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Research Article

Geology and Petrography of Granitoid Rocks of Anger Gute Area, an Implication of Dimension Stone, East Wollega, Western Ethiopia

Faye Abule*, **Dereje Kenea**, **Firawalin Desalegn**

Department of Earth Sciences, College of Natural and Computational Science, Wollega University, Nekemte, Ethiopia

ABSTRACT

The Anger Gute area is located in the metamorphic terrains of Western Ethiopian Basement within the Nekemte map sheet. It occupies kilometres of metamorphic outcrops with a felsic granitoid intrusion. These granitoid intrusion cut across in the form of lineament that emplaced along with the lithological contact of low and high-grade rocks with decreasing of metamorphic grade from the lower to the upper complex. There are different microstructures and textures such as; perthites, mrymekite, quartz-vein, and joints with minimum space which indicates the tectonic evolution and metamorphic processes of granitoid rocks of the Anger Gute area. Anger Gute granite has been emplaced pre, syn/late-to post tectonically associated with the major deformation events. The deposits from massive boulders, big hills, mountain chains with minimum discontinuities afford the wide possibility for the extraction of large volumes of commercial valuable-sized dimension stone. Petrographically, this granite is characterized by coarse grain to medium grains and dominantly consists of alkali feldspar (K-feldspar) phenocrysts, quartz, plagioclase, and biotite as major components. Epidote, Muscovite Fe-Ti oxide (Opaque) as minor components and also Sphene and hornblende as trace minerals. The mineralogical composition is the main property controlling the rock strength. The Anger Gute Granitoid rocks compositionally contain Quartz, orthoclase, and garnet that indicate good strength and less strength depending on the percentage of Plagioclase, biotite, and muscovite minerals. The strength increases as the mean grain size decreases and the strength increase as the quartz and orthoclase content increases.

Keywords: Dimension stone; Discontinuities; Geological structures; Granitoid; Petrography analysis; Strength

INTRODUCTION

Background of the study

The western part of Ethiopia is largely covered by Precambrian basement rocks which are the largest Precambrian block in the country (i.e. Extend northwards from 60°N for about 650 km) according to Alemu, et al. [1], Two types of Pan-African belts were responsible for the formation of Ethiopian Precambrian rocks which are not fundamentally different. The Arabian-Nubian Shield (ANS) is distinguished from the Mozambique Belt (MB) by its dominantly juvenile nature, relatively low grade of metamorphism, and ophiolites. The second belt is the Mozambique Belt that essentially consists of medium to high-grade gneisses and voluminous granitoid rocks. The western Ethiopian Precambrian terrain is considered to contain lithological components common to both belts the Mozambique Belts in the South and the Arabian-Nubian Shield in the Northside [2]. This terrain forms the western and wider branch of low-grade volcano-sedimentary terrain of the Arabian-Nubian Shield bounded both to the east and the west by the gneiss terrain of the Mozambique Belt.

As Kazmin, et al. [2] discussed as the geology of Western Ethiopia is classified into main five tectonic zones. These include; 1) An Eastern block of high-grade pre-pan African basement rocks, 2) An ophiolite belt; 3) A zone of dioritic/granodioritic batholiths and associated intermediate volcanic; 4) A metavolcanic-sedimentary belt, and 5) A western block of the high-grade pre-Pan-African basement. Based on the stratigraphy of Western Ethiopian Precambrian Terrain, the high-grade gneiss and migmatites are referred to as lower complex while the low-grade metavolcanic-sedimentary rocks are referred to as upper complex as discussed by Kazmin [3]. In terms of age, the gneissic rocks, the metavolcanic-sedimentary and mafic-ultramafic sequences of Western Ethiopia have almost near to similar ages as discussed [4-6]. According to the above Authors, "Geochronological data indicate that the gneissic rocks, mafic-ultramafic and metavolcanic-sedimentary sequences of Western Ethiopia show similar ages and involved between 900 Ma and 500 Ma". Granitoid constitute a significant proportion of the Western Ethiopian Precambrian rocks. Field relationships and petrography, geochemistry, and petrogenesis of the granitoid rocks intruded into the High-grade gneisses, low-grade metasedimentary, and meta-volcanic rocks were recently studied by Kebede, et al. [7].

Correspondence to: Faye Abule, Department of Earth Sciences, College of Natural and Computational Science, Wollega University, Nekemte, Ethiopia, Tel: 251910745563; E-mail: fayabule2015@gmail.com

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During the last 15-25 years the use and the production of building stones have steadily increased and recently dimension stone has reached a maximum position as one of the world's most crucial mineral resources. For many countries, the export of stone has become a significant economic activity while for others the credit of local sources of dimension (building) stone has secured a steady supply of minimum price and long-lasting construction materials for domestic purposes especially, in Ethiopia. Almost any type of rock that can be shaped and appareled into building blocks and slabs can be considered as a potential building stone source. The most ordinarily exploited were massive rocks such as granite and other igneous rocks, marble, limestone, sandstone, and slab rocks such as slate and flagstone [8].

Throughout the last decades and particularly during the 1990s, the systematic exploring of building stone in Ethiopia has been accomplished by both the EIGS and private companies, and several building stone deposits throughout the country have been put into consideration and production. This implies that the broad use of Ethiopian building stone in new buildings throughout the capital, and other cities. The bedrock Geology of Ethiopia embraces a great variety of rock types within a wide age range (Figure 1) [9]. Dimension stone is a corporate term for several natural stones that have been selected and fabricated (trimmed, cut, drilled, ground) to specific sizes or shapes used for structural or decorative purposes in construction and monumental applications. The setting feature of dimension stone is unlike other mineral goods which have value mainly as a result of their physical properties. The physical properties of the rock are merely the minimum qualification in determining whether it is fit for use in dimension stone applications. The pattern, color, texture, and surface finish of the stone are normal requirements. Another significant selection standard is durability, the time measure the ability of dimension stone to endure and to maintain its essential and distinctive characteristics of strength, resistance to decay, weathering, and appearance.

The Precambrian basement rocks of Ethiopia upon which volcanic and younger sedimentary rocks were exposed in the Harar, Gojam, Wollega, Gondar, Tigray, Sidamo, Bale, and Illubabore parts of the country. The majority of the outcrop is found in the peripheral regions, where younger rocks have been removed by erosion agents. Different igneous rocks, predominantly granitoid of Proterozoic to Early Paleozoic age, occur as plutonic bodies within the Precambrian metamorphic units.

The former group is possible of Achaean age and, at present; the National Mining Company is exploiting deposits in the Harar area. The deposits are situated close to the small town of Babile, and form massive boulder sand, small hills, giving good opportunities for the extraction of large volumes of commercial-sized blocks. The Babile granite is a medium-grained, pink to red granite with a variegated, veined structure (Figure 2A), reflecting its close relationships with the surrounding migmatitic gneisses [8]. By comparison with other commercial ‘schlieren’ granites on the international market, a low- to medium-price level is estimated. The structure of the granite may vary within small areas between more or less gneissose giving possibilities for extraction of several commercial stone types, but also demanding care in the prediction of uniform future reserves.

