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ARTICLE

Evaluating Rock Construction Materials Using Petrography, Engineering Properties and Geophysical Investigation Around Hawassa, Sidama, Ethiopia

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Abstract

The petrographic description, engineering physical properties, and resistivity characteristics of rock construction materials determining the quality, durability and economic efficiency of infrastructures. The study area is situated at the marginal settings in the central and southern part of main Ethiopian rift, comprises diverse volcanic and pyroclastic rocks that are widely used in the varies construction materials but poorly characterized. The civil engineering infrastructures in Hawassa city and the Sidama regional state are deteriorating due to the inappropriate use of rock materials. Comprehensive studies on these construction materials have not yet been carried. The objective of the study was to evaluate quality of rock construction materials using petrography analysis, engineering physical property assessments and geophysical investigation. To attain this objective, 24 petrographic descriptions, 10 rocks engineering properties and 5 resistivity survey data were analyzed. The rock construction materials identified in the study area, including andesite, scoria, rhyolitic ignimbrite, ignimbrite, welded tuff, and pumice. From these, the andesite rock is composed of pyroxene (60%), plagioclase (35%), biotite (10%), and muscovite (10%) minerals, whereas the rhyolitic ignimbrite shows a flow banding texture, which contains feldspar (40%), plagioclase (25%), biotite (15%), quartz (10%), and volcanic glass (10%) minerals. The dominant structures of the study include joints, cracks, and faults are oriented NE to SW which controlled by main Ethiopian Rift system. The vertical electrical sounding results indicate that the Alamora andesite outcrops, the Boricha quarry site and Gemeto Gale area contain a potential rock layer that suitable for various infrastructures. The lowest and highest compressive strengths are observed in the Galoko Haro quarry site and Alamora andisite rock, which have values ranging from 8 N/mm² to 300.5 N/mm², respectively. The study identified potential rock for sustainable use in various infrastructure developments, providing a foundational dataset for researchers and the Sidama Regional State Mining and Energy Bureau.

Keywords: Characteristic; Rock Construction; Quarry Site; Resistivity; Sidama; Ethiopia

1 Introduction

Main Ethiopian rift is part of the east African rift system and is an active continental rift that extends from the Afar Depression in the northeast to the Omo Rift in the southwest (Corti, 2009; WoldeGabriel et al., 1990). It consists of northern, central and southern sectors, which differentiated by their deformational patterns and volcanic activity (Corti et al., 2020). The Northern Main Ethiopian Rift (NMER) is dominated by active volcanism, the Central Main Ethiopian Rift (CMER), shows moderate volcanic system alongside fault activity, whereas the southern (SMER) is characterized by minimal volcanism (Keir et al., 2006; Muluneh et al., 2021).

Hawassa and its surrounding geological settings lies within the central and southern Main Ethiopian Rift (MER). Regional geology of the central and southern (MER) sector is characterized by felsic, intermediate, and mafic volcanic rocks, often associated with caldera-forming volcanic phases and lacustrine sediments (Abebe et al., 2007; Hutchison, 2015; Peccerillo et al., 2003). Evaluating the properties of massive rock materials determines their suitability for the construction industry (Ahmad & Jamin, 2018; Alshkane, 2020). The inappropriate uses of these rock construction materials might challenge the geotechnical engineers. The assessment of subsurface rock layers, geophysical resistivity measurements, and geotechnical studies affect the civil engineering design (Butchibabu et al., 2019; Zhang et al., 2015). The study area, extending from Hawassa to Yirgalem, is located in the central and partially in the southern parts of the main Ethiopian rift and includes the Hawassa Caldera which hosts Lake Awassa. According to Japan International Cooperation Agency (JICA) (2012), the Hawassa caldera resulted from the large ignimbrite volcanic eruptions (Žáček et al., 2014, 2015). The caldera composed of three stages of voluminous ignimbrite volcanic eruptions, dated at about 0.9, 0.67 and 0.2 Ma, respectively (Japan International Cooperation Agency (JICA), 2012; Žáček et al., 2014). Nowadays, the construction industry extensively uses appropriate rock materials for structural loading, foundations, roads, fencing, pavements and cobblestone. It is obvious that a variety of civil engineering construction projects have been implemented around Hawassa and Yirgalem. Hence, local and regional infrastructures, such as roads, housing developments, huge buildings, bridges, etc., need a sufficient supply of suitable rock quarry products. Despite the Sidama Regional State's abundance of geologic construction materials and diverse socio-economic contexts, the potential quarry sites for rock construction materials have not been thoroughly studied. In addition, the rock construction material quarry sites are not well investigated and identified. The main objective is to evaluate quality of rock construction materials using petrography descriptions, engineering properties analysis, and geophysical survey techniques at a scale of 1:50,000 unit. To map and characterize these geological constructions resources, field investigation, laboratory analysis (i.e., thin-sectioned, rock engineering properties) and resistivity survey were applied to understand the rock construction characteristics. According to Goodman (1992), volcanic rocks are widely used as engineering material worldwide, serving as aggregates in cement and asphalt concrete, rock fill dams, railway ballast, and highway base. These geologic quarry resources have been shown to be a potential contributor to the socio-economic growth of unemployed local people of the region, and Ethiopia as a whole. Gravel and cobblestone roads often constitute the majority of the public road network in the Sidama regional state. Since the geologic materials are used for infrastructures (i.e., gravel and cobblestone roads), it is also possible to use it for building construction. Like any other standard type of road, the construction of quality gravel and cobblestone road requires sound engineering knowledge and vocational skills to secure the desired. The decorative dimension stone becoming very popular for the fascinating architects of modern buildings. These dimension stones were sold in either natural broken sizes or shapes. Engineers usually use without adequate justification of the quality of the rock material according to the requirements in different infrastructure construction works. Therefore, to assess the geological resources, a scientific study was conducted involving quarry site mapping and evaluation of the quality of construction rock materials to address the aforementioned issues. The integrated results and analysis of rock samples characterized the engineering properties of the rocks and identified potential geological quarry sites for sustainable uses and resource management in the construction industry. The results of this study, provided the fundamental database that supporting geological resource mapping and the identification of potential construction rock quarry sites. Hence, it is intended to assist researchers, governmental bodies, policymakers, and the Sidama Regional State Mining and Energy Bureau in making decisions regarding economic quarry site licensing and sustainable resource development.

2 Objectives

2.1 Main Objective

The main objective of this study is to evaluate valuable quality of rock construction materials using petrography, engineering properties, and geophysical investigation around Hawassa, Sidama Regional State, Ethiopia.

2.2 Specific Objectives

The specific objectives of the study are:

- To explore petrographic analysis and rock engineering properties
- To investigate geophysical resistivity surveys to identify subsurface lithological natures and characterize the quality of available rock construction materials
- To produce a geological map at a 1:50,000 scale and classify rock construction materials

2.3 Description of the study area

The study area Hawassa to Yirgalem is situated in the Sidama regional state. It is part of the the central and partial southern (MER) and it is bordered in the south by Aleta Wondo, in the east by Hula and Shebedino, in the north by Hawassa city and Shebedino, and in the west by Dale and Shebedino woredas, respectively (Fig. 1). Geographically, it is bounded in the Adindan Mean Universal Transverse Mercator (UTM) zone 37N, between 430000–450000 E and 746000–779800 N. The total land cover of the study locality is about 750 km². The site is accessible through main route from Addis Ababa, the capital city of Ethiopia via Hawassa city and reached through unpaved roads to the study locality (Fig. 1b, c). It forms gentle topography in the central section and moderate cliffs in the eastern and northwestern parts of the study area. The maximum and minimum altitude of the study locality range from 3000 to 1700 meters above sea level, respectively. In general, the study area shows a gradient towards the north and northwestern directions. The climatic parameters of the study area contain arid to semiarid and register the mean annual temperature range 11°C and 33°C, with an annual rainfall of 678–1286 millimeter's (Hawassa Meteorological Agency, 2010).

