The Suitability of Mesozoic Limestone Aggregate for Possible use as Pavement Material in Harer-Dire Dawa Area.

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Abstract

Road construction requires a prime quality and a tremendous amount of aggregates, within which their quality is set by geological and geotechnical properties. Therefore, the Mesozoic limestone was studied in the vicinity of Harer and Dire Dawa towns, for the fundamental engineering assessments.

Thirty-seven Mesozoic limestone samples obtained from the area were subjected to petrographic and geotechnical analyses to work out the suitability of the rock as a road aggregate. Physical properties were investigated using ultrasonic pulse velocity (UPV), water absorption, Na_2So_4 soundness, and specific gravity tests. However, the mechanical properties were determined using unconfined compressive strength (UCS), Aggregate crushing value (ACV), Aggregate Impact Value (AIV), and Los Angles Abrasion value (LAAV).

The study aimed to see if the limestone aggregate complies with the globally accepted standards by employing geotechnical laboratory analyses and petrographic examination.

The petrographic observations reveal the Mesozoic limestones of the area are dominantly composed of micrite, sparite, and bioclasts with subordinate intraclasts, ooids, Fe-oxides, and dolomites. Results of the physical properties show the rock has a mean UPV of 4859 m/s, a dry specific gravity of 2.64, and very low water absorption ranging from 0.2-5.7%, and Na_2So_4 soundness ranges from 1-14%. Among the mechanical properties, UCS, AIV, ACV, and LAAV range from 20.5-180.5Mpa, 8-20%, 24-34%, and 18.9-31.1%, respectively.

Based on the aforementioned results, the limestones of the area are suitable for aggregate in road construction as they're complying with ERA, AASHTO, ASTM, and BS standards used for pavement works.

1. Introduction

Though limestones are hard, durable, and can be used as aggregate, the suitability of limestone for aggregate depends on several geological factors such as the type of minerals present, its strength, porosity, and durability (Adeyi, Mbagwu, Ndupu, & Okeke, 2019). Other factors also include proportions of mineral grains; the type of contacts between the mineral grains; the layering of minerals; and the presence and interconnection of voids. These properties of crushed rock result from the origin and mineralogy of the source rock and its subsequent alteration and weathering. In general, older and more hardened limestone exhibits higher strengths and is suitable for road surfacing applications, as well as for use in the lower parts of the road pavement.

In road construction, more than 90% of asphalt pavements and 80% of rigid pavements are aggregates. Thus, understandably the properties of aggregates commonly affect the durability and performance of pavement projects; and it is essential to obtain the right type and best quality aggregates.

Huge sources of limestone rock which is about 750 meters thick and consists of predominantly fossiliferous yellow limestone are distributed randomly in the Mesozoic succession of the Harer area. Most people in the Harer area are using the limestone without checking the quality of the aggregates and it has shown different types of defects on the projects. In Ethiopia, limestone rock accounts for 10% of the total volume of all sedimentary rocks (Wondafrash, Sentayehu, and Geremew, 2009). In the area, identification of the limestone in particular (Wondafrash et al., 2009) and Mesozoic rocks, in general, was carried out by (Bosellini, Russo, & Assefa, 2001).

In the area particularly, Haromaya watershed, hydrogeological investigation, and groundwater potential assessment were made by (Nata, Bheemalingeswara, and Abdulaziz, 2010). In the Dire Dawa area, the estimation of groundwater recharge and an assessment of the anthropogenic impact on groundwater resources were conducted by (Tilahun and Merkel, 2009) and (Abate, 2010) respectively. Additionally, comprehensive geological studies were carried out by the Geological Survey of Ethiopia (GSE), particularly, (Kibrie and Yirga, 2008 and Workineh, 2010) has produced geological maps of scale 1:250,000 for Dire Dawa and Harer sheets, where two sub-units of the limestone rocks were characterized.

Generally in Ethiopia, the characterization of rocks for their use in engineering applications is very rare except for very few works conducted by (Aragaw, 2008; Engidasew and Barbieri, 2014; Yirga, Weldearegay, and Abebe, 2017). However, the above investigations determine the suitability of aggregates for concrete works except (Engidasew and Barbieri, 2014) partly checked the application of Tarmaber basalt for pavement works. The suitability of volcanic rocks and their petrographic and physicomechanical behavior were evaluated for their use as construction materials in the city of Addis Ababa by (Tesfaye and Asmelash, 2016).

