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Quality and Quantity Assessments of Marble Deposit in Benishangual Gumuz, Regional State, around Daleti area.

By:

Hafis Mohammednur

Advisor: Dr. Worash Getaneh

Co-Advisor: Dr.Tesfaye Asresahagne

A thesis submitted to the school of Graduate studies of Addis Ababa University, in partial fulfillment of the requirement for the degree of Master of Science in Resource Geology (Mineral Deposits).

June, 2019

Addis Ababa, Ethiopia

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BY

Hafis Mohammednur

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Statement of originality

With this statement, I hereby confirm that this MSc thesis work is my own original work under the supervision of Dr. Worash Getaneh and Dr. Tesfaye Asresahagne, Addis Ababa University, School of Earth Sciences, in the year 2019. I also declare that this work has not been submitted in any university or other institution. Data used from the published and unpublished work of others has been appropriately acknowledged.

Hafis Mohammednur Signature: ______________________Date: __________________

To the best of our knowledge, we recognized that the above statement made by the MSc candidate is correct.

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Dr. Tesfaye Asresahagne (Co-advisor) Signature: ____________Date:_______________

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List of acronyms

a.s.l	Above sea level
ANS	Arabian-Nubian Shield
DEM	Digital Elevation Model
EARS	East African Rift System
EIA	Environmental Impact Assessment
EIGS	Ethiopian Institute of Geological Surveys
EMP	Environmental Management Plan
EPA	Environmental Protection Agency
ETM+	Enhanced Thematic Mapper
GCP	Ground Control Points
GIS	Geographic Information System
GPS	Global Positioning System
GSE	Geological Survey of Ethiopia
GWE	Geology of western Ethiopian
LOI	Loss on Ignition
MB	Mozambique Belt
MOME:	Ministry of Mine and Energy
P	Permanent
PPL	Plane Polarized Light
T	Temporary
XPL	Cross Polarized Light
XRD	X-ray Diffractometer
WES	Western Ethiopian Shield
-1	Minor negative
-2	Medium negative
-3	Adverse
+1	Minor positive
+2	Medium positive
+3	Major positive

Abstract

Daleti marble deposit is situated in the Western part of Ethiopia near Oda Beldeglue woreda, Daleti Keble, which is about 665 km from Addis Ababa and at an elevation of between 590 to 2491 m above mean sea level. Geology of the marble district is composed of metasedimentary schists, which are of low metamorphic grade; consist of intercalated greenschist, quartzo-feldspathic schist, graphite schist, phyllite, quartzite with lesser biotite schist, metaconglomerate and marble. Based on petrographic study, the main minerals identified in these basement rocks include calcite, muscovite and opaque mineral. The parent rock, calcite and dolomite have been partly and completely transformed to marble. The main aim of the present study is to assess the qualitative as well as quantative features of this marble deposit. An integrated study combining geological, petrography, mineralogical (XRD) and physical and mechanical test (compressive strength, porosity, water absorption, bulk density) data as well as cut and polish section were carried out in order to characterize the quality and quantity of marble deposit in the study area as well as to assess the environmental impact of mining. Data obtained from morphological study and available physical property tests were also examined to see the possible industrial applications.

Usually the company uses highly sophisticated technologies where both cutting by diamond wire and water jet are applied. Marble is used in a variety of applications as flooring tiles in bedrooms, bathrooms, kitchens, restaurants and public places like hotels, public toilets churches and town halls. Therefore, these areas could be developed for dimension stone quarry and exploitation of these rocks could be as rough unprocessed building stone or better polished natural stones for a variety of uses.

Key words: Daleti, genesis, marble, Physico-mechanical properties, Petrography, mine.

Chapter one

Introduction

1.1.Background

Ethiopia consists of large deposits and varieties of marble rock in different parts. The northern and western parts of the country are mainly known for numerous extensive deposits and hill forming of marble. In the country only a small marble deposits have been exploited so far and there is thus a huge potential of the resource for expansion of marble production and export.

The Daleti Marble deposit in Benishanguel-Gumuz is situated 110 km south of assosa at the road connecting Addis Ababa, Assosa and Mendi. The marble beds are confined to meta-sedimentary rock sequences. The marble is mostly homogeneously white or pink but also banded and mottled varieties occur. Medium and coarse grained types predominate. Reserves of marble at this area (twelve marble occurrences are known) is estimated, to over 50 Mt (EGS, 1989).

The oldest rocks in the country belong to Precambrian era and they are formed before about 600–3000 million years and include various lithological types more or less intensively affected by metamorphism: gneisses, phyllite, quartzite, schists, and granitoids (Getaneh Assefa *et al*., 1981). This Precambrian rocks are originally related to the orogenic event known as Pan African Orogeny and they particularly belong to the so called Mozambique belt (Kazmin,1971), which was peneplained during the Paleozoic.

Marine sediments of Mesozoic era such as sandstones, limestone, conglomerates, evaporate etc. unconformably cover this Precambrian basement (Getaneh Assefa *et al*., 1981).

The Precambrian basements host most of the economic metallic mineral deposits that include primary and secondary enriched deposits of gold, platinum, platinum group elements (PGE), nickel, tantalum, base metals, industrial minerals like phosphate, iron ore, gemstones (like ruby, emerald, sapphire, garnet, etc.) and also decorative and dimension stones such as marble, granite and other colored stones (Ministry of Mines and Energy, 2009).

Other areas of the uses of marble are in sculpture, monumental, shop fittings, electrical and decorative as well as dietary calcium supplement (Herbert et al; 1990).

1.1.Geographic setting of the study area

1.1.1. Location &Accessibility

The proposed study area is locatedin Western Ethiopia basement at Daleti localities, Oda Buldigilu woreda, Asossa zone, Benishangule- Gumuz National Regional State of Ethiopia, it is accessible along the road, Addis Ababa-Nekemte-Gimbi-Najo-Mendi, asphalt with a distance of approximately 587 km west of Addis Ababa (see figure1.1) and all weathered gravel road from Mendi to the project area, 48km which are the total of 635km. The UTM (Universal Transverse Mercator) coordinates shows that the area is bounded by 35.25083333N to 10.0069444 E and35.25083333N to 10.00638893E.The whole Daleti coverage an area of approximately 60 km^2, while the quarry site cover an area of 900,000m^2 .This makes the planed project area accessible given the vehicle made available for the exploration work.

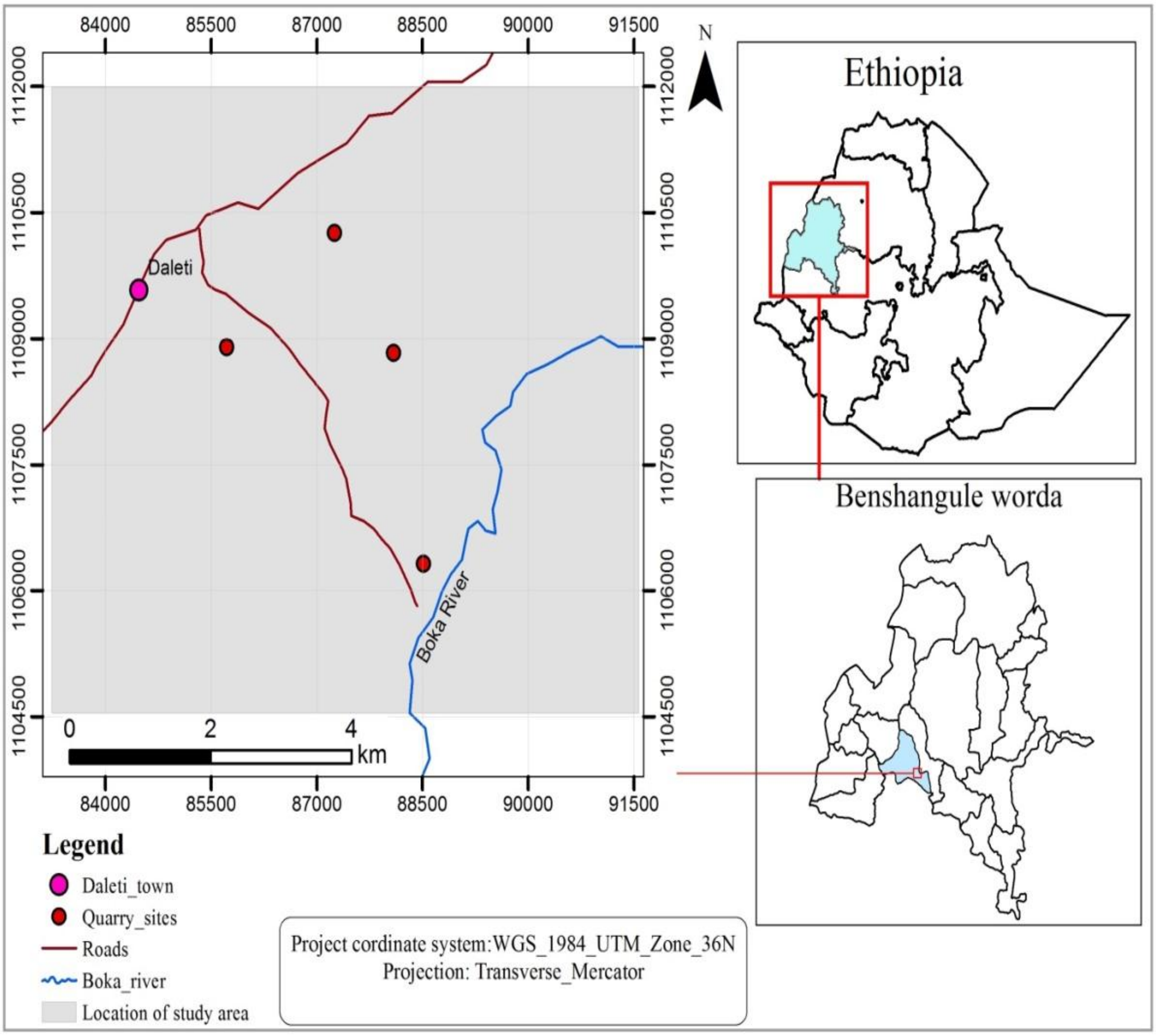

Figure 1.1: Location Map of the Project Area.

1.2. Physiography and climate of the study area

The physiographic nature of the area indicates that the proposed area lies in the lie within the Nile river basin and hence is lowland Nevertheless, hill forming marble outcrop here and there. Elevations of the area ranges between to 590 meters along plains and rising to 2491 meters above sea levels, at the ridges (figure1.2). This would be Marble exploration project site is characterized by topography ranging from plain low land to slightly rugged terrains. Most of the rivers are seasonal and dry, except the Boka River and few others found at close proximity. The soil types based on the UNESCO soil classification scheme includes, nit soils, with minor humid camisoles and chromic vertisols.

Typical drought resistant vegetation, such as, acacia Abyssinia, baobab Abyssinia, short sturdy bushes and the savannah grass are the floras here, while fauna pre-set are snakes of different types and birds. Sorghum and maize are the main crops cultivated by the inhabitants.

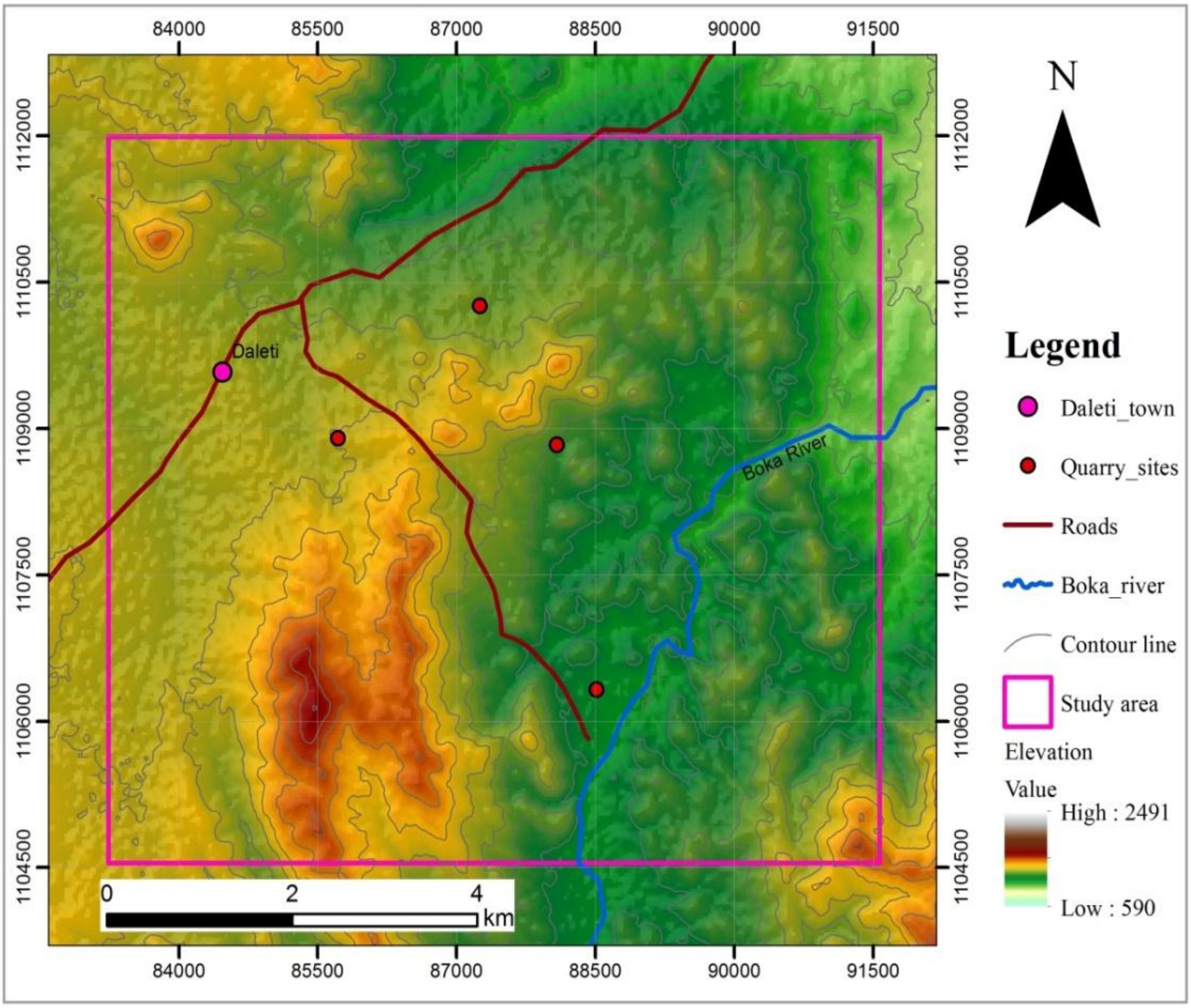

Figure1.2: Physiography of the study area.

As far as climatic condition is concerned, the area is characterized by tropical climate, with significant topographic induced variation. Generally, the area can be termed as 'semi-arid' region with a two rainy season. The first rainy season being from late May to late September with possible continuation up to mid-October and the second, from mid of March to mid of April. From February to May are relatively warmest months in the area, while the coldest months are July and August. According to Ethiopia Metrological Authority, the mean annual rainfall is 1000mm -1400mm per year. The temperature is between 25-30c.

Temperature	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Mean max (°C)	30.6	30.5	29	30.2	30.5	28.5	30	29	29.5	31
Mean min (°C)	17.1	18.9	16.6	15.8	17.6	16.3	18.1	19	19.3	19.7

Table.1.1: Annually mean maximum and minimum temperature value of daleti town (2009-2018).

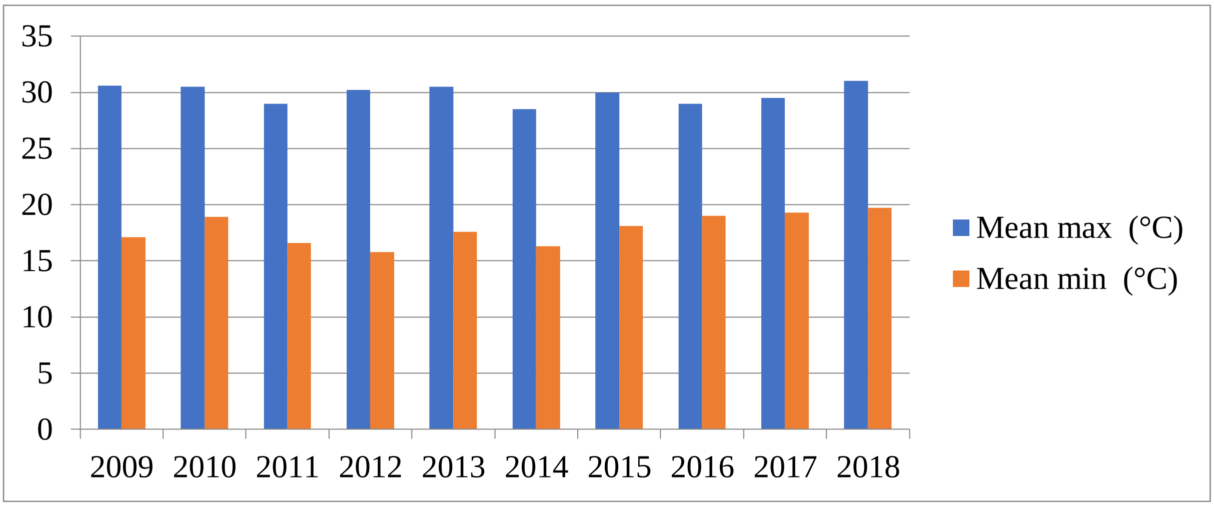

Figure1.3: Bar chart, depict annually mean maximum and minimum temperature value of study area (2009-2018).

1.3. Population and Settlement

The local communities living in the project area are settled just at a significant distance in the Keble center and far away about 5-6 km. Considerable numbers of Oromo people are also found in Benishangul-Gumuz, especially along the main roads and in small towns and villages. The Daleti area including the study region has an estimated total population of 17,526 inhabitants.

Among these people Berta are the main ethnic groups in origin, followed by Oromo, and other nation. The area is mainly inhabited by Berta people whose native language is Bertigna.

Whilst the southeast part of the area is inhabited by Oromo people whose native language is oromigna, Amharic being the official working language of the area.

As far as religion is concerned, Islam is dominant religion of the people in the area, followed by Orthodox Christians and Protestants. The inhabitants' means of existence is mainly based on cultivation, domestic animal breeding, honey bee husbandry and trading. With regard to economic production, it can be said that the Berta people are mainly engaged in agriculture of slush and burn/shifting cultivation type. Hunting & gathering, livestock & honey production is also practiced in the area. Another most important source of livelihood remains to be traditional gold mining while other activities such as handicraft making, petty trade and charcoal making are used as subsidiary livelihood sources.

1.4. Statement of the problem

Marble is used as tiles, slabs for facing buildings, stairs, tombstones and other uses. The production of marble is gaining popularity due to increase in its usage in the construction industry in Ethiopia. Today almost all the modern architectural designs of buildings include the final touch of beautiful shades of marble in exterior as well as interior positions.

The Daleti Marble deposit in Wollega (Malish and Dejene, 1983) is situated 40 km north of Mendi at the road connecting Addis Ababa and Assosa. The marble beds are confined to Meta sedimentary rock sequences and are mostly homogeneously white or pink but banded and mottled varieties also occur. Medium- and coarse-grained types predominate.

Reserves of marble in this area (12 marble occurrences are known) are estimated to be over 50,000,000 t (EIGS, 1989). Moreover deposits of raw marble of varied quality are found in Beneshangul-Gumuz, especially in Daleti area with different color. However, the area remains poorly researched in terms of quality evaluation of mineralization and geochemistry, as well as other mechanical and physical test such as compressive strength, porosity, water absorption and bulk density and other associated minerals.

Therefore, this Assessment aims to study the mineral quality, petro-genesis and geochemistry of the mineral as well as to identify the probable process to evaluate on the quality and quantity of marble deposits.

1.5. Objective of the Study

1.5.1. General Objective

The main objective of the research is to determine quality and quantity of marble deposit in daleti area.

1.5.2. Specific Objective

The specific objectives of this Study are:

- To determine the quality and quantity of the marble deposit
- To produce geological map of the study area at the scale of **1:50,000**;
- To characterize the petrography and geochemistry of the mineralized rocks; and finally
- To assess environmental impact of marble mining in the study area

1.6. Methodology

The general frameworks; Pre-field work, field work and post-field work activities are employed in achieving the complete research project. The pre-field work is commenced by assessing study related literatures, reports and by important discussions with advisors and other peoples. During fieldwork collecting primary data were the main tasks. To come up with the conclusions, those data collected and studied thoroughly at the time of pre-field work and field work are passed through analysis, synthesis, interpretation and presentation during post field work time.

In the preliminary stage of this project, relevant literatures that are closely related with the study are reviewed to know the methodologies that would be followed for this study. Moreover, the literatures were helpful in understanding the regional geological settings and structures. Study specific published and unpublished geological reports are also studied to acquire more information on the study area. In addition, geological structures (joint) are delineated and simple lithological units are discriminated using ARC map10.5software.

1.6.1. Field work and geological mapping

This activity was commenced from October 25 to November 10. During this time, representative sampling of encountered lithological units and transferring of these units and other geological structures into the existing base map were the main tasks. In doing these**,** geological exposures were surveyed including sections along roads, mining excavations and in river banks. Along recording this geological information on the base map, important descriptions of the units and structures were taken using field note book.

The rock samples are collected considering lithological variations and marble host rock. While marble ore samples are collected based on the lateral and vertical variations (in color, texture grain size, etc.) observed in marble exposures. Transferring lithological units and geological structures are done by taking GPS control points (GCP) and locating them on the base map.

The information from GCP finally helped in producing geological map at a scale of 1:50,000. All these activities were accomplished by selecting traverses across the strike of geological units.

1.6.2. Analytical methods and data analysis

After finishing the field work, the collected samples are submitted to laboratory for different analysis. The purpose of these analyses is to get vital information to assess Daleti marble deposit from quality and quantity points of view. These different analyses include; petrography, cut and polishes section, physical tests, mineralogical X-ray Diffractometer (XRD) and remote sensing and GIS.

a) Mineralogical analysis

This analysis is performed to unveil the minerals present in the marble samples and to know how much percent of each mineral is found. This qualitative and quantitative information of the minerals found in marble samples are determined by X-ray Diffractometer (XRD). Six representative marble samples are selected for this analysis. The samples are collected based on the observed vertical and lateral feature (color, grain size, texture and so on) variations. The Sample preparation is done in Geological Survey of Ethiopia.

The preparation passes through three principal steps. First, the marble sample is dried by air. Then the sample is milled using mortar. Finally, it is allowed to pass through a 65µm size sieve until we get the desired amount of powdered marble (i.e.250gm). This under size powdered marble is the required amount to be used for XRD. To minimize contamination, the caution was always there during preparation by washing all the materials (Mortar and sieve) after milling and sieving individual sample.

The powdered samples are then sent to a laboratory in the University of Mekelle, Tegraye department of mechanical engineering, for qualitative and quantitative mineralogical identifications.

The diffractograms were recorded with BX2700 diffractometer equipped with a copper tube, operated at 40kV and 30nA.Qualitative phase determination was performed with the MDI jade 6.5, database.

Quantitative Mineralogy was determined by Rietveld refinement using the software TOPAS by Brukert, that have an starting angle of 3 and end angle 70. Data presentation and interpretation is done using graphs and some figurative explanations.

b) Physical tests

This test is aimed at seeing the suitability of marble in different industrial applications by comparing with different standard. The performed tests are porosity, specific gravity, bulk density and water absorption. For this purpose four marble samples are selected; as well as cut and polish properties**.** All the tests are done in central Geological Survey of Ethiopia.

c) Mechanical tests

This test is aimed at seeing the suitability of marble in different industrial applications. The performed tests are compressive strength. For this purpose four marble samples are selected. Whereas**.** All the tests are done in central Geological Survey of Ethiopia.

d) Petrographic analysis

Ten rock samples representing the study area are selected based on their variability and association with the marble deposit of the area. The thin section preparation is done in Geological Survey of Ethiopia. While the microscopic examination of thin sections is carried out in central Geological Survey of Ethiopia laboratory. The thin section of parent rock is examined to identify the primary minerals of the host rock.

e) Remote sensing and GIS

This method has been used thoroughly throughout the course of this research project activity. Moreover, these images were used to discriminate features like lithology and structures. This is done by employing, Arc GIS 10.5 by juxtaposing the imageries with geological map (1:50,000) of the study area and Arc GIS 10.3, digital elevation model (DEM) data. The analysis is also aided by software like Global mapper and Google earth as well as satellite image.

1.7. Significance of the study

Daleti marble has not so far been studied in the aspects of formation, composition, physical test as well as the application and the environmental issue of mining. A few is also known on its suitability for different construction industry. Therefore, this research study will have the following contributions and outcomes.

The suitability of Daleti marble for some industrial applications will be indicated based on available laboratory tests. However the output of the proposed research will provide the basic geological information about the area. Interpretation of the mineralogical data from thin section analysis, and mechanical and physical test data to understand the genesis.

Moreover, it is also serves as background information for future researcher, different Organizations, and institutions, for example of Benshanguel-Gumuz regional state mine bureau. In addition, for Assosa University it could help as a source for teaching materials and so forth.

1.8. Thesis overview

This thesis work is organized by dividing in to eight chapters. The first chapter gives a general introduction to the study and methodologies employed. Chapter two is a review of the previous research papers relevant to the genesis, application and other important issues on marble deposit. Chapter three, deals with the regional geological settings and chapter four about geology of the study area. In chapter five, Daleti marble deposit. Chapter six the mineralogical (XRD) and physical test data analysis results are presented. Chapter seven, about Environmental impact of Daleti marble mining. The final part, chapter eight consists of the conclusion and recommendation. Finally, some study related issues are incorporated in the index part.

CHAPTER TWO

2. Literature review

2.1. Marble

Marble is a metamorphic rock resulting from regional or at times contact metamorphism of sedimentary carbonate rocks, either limestone or dolostone.

The late Proterozoic to early Paleozoic marbles of the Tseahit and Tembien groups are known not to have complete recrystallization upon transformation of the parent, limestone to marble. Such conditions of marble are very ideal for dimension stones, and they are commonly found in northern Ethiopia. These rocks reveal characteristics of limestone and marble, although referred to as massive black limestone, Mai Kendal limestone (800m thick), and Assam limestone (300 m thick) and commonly occur in association with interbeds of slate, marble, and dolomite. In this connection, the Dedik formation, 'the youngest of the Proterozoic rock, (1,500 m thick). (MC, 2003) consists of creamish to ‘white dolomite. This unit is also found exposed in the Danakil depression.

Hunting Geology & Geophysics Ltd. (1969), based on aerial photograph interpretations identified the Gneiss group, the schist & Amphibolites group, the older intrusive, the Phanerozoic sediments and volcanic.

Many recently published studies of metamorphic carbonate rocks have concluded that metamorphism occurred in the presence of a fluid phase in excess. This fluid was assumed to be a binary mixture of CO_2 and H_2O and it has been demonstrated in many cases that the composition of such a fluid was controlled by the solid phase assemblage (Trommsdorff, 1972; Rice, 1977; Kerrick, Crawford & Randazzoo, 1973).

Metamorphism therefore occurred in a closed system with pressure and temperature as the only parameters controlling the mineralogy of a rock of given bulk composition. From an analysis of a Norwegian field example of Glassley (1975) concluded that, in relatively small marble lenses embedded in large gneiss masses, the system may become open to volatile and highly soluble components. In addition to pressure and temperature, chemical variables such as the chemical potentials of CO_2, H_2O, HF, Na_2O, K_2O were shown to be limiting to the solid phase assemblage (see also Tanner, 1976). Metamorphism of systems open to CO_2 and H_2O have been described by Moore & Kerrick (1976), Hewitt (1973) and Taylor & O'Neil (1977).

The coexistence of alkali feldspar + sillimanite (Evans, 1965) and of almandine + sillimanite (Richardson, 1968) together with the abundant occurrence of migmatites suggests that temperatures in excess of 650 °C were reached during the regional metamorphism under medium pressure conditions. While there is very little information on the pressure during metamorphism, the absence of cordierite (Richardson, 1968) and kyanite (Holdaway, 1971) is consistent with pressures above 4 kb and below 6-5 kb at 650 °C.

Besides statically recrystallized microstructures, two end members of dynamically recrystallized microstructures are preserved in Carrara marble (Molli et al. 1997, Molli & Heilbronner 1999, Molli et al. 2000). Both end members can be related either to sub grain rotation (SGR) recrystallization or to grain boundary migration (GBM) recrystallization, respectively.

However, recent field studies in the Alpi Apuane (Molli et al. 1997, Molli et al. 2000) showed that a large variety of dynamically recrystallized microstructures are preserved. These “dynamic “microstructures are related to two deformation events (D1 and D2), which are related to subduction, napped stacking and exhumation. Folds and shear zones of these deformation events show various overprinting relationships on the meso- and the microscale. The presence of dolomite in the calcite rocks makes it possible to determine the temperature during which deformation took place, using calcite-dolomite thermometry.

Numerous studies (e.g. Rutter 1974, Schmid et al. 1980, Schmid 1981, Schmid et al. 1987, Wenk et al. 1987, De Bresser 1991, Rutter 1995) investigated the mechanical properties and the characteristics of microstructure and texture of Carrara marble under laboratory conditions. It became evident that Carrara marble deforms under experimental conditions only by dislocation creep. Dislocation glide and mechanical twinning are only active at high stresses / low temperatures and at low strains; diffusion creep has never been achieved in experiments of Carrara marble.

