Journal of Mining and Environment (JME) Vol. 16, No. 1, 2025, 39-56

Shahrood University of Technology

Journal of Mining and Environment (JME)

Journal homepage: www.jme.shahroodut.ac.ir

Iranian Society of Mining Engineering (IRSME)

Geotechnical and Geochemical Analysis of Dichinama Marble in Northern Ethiopia: Quarrying Insights

Assefa Hailesilasie Wolearegay[1], Yowhas Birhanu Amare[1], Asmelash Abay Hagos[2], Kassa Amare Mesfin[2], Hagos Abraha[3] , Bereket Gebresilassie[3] , Nageswara Rao Cheepurupalli[3*] and Yewuhalashet Fissha[3,4]

1. Department of Geology, College of Natural and Computational Sciences,. Adigrat University, Adigrat, Ethiopia
2. School Earth Science,. Mekelle University, P.O box, 231, Mekelle, Ethiopia
3. Faculty of Mines, Aksum Institute of Technology,. Aksum University, Aksum, Ethiopia
4. Department of Geosciences, Geotechnology and Materials Engineering for Resources, Graduate School of International Resource Sciences, Akita University, Akita 010-0852, Japan

Article Info

Received 9 May 2024
Received in Revised form 20 June 2024
Accepted 23 July 2024
Published online 23 July 2024

DOI: 10.22044/jme.2024.14501.2724

Keywords

Marble
Geotechnical
Quality
Recovery
Implications

Abstract

The Dichinama area in northern Ethiopia is a potential source of dimension stone, but the quality of the marble has been a major challenge for mining operations. This research aims to evaluate the quality of dimension stone by conducting a comprehensive study involving geological mapping, geotechnical testing, and geochemical analysis. The study collected nine rock samples from three active mining sites in the Dichinama area, analyzing properties such as density, water absorption, compressive strength, flexural strength, and abrasion resistance. Additionally, ten samples were collected for geochemical analysis, focusing on parameters like calcite, CaO values, LOI, SiO2 content, and other oxide concentrations. The geotechnical tests revealed that the properties of the marble in the Dichinama area were mainly calcite, with compressive strength values ranging from 29.6 to 74.5 MPa, flexural strength from 7 to 52.5 MPa, abrasion resistance from 8.3 to 17.2, density from 2257 to 2562 kg/m3, and water absorption from 0.12 to 0.93. However, most of these parameters fell below the minimum ASTM standards for marble dimension stone. The results suggest that these inferior characteristics negatively affect the recovery and quality of the dimension stone.

1. Introduction

Ethiopia is a country blessed with an abundance of valuable natural minerals and rocks, including dimension stone, which serves as an important building material [1–5]. As urbanization continues to grow, the demand for dimension stones is increasing worldwide, providing opportunities for the exploration and exploitation of dimension stones [6–11]. Ethiopia has a long history of using dimension stone for construction, ornamentation, and tombstone purposes, with famous structures such as the Axum obelisk and the ruins of King Kaleab's palace and King Gebremeskel's tomb in the Axum area [12,13]. However, systematic geological exploration of dimension stones for industrial purposes has a short history in Ethiopia. In recent decades, especially since the 1990s, systematic exploration of dimension stones in Ethiopia has been carried out by both the Geological Survey of Ethiopia and Ethiopian-Norwegian cooperation projects [12,14,15]. The Dichinama research area is located in the northern part of Ethiopia, Tigray National State, Western Zone. Geographically, it is bounded between UTM coordinates of 337034-346216 m E longitude and 1585168-1591281 m N latitude (Figure 1) [16–18]. This research area, currently owned by Saba Dimension Stone Private Limited Company (SDSPLC), is an active quarry site for marble dimension stone. However, the company's production capacity is currently only 35% of the planned production level of 70% (Saba Dimension Stone PLC, 2017). To address this production gap, a comprehensive study was conducted to assess the geological structure, quality, and strength of the marble at Dichinama.

Corresponding author: nageswararaomines@aku.edu.et (N. R. Cheepurupalli)

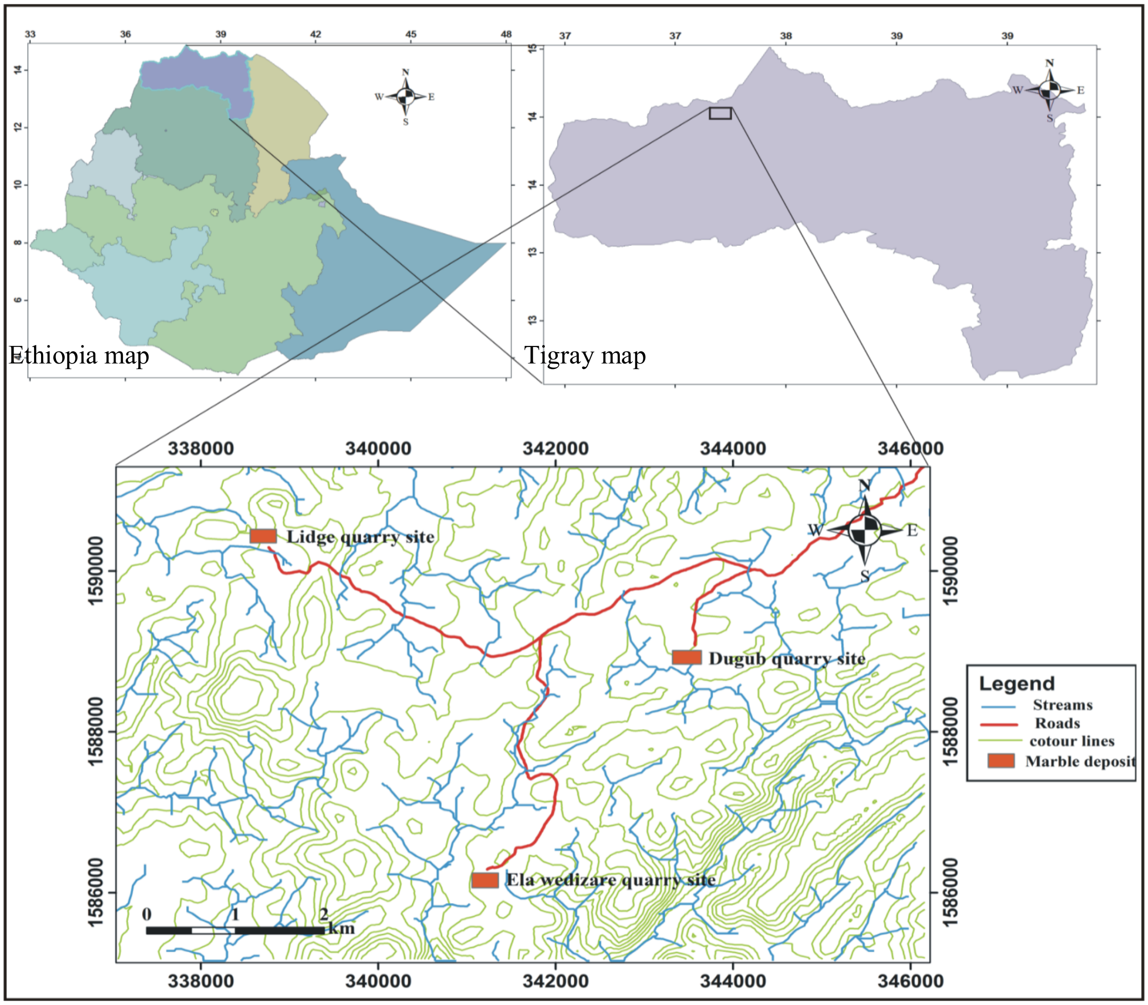


Figure 1. Location map of the Dichinama area concerning Ethiopia and Tigray (with a contour interval of 20m.)

2. Materials and methods

Three mining sites were carefully selected for extensive geological mapping and sampling. A combination of field investigation, Landsat imagery, and the latest version of Google Earth Pro (2023) were used to collect primary data. In addition, extensive field surveys were conducted at three quarry sites and surrounding areas to assess the geological structures present. To produce a detailed geological and structural map, the acquired images were accurately processed and interpreted using ENVI4.5 (2010) and ArcGIS10 software. In addition, by the recommendations of ISRM (1981), a thorough and systematic measurement and documentation of discontinuities, including spacing, aperture, and orientation, was carried out on various surface exposures and quarry faces within and around the study areas. Ten samples of marble rock were collected from the Ela-wedizare, Dugub and Lidge quarries for geochemical analysis of major oxides. In addition, nine samples, three from each site, were carefully selected for laboratory testing to assess the physical and mechanical properties. These properties included water absorption, density, compressive strength, flexural strength, and abrasion resistance. Geochemical analysis was performed at the Australian Laboratory Service (ALS) using an X-ray fluorescence spectrometer (XRF). As for the physical and mechanical tests, they were conducted in the laboratories of the School of Civil Engineering, Mekelle University, according to the guidelines of the American Society of Testing and Materials (ASTM, 503C) (2008). The flow chart of the research methodology is depiced in Figure 2.

