by an abundance of medium-sized sand grains, as shown by the values of medium-sized sand grains (D50), which vary from 0.29mm to 0.49mm (avg. 0.35mm). Based on the aforementioned suggestions, the investigated silica sand deposit's properties make it a suitable resource for sand used in water filtration and treatment systems.

The uniformity of grain size also affects whether or not the sand is suitable for filtering. According to BS EN: 12904 (2005), coefficient of uniformity (Cu), and effective grain size (D10) of silica sand are critical parameters for filter media (Table 6.3). According to these standards, Tegora's silica sand resources are visible as poorly graded sand grains, as shown by the mean values of Cu (3.01), Cc (1.2), and D10 (0.15 mm). As a result, the examined silica sand deposit's characteristics make it a suitable deposit from which filter media sand, in particular, utilized for slow filtering system.

According to BS EN 12904: (2005) and IS 8419: (1977), angular and elongated grains lock and hinder flows in the filtering media. Samples collected from the study area were analyzed using SEM, which indicates that the bulk of the sand grains dominantly have angular to sub-angular and less spherical grain shapes. Tegora silica sand grains are determined to have an unacceptable limit of roundedness and sphericity to be employed in water filtration and treatment use.

The most important factor in choosing filter sand is its chemical inertness (McLaws, 1971). BS EN 12904: 2005 assigned the minimum and maximum quantity of SiO2 and Fe2O3 required for type2 and the lowest grade (type3) filter media is 80% and 2% respectively. In addition, IS: 8419 (1977), recommended employing high silica sand as a filtering medium if it had a minimal SiO2 content of 90% and an ultimate LOI value of 0.7% (Table 6.4). Accordingly, Tegora silica sand samples contain an average of 92.25% of SiO_2, 0.63% of Fe_2O_3, and 2.15% of LOI. Except for the LOI, the percentage of SiO_2 and Fe_2O_3 of the deposit is found in the specified limit for use in water filtration and treatment, particularly in medium grade (type2) and lowest-grade (type3) filter media.

Table 6.4: Chemical and physical specifications for using Tegora silica sand in water filter media (IS 8419: 1977, and BS EN 12904: 2005).

Chemical compositions (wt. %)	BS EN 12904: 2005				IS 8419: 1977	**This study**	Suitability of Tegora silica with a given standard for water filtration and treatment
	Type 1	Type 2	Type 3				
			D10<2mm	D10>2mm			
SiO2 (min)	96	80	80	80	90	92.25	Suitable for type 2 and type 3 filter media
Fe2O3 (max)	2	10	2	2	-	0.63	Suitable for all grade filter media
LOI (max)	-	-	-	-	0.7	2.15	Do not meet the specification

Physical properties	BS EN 12904: 2005		IS 8419: 1977	**This study**	Suitability of Tegora silica with a given standard for water filtration and treatment
	Fast filtration	Slow filtration			
Grain morphology	Rounded	Rounded	Rounded	Dominantly angular to sub angular	Do not meet the specification
Cu	<1.5	1.6-3.0	-	3	Suitable for slow filtration
D10	> 0.55mm	0.15-0.55mm	-	0.15mm	Suitable for slow filtration
Fineness amount (<0.075mm)	-	-	<5.0%	2.40%	Suitable for filter media

6.3.6 Cement industry

To make up for the lack of silica in the raw material mix, silica sand is used as an additive in cement manufacturing (IBM, 1993). IS: 488 (1980) recommended a minimum of 65% of SiO2 for the cement product. Additionally, BS: 2975 (1988) set out a maximal of 1.5% of MgO and less than 6% of Fe2O3 content to be selected for the cement industry. In a similar fashion to the above specifications, the Tegora silica sand samples contain an average of 92.25% of SiO2, 0.63% of Fe2O3, and 0.05% of MgO. Thus, the chemical characteristics of the studied sand are found within the desirable limit for using deposits as cement raw material.