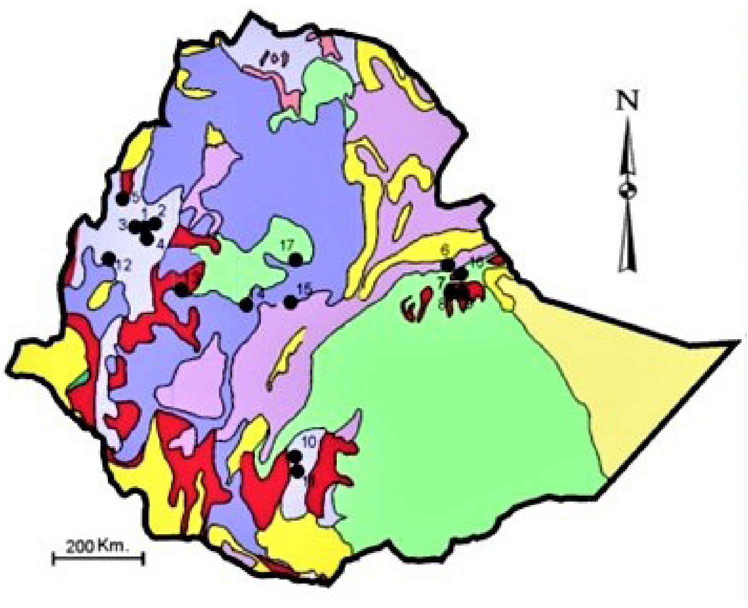

Figure 1: Simplified geological map of Ethiopia with localities of building stone in the central and southern parts of the country. Note: Deposits: 1.More and Bapuri marbles 2. Blue and Ganzi marbles 3. Baruda (Moye) marbles 4. Dehane granite 5. Mankush marble 6. Degachebsi limestone 7. Hakime gara limestone 8. Hamaresa granite 9. Babile granite 10. Melika granite 11. Kenticha serpentinite & soapstone 12. Daleti marble 13. Anger gute granite 14. Ambo sandstone 15.Addis ababa ignimbrite 16. Konboicha granite 17. Wonchit & James limestone 18. Zigi soapstone.
Note: Generalized geology: ( ) Quaternary cover (undifferntialised), ( ) Quaternary-tertiary rift sediments & volcanic, ( ) Tertiary sedimentary rocks ( ) Tertiary volcanic rocks, ( ) Mesozoic sedimentary rocks, ( )Palaeozoic sedimentary rocks, ( ) Proterozoic metamorphic rocks, ( )Archaean rocks

Figure 2: A) Polished surface of the variegated Babile granite (right) and flamed and honed tiles of the Porphyritic Anger Gutin granite (left) Sheraton hotel in Addis Ababa. B) Raw block surface of the Anger Gutin granite in the quarry (cut perpendicular to the foliation. Drill holes are approximately 25 mm wide.

As Walle, et al. have been discussed Pre-and syn tectonic granitoid within the Middle and Upper Complexes comprise medium-grained grey granodiorites, fine-grained pink to red granite, coarse-grained pink granite, and porphyritic pink to grey granites, all estimated to belong to a low-to-medium price level at the market. Some intrusive rocks may show a discriminating foliation across their entire thickness, or have a foliated margin with a massive, non-foliated core [8]. The Anger Gute granite, Wollega (sometimes called the Gutin granite), is presently exploited by the National Mining Company. This is foliated Anger granite, with large, pink phenocrysts of microcline in a brownish-grey groundmass of biotite, plagioclase, quartz, and potassium feldspar (Figures 2A and 2B). The granitoid and other metamorphic exposures occur in the area by forming smooth hills and ridges with a steep foliation alleviating the extraction by different geophysical methods and by drilling, blasting, and wedging. Variations in color and structure may occur, especially due to the heterogeneous distribution of the phenocrysts and a varying degree of foliation development. The present phenocrysts are normally rounded and rotated by strain.

Some structures like aplitic veins of various generations are ample and may add to an increasing waste ratio in some of the deposits. Joint spacing in the area varies significantly, but some small hills show a spacing of more than 1.5 m on average, which may be sufficient for large block production. Much other granite and metamorphic rocks outcrop may be of future interest for dimension stone production. These include the Dehaene granite, close to Mora in Gojam. This is coarse-grained pink granite, forming huge hills and ridges of boulder deposits, which by reconnaissance appear to be very homogeneous in color and structure. Joints are widely spaced, facilitating the production of large blocks. In the south, the pilot quarrying of fine-grained pinkish-grey granite has been carried out near Kibre Mengist in the Sidamo area, where several small, syn-tectonic granite plutons occur and these granites are tightly jointed, and locally thick kaolin zones are developed in the weathering profile.

As Kebede, et al. discussed, A-type granitoid, either intruded into a greenschist facies volcano-sedimentary sequence or emplaced at the contact zone between high and low-grade terrains, appoint a significant ratio of the granitoid rocks in the Precambrian shields of western Ethiopia. They argued that in the case of Western Ethiopia, the granitoid intrusions were formed either intruded into a greenschist facies volcano-sedimentary sequence or emplaced at the contact between low and high-grade terranes (i.e. A-type granitoid) and considered an orogenic granite [6].

Statement of the problem

Dimension stone is a mineral aggregate natural rock that has been selected and fabricated to particular sizes, shapes, durability, time measures of the ability of dimension stone to endure and to maintain its essential and distinctive characteristics of strength, resistance to weathering, and appearance. Most commonly exploited are massive rocks such as granite rock, marble, limestone, and sandstone, and slab rocks such as slate and flagstone [8]. Granitoid rocks are formed when magma cools down and hardens before it reaches the surface of the Earth. For instance, granites were originated by the melting of a pre-existing meta-sedimentary or sedimentary source rock and igneous type sources [6]. Granioied suites include Gabbro, darts, quartz monzonites, granodiorites, and granites that show mild to no Fe-enrichment. Under these circumstances, the crystals have enough time to form crystals and grow very large phenocrysts. The present project uses both petrographical and geological data to characterize the potential assessment of dimension stone and the structures that affect the quality of dimension stone of granitoid rocks from the Anger Gutin area.

Significance of the study

The project helps individual researchers and research organizations by providing different geological and petrographic data that will be useful for non-governmental organizations and different companies whose focus on raw materials for different construction and dimension stone that use for different ceramics production. Furthermore, the study may give some understanding of the methodology followed in this research, geological and petrographic data analysis techniques that will be used as a reference framework for another research work after publication. The petrographic details of the granitoid rocks with their field observations will have paramount importance to understand the potential, tectonic and magmatic evolution of the granitoid rocks of the Anger Gute area. Finally, it will be used as input for advanced scientific research works on dimension stone. The benefiting body from this project is most probably the country in general by using the outputs of the current project for further investigations of natural resources of the area like economic minerals, constructional materials for buildings, ceramics, and different rocks for dimension stone, etc.

Objectives of the study

General objective: The General objective of the study is to characterize the geology and petrography of granitoid rocks from the Anger Gute for an implication of dimension stone Assessments.

Specific objectives:

- To reproduce the geological map of the Anger Gute area.
- To describe and classify the rocks based on the petrographic and geologic properties.
- To assess the potential of dimension stone of the Anger Gute granitoid rocks.
- To identify a different geologic structure that affects the quality of dimension stone.
- To understand the tectonic evolution of the area.

GEOLOGICAL SETTING AND PETROGRAPHIC ANALYSIS

Regional geology setting

APan-African Orogeny is used to describe the tectonic, magmatic, and metamorphic activities of Neoproterozoic to the earliest Paleozoic age (particularly for a 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 [10,11]. This is due to the result of a continent-continent collision and the combination of many oceanic arcs and remnants of the oceanic lithosphere that once separated the cratons. It has come along through the final collision between East and West Gondwana. The collision was followed by the closure of the Mozambique Ocean forming the East African Orogeny. The East African Orogeny enclosed both Arabian–Nubian Shield in the north and the Mozambique Belt in the south. Those and many orogenic belts are commonly referred to as Pan-African belts [12].

Several distinct belts in Africa and other continents with deformation, metamorphism, and magmatic activity were spanning the period of 800-450 Ma. Pan-African tectonic-thermal activity in the Mozambique Belt was broadly contemporaneous with magmatism, metamorphism, and deformation in the Arabian–Nubian Shield. Between these two belts, there is a difference in lithology and metamorphic grades. Accordingly, the Mozambican rocks are interpreted as lower crustal equivalents to the juvenile rocks in the Arabian-Nubian Shield. The recently geochronological data indicate the presence of two major Pan-African tectonic events in East Africa. The East African Orogeny has an age interval from 800a-650 Ma [12], and it represents a discrete series of events that take place within the Pan-African of central Gondwana that is responsible for the assembly of greater Gondwana. Relatively, the low-grade rocks of western and Southern Ethiopia are considered to be part of the Arabian-Nubian Shield, and high-grade gneiss rocks that adjacent to these rock assemblages were considered as older/Achaean to Neoproterozoic basement as discussed by Kazmin [13].