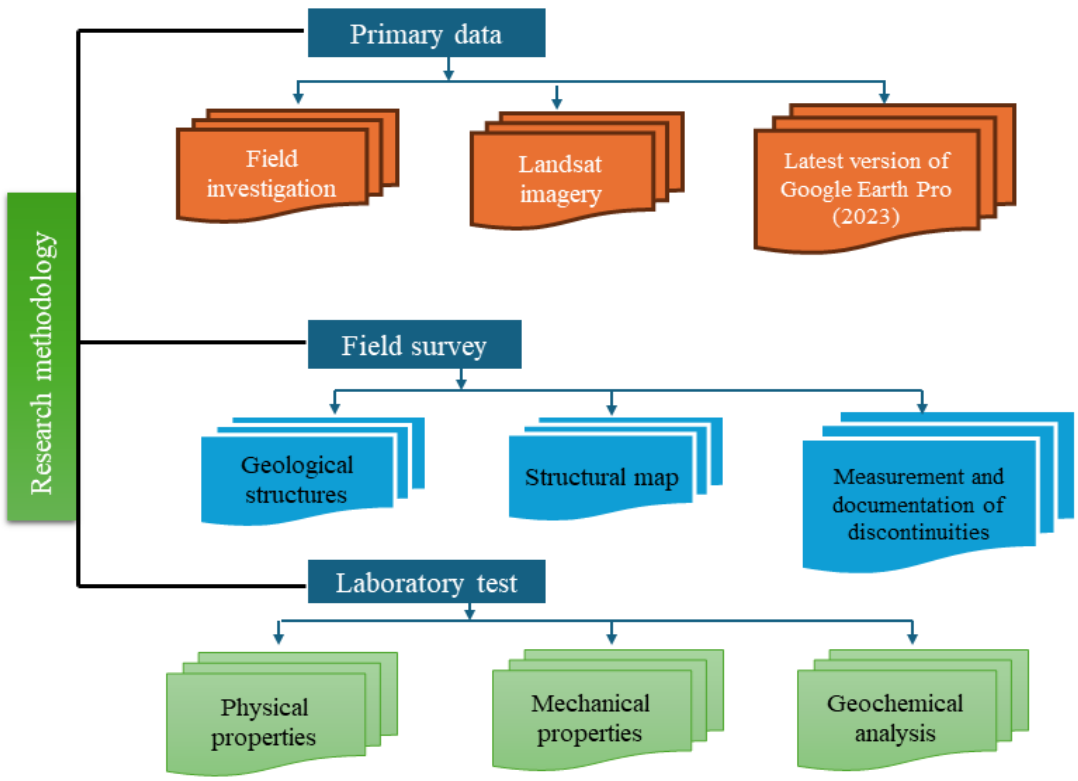


Figure 2. Flow chart of the study methodology

3. Geology of the area

The Ethiopian basement rocks can be classified into two major blocks that have been delineated based on geochronological, thermochronological, geochemical, and lithotectonic data[3,19,20]. The first major block is the gneissic and magmatic terrain, mainly composed of the Lower and Middle Complex. This block is closely related to the Mozambique Belt and has a combination of gneissic and magmatic rock formations [21]. The second major block corresponds to the low-grade volcanic-sedimentary terrain, comprising the rocks of the Upper Complex. This block correlates with the Arabian Nubian Shield and presents a collection of volcanic sedimentary rocks that have undergone low-grade metamorphism [22]. The geology of northern Ethiopia specifically belongs to the Neoproterozoic Pan-African Arabian Nubian Shield. This region is characterized by the presence of low-grade metavolcanic-sedimentary rock assemblages, mainly found within the Upper Complex. Within this complex, two distinct groups can be identified: The Tsaliet group and the Tambien group [23,24]. These groups are indicative of the geological formations and processes that have shaped the northern Ethiopian landscape.

The Dichinama area, located within the Upper Complex, is an integral part of both the Tsaliet and Tambien groups. This region exhibits a diverse range of lithological units, prominently represented by metavolcanic and metasedimentary rocks such as schist, phyllite, and marble. As shown in Figure 3 and 4, these lithological units form parallel narrow ridges that create distinct outcrops in the area. The marble rock formations found at Dichinama exhibit a striking array of colors due to the presence of impurities and intercalation with shale and metavolcanic units. This combination of different rock types contributes to the visual variation and unique characteristics of the marble formations.

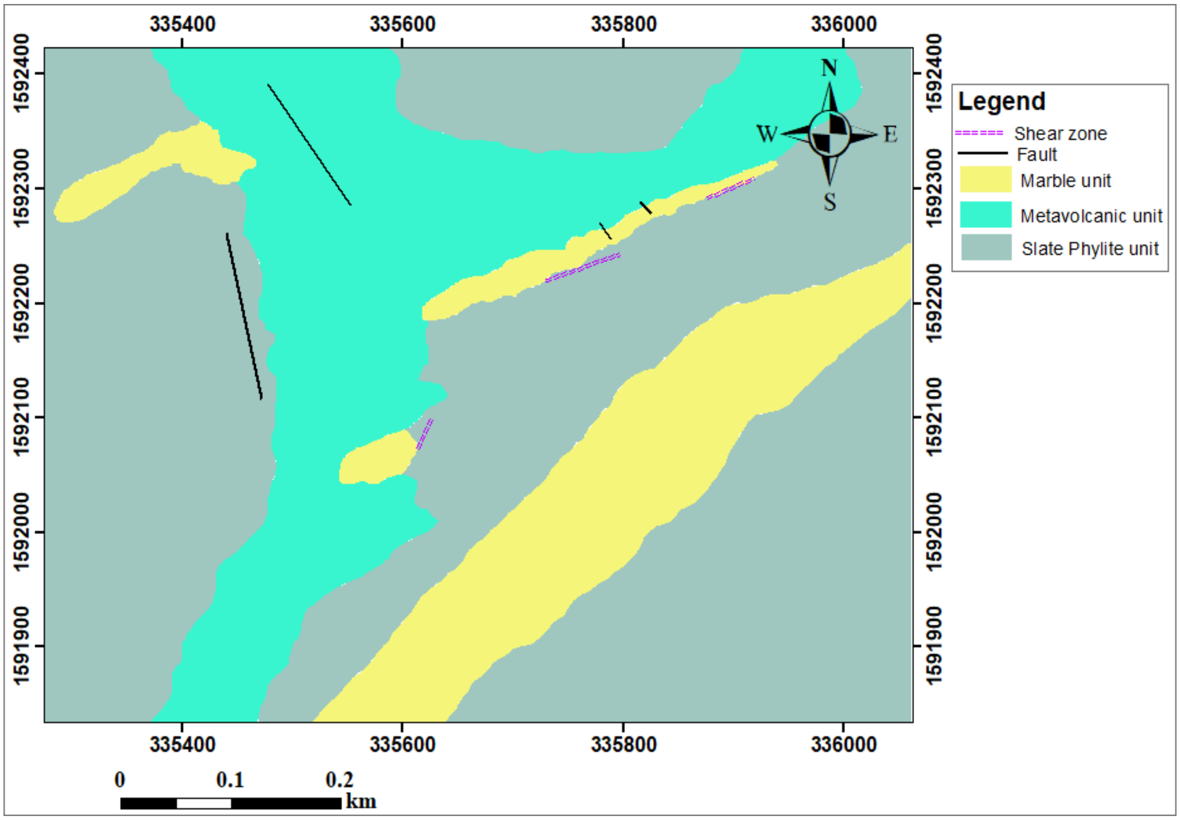


Figure 3. Geological map of the study area

The geological structures in the area are mainly composed of joints with different orientations as documented in Table 1. These joints play a significant role in shaping the physical and mechanical properties of the rocks, particularly due to their close spacing, which ranges from 0.18 to 6 meters. The proximity of these joints influences properties such as rock strength, permeability, and fracture patterns, thus affecting the overall behavior and stability of the rock formations in the Dichinama area.

Figure 4. A) The first arrow indicates massive marble on the 3rd and 4th benches; B) The second arrow indicates closely spaced, jointed marble on the 1st and 2nd benches, and highly weathered.

Table 1. Structural data showing orientations and spacing of joints

Stations	Easting	Northing	Joint	Dip direction	Dip amount	Spacing(m)	Aperture	Infilling material
S1	341125	1586397	J-1	130	55	0.6-1.5	1cm	None
			J-2	70	50	0.4-0.75	1.2m	None
S2	341083	1586359	J-1	220	30	0.94-2.4		Quartz
			J-2	230	55	0.23-0.63	2cm	None
S3	338651	1590438	J-1	120	50	0.86-6	5cm	Calcite
			J-2	90	88	0.2-4	<1cm	Clay
S4	338644	1590442	J-1	150	60	0.35-2.1	2cm	None
			J-2	90	90	1-2.5	1cm	None
S5	343509	1589065	J-1	300	65	0.18-2	1cm	Clay
			J-2	30	20	1-2	0.2-1m	None
S6	343450	1589101	J-1	290	50	0.3-2	3cm	None
			J-2	220	67	2-3	0.1-.5m	None
S7	343817	1589245	J-1	80	56	1-3	2cm	None
			J-2	90	90	0.3-1	1cm	None

4. Results and discussion

When evaluating the quality of marble deposits for dimension stone purposes, several key parameters come into play. Physical and mechanical properties, geochemistry, and geological factors are among the most important considerations [4,10,25]. The physical properties of marble include characteristics such as color, texture and density [26]. These properties can vary due to the presence of impurities within the marble. Variations in texture and mineralogy influenced by impurities can significantly affect the physical and mechanical properties of the marble [27]. For example, the presence of certain impurities can affect the hardness, strength, and durability of the marble, which are critical factors in determining its suitability for use as dimension stone.

Geochemical properties also play a crucial role in assessing the quality of marble deposits. The geochemical composition of the marble can provide insight into its chemical stability, resistance to weathering, and susceptibility to acid corrosion [26,28–30]. These factors are important considerations in determining whether the marble can withstand external environmental conditions and maintain its aesthetic appeal over time. In addition, geological factors are considered when evaluating the quality of marble deposits. The geological environment in which the marble was formed can influence its structural integrity, fracture patterns, and overall suitability for extraction and processing. Understanding the geological context helps to assess the potential challenges and opportunities associated with extracting and using the marble for dimension stone purposes.