The Hakim Gara limestone occurring near Harer, Delga Chebsi limestone located 23 km northeast of Dire Dawa, Mesobo limestone near Mekele, and also the Jemma-Wonchit and Muger valley limestone of Northern Shewa are suitable as dimension stone and material for cement with resource within the order of innumerable tons. In Ethiopia, the Antalo limestones are mainly utilized for cement and dimension stone.

To the author's knowledge, no research was made and no information is out there on the geotechnical and petrographic properties of the Mesozoic limestone for its use in road construction. Therefore, full knowledge of the physical, mechanical, and petrographic behaviors of the limestone rock (Dweirj, Fraige, Alnawafleh, & Titi, 2017) and determining the suitability of a rock for construction should be made before construction for the safe design of structures (Okogbue & Aghamelu, 2013).

Most specifications and standards (AASHTO, ASTM, BS, and ERA), state the aggregate shall encompass "hard, strong, durable" particles. Weak aggregate isn't acceptable and will not be used. It's therefore important to use the only aggregate produced from strong limestone (good compressive strength). The properties are determined by simpler methods that dictate a load that can be absorbed before the failure of rock and commonly utilized to assess the standard of road stones. The principal laboratory tests include aggregate crushing tests, aggregate impact tests, aggregate abrasion resistance test, aggregate water absorption, specific gravity, and density test, compressive strength, and mineralogical characteristics of rock (Jethro, Shehu, & Olaleye, 2014).

Therefore, the massive quantities of Harer limestone, low cost, and also the lack of knowledge about their engineering properties, additionally to the expected future about to use the Harer limestone in pavement works, have encouraged the authors to hold out this research work.

Any geological material is used as construction aggregate as long as it satisfies the wants of the end-use specification (Adeyi et al., 2019). Aggregates used as road stones must possess high resistance to crushing and wishes to face up to the heavy load because of traffic wheel load, has to be tough enough to resist high impacts caused by the jumping of the steel tyred wheels and severe abrasion resistance, and it has to be sound enough to face up to the weathering action. It must even be impermeable, chemically inert, and possess a low coefficient of expansion. Therefore, this work emphasizes the detailed investigation and geomechanical characterization of the suitability of Harer limestone for pavement works. For this particular area; this research is the primary study and functions as a basis for future studies.

2. The Study Area, Materials, And Methods

2.1 Location of The study area

The study area is found in Eastern Ethiopia about 520km far away from the national capital and extends 65km from Dire Dawa town looking at the provision of limestone (Fig.1).

Dire Dawa will be accessed either by road, by air, or by train through Addis Ababa to Djibouti railway. But Harer town is accessible from the capital of Ethiopia through asphalt road. The topography of the area is hilly and rugged with 3378 and 976 masl max and min elevations respectively.

The temperature is hot throughout the year with minor differences due to the season and progressively increasing towards the north. The rainy seasons are from March to September, with a regular maximum rainfall from July to September.

2.2 GEOLOGY OF the study area

The regional geology of the study area consists of rock units starting from Precambrian basements up to recent sediments (Fig.2). The basements include high-grade gneisses, migmatites, fine to medium-grained amphibolite, and low-grade quartz-mica schist. Hill forming massive granite is exposed to underlying lower sandstone. Phyllite, greenstone, chert, serpentinites, and talc schist are exposed within the study area. The Mesozoic succession consists of the lower sandstone, carbonate, and upper sandstone (Bosellini et al., 2001).

Biostratigraphic consideration shows that the lower sandstone is correlated to Adigrat sandstone. However, the carbonates are correlated partly to Hamanlei and Uarandab sequences. In the end, the upper sandstone is an element of the Yesomma sequence (Balemwal, 1991). Volcanic basalts are exposed at the plateau, though not evenly distributed, and are generally exposed at isolated locations only. Further, the rift plain and parts of major valleys on the plateau contain alluvial sediments.