Marble is used widely in buildings, monuments and sculptures. Its utility value lies in its beauty, strength and resistance to fire and erosion. Marble has its application in interior and exterior wall cladding, interior and exterior paving, fireplace facing and hearth, lavatory tops, residential and commercial counter tops, table tops, statues and novelty items. The other nonconventional uses of marble are in toothpaste, paint, whiting, agricultural lime, etc.

Their use as structural elements (masonry), statues, epitaphs, graves, etc. is quantitatively less with funeral art accounting for the largest percentage. In interior applications such as, for floors, marble is used in the form of 20 mm thick cut-to-size slabs. The slabs are also used for interior and outer facings, stairs, table tops, kitchen platforms, etc.

The tiles in sizes ranging from 10 x 10 cm to 60 x 60 cm are used for floors, dadoes and for skirting in thickness ranging from 10 to 20 mm.

The selected marble blocks free from cracks and other inclusions are used for making artifacts, such as, carved figures, handrails and balustrade for staircases, jalis, fire places, flower vases and many other pieces of art. The marble has high economic values classified by 6 broad categories namely: metallurgical, chemical, environmental, construction, refractory and agriculture (Scott and Durham, 1984). Each of this group requires a specification for the marble to be useful.

2.2. Mechanism of formation of marble deposit

Marble is a rock resulting from metamorphism of sedimentary carbonate rocks, most commonly limestone or dolomite rock. Chemically it is similar to limestone. Metamorphism causes variable recrystallization of the original carbonate mineral grains. Marble is a metamorphic rock composed essentially of calcite ($CaCO_3$), dolomite [$CaMg\ (CO_3)^2$], or a combination of the two, with a fine- to coarse-grained crystalline texture (Serra, 2006).

The resulting marble rock is typically composed of an interlocking mosaic of carbonate crystals. Primary sedimentary textures and structures of the original carbonate rock (protolith) have typically been modified or destroyed. Geologically it is different from limestone because it is metamorphic rock.

In fact marble is limestone, which under centuries of high pressure and heat in the earth’s crust changed from a sedimentary rock to metamorphic rock. Because of pressure and heat, marble is stronger and denser than the original limestone. It takes a good polish, Color usually range, white to black, pink, and so on. Vulnerable to acid attack.

Pure white marble is the result of metamorphism of a very pure (silicate-poor) limestone or dolomite protolith. The characteristic swirls and veins of many colored marble varieties are usually due to various mineral impurities such as clay, silt, sand, iron oxides, or chert which were originally present as grains or layers in the limestone. Green coloration is often due to serpentine resulting from originally magnesium-rich limestone or dolostone with silica impurities.

These various impurities have been mobilized and recrystallized by the intense pressure and heat of the metamorphism.

Most marble forms at convergent plate boundaries where large areas of Earth's crust are exposed to regional metamorphism. Some marble also forms by contact metamorphism when a hot magma body heats adjacent limestone or dolostone.

Before metamorphism, the calcite in the limestone is often in the form of lithified fossil material and biological debris. During metamorphism, this calcite recrystallizes and the texture of the rock changes. In the early stages of the limestone-to marble transformation, the calcite crystals in the rock are very small. In a freshly-broken hand specimen, they might only be recognized as a sugary sparkle of light reflecting from their tiny cleavage faces when the rock is played in the light.

As metamorphism progresses, the crystals grow larger and become easily recognizable as interlocking crystals of calcite. Recrystallization obscures the original fossils and sedimentary structures of the limestone. It also occurs without forming foliation, which normally is found in rocks that are altered by the directed pressure of a convergent plate boundary.

Recrystallization is what marks the separation between limestone and marble. Marble that has been exposed to low levels of metamorphism will have very small calcite crystals. The crystals become larger as the level of metamorphism progresses. Clay minerals within the marble will alter to micas and more complex silicate structures as the level of metamorphism increases.

Calcite ($CaCO_3$) and dolomite ($CaMg\ (CO_3)^2$) are the most abundant minerals of the rock forming carbonates. More than 90 % of the naturally appearing carbonates are formed by calcite and dolomite. Both minerals are of trigonal symmetry; calcite has the space group R-3c and dolomite the space group R-3 Calcite has a fairly simple structure, which can be described as a close packing of anion groups $(CO3)^{2-}$) with cations (Ca^{2+}) in octahedral interstices. Magnesite ($MgCO_3$), siderite ($FeCO_3$) and rhodochrosite ($MnCO_3$) have the same structure as calcite.

In first approximation the calcite structure can be considered as the one of halite (NaCl), which was compressed parallel to one of the four triad axis (parallel to one of the body diagonals). Na^{2+} cations are replaced by Ca^{2+} ions and Cl^{2-} anions by CO_3^{2-} groups.

The resulting face-centered rhombohedral cell has a lattice distance of a rh 6.42 Å and an angle between the crystallographic directions of $\alpha = 101.92°$.

This morphologic pseudo cell (cleavage rhomb) contains 4 $CaCO_3$, corresponding to the 4 NaCl in the cubic halite unit cell. The comparison to the NaCl cell, however, is not completely correct, because of the orientation of the CO_3^{2-}groups in the crystal lattice.

The carbonate ($CO3_{2-}$) groups are arranged in layers normal to the three fold inversion axis.

The orientation of the CO_3^{2-} groups is constant in each layer; successive layers are characterized by a rotation of the CO_3^{2-} groups of 180° about the layer normal.

A true face centered rhombohedral unit cell has an a rh of 2 x 6.42 Å and an α of 101.92° and it contains 32 $CaCO_3$.

The rhombohedron with α = 101.92° corresponds to cleavage rhomb of calcite, which has the Miller-Bravais index {10-11}. For the description of the calcite lattice a smaller rhomboherdal cell (primitive cell), with 2 $CaCO_3$ and a rh = 6.37 Å and α = 46.08° can be chosen. Its faces correspond to {10-14} in Miller-Bravais indices. In the case of calcite the anion layers alternate with layers of Ca^{2+}. In dolomite every second cation layer is composed of Ca^{2+} and Mg^{2+}, respectively.

Carbonates with cations larger than Ca^{2+} (e.g. Sr and Ba) crystallize in hexagonal-close-packing, because Ca^{2+} is near the limit of the 6-fold coordination (octahedral coordination). At elevated pressures (e.g. 100 MPa at 400 °C) the calcite structure breaks down to the aragonite structure, which crystallizes in 9-fold coordination. The following figures and tables are copied from Wenk (1985) and De Bresser (1991) and are intended to illustrate the crystallography of calcite and dolomite. Furthermore the most important Burgers vectors slip systems and flow laws are listed (figure2.1).

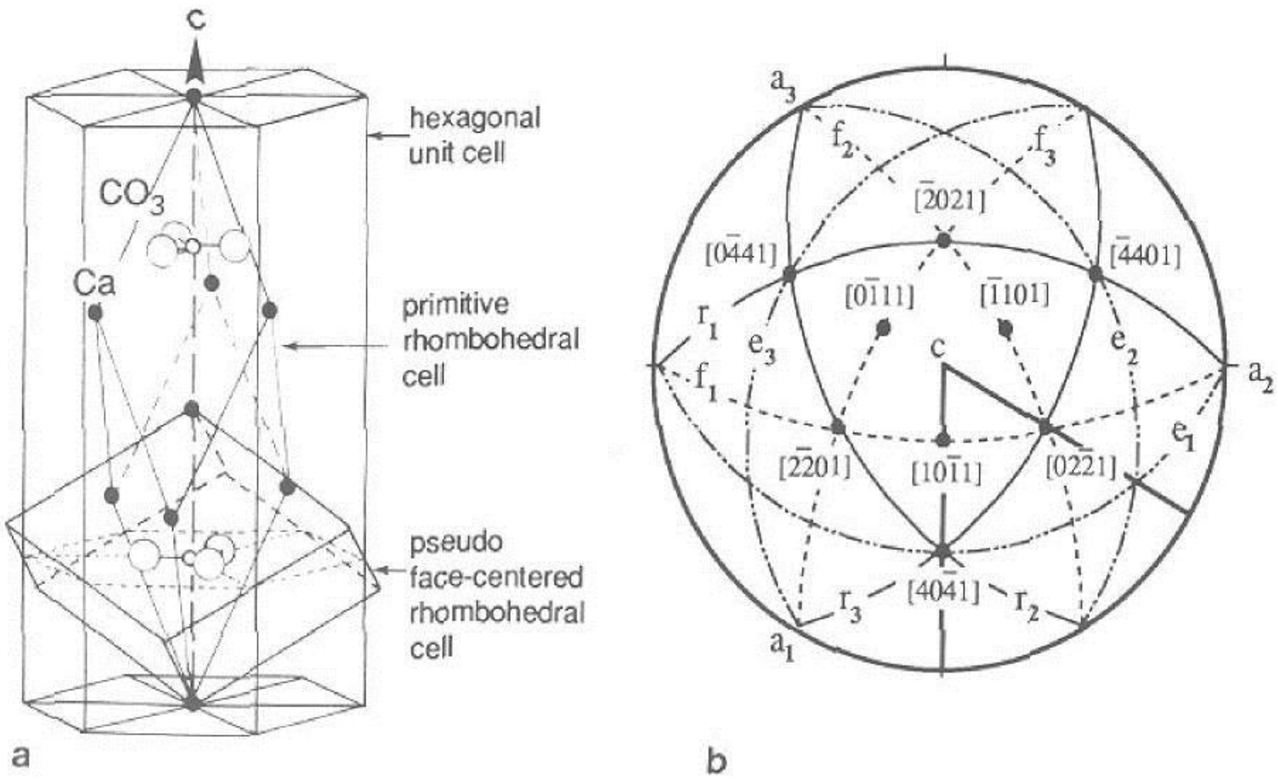

Figure 2.1: Structure of calcite (a) and stereographic projection (b) (upper hemisphere, equal angle projection). Adapted from Bresser (1991).

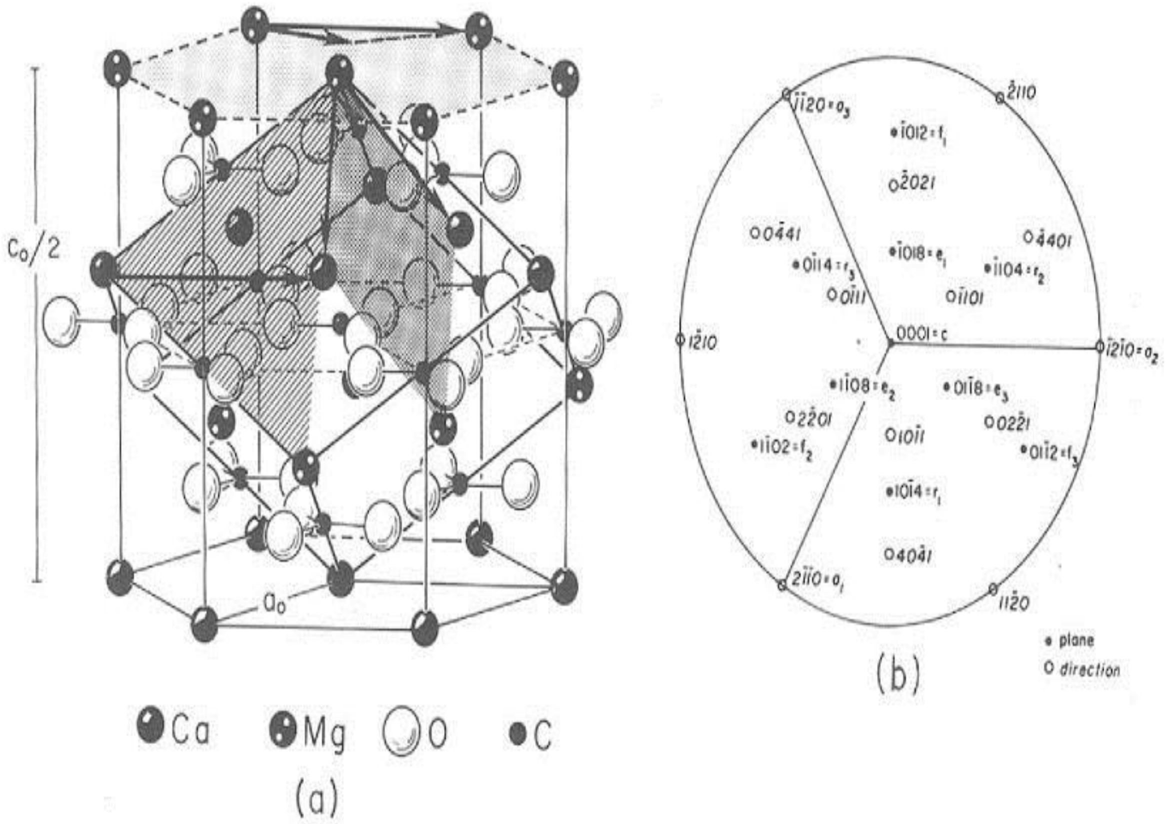

Figure2.2: illustres Structure of dolomite and stereographic projection (upper hemisphere, equal area projection). The most important slip planes (c light shading, t lined and f dark shading) and Burgers vectors are indicated. From Wenk (1985).

2.1.3. Genesis of marble

Marbles are generally metamorphic derivatives of sedimentary carbonates. They have been known to be relatively impermeable during metamorphism (Nabelek, 1991).

Basement rock exposures in the Lokoja-Jakura schist belt are dominated by metasedimentary rocks, chiefly, quartz mica schist with small occurrences of quartzite, marble and silicate facies iron-formation. These metasedimentary rocks are inter banded with meta-igneous rocks such as granite gneiss. Chemical data on major and trace elements of the sheared and unsheared varieties of quartz mica schist from the Obajana area, reveal a composition comparable to that of semipelitic metasediment (Olobaniyi, 2003).

Jordanian marble is hard, dense, partially recrystallized and strongly affected by tectonic movements. It is varicolored by iron oxides, bituminous matter and traces of chromium, nickel, vanadium and uranium bearing minerals (Nassir and Khouri, 1982).

From a mineralogical point of view Carrara marble is also known for the numerous fine and rare minerals that occur within small cavities hosted by typical metamorphic structures, such as boudins or tension gashes.

The cavities lie within definite levels, generally dolomitic horizons that underwent brittle deformation during Tertiary metamorphism (Orlandi and Franzini 1994). Metamorphic solutions circulating within the cavities were responsible for a small and sporadic mineralization characterized by many rare mineralogical species, present as minute and well-defined crystals. The minerals were deposited over a range of temperatures from about 350 °C to room temperature.

Marble was found at the Gioia quarry in the Colonnata valley, where it occurs in calcite vein cavities within the marble, together with azurite and volborthite, as hydrothermal alteration product of copper-vanadium sulfides such as sulvanite and colusite; in fact colusite crystals with germanium contents of 1.3 wt% were found in the Carrara area (Orlandi et al. 1981).

Among the marble many possible causes of decay, temperature fluctuations play an important role. There have been many studies (KESSLER, 1919; SAGE, 1988; TSCHEGG, 1999; ROYER-CARFAGNI, 1999; SIEGESMUND, 2000) describing the temperature expansion of marble and of other stone types. Besides these studies on the rheological behavior of Carrara marble a large number of studies considered the physical properties of calcitic rocks. (e.g. Burlini & Kunze 2000, Leiss & Weiss 2000).

Marble is frequently used as facade stone, which is why it is subjected to extreme variations in climatic conditions (temperature, humidity, and chemical influences). Because of this reason the weathering of marble and the restoration of weathered, usually such marble is the topic of many recent studies (e.g. Siegesmund et al. 2000, Leiss & Weiss 2000, and Siegesmund et al. 2003).

The Itobe marble occurs in association with Precambrian basement rocks comprising biotite schist, mica schist, quartz-schist, biotite hornblende schist, felsdapthic quartzite, quartzitic schist, gneissic granite and minor intrusive rocks including pegmatite and quartz veins.

According to (Garrels and McKenzie, 1971) shows that the Itobe marble body falls within the field of sedimentary/metasedimentary field, thus confirming field and petrographic evidence which shows the interbeddding of the marble with schists and quartzites, a characteristic used in classifying them as metasedimentary in origin.

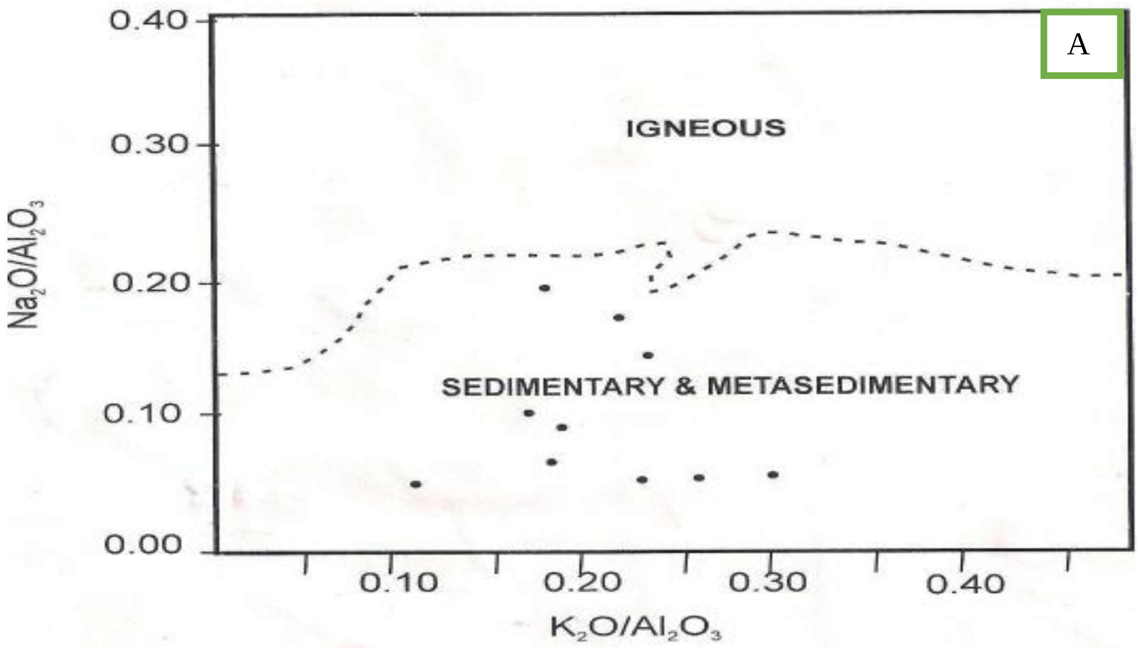

Figure2.3: Na_2O/Al_2O_3 vs. K_2O/Al_2O_3 Variation Diagram of Itobe Marble-Mass I (After Garrels and Mackenzie, 1971).

2.2. Exploration, mining and processing of marble

Site inspection method is used for observation of out cropped marble deposit are grid traverse at grid of using GPS along over the top of hill and across the mountain. To detect and study the geology, marble color, marble texture, grain size and its structure topographic map and the geologic map is used and The factors that determine the mining method selection for exploration of the deposit are governed in six categories:-Spatial characteristics of the deposit, Geologic and hydrologic conditions, Geotechnical considerations, Economic considerations, Technological factors and Environmental concerns.

The cutting properties of the marble slabs have sharp edges without any chips in both the fine-and coarse-grained types. Polishing the slabs obtain a very smooth surface without scratches and chips.

The slabs have a high gloss, and the average type has snow white and white banded dark gray color. Thus, the marble has a nice contrast rich appearance, which would be considered as interesting in the market and a uniform and 'sound' quality suitable for the production of thin tiles. Concerning the physical tests (density, porosity and water absorption) the results show that the marble is found good within the acceptable limits.

The development of new quarrying techniques, like blasting, the diamond wire saw and the chain saw, enhanced the productivity extremely (Bradley 1999).

The mining area marble appears massive and less fractured and jointed on the surface except on some localities. There are long and continues hills, which can give commercial size blocks provided that the uppermost, weathered part and top covered soil will properly remove. The fractures and joints, especially foliation parallel, may not be penetrative below the weathering zone. Since the marble deposit is dominated by massive marble deposit with less fracture, it suitable to extract any block size in required damnation.

The marble industry can be divided into mining, processing & marketing. The mining involves production of blocks, whereas processing segment involves slabbing, sizing and polishing operations. The end products can be 8/18/20 mm slabs / tiles (polished, unpolished) or special monuments, articles, crazy, chips and waste. Marble being a dimensional stone is mined out and processed in a completely different manner then any conventional mining and processing activity.

The quarrying of marble is different from the mining of other minerals. In marble quarrying large size of blocks are excavated. Earlier extraction of marble was done manually by using jack hammer and jib crane.

The extraction techniques are highly sophisticated, where both cutting by diamond wire and water-jet technology are applied. For the multicolor and grey types, due to the wide spacing of joints, a high portion of large blocks is possible.

Moreover Horizontal & vertical cutting with jet belt/chain perforation & cutting with diamond wire-jacking- partitioning-loading Tunneling by cutting vertical & horizontal by tunneling machine & taking out the block using winch to drag & loader with fork attachment.

Using stone cutter that travels with rails to cut vertical & the horizontal is drilled & wedged to get big quarry block & partitioned to get loading size block. In most large marble quarries throughout Europe; wire sawing is the far most important way of extraction-in some quarries even the only way. Not only because marble is a soft rock, easy to cut, but also since marbles are more risky and difficult to blast or split than granites. In addition to wire saws, chain saws and diamond belt saws are increasingly applied in marble quarries, especially for making openings and “blind cuts” in underground operations. For final squaring of commercial blocks, stationary wire saws or disc saws are frequently applied (figure5.3).

2.3. Quality and Marketability of dimension stone

Dimensional stones are characterized by aesthetics/ acoustics and practicality in use. Their apparent occurrences have lent them to many uses for centuries particularly construction and allied uses. Their different chemical, mineralogical & physical properties determine their appropriate extraction and processing requirements, in addition to bearing upon their end use

The acceptability of dimension stones for various uses is determined by geological nature, physical and mechanical characteristics, aesthetic and psychological appeal, techno economic factors and, in a lesser degree, chemical or mineralogical composition.

Marble is used in a variety of applications as flooring tiles in bedrooms, bathrooms, kitchens, restaurants and public places like hotels, public toilets churches and town halls.

These tiles give a feel of luxury and a soothing cooling touch due to low heat conduction properties. Tiles provide glistering appearance and aesthetic luster. Other areas of the uses of marble are in sculpture, monumental; shop fittings, electrical and decorative as well as dietary calcium supplement (Herbert et al; 1990).

Paint manufacturing requires both the physical and chemical properties of marble. Essential physical requirements include good white or pink colour, small particle sizes (98% passing through 325 mesh) and absence of hard particles while chemical specification provides that $Al2O_3$ must be greater or equal to 2%, MgO + SiO_2 must be equal to 75% and LOI must be within the range of 4% - 8%.(Robert, 1979). It is good to note that each of these applications depend on specific properties and processing methods.

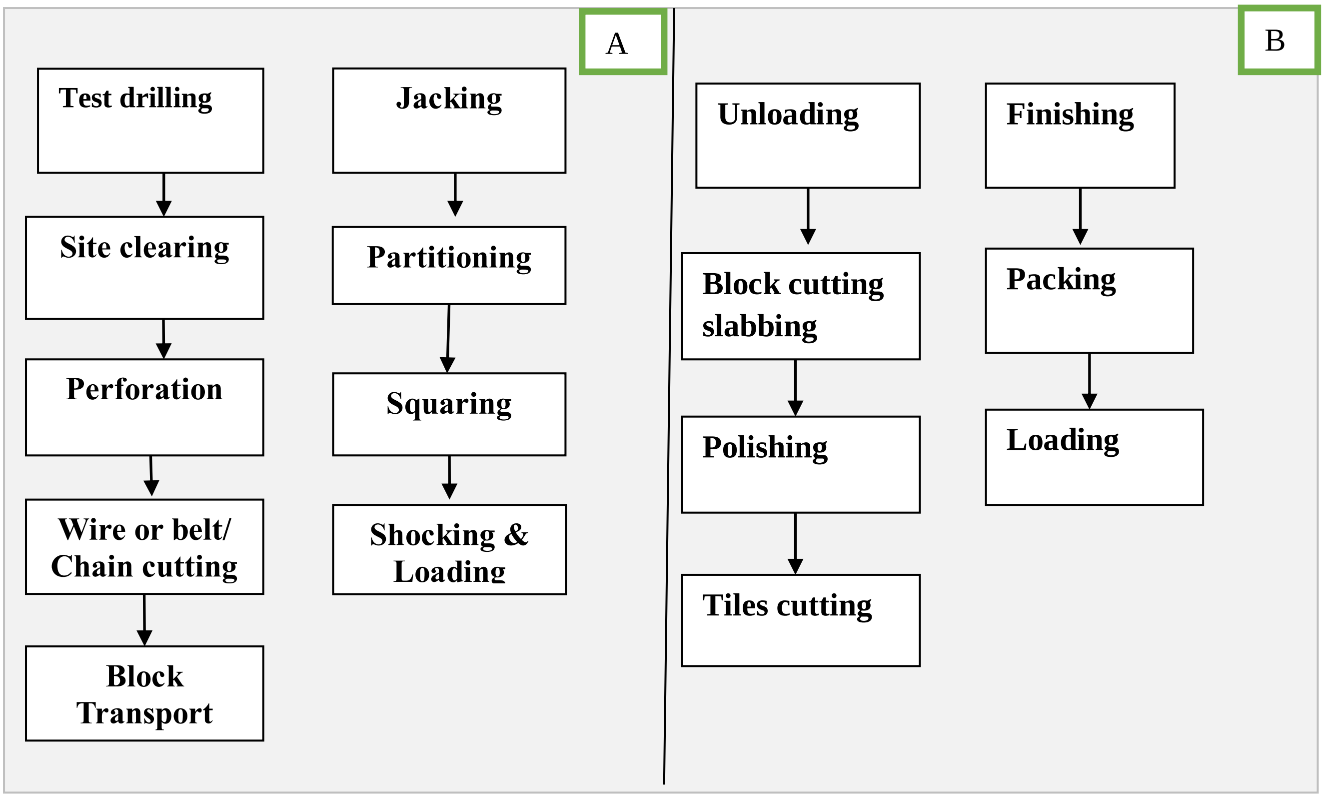

Figure 2.4: Process flow chart for marble mining (A) Process flow diagram for marble processing (B).

2.4. Previous works on marble deposits of Ethiopia

Several workers have investigated western Ethiopia in the past 30 years who have conducted geological mapping and mineral exploration activities. Some of the previous works are summarized as follows:-

Marble has been quarried in such localities as; Daleti (Wollega), Metekel region (Mora, Baruda, Mankush and Bulen), Mai Daro, Filafil, Nohal Ebini, Adi Hatsiro, Enda Tikurir, Newi, Akmara, Dichinamo (Tigray), Hula Muni and other valleys of Chercher Mountain area in Hararghe. Marble reserves at Mora and Baruda (Metekel) have been estimated to be over 46.54 Mt and 13.58 Mt respectively (Gebre W.M., 1991).

The marble in Baruda and Bulen is grey to dark grey, while the marble in Mora is of white grey. Marble reserves in Tigray were estimated to be over 10 Mt for five sites in Tigray (Befekadu and Senbeto, 1993).

Hunting Geology & Geophysics Ltd. (1969), based on aerial photograph interpretations identified the Gneiss group, the schist & Amphibolites group, the older intrusive, the Phanerozoic sediments and volcanics.

(Kazmin, 1972) & (Kazmin et al., 1978) have proposed a three-fold classification scheme to the Precambrian rocks of Ethiopia as a whole.

They have identified the Lower & Upper Complexes in western Ethiopia with their respective inferred lithostratigraphic sequences ranging from Archean to Upper Proterozoic age.

Alemayehu (1989),have identified the existence of high-grade (Amphibolite facies) gneisses which are overlain by metavolcano-sedimentary succession comprised of terrigeneous & carbonate sediments, felsic to mafic metavolcanics that were subjected to green schist facies metamorphism.

(Mengesham, 1990) proposed two major age divisions: the Middle Proterozoic rocks, consisting of gneisses of various types, amphibolite & schists and the Late Proterozoic rocks

Nearly all earlier publications on the geology and mineral potential of Ethiopia include some reference on the marble occurrences of the country. To mention but few are L. Usoni (1952), P.Mohr (1960), D. Jelenic (1965), Hunting's (1969, UND (1972), and Ethio- Nippon (1970).

According to L. Gumarov and Tesfaye Bahita (1979), the geological setting of marble body, which is the part of the proposed license project area and surrounding lies within a major NS trending Daleti-Sirba Abay belts of Metavolcano-plutonic rocks.

This belt consists of thick amphibolites schist or diorite rocks in tectonic contact with variable marble types. The marble is the locality is predominantly white with minor dark, dark grey, rose, green and blue marble type (similar to Daleti-SirbaAbay marble type) with minor variations. The Amphibolites and associated metavolcanics and the marble unit extend from the Daleti Town to the south and north. Around Oda and Bedekorro area (west of the project area), the marble also extend from south and north with regional foliation striking NS to NNW-SSW trend.

Northwards, the marble is intruded by thick diorite and granitic rocks (meta-diorite-granite) assemblage which forms a hill.

Regional geological map at the scale of 1:250,000, geochemical and mineral surveys were conducted by Dawit Birhanu and MengeshaTefera (1988).