6.4 Beneficiation methods for Tegora silica sand resource

As discussed in this chapter (section 6.3), the technological properties of most Tegora silica sand resources satisfy the specifications of different products. However, the deposit's chemical makeup does not fulfill the requirements for its use in the glass and ceramic industries. Fe2O3, Al2O3, and TiO2 are common impurities that inhibit the suitability of Tegora silica sand resource in the glass and ceramic industries. Due to the high purity of the investigated silica sand, upgrading the deposit can result in the production of further excellent-quality silica sands to meet the requirements of these industries. Kogel et al. (2006) suggested that washing, attrition scrubbing, and magnetic separation methods can remove metallic oxides present on the surface of sand particles. A typical example of silica sand deposit beneficiated by using this method was white silica sand deposits in the northeastern desert part of Egypt. As sampled Wadi Qena sand contains 81.284% of SiO2, 13.595% Al2O3, 0.109% Fe2O3, 0.192% TiO2, and 4.609% of LOI. After beneficiation, the percentage of SiO2 becomes 98.168%. In contrast, the concentration of Al2O3, Fe2O3, TiO2, and LOI attains 0.378%, 0.027%, 0.057%, and 1.307% respectively (Ismaiel et al., 2017). On the other side, Veglio et al. (1999) and Tarasova et al. (2001) suggested acid-leaching techniques for the effective enhancement of silica quality and removal of iron and other metallic contaminants found in the silica sand resource. For instance, this method was used to enhance the River Benue silica sand deposit in Nigeria's north-central region. The raw sand includes 0.71± 0.10% Fe2O3 and 93.95± 0.48% SiO2. After treatment with acid leaching methods, the amount of silica (SiO2) increases to 96.16 ± 0.07%, while the content of iron oxide (Fe2O3) decreases in a similar fashion to 0.42 ± 0.001% through samples (Edem, 2014). By considering the nature of materials (type of contaminants) present in the Tegora silica sand resource and the intended range of end uses, the aforementioned techniques of treatment could upgrade the contents of studied silica (SiO_2), with a corresponding decrease in the concentration of impurities. Ultimately may become the acceptable limit for various industrial uses. However, choosing the most appropriate techniques and correlating factors during beneficiations like geological, environmental, social, political, and technical factors requires further studies.

6.5 Economic aspects of Tegora silica sand deposit

Tegora silica sand deposit is manifested by a considerable number of important economic factors relating to sand deposits, such as the existence of local demand, a sufficient silica sand reserve, and its location near to the market, transportation, and processing facilities. Around 4.22 billion tons of silica sand are present in the Tegora area and fall within the category of indicated resources. Tegora's silica sand deposit is grouped into a large category of deposits according to Kuzvart (1984) since it has a deposit size of more than 5 million tons. This resource of the studied area can be mined for 50 years based on Ethiopia's present annual silica sand demand (84.5 million tons) (FDRE MoM, 2011).

The silica sand deposit under-investigated is accessible by a gravel road that connects Meranya town to the Tegora silica sand deposit area, which is close to Meranya town. Furthermore, in terms of distance to local demand, the Tegora silica sand resource is accessibly situated about 229 km and 180km from Addis Ababa and Debre Berhan respectively.

As discussed earlier, to improve its quality, industrial sand is frequently processed in various ways. Almost all processing methods use water to carry them out (Kogel et al., 2006). In order to ensure optimal processing, there should be a sustainable supply of water. In the researched area, the Jara River, a permanent river located approximately 3-5 km from the deposit site, can provide the water required for processing.

CHAPTER SEVEN

CONCLUSION AND RECOMMENDATION

7.1 Conclusion

The objective of this study was to determine the geology, physicochemical characteristics, and possible industrial use of Tegora Silica sand occurrence, in Central Ethiopia. In order to conduct these goals, different types of technical works and materials were conducted. It includes reviewing of literature, field geological observation, and analytical investigations (geophysical and geochemical laboratory analyses) were employed. From detail, geological, geophysical, geochemical, and mineralogical examinations of the Tegora silica sand deposit the following conclusions have been listed.