However, the recent zircon dating has proved that there are no Archaean to Mesoproterozoic according to Yibas et al. [14], rocks in western and southern Ethiopia. The ages of the above rocks range from 900 Ma to 580 Ma for pre and sign-tectonic, arc, and collisional granitoid gneisses followed by 550-530 Ma post-orogenic granites. This age range is similar to that detected in the ANS of Arabia and Sudan as well as to high-grade granitoid rocks in Tanzania and Madagascar.

The Precambrian basement and related intrusive igneous rocks make up 25% of the country's landmass. These rocks have a fundamentally important tectonic setting. They occupy the interface between the Arabian-Nubian Shield in the north and the Mozambique belts to the south [12]. The Precambrian rocks of Ethiopia are revealed around the Eastern, Western, Southern, and Northern parts of the country [2,9]. The exposure of the Ethiopia basement comprises a variety of volcano-sedimentary and plutonic rocks metamorphosed to varying degrees from greenschist to amphibolite-facies and locally granulite facies condition [15].

Similar to the other Precambrian terrains in Ethiopia, western Ethiopia Precambrian terrain has relationships with Pan-African belts. Two terrains Arabian-Nubian Shield (ANS) and Mozambique Belt (MB) are not different. But, they appoint different crustal levels of collisional and/or accretional systems as discussed in Kazmin et al. [2]. According to the above authors, these belts are the upper crustal Arabian Nubian Shields and the lower crustal Mozambique Belt. ANS is differentiated from MB by its dominantly juvenile nature, relatively low grade of metamorphism, and ophiolites. But, the MB belt fundamentally consists of medium to high-grade gneisses and voluminous granitoid.

Lithology and Stratigraphy of Western Ethiopian Shield indicate that the Precambrian geology of western Ethiopian terrain consists of volcano-sedimentary terrain, gneissic terranes, and ophiolitic rocks which are similar to Neoproterozoic rocks of the ANS and rocks of the MB [2,4,16]. The lithological components found in this region include; high-grade metamorphic rocks; ophiolite belts; dioritic to granodioritic batholiths and associated intermediate volcanic; metavolcanic-sedimentary rocks [2]. By different authors, in different times the western Ethiopian shield has been divided by tectonic evolution into the Gore-Gambella area which comprises Birbir, Baro, and Geba domains [17], and the Tulu Dimtu belt which includes (Aba Sena-Gimbi-Inango-Ayra transects) and comprises five domains from west to east; Daka domain consists of lithological units that are characterized by high-grade rocks such as; moderate-high grade poly-deformed gneisses and intruded by syn-kinematic granitoid and banded ortho-pyroxene bearing granulite facies.

Sirkole Domain consists of mafic to felsic metavolcanic, moderate grade poly-deformed gneisses, and low to moderate grade metasedimentary rocks intruded by deformed and undeformed granitoid plutons. The Grade of metamorphism in this area is characterized by amphibolite facies assemblages that occur in both the gneiss and the volcano-sedimentary successions [18]. Katta Domain enclosed Dengi formation with metamorphosed sandstone and conglomerate with subordinate sericite/muscovite schists, phyllites, and metatuff. Besides, Gulisoo formation contains interlayered psamites and pelites with variation facies. Stratigraphically, the formation shows coarser grain at the bottom and finer at the top layer. The other unit is Daleti formation also admitted under this domain which shows medium-grained calcite marble that cut across by dolerite dike. Also, metasediments and metavolcanics are the other forms found in the domain. Metasediments comprise graphite-quartz-mica-schist/phyllite, graphite schist, quartzite, metasandstone, and chlorite-quartz schist. The metavolcanics are mainly basic and related to chlorite schist and amphibolite. They are intruded by voluminous pre-tectonic gabbroic to granite intrusions [1]. Aba Sena Domain contains Sayi Chenga group and gneissic associations which are related to metavolcanic mainly basic and metasediments. This admits quartzite and graphite, semi pelitic schists and phyllites, and marble. Generally, this domain is characterized by mid to upper greenschist facies of metamorphism. Besides, there is migmatitic biotite gneiss, biotite-hornblende gneiss, and granitoid orthogenesis with minor intercalations of metasediments and amphibolite facies of metamorphism. Geochronological investigations from plutonic rocks suggest that the age of the low-grade rocks ranges from ~830 to ~540 Ma [4]. Based on the field observation, lithologic units, geochemical and geochronological grounds, low grades of Western Ethiopia were correlating to the Juvenile pan-African assemblage northern Ethiopia, Eritrea, and Southeastern Sudan. Didesa domain is characterized by moderate grade para- and ortho-gneiss, intruded by Neoproterozoic intrusive rocks like poly-deformed gabbroic and granitoid bodies and post kinematic mafic and felsic plutons [18].

Para-gneisses in this domain include biotite-amphibole gneiss, garnet-biotite gneiss, and quartzo-feldspathic gneiss, and ortho-gneisses are consists of banded mafic gneiss containing ultramafic bands and derived from a layered mafic intrusive body [1]. Most of the lithologic units found in the Didesa Domain show strongly foliated and undergone intense folding with abundant refolded folds indicating polyphase folding. Tectonic contact marked by the N-S trending Chugi Shear Zone separates this domain from the adjacent Kemashi Domain to the west [18]. Dengi, Kemashi, and Didessa classification is based on the grade of metamorphism and also on lithological similarities within the same domain [19].

The Western Ethiopian Granitoid studies indicate that plutonic rocks of variable composition and age intruded the basement rocks, particularly the low-grade volcano-sedimentary sequence. Pre-to syn and post-tectonic plutonic suites constitute the basement and are prevailed by granites and granodiorites. Some diorites, tonalities, and gabbroid are also present. The low-grade terrane is delimited to the east and west by high-grade gneisses and a migmatised terrane [7]. Granitoid intrusions in the high-grade terrane are restricted to both compositionally (diorite/granodiorite to granite) and geographically, they take place only in a few locations. For instance, Ujjukka granite and granodiorite and DhagaaBooqa granite are a leucocratic to mesocratic, medium to coarse-grained, hypidiomorphic granular rocks, which forms prominent outcrops. The intrusive rock is predominately composed of alkali feldspar (microcline+perthite), plagioclase, quartz, and biotite, with subsidiary sphene and zircon. When albite overgrowth both alkali feldspar and plagioclase is common while plagioclase is extremely altered to sericite, clinozoisite, and epidote, and intergrowths of plagioclase with quartz form a myrmekite. Quartz occurs in clusters that are elongated along with preferred mineral orientation directions. Biotite is the merely primary mafic mineral in this rock. It is commonly altered to epidote, chlorite, and hydrobiotite [7].

The Ganji monzogranite, Homa gneissic granite, Tuppii granite, and TulluKapii quartz syenite from western Ethiopian Precambrian terrain have chemical and mineralogical categorized under within-plate granite and these types of rock units were generated and emplaced along with an extensional tectonic environment. Structural and metamorphic features indicate that the syn-kinematic Homa gneissic granite predates the emplacement of the Ganjii, Tuppii, and Tullu Kapii granitoid. Major and trace element modeling shows that the Ganjii monzogranite was formed by fractional crystallization of largely hornblende, plagioclase, and biotite from a Monzo-dioritic magma that enriched in incompatible elements including LILE, HFSE, and REE which requires a low degree of partial melting [6].