The target commodity is well exposed in the meta-intrusive plutonic rocks assemblage in central zones bounded by the greenstones and grouped within the Birbir group.

This unit is well exposed around the Daleti, OdaGodore, Bedekorro, Bendikore, SirbaAbay, etc., and in Bulen and Debate (Benishangul Gumuz Region) within the Abay (Blue Nile) Basin. the authors made reconnaissance exploration around Daleti area and the lower Dabus river valley reporting the existence of extensive deposits of marble with high quality that can be somewhat compared to that of Carrara Marble of Italy.

Consequentially the promoter has selected Boka Locality for Marble development mainly based on L. Gumarov and Tesfaye Bahita (1979), and to less extent used some data from Dawit Birhanu and MengeshaTefera (1988).To the west of Bendikoro, the Marble body changes gradationally to meta-sediments of marginal basin that imply end of marble body.

According to kazmin et al (1979), the main rock units of the area are composed of orthogenesis, paragenesis, andesitic, dacitict-ryholitic Meta sediments, syntectonic granites and granodiorites.

Through the recommendation, Girma, Dejene (1981) mapped twelve marble hills. Specimens where tested for physico- mechanical properties, which proved excellent quality. In 1984 the Ethio-Libyan joint mining company (ELMICO), had taken the initiative to open a quarry at selected sites. Later in 1993 National Mining Corporation PLC, (NMIC) purchased what was owned by ELMICO & continued quarrying.

According to Heldal, and Wale (2000). Marble deposit of west Ethiopia is not different from that of the northern except the age, the grain size and color. It is fine grained with appearance closer to the originated limestone.

These variations are accounted for the low degree of metamorphism White, yellow and violet verities of colors are common.

Walle and Heldal, 2001 also studied, the deposit is flat to hill forming, generally exhibits variety of colors ranging in white, dark-gray, gray, pink, blue and green patches (Multicolor).

The pink, silicate rich marble and sky blue marble occur around the contact zones with basic dykes. However ,this different in color and grain sizes, such as coarse grained white marble with minor graphitic bands, and white fine-grained with green to grey patches; fine to medium grained white marble are some of the varieties present in area. However quartz is usually present as nearly horizontal veins and as scattered aggregates.

Heldal, and Wale, 2000 and Ministry of Mines 2002 operates several quarries such as Pure calcite is white in color, Iron and magnesium and some silicate minerals give a significant green color; graphite gives dark, pyrite greenish grey and hematite color marble pink. Some rare colors like sky-blue are due to impurities or “failure” within the calcite crystals however, Dolomitic marbles are also locally present in the area.

On other hand Ethiopian Geological Survey (EIGS, 1989) estimated the reserves of marble in this area (12 marble occurrences are known) to be over 50,000,000 t.

Finally, based on different authors, it is concluded that Marble from Daleti, (western Ethiopia) is mostly calcite marble.

CHAPTER THREE

3. REGIONAL GEOLOGICAL SETTING

3.1. Introduction: The Pan African Orogeny

The term 'Pan-African' was coined by Kennedy (1964) on the basis of an assessment of available Rb-Sr and K-Ar ages in Africa. In Early days the Pan-African was interpreted as a tectonothermal event of some 500 Ma, during which a number of mobile belts formed surrounding the older cratons (Kröner and Stern, 2004). The concept then extended to the Gondwana continents (Fig. 3.1) and the thermal event was later recognized to constitute the final Part of an orogenic cycle, leading to orogenic belts which are currently interpreted to have resulted from the amalgamation of continental domains during the period of 870 to 550 Ma (Kröner and Stern,2004).

Relatively, the low-grade rocks of western and Southern Ethiopia are considered to be the part of Arabian-Nubian Shield and the high-grade gneissic rocks that adjacent to these rock assemblages were considered as older/Achaean to Neoproterozoic basement (Kazmin, 1971). Currently, the term Pan-African is used to describe all Neoproterozoic to early Paleozoic phenomena of tectonic, magmatic, and metamorphic activities related to crust that was once Part of Gondwana.

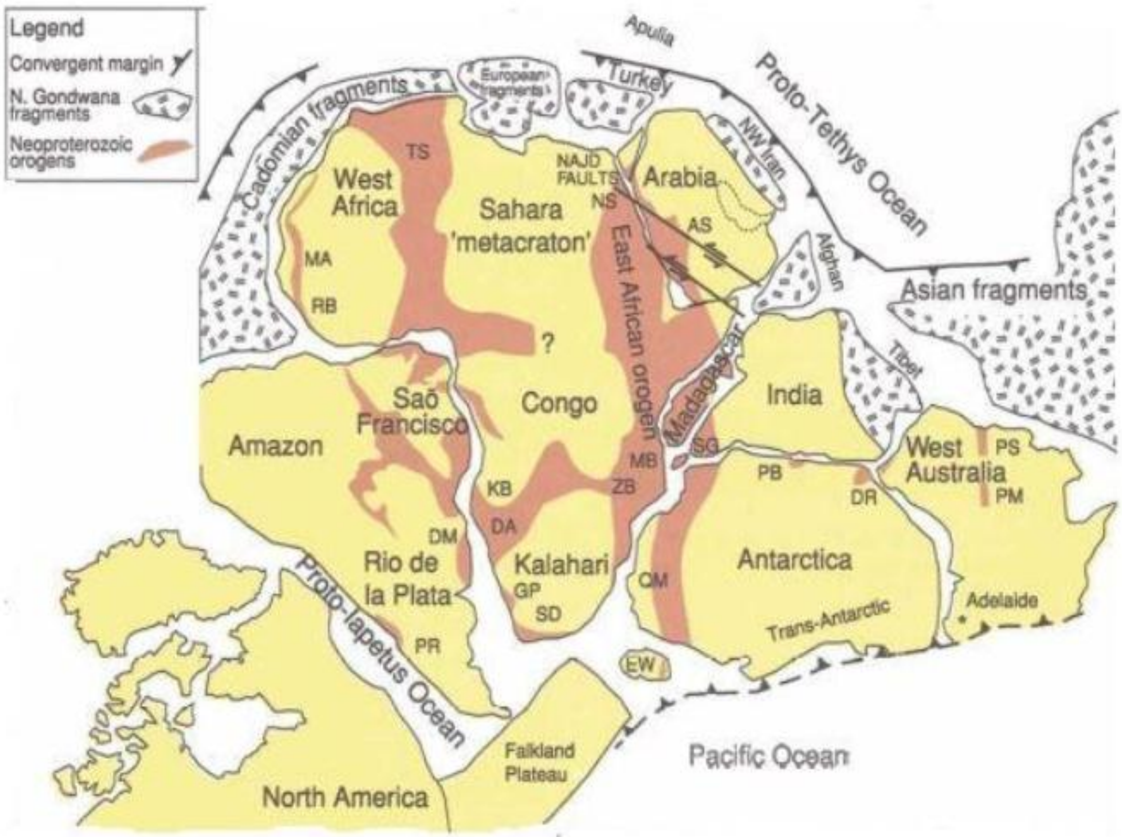

Figure3.1: Gondwana at the end of Neoproterozoic time (~540 Ma); the general arrangement of Pan African belts (Adopted from. Kröner & Stern, 2004).

The term Pan-African Orogeny is used to describe tectonic, magmatic, and metamorphic activities of Neoproterozoic to earliest Paleozoic age. Especially for crust that was once part of Gondwana. According to different authors, in different time reports, East African Orogeny has long been considered as the best exposed bowels of former mountain building.

The WES geotectonically evolved through different processes beginning from early rifting and associated sedimentation followed by subduction and island arc formation, arc-accretion and, finally, continent-continent collision (e.g., Kazmin et al., 1978). The cause for the latter stages, collectively called 'the Pan African orogeny', is believed to be collision of east and west Gondwana (e.g., Stern, 1994) which caused severe E-W crustal shortening (Teklewold Ayalew and Johnson, 2002).

Generally the Pan-African orogenic cycle was the result of different combined activities. Ocean closure and arc and micro continent accretion are both parts of Pan-African orogenic cycle along with the final suturing of continental fragments which is responsible for the formation of the supercontinent Gondwana (Kröner and Stern, 2004).

Despite early suggestions claiming opening of large Neoproterozoic oceans between different cratons (Fig. 3.1) to be result of breakup of the Rodinia supercontinent some 800-850Ma, current data indicate that the African and South American cratons were never Part of Rodinia (Kröner and Stern, 2004).

A Neoproterozoic crystalline basement ranging from 880 to 550 Ma constitutes the crustal backbone of the Ethiopian region with wide exposures in the southern and western Ethiopia and, to a lesser extent, in the northernmost Ethiopia (Abbate *et al.*, 2015).The Proterozoic terrains in Ethiopia are related to the East African Orogen (Stern 1994), a N–S elongated mega collisional structure stretching from Israel to Madagascar and produced between West and East Gondwana by the closure of the Mozambique ocean (Abbate *et al*., 2015) (Fig. 3.1).

In the north, the East African Orogeny constitutes the Arabian–Nubian Shield and in the south the Mozambique Belt. In northern Ethiopia, the Nubian portion of the Shield is prevalent, with dominantly low-grade volcano sedimentary rocks overlain by metasediments (stromatolitic carbonates and diamictites) associated with "Snowball Earth" (Beyth et al., 2003). In southern Ethiopia, the Mozambique Belt exposes abundant amphibolites and granulite facies metamorphic rocks and gneiss terrains (Abbate, 2015).

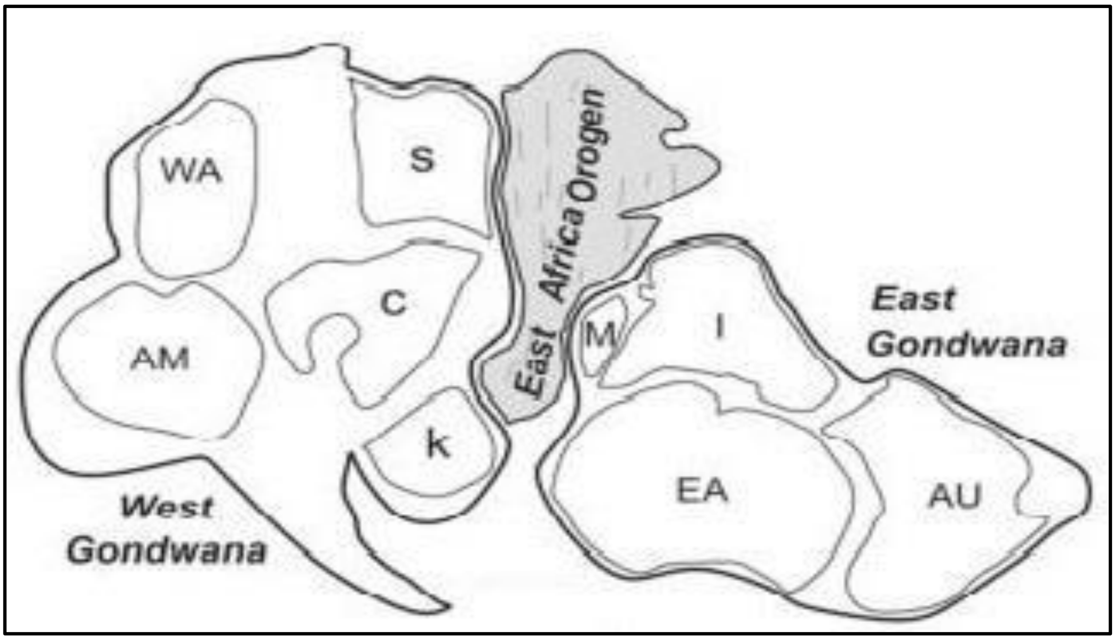

Figure3.2: The East Africa Orogen squeezed between West and East Gondwana. Adopted from Meert and Lieberman (2008).

3.2. The Mozambique Belt

The Mozambique Belt, a part of the Pan African East African Orogen is a roughly N-S oriented mountain range that formed by the collision of East and West Gondwana (Tenczer *et al*., 2005). The cause of this collisional event is believed to be a long-lived subduction system along which island arcs were accreted between 750-500 Ma (Tenczer *et al*., 2005).

This study also claims that the tectonics related to this event resulted in the formation of thrust propagating onto different Cratons. The propagation of these thrusts formed a Pan-African metamorphic overprint with a gradient from greenschist facies to high pressure granulite facies in different Cratons in Africa (Tenczer et al., 2005). Closure of the oceanic basin occurred at ~760 Ma and was followed by the formation of major north trending transcurrent faults at ~ 635 Ma (Abdelsalam and Stern, 1996).

Cutten et al. (2006) identified two principal domains in Mozambique Belt namely, Western Mozambique Belt (WMB) and Eastern Granulites (EG). The Western Mozambique Belt (WMB) comprises upper amphibolite facies gneisses with emplacement ages predominantly between 2970 to 2648 Ma (Johnson et al., 2003) but also as young as 1837 Ma, and represent reworked rocks of the Tanzania Craton and Usagaran Belt. As yet, no igneous rocks of Pan African age are identified in Western Mozambique Belt (Cutten et al., 2006).

On the other hand, the Eastern Granulites (EG) are high-grade, arc-derived lithologies of Pan-African- aged emplacement ages ranging between 841 Ma and 632 Ma (Cutten et al., 2006).

Both terranes include Neoproterozoic metasedimentary rocks on their lithological make up (Cutten et al., 2006).

In its Northeastern branch, the Mozambique belt is largely concealed by Phanerozoic cover and the Precambrian rocks expose only in restricted areas. The areas where the Precambrian rocks are exposed are restricted to the Kenyan and Southern Ethiopian basement, inliers in eastern Ethiopia and southern Somalia and an isolated strip of Precambrian in northern Somalia (Warden and Horkel, 1984). However, different authors (e.g. Braathen et al. 2001, Kazmin et al., 1978, Taddesse Alemu and Tsegaye Abebe, 2007) added the Western Ethiopian shield to North-eastern part of Mozambique Belt where Precambrian rocks are exposed.

Generally, the well-established Precambrian outcrops in this part of the Mozambique belt include Precambrian rocks of Southern Kenya, Southern Ethiopia, Eastern Ethiopia, Northern Somalia, Western Ethiopia and to lesser extent Northern Ethiopia (Kazmin et al., 1978, Warden and Horker, 1984, Taddesse Alemu and Tsegaye Abebe, 2007).

3.3. The Arabian-Nubian Shield (ANS)

3.3.1. Origin and Tectonism

The Arabian-Nubian Shield (ANS) in North East Africa and West Arabia is the largest tract of juvenile continental crust originated during Neoproterozoic age and affected by the Pan African orogenic cycle (Patchett and Chase, 2002; Kröner and Stern, 2004, Avigad and Gvirtzman, 2009). It makes up the northern half of the East African Orogen and stretches from southern Israel and Jordan as far as Ethiopia and Yemen, where it makes transition into the Mozambique Belt (Blasband et al., 2000; A. Kröner & Stern, 2004).

The ANS is suggested to be a crust that was generated during the formation of smaller terrains of arc and back arc crust within and around the margins of a large oceanic tract known as the Mozambique Ocean, which formed in association with the breakup of Rodina ~ 800–900 Ma (Stern, 1994). Oceanic plateaus are also thought to be accreted (Stein and Goldstein, 1996) and their crustal fragments collided as the Mozambique Ocean closed, forming arc-arc sutures, composite terrains, the ANS and the larger collisional belt known as the East African Orogen (Stern et al., 2004; Stern, 1994).

In the course of its Neoproterozoic evolution, number of tectono-metamorphic and igneous cycles have processed the ANS; but two major tectono metamorphic phases were the most prominent (Abdelsalam and Stern, 1996; Johnson and Woldehaimanot, 2003 as cited in Avigad & Gvirtzman, 2009).

The first phase, the older phase at around 750 Ma followed the cessation of most island-arc igneous activity and probably pertains to the accretion and assembly of ANS island arcs (Abdelsalam and Stern, 1996; Johnson and Woldehaimanot, 2003 as cited in Avigad and Gvirtzman, 2009). The second phase is subsequent tectono-metamorphic phase which followed a period of reduced igneous activity at around 700 Ma causing thickening of the previously stitched island-arc complexes and formed tight, roughly N–S trending upright folds (Avigad et al., 2007 as cited in Avigad and Gvirtzman, 2009).

The Arabian-Nubian Shield was sandwiched between fragments of East and West Gondwanaland as these collided at about 600 Ma (Meert, 2003) to form a supercontinent variously referred to as Greater Gondwanaland (Stern, 1994) or just Gondwanaland. The ANS was subsequently buried by Phanerozoic sediments but has been exposed by uplift and erosion on the flanks of the Red Sea in Oligocene and younger times (Robert et al., 2004). A broad region uplifting occurred in association with Cenozoic rifting and formed the Red Sea, exposing a large tract of mostly juvenile Neoproterozoic crust which comprises ANS (Kröner & Stern, 2004).

3.3.2. Litho-stratigraphy

The Arabian-Nubian Shield consists variety of rocks including gneisses, granitoids, various metavolcanic and metasedimentary rocks (Blasband et al., 2000). The western margin of ANS is defined by juxtaposition of ophiolite-decorated volcano-sedimentary sequences and juvenile Neoproterozoic arc magmatic terranes with the Eastern Granulite complex of the MB, the Archean Congo Craton and the Sahara Metacraton (Fritz et al., 2013).

However, this margin is not defined in the north because it is covered by Mesozoic to Cenozoic sedimentary rocks but it extends along the line of the Nile Valley and crops out in the Keraf arc-continent suture in northern Sudan (Abdelsalam et al., 1998 as cited in Fritz et al., 2013).

Highly deformed mafic ultramafic bodies also expose within low-grade (ANS) terrains making linear belts which are interpreted as dismembered ophiolitic rocks (e.g., Kazmin et al., 1978; Warden et al., 1982;Seife Michael Berhe, 1990; Teklewold Ayalew et al., 1990; Abdelsalam and Stern, 1996).

Abundant tonalitic to granodioritic plutons stich the ANS terrains together and terrain boundaries are frequently defined by suture zones that are marked by ophiolites (Kröner & Stern, 2004).

Most of these ophiolites as identified by Kroner & Stern (2004), have trace element chemical compositions suggesting formation above a convergent plate margin, either as part of a back-arc basin or in a fore arc setting. Its dominantly juvenile nature, relatively low grade of metamorphism and abundance of island-arc rocks and ophiolites make ANS distinct from Mozambique Belt (Kröner & Stern, 2004).

3.4. Geology and Geotectonic Evolution of the Western Ethiopian Shield (WES)

3.4.1. Litho-stratigraphy

Despite scarcity of well-established geological investigations of the relationship between the Neoproterozoic rocks of the Arabian–Nubian shield (ANS) and rocks of the Mozambique belt (MB), different studies (e.g. Kröner, 1985; Vail, 1985; Stern 1994) have confirmed that three types of lithotectonic assemblages: volcano-sedimentary terranes, gneissic terranes and ophiolitic rocks are recognized. According to (Kazmin *et al*., 1978) western Ethiopia comprises both the low-medium grade metamorphic rocks of Arabian-Nubian Shield (ANS) and the generally high-grade reworked rocks of Mozambique belt (MB).

Braathen *et al*., (2001) also stated that Western Ethiopia shows a division of two Precambrian provinces: Archaean Palaeoproterozoic gneisses in the east, Neoproterozoic and Palaeoproterozoic gneisses to the west. The Precambrian of this region consists of high grade gneiss and migmatite in the east and west and low grade metavolcano-sedimentary rocks in the middle bounded by NNE-SSW trending ophiolitic belts (Tulu Dimtu belt and Assosa-Kurmuk belt) (Tadesse Alemu and Tsegaye Abebe, 2007).

Benzu Gold Mining Ethiopia PLC, (2013) reported that the exposed rocks in Western Ethiopia consist primarily of Lower Complex gneisses and migmatite. They are coarse grained, well foliated and banded, strongly deformed and metamorphosed to amphibolite facies and overlain by the Upper Complex which consists of metavolcanic and metasedimentary rocks of low grade greenschist to amphibolite facies (Benzu Gold Mining Ethiopia PLC, 2013).

The metavolcano-sedimentary lithology include graphitic phyllite, carbonate schists and marble and Ultrabasic to acidic intrusive related to the Upper complex intrude the Lower Complex (Benzu Gold Mining Ethiopia PLC, 2013).

Together, these rocks form the Western Greenstone Belt with predominant lithology including chlorite-graphite-sericite schists, phyllite, quartzite, andesite and rhyolites (Benzu Gold Mining Ethiopia PLC, 2013). Teklewold Ayalew and Johnson (2002), also confirm presence of rocks of varying grades.

These wide range rocks in WES have been categorized in to different groups using different classification schemes (e.g., Mengesha Tefera and Berhe, 1987; Allen and Gebremedhin Tadesse, 2003).

They broadly fall into three groups of lithotectonic units; the Birbir Domain, Geba domain and Baro domain (Teklewold Ayalew and Peccerillo, 1998; Mengesha Tefera and Seife Michael Berhe, 1987 as cited in Teklewold Ayalew and Johnson, 2002). This classification is primarily based on grade of metamorphism and also lithological similarities within the same domain (Teklewold Ayalew and Peccerillo, 1998).

According to these authors the Birbir domain encompasses an assemblage of mafic to felsic intrusive and extrusive rocks and mainly volcanogenic sedimentary rocks which are enclosed between the dominantly orthogenesis Baro and Geba domains. Monotonous quartzo-feldspathic gneisses are reported to be the dominant lithologic units in the easterly Geba domain. This domain is categorized under gneissic terrain encompassing strongly foliated, medium- grained biotite and hornblende biotite gneisses as predominant rock types (Teklewold Ayalew and Johnson, 2002).

The Geba domain also contains very high temperature rocks as some of the gneisses are migmatitic and contain numerous sub-concordant lenses of granitic and pegmatitic material (Teklewold Ayalew and Johnson, 2002). The Baro domain is similarly dominated by the ortho-gneissic biotite gneiss and hornblende gneiss but, in its easterly edge where it makes contact with Birbir domain, it is characterized by paragneisses.

Based on classification made by Allen and Gebremedhin Tadesse (2003) also puts the rocks in to five categories: Didessa domain, Daka domain, Kemashi domain, Sirkole domain and Dengi domain. This classification discusses the rocks as the following.

3.4.1.1. Didessa Domain

This domain extends from approximately 5km east of Didessa River in Wollega area covering about 70km up to about 25km west of Gimbi town. It is differentiated from the adjacent Kemashi Domain to the west by distinctive lithological and structural characteristics. Banded mafic gneisses in ortho gneisses of Didessa domain contain ultramafic bands derived from a layered mafic intrusive body, and very coarse granitoid gneiss and intruded by Neoproterozoic intrusive rocks. The rocks within this domain are moderate grade para-gneisses which consist of interlayered biotite amphibole gneiss, garnet-biotite gneiss and quartzo-feldspathic gneiss and ortho-gneisses which consist banded mafic gneiss.

This domain makes a contact with the nearby Kemashi domain which is marked by the N–S trending Chugi Shear Zone, consisting of strongly N–S cleaved phyllonitic rocks derived from the Didesa Gneiss.

The classification by Allen and Gebremedhin Tadesse (2003) concluded that this domain is the eastern edge of the Tulu Dimtu belt. Partial melting and deformation events are reported to occur in the Didesa Terrane at ca. 660 Ma (Blades et al, 2015).

3.4.1.2. Kemashi Domain

The Kemashi domain is located northeast of the study area which far approximately 106 km from the research area. The narrow 10-15 km wide domain paralleling the trend of Tulu Dimtu belt. Sequences of metasedimentary rocks of marine origin, mafic to ultramafic metavolcanics and associated plutonic rocks of wide variety make up the domain. The metasedimentary rocks consist of dark, highly pyritized, pelitic to psammitic schists, intercalated with chert, graphitic phyllite and marble.

3.4.1.3. Dengi Domain

The main units characterizing this domain include deformed and metamorphosed volcano sedimentary sequence, a coarse-grained para- and ortho-gneissic unit and mafic to felsic intrusive bodies intruding to the later. The gneisses and the volcano-sedimentary succession are in tectonic contact across both the N-S Gember Shear Zone and the later crosscutting NW-SE Chochi Shear Zone.

It crops out to the west of the Kemashi Domain and has 120km width and indicates two pulses of magmatism at 850-840 Ma and 780-760 Ma in similar way to Didessa domain (Blades et al, 2015). The gneissic assemblage consists of biotite hornblende paragneiss and pelitic gneiss, together with mafic and garnetiferous granitoid orthogneiss. The gneisses are locally migmatised, and the assemblage as a whole is intensely folded and veined.

3.4.1.4. Sirkole domain

The Sirkole Domain was understood to occupy west of Assosa town extending into Sudan, and therefore its western limit is unknown. It consists of different N-S elongated blocks which have only a few km widths. This domain consists of either medium grade gneisses or metavolcanic rocks intruded by foliated and massive granitoids. There are two major units that make up the areas gneissic lithology. The first one is Tosho gneiss, heterogeneous gneiss which includes undifferentiated complex of biotite-amphibole gneiss and amphibolite and Granitoid gneiss.

The other one is Yangu Granitoid, large homogeneous anatectic granite gneiss formed by partial melting of the Tosho Gneiss.

The volcano-sedimentary succession encompasses a thick sequence of mafic metavolcanic and interbedded metasedimentary rocks subjected to folding and strong cleavage. The folding and cleavage are primarily strong in graphitic schists. The volcano-sedimentary succession is folded and strongly cleaved with a N–S striking, easterly dipping schistosity, and a mineral stretching lineation plunging gently eastwards. Amphibolite facies assemblages occur in the gneiss and the volcano-sedimentary successions, the presence of rare kyanite in the graphitic schists reflecting medium to high-pressure conditions.

3.4.1.5. Daka domain

The predominant rocks in this domain are gneissic and they encompass three lithological units (Allen and Gebremedhin Tadesse, 2003). Allen and Tadesse correlated two of the units with the two gneissic units of the Sirkole Domain, i.e. the Tosho Gneiss, and the Yangu Granitoid Gneiss. The relationship between these two units is more clearly delineated in this domain. The Tosho gneiss belongs to amphibolite facies and grades from east to west into the granitoid gneiss through a zone of increasing metamorphic grade and migmatisation.

The increment in grade of metamorphism of Tosho gneiss towards the west is interpreted to represent formation of Yangu granitoids by anatectic partial melting of the Tosho Gneisses.

Daka Domain's another gneissic unit is a banded orthopyroxene-bearing granulite facies unit termed Daka Gneiss (Tadesse and Tesfaye, 1999 as cited in Allen and Gebremedhin Tadesse, 2003). It crops out in south of the other two units and is in tectonic contact with the other two along the E–W trending Daka River Thrust (Allen and Gebremedhin Tadesse, 2003).

This occurrence is significant as granulite facies terranes are rare within the northern part of the EAO. The presence of garnet-clinopyroxene assemblages within the granulite, suggests high pressure conditions of metamorphism for the Daka Gneiss. Fabrics in the Daka Gneiss, which have an E–W strike and dip gently to moderately southwards, are mylonitic, and related to the formation of the Daka River Thrust.

3.4.2. Origin and tectonic setting

The WES geotectonically evolved through different processes beginning from early rifting and associated sedimentation followed by subduction and island arc formation, arc-accretion and, finally, continent-continent collision (e.g., Kazmin et al., 1978).

The cause for the latter stages, collectively called 'the Pan African orogeny', is believed to be collision of east and west Gondwana (e.g., Stern, 1994) which caused severe E-W crustal shortening (Teklewold Ayalew and Johnson, 2002).

The lithological, structural and metamorphic similarities of the gneissic rocks of WES with the basement exposed in further south (in Kenya, Uganda and SE Sudan) infer that the gneissic rocks of WES are a northwards continuation of the Mozambique Belt (Kazmin et al., 1978; Seife Michael Berhe, 1991; Samuel Gichile and Fyson, 1993).

Different evidences suggest that bodies within the WES have an intrusive nature (Grenne *et al*., 1998; Aberra Mogessie *et al*., 1999 as cited in Teklewold Ayalew and Johnson, 2002). Among the intrusive bodies of WES, A-type granitoids of Wollega area have been identified to include three domains; the Ganji monzogranite, Homa gneissic granite and Tuppi granite (Tesfaye Kebede and Koeberl, 2003). These granitoid bodies are understood as they either intruded into greenschist facies volcano-sedimentary sequence or emplaced at the contact between low- and high-grade terranes (*e.g.*, Braathen *et al*., 2001, Tesfaye Kebede and Koeberl, 2003).

The granitoid rocks in the area are categorized as pre- to and post-deformation granitoids of within plate and volcanic arc settings. Teklewold Ayalew and Peccerillo (1998) indicated that pre- to syn-tectonic granitoids appear to be the product of magmatic arc activity (VAG), whereas the other granites fall in the field of within-plate granites (WPG).

3.4.3. Metamorphism and deformation

Teklewold Ayalew and Johnson (2002) categorized the WES rocks into different metamorphic facies. Accordingly, the metabasites of the region fall into greenschist to lower amphibolite facies in the juvenile ANS domain and mid to upper amphibolite facies in the gneissic domains.

The mineral assemblage of metapelites of Birbir domain were interpreted by Teklewold Ayalew (1997) and showed condition of 520oC and 4kbar. On the other hand, the P-T condition of the metapelites in Baro domain was deduced to be 700oc and 7K bar which marks steep metamorphic gradient among the areas at the transition of the domains. A uniform granitoid composition and lenticular texture over hundreds of square meters of outcrop suggest that the majority of biotite granite and hornblende biotite granite are tonalitic or granodioritic orthogneisses. The protolith of rare garnet-bearing and commonly epidotised gneissic rocks are interpreted to be more probably igneous rocks.