- ♦ The area's geological investigation reveals the presence of a variety of clastic to marine sedimentary strata, including limestone, mudstone, sandstone, and basalt, which are unconformably overlain by thick volcanic rock. The sandstone unit contains the quartz sand deposit in the Tegora area. In the study area's sandstone unit, it appears as white to light grey, poorly-consolidated sand layers interspersed with siltstone and conglomeratic beds.
- ♦ Physicochemical and mineralogical evaluation of silica sand resource from the Tegora area was conducted in this research study. The results revealed that;
    - ✓ The grain size of the Tegora silica sand deposit is dominated by sand-size grains (avg. 96.38%). From this, 92.54% falls within the recommended screen size (0.6mm- 0.106mm). Gravel (avg.1.25%) and mud (2.37%) together constitute the rest proportion of the deposit.
    - ✓ The Tegora quartz sand deposit is mostly composed of angular to sub angular and less spherical sand grains shape, according to SEM morphological analyses of the individual grains.
    - ✓ The studied sand deposit is very well-sorted, poorly graded, and mostly composed of medium-sized sand grains, as shown by the average values of σi (0.36), Cu (3), Cc (1.2), and D50 (0.35 mm).
    - ✓ As the result of the bulk density test, the investigated silica sand deposit is 1.79 g/cm^3.
    - ✓ Based on chemical composition analyses, silicon dioxide (SiO_2), which has an average concentration of 92.25 percent among all silica sand samples, is

the main metal oxide, followed by (Al_2O_3=6.45), (Fe_2O_3=0.63), (K_2O=0.3),(TiO_2= 0.17), (Na_2O= 0.11), (P_2O_5=0.08), (MgO=0.05), and trace contents of CaO, MnO, and Cr_2O_3.

- ✓ According to results of XRD analysis of the silica sand samples, quartz, kaolinite, feldspar and tridymite show the most diffraction picks. From the analysis of the findings that quartz (SiO_2), which revealed a high phase average proportion of above 80%, is the major crystalline component in each of the selected Tegora silica sand samples.

- ♦ Oxides of TiO_2 versus Al_2O_3 relationships reveals that the majority of the Tegora silica sand samples originated from felsic igneous rocks whereas some are sourced from the intermediate to mafic igneous source rocks. In similar manner, the field investigation of lithofacies evidences, the depositional environment of the examined industrial sand deposit is might to be continental alluvial to fluvial settings.
- ♦ The technological characterization of Tegora silica sand resource shows the deposit has a desirable quality to be a raw commodity for different industries like water filtration and treatment, abrasive, foundry, and cement industry without further beneficiation. Conversely, with the beneficiation of the deposit, the improved silica sand is utilized for glass and ceramic industries.
- ♦ By applying the conventional reserve estimation approach a total of 4.22 billion tons of silica sand resource have been estimated under indicated mineral resource category in the area. According to Ethiopia's current yearly silica sand demand (84.5 million tons), the resource might be continuously extracted for 50 years.

7.2 Recommendation

- The conventional resource estimating method used for this study only takes into account the area from the geological map and the thickness from geologic cross section. So, further drilling has to be recommended in order to scale up the deposit to a reserve level and more clearly see it in three dimensions.
- The present study mainly conducted by on site investigation, physicochemical and mineralogical analysis. In order to delineate further extension of the deposit towards northern, northwestern and southwestern segments outside of the study area, remote sensing method should be employed.
- Depending on the nature of the materials (the varieties of contaminants it contains), the desired range of end uses, market conditions, and financial circumstances, this study

suggested various techniques for increasing the quality of the Tegora silica sand deposit. Comprehensive investigations incorporating pilot testing of efficient beneficiation techniques should be carried out and advised in order to conduct the most effective methodology of beneficiation.