3 Materials and Methods

The study design and approaches were based on the specific characteristics of the locality and objective of the survey. Field data were gathered on rocks and geophysical resistivity. To meet the goals of the research mentioned, petrography descriptions and rock engineering properties were examined and geophysical resistivity data were analyzed. The geological tools required for the completion of the work include a basemap map at 1:50,000 scale, satellite image, Terrameter SAS 300B™, Brunton compass, Geographic Positioning System, geological hammer, sample bag, petrographic microscope and computer software. The integrated study methodology is illustrated below in Figure 2.

3.1 Sample collection procedures

There were about 36 rock samples, and 5 geophysics resistivity surveys were collected from different localities within the study area. The representative rock samples are collected and properly coded with Parker, kept in the sample bag, and taken to the laboratory for petrographic and rock engineering property analysis. Among the collected rock samples, 24 thin-sections and 10 rock engineering tests were analyzed in the petrographic and geotechnical laboratory at the Geological Institute of Ethiopia, Addis Ababa, respectively. Whereas 5 geophysics resistivity survey measurements are recorded during the fieldwork. These rock samples, structural data, and geophysics resistivity locations are shown (Fig. 4). The laboratory procedural techniques used for analysis have been different for thin-section and rock engineering cases and resistivity measurements are explained as follows:

3.2 Thin-section analysis

Out of the total 36 rocks sampled that were collected, only 24 samples were prepared for thin-section analysis and interpretation. The rock samples were cut by using the rock-cutter at the petrological laboratory in Geological Institute of Ethiopia to produce slabs of about 4x2 cm size. All the prepared thin-sections were studied for petrographic details using a transmitted light microscope in the laboratory of the Geological Institute of Ethiopia.

3.3 Geophysical Terrameter Electrical Resistivity Survey

This resistivity survey is collected using electrode resistivity (Schlumberger), which comprise of a transmitter and receiver. The Terrameter SAS 300B™ device involved for the vertical electrical sounding (VES) measurements (Fig. 3a). It is used to measure and detect resistance ($\Delta V/I$), through apparent resistivity computed. The apparent resistivity values detect by increasing the electrode spacing against the half electrode separation (AB/2) to produce the field resistivity curve (Fig. 3b). An electrical current was run through a pair of electrodes (A and B) placed at varies points symmetrically from a central point, while a pair of electrodes (M and N) measured the surface features (Fig. 3b). The separations of the current electrodes (AB/2) were 1.13, 1.68, 2.18, 3.66, 4.74, 6.15, 7.96, 10.33, 13.38, 17.35, 22.49, 37.75, 48.78, 63.48, 82.27, and 106.6 m. The spacings were specific to carry out VES, which provides more lithological detail at shallow depths.

After detailed surface geological investigations, 5 vertical electrical sounding (VES) localities are selected and conducted within the study locality. The VES data was interpreted using lithological layers knowledge and its resistivity values of the subsurface formations. The location of VES points and UTM coordinates are illustrated below in Table 1.

3.4 Rock Engineering Properties Analysis Techniques

Ten rock samples are analyzed at the laboratory of Geological Institute of Ethiopia to determine rock engineering properties including compressive strength, bulk density, porosity and water absorption. Initially, the rock samples were cut using a rock cutter for rock engineering properties analysis to the standard BS 1377 part 1:1990 in the laboratory. Rock density was determined by measuring bulk mass, saturated-surface-dry mass, and submerged mass, allowing calculation of bulk volume and density. Porosity and water content were measured using the same procedure after drying samples at 105°C to constant mass, and cooled for 30 minutes in a desiccator, and the dry mass (Mdry) is measured. Compressive strength was tested on prepared cylindrical samples instrumented with axial and circumferential LVDTs and loaded at a constant strain rate until failure. Strength was calculated from the failure load and initial cross-sectional area.

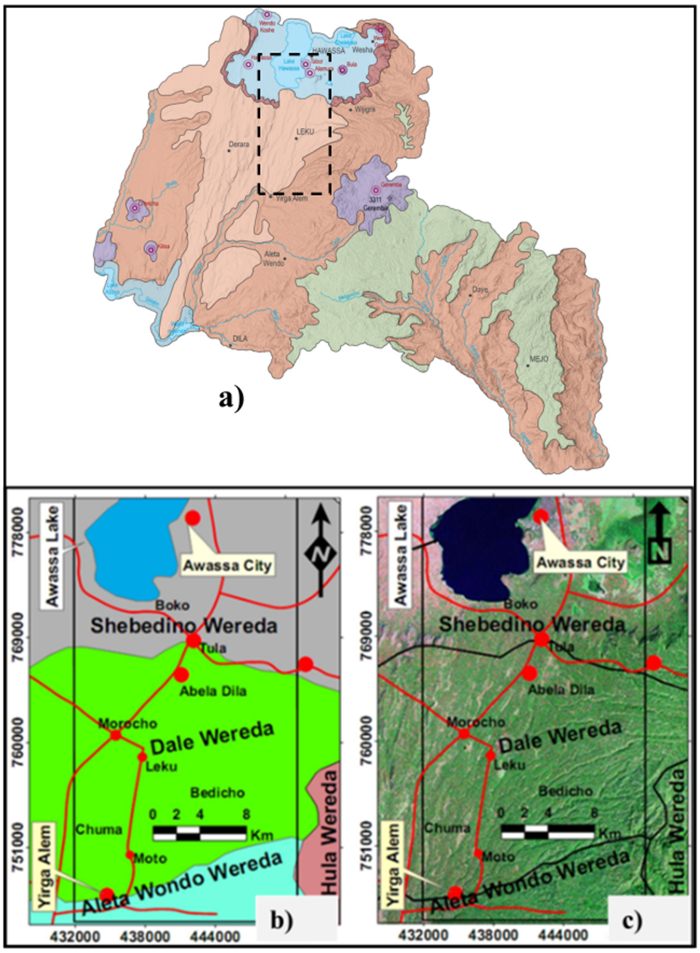


Figure 1: a) Schematic map of Sidama Regional State. b) Location and accessibility of the study area (inset broken rectangular) with respect to surrounding Sidama woredas, and c) Satellite with accessibility image of the study area.