4.1. Physical and mechanical property of marble

The dimension stone, marble shows significant variation in physical properties (density, water absorption) and mechanical properties (uniaxial compressive strength, flexural strength, and abrasion resistance) and the results are in Table 2 compared with ASTM standard.

Table 2. Laboratory test results of the physical and mechanical properties

Site name		Ela- wedizare Sample code of Ela- wedizare			Dugub Sample code of Dugub			Lidge Sample code of Lidge		
Physical and Mechanical property tests	ASTM Min. requirement (ASTM 503C,2008)	EW_1	EW_2	EW_3	D_1	D_2	D_3	L_1	L_2	L_3
Compressive Strength (Mpa)	52	48.4	61.2	52.1	73	74.5	74.2	29.6	61.2	50.5
Flexural strength (Mpa)	7	27.2	40.2	23.8	7	7.7	7.2	41.5	52.8	45.1
Abrasion Resistance	10	16.3	17.2	16.6	7.8	8.8	8.3	9.5	13	9.2
Density (Kg/m^3)	2595	2490	2438	2474	2447	2440	2453	2257	2562	2501
Water Absorption (%)	0.2	0.47	0.4	0.93	0.35	0.32	0.36	0.17	0.12	0.41

4.1.1. Uniaxial compressive strength (UCS)

The uniaxial compressive strength (UCS) values of marble samples from different locations in Dichinama show a range of values. For Ela-wedizare, the UCS values vary from 48.4 to 61.2 MPa, for Dugub from 73 to 74.5 MPa, and for Lidge from 29.6 to 61.2 MPa. However, it is important to note that one sample from Ela-wedizare and two samples from the Lidge site do not meet the minimum UCS requirement specified in ASTM 503C (2008), as shown in Table 2 and Figure 5. This variation in UCS values can be attributed to two main factors. First, the presence of thin intercalations of shale and phyllite within the marble act as impurities that affect its strength. Secondly, localized shear effects and the development of joints as part of the structural evolution of the deposit contribute to the variation in UCS values.

The non-uniform nature of these variations appears to be responsible for a decrease in UCS, particularly in samples EW1, L1, and L3. Compared to other marble deposits in Ethiopia, the Dichinama marble deposits exhibit lower quality in terms of UCS. For example, the UCS values for the Daleti marble deposit in the Welega region range from 76.8 to 156 MPa [6,31,32], which is significantly higher than those observed in the Dichinama deposit. The difference in UCS values between the deposits can be attributed to several factors. The Daleti marble has undergone a higher degree of metamorphism, resulting in a stronger rock with fewer impurities. In addition, the greater density of joints in the Daleti marble contributes to its higher UCS values compared to the Dichinama marble. Based on the UCS values, the quality of Dichinama marble is considered low for use as a dimension stone. The lower strength and the presence of impurities make it less suitable for applications requiring high durability and load-bearing capacity.

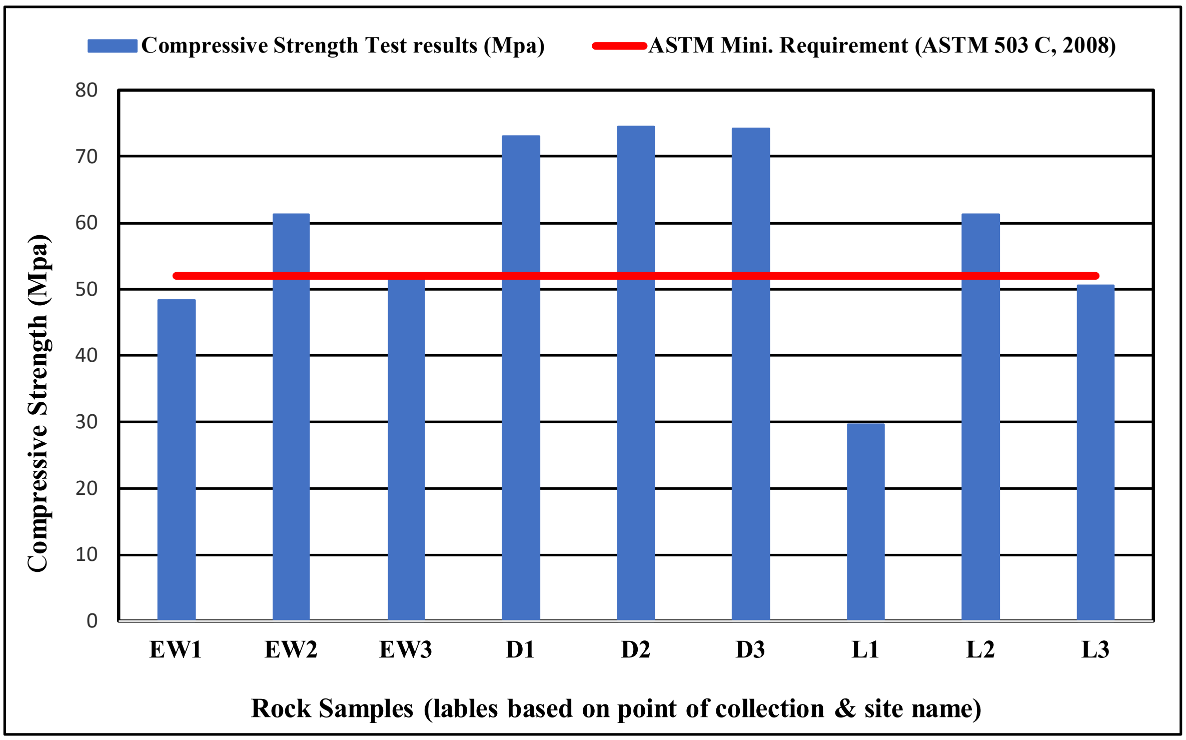


Figure 5. Uniaxial compressive strength test results

4.1.2. Flexural strength

Flexural strength is a measure of the tensile strength induced by bending in rocks. The flexural strength of rocks generally increases as water absorption decreases, assuming the same grain size. In the case of Dichinama marble, the flexural strength values show variations between different quarry sites [33,34]. At the Ela-wedizare quarry site, the flexural strength of Dichinama marble ranges from 23.8 to 40.2 MPa. At the Dugub site, the values range from 7.0 to 7.7 MPa, while at Lidge they range from 41.5 to 52.8 MPa. These values are all higher than the minimum requirements specified in ASTM 503C (2008) for dimension stone, as shown in Table 2 and Figure 6. Comparing the flexural strength values between the sites, it can be observed that the marble from Ela-wedizare and Lidge has higher flexural strength compared to the marble from Dugub. This difference is due to two factors. First, the marble at Ela-wedizare and Lidge has a fine grain size, which contributes to its higher flexural strength. Secondly, the presence of large joint spacing at these sites increases the overall strength of the marble. In conclusion, the flexural strength values of Dichinama marble meet the minimum requirements for dimension stone according to ASTM 503C (2008). The marble from the Ela-wedizare and Lidge sites exhibits relatively high flexural strength due to its fine grain size and the presence of wide joint spacing.

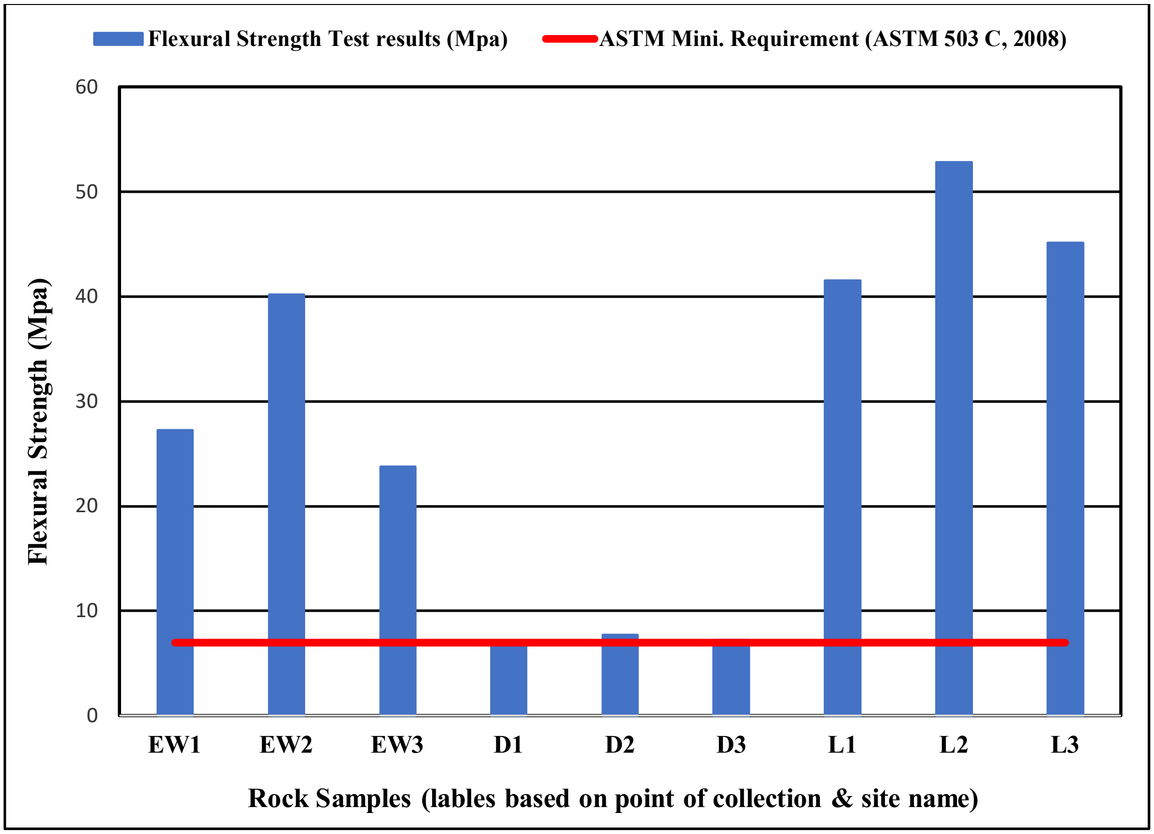


Figure 6. Flexural strength test results

4.1.3. Abrasion resistance

The range of abrasion resistance values differs among the Ela-wedizare, Dugub, and Lidge sites, as shown in Table 2 and Figure 7. Specifically, for the Ela-wedizare marble, the values range from 16.3 to 17.2. For Dugub marble, the range is from 7.8 to 8.8, while for Lidge marble it is from 9.2 to 13. These values are compared to the minimum acceptable value specified in the ASTM C503 (2008) standard. Among these sites, only the abrasion resistance values for the Ela-Wedizare marble meet the required standard. However, the Dugub marble does not meet the required standard, while the Lidge marble only partially meets the standard. This variation in abrasion resistance values can be attributed to the presence of tight joints and shearing, which are more pronounced at both the Dugub and Lidge sites. These factors negatively affect the overall abrasion resistance of the marble, resulting in lower values.