Local geology

The geographical location of Anger Gute is in Western Ethiopia, in East Wollega Zone by relative location and astronomically located in between 9°40'0"-9°53'30" Northing and 36°36'0"-36°43'0" Easting. The map is represented only to show the location of the study area (Figure 3). Intrusive igneous rocks are common in the Precambrian basement rocks of Ethiopia and range from granitic bodies within the migmatites of the Lower Complex, to pre-, syn, and post-tectonic intrusions in the Middle-Upper Complexes [20,21]. Anger Gute area is located in the Precambrian basement rocks of Ethiopia and also there is granitoid intrusion (especially, granite and other intrusive igneous rocks) as well as different metamorphic rocks like gneiss.

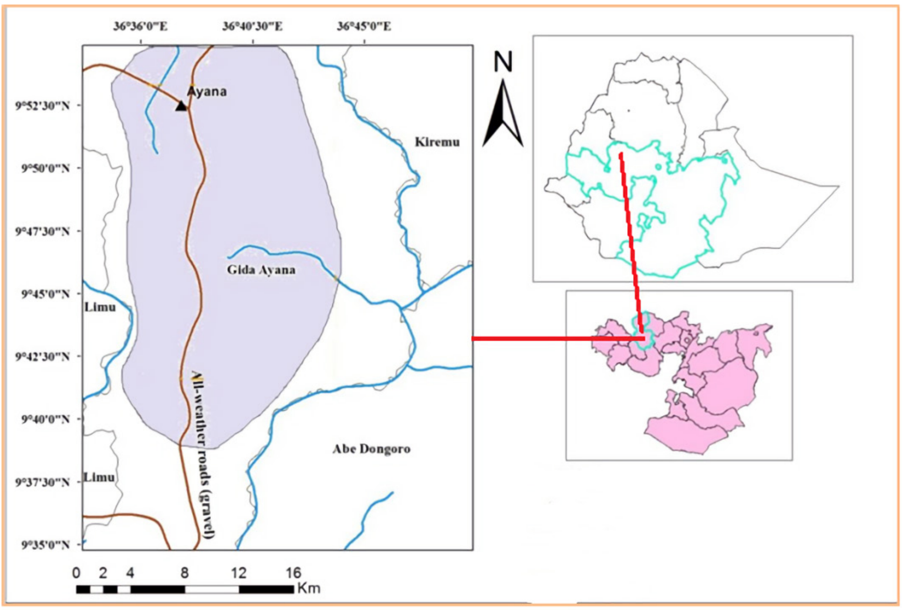

Figure 3: Location map of the study area. **Note:** (▲) Towns, (—) Road, (—) River, (■) Study area

This rock is exposed near the small village of Aba Musa, Anger Gute Town, and Andode by forming massive boulders and mountain chains that give good opportunities for the extraction of large volumes of commercial-sized and dimensioned blocks of granite rocks. Generally, thirteen rock samples were collected and separated into three categories based on their textural and structural characteristics. These are 1) Coarse grain granite rocks, 2) Coarse-medium grain slightly foliated and lineated granite-gneiss rocks and 3) Medium-fine highly foliated and lineated gneiss rock samples [22].

Dimension stone sold as granite admits all feldspathic crystalline rocks of mainly interlocking texture and with individual grains that are seeable to the naked eye. Granite includes such rock types as anorthosite, gneissic granite, granodiorite, monzonite, syenite, and all other intermediate igneous rocks and coarse-grained metamorphic rock types. The colors of mercantile granite are primarily white, gray, pink, and reddish. Green and brown colors are secondary colors and black granites are also admitted in this rock type but are not true granites. Mineralogically, black granites are compositionally mafic rock types, for instance, diabase, diorite, and gabbro. A usual sub-classification system divides dimension stone into calcareous materials (i.e. limestones, marbles, travertines, etc), siliceous materials (i.e. quartzites, granites, and sandstones), and as well as slate. For the exploration of dimension stone, there are a set of criteria, namely the color, the texture, and the presence or absence of discontinuities, however, the color and pattern of the stone must be homogeneous across the deposit that the market can identify different blocks as being the same product.

Granitoid rocks of Anger Gute area: Granitoid rocks especially the granite rock of Anger Gute are exposed near the local name of Aba Musa village and Tulu Gora mountain chain. This granite is coarse-grained K-feldspar granite that is characterized by large phenocrystic grains of pink K-feldspar embedded in a relatively fine-grained groundmass of microcline, plagioclase, quartz, biotite, and accessory minerals (Figure 4A). There is a variegated, veined structure that shows its close relationships with the surrounding migmatitic gneisses. The structure of the granite may vary within small areas between more or less gneissose giving possibilities for the extraction of various commercial dimension stone types and also demanding attention in the estimation of uniformity in future reserves. Both Aba Musa granite and Tulu Gora granite are pre-and syn-tectonic granitoid within the Middle and Upper Complexes characterized by coarse-grained, pink granite, and porphyritic pink granites (Figure 4B).

Tulu Injiro Granite and Andode Granitic-gneiss are pre-and syn-tectonic granitoid within the Middle and Upper Complexes comprise coarsely grained to medium-grained porphyritic grey granites. These plutons may show a penetrative foliation throughout their entire thickness, or have a foliated margin with a massive, non-foliated core (Figure 5A). Tulu Injiro granite is sometimes called the Angar Gute granite. This granite has a small degree of foliation, with little or no large pink phenocrysts of microcline in a brownish-grey groundmass of biotite, plagioclase, quartz, and potassium feldspar compared to Andode Granitic-gneiss which is characterized by medium percentage phenocrystic grains of pink K-feldspar embedded in a relatively high fine-grained groundmass of microcline, plagioclase, quartz, biotite, and accessory minerals (Figure 5B). Many granite deposits occur in the area by forming rough to smooth hills and chain ridge morphology, with a steep foliation facilitating extraction by drilling, blasting, and wedging. Variations in color and structure may occur, especially due to the heterogeneous distribution of the phenocrysts and a varying degree of foliation development. The phenocrysts are commonly rounded and rotated by strain [8].

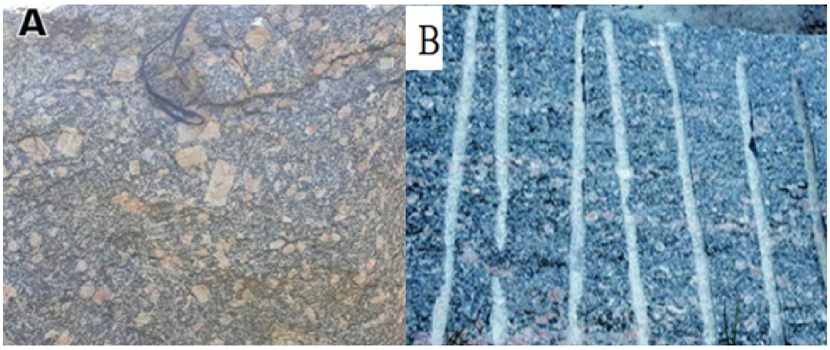

Figure 4: A) Granite rocks from Aba Musa area which is highly dominated by pink k-feldspar and B) Raw block fresh surface of the Anger Gute granite in the quarry (cut perpendicular to the foliation), drill holes are approximately 25 mm wide.

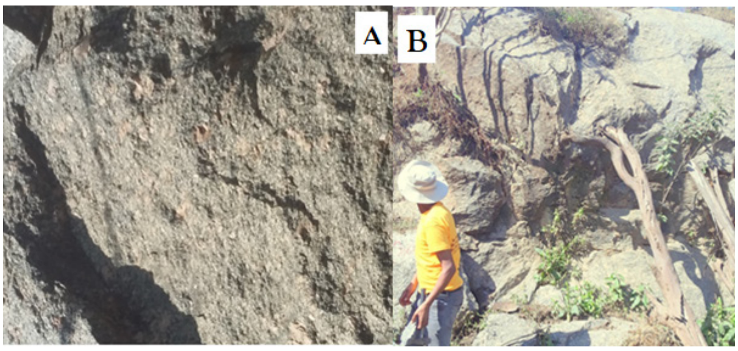

Figure 5: (A,B); Tulu Injiro massive granite which is highly dominated by quartz and Andode Granitic-gneiss without some large crystal of alkali feldspar respectively.