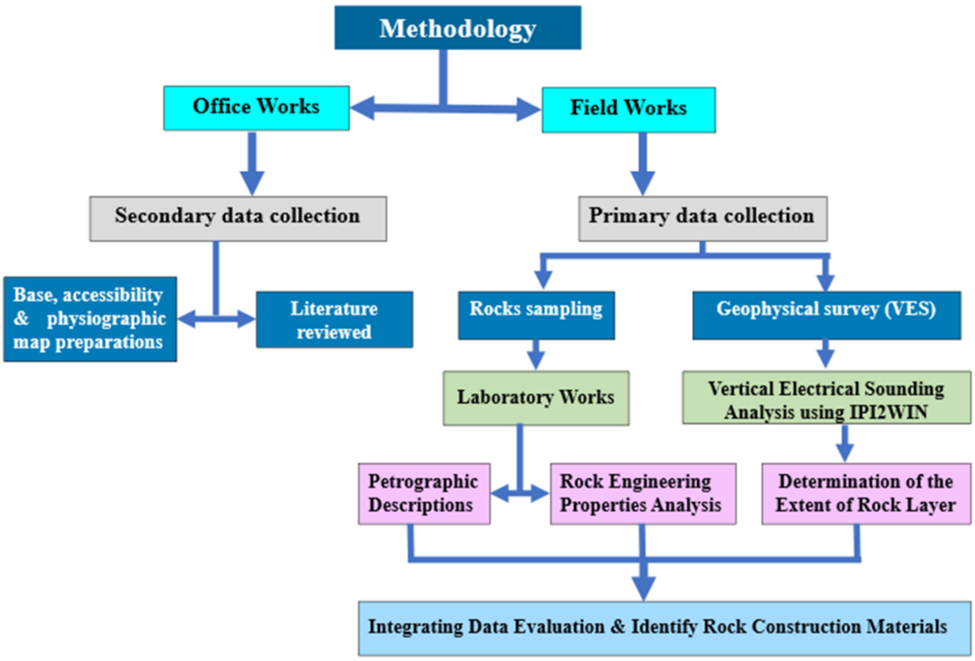


Figure 2: The general workflow of the study

3.5 Data Management and Analysis

The collected primary and secondary data are intended to be analyzed in line with mentioned objective. Data obtained from

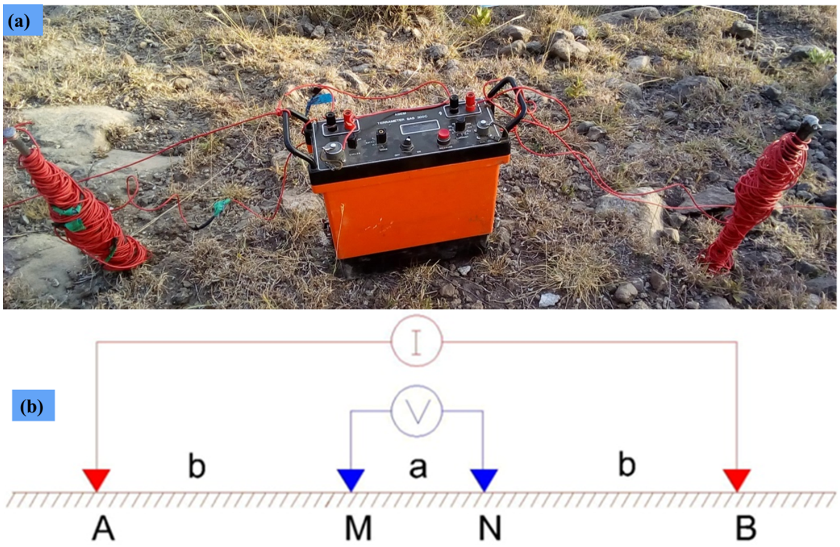


Figure 3: (a) Electrical resistivity test during geophysical survey for data acquisition. (b) Schlumberger Electrode Configuration.

Table 1: Location of VES point within the study area.

VES No.	Elevation (m)	Easting	Northing	Site Name and Landform
VES 1	1716	434614	770860	Crack Area
VES 2	1905	432747	762418	Boricha Ridge
VES 3	1811	437491	754395	Tariku Kaba Spot (Dale Woreda)
VES 4	1738	443453	773236	Gemto Gala kebele
VES 5	1709	447250	772814	Filwha area

fieldwork and laboratory analysis were organized, processed, and interpreted. The data analysis and evaluations involved the determination of rock constructions characteristics and identifications.

4 Results

4.1 Lithology and Petrography

A surface and subsurface investigation was carried out in the study area Hawassa to Yirgalem with the aim of evaluating the rock construction materials potential and quality. The rocks of the study area specifically comprise andesite, scoria, rhyolitic ignimbrite, ignimbrite, unwelded ignimbrite, lithic ignimbrite, welded tuff, unwelded tuff, pumice, colluvial sediment, and lacustrine sediment (Fig. 4).

Andesite unit

This unit was mapped in the north-central part of the study locality (Fig. 4). This rock is mainly exposed on the gentle south cliff of Alamora Mountain (Fig. 5). The andesite hand specimen description is dark grey and fine-grained texture.

Microscopically, thin section observation of the rock composition shows pyroxene (60%), plagioclase (35%), biotite (10%), and muscovite (10%) minerals (Plate 1). The contacts with the adjacent lithological units in the eastern, northern, and southern areas are unwelded ignimbrite, rhyolitic ignimbrite, and unwelded ignimbrite, respectively.

Scoria Unit

Scoria is mapped in the north-central part of the study area, and mainly exposed as a scoria domes. Scoria is glassy in composition and resulted from a vent during explosive eruption. The scoria hand specimen description is red to dark gray to black and show vesicular texture.

Rhyolitic Ignimbrite Unit

The rhyolitic ignimbrite with subordinate pyroclastic deposit is produced by voluminous eruption of rhyolitic magma ejected from the Hawassa Caldera (Rapprich et al. 2013). The out-crop samples and hand specimen description is light gray and develops a flow-banded texture (Fig. 6).

The thin-sections were observed under a transmitted light microscope with a magnification of 4x (objective) and 10 x (ocular). Based on petrographic information, the lithologies are named as rhyolitic ignimbrite rock. Microscopically, thin sections were observed under a transmitted light microscope with a magnification of 4x (objective) and 10x (ocular). Based on petrographic observation, the rock unit is composed of feldspar (40%), plagioclase (25%), biotite (15%), quartz (10%), and volcanic glass (10%) minerals (Plate 2).