Reworked sediments occur on gentle slopes, and wide valley floors, and therefore the rift zones (Workineh, 2010). The local geology of the area is dominantly covered by the Antalo limestone (Fig.2). Gildessa limestone exposed in NE of Dire Dawa consists of massive, oolitic, coarse grainstone, parallel and cross lamination with marine coral fragments, bioturbated marly limestone with sparse fossils. It also consists of Dire Dawa Formation-black micritic limestone and marls rich in belemnites, ammonites, and gryphaea and marly limestone and marls rich in ammonites and mollusks. The Antalo limestone overlies the Lower Adigrat sandstone. The top parts of the limestone are weathered and in the Dire Dawa area, the limestone covers the escarpment zone (Ketema, 1982). It covers the up-thrown side of the block and the downthrown side is covered by the alluvium. In Hakimgara, large potential and easily accessible limestone deposits are found, forming hills and beds varying from tens of (cm) to several (m) in thickness (Walle, Zewde, & Heldal, 2000). The well-sorted upper sandstone of the Mesozoic Era is exposed around Dire Dawa with intense weathering and erosion overlaying the antalo limestone.

The geologic structures within the limestone unit are joints, bedding, and solution cavities. They're developed along the bedding planes and along with the foremost tectonic directions. The limestone beds dip towards S and SW and strike E-W and NW-SE direction around Dire Dawa (Ketema, 1982). It always has a horizontal orientation (dips $<10^0$). Major joints run in the N-S direction along with the Ethiopian rift system while minor joint sets are perpendicular to the main joints. The joints have calcite and clay infillings with few mm wide openings; sometimes 20-30cm.

2. 3 Materials

The previous preliminary suitability map (Fig.3 (a)) prepared for quarry sites in the area were used as a base map in the present investigation for rock sample collection. The highly and moderately suitable limestone sections were selected, from the previous suitability map by disregarding the unsuitable and low suitable limestone locations (Fig.3 (b)).

All engineering properties tests were carried out at Adama Science and Technology University with different aggregate testing apparatuses like Aggregate Impact Value (AIV) apparatus, sieves, flakiness, and elongation apparatus, Los Angles abrasion apparatus, water immersion bath, and compressive machines were used for the characterization purposes. A hydrometer was also used for specific gravity measurements of the Na_2So_4 solution during the preparation of the solution for the weatherability test. Additionally, thin section studies were done at Addis Ababa Science and Technology University with a petrographic plane polarizing microscope. Photographs of thin sections were also captured by a camera mounted petrographic microscope.

2.4 Methods (Determining Engineering and Petrographic properties)

Generally, the study encompasses the Geo-Engineering characterization of limestone for the evaluation of the limestone for pavement works. Particularly the investigation involves collecting rock block samples. Then cutting and preparation of cubic rock sample, rock crushing and aggregate sample preparation, geotechnical laboratory characterization, and evaluation of the aggregate samples. Last but not least is chemical characterization or determination of major oxide chemical composition, thin-section preparation, and petrographic description. The main points are presented within the following sections.

2.4.1 Rock Block sample collection

In the preceding study, among the whole of 101 slope sections investigated, thirty-seven sections were selected and identified as potentially suitable and planned for rock block sample collection. Accordingly, thirty-seven block samples were collected from highly and moderately suitable locations for geotechnical laboratory evaluation. Oversized block samples were collected and cut into many pieces so that the subsequent number of tests would be conducted upon it.

2.4.2 Sample Preparation

For the subsequent rock properties characterization, cubic samples were cut from each sample (Fig.4 (b)). A test specimen with dimensions of 70±5mm was cut using a Red Band masonry saw (Fig.4 (a)). Red Band has an enclosed diamond blade, tilting table, and in-built pump for wet cutting. However, for the determination of most mechanical properties (except UCS), the rock blocks were crushed into aggregates. Coarse aggregate sample preparation and/or crushing were done manually by the laborer for all the samples.

2.4.3 Physical properties Examination

The limestone samples collected from selected sections were subject to index property and strength characterization. The geotechnical laboratory characterizations performed during this study include some principal tests to determine intact rock properties, particle shape, durability/or soundness, abradability, and particulate properties.

Particle shape characteristics, durability, and abradability were performed on crushed and graded; mostly coarse aggregates, and sometimes on fine aggregates, measuring fines generated under standard test conditions. Physical characteristics of the rock determined on cubic samples before loading under compressive machine are properties like UPV, dry density, specific gravity, water absorption, and porosity, etc.