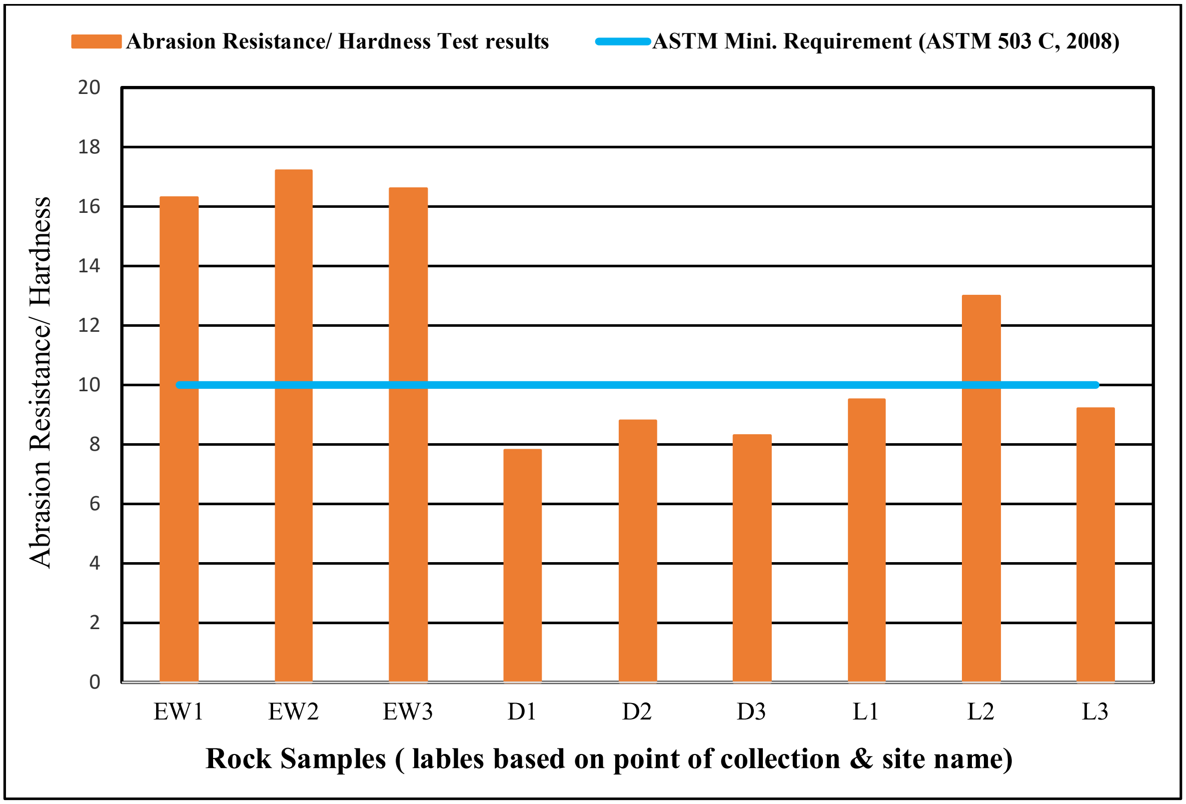


Figure 7. Abrasion resistance laboratory test results

4.1.4. Water absorption

Water absorption is an important indicator of rock durability (Daka et al., 2009). The water absorption values vary for different types of marble, especially for Ela-wedizare, Dugub and Lidge, as shown in Table 2 and Figure 8. For Ela-wedizare marble, the water absorption values range from 0.41 to 0.93%. For Dugub marble, the range is from 0.32 to 0.36%, while for Lidge marble it is from 0.12 to 0.41%. These values are compared with the maximum value recommended by the ASTM 503C (2008) standard for the use of marble in dimension stone, which is 0.2%. Based on this comparison, it is clear that both Ela-wedizare and Dugub marble do not meet the recommended value for water absorption, making them unacceptable in terms of water absorption. However, the Lidge marble is partially acceptable as one sample meets the criteria. The variation in water absorption values and the higher values can be attributed to factors such as fracturing, shearing and weathering, which increase the water absorption capacity of the marble. Compared to other marble deposits in Ethiopia, such as Daleti, which has a water absorption range of 0.12% to 0.18% [31], the water absorption value of Dichinama marble falls within the unacceptable range, indicating that it is not durable.

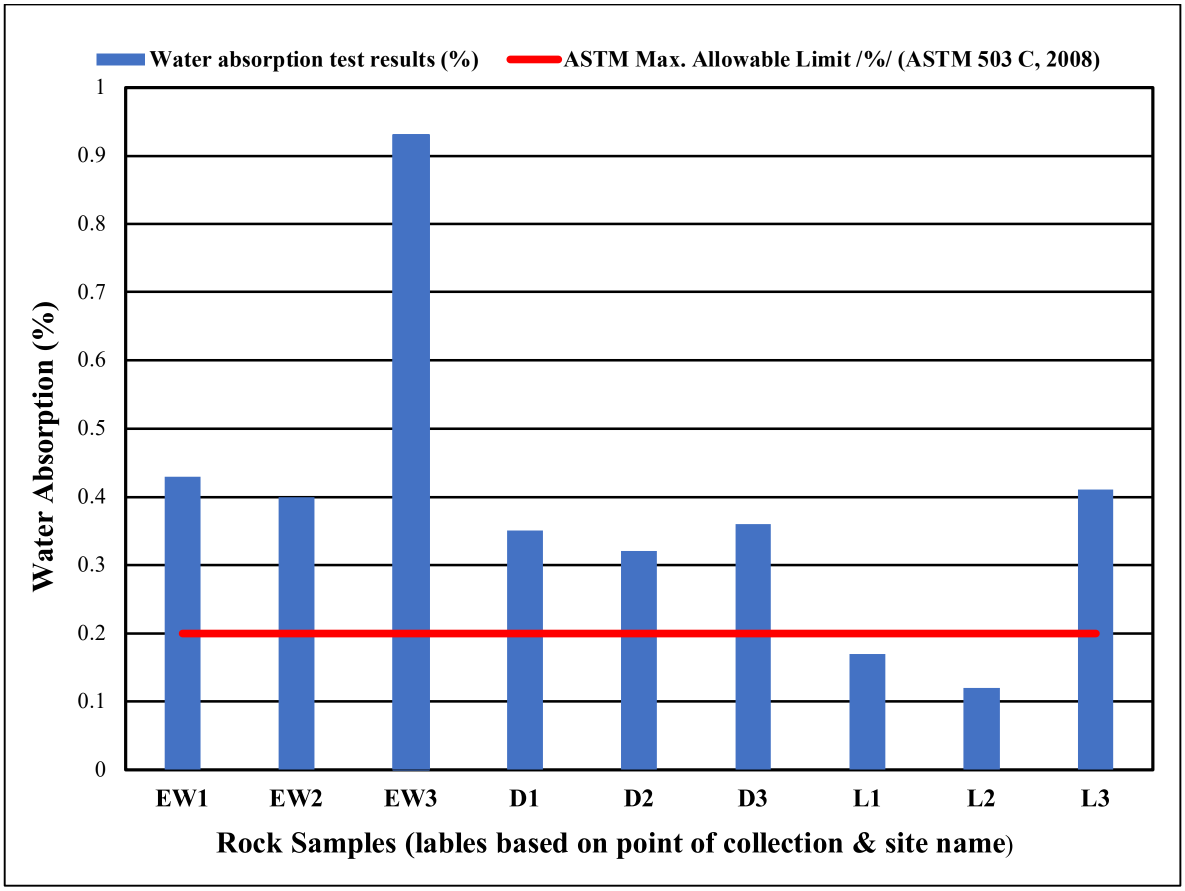


Figure 8. Water absorption laboratory test results

4.1.5. Density

According to the ASTM 503C (2008) standard, the minimum density required for marble to be used as a dimension stone is 2595 kg/m^3. However, in the Dichinama area, the density values for the Ela-wedizare marble range from 2438 to 2490 kg/m^3, for the Dugub marble from 2440 to 2453 kg/m^3 and the Lidge marble from 2257 to 2562 kg/m^3. These values indicate that all density values are below the required standard. The Lidge marble has significantly lower density values due to the presence of impurities, especially phyllitic/schistose rocks, and the effect of shearing along the contact with the schistose country rocks. These factors contribute to a decrease in the overall density of the Lidge marble. In comparison, the density values of the Daleti marble in southern Ethiopia, which range from 2720 to 2900 kg/m^3 [31], are much higher than those of the Dichinama marble. This clear difference in density values between Dichinama and Daleti marble indicates the effect of impurities on the density of Dichinama marble. Figure 9 shows the density graph of the study.