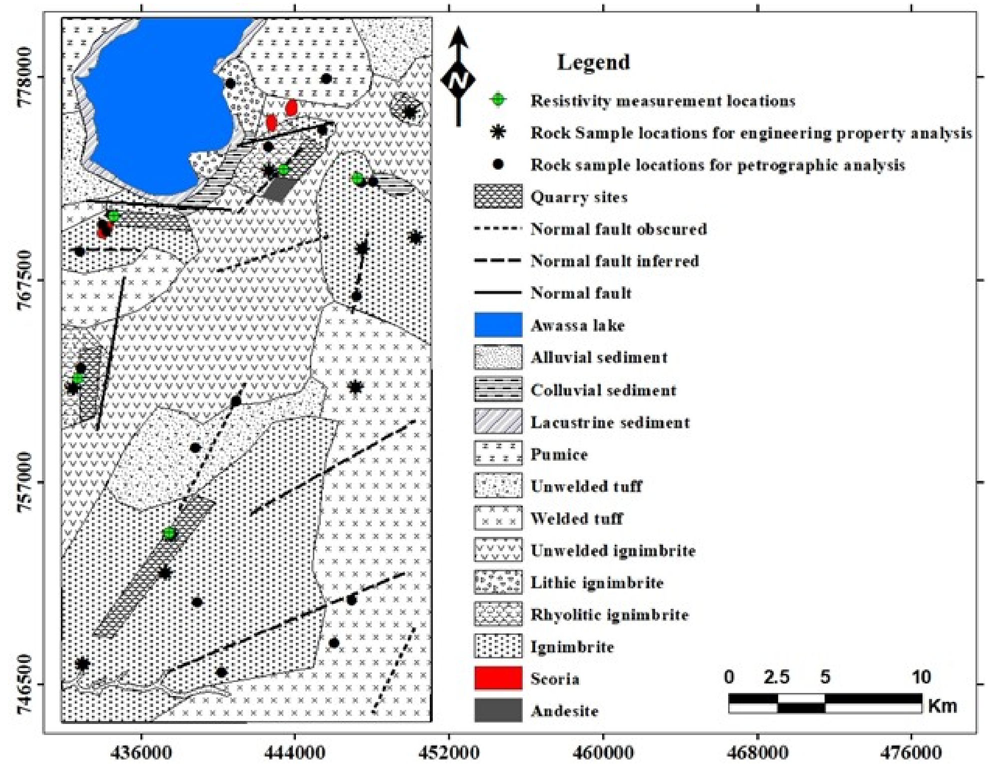


Figure 4: Geological and structural map showing sample and resistivity measurement locations of the study area.

Figure 5: Field photograph showing the andesite unit exposed in the study area.

Ignimbrite Unit

Ignimbrite lithology is mapped along southwestern and northeastern parts of the study area and is mainly exposed in quarry sites and along gentle mountain cliffs (Fig. 4). The ignimbrite hand specimen description is light gray and characterized by fiamme with eutaxitic texture. Microscopically, thin-section observation shows sanidine (40%), feldspar (35%), quartz (15%), and plagioclase (10%) minerals (Plate 3).

Lithic Ignimbrite Unit

Lithic fragments occur within unwelded ignimbrites and originate from wall-rocks that were incorporated during eruption. Crystal fragments are common in the main pyroclastic-flow body, where elutriation removes fine vitric ash and concentrates the denser crystals relative to glass shards.

Unwelded Ignimbrite Unit

This unit is mapped in the west and central parts and extended in the southwestern to northeastern sections within the study area. The unwelded ignimbrite out crop and hand specimen description is light to gray and fine-grained in texture. Microscopically thin section observation shows the rock unit is composed of sanidine (60%), pyroxene (25%), opaque (5%), and plagioclase (20%) minerals. Except for the opaque minerals, the rest of the minerals have developed flow texture.

Welded Tuff Unit

This unit is majorly exposed along the ragged terrain and sub-elevated along the southeastern of the study area (Fig. 4). A microscopically thin section shows mineralogical composition in percentage as volcanic glass (95%) and opaque (5%) minerals.

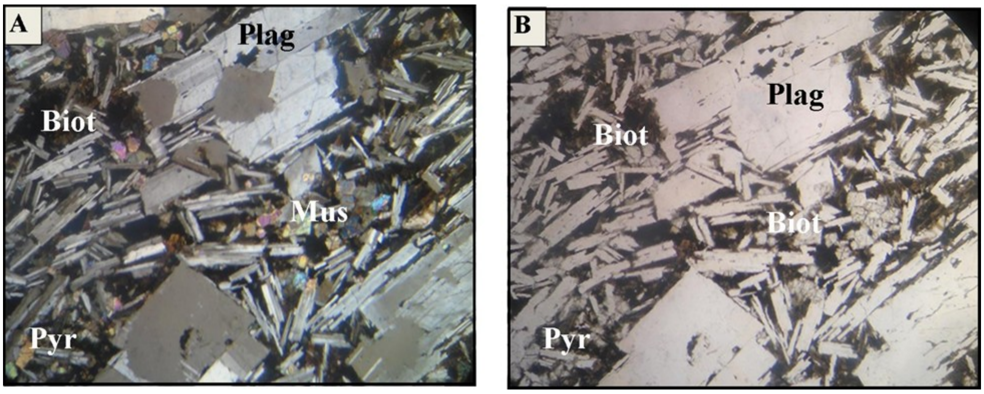


Plate .1: Microphotographs of andesite rock under XPL (A) and PPL (B) (NB. 40 time's magnification). (Abbreviations: Pyr= pyroxene, plag= plagioclase, Biot= biotite, Mus= muscovite).

Figure 6: Field photographs of rhyolitic ignimbrite unit observed during sample collections.

The rock unit is associated with fragment rock.

Pumice Unit

This unit crops out along the northern margin of the study area (Fig. 4). It covers some parts within the Hawassa Caldera. The color of the rock is light, vesiculated, fine-grained texture. Mineralogically, they are composed of volcanic glass (90%), quartz (7%), and opaque (3%) minerals (Plate 4).

Obsidian Unit

Obsidian is formed because of very rapid cooling of lava and characterized by a glassy texture. The rock unit is exposed in the central part, specifically associated with rhyolitic ignimbrite rock at the back of Alamora Ridge in the study area. Obsidian is black, dark, and green in color.

Colluvial and Lacustrine Sediment

Colluvial sediments occur locally along steep slopes and fault scarps, consisting of weathered ignimbrite and pyroclastic rock blocks accumulated at the lowlands near landslides and rockfalls. Their observed thickness is about 5 m. Lacustrine sediments occur around the swamps of Lake Hawassa and within endorheic graben depressions. They consist of unconsolidated mud, silt, sand, gravel, and conglomerate.

Alluvial Sediments

Alluvial sediments are found in the southern part of the study area within recent alluvial fans, formed where eroded material is deposited at abrupt gradient changes. These fans occur at valley mouths where streams flow into valleys and consist of re-deposited soil and fine- to medium-grained sands rich in weathered volcanic and volcaniclastic rocks, commonly containing angular pumice clasts.