2.4.3.1 UPV: The UPV measurements of compressional waves were carried out in line with (ASTM D2845, 2000) employing a high-energy pulser on the driving side and a 2-channel digital storage oscilloscope on the receiving side for recording time traveled. The UPV was determined by using the time-of-flight measurement technique at 82 kHz frequency as the sample size allows good contact with this transducer. Energy transmission between the specimen and every transducer is also improved by employing a thin layer of a coupling medium like high vacuum grease, and by pressing the transducer against the specimen with a small seating force.

For a cube, the UPV was measured on three pairs of faces and three measurements were recorded for one pair of the face. Thus, there is a total of 9 records for one cube. Hence 37 samples multiplied by 9 records equals 333 records of UPV measurements were recorded.

2.4.3.2 Water absorption: The water absorption of the limestone cube was determined according to ISRM suggested methods. It had been determined by measuring the rise in weight of an oven-dried sample when immersed in water, for twenty-four hours with the surface water being removed. The water absorption of the sample (%) is then calculated from the ratio of the difference between the weight of the saturated and surface dry sample (kg) and the weight of the oven-dry sample (kg) to the weight of the oven-dry sample (kg) multiplied by 100. Regarding the number of data, a total of 148 records of water absorption were measured from all cubic samples.

2.4.3.3 Dry density: The dry density (kg/m^3) of a cube was determined following the ISRM suggested method. It's obtained by the ratio of oven-dried mass (kg) of the cube to the bulk volume of the cube (m^3). The cubes were dried in an oven capable of maintaining a temperature of 105°C for twenty-four hours and weights of every cube were recorded using a balance accurate to 0.1g. The simplest direct method for determining the bulk volume of a consolidated sample with a good design geometric shape is to measure its dimensions. Thus, for the dry density measurement, bulk volumes were calculated from dimension measurements using the caliper technique. By using a vernier caliper, the dimensions of cubic samples were measured thrice at different locations for accurate computation of bulk volume, and averages of those three records were taken within the computation of the dry density. Thus, a total of 148 records of dry density were measured from all cubic samples.

2.4.3.4 Specific Gravity: The specific gravity was resolute using the buoyancy method following ISRM suggested methods. The bulk volume of regular or irregular specimens could also be calculated using the Archimedes principle, from the saturated-submerged sample weights. The standard procedure is to determine the volume of fluid displaced by the sample. The fluid volume that the sample displaces is often determined volumetrically. The displaced fluid should be prevented from penetrating the pore space of the sample. During this study, the fluid was prevented from penetrating the pore space of the sample by saturating the rock with the fluid into which it's to be immersed, and therefore the volume of the displaced fluid was determined volumetrically.

The saturated-submerged mass M_{sub} is decided to an accuracy of 0.1g from the displaced volume of the saturated-submerged mass of the sample multiplied by the density of water (which is 1Kg/m^3). An oven-dried mass M_{oven}, using an oven capable of maintaining a temperature of 105°C was also determined to an accuracy of 0.1g. The specific gravity is then obtained from the ratio of the mass of the oven-dried sample to the mass of an equal volume of displaced water.

2.4.3.5 Effective Porosity: The effective porosity is defined as the ratio of the volume of voids (V_v) to bulk volume (V_{bulk}) of the cubes multiplied by 100, expressed in percentage. Therefore, effective porosity is the percentage of interconnected void space concerning the bulk volume.

2.4.3.6 Soundness: The soundness of the aggregate was performed using anhydrous Na_2So_4 chemical and also the test was performed following the test procedure in ASTM C88-99a, (1999). The test was performed by repeated immersion in saturated solutions of sodium sulfate followed by oven drying to partially or completely dehydrate the salt precipitated in permeable pore spaces. During this study, soundness tests were done on fine proportion for the very fact that a much higher amount of coarse aggregates are required if the coarse aggregate is to be used. Two determinations were performed for every sample and a complete of 74 data was recorded in aggregate soundness test.

2.4.3.7 Aggregate Particle Shape: Aggregate particle shape including flakiness and elongations were performed for all 37 aggregate samples. Two determinations were conducted for both flakiness and elongation tests. The flakiness and elongation indices were determined consistent with the procedures given by BS812-105.1, (1989) and BS 812-105.2, (1990).