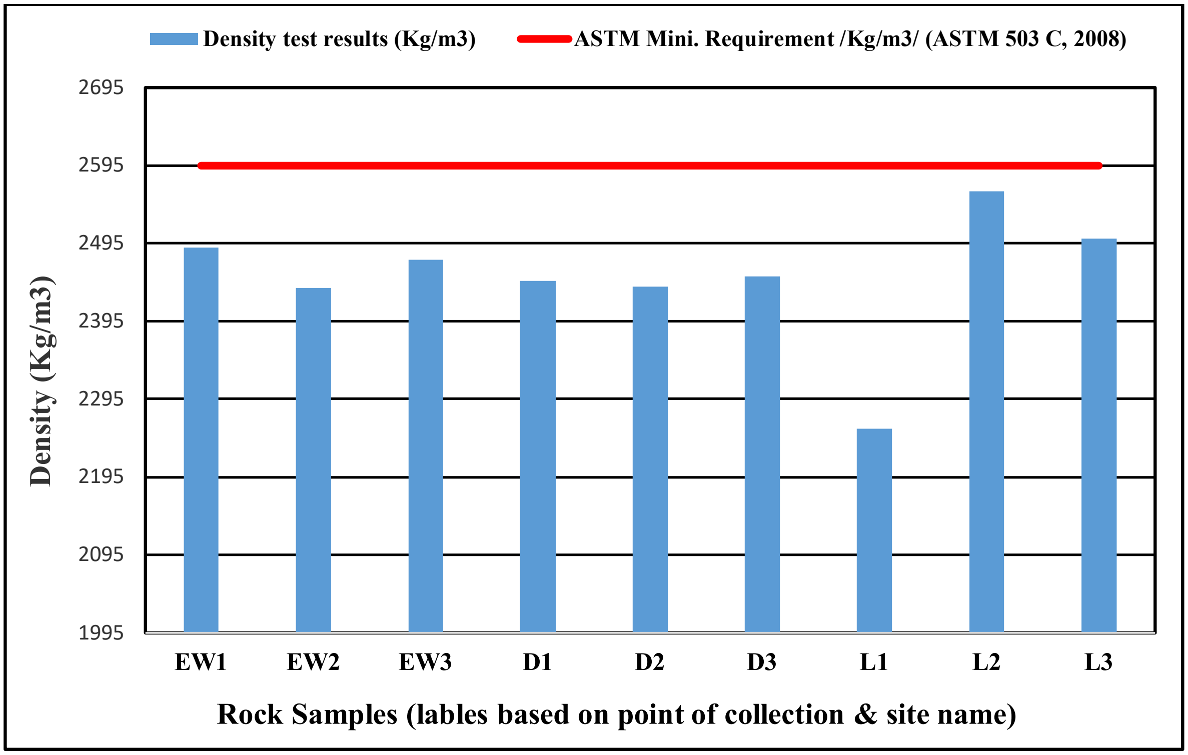


Figure 9. Density laboratory test results

4.1.6. Geochemistry of Dichinama marble

Lipmann (1973) emphasizes the importance of evaluating the chemical purity of marble when considering its suitability for specific applications, including dimension stone [33–36]. The quality evaluation of marble is based on the presence of major and minor oxides such as d minor oxides such as CaO, Al_2O_3, Fe_2O_3, SiO_2, MgO, Na_2O, K2O, MnO, and P_2O_5 [30,33,37–39]. Pure carbonates have a total carbonate content of 70% or more by weight in the form of $CaCO_3$ or $CaMg(CO_3)_2$, while rocks with carbonate values between 40% and 70% by weight are considered impure carbonates. Other oxides such as Al_2O_3, Fe_2O_3, SiO_2, MgO, Na_2O, K_2O, MnO, and P_2O_5 are typically present as impurities in marble and usually account for less than 1% by weight. To determine the percentage of $CaCO_3$ in marble, the percentage weight of CaO is multiplied by a factor of 1.78, while the percentage of $MgCO_3$ is obtained by multiplying the percentage weight of MgO by 2.09. Marble is a metamorphic rock primarily composed of calcite or dolomite. It is classified into calcitic and dolomitic types based on their respective contents of calcium oxide (CaO) and magnesium oxide (MgO) [42]. The calcitic marble, CaO values range from 50% to 56% by weight, loss on ignition (LOI) between 40% and 44% by weight, and MgO content below 15% by weight. The range of values for CaO and other oxides as a criterion for determining good quality marble for use as dimension stone [40,41]. Accordingly, CaO should be between 50% and 56% by weight, LOI between 40% and 44% by weight, and other oxides (Al_2O_3, Fe_2O_3, SiO_2, MgO, Na_2O, K_2O, MnO, P_2O_5) considered as impurities should be below 1% by weight. The results obtained for 10 marble samples from the Dichinama area are presented in Table 3.

Table 3. Geochemical analysis of marble samples from 3 different sites (in wt%)

Site name	Sample code	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O	MnO	P_2O_5	LOI	Sum
Ela wedizare	EW1	8.79	0.12	0.52	46.8	0.34	<0.01	<0.01	0.18	0.08	39.8	96.65
	EW2	7.89	0.17	0.32	52	0.35	<0.01	0.02	0.11	0.05	36.8	97.72
	EW3	7.89	0.97	0.46	51.5	0.37	0.04	0.16	0.08	<0.01	39.9	101.37
Lidge	L1	2.95	0.32	0.37	53.1	1.22	<0.01	0.09	0.24	<0.01	42	100.29
	L2	0.46	0.22	0.15	56.4	0.61	<0.01	0.02	0.11	<0.01	43.3	101.27
	L3	4.46	1.20	0.67	51.2	1.12	<0.01	0.30	0.12	0.02	41	100.09
Dugub	D1	1.77	0.28	0.20	54.6	0.28	<0.01	0.01	0.06	0.06	42.9	100.16
	D2	2.81	0.24	0.21	54	0.18	<0.01	<0.01	0.01	0.10	42.4	99.95
	D3	1.60	0.19	0.15	54.9	0.25	<0.01	0.01	0.06	0.02	42.7	99.88
	D4	4.75	0.88	0.46	52.5	0.48	0.08	0.05	0.11	0.06	41.2	100.57

SiO_2: Silicon Dioxide, Al_2O_3: Aluminum Oxide, Fe_2O_3: Iron(III) Oxide (Ferric Oxide), CaO: Calcium Oxide, MgO: Magnesium Oxide, Na_2O: Sodium Oxide, K_2O: Potassium Oxide, MnO: Manganese(II) Oxide, P_2O_5: Phosphorus Pentoxide, and LOI: Loss on Ignition

The average content of $CaCO_3$ in the Dichinama marble is calculated to be 93.81% by weight, while the average content of $MgCO_3$ is 1.09% by weight. These values are obtained by multiplying the CaO and MgO values by the factors 1.78 and 2.09, respectively. In Ela-wedizare, the CaO content of the marble varies from 46.8% to 52% by weight, the LOI from 36.8% to 39.9% by weight, the SiO_2 content from 7.89% to 8.79% by weight, and the Al_2O_3 content from 0.12% to 0.97% by weight. The other oxides (Fe_2O_3, SiO_2, MgO, Na_2O, K_2O, MnO, and P_2O_5) present in the marble are less than 1% by weight, indicating their presence as impurities. For the Lidge site, the values for CaO range from 51.2% to 56.4% by weight, LOI ranges from 41% to 43.3% by weight, SiO_2 content ranges from 0.46% to 4.46% by weight, and Al_2O_3 content ranges from 0.22% to 1.2% by weight. Similar to Ela-Wedizare, the other oxides (Fe_2O_3, MgO, Na_2O, K_2O, MnO, P_2O_5) are present in the marble below 1% by weight. Similarly, for the Dugub site, CaO values range from 52.5% to 54% by weight, LOI from 41.2% to 42.4% by weight, SiO_2 content from 1.6% to 4.75% by weight, and Al_2O_3 content from 0.19% to 0.88% by weight. The other oxides in this case are also less than 1% by weight. Based on the CaO values, most of the samples from the three sites at Dichinama are considered to be of calcitic type according to the classification of Goldschmidt (1955) [42]. The majority of samples from all three sites meet the criterion for LOI, with values above 40% by weight, except for one sample from Ela-wedizare.

However, a major problem arises concerning the SiO_2 content, where most of the samples show values above 1% by weight, and one sample from Ela-wedizare even reaches 8.79% by weight. Similarly, a few samples approach 1% by weight in terms of Al_2O_3 content. The remaining oxides are less than 1% by weight. The remaining oxides are less than 1% by weight. In terms of CaO and SiO_2 content, the quality of the marble from Dugub and Lidge is relatively better than that from Ela-wedizare. Compared to Daleti marble in western Ethiopia, where CaO values range from 51.4% to 54.6% by weight, LOI ranges from 41.6% to 42.8% by weight, and other oxides (SiO_2, Al_2O_3, Fe_2O_3, MgO, Na_2O, K_2O, MnO, and P_2O_5) are below 1% by weight[31], Dichinama marble is of lower quality.

Figure 10 shows Pearson correlation plot which ranges from -1 to 1, this is vital to understand the correlation of each element. We can use this method when we think the variables are linear. Based on this Sio2, Fe203, Al203, Cao, and LoI are positively correlated with a range of 0.64 to 0.71 value.