Light color (aplitic) veins of several generations are abundant and may be increasing waste ratio in some of the outcrops. Joint spacing that occurs on the exposure rocks varies significantly, but some small outcrops show spacing of joints more than 1.25 m on average, which may be ample for large block production. So, another several granite exposures of the area may be future interest for building stone. These include the Homa granite and Ganji granite both in West Wollega while Loko granite and Welkite granite close to the study area in East Wollega. This is coarse-grained, pink granite, forming huge hills and ridges of boulder deposits, which by reconnaissance appear to be very homogeneous in color and structure. Joints are widely spaced, facilitating the production of large blocks and however, these area granite rocks are tightly jointed. The thick kaolin zones are locally developed in the weathering profile. Thus, these granites are probably not of great interest as dimension-stone prospects [6].

Dicho gneiss rocks of Anger Gute area: Dicho gneiss is a type of metamorphic rock that was metamorphosed from granite protolith rocks at suitable pressure and temperature. It is a course, foliated metamorphic rock in which bands of granular minerals (commonly feldspar and quartz) alternate with bands of flaky or elongate minerals like pyroxene and micas. Within this rock, less than 50% of the minerals are aligned in a parallel orientation. Gneiss rock unit is characterized by foliation and lineation structures that formed due arrangements of a set of minerals in parallel, sheet-like layers that lie perpendicular to the flattened plane of rocks and a general term applying to any linear features in a metamorphic rock respectively (Figure 6). The stripe (banding) is commonly due to the presence of differing proportions of minerals in the several bands; light and dark bands may alternate due to the separation of mafic (dark) and felsic (light) minerals. Banding can also be caused by dissenting grain sizes of the same minerals (Figure 7).

Figure 6: Dicho gneiss with visible foliation and fold structure.

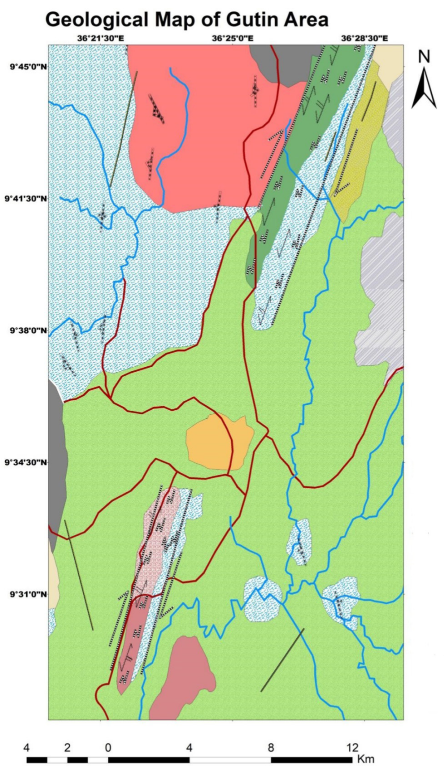

Figure 7: Geologic Map of Anger Gute Area. **Note:** ( ) Quaternary sediments, ( ) Paleozoic sandstone, ( ) Lower Basalt, ( ) Dicho gneiss, ( ) Meta-gabbro, ( ) Graphite muscovite quartz schist, ( ) Tulu injiro granite, ( ) Tulu gora granite, ( ) Aba musa granite, ( ) Quartizo-feldsphatic granite, ( ) Endode granite, ( ) Main road, ( ) River feature, ( ) Fault and shear zone, ( ) Foliation, ( ) Lineaments, ( ) Strike and dip of foliation.

MATERIALS AND METHODS

Introduction

To achieve the general and specific objective of the project and come up with the expected result, the research is mainly divided into three phases.

Field evaluation

During this phase, the general physical properties of the rocks such as color and hardness are defined. If the color appearance of the rocks is acceptable it indicates that the formation of the rocks is in good physical shape. The second step is to study the formation of the rock outcrop to ascertain the possibility of producing blocks of commercial size. In some circumstances, field evaluation is averagely easy because there are solid outcrops on which veins and joint spacing can be readily assessed where are there are no solid rock exposures, the size of boulders on the surface can give some denotation the possibility of producing blocks of dimension stone. Where there are exclusively very small boulders present and unlikely that it will be potential to produce blocks of marketable size, as in general the jointing and veining in the host rocks control weathering that produces boulders. Small boulders are usually indicative of closely spaced joints and veins in the underlying solid rocks. The size of the exposure consistency should be evaluated at this phase.

The next step should be to remove several samples of the rocks for cutting and polishing. Small boulders that can be carried by hand can be removed, or else samples of approximately 30cm cubic can be extracted from the solid rock or large boulders using a petrol-powered rock drill and plugs and feathers. By removing these at several points around the formation, an idea of the consistency of the color can also be gained. These samples can be compared against existing products on the markets and used to obtain feedback from customers as to the demand and expected price for the material. These samples will also give an idea of whether or not the stone can be polished to an acceptable finish, as well as indicate the hardness of the stone from a sawing and finishing point of view.

Finally, in the case of an established material, the final phase of prospecting is test quarrying. The purpose of test quarrying is to fully evaluate the recovery of marketable blocks within the formation to determine whether full-scale mining is economically viable, as well as to evaluate the implications of extraction methods on the economically valuable rock exposure of quarrying. characterize quarrying is required because other methods mentioned above can only indicate the range of possible retrieval, and the actual recovery possible can only be established by actual mining of the formation and recording the resultant production and its costs. It also allows for the adjustment of extraction methods to determine the most feasible method to be employed. While recent advances in dimension stone quarry evaluation have shown that there is potential for geostatistical methods to provide reasonable assessments of the potential exploitability of a quarry, the authors would be somewhat hesitant to use this as a substitute for test quarrying before proceeding with the development of a full-scale quarry, which has significant cost implications, as well as being substantially more impact to the environments. Test quarrying should however be conducted on as small a scale as possible to minimize the impact of quarrying development on the environment.

Fieldwork and sample collection processes

In addition to secondary data collected from different sources that existed before this research, the primary data are used. The main methods of collecting primary data are fieldwork. The purpose of this fieldwork is to know the distribution of lithologies, formation, deposition, accessibility, and geology of the area as much as possible and to take representative samples for laboratory analysis (especially for petrographic data analysis) based on visible outcrops. During this work, the measurement is undertaken by following preplanned GPS points and a systematic sampling method. The sampling methods are following road cut, river cut, outcrops of intrusions, quarry sites, and different weak zones of the rock bodies. The representative samples collected are through areal mapping techniques according to their variation in color, textures, structures which are visible to our necked eye and their mineral constituents, etc.

Laboratory and data analysis

Petrographic analysis: For petrographic analysis granite, granitic-gneiss, and gneiss rock samples were collected for thin-section analysis. Thin-section was prepared in the Geological Survey of Ethiopia, at a thin-section and sample examination room. The selection of samples that are used for thin-section is based on the variety of lithologies, their importance, and their difficulty to identify during the fieldwork. The main output results of the thin-section analysis are the average grain shape of those existing minerals, the modal proportion of minerals, the grain to grain relationship of the phenocrysts, and the identification of microstructures found on the rocks. These processes will help mainly in the rock classification, textures, mineral contents, to determine different structures and understand the tectonic evolution of the Anger area.