- Only a small scale of the construction is currently undertaken using the silica sand resource of the studied area. The resource has the potential to be used in a variety of industries, including water filtration and treatment, foundries, the cement industry, and more, as the current study demonstrates. This report recommends other industries extensively utilize the Tegora area's silica sand deposit.
- The appropriateness of the commodity for various sectors is demonstrated in this study using the standards set by other countries. Ethiopia should establish thorough local standards for the typical application sectors of silica sand, in order to evaluate the applications of the resource for different industries.
- Additional study with the help of petrography and geochemistry method should be applied in order to determine the provenance and depositional setting of Tegora silica sand deposit.

References

Anaekwe, N., & Yusuf, H. (2017). Chemical Evaluation of the Glass Making Potentials of Silica Sand Deposits Along Cross River in Cross River State, South–East of Nigeria. *European Journal of Engineering Research and Science,* 2(6), 12–17.

Assefa, G. (1981). Gohatsion formation: A new lias-malm lithostratigraphic unit from the Abay river basin, Ethiopia. *Geoscience Journal*, 2(1), 63–88.

Assefa, G. (1991a). Lithostratigraphy and environment of deposition of the Late Jurassic-Early Cretaceous sequence of the central part of Northwestern Plateau, Ethiopia. *Neues Jahrbuch Für Geologie Und Paläontologie-Abhandlungen*, 182(3), 255–284. https://doi.org/10.1127/njgpa/182/1991/255

Assefa, G. (1991b). The mineral resources potential of Ethiopia. *Bulletin of Chemical Society of Ethiopia*, 5(2), 111–137.

Assefa, A., & Knoth, W. (1992). Geological Research and Evaluation for Sheet Glass Raw Materials in Shewa, Harerge and Sidamo Administrative Regions. GSE, Addis Ababa, Ethiopia.

Ayalew ,D. & Yirgu, G. (2003). Crustal contribution to the genesis of Ethiopian plateau rhyolitic ignimbrites: Basalt and rhyolite geochemical provinciality. *Journal of the Geological Society*, 160(1), 47–56. https://doi.org/10.1144/0016-764901-169.

Ayers, J.C., Watson, E.B., 1993. Rutile solubility and mobility in supercritical aqueous fluids. Contributions to Mineralogy and Petrology 114, 321–330

Berhe, S., Desta, B., Nicoletti, M., & Teferra, M. (1987). Geology, Geochronology and Geodynamic Implications of the Cenozoic Magmatic Province in W and SE Ethiopia.” *Journal - Geological Society*, 144(2), 213–26.

Beyth, M. (1972). Paleozoic-Mesozoic Sedimentary Basin of Mekele Outlier, Northern Ethiopia. *AAPG Bulletin*, 56(12), 2426–39.

Boggs, S. Jr. (2014). Principles of sedimentology and stratigraphy. *Pearson Education*(n.d).

Bourne, H. L. (1994). Glass raw materials. In D. D. Carr (Eds.), Industrial minerals and rocks. Littleton, CO: *Society for Mining, Metallurgy, and Exploration*, 543-650.

British Geological Survey. (2009). Silica Sand. BGS, London, England

Brown, J. (2000). Foseco Ferrous Foundryman's Handbook. Oxford, United Kingdom: Foseco International Ltd.

Central Statistical Agency of Ethiopia (2007). Population of Mida Woremo Woreda. accessed on 8 November 2022 (http://www.statsethiopia.gov.et/).

Chatterjee, K., (2009). Uses of Industrial Minerals, Rocks and Freshwater. New York: Nova *Science Publishers*.

Christidis, G. (2011). Industrial Minerals. Significance and Important Characteristics. In G. Christidis (Ed.), Advances in the Characterization of Industrial Minerals (Pp. 1–12). Chania, Greece.

CIM. (2010). CIM Definitions Standards:-For Mineral Resources and Mineral Reserves. *514*, 1–10.

Crockford, M.B.B (1949). Geology of the Peace River glass sand deposit; *Research Council of Alberta, RCA/AGS Information Series* 7, 24 p.