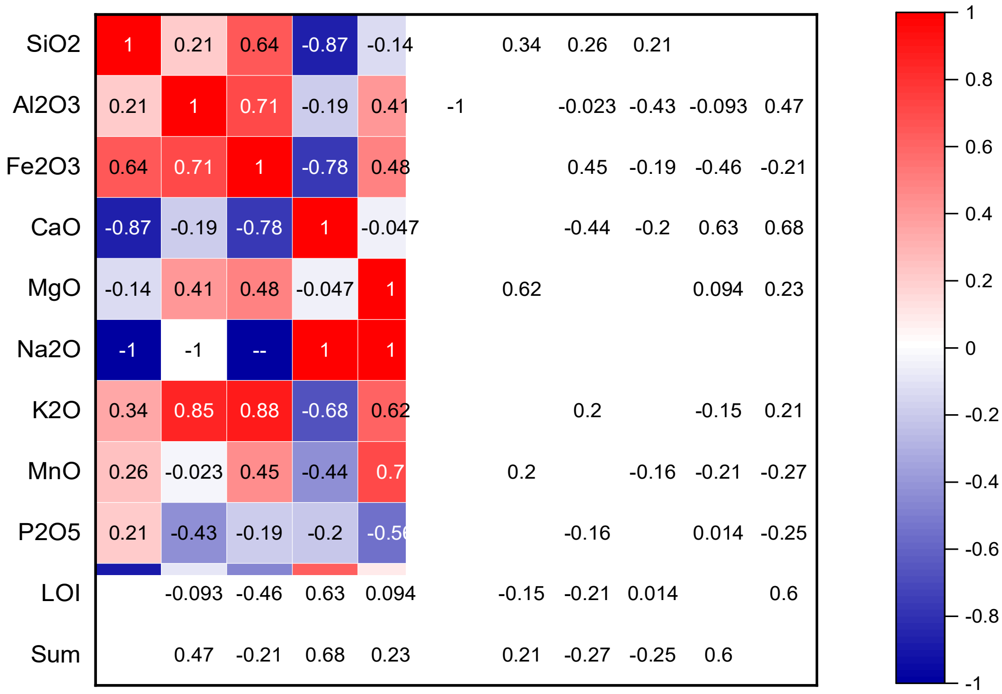


Figure 10. Pearson correlation plot of all elements in different samples

Box plots, also known as box-and-whisker plots, are valuable tools in statistics for visually representing the distribution and central tendency of a dataset. The box plot displays key summary statistics, including the median, quartiles, and potential outliers. The range from the 25th percentile (Q1) to the 75th percentile (Q3) is depicted within the box portion of the plot. In this study the box plots show the quartile at 25% and 75% with the median value of each variable. Figure 11 illustrates the violin plot of this study.

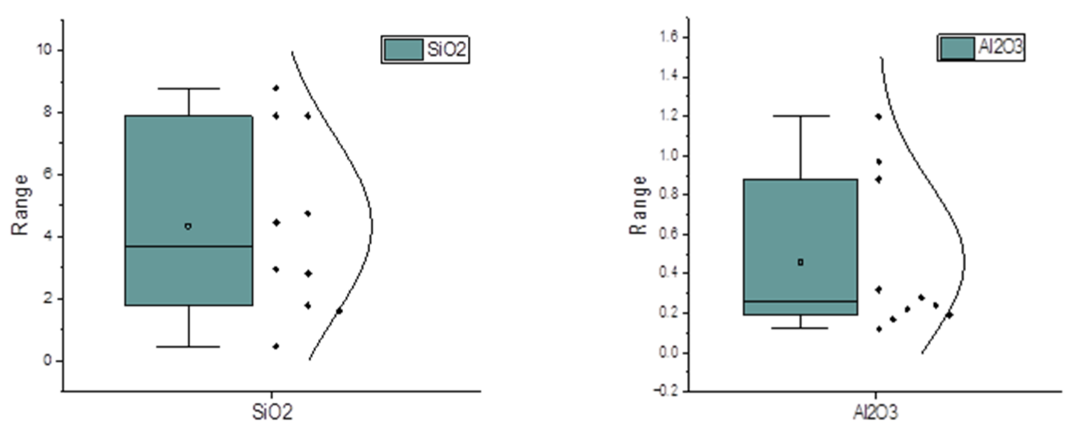
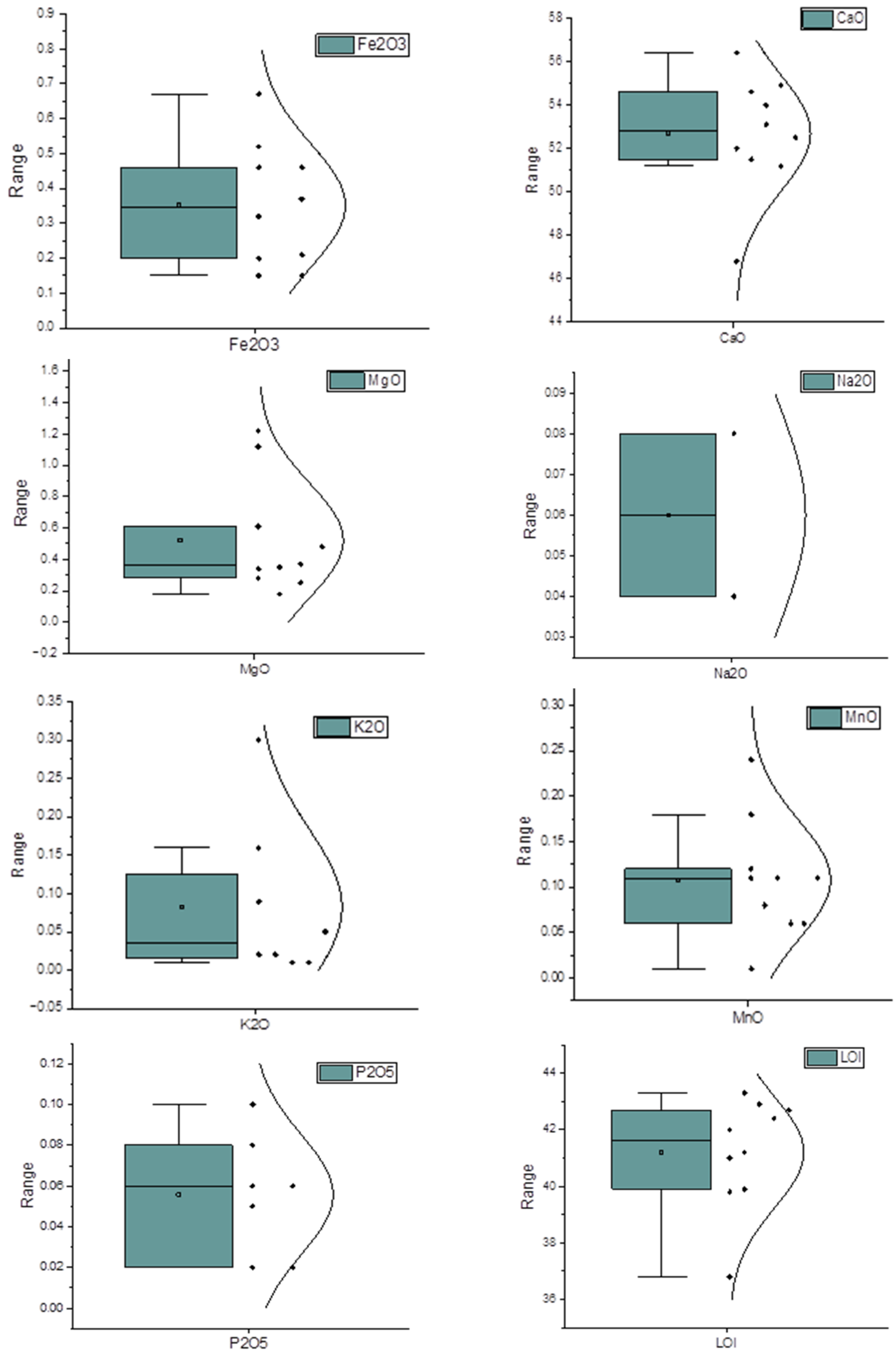


Figure 11. violin whiskey plots of all elements



Continuous of Figure 11. violin whiskey plots of all elements

Utilizing 3D map plots by incorporating all variables like the different elements in this study is vital to understand the interaction in 3D scatter. These visualizations provide simultaneous insights into multiple dimensions, facilitating a deeper grasp of the relationships between the elements and each sample code. Figure 12 depicts the 3D map plot of the elements in this study.