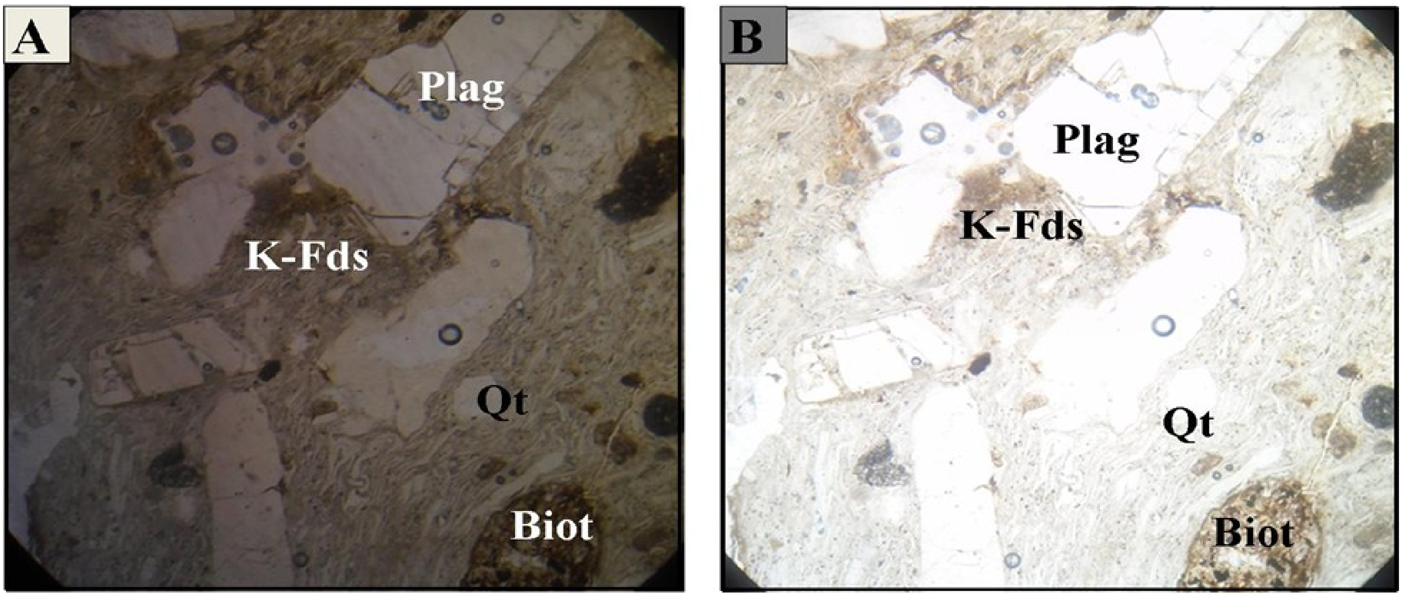


Plate .2: Microphotographs of rhyolitic ignimbrite rock under XPL (A) and PPL (B) (NB. 40 time's magnification). (Abbreviations: plag= plagioclase, Qt = quartz, K-Fds= k-feldspar and Biot= biotite).

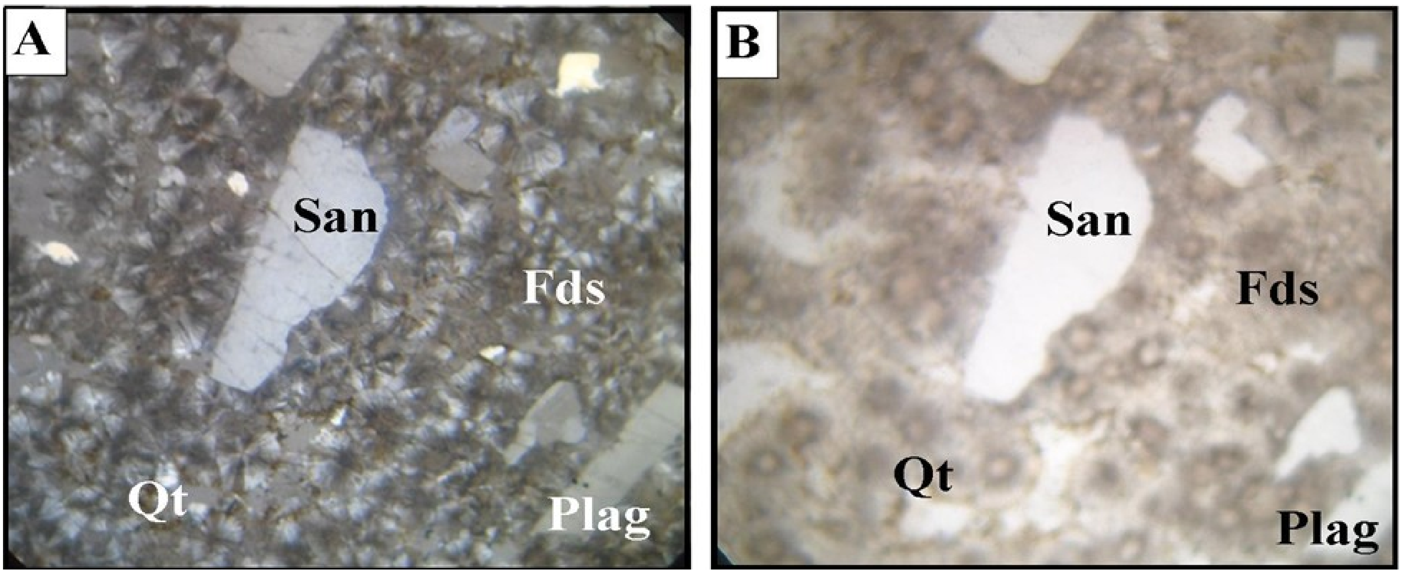


Plate .3: Microphotographs of ignimbrite rock under XPL (A) and PPL (B) (NB. 40 time's magnification). (Abbreviations: San = sanadine, Fds= feldspar, Qt = quartz and Plag= plagioclase).

4.2 Structural Geology

Mainly the structures of the study area are orientated in NE–SW directions which implies controlled by main Ethiopian rift. The dominant structures of the study are included: calderas, joints, cracks, and faults. Awassa caldera is a semicircular shape and forming a topographic depression of 35 × 20 km that results from magma erupting from a shallow magma reservoir. This leads to a loss of structural support for the overlying rock, collapse of the ground and formation of a caldera depression. Different faulting orientations are formed during caldera collapse (WoldeGabriel et al., 1990). The caldera is mainly characterised with silicic lava flows, pumices, welded and unwelded tuffs. Joints and cracks are dominant in the trachytic unit, whereas faults are common in the ignimbrite unit. A set of N-S trending vertical to sub-vertical joints and cracks were formed on the welded tuff (Fig. 7).

4.3 Electrical Resistivity Test and Analysis

Crack Area Vertical Electrical Sounding 1 (VES 1)

The apparent resistivity model curve for VES1 reveals a three-layers subsurface structure with resistivity varying between 78.33 Ωm and 1091 Ωm (Table 2). The topsoil was 2.9 m thick and had a resistivity range 78.33 to 572.3 Ωm, whereas, the second layer had a thickness of 19 m with a resistivity of 524.5 Ωm. The resistivity of the third layer is 1091 Ωm. Deductions made from the results suggest loose topsoil material at the top, possibly continuing to the depth of 21.92 m as volcanic ash.