Crow, J.M. The concrete conundrum. *Chem. World* 2008, 5, 62–66.

Daba, B., Abate, A. , Mulu, R., and Metasebiya, M., (2016). Silica Sand Exploration and Evaluation in Atsbi Wonberta and Sasete Saedamba Woredas in Tigray National Regional State. GSE, Addis Ababa, Ethiopia.

Daniel, M., Dejene, H., and Abrham, M., (2010). Geology of Debrebrhan area. GSE.

Daniel, M., and Ryuichi, S., (2007). Crystal contamination and diversity of magma sources in the northwestern Ethiopian volcanic provinces. *Mineralogical and Petrological Sciences.* 102:272-290.

Das, B. (2002). Soil Mechanics Laboratory Manual (6 th ed.). Oxford, United Kingdom: Oxford University.

Lebenie ,D. (2010). Adigrat Sandstone in Northern and Central Ethiopia: stratigraphy, facies, and depositional environments. Unpublished Ph.D. thesis Technische Universität, Berlin. 166 pp.

Dolley, T. P. (2004a). Silica: 2004 Minerals yearbook (Vol.1). Washington DC: U.S. Geological Survey, 1-14.

Dowdeswell, J. (1982). Scanning Electron Micrographs of Quartz Sand Grains from Cold Environments Examined Using Fourier Shape Analysis. *Journal of Sedimentary Petrology,* 52(4), 1315–23.

Dustman, J., Gulbransons, B., Bell, P., Gregg, W. (2011). Characteristics of High Quality Frac Sand, and Where to find it in the Upper Midwest. *Geological Society of America*, 43(5), 1–2.

Duvuna, G. A., Ayuba, A., Zhigilla, Y. I., & Tashiwa, Y. I. (2019). An investigation on the chemical and physical properties of gada and muvur silica sand for glass making. *Nigerian Journal of Technology*, *38*(4), 871.

Edem, C. A. (2014). Characterization and Beneficiation of the Glass Making Potentials of Silica Sand Deposit from River Benue North Central Nigeria. *Journal of Natural Sciences Research*, *4*(19), 49–59.

FDRE MoM. (2011). Minerals for Agricultural Industrialization Minerals for Food Self SufficiencyQuartz/Silica Sand Soda Ash. (Retrieved 12November, 2022(http://www.mom.gov.et/Industrial.aspx?id=34.

Freestone, I. C. (2005). The provenance of ancient glass through compositional analysis. *Materials Research Society Symposium Proceedings*, 852, 1-14.

Getaneh, W. (2002). Geochemistry provenance and depositional tectonic setting of Adigrat Sandstone northern Ethiopia. *Journal of African Earth Sciences*, 35: 185-198.

Getaneh, W. & Tadesse,S. (2015). Text book of Economic Geology. Addis Ababa, Ethiopia: Addis Ababa University.

Goldman, H. B. (1994). Glass raw materials. In D. D. Carr (Eds.), Industrial minerals and rocks. Littleton: *Society for Mining, Metallurgy, and Exploration*, 869-877.

GWP Consultants. (2010). A Study of Silica Sand Quality and End Uses in Surrrey and Kent. Surrey and Kent Councils, Oxford, United Kingdom .

Hamidullah, S., Tahir, S., & Asif, K. (1996). Identification and Characterization of the Quality of Silica Sand Resources from Munda Gucha, District Mansehra, in Glass Making. Geol. Bull. Univ. Peshawar, 29, 59–68.

Harris TS. (1986) Extender and filler mineral markets in the western United States and Canada. *CIM Bull*., May, 48-51.

Hayashi, K., Fujisawa, H., Holland, H., Ohmoto, H., 1997. Geochemistry of ~1.9 Ga sedimentary rocks from northeastern Labrador, Canada. *Geochimical Cosmochimica Acta* 61, 4115–4137.

Heck, M. & Hoffmann, P. (2002). Analysis of early medieval glass beads: The raw materials to produce green, orange and brown colours. *Mikrochimica Acta*, 139, 71-76.