Generally, metamorphism in WES occurred in wide range of metamorphic grades beginning from low grades like greenschist facies and lower amphibolite as in Birbir domain to very high grades like upper amphibolite and granulite facies as in Geba and Baro domains (e.g. Teklewold Ayalew and Peccerillo, 1998, Mengesha Tefera and Seife Michael Berhe, 1987).

In the higher grade ortho- and para-gneisses and migmatites there is no evidence of primary sedimentary or volcanic features that can be observed on the rocks.

The assemblage in high grade gneissic rocks of Baro domain was interpreted by Teklewold Ayalew *et al*., 1990 to be high-grade garnet-sillimanite, garnet-cordierite-gedrite, and biotite–hornblende assemblages which is an indicative of higher amphibolite facies. Multiple phases of deformation are recorded in the Western Greenstone Belt.

The regional strike of the foliations ranges from N-S to NW-SE and NE-NW and the predominant direction of foliation in the region is NE-SW (Benzu Gold Mining Ethiopia PLC, (2013).

According to different authors, pre-kinematic plutons (830-780 Ma) and volcanic and sedimentary units were affected by regional deformation and low-grade metamorphism (Braathen *et al*., 2001). Allen and Gebremedhin Tadesse (2005) declared that the structural evolution of Western Ethiopia involved three deformational stages (*D1*, *D2*, *D3*), applied only to the volcano-sedimentary units and represented the Pan African deformation sequence.

The approximately E-W shortening event, designated *D1* in Abraham (1989) is responsible for formation of a penetrative, axial plane-parallel foliation, striking NNE-SSW (Braathen *et al*., 2001). The D1 deformation event resulted in the overall N-S-striking and steeply E-dipping D1 foliation which is the most pronounced and penetrative in supracrustal rocks, but is also well developed in marginal parts of the intrusions (Grenne *et al*., 2003).

High-strain zones are found along lithological contacts, and also make up the bulk of the kilometer wide Baruda shear belt (Grenne *et al*., 2003). Highly *D1*-strained rocks show a stretching lineation that commonly plunges to the east (Grenne *et al*., 2003). A later, localized*D*2 sinistral-transcurrent phase reached amphibolite facies in narrow, discrete shear-zones. This deformation event resulted in steepening and tightening of *D1* folds and followed by *D3* which resulted in shearing and faulting of the structures (Braathen *et al*., 2001). The metasedimentary and metavolcanic sequences existing in West Ethiopia's tansect are intruded by plutonic complexes (Tefera, 1991, 1997).

These units intruded by plutonic complexes were variably deformed during the main *D1* contractional event and the accompanying metamorphism was generally of greenschist facies but reached lower amphibolite facies locally (Braathen *et al*., 2001). The supracrustal units are intersected by a major *D1* shear-zone referred to here as the Baruda shear-belt. Two narrow *D*2 shear-zones are also found in central parts of the transect (Braathen *et al*., 2001).

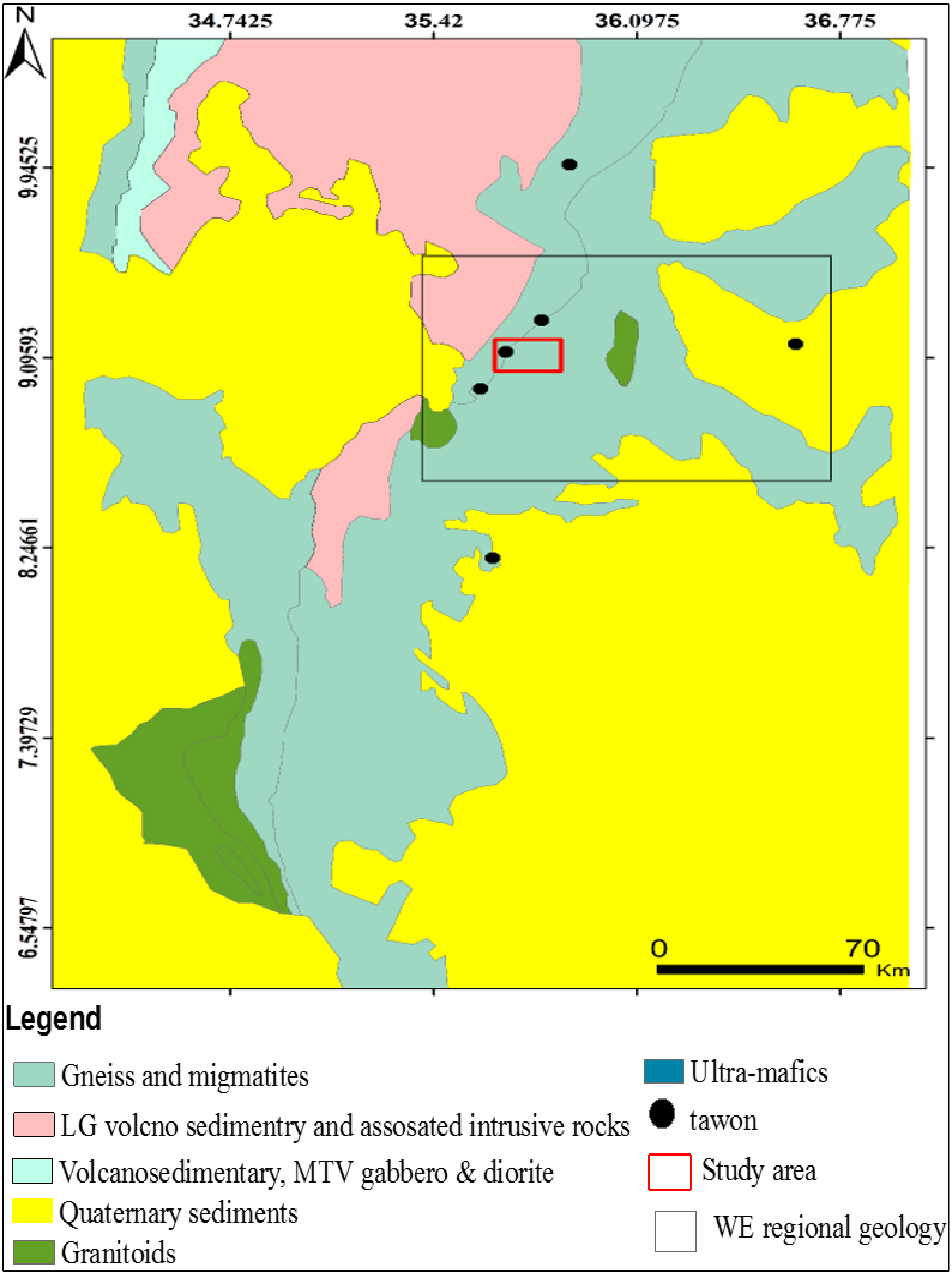

Figure 3.3: Simplified geological map of Western Ethiopia. Area of study has been highlighted with the use of a box. Taken and adapted from (Tadesse and Allen 2004).

3.4.4. Economic minerals and rocks resources

Economic minerals occurrence in western Ethiopian shield has been identified in different parts of the area. Kebede H. Belete *et al*. (2002) reported occurrence of several PGM in the disseminated chromites and altered silicates associated with the serpentinized dunite in Yubdo.

Gold mineralization is also observed in the area and different companies are currently exploring and mining. Three styles of gold mineralization, i) syenite intrusions related mineralization, ii) skarn gold type mineralization and iii) fault-shear hosted gold mineralization in metasediments are recorded in the area (Benzu Gold mining Ethiopia, 2013). Solomon Tadesse (2009) stated four belts in western Ethiopian domain host different economic minerals.

The mineralization associated with these belts include primary gold deposits (e.g. Dul, Oda-Godere), the platinum deposit and occurrences (Yubdo and Daleti-Tuludimtu respectively), the iron deposits (Bilikal, Chago, Gadma) and base metals prospects (Abetselo, Kata) of volcanogenic-volcano sedimentary type. Bullock and Morgan (2015) recently reported that they discovered potentially economic graphite-bearing schist units in the Assosa region of western Ethiopia.

According to their report, this graphite covers an area of 37 km^2 and is hosted predominantly by quartz-graphitic schist, quartz-feldspar-mica schist and quartzite. Apart from metallic minerals, the area has been an exploration and mining target for different industrial minerals and rocks.

Extensive deposits of marble are found in the Precambrian metamorphic terrain of western Ethiopia and known deposit occur around Daleti, Bulen, Mora, Zigi, Baruda and Mankush. (Heldal, *et al* 1987 as cited in Sentayehu Zewdie, 2011). These deposits form different geo-morphological features and Pink, greenish and sky-blue varieties of them are reported.

A variety of igneous rocks, predominantly granites of Proterozoic to Early Paleozoic age, occurring as intrusive bodies within the Precambrian metamorphic of the western Ethiopia are reported to be of dimension stone value (Sentayehu Zewdie 2011). The dimension stone value possessing granites are identified in localities Bure, Anger, Guttin, and Dehan from Wollega and Benishangul areas.

Chapter four

4. The geology of the study area

4.1. Regional Geology

Western Ethiopia is underlain by two main rock types: tertiary volcanoes and Precambrian basement rocks. The former consist of thick piles of basaltic volcanic flows, hundreds of meters thick and are restricted to the high land plateau areas.

Precambrian basement is divided in three groups of rocks: the eastern, western, and central high grade domains. The high grade domains are made up of middle to upper amphibolite's facies, magmatic gneissic rock of Archean or lower Proterozoic age.

According to kazmin et al (1979), the main rock units of the area are composed of orthogenesis, paragenesis, andesitic, dacitict-ryholitic Meta sediments, syntectonic granites and granodiorites.

The regional strike of the area is NE-SW and swings from NE to NW. the area lies in greenschists facies represented by chlorites, marble and greenstones.

The tectonic history has been described by Amenti Abraham (1989). According to him the meta volcano sedimentary rocks are affected by deformation which caused the mineral producing the regional foliation trends of the area.

This was followed by D2 deformation event with concomitant regional shearing. The last tectonic thermal event is D3 deformation which is accompanied by syn & post tectonic intrusive of both basic & acidic composition.

The marble is found within Proterozoic metasedimentary and metavolcanic successions (quartzite, greenschist, schist and marble). Mafic and granitic intrusions, formed at various stages in the tectonothermal history of the supracrustal rocks, are common in the area. The surrounding highland is capped by Tertiary basalt and tuff. Found within the metasediments of the Precambrian basement rocks of Western Ethiopia Syn. & post tectonic intrusive of basic & acidic composition are common. The metamorphic grade is represented by chlorite, marble & greenstones. Locally, it occurs in a sequence of siliceous metasediments. Calc-silicates in the form of veins & incrustation are sometimes found on the marble.

The regional geologic setting indicate that the area is lying on the western Ethiopia green stone belts which accounts for old rocks of the Precambrian age which is similar to Arabian Nubian shield (ANS) and the Mozambique belt.

The Precambrian of western Ethiopia consists of high-grade gneiss rock associated with low grade volcano–sedimentary and associated Sin-to Post-tectonic Plutons. Tertiary volcanic rocks overlie the crystalline basement rocks.

Low grade metamorphic rocks and high-grade metamorphic rocks are separated by shear zones. The project area is situated in southwestern part of the country. Marbles, dolomites, Gneiss, Green Schist and intrusive rocks such as Granites, Granitites and varieties of Gabbro characterizes the regional geology of the project area.

The region is underlain by Proterozoic metasediments and volcanics (quartizites, greenschists, marbles and tuff) which are tectonically deformed and block faulted. The schists are intruded by syntectonic metadiorites and post tectonic granites, diorites and basalts. The surrounding highlands are capped by tertiary basaltic flows.

4.2. Local Geology

The rock units in the study area are described based on their actual field association and data obtained from previous works. From oldest to youngest age the main lithologic units Identified in the area include; alluvium, greenshist, marble, granite, Meta diorite, tufficous schist, quartzite.

4.3. Lithology and Petrography analysis

4.3.1. Greenschists

Greenschists, which increase in volume eastwards, are of terrigene-volcanogene and volcanogenic origin and contain carbonate material in varying proportions. Generally the greenschists are fine grained, rarely medium grained and laminated. Lamination is up to 3-4 cm thick. When interlayered with phyllite they easily split into thin, perfect parallel foliation.

In some outcrops laminations are marked by accumulations of metallic minerals, the site is more predominantly covered by schistose white marble with the coverage of more than 80 percent. The level of white marble coverage varies from block to block and deposit to deposit. The texture varies from very course grain to medium grained. Regarding to grain size, the deposit have sugar and salt related texture in grain size.

4.3.2. Marble

Marble is outcropping in the river cuts and gully cuts. The marble has different colors gray, light gray, pink and white but dominantly light gray, white and multicolor marble. The gray color shades from black to light gray and has intricate patterns. The grain size ranges from fine grained to coarse grained but is dominantly medium grained. It is generally massive, at fractured with widely spaced joints and karstification.

Concordant and dis concordant calcite and schist are found within the marble unit as minor lenses here and there; possibly felsic dykes and rare lenses of basic rocks which are later metamorphose with the marble unit.

Figure 4.1: Daleti marble quarry site exposure in the northern part of the area.

4.3.3. Granite

The granite unit is found in the north east part of the mapped area. It is usually exposed in the gentle slope to flat outcrop. Floats of granite boulders are observed scattered within the mapped area. It contains xenoliths of different undifferentiated metavolcanic-sedimentary rocks and at places intercalated with sheared quartz-sericite or biotite schist. It shows varies in composition and texture. It is generally pinkish grey, medium to fine grained. Detail mapping might be necessary to investigate its application as dimension stone.

4.3.4. Quartzite

This unit is exposed mainly in the north east and North West part of the exploration area. The quartzite is exposed as scattered in many parts of the area as floats or fragments. It is light brownish to white in colour and fine to medium grained. At places some smoky and sugary varieties of quartzite are also observed. This unit form small hills, moderate cliffs and especially scattered at flat topography. The surface of the quartzite is usually stained with limonite that resulted to brownish yellow colour. Ferruginous quartzite is occasionally encountered. Quartzite commonly forms narrow resistant beds in phyllite, graphite schist and quartzo-feldspathic schist.

4.3.5. Metadiorites

It is exposed in the northern and southern parts of the study area. It forms small hill and exposed as rounded boulders usually. It is fine to medium grained and dark grey in color. In this area large orthoclase crystals have been observed in the granodiorite and even in the contained xenoliths, generally near pegmatite veins. The material that gave rise to the orthoclase probably originated from these pegmatites. About five kilometers northwest of Abijendo village, the granodiorite is in contact with the marble unit.

Near this contact the granodiorite is enriched in brown garnet which is probably of end metamorphic origin. In the vicinity of Ondonok village and around Agubella village, hornblende is dominant with lesser biotite. Here the rocks commonly grade to diorite and tonalite.

4.3.6. Alluvium

Areas of Quaternary cover are an area as shown on the geological map. In places in the map area, the marble rock is extensively covered by thick soil. The low lying areas several other flat areas and valleys in the map area are underlain by alluvial deposits of silt, sand and gravel. Where dissected these deposits are seen to be several meters thick and lying directly on the peneplaned surface of the basement complex. Many of these deposits are sources of placer gold at present. Pits up to 20 m deep worked by the local people are commonly encountered along streams, river banks and terraces.

4.3.7. Tufficeous schist

The region is underlain by Proterozoic metasediments and volcanics (quartizites, greenschists, marbles and tuff) which are tectonically deformed and block faulted. The schists are intruded by syntectonic metadiorites and post tectonic granites, diorites and basalts. The surrounding highlands are capped by tertiary basaltic flows.

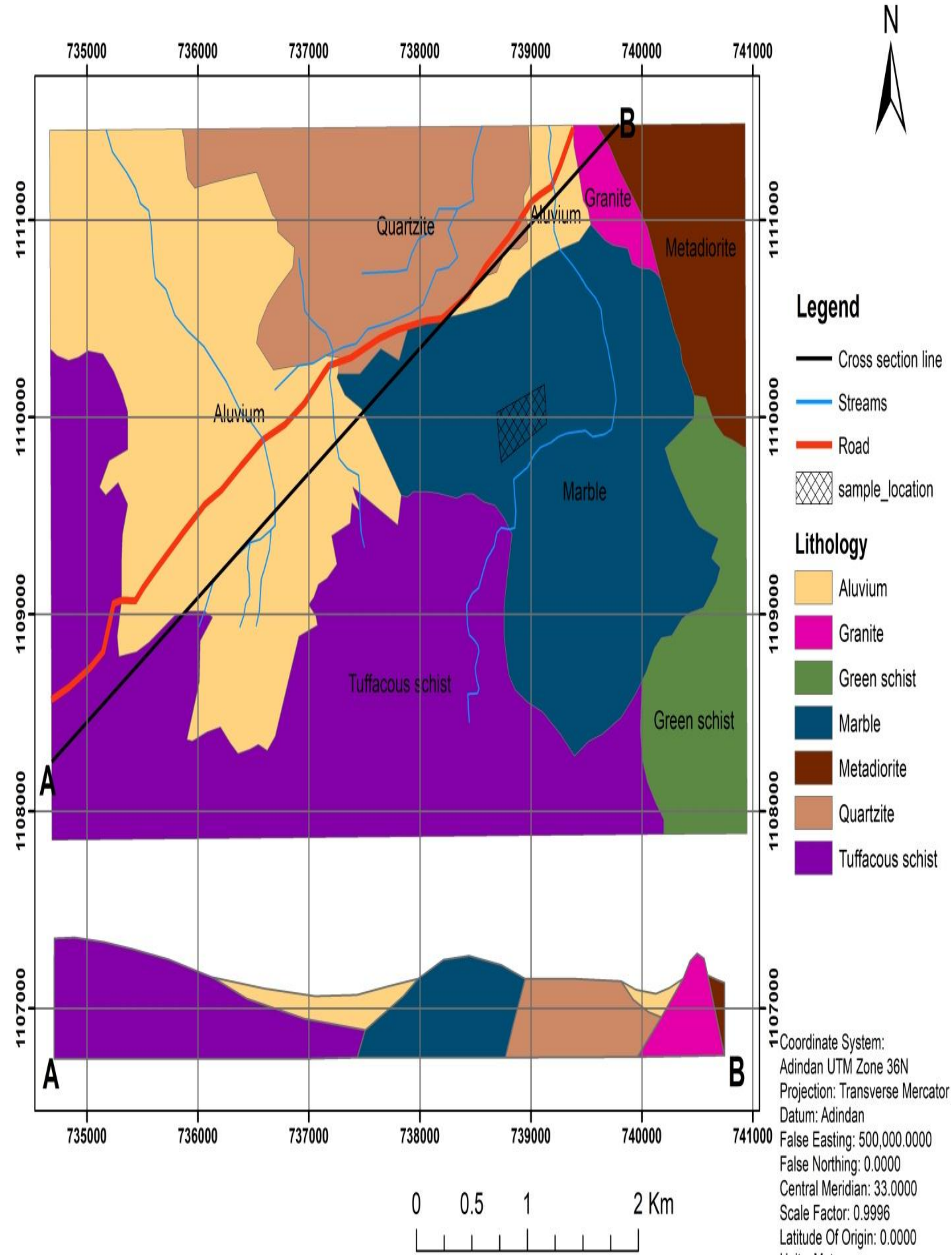

Figure 4.2: Geological map of the study area (A) and (B) geologic cross section along A-B traverse.

4.4. Petrographic Examination

A total of 44 rock samples were collected during field works for both petrographic and mineralogy, physico- mechanical, cut and polish section analysis purpose from marble rocks of the area for first time and submitted to the Central Geological Laboratory for mineralogical analyses. Out of these only ten representatives' rocks samples selected for petrographically description purpose and three rock sample mineralogy analysis based on mineralogical and color criteria.

Detail description of each thin section samples were made using both reflected light and transmitted light identifying mineral assemblage and to describe rock textures. The mineral constituents of the rocks are, calcite and muscovite, and probably, opaque, as a minor mineral constituent (table 4.1).

In order to identify major & minor mineral components. Texture & alteration products can also be detected. Boka marble is fine grained. Moreover Ten rock samples NW(01,02,03,04,05,06,07,08,09 and 10),which prepared for petrographic examination they have fine- medium to coarse grained texture. Marble rock from an area is mainly composed of calcite with other accessory minerals that incorporated in small present. The rock unit of area has an average mineral composition of calcite 96% or accessory (muscovite, opaque mineral (Fe-oxide) 4% respectively.

The calcite marble (NW-01 & NW-10) from the area is characterized by large Xenoblastic grain/large crystal shape of calcite embedded in a relatively fine-grained. While Matrix mainly composed of calcite grains and minor amount of muscovite and opaque (Fe-oxide) texture is usually Granoblastic texture is common.

(Figure.4.3. b & c). This rock is principally composed of calcite and as minor they may contain Opaque mineral (Fe-oxide).

Rock units from Daleti hill (NW-01 and NW-08) mainly contain white to light grey color calcite and large Xenoblastic of calcite with light to pink, blue color with minor accessory opaque minerals (Fe-oxide).This rock unit have fine-medium grained in texture during field hand specimen description. *Table 4.1 below, showed, Summary of major petrography tests results of Daleti marble.*

No	Sample No.	Mineral	Model (%)
1	BMC1	Calcite	99
		Opaque(Fe-oxide)	1
2	BLUE	Calcite	96
		Muscovite	3
		Opaque(Fe-oxide)	1
3	PINK1	Calcite	90
		Muscovite	10
		Opaque(Fe-oxide)	trace
4	BLACK1	Calcite	95
		Opaque(Fe-oxide)	5
5	BLUE1	Calcite	93
		Muscovite	6
		Opaque(Fe-oxide)	1
6	BMC2	Calcite	99
		Opaque(Fe-oxide)	1
7	BLUE2	Calcite	96
		Muscovite	3
		Opaque(Fe-oxide)	1
8	PINK2	Calcite	91
		Muscovite	9
		Opaque(Fe-oxide)	trace
9	BLACK2	Calcite	95
		Opaque(Fe-oxide)	5
10	BLUE3	Calcite	94
		Muscovite	5
		Opaque(Fe-oxide)	1

Table 4.1: illustrates different sample of Daleti marble, mineral composition, as well as their textural form.

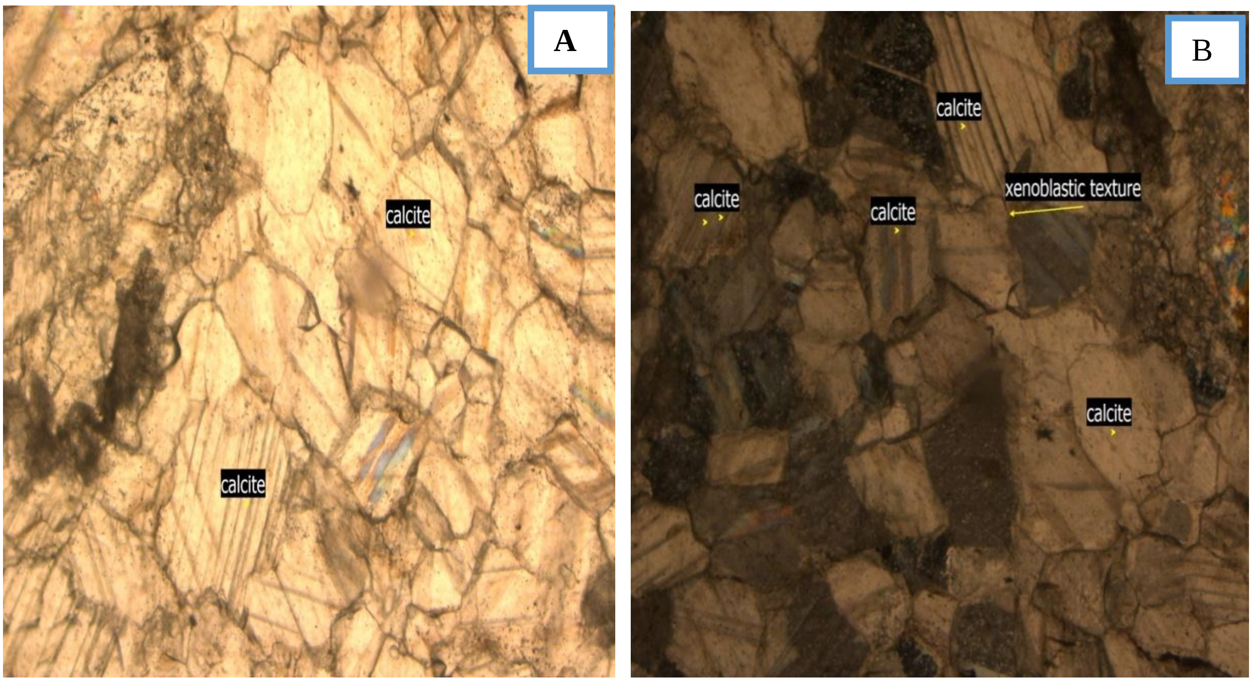

Figure 4.3: Micro-photo picture of Black marble; *sample number 01 in PPL (left) and XPL (right) in 200px magnification, show that xenoblastic texture.*

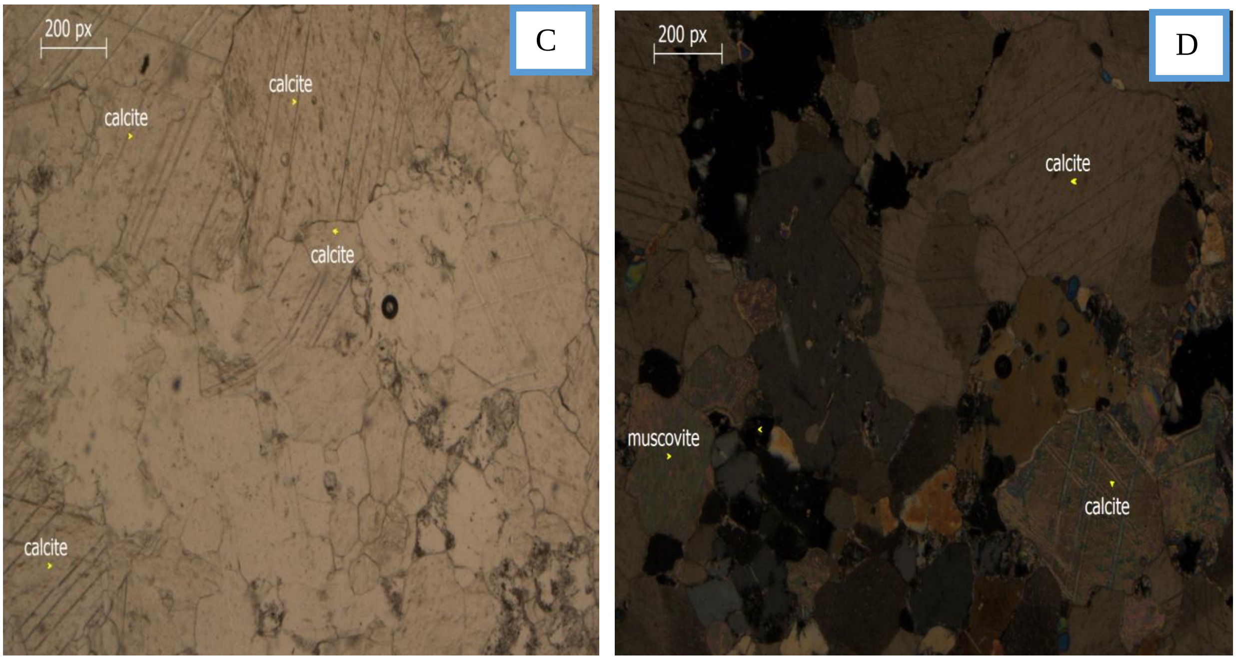

Figure 4.4: Micro-photo picture of Blue marble; *sample number 02 in PPL (left) and XPL (right) in 200px magnification, illustrate the marble dominated by calcite with minor muscovite.*