Generally, after the above three phases of methods; analyzing, synthesizing, presenting, and interpreting of data were done. Most of the analyses will be done in the laboratory for petrographic analysis. The process of data synthesis involves collecting and combining (integrating) different data sets into consistent information for interpretation. So, all data including both those from literature and collected through the fieldwork will be analyzed, interpret, and presented together. The presented data is being put into a regional context by comparing relevant literature on nearby or similar plutonic rocks and granitoid of the area. Finally, all collected data and a discussion of interpretation are being written up in a final project report. During different phases, a variety of materials are used. These materials including topographic maps and geological maps at a scale of 1:50,000, standard field sampling and measuring tools, Arc GIS, and Google Earth software packages were used.

RESULTS

Geology of the area

In geologic surveying for locating rocks suitable for quarrying operations, the first requirement in identifying a rock for use as dimension stone is petrographic analysis. This will help to identify the rock's mineralogy, grain size, texture, fabric, and weathering conditions. Geological processes control the movement and redistribution of elements through the rock cycle, whereby deposition of different rocks takes place by physical and chemical reactions, such as weathering and erosion of rocks at the surface and metamorphism and melting of rocks at depth within the earth's crust. The deposition of rock for processing into dimension stone is largely associated with internal processes that take place at variable depth within the earth at high temperature and pressure and largely associated with igneous and metamorphic rocks being gradually exposed to the surface by processes of denudation.

All these processes are in turn determined by the geological processes which form the rock. Understanding such processes and effects will enable one to ascertain a rock's availability, suitability, and uniform production. The rocks of interest are the granite from igneous rock, while gneiss from metamorphic rock. The high resistance of the granite and its low water absorption could be imputed to its mineralogical composition of feldspar, quartz, biotite, and accessory minerals and formed as a result of a slow cooling rate with grain boundaries interlocked.

Petrographic analysis

The Aba Musa and Tulu Gora K-feldspar granite are characterized by large phenocrystic grains of pink K-feldspar which are embedded in a relatively fine-grained groundmass of microcline, plagioclase, quartz, biotite, and accessory minerals (Figures 8A and 8B). The above granite also contains mafic enclaves of various sizes and shapes. These enclaves are composed of biotite and feldspars and occur in lenses, with their long dimensions aligned parallel to the gneissosity in the granite (Figure 8C). This rock is principally composed of K-feldspar (microcline ± perthite), plagioclase, quartz, biotite, and hornblende, as well as minor sphene, zircon, and opaques. Microcline occurs as megacrysts and microplastics. The megacrysts grains contain inclusions of albite, biotite, graphic quartz, epidote, zoisite, sphene, opaques, zircon, and carbonates. Recrystallized quartz, epidote, and biotite rim these K-feldspar megacrysts [7].

The plagioclase grains occur as porphyroblasts enclosed by a fine-grained matrix of quartz, biotite, epidote, clinozoisite, and sphene, and also, partially plagioclase is altered to clinozoisite, epidote, and sericite as well as it exhibits deformation of twin lamellae. Alteration is more intense towards the center of the crystals, suggesting compositional zoning. On the other hand, quartz appears in various forms such as clusters, as small granular crystals in matrix, graphic quartz in k-feldspar, and elongated quartz ribbons. Biotite and other mafic minerals define the gneissosity (Figure 8C) and biotite is commonly altered to hydrobiotite, epidote, and less commonly chlorite. Infield view of biotite inclusions of Zircon with pleochroic haloes is detected. Well-crystallized euhedral sphene grains are abundant, particularly in the less-deformed portion of the granite, and are preferentially aligned parallel to the gneissosity. The mylonitic portion of this unit has the same mineral composition with a less deformed part of the granite and the proportion of felsic constituents (i.e. feldspar and quartz) is increased at the expense of mafic minerals like biotite and hornblende). Remnants of K-feldspar and plagioclase porphyroblasts are enclosed in a fine-grained, recrystallized matrix while the mafic minerals mainly biotite forms stringers that explain the mylonitic microstructures.

Granite rock units from the Anger Gute area are mainly dominated by two K-feldspars (microcline and orthoclase), quartz, and plagioclase under a petrographic microscope representative sample in Figure 8B and Figure 8C. Quartz is recognized in the PPL view by the absence of alteration. Except for biotite and opaque minerals; the other minerals show colorless in PPL. Quartz is xenomorphic and appears as small crystals (0.50 mm) scattered in the rock and occurs as rounded to subhedral crystals or appears as clusters between the feldspars and granophyric intergrowth of quartz and feldspar were also observed.

The most common mineral assemblage of these rocks of the project area is mainly composed of K-feldspar from (45%-65%), quartz from (20%-31%), plagioclase from (3%-10%), biotite (<11%), as major components; Epidote (<7%), muscovite (sericite) with (<8%), and opaque (Fe-Ti oxide) with (<5%) as minor components and sphene with (<3%) and hornblende with (<2%) as accessory minerals. Zircon and apatite are present as trace amount components in these rocks. There is an alteration features are common and represented by sericitization of plagioclase and K-feldspar was apparent (Table 1 shown in appendix I).

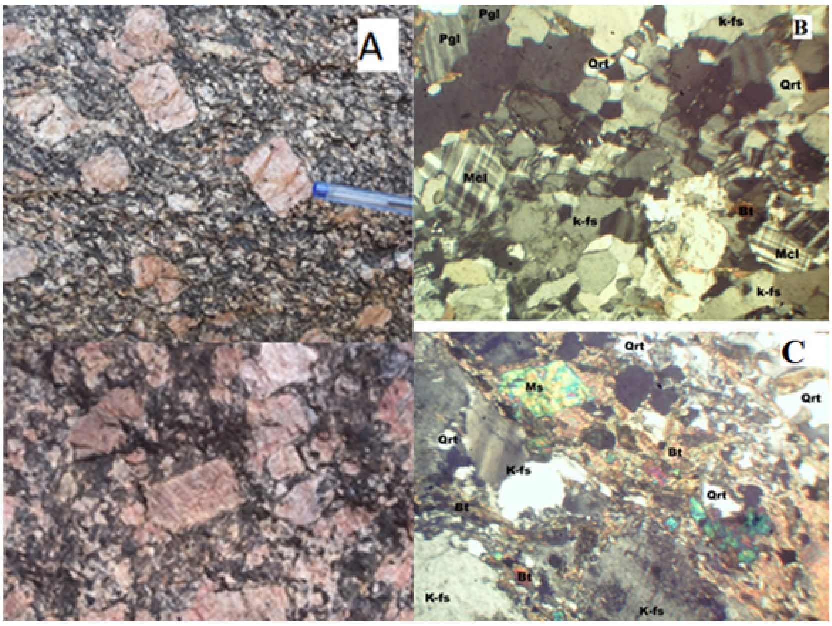

Figure 8: A) Aba Musa and Tulu Gora k-feldspar granite and B) Microphotograph of Aba Musa granite C) Microphotograph of slightly foliate Andode granitic-gneiss of Anger Gute area.

Table 1: Field description of thirteen different rock types and their microscopic descriptions.

#Sample	Formation	Mineralogical description	Composition	Rock type
FD-1	By magmatism process	Characterized by light gray and coarse-grained	Mainly composed of K-feldspar, Quartz, Biotite, Muscovite, and Sericite	Granite
FD-2				
FD-3				
FD-4				
FD-5				
FD-6				
FD-7				
FD-8				
FD-9				
FD-10	By slightly magmatism to magmatism processes	Characterized by light gray, coarse-grained, crystalline, and randomly oriented minerals	Mainly composed of K-feldspar, Quartz, Biotite, Muscovite, Sericite, and some Micas	Granite-gneiss
FD-11				
FD-12	By magmatism processes	Characterized by light gray, coarse-grained	Mainly composed of K-feldspar, Quartz, Biotite, Muscovite, and Sericite	Granite
FD-13	By metamorphism processes	Characterized by dark, fine to medium-grained, foliated, and porphyroblastic gneissosity texture	Mainly composed of feldspar, Quartz, Biotite, Muscovite, Micas, pyroxene, and hornblende	Gneiss

In the above microphotograph field of view (Figure 8B), some plagioclase crystals exhibit a simple twinned crystal with very dark grey interference colors. The plagioclase is mostly subhedral-euhedral and zoned with laths. The euhedral to subhedral phenocrysts of plagioclase are common. Sometimes plagioclase appears with zircon inclusions and biotite occurrence. The other minerals that are presented in this field of view are biotite and muscovite crystal. Biotite and muscovite exhibit platy and Tiny-platy textures respectively. Biotite occurs in anhedral flakes occupying interstices between plagioclase crystals. The presence of hydrous minerals muscovite, chlorite, and biotite may indicate a retrograde metamorphism phase caused by fluids. In addition to mineral composition also there are different microstructures and textures are identified under a petrographic microscope which indicates the tectonic evolution and metamorphic processes of granitoid and metamorphic rocks of the Anger Gutin area.