Heinrich, E. (2001). Economic geology of the sand and sandstone resources of Michigan. Michigan Department of Environmental Quality (DEQ) *Geological Survey Division* (GSD), Michigan

Hofmann, C., Courtillot, G., Rochette, P., Yirgu, G., Ketefo, E., & Pik, R. (1997). Timing of the Ethiopian Flood Basalt event and implications for plume birth and global change. nature, 389(6653), 838–41.

Ismaiel, H., Mohamed, H., Askalany, M., & Ali, I. (2017). Evaluation of White Silica Sands in North Eastern Desert, Egypt. *International Journal of Scientific & Engineering Research* 8(5), 1713–22.

Jelenc, D. (1964). Report on Silica Sand Occurrences in Ethiopia. GSE, Addis Ababa, Ethiopia.

Jie, Y., Xianguang, H. O. U., & Bergstro, J. A. N. (2006). Distinguishing anomalocaridids from arthropods and priapulids. *Geological Journal*, 269(August), 259–269. https://doi.org/10.1002/gj

Kalinski, M. (2011). Soil Mechanics Lab Manual. New York: John Wiley &Sons.

Kazmin, V., 1972. The Precambrian geology of Ethiopia and some aspects of the geology of

the Mozambique belt. *Bulletin of the Geophysical Observatory* 15, 27–43.

Kazmin, V., (1975). Explanations of the Geological map of Ethiopia. Ethiopian Geological Survey, *Bulltein*. 1: 1-15.

Ketner, K. B. (1973). Silica sand. In D. A. Brobst and W. P. Pratt (Eds.), United States mineral resources professional paper 820. Washinton, DC: U.S. Geological Survey, 577-580.

Kieffer, B., Arndt, N., Lapierre, H., Bastien, F., Bosch, D., Pecher, A., Yirgu, G., Ayalew, D., Weis, D., Jerram, D., Keller, F. and Meugniot, C. (2004). Flood and shield basalt from Ethiopia: magmas from African supper swell. *Journal of petrology*. 44:793-834.

Kogel, J., Trivedi, N., Barker, J., & Krukowski, S. (2006). Industrial Minerals and Rocks (7 th ed.). Littleton, CO*: Society for Mining, Metallurgy and Exploration*.

Kogel, J. E., Trivedi, N. C., Barker, J. M., & Krukowski, S. T. (Eds.). (2006). Industrial minerals and rocks: Commodities, markets, and uses (7th ed.). Littleton, CO: *Society for Mining, Metallurgy, and Exploration*, Inc.

Kuzvart, M. (1984). Industrial Minerals and Rocks. Amsterdam: The Netherlands Elsevier.

Langer, W. H. (2003). A general overview of the technology of in-stream mining of sand and gravel resources associated potential environmental impacts, and methods to control potential impacts. In U.S. Geological Survey Open File Report OF-02-153 (version 1.0).

Leonid, L., Tibebu, M., Tesfaye, E., Hagos, Tadele., & Mamo, W. (1989). Evaluation of Sheet Glass Raw Materials (Silica Sand, Dolomite and Calcite Marble, Feldspar at North Shoa, West Harerge and Sidama). GSE, Addis Ababa, Ethiopia.

Lewin, A., Meinhold, G., Hinderer, M., Dawit, E. L., and Bussert, R.: Provenance of sandstones in Ethiopia during Late Ordovician and Carboniferous–Permian Gondwana glaciations: petrography and geochemistry of the Enticho Sandstone and the Edaga Arbi Glacials, Sediment.

Lewis, J. (2001). Michigans Industrial Sand Resources. Michigan Department of Environmental Quality (DEQ) Geological Survey Division (GSD), Michigan

Malu. S, Edem. C, Ita. B. 2015. Chemical Characterization of Silica Sand Deposit from River Katsina-Ala, North Central Region of Nigeria. *Global Journal of Pure and Applied Physics*, 3(1), 26–37.