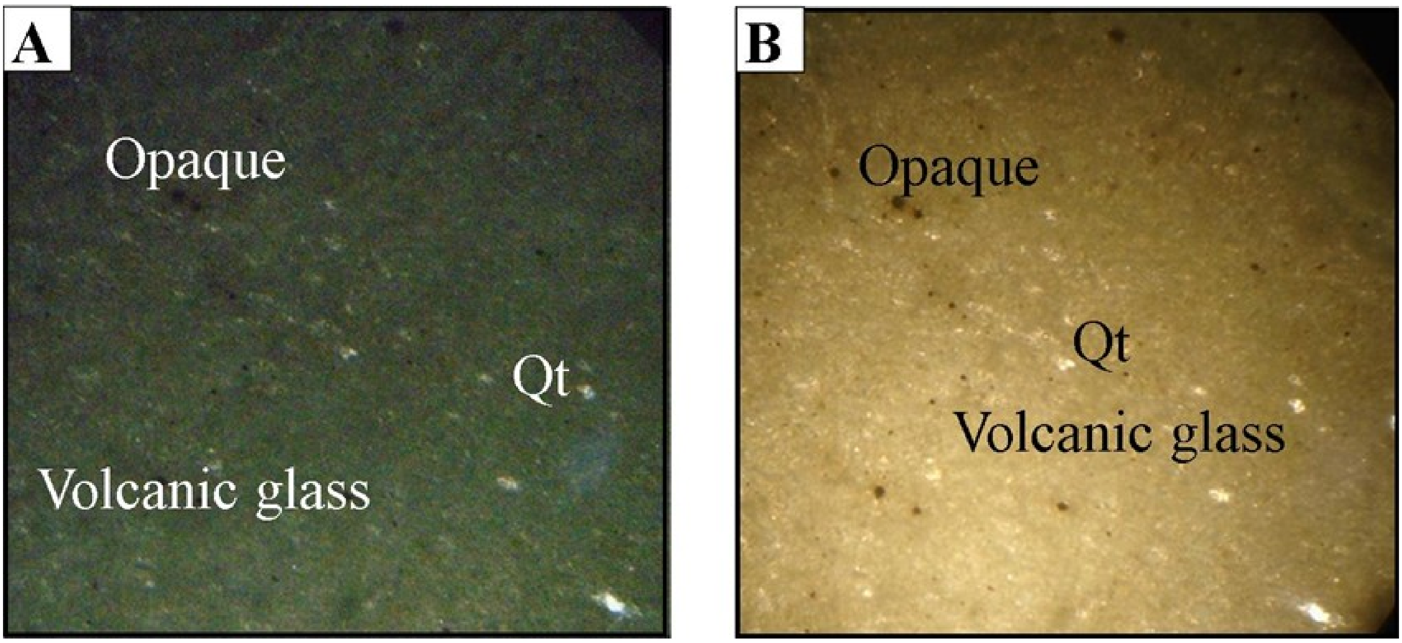


Plate .4: Microphotographs of pumice Under XPL (A) and PPL (B) (NB. 40 time's magnification). (Abbreviations: Qt = quartz).

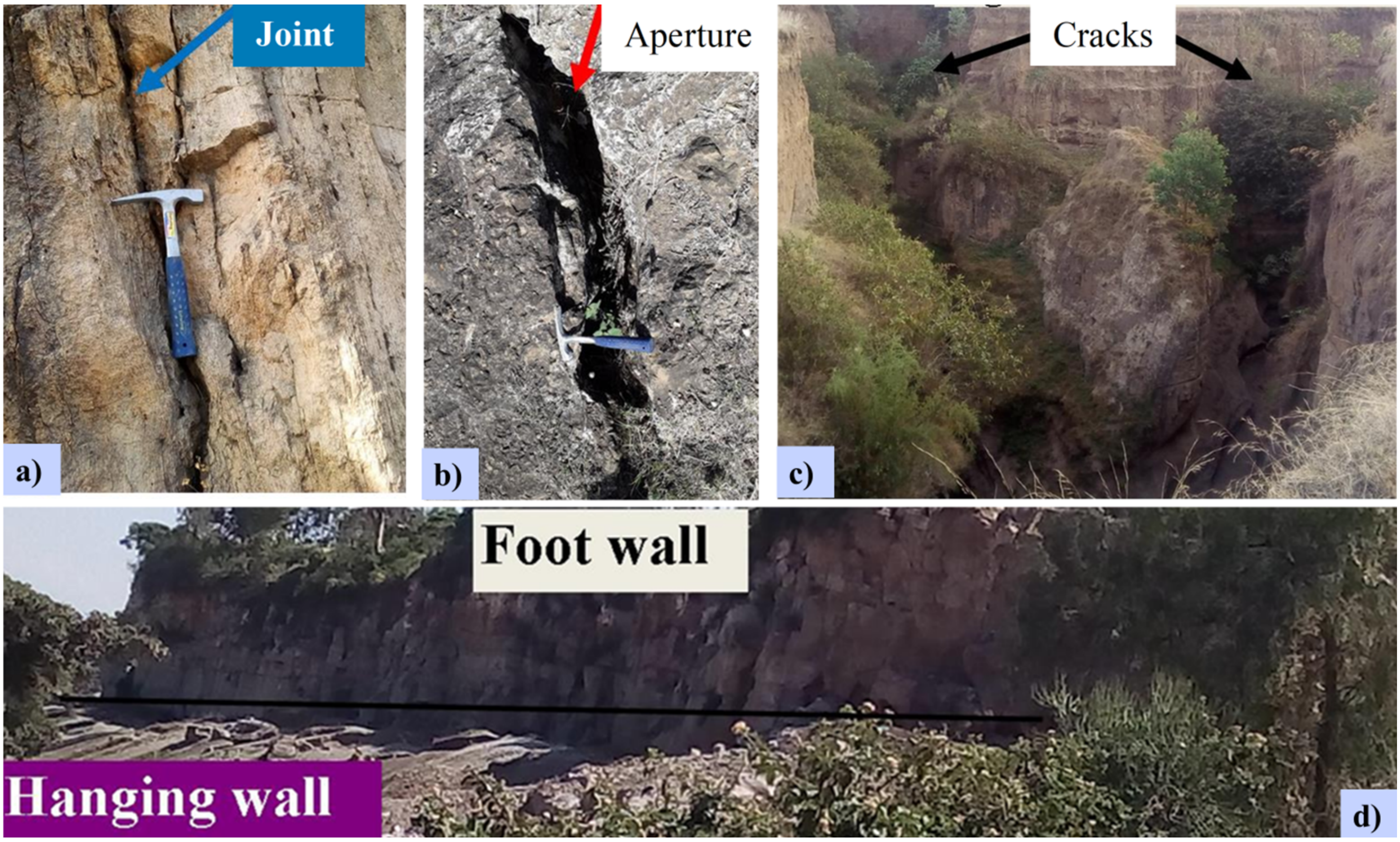


Figure 7: a) N-S trending joints, b) Apertures fracture, c) Big cracks and d) Norma fault within the ignimbrite rocks near the central part of the study area.

The third layer shows increasing resistivity suggest volcanic rock. The model curve and subsurface layers derived from VES 1 conducted around the crack area are shown (Fig. 8).

Table 2: Model layer resistivity and thickness of VES-1

Layer	Resistivity ohm-m	Thickness (m)	Depth (m) From	To	Possible Interpretations	Remarks
1	572.3 78.33	0.48 2.42	0 0.48	0.48 2.9	Top soil	Loose material
2	524.5	19	2.9	21.92	Volcanic ash	Semi-Consolidated
3	1091	-	21.92	>21.92	Volcanic rock	Massive

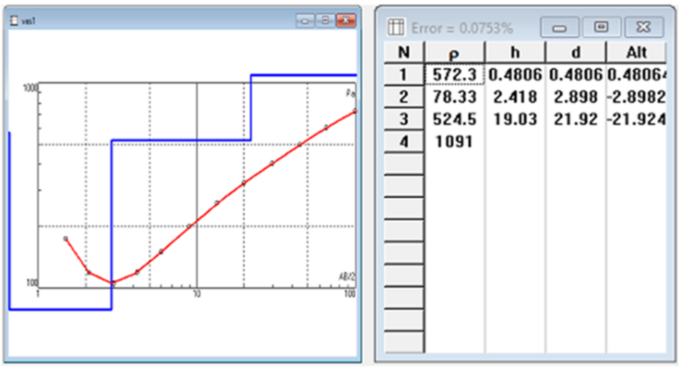


Figure 8: Vertical Electrical Sounding 1 (VES 1) model curve and layers near the crack area.