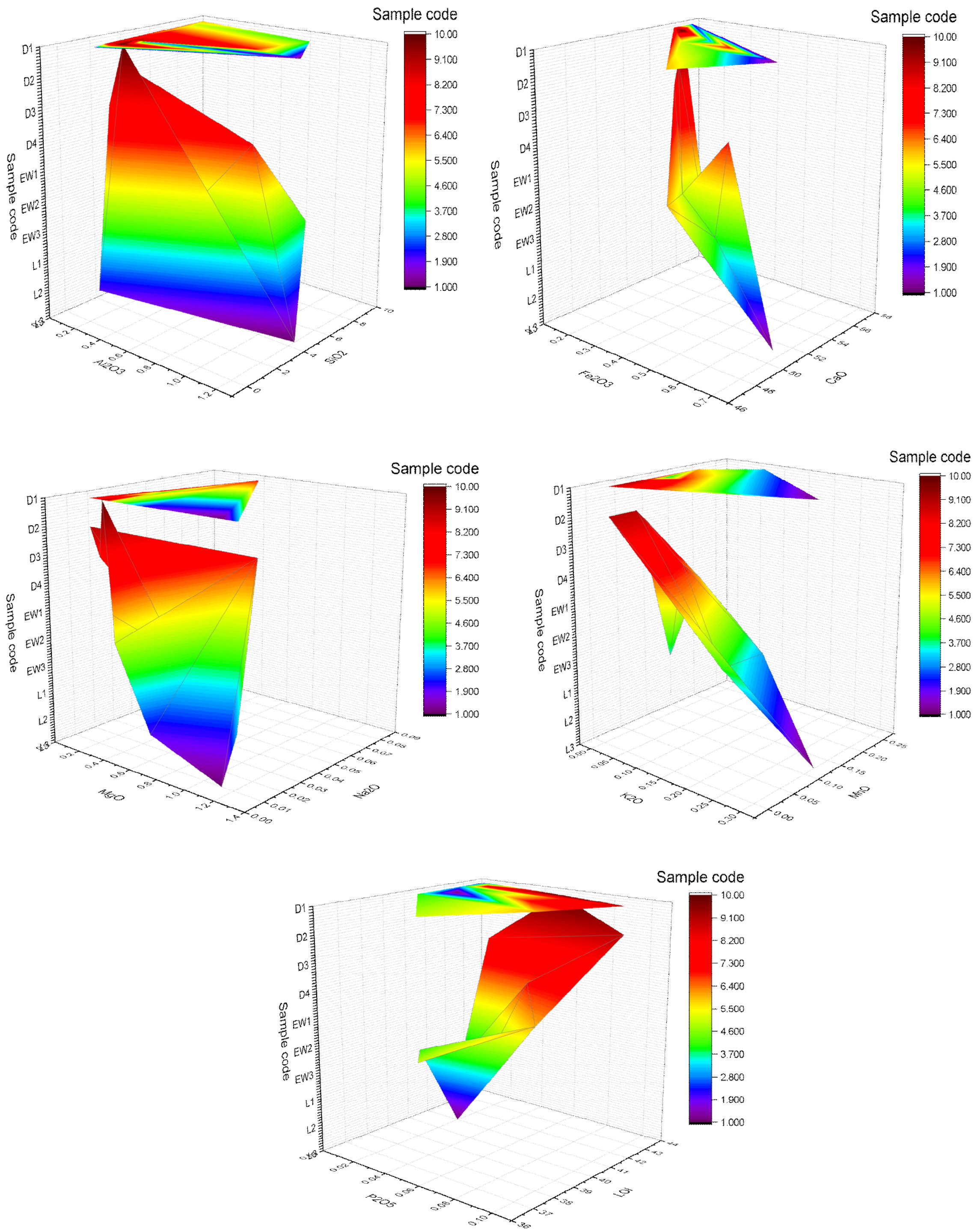


Figure 12. 3D surface plot of sample code with each two elements

5. Conclusions

The Dichinama area in northern Ethiopia is a potential source of dimension stone, but the quality of the marble has been a major challenge for mining operations. This research aims to evaluate the quality of dimension stone by conducting a comprehensive study involving geological mapping, geotechnical testing, and geochemical analysis. The physical, mechanical, and geochemical data obtained from the marble samples collected from the three sites were compared to the criteria established by the ASTM standards. However, when compared to the standards established for the use of marble as a dimension stone, the marble deposit has significant limitations. Most of the physical and mechanical properties of the marble do not meet the ASTM standard criteria. Most of the flexural strength values meet only the lower end of the required range. Properties such as UCS (unconfined compressive strength), abrasion resistance, density and water absorption have values well below the required criteria. Based on the analysis this study concludes the following points:

- The presence of three sets of joints dipping in different directions (NW-SE, E-W, NE-SW) with sub-vertical to vertical dips, along with variations in spacing and aperture, greatly affect the production of marble blocks, as well as the recovery and overall quality of the marble. In particular, the closely spaced joints pose significant challenges in the production of marble blocks. In addition, shear zones along the contacts further affect the strength and quality of the marble.
- From a geochemical point of view, the results indicate that the marble deposit is mainly composed of pure carbonate and belongs to the calcitic type with a range of 83.3% to 98% calcite content. The dolomite content is relatively low, ranging from 0.37% to 2.55%. However, the presence of silica impurities causes difficulties during the polishing process. To improve the recovery and quality of the marble, advanced methods such as sealing the joints and implementing improved mine design techniques can be used.
- The study greatly benefits the research community by providing comprehensive geological and geochemical information on marble from Northern Ethiopia, which enhances the understanding of its formation, composition, and characteristics. This research is essential for civil and mining engineering and construction, offering valuable insights into the marble's mechanical properties and potential applications. By contributing to the global geological data pool and improving analytical techniques, the study enables comparative research and promotes international academic collaboration, thereby advancing geological knowledge on both regional and global scales.
- The main limitations of the current study are its geographical focus on Dichinama marble limits generalizability, and a potentially small or non-representative sample size may affect reliability. Findings are based on temporal conditions, which can change over time, and are influenced by the accuracy of the analytical techniques and equipment used. Data interpretation can be subjective, and external factors like climate and human activities might not be fully accounted.

Reference

[1] Wassie, S. B. (2020). Natural resource degradation tendencies in Ethiopia: a review. *Environmental Systems Research*, *9(1),* 1–29.

[2] Duan, Z. P., Jiang, S. Y., Su, H. M., Zhu, X. Y., Zou, T., & Cheng, X. Y. (2021a). Geochronological and geochemical investigations of the granites from the giant Shihuiyao Rb-(Nb-Ta-Be-Li) deposit, Inner Mongolia: Implications for magma source, magmatic evolution, and rare metal mineralization. *Lithos, 400–401*(April), 106415.

[3] Khan, J., Yao, H. Z., Zhao, J. H., Tahir, A., Chen, K. X., Wang, J. X., Song, F., Xu, J. Y., & Shah, I. (2024). Geochronology, geochemistry, and tectonic setting of the Neoproterozoic magmatic rocks in Pan-African basement, West Ethiopia. *Ore Geology Reviews*, *164*, 105858.

[4] Bukhari, S. A. A., Basharat, M., Janjuhah, H. T., Mughal, M. S., Goher, A., Kontakiotis, G., & Vasilatos, C. (2023). Petrography and Geochemistry of Gahirat Marble in Relation to Geotechnical Investigation: Implications for Dimension Stone, Chitral, Northwest Pakistan. *Applied Sciences (Switzerland)*, *13(3).*

[5] Hailemariam, Y. K., Fissha, Y., & Gebretsadik, A. (2020). Determining the Recovery Rate of Dichinama Marble (Lidge Mariam) Quarry Site At Northwestern Zone, Tigrai, Ethiopia. *International Journal of Engineering Applied Sciences and Technology, 5(5),* 166–183.

[6] Seelow, A. (2017). Exploring Natural Stone and Building a National Identity: The Geological Exploration of Natural Stone Deposits in the Nordic Countries and the Development of a National-Romantic Architecture. *Arts, 6(4),* 6.

[7] Nasuti, A., & Roberts, D. (2023). Using geophysics to follow and model the Precambrian basement terranes beneath the Caledonian nappes in Finnmark, northern Norway: A case study. *Precambrian Research*, *384*, 106934.

[8] Asefa, M., Cao, M., He, Y., Mekonnen, E., Song, X., & Yang, J. (2020). Ethiopian vegetation types,

climate and topography. *Plant Diversity, 42(4),* 302–311.

[9] Walle, H., Zewde, S., & Heldal, T. O. M. (2000). Building stone of central and southern Ethiopia : deposits and resource potential. *Building*, 175–182.

[10] Samarakoon, K. G. A. U., Chaminda, S. P., Jayawardena, C. L., Dassanayake, A. B. N., Kondage, Y. S., & Kannangara, K. A. T. T. (2023). A Review of Dimension Stone Extraction Methods. *Mining, 3(3),* 516–531.

[11] Revuelta, M. B. (2021). Chapter 6: Cement. In *Construction Materials: Geology, Production and Applications*.

[12] Macedo, D., Mori Junior, R., & Pimentel Mizusaki, A. M. (2017). Sustainability strategies for dimension stones industry based on Northwest region of Espírito Santo State, Brazil. *Resources Policy*, *52*, 207–216.

[13] Abebe, A. H., & Gatisso, M. M. (2023). The role of indigenous knowledge regarding the history and building of the Kawo/King Amado Kella defensive wall in Wolaita, Ethiopia, including its significance and intended use. *Heliyon, 9(11),* e20990.

[14] Baker, R. E., Mahmud, A. S., Miller, I. F., Rajeev, M., Rasambainarivo, F., Rice, B. L., Takahashi, S., Tatem, A. J., Wagner, C. E., Wang, L. F., Wesolowski, A., & Metcalf, C. J. E. (2022). Infectious disease in an era of global change. *Nature Reviews Microbiology, 20(4),* 193–205.

[15] Okada, K. (2021). A Historical Overview of the Past Three Decades of Mineral Exploration Technology. *Natural Resources Research, 30(4),* 2839–2860.

[16] Abbate, E., Bruni, P., & Sagri, M. (2015). Geology of Ethiopia: A Review and Geomorphological Perspectives. In *World Geomorphological Landscapes* (Issue March 2015). https://doi.org /10.1007/978-94-017-8026-1_2

[17]. Zhang, Y., Zhang, D., Liu, K., Mo, X., Wang, S., Zhao, Z., He, X., & Yu, T. (2023). Geological Significance of Neoproterozoic Intrusive Rocks in the South Section of the Ailaoshan Orogenic Belt, SW China: Insights from Petrology, Geochemistry, and Geochronology. *Minerals*, *13*(3).