Marshak, S. (2004). Essentials of Geology (4 th ed.). New York: w.w. Norton & company.

McLaws, I. (1971). Uses and Specifications of Silica Sand. Research council of Alberta, Alberta.

Mengistu, T., & Fentaw, H. (2003). Industrial Mineral and Rocks Resource Potential of Ethiopia. GSE, Addis Ababa, Ethiopia.

Mogessie, A., Krenn, K., Schaflechner, J., Koch, U., Egger, T., Goritchnig, B., Kosednar, B., Pichler, H., Ofner, L., Bauernfeind, D., Tadesse, S., Hailu, K., & Demessie, M. (2002). A geological excursion to the Mesozoïc sediments of the Abay basin (Blue Nile), recent volcanics of the Ethiopian Main Rift and basement rocks of the Adola Area, Ethiopia. *Mitteilungen Der Österreichischen Mineralogischen Gesellschaft*, 147, 43–74.

Mohammedyasin, M., & Gashaw, W. (2019). Provenance of the Cretaceous Debre Libanos Sandstone in the Blue Nile Basin, Ethiopia: Evidence from Petrography and Geochemistry. *Sedimentary Geology*, 379, 46–59.

Mohr, P. (1983). Ethiopian flood basalt province. *Nature*, 303: 577–584.

Mohr, P. and Zanettin, B. (1988). The Ethiopian flood basalt province. In Continental flood basalts, edited by McDougall, J.D., Kluwer Acadamic Publication, Dordrecht, 63-110.

Moon, C., Micheal, E., Whateley, G., & Anthony, E. (2006). Introduction to Mineral Exploration (2 nd ed.). Oxford, England: *Blackwell Publishing*.

Nasri, H., Kermani, S., Abbassi, M. A., & Omri, A. (2021). Characterization of Sand From

Jebel Ad-Darin Sened (Gafsa-Tunisia). *Silicon*, *13*(11), 3827–3834.

No, C. R. (2004). Commissioned report. Heritage, 018(018).

Norton, F., (1957). Elements of Ceramics. Reading, MA: *Addision-Wesley Publishing*.

Pik, R., Catherine, D., Christian, C.,, Yirgu,G.., Corine, H., & , Ayalew, D., (1998). The Northwestern Ethiopian Plateau Flood Basalts: Classification and Spatial Distribution of Magma Types. *Journal of Volcanology and Geothermal Research*, 81(1–2), 91–111.

Platias, S., Vatalis, K., & Charalampides, G. (2014). Suitability of Quartz Sands for Different Industrial Applications. *Procedia Economics and Finance*, 14(14), 491–498. https://doi.org/10.1016/s2212-5671(14)00738-2.

Pohl, W. (2011). Economic Geology Principles and Practice: Metals, Minerals, Coal and Hydrocarbons–Introduction to Formation and Sustainable Exploitation of Mineral Deposits. Oxford, United Kingdom:*Blackwell Publishing*. https://doi.org/10.1016/B0-12-369396-9/00458-5.

Potter, P.E., (1978). Petrology and Chemistry of modern Big River Sand. *Journal of Geology*, 86(4): 423-449.

Press, F. & Siever, R. (2001). Understanding earth (3rd ed.). New York: W.H Freeman, 1-225.

Ramadan, F. (2014). Characteristics of White Sand Deposits in Southern Sinai Region, Egypt. *Middle East Journal of Applied Sciences*, 4(1), 1–10.

Reedman ,J. (1979).Techniques in mineral exploration. *App Sci,* London, 533 pp.

Robert, M. B., Jeffry, C. R. & William, M. (2002). Suitability of the pine formation as a glass, Richmand Country, North Carolina. Unpublished PhD thesis, Department of Environmental Studies. CPO 2330, UMC- Asheville, Ashiville, NC 28804-8511.

Rodriguez, J., Tommy, E., & Sven, K. (2013). Particle Shape Quantities and Measurement Techniques. A *Review. Electronic Journal of Geotechnical Engineering* 18, 169–98.