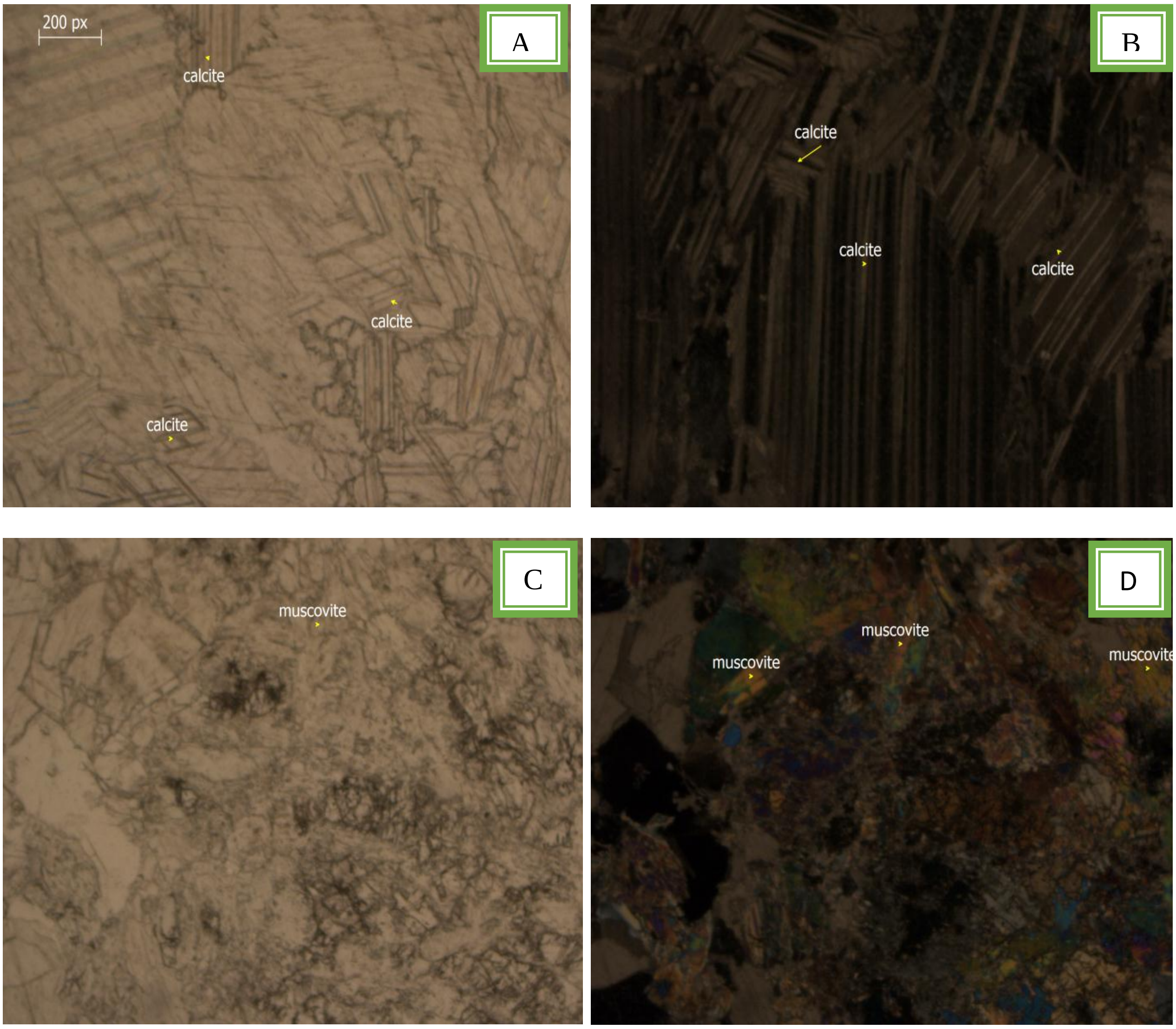

Figure 4.5: Micro-photo picture of **Pink marble***; sample number 03 in PPL (left)and XPL (right) in 10X magnification, show that abundant of calcite and minor amount of muscovite.*

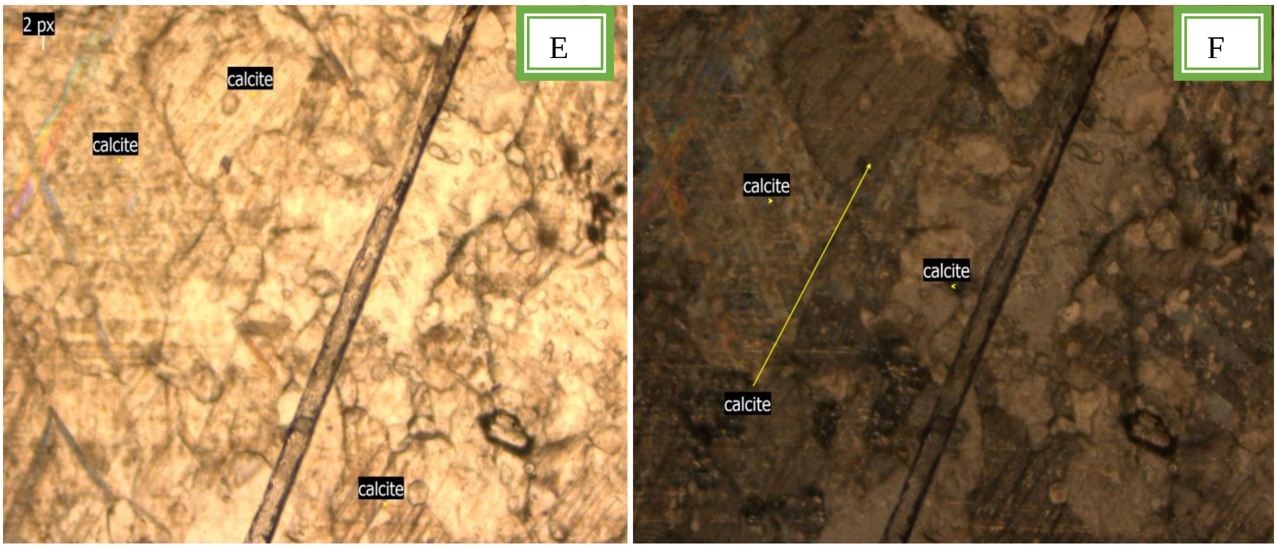

Figure 4.6: *Micro-photo picture of BMC marble; sample number 04 in PPL (left) and XPL (right) in 2px magnification, show calcite is the dominant mineral.*

4.5. Mineralogy

X-Ray Diffraction is a destructive technique, which is used to characterize and identify the crystallographic structure of natural and manufactured materials. It is one of the most powerful and well-established techniques for qualitative and quantitative analysis of crystalline compounds (Zussman, 1967).X-ray diffraction (figure 4.7, 4.8, and 4.9); reveal that Daleti marble bodies are composed dominantly of calcite with minor amounts of dolomite and lithium bismuth (tungsten oxide) which may have additional application**.**

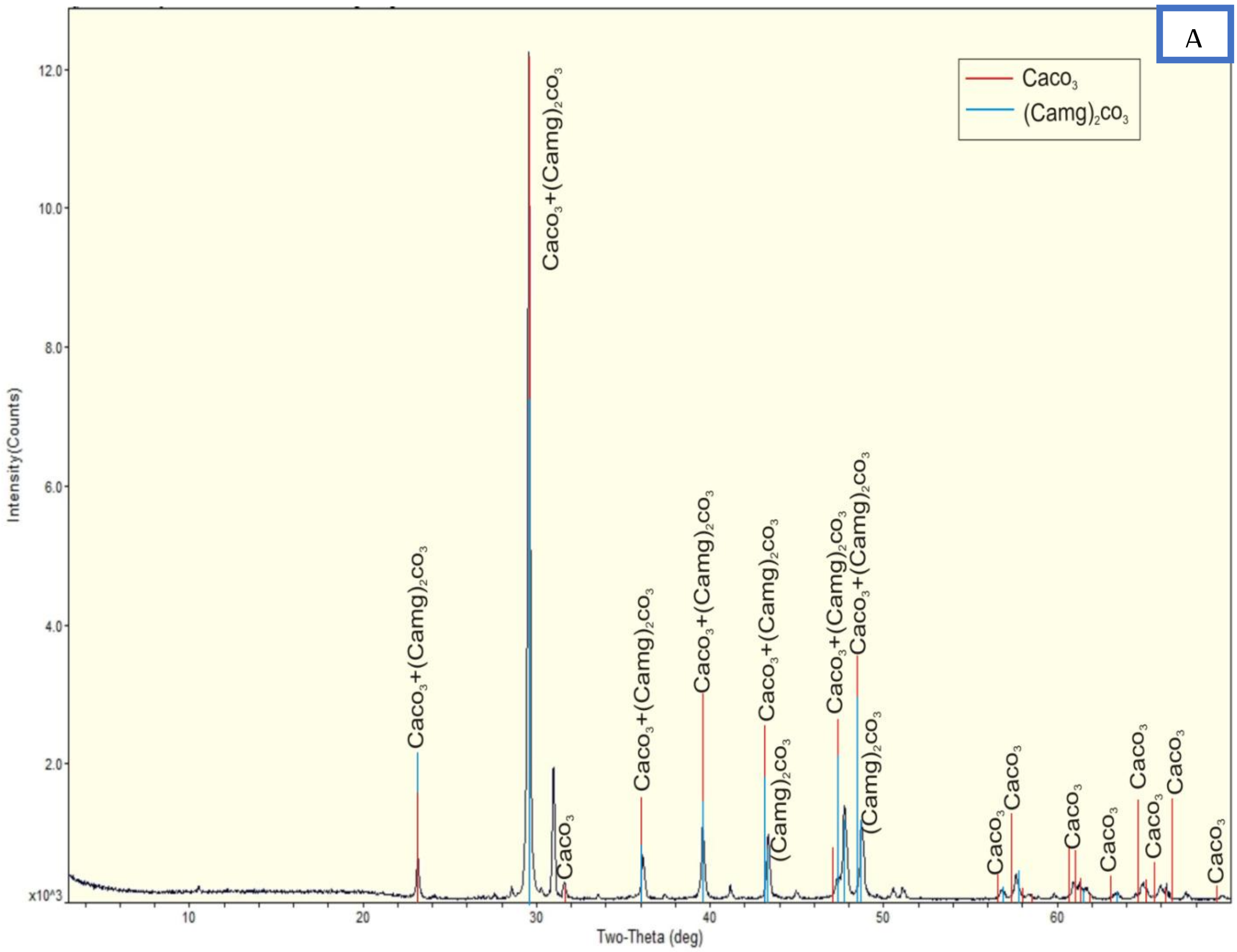

Figure4.7: X-ray diffraction for Daleti pink marble sample G1 showing calcite (abundant) and dolomite (very minor).

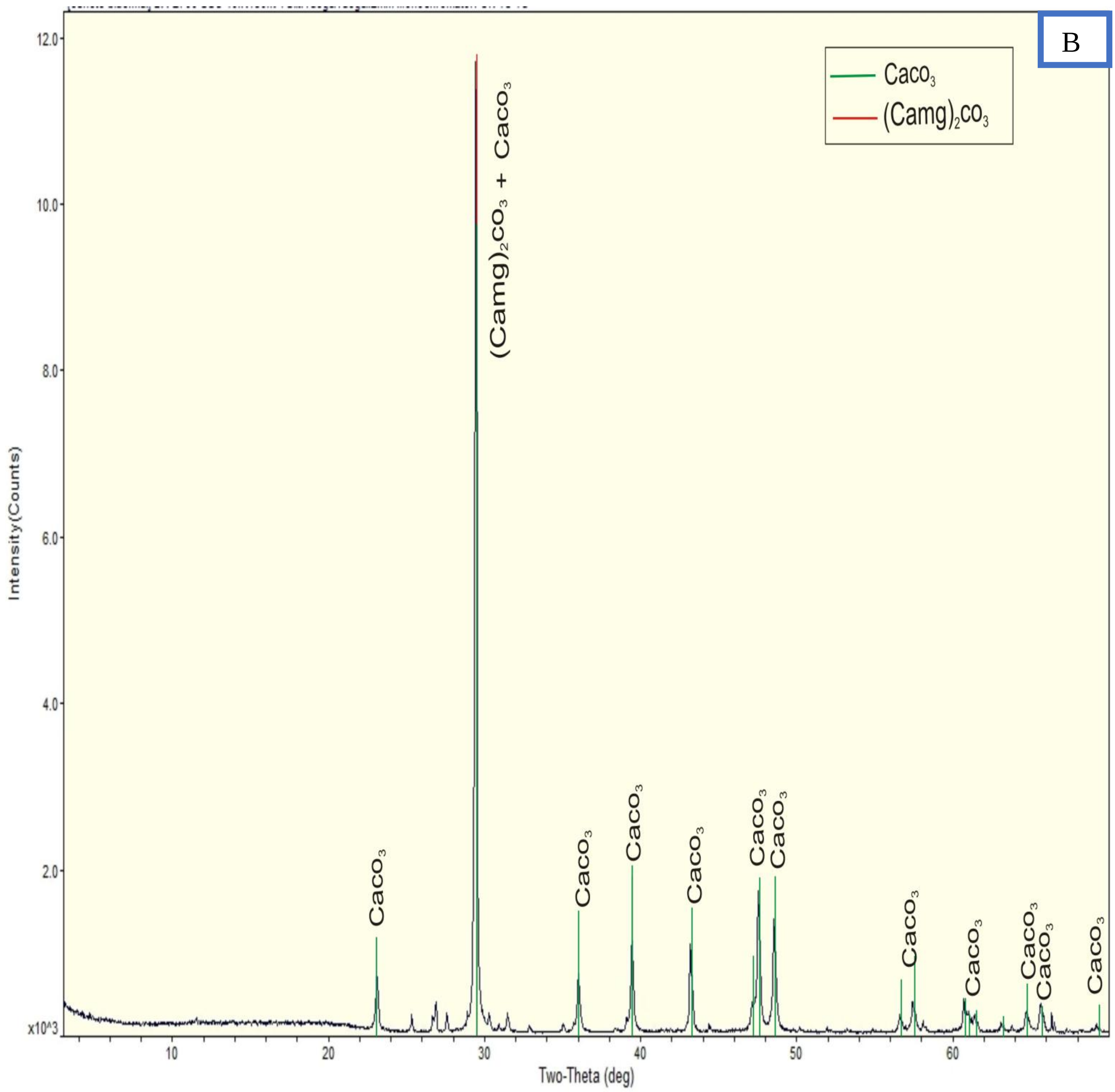

Figure 4.8: X-ray diffraction for esthete blue marble sample G2 showing calcite (abundant) and dolomite (very minor).

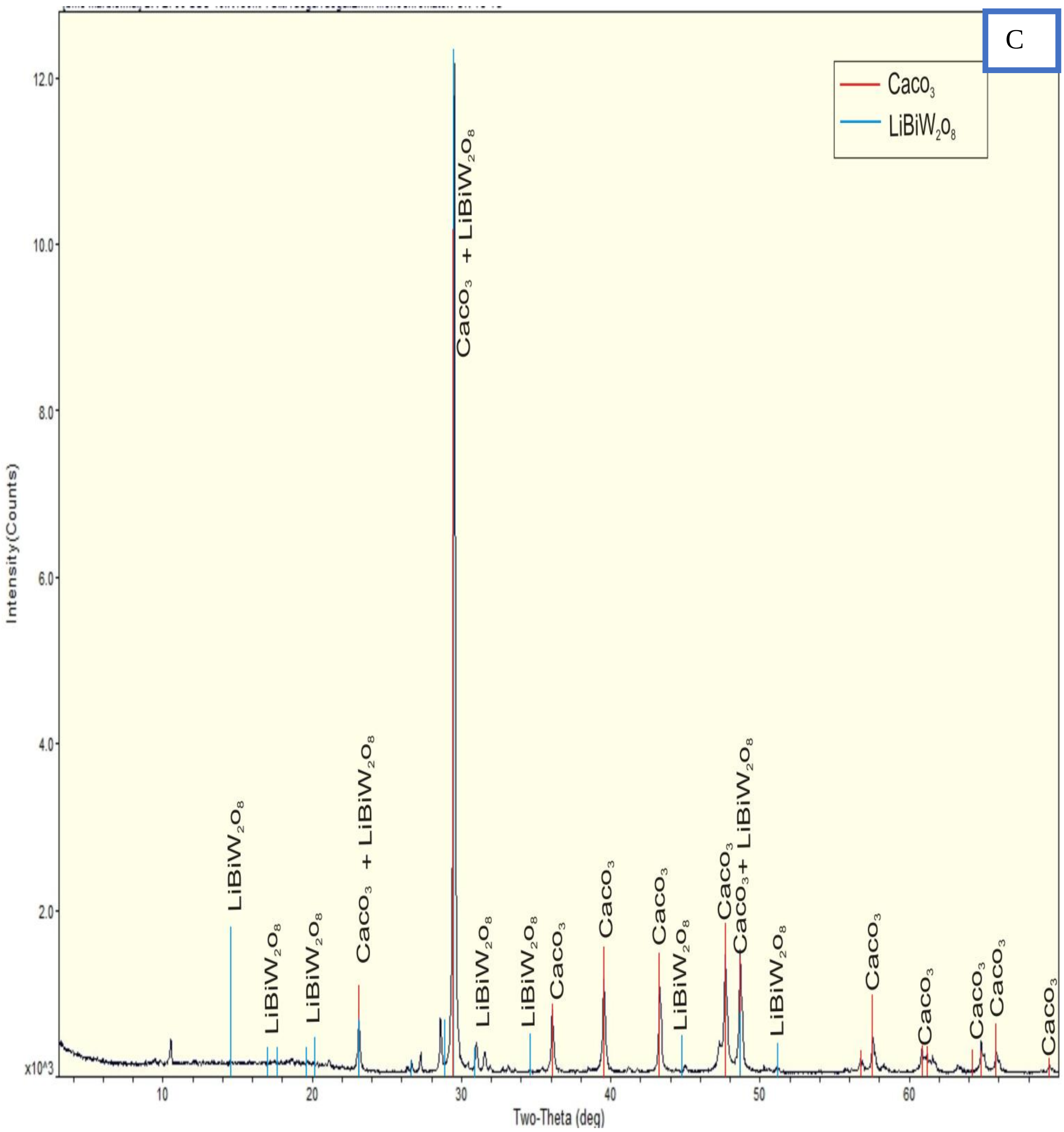

Figure 4.9:X-ray diffraction for Boka multi-color (BMC) marble sample G3 showing calcite (abundant) and lithium bismuth (tungsten oxide) (very minor).

4.6. Geological structure

The detail geological mapping is done at a scale of 1:50,000 for the site using topographic map of the region. Structurally the map zone has flat topography from the bottom with gently rising from west to east with flat slope.

The major faults of the study area include normal faults, in a direction NW. The Daleti marble occurrence has a general strike of N-S dipping vertically. The marble is jointed in the surface and massive in the stream cut and unlimited block size can be quarried deeper. Randomly and eastern direction near the contact with the schist the marble is fractured, it show Three set of joint, prevail N40-70E , dip N80-90E, joint spacing 1-3mts, N25-40E , dip 80-90NW, average joint spacing of 1.5m. S90-90E, dip 35-45 NE.

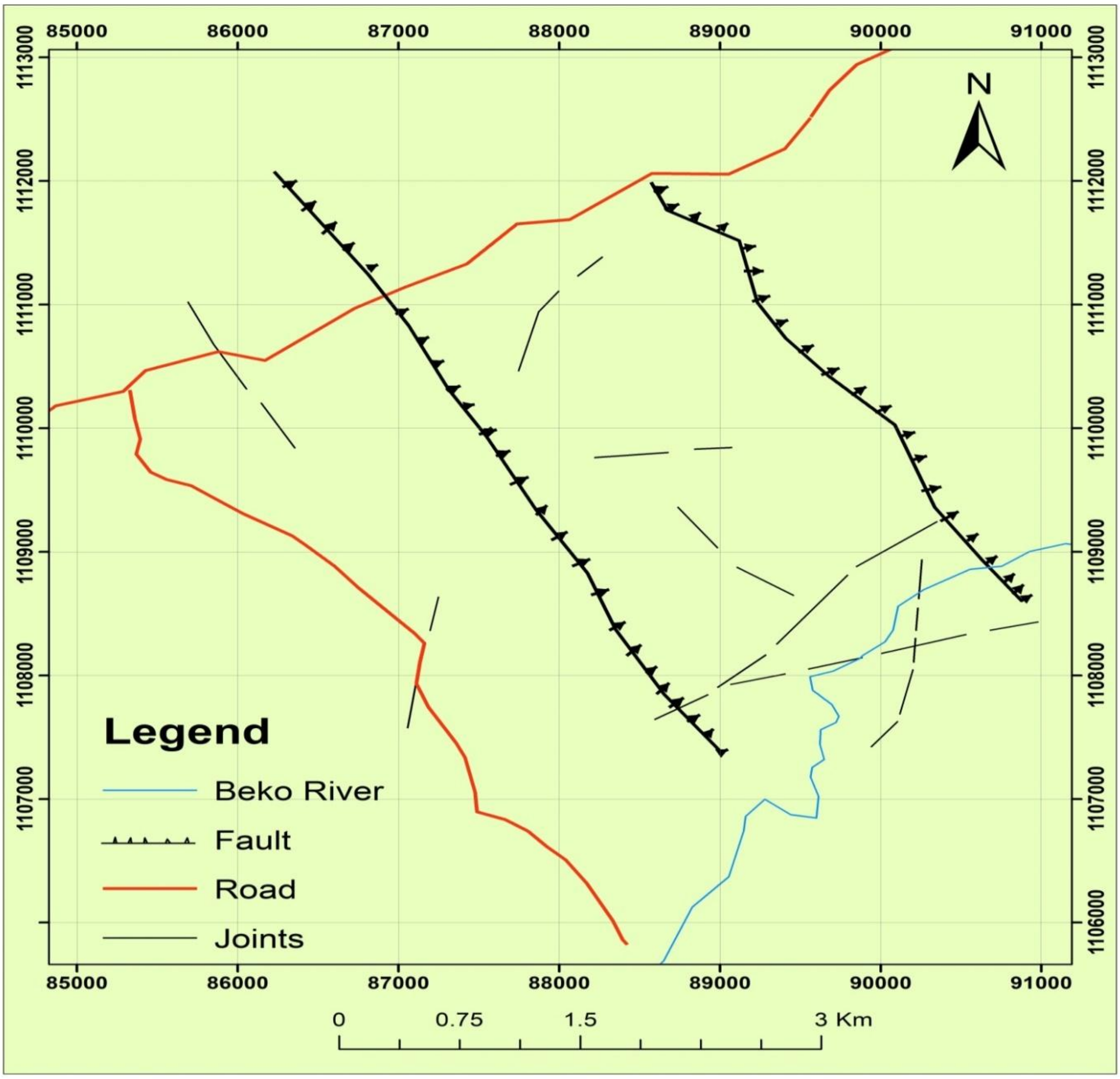

Figure 4.10: illustrates Geological structure of sampled area.

Chapter five

5. Daleti marble deposit

5.1. Introduction

In this section, the investigation results of Daleti marble deposit from field observations (geological settings) and different laboratory analyses techniques including, thin section as well as cut and polish section, physical and mechanical tests such as compressive strength, bulk density, porosity, water absorption and mineralogy, are presented. These analyses are employed in order to examine the qualitative and quantative of the daleti marble.

5.2. Description of the study area

The marble unit occurs extensively in three separate areas as small lenses throughout the study area. Marble is a potential source of building material (Gumerov et. al., 1979). Marble bearing schists are limited to the ‘north bounded by the SW - NE fault as observing reconnaissance traverse. However north of this line to the Blue Nile basin only diorite and lateritic soils were observed. To the east, the marble is limited by the Jongi mountain lineament but to the south the marble continues beyond the current study area.

Several marble beds alternating with metasediments were observed in the study area. The thickness of the marble beds does not exceed 100 m except at the noses of folds where they have been thickened by deformation and form lense-like Boudin thinning to nothing on the limbs. It is these anticlines that generally hosts the marble deposit and worth of study.

Daleti Marble deposit occurs in sequences of siliceous metasediments, gray green to reddish brown and multicolor dominant green, pink, and blue tints. At places, it is strongly weathered and composed of quartz grains and oxidized mafics in a fine grained ground mass. Quartz in the form of veins and incrustations are found all over the marble body. Intrusions of diorites and acidic rocks are common.

The Marble near Daleti village is being mined by the Ethio-Libyan Mining Corporation. It is used both locally and exported to foreign and local market. The marble deposit is found in a hilly topography and clearly exposed in the current mine site. The mineralogical composition from XRD analysis result showed that the dominate minerals is, calcite with minor amount of dolomite mineral and lithium bismuth (tungsten oxide).

5.3. Daleti marble mining

The daleti marble deposit is exposed to the surface, thus the topography of the land and the nature of the deposit favor for both underground and open pit (surface) mining but the current study focuses on open pit bench mining or cliff cutting.

During the extraction process, massive cube-like pieces of marble are cut out of the ground and transported from the quarry. To minimize the risk of cracks, fissures and other aesthetic damage to the stone, fabricators use a process known as "wire sawing" to gently separate the marble blocks. Two 3-inch wide holes are drilled perpendicularly to each other. Once the holes connect, a heavy-duty wire embedded with artificial diamonds is fed through and secured to a flywheel, forming a loop.

A powerful engine applies massive torque to the flywheel, which circulates the marble diamond-embedded wire at a very fast rate. Since diamond is much harder than the marble, the friction quickly wears it away, leaving a smooth cut plane. Finally, quarrying of Daleti marble will be accomplished with open pit mining/cliff cutting which guides to bench mining method by developing benches following the beds and joint plane of the marble deposit.

5.3.1. Selection of appropriate mining method

Based on the aforementioned methodology set for mining of Daleti marble deposit and basic factors, the specific condition of the deposit has been analyzed. The Daleti marble occurs in most cases exposed to the surface as indicated in the geological map & section, (figure 4.2).

The nature of Daleti marble is massive and partly fractured on the exposed part and become fresher as depth increases. Usually, Daleti marble deposit is covered by topsoil followed by weathered and fractured marble for about 6m depth from the surface and become homogenous and fresh at depth.

The mining method for Daleti marble deposit is an open pit quarrying, adopting lateral-advance and vertically descending of multi-bench to extract marble blocks using wire saw cut, block cutting machine, diamond cutting disk that could be assembled on excavator boom (figure, 5.4). Usually, drilling and soft blasting can be implemented. However, block production methods evolved benching with banquette system of block production that uses wire cutting (Fig.5.4) instead of the traditional drilling method are practiced.

5.4. Machinery and equipment

The Daleti marble quarry operation uses, Perforators, Diamond wire plants, Air compressors, Jet, Pneumatic hammers, and Tunnel belts and Stone cutters. Jet hammer is the main machinery and equipment used for mining in the study area (figure5.2).

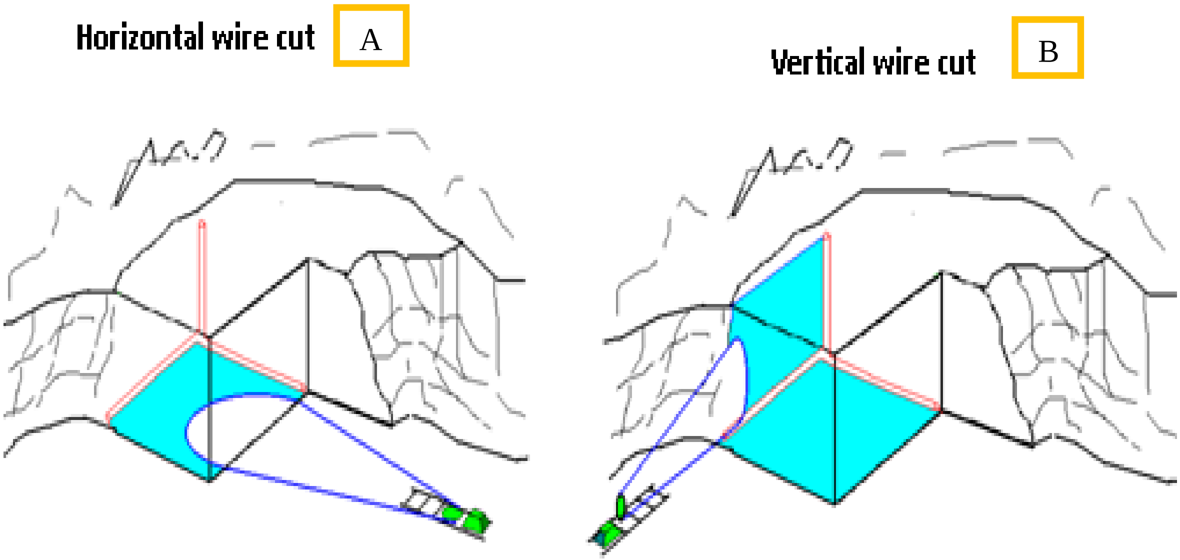

Figure5.1: Wire saw cutting machine used in vertical and horizontal direction.

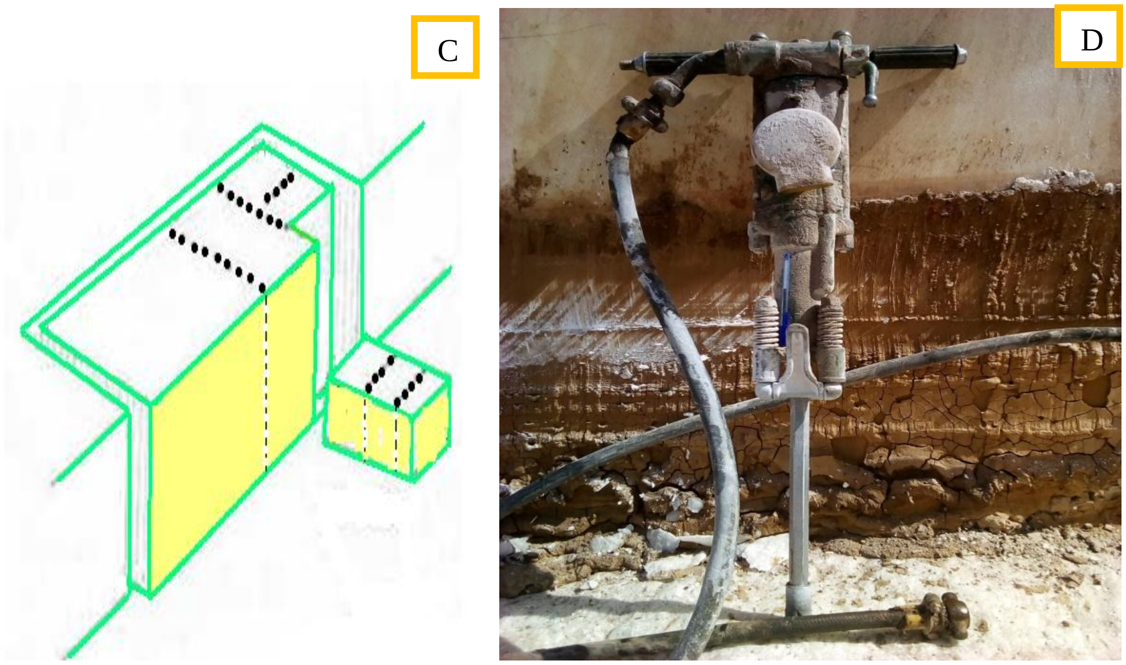

Figure5.2: Daleti marble mining(c and d) using soft blasting and jack hammer also employed for drilling.