DISCUSSION

Geology, Rock mass characteristics, and discontinuity

The desirable criteria for potential dimension stone prospects are substantial exposure, lithological uniformity, and continuity, low density of joint and joint space and fractures, durability, attractiveness, and absence of deleterious materials. Low water absorption or porosity values generally indicate more durable rocks because the water is the main agent of weathering, has less ability to penetrate non-porous rock types, and therefore, is less able to cause damage. For the transportation and calculating the weight of flooring, walling, or cladding panels used in the design of foundations and buildings density data is playing a great role. Most of the rocks around the Anger Gute area were show little to no discontinuities and geologic structures that affect the commercial values of dimension stone. However, the joint density of the rocks observed during field works is the minimum joint spacing in centimeters. This minimum joint spacing does not affect the quality of the dimension stone. From the field observation especially granite rocks of the area were forming hills and mountain chain morphology which indicates that the high potential of these granite and granite-gneiss rocks for dimension stone. Because most of the time these granitoid rocks were come to the surface through intrusion by forming a batholith, or other intrusion bodies. There were some previous quarries within the study area which indicates the high potential of granite rock deposits and these rocks are very good for dimension stone. But highly foliated gneiss is poor for dimension stone due to being highly affected by foliated and there is quartz vein that developed during post mineralization stage and during and after metamorphisms. The existence of such structures affects the quality of dimension stones obtained from such rocks.

Generally; the exploitability of granite as being determined by structural characteristics such as continuity, orientation, discontinuity, extension, and persistence irrespective of whether the joints and other fractures are primary or secondary in origin. So, the quality depends on various factors such as grain size, color, degree of weathering, and the presence of structures. Similarly, the following defects which affect the quality and exploitability of a dimension stone deposit are color variations, textural characteristics, and textural variation, structural and macro discontinuities, micro-discontinuities, accessory minerals, contact zones, and mineral alterations.

Petrographic analysis, structural and metamorphism evaluation

The mineralogical composition is one of the main properties controlling the rock strength. The more rock strength depends on the percentage of minerals like quartz, orthoclase, and garnet and the less strength of rocks depends on the percentage of minerals such as plagioclase, biotite, and muscovite found within the rocks. The quartz to plagioclase ratio has an impact on the uniaxial compressive strength of the granitic rocks while the mean grain (mineral size) has an impact on the strength of the rock. Therefore, as the main grain size decrease, the strength of the rock increases. As the percentage of quartz and orthoclase in the rock increases, the strength increases. Most of the texture and microstructures observed on k-feldspar (especially on plagioclase, microcline, orthoclase) and some on the quartz (i.e. change in shape), on mafic minerals like biotite and muscovite aligned parallel to foliation and gneissosity due to different tectonic and metamorphism processes. Some textures and structures are shown in the above microphotographs (Figures 9A and 9B).

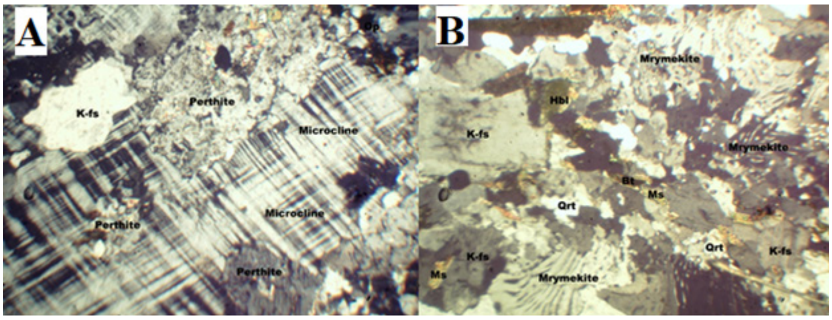

Figure 9: A and B shows some micro-textures and structures that exist on granite rocks from Gute-Area.

K-feldspars are dominated by microcline, orthoclase, and microcline-perthite and occur as subhedral to anhedral grains. In the perthite, the exsolved plagioclase component occurs within the host microcline as microscopic lamellae. In the thin section of these granite rocks, the microcline is identified by the typical cross-hatched twinning. Also, there is a sign of perthitic and micro-perthitic texture caused by un-mixing, exsolution, or separation of Na+ and K+ as the feldspar cools may indicate stages of granitic magmatism. The micro-perthitic to perthitic intergrowth was also observed in the twin lamellae of K-feldspar and plagioclase may be due to deformation. This crystal is represented here by small crystals of microcline (from 0.68 mm to 2.5 mm). Generally, from the microphotographs in Figure 9 and thin-section analysis, some grains of K-feldspar (microcline and plagioclase) lose twin lamella due to deformation. In addition to this, K-feldspar (microcline and orthoclase) altered to sericite and biotite replaced by muscovite. Also, K-feldspar (microcline and orthoclase) and plagioclase show curved twin lamella due to deformation. Biotite and muscovite show sub-parallel alignment.

Furthermore, there are common textures observed in these granite rock thin sections. Such as 1) Perthite; An intergrowth that occurs when plagioclase encloses potash feldspar and an intergrowth on feldspar formed due to un-mixing, exsolution, or separation of Na+ and K+ as the feldspar cools respectively. 2) Myrmekites; which develop at the level of K-feldspars-plagioclase contact. It is an intergrowth of dendritic quartz and plagioclase at the K-feldspar/plagioclase interface. It is related to a deuteric (late magmatic) effect or related to deformational recrystallization in some cases. Some Sphene grains are rimmed by Opaque minerals. Secondary minerals are represented by Epidote, sericite, and myrmekites crystallizing according to the primary phases. For instance, minerals like allanite and epidote are secondary minerals issued from the transformation of plagioclases and biotite, and minerals including apatite, zircon, and oxides are accessory minerals. 3) Quartz Vein; the simplest type of quartz vein is the filling of an already present crack in rocks. The crack might form; when pressure decreases during the uplift of rock, during folding of the rock in mountain-building processes, by shattering during tectonic events, or due to cool down and shrinks of rocks. In the thin section field of view, the veins are generally thin (<2 cm wide) and parallel to the foliation S1.

The degree of the foliation of Andode granite is higher than those of Aba Musaa, Tulu Gora, and Tulu Injiro granites. This indicates that the degree of metamorphism is increasing from Aba Musaa to Andode granitic-gneiss. The evidence for the increasing degree of metamorphism is the percentage of large phenocrystic grains of pink K-feldspar is decreasing toward Andode granite.

Dimension stone implication

Granite: Dimension stone sold as granite includes all feldspathic crystalline rocks of mainly have minerals interlocking textures and show individual grains are easily visible by the hand lens or nacked eye. The rocks such as; anorthosite, granite, granodiorite, monzonite, syenite, gneiss, and other intermediate igneous rocks and metamorphic rocks are mainly used for dimension stone. The colors of commercial granite are primarily white, gray, pink, and red as primary colors, and the green and brown colors of granite are secondary. Good quality granite outcrops are exposed in most parts of the Anger Gute area around Andode, Angar Gute town, Tulu Gora, and the Aba Musa area. It does not affect the high intensity of deformation. The exposures of this lithologic unit are considered to have the best potential for dimension stones. It is used as a dimension stone and crushed stone. Granite in this area is shown variously colored like red, white, grey, and pink. It is highly resistant to weathering, shearing, and tearing.