Boricha Ridge Locality Vertical Electrical Sounding 2 (VES 2)

The geological section at VES 2 suggests that the subsurface is made up of three layers with apparent resistivity values ranging between 64.7 Ωm and 3108 Ωm (Table 3). The upper layer, which has an apparent resistivity of 64.7 Ωm, is 1.13 m thick, is followed beneath it by a second layer of resistivity, 3108 Ωm, and thickness of 14.3 m. The third layer, which is the deepest layer, has an apparent resistivity of 1748 Ωm. It is inferred from these results that the top layer is loose soil and is underlain by a massive ignimbrite layer. Decreasing the apparent resistivity in the third layer indicates that the rock could be weathered or have fractures with water. The model curve and subsurface layers derived at VES 2 carried on the Boricha ignimbrite quarry site (Fig. 9).

Table 3: Model layer resistivity and thickness of VES-2

Layer	Resistivity ohm-m	Thickness (m)	Depth (m) From	To	Possible Interpretations	Remarks
1	64.7	1.13	0	1.13	Top soil	Loose
2	3108	14.3	1.13	15.5	Ignimbrite	Massive
3	1748	—-	15.5	>15.5	Slightly weathered Ignimbrite	Weathered

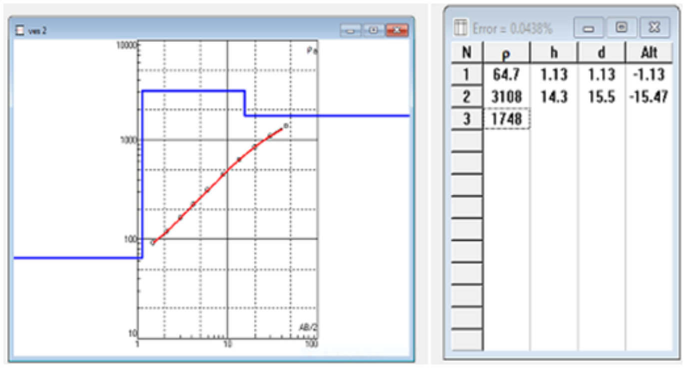


Figure 9: Vertical Electrical Sounding 2 (VES 2) model curve and interpreted subsurface layers at the Boricha ignimbrite quarry site.

Tariku Kaba Spot (Dale Woreda) Vertical Electrical Sounding 3 (VES 3)

From the VES 3 curve of the station, the subsurface consists of two layers. The apparent resistivity values range from 7.61 Ωm to 361 Ωm (Table 4). The thickness and apparent resistivity of the first layer is 2.17 m and 7.61 Ωm. The second layer has a resistivity of 361 Ωm (Fig. 10). It is apparent that the top layer might be loose silty clay soil with moisture content. The resistivity of the second layer suggests a massive formation.

Table 4: Model layer resistivity and thickness of VES-3

Layer	Resistivity ohm-m	Thickness (m)	Depth (m) From	To	Possible Interpretations	Remarks
1	7.61	2.17	0	2.17	Silty CLAY soil	Loose & moist
2	361	—	2.17	>2.17	Ignimbrite	Massive

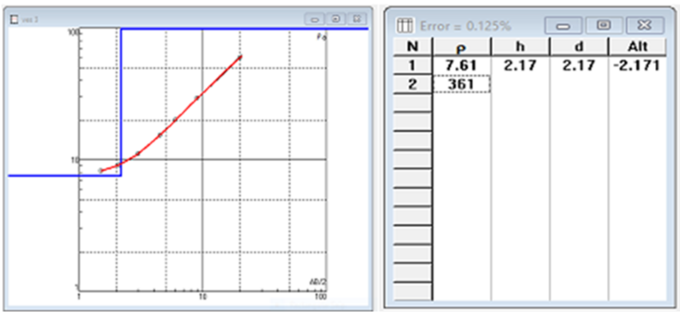


Figure 10: Vertical Electrical Sounding 3 (VES 3) model curve and interpreted subsurface layers at the Tariku Kaba site (Dale Woreda).

Gemto Gala Locality Vertical Electrical Sounding 4 (VES 4)

The subsurface structure at station VES4 is made up of 2 layers of apparent resistivities ranging between 277 Ωm and 15040 Ωm (Table 5). The results reveal that the topsoil has an apparent resistivity of 277 Ωm and is 0.48 m thick. The second layer has an apparent resistivity of 15040 Ωm. The analysis of these results reveals a fairly weathered upper layer and a massive basalt second layer. The model curve and subsurface layers derived at VES 4 measured at the Gemto Gala locality (Fig. 11).

Table 5: Model layer resistivity and thickness of VES-4

Layer	Resistivity ohm-m	Thickness (m)	Depth (m) From	Depth (m) To	Possible Interpretations	Remarks
1	277	0.48	0	0.48	Top soil	Loose
2	15040	—	0.48	>0.48	Very strong Tracy-basalt	Very Massive

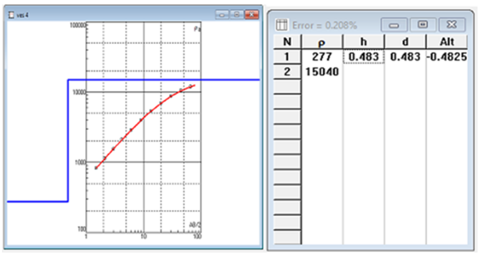


Figure 11: Vertical Electrical Sounding 4 (VES 4) model curve and interpreted subsurface layers at the Gemto Gala locality.

Filwha Area Vertical Electrical Sounding 5 (VES 5)

From the vertical electrical sounding curve of station VES 5, the subsurface consists of three layers. The apparent resistivity values range from 122 Ωm to 922 Ωm (Table 6). The thickness and apparent resistivity of the first layer are 0.9 m and 304 Ωm. The second layer is 3.02 m thick and has a resistivity of 122 Ωm. The third layer, however, has the apparent resistivity of 922 Ωm. It is apparent that the top layer might be loose topsoil and is underlain by a weathered second layer. The resistivity of the deepest layer suggests a massive formation. The model curve and subsurface layers derived near the Zelalem Filwha locality (Fig. 12).

Table 6: Model layer resistivity and thickness of VES-5

Layer	Resistivity ohm-m	Thickness (m)	Depth (m) From	Depth (m) To	Possible Interpretations	Remarks
1	304	0.9	0	0.9	Top soil	Loose
2	122	3.02	0.9	3.92	Volcanic rock	Weathered
3	922	—	3.92	>3.92	Volcanic rock	Massive

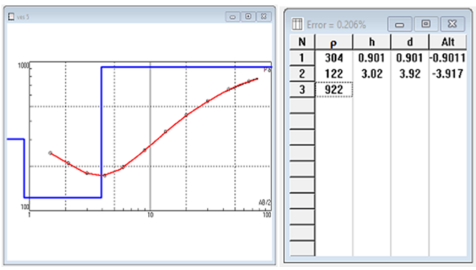


Figure 12: Vertical Electrical Sounding 5 (VES 5) model curve and interpreted subsurface layers near the Zelalem Filwha locality.