The marble mining is to be materialized only to the level of the lowest surface in the area and the depth mining shall only be undertaken once the above surface reserve has been utilized.

Figure 5.3: A and B, Excavator mounted diamond cutting circular saw is used to produce very large blocks for export.

Figure 5.4: C Diamond wire saw used in cutting stone in Daleti marble quarry.

Figure 5.5: Photo: A, B, C and D illustrates Daleti marble quarry stone cuter machine.

Figure 5.6: photo above:shows that, Quarry in Daleti marble where huge blocks are extracted using diamond chain saws.

5.5. Processing of Daleti marble

The marble processing Plant is located at Awash, 225 km East of Addis Ababa. The Process starts by unloading blocks arrived at the site, to be cut by gang saws and block cutters to get raw slabs. The raw slabs are polished using polishing machines, however the slabs are further processed to different sizes and shaped according to customer order.

Figure5.7: A, shows, agglomerate polishing line on the left and B, Agglomerates pressing machine on the right side of the picture.

Figure5.8: illustrates, Super mored70 marble Gang saw for Processing of Daleti marble.

5.6. Physical and mechanical properties of marble

Deposits of dimension stone are subjected to much greater selectivity with respect to physical properties, uniformity, and modes of occurrence; these demand a much more critical and detailed study of geologic and mineralogical features (Currier, 1961). The result of physico-mechanical test is shown in (table 5.1).

Coll No		Wight of dry sample (gm)	Wight of wet sample (gm)	Suspended weight(gm)	Water absorption %	Porosity %	Bulk density (gm/cm^3	Compressive strength N/mm^2
Esthete blue		71.91	72.19	45.74	0.38	1.05	2.72	**79.1**
		114.94	115.36	73.5	0.36	1.0	2.74	
	Average	**93.425**	**93.775**	**59.25**	**0.37**	**1.02**	**2.73**	
Boka multi color (BMC)		69.22	69.67	44.52	0.65	1.78	2.75	**86.6**
		96.39	96.82	61.49	0.44	1.21	2.73	
	Average	**82.805**	**83.245**	**53.005**	**0.54**	**1.49**	**2.74**	
Pink marble		90.95	91.1	58.05	0.16	0.45	2.75	**57.0**
		112.86	113.07	71.9	0.18	0.51	2.74	
	Average	**101.905**	**102.085**	**64.975**	**0.17**	**0.48**	**2.74**	
Daleti black marble		80.48	80.61	51	0.16	0.44	2.71	**68.4**
		108.53	108.73	68.79	0.18	0.50	2.71	
	Average	**94.505**	**94.67**	**59.895**	**0.17**	**0.47**	**2.71**	

Table 5.1: Summary of major physical and mechanical tests of Daleti marble.

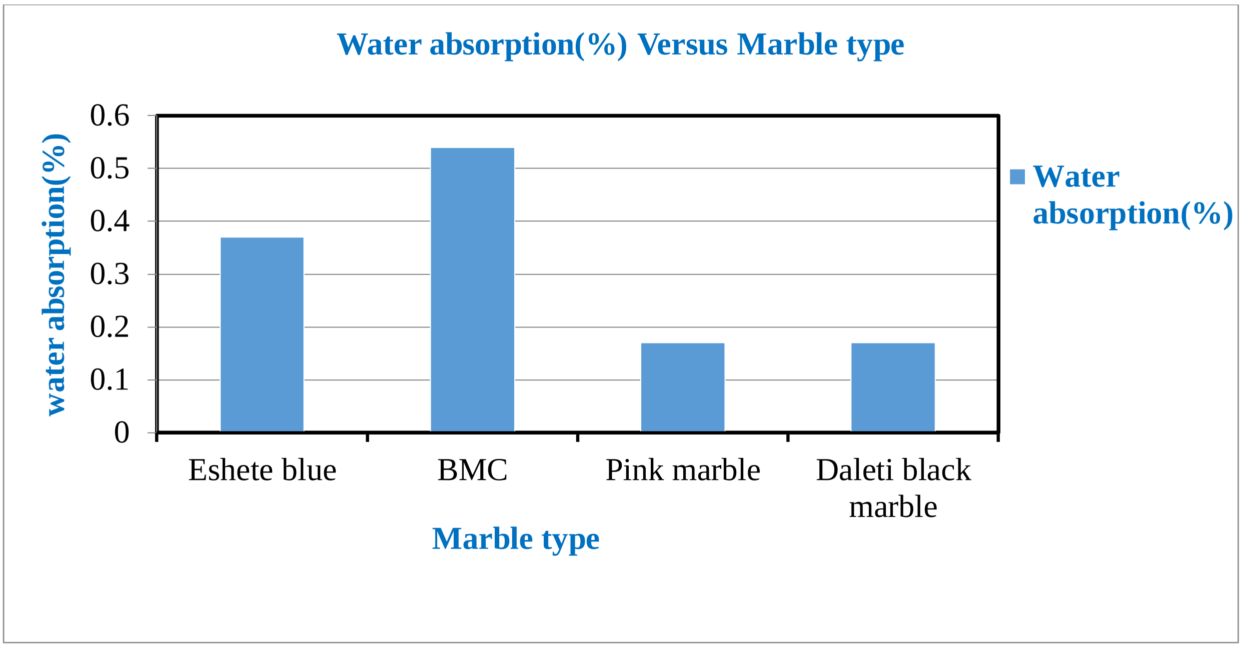

Figure 5.9: Bar Chart shows: water absorption among the rock samples.

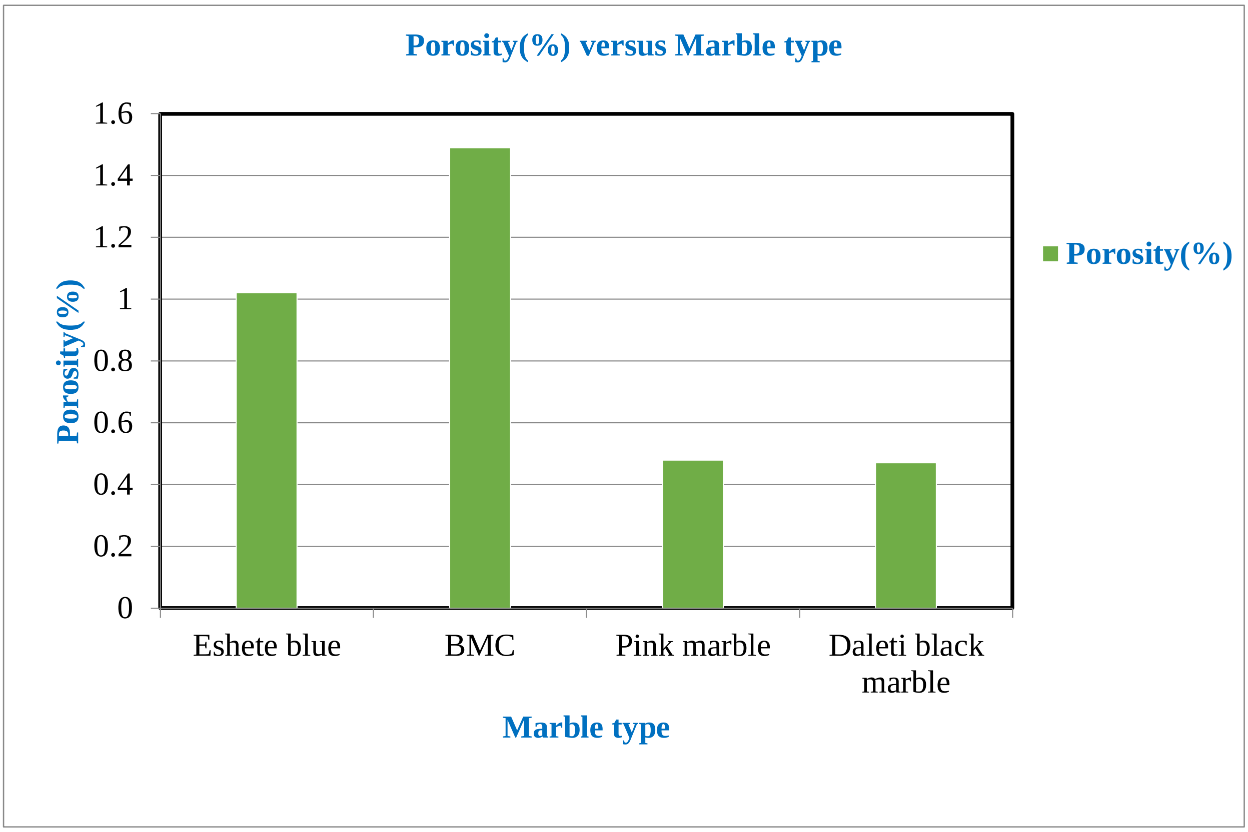

Figure5.10: Bar chart depict: A variation of porosity among the rock samples.

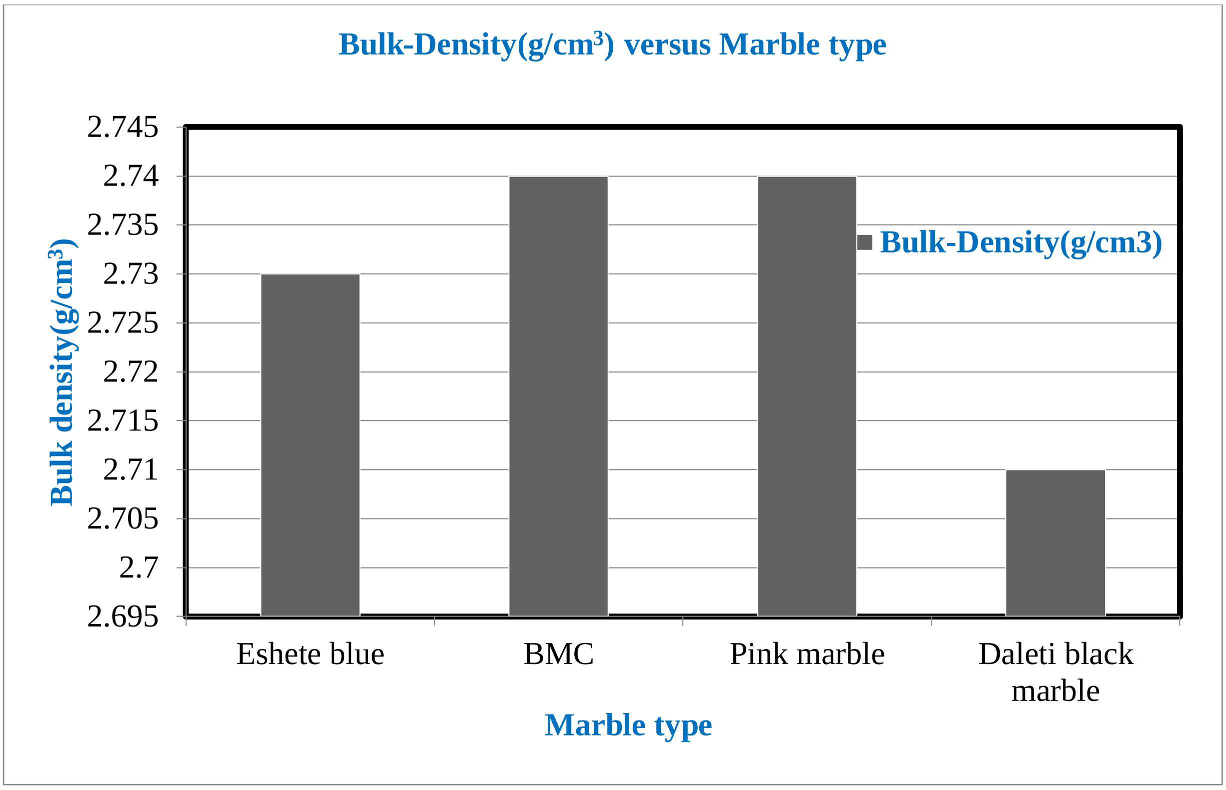

Figure 5.11: Bar chart illustrates a variation of bulk density among the rock samples.

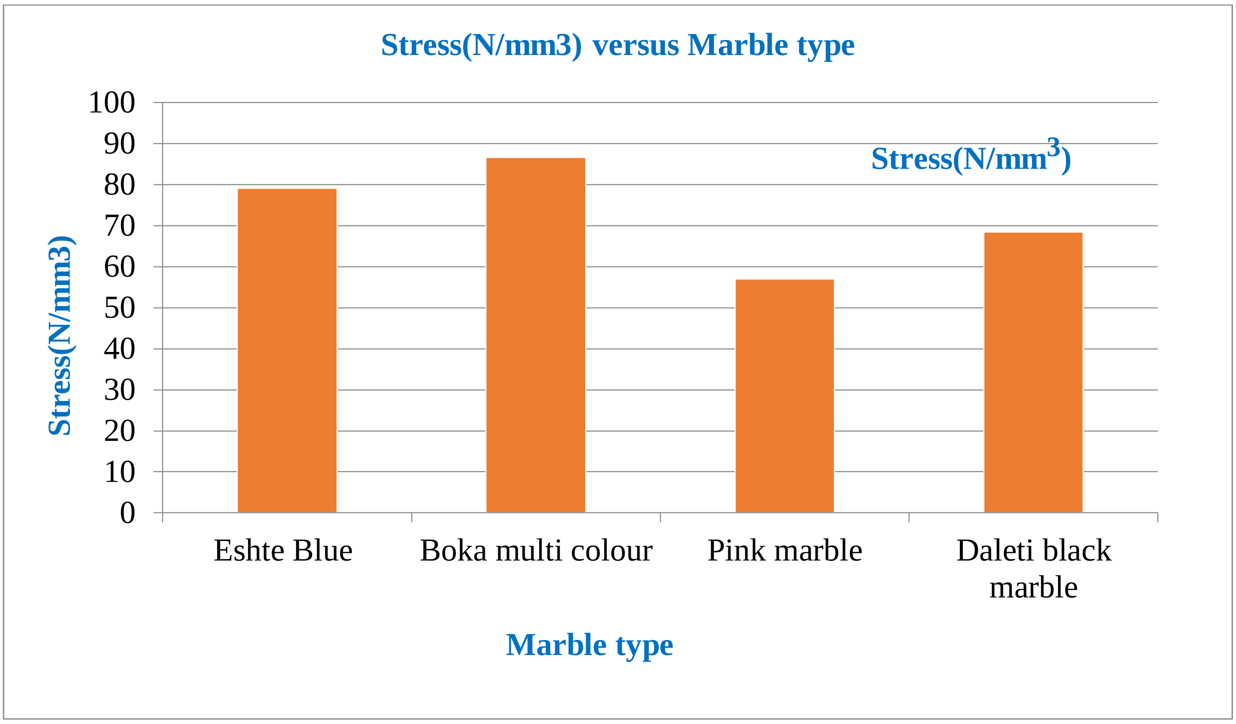

Figure: 5.12: Bar chart deals a variation of compressive Strength among the rock samples.

Item No	Standard	Test	Standard value	Daleti marble			
				Esthete blue	Boka multi color (BMC)	Pink marble	Daleti black marble
1	ASTMC530	Water Absorption	0.2%minimium	0.37%	0.54%	0.17%	0.17%
2	ASTM 503C	Compressive strength	52MPa(52N/mm2)	79.1/mm^2)	86.6/mm^2)	57.0/m m^2)	68.4/m m^2)
3	ASTMC530	Porosity	0.6-2.5 %	1.02%	1.49%	0.48%	0.47%
4	ASTMC99	Bulk density	2.5-3.2 gm/cc	2.73 gm/cc	2.74 gm/cc	2.74 gm/cc	2.71 gm/cc

Table 5.2: Comparison of Physical and mechanical properties of Daleti marble with ASTM standards.

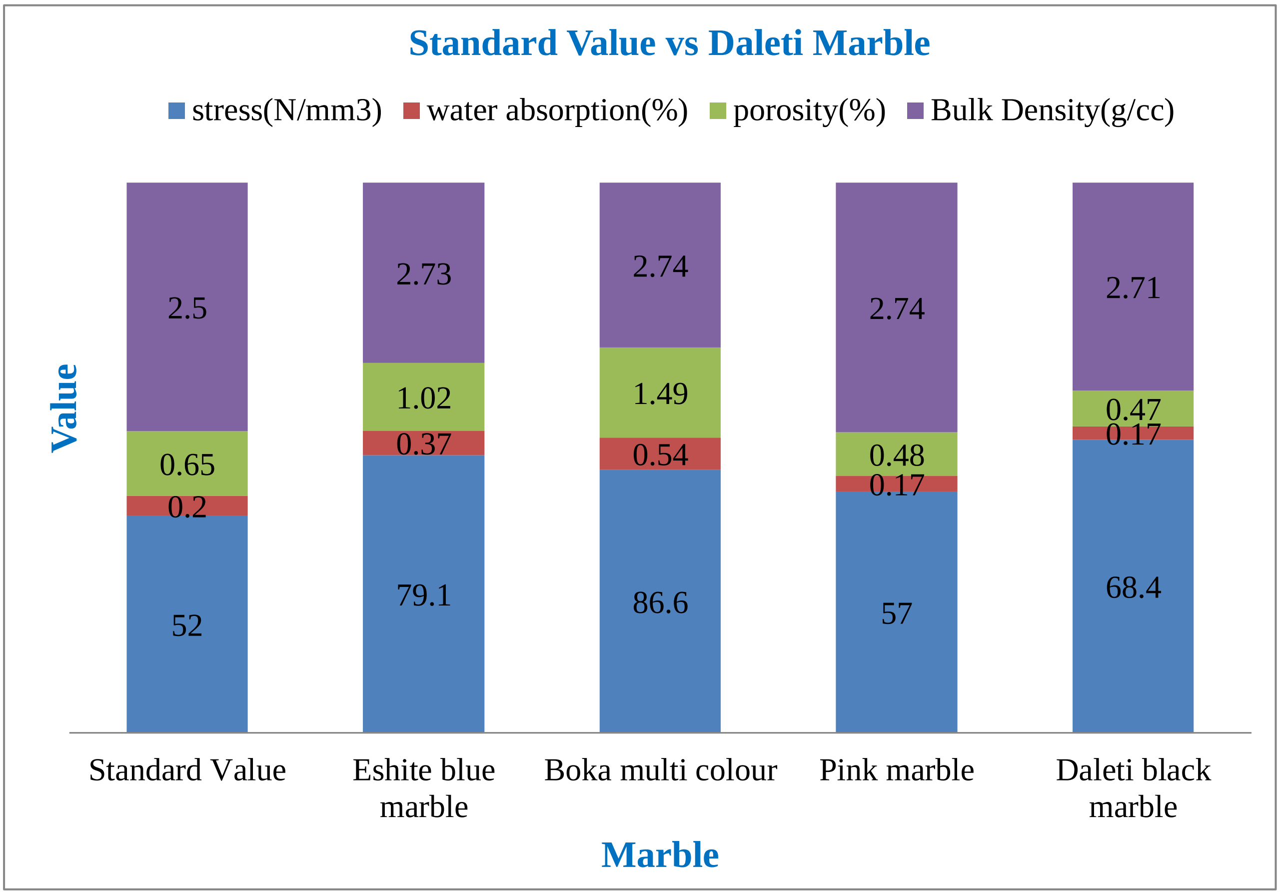

Figure 5.13: Chart showing the test results of Daleti Marble has met the requirements of international standard (ASTM standard).

5.7. Cutting and Polishing Properties of Daleti marble

This property has been determined on the calcite marble with the intention of evaluating the marble rock as resource of dimension stone. A total of 15 samples have been submitted to Ethiopian Geological Survey, Geo-Science Laboratory Service center for cut and polish, in different sizes (figure : 5.14).

The rocks generally can be cut and polished easily and properly. After being sanded with progressively finer abrasives, marble can be polished to a high luster.

The polished surfaces are attractive and beautiful. The fine grained marble variety cut best. The edge of the slabs was sharp. The medium grained marble tended to be rounded at sledge and the coarse grained marbles tended to chip or crumble at the edge.

This allows attractive pieces of marble to be cut, polished, and used as floor tiles, architectural panels, facing stone, window sills, stair treads, columns, and many other pieces of decorative stone.

Figure 5.14: Photo, shows cut and polish sections of calcite marble samples, found in Daleti quarry with different colour.

5.8. Resource evaluation and estimation of Daleti marble

The quarry site area is calculated using Arc-GIS/ MapInfo X software tracing the actual out crop area of marble which is enclosed in the study area. Moreover, calculation of the average thickness of marble deposit of the study area has been taken from drilling data and bulk density (ρ) was taken from laboratory test. The approximate Resource (marble deposit) = (A) x (h) x (ρ).where, A= area in m^2, H= thickness/height in m, S= in g/cm^3.

= (900,000 m2) x (20 m) x (2.73 g/cm3)

= 49,140,000 tons

The mineral resources are classified according to the guidelines and reporting standard set out in the Canadian code for reporting exploration results, mineral resources and mineral reserve, N143-101. In the course of production, we intend to upgrade the exploration stage to arrive at possible and probable reserve category to the next level by performing detail exploration.

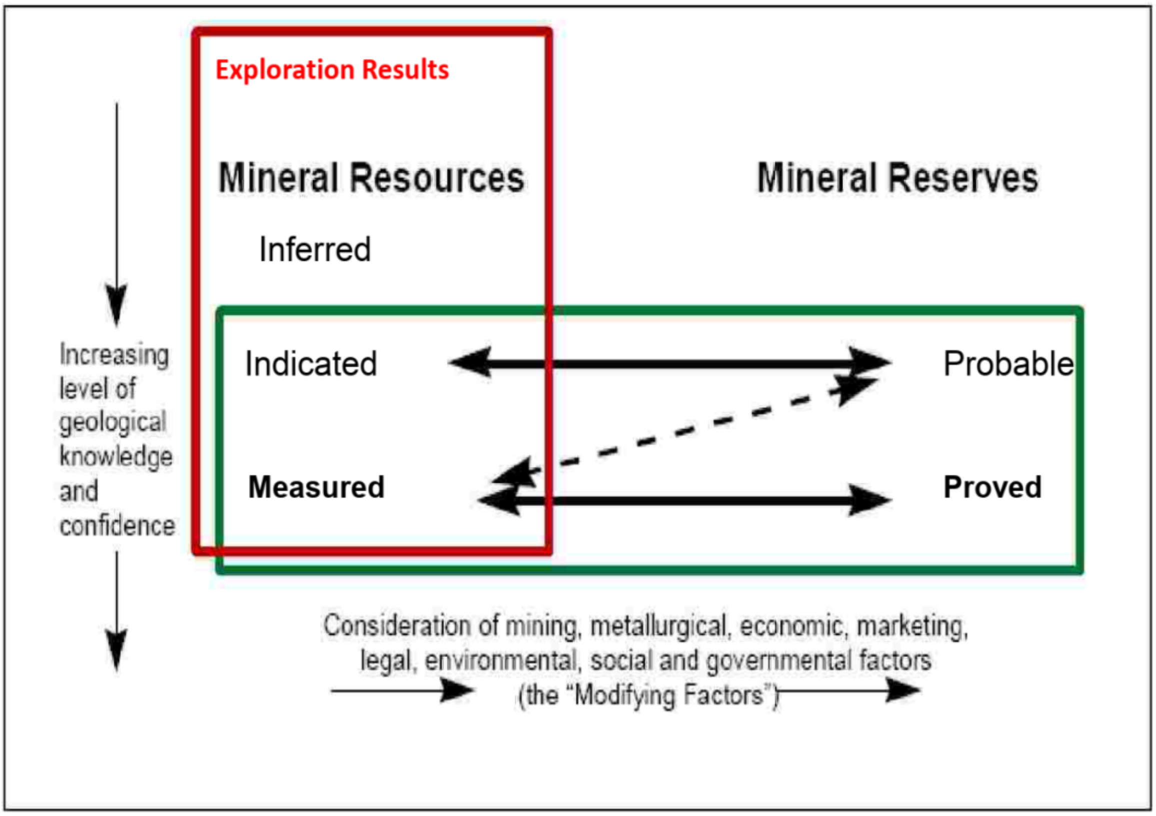

Figure 5.15: General relationship between exploration result, mineral resource and mineral reserves (CRIRSCO Template).

The above resource estimation considers only marble deposit. Moreover, it should be noted that this tonnage represents those marble resources found in Daleti area (49,140,000 tons). Based on the level of geological knowledge and confidence, this resource is classified under indicated mineral resource.

Chapter Six

6. Discussion

The Mineralogical determinations agree with the petrographic results. Thus, XRD analysis identified only calcite as major phases in the mineralogical compositions of the marble deposits. The minerals identified under plane and crossed polarized light include calcite, muscovite, and probably opaque (Fe-Oxide) in a minor amount.

The physico-mechanical properties conducted were: a) porosity; b) bulk density c) water absorption; d) compression strength**:** The samples utilized for conducting these tests, however, remained confined to the specific target areas. The results helped to identify rock at Daleti area indicated minerals which potentially provide greenish tint in Boka multi colour and pinkish, blue colors, as well as black colour in addition to other anticipated coloration.

The results of the 16 samples collected from four different sites which were subjected to physico-mechanical tests at Ethiopian Geological Survey Central Laboratory (CGSE) are listed in Table 5.1. Similarly, petrographic studies on ten samples are displayed in Table 4.1. These results are interpreted based on the ASTM (ASTMC530, ASTM 503C, ASTMC530, ASTMC99 and, International Society for Rock Mechanics (ISRM) for dimension stone.

Sample site (1) Boka multi-color: This target area is located on the north to south and four samples were collected and studied. The compression strength is (86.6MPa) with excellent porosity and water absorption properties. Therefore, the area could be further studied and used for dimension stone quarry.

Sample site (2) Daleti black marble: Four samples were collected from an extensive quarry of Daleti area. The samples showed, compressive strength (68.4MPa) and relatively good water absorption and bulk density. The medium compressive strength warrants to be used as structural loading, where there is no direct contact to ground water or rain water.

Sample site (3) Pink marble: Four samples were taken from this target area, which is located on the north south part of the study area .The samples show pink color. The laboratory results of these samples show good results of strength, water absorption, bulk density and Porosity. So, the samples meets meet the specification of ASTM: ASTMC530, ASTM 503C, ASTMC530, ASTMC99.

The compression strength give an average value of (57MPa) may be due to the presence of fracture, but still it is above the acceptable limit.

Sample site (4) Esthete blue marble: Four marble samples were collected from active quarry sites in Boka area. Despite its excellent appearance the samples showed relatively high strength which is about an average of (79.1MPa). The high porosity which makes it vulnerable to degradation/weathering. So, these samples could not be used as corridor pavement and masonry but to a certain extent it could be used as cladding stone cutting in smaller pieces for internal use.

The bulk density and water absorption is still above the acceptable limit. Therefore, in view of these discouraging results the use of this site as dimension stone source is unlikely or impossible with respect to the current tight specifications; however, for domestic use it could serve as interior decorative stone where there is no frequent water contact and abrasion.

6.1. Critical properties controlling quality assessment of dimension stone

Many authors addressed the issue of quality (Ramsay et al., 1974; Smith and Collis, 2001) in which rocks quality for construction material is governed by petrographic composition, texture, particle shape, porosity, among others. These properties directly affect the mechanical behavior of the rock in question.

Construction stone has a wide variety of uses, but it is convenient and practicable to classify it in two main categories, namely, crushed and broken stone and dimension stone. This study shall concentrate only on dimension stone (cobblestone, pavements, structural loading, cladding stone, floor tails, fencing, ceiling, corner stone etc.). Dimension stone is a collective term for various natural stones used for structural or decorative purposes in construction and monumental applications (Merke, 2000). Other areas of the uses of marble are in sculpture, monumental; shop fittings, electrical and decorative as well as dietary calcium supplement (Herbert et al; 1990).

All these processes are in turn determined by the geological processes which formed the rock. A good understanding of these processes and effects will enable to determine a rock's suitability as construction materials. For precise description of the rocks, ten thin sections from the most abundant rocks of the study area were prepared and studied under polarizing microscope. Even though, the aim of this examination is the classification of the natural stone, also observations of features that influence its chemical, physical and mechanical behavior are carried out. Generally, the petrographic examination of rocks used for dimension stone and aggregate are crudely categorized into three steps, a) classification, b) an aid in the assessment of aggregate performance, c) detection of potentially deleterious constituents.

Geological construction materials form the major part of all construction materials used in civil engineering projects. Despite their low unit value these ‘geomaterials’ are of prime economic importance because of huge tonnages used each year. Like all construction materials, geomaterials must comply with certain specifications for an application. These specifications concern the physical, chemical and mechanical durability characteristics. By meeting these durability specifications, the geomaterials should maintain their physical, mechanical and chemical integrity throughout the life time of the construction in which they are applied. Because of the compositional variability of geo-materials, which is inherent to their natural origin, the assessment of their durability properties is not obvious.