CONCLUSIONS

1. Anger Gute area encompasses a variety of igneous and metamorphic rock types. The igneous rock consists of a variety of granitoid and volcanic rocks whereas the metamorphic rocks include: High-grade rock like gneiss.

2. Petrographically, granite rocks from Anger Gute are mainly composed of K-feldspars (i.e. contain microcline and orthoclase, perthitic, myrmekitic), quartz, plagioclase, biotite as major, muscovite, apatite (ilmenite and magnetite/Fe-Ti oxides) as minor and Sphene, hornblende, and zircon as trace amounts. From the petrographic analysis, there is a sign of deformation recognized because some grains feldspar (microcline) and plagioclase lose twin lamella. Some rocks have interlocked grain boundaries; particularly granite and granitic-gneiss rocks which have important properties in the economic evaluation of a rock for dimension stone production. This probably makes granites, most suitable for the production of dimension stone in the area.

3. The rock strength is mainly controlled by the mineral composition of the rocks that the percentage of strength minerals (i.e. Quartz, orthoclase, garnet) and percentage of weak minerals (i.e. plagioclase, Biotite, Muscovite) can have effects on the strength parameters of the rocks. The quartz to plagioclase ratio has an impact on the uniaxial compressive strength of the granitic rocks. The mean grain (mineral) size has an impact on the strength of the rock. The Anger Gute Granite rock is a good rock for extraction of commercial-sized and dimensioned blocks because of highly dominated by a high percentage of strength minerals like quartz and feldspar. The strength increases as the quartz and orthoclase

content increases.

4. Gute area is highly characterized by gneiss, granitic-gneiss, and granite rocks that have been emplaced pre-, syn/late-to post tectonically with associated the major deformation events. The deposits are from massive boulders and big hills, mountain chains, minimum densities of discontinuity, giving good opportunities for the extraction of large volumes of commercial-sized and dimensioned blocks granite rocks for dimension stone.

5. Dimension stone is a good material for pavement construction and plays a great role in constructing structures that are destined to be strong, appealing, and economical and there is high availability of granite, granite gneiss, and gneiss that show sufficient quantity (high potential) for dimension stone around Anger Gute area. This potential is identified from the morphology, geology, and previous quarries of the granitoid rocks of the area.

6. Color is the property of appears and gets involved where the stone is used in construction exposed to public view. For instance; in the case of a residential or official building, it becomes a property of major importance. The color of a rock is a geological character depending upon the type of rock and more precisely upon the composition of the rock. For example; granites have light-colored. So, granite rocks from Anger Gute show a good attractive color for dimension stone (i.e. because the rock is mainly dominated by white or light-grey quartz and pink k-feldspar minerals).

RECOMMENDATIONS

The country can benefit from dimension stone mining and production, the rock boulders can be exported as a raw block, or finished products as bathroom vanities, countertops, tiles, monuments, exterior building components, and flagstone. For these reasons, additional analysis of dimension stone quality like geochemical analysis, and Engineering properties are required. Conducting core drilling to different depths to determine the depths affected by vertical and horizontal ground movement is also needed. Mining and exploiting these rocks always results in environmental degradation, and this can be minimized by incorporating the land reclamation and assessments of environmental impacts after quarrying.

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CONFLICTS OF INTEREST

The authors whose names are listed immediately below certify that they have NO affiliations with or involvement in any organization or entity with any financial interest (such as honoraria; educational grants; participation in speakers' bureaus; membership, employment, consultancies, stock ownership, or other equity interest; and expert testimony or patent-licensing arrangements), or non-financial interest (such as personal or professional relationships, affiliations, knowledge or beliefs) in the subject matter or materials discussed in this manuscript.

REFERENCES

1. Alemu T, Abebe T. Geology and tectonic evolution of the Pan-African Tulu Dimtu Belt, Western Ethiopia. Online J Earth Sci. 2007;1(1):24-42.
2. Kazmin V, Shifferaw A, Balcha T. The Ethiopian basement: Stratigraphy and possible manner of evolution. Geol Rundsch. 1978;67(2):531-546.
3. Kazmin V. Geology of Ethiopia. 1973.
4. Ayalew T, Bell K, Moore JM, Parrish RR. U-Pb and Rb-Sr geochronology of the western Ethiopian shield. Geol Soc Am Bull. 1990;102(9):1309-1316.
5. Kebede T, Koeberl C, Koller F. Magmatic evolution of the Suqii-Wagga garnet-bearing two-mica granite, Wallagga area, western Ethiopia. J African Earth Sci. 2001;32(2):193-221.
6. Kebede T, Koeberl C. Petrogenesis of A-type granitoids from the Wallagga area, western Ethiopia: constraints from mineralogy, bulk-rock chemistry, Nd and Sr isotopic compositions. Precambrian Res. 2003;121(1):1-24.
7. Kebede T, Koeberl C, Koller F. Geology, geochemistry and petrogenesis of intrusive rocks of the Wallagga area, western Ethiopia. J African Earth Sci. 1999;29(4):715-734.
8. Walle H, Heldal T, Sintayehu Z. Building stone of central and southern Ethiopia: Deposits and resource potential. 2000.
9. Mengesha T, Tadiwos C, Workineh H. Explanation of the Map. Realities Irish Life. 1996;363-366.
10. Stoeser DB, Camp VE. Pan-African microplate accretion of the Arabian Shield. Geol Soc Am Bull. 1985;96(7):817-826.
11. Fritz H, Abdelsalam M, Ali KA, Bingen B, Collins AS, Fowler AR, et al. Orogen styles in the East African Orogen: A review of the Neoproterozoic to Cambrian tectonic evolution. J African Earth Sci. 2013;86:65-106.
12. Stern RJ. Arc assembly and continental collision in the Neoproterozoic East African Orogen: Implications for the consolidation of Gondwanaland. Annu Rev Earth Planet Sci. 1994;22(1):319-351.
13. Kazmin V. Precambrian of Ethiopia. Nat Physic Sci. 1971;230(16):176-177.
14. Yibas B, Reimold WU, Armstrong R, Koeberl C, Anhaeusser CR, Phillips D. The tectonostratigraphy, granitoid geochronology and geological evolution of the Precambrian of southern Ethiopia. J African Earth Sci. 2002;34(1):57-84.
15. Asrat A, Barbey P, Gleizes G. The Precambrian geology of Ethiopia: A review. Africa Geoscience Rev. 2001;8(3):271-288.
16. Ayalew T, Johnson TE. The geotectonic evolution of the Western Ethiopian shield. SINET: Ethiopian J Sci. 2002;25(2):227-252.
17. Ayalew T. Metamorphic and structural evolution of the Gore-Gambella area, Western Ethiopia. SINET: Ethiopian J Sci. 1997;20(2):235-259.
18. Allen A, Tadesse G. Geological setting and tectonic subdivision of the Neoproterozoic orogenic belt of Tuludimtu, western Ethiopia. J African Earth Sci. 2003;36(4):329-343.
19. Alemayehu TA. Geology, geochemistry, age and tectonic setting of the Gore-Gambella plutonic rocks, western Ethiopia. 1988.
20. Walle H, Heldal T. Natural stone in Ethiopia: Report from the ETHIONOR program 1996-2001.
21. Kazmin V. Granulites in Ethiopian basement. Nat Physic Sci. 1972;240(100):90-92.
22. Kebede T, Koeberl C. Geochemistry, petrogenesis and metallogeny of granite-granodiorite plutons, Central Wallagga Area, Western Ethiopia. Mineral Mag. 1998;62(2):755.