4.4 Rock Engineering Properties Analysis Techniques

The collected fresh representative rock was subjected to laboratory analysis, which includes bulk density, porosity, water absorption and compressive strength tests. The physical tests were conducted in the central laboratory of the Geological Institute of Ethiopia at Addis Ababa, which has a good reputation for such tests. The lists of selected tests and results from the Geological Institute of Ethiopia are given in Table 7 separately.

5 Discussion

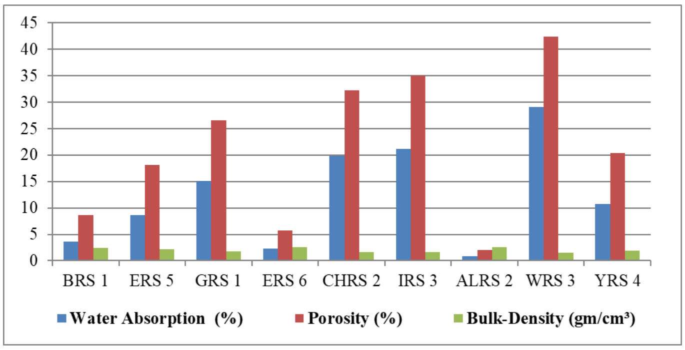
The field and laboratory work carried out during the research activities were compiled and compared together to reveal the engineering performance of the rock mass in terms of construction material suitability. The exposed lithology shows a variety of textural and mineralogical characteristics, which affect their physical, chemical and construction material properties. From the interpretation of VES 1 (near the crack area): The third layer may be a good potential zone for infrastructures purposes which characterized by the resistivity value of 1091 Ωm. This resistivity value indicates that there is less dense volcanic rock, possibly ignimbrite with saturated pore water. At VES 2 (Boricha quarry site): The second layer could be a promising zone characterized by a high resistivity value of 3108 Ωm. This high value suggests massive ignimbrite without saturation and promising for constructions. At VES 3 (Tariku Kaba quarry site): After topsoil, the resistivity value for the second layer increased to 361 Ωm. This low value suggests that the layer is fractured unevenly, though it could be a good potential zone with low quality. At VES 4 (Gemto Gala Kebele): Unlike other rocks, this site shows the very highest resistivity value of 15040 Ωm for the second layer. This highest value shows that the layer is highly massive basalt without weathering and fractures, hence a potential zone for infrastructures. In contrast, at VES 5 (near Zelalem Filwha area or hot spring site): the resistivity value of 922 Ωm for the third layer suggests that the layer could be massive volcanic rock but possibly weathered and slightly fractured. Out of the five resistivity survey sites, VES 2 and VES 4 highly promising zones for future potential zone of quarry sites.

The physical properties, particularly water absorption, density, compressive strength and porosity have been found to be useful properties in assessing the rock material quality. Water absorption is important indicator of weathering resistance. Water absorption and bulk density vary from 0.80 to 29.13% and from 1.45 to 2.56 gm/m^3, respectively. The lowest water absorber among the rock samples is ALRS 2, while the highest one is the WRS3 sample. The porosity value is low in ALRS2 and highest in the WRS3 sample. The lowest water absorption and lowest porosity were observed in the ALRS 2, but bulk density is high. The highest water absorption and highest porosity were observed in the WRS 3 sample, which shows the linear relationship. The moderate values are found in the BRS1, ERS5, and YRS4 samples (Fig. 13 a). The strength of a rock's construction materials is of crucial importance in the

Table 7: Summarized rock engineering results of the study area.

Sample ID	Water Absorption (%)	Porosity (%)	Bulk-Density (gm/cm^3)	Compressive Strength (N/mm^2)
BRS 1	3.63	8.67	2.38	197.8
ERS 5	8.62	18.16	2.11	143.7
GRS 1	15.13	26.61	1.75	77.2
ERS 6	2.29	5.75	2.50	8
CHRS 2	19.84	32.26	1.62	45.5
IRS 3	21.17	34.98	1.65	35.0
ALRS 2	0.80	2.06	2.56	300.5
WRS 3	29.13	42.44	1.45	21.0
YRS 4	10.76	20.36	1.88	94.6

construction industry and for engineering purposes. The lowest and highest compressive strengths were observed in the ERS 6 and ALRS2 samples, respectively, and the values range from 8 N/mm^2 to 300.5 N/mm^2. The moderate values of 143.7 and 197.8 N/mm^2 were found in the ERS5 and BRS1 samples, respectively (Fig. 13 b).



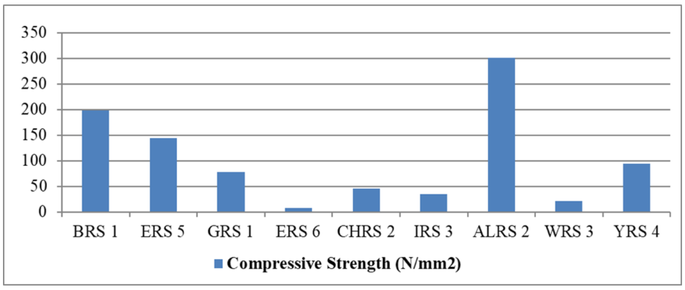


Figure 13: a) The physical properties of selected rock samples and b) The graph shows the lowest and highest compressive strength at selected rock samples.

6 Conclusions

Based on the field investigations and laboratory results acquired from the study locality, the following conclusions are drawn: -

- The lithologic formation of the study area specifically comprises of andesite, scoria, rhyolitic ignimbrite, ignimbrite, unwelded ignimbrite, lithic ignimbrite, welded tuff, unwelded tuff, pumice, colluvial sediment and lacustrine sediment.
- Andesite, rhyolitic ignimbrite and ignimbrite rocks within the study area are the most and a vital role in constructing the infrastructures structures which are destined to be strong, appealing and economical.
- Geologic setting of the study area belongs to central and southern parts of main Ethiopian rift (CMER). Therefore, the study locality lies on the main Ethiopian rift axes and highly affected by divergent forces.
- A combination of laboratory testing of samples, empirical analysis and field observations might be employed to determine the geology and requisite engineering properties.
- The laboratory test results from Alamora andisite rock (ALRS2), Boricha ignimbrite quarry site (BRS1) and Galoko Haro quarry site (near Leku Woreda) (ERS5) rock samples show good engineering properties in terms of strength values ranging from 143.7 to 300.5 N/mm^2, and relatively low water absorption and porosity suggests qualifying and suitable materials for structural load-bearing applications.
- The laboratory test results of rock samples from the Gane quarry site (GRS1, near Yirgalem), near Chuma town (CHRS2), Hanta area (IRS3), and Abela Wendo (YRS4) indicate relatively moderate compressive strength values ranging from 35 to 94.6 N/mm^2, accompanied by high porosity. The elevated porosity makes these rocks susceptible to weathering and degradation, particularly in environments with frequent water exposure. Due to their relatively high porosity, these rock materials are not recommended for use as humus stones or corridor pavements where moisture contact is common. However, they are suitable for cobblestone urban roads, box culverts and local buildings applications purposes.

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Conflicts of Interest

The authors declare that there are no conflicts of interest.

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