Many attempts have been made to relate the durability characteristics measured in the laboratory to their behavior in engineering structures, often without much success. Majority of the rocks near the earth’s surface are affected by natural weathering processes. In every rock, even if classified as ‘fresh’, minor amounts of secondary minerals may be present. Their presence can have detrimental effects and lead to accelerated degradation when the material is ‘in service’ in the engineering structure. (as cited in Tesfaye, 2013).

Porosity is a fundamental property of rocks. It refers to the ratio of the volume of voids to the total volume of the rock, expressed as a percentage. In general, porosity can be classified based on different geometric, morphologic and digenetic aspects or criteria. On the basis of petrogenesis, the porosity of a rock can be divided into primary porosity which refers to the porosity at the time of deposition or formation and secondary porosity that develops long after the rock’s formation (Tucker and Wright 1990; Fitzner and Basten, 1994).

Deposits of dimension stone are subjected to much greater selectivity with respect to physical properties, uniformity, and modes of occurrence; these demand a much more critical and detailed study of geologic and mineralogy features (Currier, 1961).

Physical properties, such as durability, strength, and the ability of the stone to hold a surface finish, are important in the industry and to the customer as are esthetic properties such as color, texture and pattern, and surface finish (Dolley, 2004).

The color and overall tone of a dimension stone must be compatible with the present market trends. For example; if yellow granite is in, then the shade of yellow and consistency of the shade of yellow across the block or slab is evaluated. If the stone is green colored granite, then the shade of green, whether dark or light or olive-green, will make or break the sale of the stone. The presence of mottled color or distinct discoloration or tonal changes must be noted and evaluated.

The grain size refers to the actual size of the individual grains or crystals that together make up the stone. Some stones are homogenous, showing a consistent grain size throughout the rock. The grain size may be fine grained (i.e.: individual grains are < 1mm in size and difficult to see with the naked eye), medium grained (i.e.: individual grains are 1-2mm in size with individual grains visible to the naked eye), or coarse grained (i.e. individual grain area >2mm in size).

Other stones are inhomogenous, showing larger clasts, grains, phenocrysts or augen surrounded by, or “floating” in, a groundmass of smaller grains. The grain size characteristic of a stone is extremely important during the evaluation of the stone’s dimension stone potential. The grain size affects the overall color and texture of the stone, and therefore it’s distinct visual character.

The texture of a stone refers to the characteristic visual features including: mixtures of larger and smaller crystals, regular or irregular banding (i.e.: primary igneous banding, sedimentary layering, secondary gneissic banding or foliation, styolitic banding in marble, etc.), linear alignments or lineations (i.e.: primary mineral alignment, grain elongation, inequant clast alignment, etc.), and individual spots or clusters of grains. A visual evaluation for both the presence and the consistency of these features through a deposit are of prime importance, even during the earliest stages of prospecting over the surface exposure of a marble body. These features are very important when selling a product, and therefore they play a large part during the evaluation of a stone’s dimension stone potential.

The mineralogy describes the types and composition of the minerals that together comprise a stone. Petrography describes the detailed characteristics and genesis of these minerals that comprise a stone. Knowing the mineralogy and petrography of a stone takes on particular importance when determining the method of extraction and the workability of a stone (how and why the stone reacts to different cutting techniques). These factors also help to understand (and possibly prevent) problems of alteration in the stone (i.e. susceptibility to color variation or decreased mechanical resistance under different polishing conditions, or color alteration under exposure to different pollutants in a variety of conditions).

In summary, the durability of geomaterials should be considered in relation to the engineering environment to which they are exposed, the expected, life time of the engineering structure and the function they have to perform in this structure. Current practice in construction requires that material testing is performed as much as possible, using the test methods described in official standards (e.g. ISO, BS, UNIEN and ASTM). Rock durability tests include density, water absorption, uniaxial compressive strength and porosity etc. (as cited in Tesfaye, 2014).

This study emphases primarily on dimension stone which in addition to the above technological requirements, involves knowledge of international dimension stone trends (i.e. what stone types to focus efforts on) and rudimentary geological factors which dictate weather a stone can be quarried. An extensive range of rock materials can be used as dimension stones and includes various types of volcanic, sedimentary and few metamorphic rocks provided that it can be cut and dressed into regular shapes or sizes for use in construction. The currently evaluated project area is metamorphic as it is situated within Daleti and surroundings.

Although, natural stone is a variable product it is important that inconsistency is kept within confines which are known and understood. In this concern, during the sequence of this study, representative sampling was carried out from the exposed fresh part of the deposits. The collected samples were subjected to laboratory analysis which includes bulk density, porosity, water absorption, compressive strength tests. Besides, both petrographic examinations were showed on selected representative samples and physical and mechanical tests were conducted in the central laboratory of Geological Survey of Ethiopia at Addis Ababa which has a good status in such tests.

6.2. Major markets and development opportunities for dimension stone

Because most industrial minerals are consumed in bulk, their tonnage can be considered as one of the main factors that could prevent a resource from being converted into a reserve.

Depending only on the present information, the tonnage of Daleti marble could be enough for the resource from its use in industrial applications requiring nearby market. Thus, from tonnage point of view the major markets could be those industries located near the market.

These industries are mainly manufacture of marble chips and blocks for the purpose of facing buildings, floor finish materials, stair, window sills, tombstones, roofing materials, walling materials and other functions.

The construction of multi-story building in the country that are sprouting in every corner of cities and towns requires large quantity of marble supply for decoration in many textures, colors, shapes and forms.

The project study in block and chip mining of marble and processing of it in to tiles and slabs of different shapes, sizes, forms, colors and textures. Most companies' targets mainly export markets neglecting local ones. The foreign markets focused are China, Middle East, India, Africa, Europe and Asian countries. Addis Ababa is the main target for local market and neighboring towns and regions are also important. In developing countries like Ethiopia, it is impossible to think about rapid economic growth without the action of construction industry as a catalyst.

In the Daleti marble deposit "modifying factors" (see Fig. 5.15) that are related to mining, processing, environmental and infrastructure can be considered as an opportunity to develop the resource. It is near to Daleti town and can be accessed by gravel road that runs from Daleti town to the marble site. The water required for processing can be also obtained from a Lake called Waue River which is about 5 km from the marble site.

Chapter seven

7.1. Environmental impact of Daleti marble mining

7.1.1. Introduction

Environment is the concern of every body's slogan for life and future generation benefit wherever and whenever on the earth. Mining is one of the important pathways by which soils are polluted (Ademoroti, 1996). Mining has considerable effect on the air and water, loss of biodiversity, soil pollution and land degradation (Kumar, 1996). Mining also results to clearing of vegetation, reduces essential nutrients and organic matter of the soil, reduces biological activity and decreases productivity of the soil (Pandey and Kumar, 1996).

Mineral exploration directly or indirectly affects both the living things and non-livings things through the physical and chemical modification of the soil environment (Ratcliffe, 1974). Excess of Ca usually results in low solubility of P, Fe, Mn, B and Zn (Pandey et al., 2005). Ca has ability to capture P to form Calcium triphosphate, thus rendering P unavailable to plants (Dutta and Agrawal, 2002). The abundance of Ca in the marble dust decreases the availability of other nutrients, especially nitrogen (Demooy and Pesek, 1996). Ca^{2+} and Mg^{2+} are chemically similar (Pandey et al., 2005).

Nitrogen is one of the major soil nutrients for good growth and yield of crops. All these, therefore may cause low productivity of crops in the areas affected by marble particulates. With increasing ion potential, the pH-value of water plays an important role in the solubility of a substance (Ollier, 1984; Neisel, 1995). The solubility of rock forming minerals increases generally with the decrease in pH of the water, i.e. in acidic solutions (Steiger et al., 2011) Generally, to ensure sustainable utilization of the environment, implementation of the project is guided by the following laws and regulations.

- The Mining Proclamation No.678/2002.
- The Environmental Impact Proclamation No. 299/2002.
- The Environmental Pollution Control Proclamation No. 300/2002.
- A Proclamation for the Conservation Development and Utilization of Act No. 94/1994. According to the EIA notification of the past Environmental Protection Authority and the then Ministry of Environment, Forests and Climate change of Ethiopia (EIA guideline, 2000), and its subsequent amendment therefore, this project falls under the Schedule 'I'projects category.

7.2. Description of the environment

7.2.1. Environmental quality of the area

The baseline environment was surveyed using a transect walk over the identified economic mineable area as well as the immediate surrounding environment. The area has observed that the project site has mountainous morphology and is dominantly covered by bushy vegetation and long massive grasses. The mother trees are found sparsely. It is endowed with permanently flowing non-turbid river just at near far. Environmental components such as meteorology, water quality, ambient air, noise level was not measured yet, but gathered from relevant institutes that are mandated to record such data. The team during the assessment was physically observing what these environmental components are looking like and gathers information from locals about their quality and quantity.

Although, the area would not find actual results of ambient air quality, it is estimated that it would have the average values and could be within the stipulated limit. This is because the pollution factors that exist in this area are very limited. The local people have also asserted that there is no significant noise in this area except certain disturbance only from transport vehicles for people living in Daleti village.

Water quality is almost optimum according to the information obtained from existing project workers. There is no high water born disease and we inferred from this information that water quality off the area is also within the standard limits of the country.

7.3. The mining project phases and processes

Any development project must pass under three phases in the entire project life cycle. It starts with preparation or construction, followed by operation and end up with decommissioning/rehabilitation phases. These project phasing are very relevant and should be followed accordingly for the mining projects. As a result the proposed Daleti marble mining project is expected to follow all of these project phases and particularly the last phase is key to environmental management issues. The proposed marble mining and semi processing project will commonly carry out various activities in each of the stated phases. Therefore, activities to be conducted during the different project phases are:

7.3.1. Construction phase

Under the construction phase, the proposed project will carry out construction of encampment facilities; (human residence, office, machinery shades, stores, kitchen, toilets etc.).

These constructions will be carried out from locally available materials such as wood, corrugated iron sheets, nails and the project will only build just similar houses that local people would have. Therefore, the project will not transport large quantities of construction materials from other areas.

7.3.2. Operation phase

The project will employ open cast mining method with the use of modern mining machines and environmentally friendly mining techniques. This will save a lot of time and minimize the generation of wastage with increasing the rate of recovery of saleable marble blocks. The project will carry out the following mining and other activities during the operation phase:

7.3.2.1. Stripping: All the top soil, bushes and trees found on the project site has to be stripped out and piled in to the prepared dumping yard just at the boundary. The soil with fractured rock of variable thickness shall be removed with the help of Hydraulic excavator & dumper combination. The top soil will be stocked in proper place and is going to be reused after mine closure for rehabilitation. The vegetation that is going to be cleared from the site will be properly collected near to the camp site and will be used for various project activities as per the mining regulations.

7.3.2.2. Dozing: marble rock boulders and smaller sized which will not be used to produce block and chips have to be dozed, transported and dumped. Similarly, the rock waste will be stocked for rehabilitation just at the boundary of the project site.

7.3.2.3. Bench Forming: for marble rock that is selected best to produce block-able marble, the production benches will be formed by cutting with use of Diamond wire saw cutting technology and blind cut technology. Once the bench forming activity is taking place the rock is ready for production of block boulders. Even though the rock characteristic naturally varies horizontally, depth & sideway, so accordingly the bench dimension may vary from 4 meter to 8 meter & the width shall not be kept less than the largest machinery size working on it.

The bench would be formed by removing the soil and weathered/eroded rock from the usable marble. After the marble deposits are well exposed the boulders will be cut using jack hammers and diamond wire saw. The mined boulder will either be transported to the processing site or processed at the mining site using the diamond wire saw cutting technology.

7.3.2.4. Block Forming: The block mining needs very keen observation and study of geological joints, cleavages, hair cracks & color patterns, etc., to generate a good quality & saleable blocks. Once again the bench height & width of the rock to be selected for cutting will also be a considerable factor for producing best quality block marble.

To achieve this objectives the company should deploy an experienced staff with better quarrying technologies. The project should employ at least one technical expertise that has adequate knowledge in identifying the proper facing for initial mine opening. By employing these techniques and expertise the expected waste generation shall be minimized.

7.3.2.5. Block cutting: block marble is going to be produced from marble boulder excavated by various techniques such as vertical and horizontal drilling and diamond wire saw cutting. To produce marble boulders the mining machineries such as excavator, Jack hammer, compressor and diesel generator will be employed.

The successful and economical working of marble and granite quarry depends up on an intelligent application of knowledge of the structure of the rock and its natural divisions in the mass, as well, as up on improved methods, tools, and quarry machinery.

7.3.2.6. Chips making: the highly weathered marble rock both on the surface and in the underground marble deposits would have large fractures and could not be used for block marble production. Consequently, the highly fractured marble rocks should be broken by labor and machineries in to coarse sized chips marble.

7.3.2.7. Loading: The loading of the block marble will be done by various types of chain loaders. The project will also load the chips marble using the excavator and loaders. Unloading of the block marble will be carried out by using derrick crane or hydraulic techniques depending on the recipient capacity.

7.3.2.8. Transportation: Blocked and chips marble shall be transported by heavy duty trucks to the marble processing plant at Addis Ababa. During this project activity the truck will cross long distance of gravel and tarmac road. Finally the slab to be produced in the factory will be exported to various countries in Europe and Asia.

7.4. Methods of Waste disposal of Daleti mining

The unused marble boulders and fragments and the over burden soil wastes will be back filled in to the quarry pits and is going to be leveled by bulldozers and excavators. So that the land will be protected from human and animal contacts until fully reclaimed and ready for other socio-economic functions.

7.5. Beneficial impacts of the project

It will create employment opportunity for large number people and there by improves the food security as well as the wellbeing of workers. As the project will provide job priority for local communities, they will be benefited more from the project than outsiders. Contribute to the growing construction sector by supplying adequate and better quality marble. Contribute to fill the demand supply gaps of marble in the domestic as well as world market.

Knowledge transfer for producing and supplying marble mineral as alternative income generating activity. The local people can grasp knowledge of marble production and create market link with this project to produce and supply for better income.

7.6. Adverse impacts of the Daleti marble mining

7.6.1. Impacts during construction phase

The proposed marble production project will generate impacts that could be insignificant or easily corrected from its construction activities. This is because the constructions to be carried out are only small sized offices, guest rooms, residences, kitchen and machinery shades. Otherwise the project will not develop any activities that would usually generate significant impacts at this period.

7.6.2. Impacts measurement during marble mining operation

7.6.2.1 Impacts during site preparation

In the mining process the site preparation stage includes at least three inter related activities, such as Vegetation clearing, earthen cutting and stripping of over burden. These activities in general will affect the ecological services and functions of the project area and the anticipated impacts while the project implements these activities are:

7.6.2.2. Damage on woodland forest resources

Damage on economic plants and consequently reduce the income/livelihoods of local people. Contribute to the disruption of micro climate and loss of protecting shades for animals and man. Reduction of biomass energy and increasing work burden on women to fetch fuel wood from long distance in the long future, Increase the rate of runoff as well as evaporation and decrease the ground water recharge, Affect the earthen stability and increase the exposure of the land for erosion, Contribute to water pollution through soil erosion and transport of the striped overburden, and Loss of grazing land & wildlife habitat as well as Dust emissions and noise

7.6.3. Likely impacts during marble mining & processing

7.6.3.1. Landscape deformation

The quarrying operation in general will change the natural landscape of the site from more or less stable mountains to deep gorges and this will result in certain adverse environmental impacts: Affecting the movement of man and animals, unable to provide economic services, create pit pond and favor vectors to hatch and can be a cause for poor aesthetics of the area and formation of quarry pits will lead to fall of man and animals from the cliff, as well as affect the earthen stability and lead to soil erosion and landslide.

Figure 7.1: Land scape deformation of daleti marble.

7.6.3.2. Forest degradation

In addition to the removal of forest resources due to land clearing, the continuous use of forest resources by the project for fuel and construction purposes will degrade the forest size of the area. The project or employs may also need to produce charcoal to use on site and take away to home. Moreover, the project is likely to cause forest fire due to deliberate burning of the grass and bush, wild honey collection by using fumigation techniques, and fire from cigarette remaining. The forest degradation impact from various sources will again bring several consequences on socio-economic and ecological environments. Impact significance: the project will have significant impacts on forest resources.

Figure 7.2: Forest degradation before and during the mine.

7.6.3.3. Wild fauna degradation

The marble quarrying activities since has a significant impact on forest resources and cause landscape deformation is believed to cause the loss of wildlife habitat. In addition, the marble quarrying project could affect the wildlife due to hunting, killing and falling from the cliff in to the deep quarry pits. Noise from machineries and employs in the forest area could also have an impact on wildlife survival in that area.

7.6.3.4. Soil and water pollution

The marble quarrying activities will have an impact on soil. Because it converts the stabilized land in to unstablized form as it stripes the over burden and quarry the marble. This is leading the soil over the quarry land and the dumped over burden to be eroded by runoff. The marble mining activities are also identified as one of the sources of soil and water pollution since the marble rock could contain numerous deleterious acidic and basic materials. Therefore, such acids and bases could be released out of the rock confinement during marble rock mining and processing. As a result, these acids and bases would get a chance to be carried away by runoff to the surrounding soil and water environments.

The human wastes, particularly human fecal is also the potential source of pollution for soil and water. This is because the quarry place is located in Abay basin and the runoff from the quarry side drains to this river. It is believed that the pollutants can be reached to Abay River through the connection of Boka River.

7.6.3.5. Air pollution

The bench forming, drilling, and marble cutting activities are sources for dust (particulate) emissions. The gas emission is also generated from machineries, trucks and generators. Dust and gaseous emissions will also occur from heavy duty trucks used to transport the mined marble from the site. The dust and carbon emissions from the project activities will contribute to significant air pollution. These emissions will cause dust powder on the workers and the nearest land and plants, inhaled by people and contribute to increase the atmospheric carbon concentration.

Figure7.3: Show that, Air compressor which causes air pollution.

7.6.3.6. Noise pollution

In marble mining operation, many activities are accounted for sources of noise pollution. Therefore, noise could be generated from the rotary drills, electric shovels, graders, dozers, excavators, saw cutters, crusher, generators water pumps, fixed/mobile plant installations, manual boulder crushing, etc. Heavy duty trucks have also produce moderate noise when they travel during the night. Projects that employ blasting techniques for marble mining would also generate significant noise to the area. The noise impact could affect the nearest people and animals. In fact, noise is very dangerous to human health and could lead to prevent sleep, insomnia and fatigue, decrease in speech reception (hearing) and communication and so forth.

Figure7.4: Generator used in producing electric at quarry site and Loader used for processing of marble block in Daleti quarrying.

7.6.3.7. Impact on social, cultural and economic conditions of the area

The investigated project is likely to create adverse impacts on socio-cultural and economic conditions of the project area. As a result the following adverse impacts are likely from the project: Contribute to increase the number of users on social infrastructures such as health posts, potable water and foods.

The indigenous cultures of the Berta people are likely to be affected by outsiders, Damage on human life and animals due to the entry in to the deep quarry pits from the cliff. The project has planned to quarry the mountain with the height of about 40-60m, Contribute to decline the production of wild honey and livelihood generation from it.

Contribute to the fuel and construction wood scarcity for locals in the long future, Rape on local females may also be a potential problem.

Increase the traffic burden and causing damage on seasonal feeder and main road and affects access to various transports (Motor bike, Ambulance and Bajaj motors), Dust emission will likely from heavy duty trucks and affects the dwellers as the village is established along the road side, Car accidents are also a significant potential problem for dwellers and the workers can steal the livestock of the community and conflict may occur between the workers and local people.

7.6.3.8. Impact on workers (occupational safety and health impacts)

The project workers may face various health risks due to unsafe working conditions. The project activities and the related factors that are suspected to cause health risks are identified as, Body injuries up to death could be likely on workers from the, Falling rocks at the upper cliff, Marble cuttings and trench collapse, Loading and unloading of the stone, Falling workers from the upper cliff during mining, Over exertion, inadequate work space and inappropriate equipment.

The land slide accident caused from the cliff instability will cause the cave-ins and Dust and exhausted gas emissions can cause nasal infections, asthma, catarrh, cough, and sinusitis.

Noise and vibration from machineries are likely to cause various health problems on workers

Pit lakes from rain and marble wet cutting discharges can create favorable conditions to vector breading (Mosquitoes, and snails) and can increase the malaria infestation.

7.3.4. Decommissioning or Rehabilitation phase

The task during this phase should carry out land reclamation or rehabilitation. The mine quarry should be rehabilitated both by physical and biological means and be able to provide the community with other economic and social services in the future. The scheme should have to develop better techniques that could rehabilitate the mined land with cheaper costs and effective out comes. For rehabilitation purposes the project will carry out land leveling, transporting the stock soil, land filling, revegetation, and guarding at least until the period of reclamation. Generally, Table 7.1, 7.2. Below show environmental impact of daleti marble deposit and their recommended measure, during mining, construction, and rehabilitation phase.

Project phases	**Activity**	**Identified significant Impacts**	**Recommended Mitigation measures**
Construction			
Contribution to upgrade existing road as well as construction access road to the project site. Encampment facility construction.	Constructing close to the river & water pollution. Soil erosion and land degradation. Damage of mother trees.	Construct the encampment just far from the river. Leave the buffer area to the river course. Construct especially the toilet just at significant distance (not less than 100 m) Construct the access road without damaging mother trees and to do select appropriate rout.	During planning and construction.
Mining operation			
Tree clearing from the mining places Earthen cutting & stripping of the over burden Transport & dumping of the stripped soil Marble quarrying	**Landscape Deformations** Unsustainable tree clearing. Dust and noise emission Ecosystem change and alteration of the land form Loss of potential grazing land and pass corridors Affect the stability of the earth and lead to land slide. Affect the movement of man and animals.	Properly clear and store the trees on the site. Properly remove & dump the overburden at appropriate place and the place must be suitable for back filling of the soil to the quarry pits. Dump the over burden near the quarry site & significantly far from the river. Apply water flashing ahead of soil striping Supply workers with safety/protective materials. Rehabilitate the land and level the quarry pits and correct the deformed structures. Fence the quarry pits and put danger symbols. Start mining from the top of the mountain and continue down to the foot by completing the mining and leveling the land structure.	As per the required time and schedule of the project.
Land clearing Conduct mining operation	**Forest degradation** clear large tract of forest land. High forest resources extraction for fuel and	Contribute to forest conservation and rehabilitate the mining place step by step. Use fuel and energy saving & solar technologies & minimize fuel wood	Apply in the entire project period

Table 7.1: Environmental effect of daleti marble during construction phase.

Project phases	**Activity**	**Identified significant Impacts**	**Recommended Mitigation measures**
throughout the project life	Construction. Induced charcoal production Cause forest fire from cigarette, grass & bush burning.	Consumption Contribute to introduce energy saving technologies for the community Aware workers on forest fire causes, problems and managements and monitor keenly.	Management plan.
Land clearing Conduct mining operation throughout the project life	**Wild fauna degradation** Loss of wildlife habitat Wildlife hunting and killing Migration due to noise Die from falling the cliff	Aware workers on wildlife management Strongly ban and control hunting by workers Properly fence the quarry pits Minimize noise generation	Apply in the entire project period.
Land clearing Conduct mining operation throughout the project life Marble processing	**Impacts on soil and water** Cause soil erosion by disturbing the stabilized land. Causes soil and water pollution by the exposed acids and bases from the marble rock. Soil and water are also likely to be polluted by human waste. High volume of water extraction. Direct contact of workers to the river.	Properly dump the overburden soil & prevent from being carried by runoff. Construct the soil and water conservation structures in the river side to control the entry of runoff from the project side. Both water from the rain and marble processing in the quarry site should be confined within the pit and don't allow to drain to the river courses. Construct adequate size of pit latrines both at the quarry and the encampment sites and forbid workers the field defecate. Conduct soil and water quality tests at regular intervals. Pump and use only the required quantity of water from the river. Do not let workers wash cloths in to the river and prepare wash troughs in the camp.	Apply in the entire project period.
Land clearing Conduct mining operation throughout the project life Marble processing	**Air pollution** Dust and particulate emission. Exhausted gas (Cox, Sox, Nox) emission Malodor from human excreta.	Flash the dust emission sources by water Carry out regular machinery maintenance. Install the dust arresting fittings. Employ wet marble cuttings. Construct pit latrines and keep sanitation. Ban open field defecation.	Apply in the entire project period.

Project phases	**Activity**	**Identified significant Impacts**	**Recommended Mitigation measures**
Conduct mining operation throughout the project life Marble processing	**Noise pollution** Machinery operations. Heavy duty truck travels.	Carry out regular maintenance on machineries. Purchase silencer fitted machineries. Avoid marble quarrying and truck movements during the night.	Apply in the entire project period.
Excavation or quarrying of the mine area.	**Impact on social, cultural and economic conditions** Increase burden on infrastructures Affect the cultural values of local people. Competition for water resources. Entry of man and animals in to the quarry pits. Contribute to decline wild honey production & harvesting. Contribute to scarcity of fuel and construction wood. Proliferation of prostitution, Rape on local females. Increase traffic burden and damage on feeder road. Impact on human & animal life due to forming quarry pits. Create car accidents. Theft of livestock may be likely from project workers. High conflict between workers and the community due to the occurrence of unwanted cases.	Establish health caring centers at the site and use private clinics. Respect the local cultures. Employ sustainable water use system and technologies. Fence the quarry pits properly. Support the local community by providing with bee hives. Introduce energy and fuel wood saving technologies. Workers should not start sexual partnership with local females Upgrade the existing road. Drive vehicles and trucks 30 km per hour around the village. Rehabilitate the quarry pits Provide support to community development programs. Give awareness about the problem of theft and formulate strong rule. The project is accountable for the lost livestock by workers.	It must be implemented throughout the entire life of the project.
Impacts on workers (occupational safety and	Provide workers with mosquito net and safety shoes to prevent malaria and bilharzias.	Implement in the entire.	The project is responsible too.

Project phases	Activity	Identified significant Impacts	Recommended Mitigation measures
(Health impacts) Physical hazards from marble cutting (body Injuries and permanent damages). Accidents from landslide. Health problems from: dust and PM inhalation and noise poor ventilation & congested room. Exposure to water born disease. Lack of hygiene.	Do not allow workers to contact the pit lake bare foot and hand. Industrial safety and health practices in place avoiding of hazardous working conditions. Personnel protection measures/equipment. (Dust protectors, noise protectors safety shoes, gloves and eye goggles must be supplied). Machineries must be fitted with dust collectors and silencers. Emergency procedures in place Workers should get training on machinery operations, social interactions & conflict resolution.	Project period	Implement the entire management plan.
Rehabilitation Phase			
Transporting the filling materials from other area. Loosened compaction of the rehabilitated land. Removing the fence before the land becomes well reclaimed.	Effect on other biophysical environments. Social conflict with dwellers. Health impact on human & animal. Lack of proper land rehabilitation. Poorly rehabilitated land transfer. Leaving out before standard rehabilitation.		The project must by any means rehabilitate the land by refilling the excavated soil in the quarried pits and should keep from any contact until will be covered by vegetation.

Table 7.2: Environmental impact of Daleti marbles during mining and rehabilitation phase and their recommended mitigation measure.

7.6. Marble mining impact analysis matrix

The potential impacts that will be likely to generate from marble mining and processing are analyzed and determined the degree of significance based on the adverse and positive impact values. Consequently, the major adverse impacts are likely to be occurred from marble mining and processing, vegetation clearing and overburden striping activities (table7.3).

No	Environmental component likely to be affected	Project activities										
		Construction period				**Operation phase**						
		Site Clearing	Access road construction	Camp construction	Water pump installation	Water pumping	Vegetation clearing	Overburden striping	Marble mining	Marble processing	Loading and unloading	Transporting
1	**Physical Resources**											
1.1	Air quality	0	-1P	-1T	0	0	-2T	-2T	-2T	-2T	0	-2P
1.2	Soil erosion	0	-1T	-1T	0	-1T	-3P	-3P	-2P	0	0	-1P
1.3	Soil physical and chemical conditions	0	0	0	-1T	0	0	0	-2P	-2P	0	0
1.4	Surface water volume	0	0	0	0	-2T	-2P	-1T	-2P	-2P	0	0
1.5	Water quality	0	-1T	0	-1T	0	-2T	-2T	-2P	-2P	0	0
2	**Biological Resources**											
2.1	Local flora	0	0	-1T	0	0	-3P	-2P	-2P	-1P	0	0
2.2	Local fauna	0	0	+1P	-1P	-2T	-2P	0	-3P	-1P	-1P	0
2.3	Aquatic life	0	-1T	0	-1P	-2P	-1P	-2T	-2P	-2P	0	0
3	**Socio-economic & Cultural values**											
3.1	Water supply	0	0	0	-1T	-3T	-1P	0	0	0	0	0
3.2	Power supply	0	0	0	0	0	0	-2P	0	0	-1P	0
3.3	Culture & life style	0	0	0	0	0	+1P	0	+P	+1P	0	+1P
3.4	Noise	0	+1T	-1T	-1T	-2P	-2T	-2T	-3P	-2P	-2P	-2P
3.5	Employment	+1 T	+1T	+1T	+1T	+1P	+3T	+1T	+2P	+2P	+2P	+2P
3.6	Occupational health	0	+1T	-1T	-1T	-2P	-2P	-2P	-3P	-3P	-1T	-1p
3.7	Economy	0	+1P	+1T	+1T	0	-2P	0	+3P	+2P	+2P	+1P
	T= Temporary **P**= Permanent	**Positive Impact indicators** **+1** = Minor positive **+2**= Medium positive **+3** = Major positive					**Adverse impact indicators** **-1** = Minor negative **-2**= Medium negative **-3** = Adverse					

Table7.3: illustrates general overview of negative and positive environmental impact of mining of marble deposit.