[18]. Song, D., Xiao, W., Collins, A. S., Glorie, S., Han, C., & Li, Y. (2017). New chronological constrains on the tectonic affinity of the Alxa Block, NW China. *Precambrian Research*, *299*, 230–243.

[19]. Qi, L., Xu, Y., Cawood, P. A., Zhang, H., Zhang, Z., & Du, Y. (2021). Implications for supercontinent reconstructions of mid-late Neoproterozoic volcanic – Sedimentary rocks from the Cathaysia Block, South China. *Precambrian Research*, *354*, 106056.

[20]. Tadesse, S., Milesi, J. P., & Deschamps, Y. (2003). Geology and mineral potential of Ethiopia: A note on geology and mineral map of Ethiopia. *Journal of African Earth Sciences, 36(4),* 273–313.

[21]. Bedassa, G., Getaneh, W., & Hailu, B. (2019). Geochemical and mineralogical evidence for the supergene origin of kaolin deposits – Central Main Ethiopian Rift. *Journal of African Earth Sciences*, *149*, 143–153.

[22]. Hamilton, M. C., Nedza, J. A., Doody, P., Bates, M. E., Bauer, N. L., Voyadgis, D. E., & Fox-Lent, C. (2016). Web-based geospatial multiple criteria decision analysis using open software and standards. *International Journal of Geographical Information Science*, *30(8),* 1667–1686.

[23] Wahab, G. M. A., Gouda, M., & Ibrahim, G. (2019). Study of physical and mechanical properties for some of Eastern Desert dimension marble and granite utilized in building decoration. *Ain Shams Engineering Journal, 10(4),* 907–915.

[24]. Gacu, J. G., & Sim, A. A. M. (2022). Effect of marble microparticles as additive on the physical and mechanical properties of concrete mixes. *Materials Today: Proceedings, 65,* 1491–1497.

[25] Lindawati, L., Yuliza, N. F., & Irwansyah, I. (2020). Thermal Conductivity of Some Marble Stones Available in South Aceh District. *IOP Conference Series: Materials Science and Engineering*, *854*(1).

[26]. Wen, X., Zhou, J., Zheng, S., Yang, Z., Lu, Z., Jiang, X., Zhao, L., Yan, B., Yang, X., & Chen, T. (2024). Geochemical properties, heavy metals and soil microbial community during revegetation process in a production Pb-Zn tailings. *Journal of Hazardous Materials*, *463*, 132809.

[27]. Gaur, N., Sarkar, A., Dutta, D., Gogoi, B. J., Dubey, R., & Dwivedi, S. K. (2022). Evaluation of water quality index and geochemical characteristics of surfacewater from Tawang India. *Scientific Reports, 12(1),* 1–26.

[28]. Nasuti, A., & Roberts, D. (2023b). Using geophysics to follow and model the Precambrian basement terranes beneath the Caledonian nappes in Finnmark, northern Norway: A case study. *Precambrian Research, 384,* 106934.

[29]. Billi, P. (2015). World Geomorphological Landscapes Landscapes and Landforms of Ethiopia. In *Landscapes and Landforms of Ethiopia* .

[30] Yao, W., Li, X., Xia, K., & Hokka, M. (2021). Dynamic flexural failure of rocks under hydrostatic pressure: Laboratory test and theoretical modeling. *International Journal of Impact Engineering*, *156*, 103946. https://doi.org/10.1016/j.ijimpeng.2021.103946

[31] Cui, Y., Xu, C., Xue, L., Dong, J., & Jiang, T. (2023). Experimental study on the reasonable proportions of rock-like materials for water-induced

strength degradation in rock slope model test. *Scientific Reports*, *13(1),* 1–18.

[32] Salem, H. S. (2021). Evaluation of the Stone and Marble Industry in Palestine: environmental, geological, health, socioeconomic, cultural, and legal perspectives, in view of sustainable development. *Environmental Science and Pollution Research*, *28(22),* 28058–28080.

[33]. Al-Bashaireh, K. (2021). Ancient white marble trade and its provenance determination. *Journal of Archaeological Science: Reports, 35*, 102777.

[34]. Ozer, O., Yalcin, F., Tarinc, O. K., & Yalcin, M. G. (2020). Investigation of suitability of marbles to standards with inequality expressions and statistical approach using some physical and mechanical properties. *Journal of Inequalities and Applications*, *2020(1).*

[35]. Sariisik, G. (2012). Determining performance of marble finished products on their usage areas by a new impact-resistance test method. *Journal of Testing and Evaluation*, *40(6).*

[36]. Deyassa, G., Kebede, S., Ayenew, T., & Kidane, T. (2014). Crystalline basement aquifers of Ethiopia: Their genesis, classification and aquifer properties. *Journal of African Earth Sciences*, *100*, 191–202.

[37]. Lee, W. H., Lin, K. L., Chang, T. H., Ding, Y. C., & Cheng, T. W. (2020). Sustainable development and performance evaluation of marble-waste-based geopolymer concrete. *Polymers, 12(9).*

[38]. Jain, A. K., Jha, A. K., & Shivanshi. (2020). Geotechnical behaviour and micro-analyses of expansive soil amended with marble dust. *Soils and Foundations, 60(4),* 737–751.

[39]. Liu, J. bin, Zhang, Z. jian, & Leung, A. K. (2022). Mesoscopic and macroscopic investigation of a dolomitic marble subjected to thermal damage. *Scientific Reports, 12(1),* 1–16. https://doi.org/10.1038/s41598-022-19655-x

[40]. Li, F., Ma, X., & Lai, X. (2022). Petrography, geochemistry and genesis of dolomites in the upper Cambrian Sanshanzi Formation of the western Ordos Basin, northern China. *Journal of Asian Earth Sciences, 223,* 104980.

[41]. Ma, X., Huang, X., Zhang, H., Hu, X., & Feng, T. (2023). Effect of calcium aluminates on the structure evolution of CaO during the calcium looping process: A DFT study. *Chemical Engineering Journal, 452(P4),* 139552.

[42]. Priyadarshi Bopegedera, A. M. R. (2022). The Analysis of Dolomitic Marble: A Multifaceted Problem for General Chemistry Students. *Journal of Chemical Education, 99(2),* 964–974.

تجزیه و تحلیل ژئوتکنیکی و ژئوشیمیایی سنگ مرمر دیچیناما در شمال اتیوپی: بینش معدن

آسفا هیلسیلاسیه ولرگای[۱]، یوحاس برهانو آمار[۱]، اسملاش آبای هاگوس [۲]، کاسا اماره مسفین[۲]، هاگوس آبراهه [۳]، برکت گبرسیلاسیه[۳]، ناگزوارا رائو چیپوروپالی[۳]* و یوهالاشت فیشا[۳،۴]

۱- گروه زمین شناسی، دانشکده علوم طبیعی و محاسباتی.، دانشگاه آدیگرات، آدیگرات، اتیوپی

۲- علوم زمین مدرسه.، دانشگاه مکل، صندوق پستی، ۲۳۱، مکله، اتیوپی

۳- دانشکده معادن، موسسه فناوری اکسوم.، دانشگاه آکسوم، آکسوم، اتیوپی

۴- گروه علوم زمین، ژئوتکنولوژی و مهندسی مواد برای منابع، دانشکده تحصیلات تکمیلی علوم منابع بین المللی، دانشگاه آکیتا، آکیتا ۰۱۰-۸۵۲۰، ژاپن

ارسال ۲۰۲۴/۰۵/۰۹، پذیرش ۲۰۲۴/۰۷/۲۳

* نویسنده مسئول مکاتبات: nageswararaomines@aku.edu.et

چکیده:

منطقه Dichinama در شمال اتیوپی منبع بالقوه سنگ های بعدی است، اما کیفیت سنگ مرمر چالش بزرگی برای عملیات معدن بوده است. هدف این تحقیق ارزیابی کیفیت سنگ ابعادی با انجام یک مطالعه جامع شامل نقشه برداری زمین شناسی، آزمایش ژئوتکنیکی و آنالیز ژئوشیمیایی است. این مطالعه ۹ نمونه سنگ را از سه سایت معدنی فعال در منطقه Dichinama جمع‌آوری کرد و ویژگی‌هایی مانند چگالی، جذب آب، مقاومت فشاری، مقاومت خمشی و مقاومت سایشی را تجزیه و تحلیل کرد. علاوه بر این، ده نمونه برای تجزیه و تحلیل ژئوشیمیایی با تمرکز بر پارامترهایی مانند کلسیت، مقادیر LOI ،CaO، محتوای SiO2 و سایر غلظت‌های اکسید جمع‌آوری شد. آزمایش‌های ژئوتکنیکی نشان داد که خواص سنگ مرمر در منطقه دیچینما عمدتاً کلسیت است، با مقادیر مقاومت فشاری از ۲۹.۶ تا ۷۴.۵ مگاپاسکال، مقاومت خمشی از ۷ تا ۵۲.۵ مگاپاسکال، مقاومت سایشی از ۸.۳ تا ۱۷.۲، تراکم از ۲۵۲۵ کیلوگرم تا ۲۵۲۵ کیلوگرم. /مترمکعب و جذب آب از ۰.۱۲ تا ۰.۹۳.با این حال، اکثر این پارامترها کمتر از حداقل استاندارد‌های ASTM برای سنگ ابعاد مرمر بودند. نتایج نشان می‌دهد که این ویژگی‌های پایین‌تر بر بازیابی و کیفیت سنگ ابعاد تأثیر منفی می‌گذارد..

کلمات کلیدی: سنگ مرمر، ژئوتکنیک، کیفیت، بازیابی، مفاهیم.