Rudolp, D. and Lubos, R. (1999). Minerals of the world. 1st Edition. *Spring Books Publishers*, London.

Russell, R., & Taylor, R. (1937). Roundness and shape of Mississipi River Sands. *Journal of Geology*, 45, 225-267.

Russo A, Assefa, G., and Atnafu, B., (1994) Sedimentary evolution of the Abay River (Blue Nile) Basin Ethiopia. *Neues Jahrbuch Fu¨r Geologie Und Palae¨ontologie Monatshefte* 5 291–308

Schrotenboer, B. R., & Arbogast, A. F. (2010). Locating alternative sand sources for Michigan's foundry industry. *A geographical approach*. *30*, 697–719.

Shaffer, N. (2006). The Time of Sands: Quartz-Rich Sand Deposits as Renewable Resource. *Electronic Green Journal*, 1(24), 1–35.

Stephenson, P. R. (2001). The JORC code. Transactions of the Institutions of Mining and Metallurgy, Section B*: Applied Earth Science*, *110*(September/December),1–44. https://doi.org/10.1179/aes.2001.110.3.121.

Sundeen, S. (2001a). Geologic Study of Sand Deposits in the State of Michigan Phase 1. Michigan Department of Environmental Quality (DEQ). Geological Survey Division (GSD), Michigan.

Sundeen, S. P. (1978). Geologic study of sand deposits in the state of Michigan-Phase I. Michigan: Institute of Mineral Research, 1-7.

Tadesse, S., Jean, P., & Yves, D. (2003). Geology and Mineral Potential of Ethiopia: A Note on Geology and Mineral Map of Ethiopia. *Journal of African Earth Sciences* 36(4), 273–313.

Tadesse, S. (2009). Mineral Resources Potential of Ethiopia. Addis Ababa, Ethiopia: Addis Ababa University.

Tarasova, I. I., Dudeney, A. W. L. & Pilurzu, S. (2001). Glass sand processing by oxalic acid leaching and photo catalytic effluent treatment. *Minerals Engineering*, 14, 639-646.

Tefera, M., Chernet, T., & Haro, W. (1996). Explanation of the geological map of Ethiopia. Ethiopian Institute of Geological Survey, Addis Ababa,3: 48pp.

Tesema, M. (2012). Silica Sand Promotion Document: Occurence of Silica Sand in Ethiopia. GSE, Addis Ababa, Ethiopia

The 2012 Australasian Code for Reporting of Identified Mineral Resources and Ore Reserves

Tsoar, H. Blumberg, D. G. & Stoler, Y. (2004). Elongation and migration of sand dunes. *Geomorphology,* 57, 293-302.

United Nations, Department of Economic and Social Affairs, "Population Division," 2019, https://www.worldometers.info/population/world/.

United Nations, Department of Economic and Social Affairs, "Population Division". World Urbanization Prospects: The 2014 Revision, Highlights (ST/ESA/SER.A/352) 2014,http://esa.un.org/unpd/wup/Publications/Files/WUP2014-Highlights.pdf (accessed on 13 November 2022).

Wilkinson, B. H. (2005). Humans as geologic agents: A deep-time perspective. *Geology*, 33

(3), 161-164.

Wolela, A. M., (2002). Hydrocarbon potential of the Blue Nile basin central Ethiopia. Ministry of mines.

Wolela, A. M. (2008). Sedimentation of the Triassic-Jurassic Adigrat sandstone formation, Blue Nile (Abay) Basin, Ethiopia. 52: 30-42.

Wolela, A. (2009). Sedimentation and depositional environments of the barremian –cenomian Debre Libanose Sandstone, Blue Nile (Abay) Basin, Ethiopia. *Cretaceous research*. 30:1133-1145.

Wonafrash Mamo Ghebre(2009), "General Review of Industrial Minerals and their Potential, Including for Value Addition". *Acta Scientific Agriculture* ,150-158.