Chapter Eight

8. Conclusion and Recommendation

8.1. Conclusion

The methodologies employed in this work (geological fieldwork, thin section, mineralogy (XRD), physical test, cut and polish section), are believed to play important roles in studying the marble deposits. These methodologies are thoroughly examined in order to come up with the following important conclusions.

With the increase in demand for tiles in various building construction projects ranging from outdoor sculpture, interior and exterior cladding, floor covering, e.tc. The exploitation of Daleti marble for tiles production will be a huge developmental growth for the Ethiopian economy, considering its good physico-mechanical properties.

The thin section and XRD analysis of Daleti marble showed good $caco_3$, average value of 95% with very low average value of muscovite and probably opaque mineral as well as trace element such as tungsten oxide 0.5%, which confirms that Daleti marble is within the accepted commercial values of calcite marble. It showed that most of the marbles samples satisfy the need of many industries and countries requirements.

The study conducted in the surrounding area of Daleti Town provided four prospective Sites for quarrying geological construction materials (dimension stones for various applications) of the pink marble and Daleti black marble, Usually all a of the sample found to be the best of in terms of physico-mechanical tests, results.

The marble samples from pink, Daleti black marble, Eshete blue marble and Boka multi-colour, exhibited low porosity, high bulk density, good comprehensive strength and very low water absorption which make them, suitable to be used as dimension stone. Moreover it meets the required standard (ASTM).

The thin section examination revealed the marble samples are composed of 95% calcite, and remaining 5% muscovite, and opaque minerals (Fe-Oxide) .The geological map of Daleti marble is produced at a scale of 1:50,000. This map can be used to further study the deposit in the upcoming exploration stages.

Following the conventional approach (Area, drilling and bulk density) of resource estimation, an amount of 49,140,000 tons of marble is estimated under indicated mineral resource category.

Cut and polished samples of the calcitic marble samples are attractive and beautiful for the construction industries. On the basis of access, morphology, quality and size of the calcite marble, the Daleti calcite marble resource is a potential for different industrial applications.

The proposed site is also appropriate as it is not used for agriculture and displaces settlements. It is also good for the project and the community that a significant distance between them is existed. Only minor impacts will appear on one farmer that will be evacuated from his farmland based on the BGR rural land proclamation requirements.

Generally, compressive strength of the intact rock of the Daleti marble is, porosity, bulk density and water absorption the result indicate that the Daleti marble can be used in both interior and exterior decorations.

According to the findings of this study, the proposed project will generate several positive impacts. On the other hand, it is also a source for many adverse impacts like noise, water pollution, land degradation, deforestation, and besides will affect both biophysical and socio-economic environments unless proper mitigation measures have to be designed and implemented accordingly.

Finally, this study is believed that it identifies the positive and negative impacts of the project, provides clear description about the environmental resources of the area, provides detail presentation about the assessment and incorporates all the relevant topics according to the national and regional EIA guidelines. This study gives full information to the decision makers to comment the way that the project should be implemented. It is also believed that it can give the required information to decide the go and not go of the project or to provide a decision about the project amendment.

8.2. Recommendations

Based on the detail geological mapping of the Daleti marble, north, north east, and south of the Daleti marble project areas hold a high potential marble source which needs further exploration works. Large marble deposits exist at many places in Daleti locality, only five flat areas are addressed in this study (the remaining seven parts of the flat area contain marble not covered by the present work), hence, it is the belief of the researcher that further research should continue to work on the rest part.

Detail topographic and geophysical exploration works are recommended at a scale of 1:2,000-1:1,000 for further exploration works. Test drilling works should be conducted for underground extension and for reserve calculations.

The grey to white variety with low impurities can also be used in other industries like fillers, chemical, agriculture, environmental protection, road and other construction activities.

The resource estimation technique followed for this study is conventional and it considers only estimated from two borehole data and area from geological map. Thus, further bore hole (30-40m) drilling should be carried out to better visualize the occurrence in three dimensions and scaling up the reserve.

Thermal expansion, ultrasonic pulse velocity or P-wave and other important technological property tests should be carried out to strengthen the industrial applications listed in this work and to further elucidate and recommend other industrial applications.

According to the analytical result, Daleti calcite marble showed to have good quality calcite and also relatively form large potential resource, however further investigations are recommended on the Daleti area supported by detail drilling to understand lateral and vertical extension of the marble resource required to establish reserves. Further use-related analytical test should be performed for any specific end use.

Based on evidence from petrography study and mineralogy analysis, Daleti marble is calcite marble. Future studies, possibly including, isotopic and geo-chronological data, would ascertain the source and nature of the calcite marble, and also shade more light on the temperature regime, as well as the actual timing of the various events within the deposits.

During field work, the researcher has tried to assess as well as physically observe what these environmental components looked like and gathered information from locals about their quality and quantity.

Lastly, the research studies recommend future research opportunity to be carried out within the region that will enrich with enormous construction raw material/dimension stone including marble rock of the area with other metallic and native mineral found within the region.

It is also recommended to conduct further researches, to measure the Environmental components such as meteorology, water quality, ambient air, noise level in the study area.

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Appendix I: ***Petrographic description of Daleti marble***

Geological Survey of Ethiopia
Mineralogy and Geotechnical Laboratory Directorate
Result Form

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

Client /Originator Name:- Hafis Mohammed Nure

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

File name:-5334/19PVT Area **Ref-:-** Benshangul/ Daleti **No of Samples:-** 10 **Sample No.** BMC1

Sample Type: - Rock **Lab No:** 5334/19

Type of Analysis:- Petrography **Preparation required:-** Thin section **Date Submitted:-** 25/03/2019

I) Hand specimen Description:. White in color and medium-coarse grained in texture.

II) Mineral composition

Mineral	Modal (%)	Texture
Calcite	99	Xenoblastic
Opaque(Fe-oxide)	1	Xenoblastic

III) Textural Descriptions / Notes: Granoblastic Texture

Matrix mainly composed of calcite grains.

IV) Rock Name:- Marble

Geological Survey of Ethiopia Central Geological Laboratory

Described By / Analysts **Checked by** **Date completed: -** 02/04/2019

Girma Asemu &

Asamnew Besufikad

Geological Survey of Ethiopia
Mineralogy and Geotechnical Laboratory Directorate
Result Form

Case Team: - Mineralogical: Lab section: - Mineralogy [√] **Physical** [ ]

Client /Originator Name:- Hafis Mohammed Nure

Client Category: - Survey [ ] **Gov.** [ ] **Pvt.** [√]

File name:-5334/19PVT Area **Ref-:-** Benshangul/ Daleti **No of Samples:-** 10 **Sample No.** BLUE

Sample Type: - Rock **Lab No:** 5335/19

Type of Analysis:- Petrography **Preparation required:-** Thin section **Date Submitted:-** 25/03/2019

I) Hand specimen Description:. Light blue in color and course grained in texture.

II) Mineral composition

Mineral	Modal (%)	Texture
Calcite	96	Xenoblastic
Muscovite	3	Flaky
Opaque(Fe-oxide)	1	Xenoblastic

III) Textural Descriptions / Notes: Granoblastic Texture

Matrix mainly composed of calcite grains and minor amount of muscovite and opaque (Fe-oxide).

IV) Rock Name:- Marble

Described By / Analysts **Checked by** **Date completed: -** 02/04/2019

Girma Asemu &

Asamnew Besufikad

Geological Survey of Ethiopia
Mineralogy and Geotechnical Laboratory Directorate
Result Form

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

Client /Originator Name:- Hafis Mohammed Nure

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

File name:-5334/19PVT Area **Ref-:-** Benshangul/ Daleti **No of Samples:-** 10 **Sample No.** Pink

Sample Type: - Rock **Lab No:** 5336/19

Type of Analysis:- Petrography **Preparation required:-** Thin section **Date Submitted:-** 25/03/2019

I) Hand specimen Description:. Light pink in color and fine-medium grained in texture.

II) Mineral composition

Mineral	Modal (%)	Texture
Calcite	90	Xenoblastic
Muscovite	10	Flaky
Opaque(Fe-oxide)	Trace	Xenoblastic

III) Textural Descriptions / Notes: Granoblastic Texture

Matrix mainly composed of calcite grains and minor amount of muscovite and opaque (Fe-oxide).

IV) Rock Name:- Marble

Described By / Analysts **Checked by** **Date completed: -** 02/04/2019

Girma Asemu &

Asamnew Besufikad

Geological Survey of Ethiopia
Mineralogy and Geotechnical Laboratory Directorate
Result Form

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

Client /Originator Name:- Hafis Mohammed Nure

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

File name:-5334/19PVT **Area Ref-:-** Benshangul/ Daleti **No of Samples:-** 10 **Sample No.** Black

Sample Type: - Rock **Lab No:** 5337/19

Type of Analysis:- Petrography **Preparation required:-** Thin section **Date Submitted:-** 25/03/2019

I) Hand specimen Description:. Gray in color and fine-medium grained in texture.

II) Mineral composition

Mineral	Modal (%)	Texture
Calcite	95	Xenoblastic
Opaque(Fe-oxide)	5	Xenoblastic

III) Textural Descriptions / Notes: Granoblastic Texture

Matrix mainly composed of calcite grains and minor amount of muscovite and opaque (Fe-oxide).

IV) Rock Name:- Marble

Described By / Analysts **Checked by** **Date completed: -** 02/04/2019

Girma Asemu &

Asamnew Besufikad

Geological Survey of Ethiopia
Mineralogy and Geotechnical Laboratory Directorate
Result Form

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

Client /Originator Name:- Hafis Mohammed Nure

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

File name:-5334/19PVT Area **Ref-:-** Benshangul/ Daleti **No of Samples:-** 10 **Sample No.** BLUE 2

Sample Type: - Rock **Lab No:** 5338/19

Type of Analysis:- Petrography **Preparation required:-** Thin section **Date Submitted:-** 25/03/2019

I) Hand specimen Description:. Light blue in color and fine-medium grained in texture.

II) Mineral composition

Mineral	Modal (%)	Texture
Calcite	93	Xenoblastic
Muscovite	6	Flaky
Opaque(Fe-oxide)	1	Xenoblastic

III) Textural Descriptions / Notes: Granoblastic Texture

Matrix mainly composed of calcite grains and minor amount of muscovite and opaque (Fe-oxide).

IV) Rock Name:- Marble

Described By / Analysts **Checked by** **Date completed: -** 02/04/2019

Girma Asemu &

Asamnew Besufikad

Geological Survey of Ethiopia
Mineralogy and Geotechnical Laboratory Directorate
Result Form

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

Client /Originator Name:- Hafis Mohammed Nure

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

File name:-5334/19PVT Area **Ref-:-** Benshangul/ Daleti **No of Samples:-** 10 **Sample No.** BMC1

Sample Type: - Rock **Lab No:** 5339/19

Type of Analysis:- Petrography **Preparation required:-** Thin section **Date Submitted:-** 25/03/2019

I) Hand specimen Description:. White in color and medium-coarse grained in texture.

II) Mineral composition

Mineral	Modal (%)	Texture
Calcite	99	Xenoblastic
Opaque(Fe-oxide)	1	Xenoblastic

III) Textural Descriptions / Notes: Granoblastic Texture

Matrix mainly composed of calcite grains and minor amount of muscovite and opaque (Fe-oxide).

IV) Rock Name:- Marble

Described By / Analysts **Checked by** **Date completed: -** 02/04/2019

Girma Asemu &

Asamnew Besufikad

Geological Survey of Ethiopia
Mineralogy and Geotechnical Laboratory Directorate
Result Form

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

Client /Originator Name:- Hafis Mohammed Nure

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

File name:-5334/19PVT Area **Ref-:-** Benshangul/ Daleti **No of Samples:-** 10 **Sample No.** BLUE

Sample Type: - Rock **Lab No:** 5340/19

Type of Analysis:- Petrography **Preparation required:-** Thin section **Date Submitted:-** 25/03/2019

I) Hand specimen Description:. Light blue in color and course grained in texture.

II) Mineral composition

Mineral	Modal (%)	Texture
Calcite	96	Xenoblastic
Muscovite	3	Flaky
Opaque(Fe-oxide)	1	Xenoblastic

III) Textural Descriptions / Notes: Granoblastic Texture

Matrix mainly composed of calcite grains and minor amount of muscovite and opaque (Fe-oxide).

IV) Rock Name:- Marble

Described By / Analysts **Checked by** **Date completed: -** 02/04/2019

Girma Asemu &

Asamnew Besufikad

Geological Survey of Ethiopia
Mineralogy and Geotechnical Laboratory Directorate
Result Form

Case Team: - Mineralogical: Lab section: - Mineralogy ☑ Physical ☐

Client /Originator Name:- Hafis Mohammed Nure

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

File name:-5334/19PVT Area Ref-:- Benshangul/ Daleti No of Samples:- 10 Sample No. Pink

Sample Type: - Rock Lab No: 5341/19

Type of Analysis:- Petrography Preparation required:- Thin section Date Submitted:- 25/03/2019

I) Hand specimen Description:. Light pink in color and fine- medium grained in texture.

II) Mineral composition

Mineral	Modal (%)	Texture
Calcite	91	Xenoblastic
Muscovite	9	Flaky
Opaque(Fe-oxide)	Trace	Xenoblastic

III) Textural Descriptions / Notes: Granoblastic Texture

Matrix mainly composed of calcite grains and minor amount of muscovite and opaque (Fe-oxide).

IV) Rock Name:- Marble

Described By / Analysts **Checked by** **Date completed: -** 02/04/2019

Girma Asemu &

Asamnew Besufikad

Geological Survey of Ethiopia
Mineralogy and Geotechnical Laboratory Directorate
Result Form

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

Client /Originator Name:- Hafis Mohammed Nure

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

File name:-5334/19PVT Area **Ref-:-** Benshangul/ Daleti **No of Samples:-** 10 **Sample No.** Black

Sample Type: - Rock **Lab No:** 5342/19

Type of Analysis:- Petrography **Preparation required:-** Thin section **Date Submitted:-** 25/03/2019

I) Hand specimen Description:. Gray in color and fine-medium grained in texture.

II) Mineral composition

Mineral	Modal (%)	Texture
Calcite	95	Xenoblastic
Opaque(Fe-oxide)	5	Xenoblastic

III) Textural Descriptions / Notes: Granoblastic Texture

Matrix mainly composed of calcite grains and minor amount of muscovite and opaque (Fe-oxide).

IV) Rock Name:- Marble

Described By / Analysts **Checked by** **Date completed: -** 02/04/2019

Girma Asemu &

Asamnew Besufikad

Geological Survey of Ethiopia
Mineralogy and Geotechnical Laboratory Directorate
Result Form

Case Team: - Mineralogical: Lab section: - Mineralogy [√] Physical [ ]

Client /Originator Name:- Hafis Mohammed Nure

Client Category: - Survey [ ] Gov. [ ] Pvt. [√]

File name:-5334/19PVT Area Ref-:- Benshangul/ Daleti No of Samples:- 10 Sample No. BULE 2

Sample Type: - Rock Lab No: 5343/19

Type of Analysis:- Petrography Preparation required:- Thin section Date Submitted:- 25/03/2019

I) Hand specimen Description:. Light blue in color and medium-coarse grained in texture.

II) Mineral composition

Mineral	Modal (%)	Texture
Calcite	94	Xenoblastic
Muscovite	5	Flaky
Opaque(Fe-oxide)	1	Xenoblastic

III) Textural Descriptions / Notes: Granoblastic Texture

Matrix mainly composed of calcite grains and minor amount of muscovite and opaque (Fe-oxide).

IV) Rock Name:- Marble

Described By / Analysts

Girma Asemu &

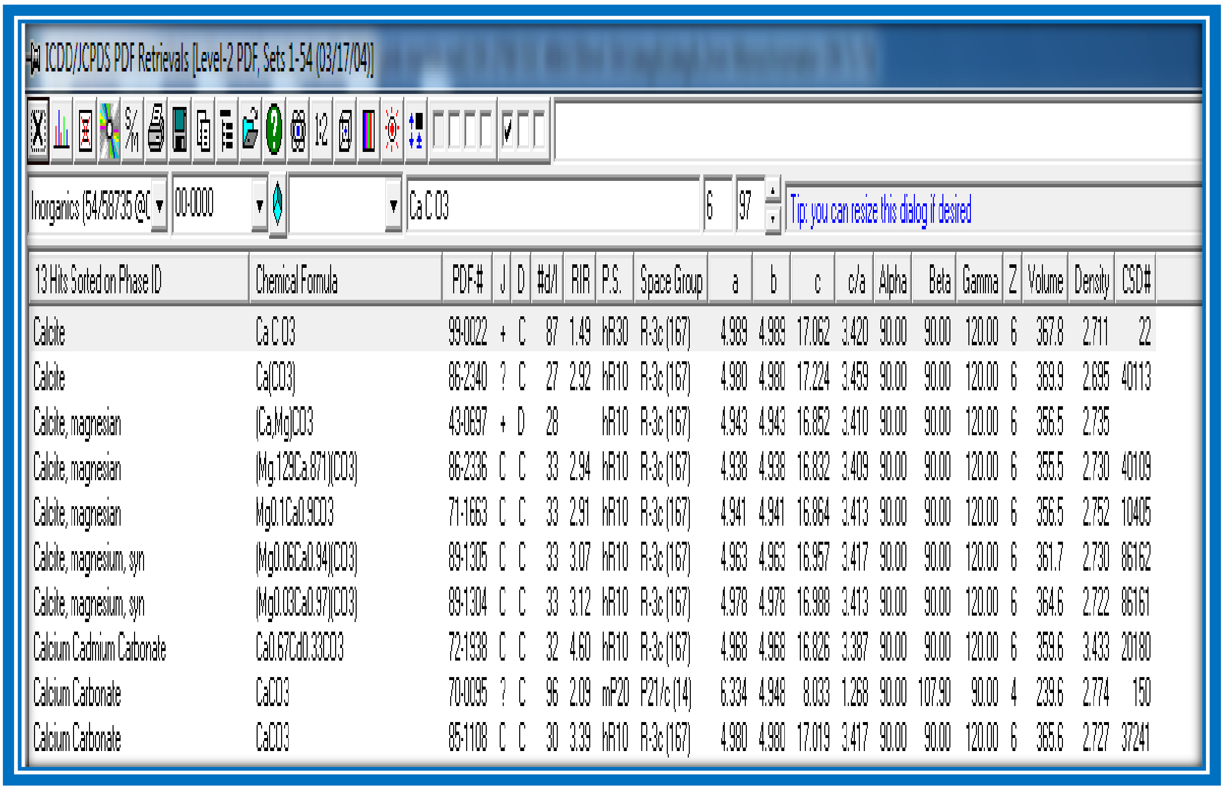
Asamnew Besufikad

Checked by

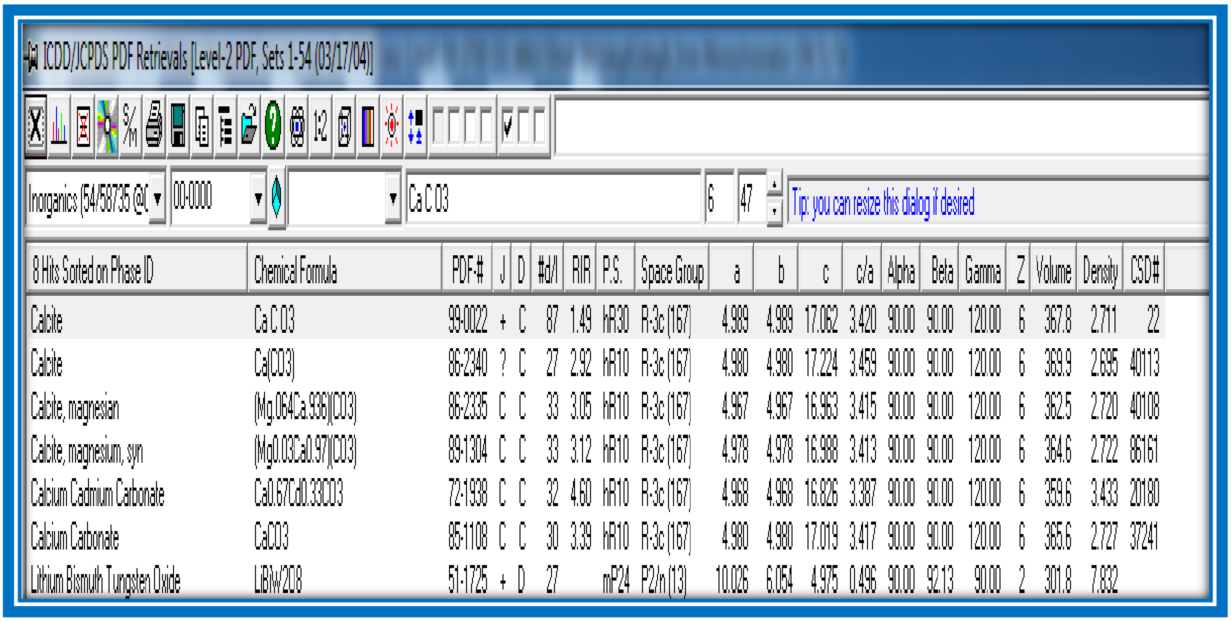
Date completed: - 02/04/2019

Appendix II: ***(2700X-Ray diffraction and micron mesh 63size, found in Mekelle University, 2019).***

Appendix III: ***Calcite as abundant mineral whereas magnesium and bismuth oxide in minor amount.***



13 Hits Sorted on Phase ID	Chemical Formula	PDF-#	J	D	#d/I	RIR	P.S.	Space Group	a	b	c	c/a	Alpha	Beta	Gamma	Z	Volume	Density	CSD#
Calcite	Ca C 03	99-0022	+	C	87	1.49	hR30	R-3c (167)	4.989	4.989	17.062	3.420	90.00	90.00	120.00	6	367.8	2.711	22
Calcite	Ca(CO3)	86-2340	?	C	27	2.92	hR10	R-3c (167)	4.980	4.980	17.224	3.459	90.00	90.00	120.00	6	369.9	2.695	40113
Calcite, magnesian	(Ca,Mg)CO3	43-0697	+	D	28		hR10	R-3c (167)	4.943	4.943	16.852	3.410	90.00	90.00	120.00	6	356.5	2.735	
Calcite, magnesian	(Mg.129Ca.871)(CO3)	86-2336	C	C	33	2.94	hR10	R-3c (167)	4.938	4.938	16.832	3.409	90.00	90.00	120.00	6	355.5	2.730	40109
Calcite, magnesian	Mg0.1Ca0.9CO3	71-1663	C	C	33	2.91	hR10	R-3c (167)	4.941	4.941	16.864	3.413	90.00	90.00	120.00	6	356.5	2.752	10405
Calcite, magnesium, syn	(Mg0.06Ca0.94)(CO3)	89-1305	C	C	33	3.07	hR10	R-3c (167)	4.963	4.963	16.957	3.417	90.00	90.00	120.00	6	361.7	2.730	86162
Calcite, magnesium, syn	(Mg0.03Ca0.97)(CO3)	89-1304	C	C	33	3.12	hR10	R-3c (167)	4.978	4.978	16.988	3.413	90.00	90.00	120.00	6	364.6	2.722	86161
Calcium Cadmium Carbonate	Ca0.67Cd0.33CO3	72-1938	C	C	32	4.60	hR10	R-3c (167)	4.968	4.968	16.826	3.387	90.00	90.00	120.00	6	359.6	3.433	20180
Calcium Carbonate	CaCO3	70-0095	?	C	96	2.09	mP20	P21/c (14)	6.334	4.948	8.033	1.268	90.00	107.90	90.00	4	239.6	2.774	150
Calcium Carbonate	CaCO3	85-1108	C	C	30	3.39	hR10	R-3c (167)	4.980	4.980	17.019	3.417	90.00	90.00	120.00	6	365.6	2.727	37241



8 Hits Sorted on Phase ID	Chemical Formula	PDF-#	J	D	#d/I	RIR	P.S.	Space Group	a	b	c	c/a	Alpha	Beta	Gamma	Z	Volume	Density	CSD#
Calcite	Ca C 03	99-0022	+	C	87	1.49	hR30	R-3c (167)	4.989	4.989	17.062	3.420	90.00	90.00	120.00	6	367.8	2.711	22
Calcite	Ca(CO3)	86-2340	?	C	27	2.92	hR10	R-3c (167)	4.980	4.980	17.224	3.459	90.00	90.00	120.00	6	369.9	2.695	40113
Calcite, magnesian	(Mg.064Ca.936)(CO3)	86-2335	C	C	33	3.05	hR10	R-3c (167)	4.967	4.967	16.963	3.415	90.00	90.00	120.00	6	362.5	2.720	40108
Calcite, magnesium, syn	(Mg0.03Ca0.97)(CO3)	89-1304	C	C	33	3.12	hR10	R-3c (167)	4.978	4.978	16.988	3.413	90.00	90.00	120.00	6	364.6	2.722	86161
Calcium Cadmium Carbonate	Ca0.67Cd0.33CO3	72-1938	C	C	32	4.60	hR10	R-3c (167)	4.968	4.968	16.826	3.387	90.00	90.00	120.00	6	359.6	3.433	20180
Calcium Carbonate	CaCO3	85-1108	C	C	30	3.39	hR10	R-3c (167)	4.980	4.980	17.019	3.417	90.00	90.00	120.00	6	365.6	2.727	37241
Lithium Bismuth Tungsten Oxide	LiBiW2O8	51-1725	+	D	27		mP24	P2/n (13)	10.026	6.054	4.975	0.496	90.00	92.13	90.00	2	301.8	7.832	

Appendix IV: *mechanical and physical test result of daleti marble.*

Geological Survey of Ethiopia

Mineralogy & Geotechnical Laboratory Directorate

Result Form

Directorate: - Mineralogy & Geotechnical Laboratory: Lab section: - Mineralogy ☐ Physical ☒ Client /Originator Name: - Hafis Mohammed Nure Client Category: - Survey ☐ Gov. ☐ Pvt. ☒

File name: - 5396/19PVT Area Ref: - Benishangul No of Samples: 4

Sample Type: - Rock Lab No: Preparation required: - Cutting and Polishing

Type of Analysis: - Compressive Strength Date Submitted: - 16/07/11

Coll. No.	Lab. No.	Reference	Sample Dimension (LXWXH)in mm	Pace rate KN/S	Peak Load(KN)	Stress (N/mm^2)
Eshite Blue	5396/19	20190404	79X69X40	3	431.4	79.1
Boka multi colour	5399/19	20190405	86X70X41	3	521.4	86.6
Pink marble	5397/19	20190406	52X48X39	3	142.3	57.0
Daleti black marble	5398/19	20190407	73X52X39	3	259.9	68.4

Geological Survey of Ethiopia

Mineralogy & Geotechnical Laboratory Directorate

Result Form

Directorate: - Mineralogy and Geotechnical Laboratory: Lab section: - Mineralogy ☐

Physical ☒

Client /Originator Name: - Hafis Mohammed Nure

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

File name: - 5392/19 PVT Area Ref: - Benishangul No of Samples: - 4 Sample No.:-

Sample Type: - Rock Lab No: -

Type of Analysis: - Bulk Density, Water absorption and Porosity Preparation required: -

Date Submitted: - 16/07/11

coll.No.	Lab.No.	Weight of Dry sample gm	Weight of Wet sample gm	Suspended weight gm	Water absorption %	Porosity %	Bulk-Density gm/cm³
Eshite Blue	**5392/19**	71.91	72.19	45.74	0.38	1.05	2.72
		114.94	115.36	73.5	0.36	1.00	2.74
		Average			**0.37**	**1.02**	**2.73**
Boka multi colour	**5395/18**	69.22	69.67	44.52	0.65	1.78	2.75
		96.39	96.82	61.49	0.44	1.21	2.73
		Average			**0.54**	**1.49**	**2.74**

Geological Survey of Ethiopia

Mineralogy & Geotechnical Laboratory Directorate

Result Form

Directorate: - Mineralogy and Geotechnical Laboratory: Lab section: - Mineralogy ☐ **Physical** ☒

Client /Originator Name: - Hafis Mohammed Nure

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

File name: - 5392/19 PVT Area Ref: - Benishangul No of Samples: - 4 Sample No.:-

Sample Type: - Rock Lab No: -

Type of Analysis: - Bulk Density, Water absorption and Porosity Preparation required: -
Date Submitted: - 16/07/11

coll.No.	Lab.No.	Weight of Dry sample gm	Weight of Wet sample gm	Suspended weight gm	Water absorption %	Porosity %	Bulk-Density gm/cm³
Pink marble	5393/19	90.95	91.1	58.05	0.16	0.45	2.75
		112.86	113.07	71.9	0.18	0.51	2.74
		Average			**0.17**	**0.48**	**2.74**
Daleti black marble	5394/19	80.48	80.61	51	0.16	0.44	2.71
		108.53	108.73	68.79	0.18	0.50	2.71
		Average			**0.17**	**0.47**	**2.71**