2.4.4 Mechanical properties Examination

The mechanical properties laboratory examination includes rock sample and aggregate geotechnical evaluations like UCS, AIV, ACV, and LAAV, etc. Generally, Mechanical properties mean the toughness and hardness of the rock materials. The mechanical properties of rock aggregates, including the AIV and ACV, were measured consistent with the test procedures described by BS812-112, (1990) and BS 812-110, (1990), respectively. However, LAAV was performed following a test procedure described in ASTM C131-96, (1996). A minimum of three determinations was conducted for every test depending on the obtained results. Therefore, there are three records for one sample multiplied by a total of 37 samples equals 101 data of every parameter is available.

2.4.4.1 UCS: The UCS test is a mechanical test measuring the amount of compressive load a material can bear before fracturing. The test piece within the sort of a cube is compressed between the platens of a compression-testing machine by a gradually applied load. During this study, the UCS test was performed as per ASTM C170, (1999) and British Standard BS-EN-1926, (2006). For the UCS, four cubic samples were cut and made ready from each sample. Therefore, four cubes per sample multiplied by a complete of 37 equals to 148 cubic specimens were utilized to characterize the UCS.

2.4.4.2 AIV: For the AIV test, BS812-112, (1990), methods for the determination of the AIV were followed. The AIV gives a relative measure of the resistance of an aggregate to sudden shock or impact. An aggregate sample of about 700g is taken and compacted in a standardized open steel cup. The specimen is then subjected to several standard impacts from dropping weight. An aggregate sample of 14mm to 10mm in size is subjected to discontinuous loading of 15 blows with a hammer. This action breaks the aggregate to a degree that relies on the impact resistance of the material. This degree is assessed by sieving the impacted specimen on a 2.36mm sieve and is taken as the AIV. The % of material passing relative to the initial weight gives the aggregate impact value.

For AIV, three repeated tests were conducted for statistical precision and therefore the average of two closely related values was considered as the final AIV. If the difference b/n the two individual AIV isn't more than 0.15 times the mean of AIV; no need to conduct further additional tests to compute the median of the four tests.

2.4.4.3 ACV: The ACV was performed following BS 812-110, (1990) Determination of ACV gives a relative measure of the resistance of an aggregate to crushing under a gradually applied compressive load. The method applies to aggregates passing a 14.0 mm sieve and retained on a 10.0 mm test sieve. An aggregate sample of not more than 1.7Kg is taken and compacted in a standardized steel cylinder fitted with a freely moving plunger. The specimen is then subjected to a nonstop load at a homogenous rate up to 400KN transmitted through the plunger. This action breaks the aggregate to a degree that depends on the crushing resistance of the material. The entire crushed sample on the tray was sieved on a 2.36mm sieve until no further significant amount passes. The fraction passing was weighed and recorded. Two additional repetitions of the test would be conducted for statistical precision and if the mean is less than 1.8 times the difference of the two values, the average of two closely related values was considered as the final ACV. However if 1.8 times the difference between the two values is larger than the average value, yet one more additional test is conducted and the median was considered as ACV.

2.4.4.4 LAAV: The LAAV was conducted according to the test procedures described by ASTM C131-96, (1996). In the LAAV test, the aggregate of specified grading is placed in a cylindrical drum, mounted horizontally. A charge of steel balls is added and therefore the drum is rotated a specified number of revolutions. The tumbling and dropping of the aggregate and also the balls lead to abrasion and attrition of the aggregate.

2.4.5 X-Ray Fluorescence (XRF)- Chemical Composition

Generally, thirty-seven powdered rock samples were submitted to Dire Dawa National cement factory for XRF-chemical composition determination of major oxides. All the samples were placed into groups with similar mineralogical and textural characteristics like roundness, matrix, cement type, and porosity.

XRF is the commonest chemical technique that helps to spot the main oxides of samples with a differing composition such as silicates, carbonates, sulfates, and phosphates from below 0.01% to 100%. The analysis is rapid and non-destructive (Jamaluddin, Darwis & Massinai, 2018) as well as widely used for elemental and chemical analysis, particularly in the investigation of geologic construction materials. The major oxides test was carried out on as little as 0.5 g of material. The sample material was analyzed as a pressed powder fused into a glass disk using a suitable flux, such as lithium tetraborate (Jamaluddin et al, 2018). Using fused samples allows an evenly dispersed primary solid solution, which enables a good range of matrix compositions to be accurately, determined through the normalization of particle size and inter-element (matrix) effects.

The elements within the sample can therefore be identified by their spectral wavelengths for chemical analysis and therefore the intensity of the emitted spectral lines enables quantitative chemical analysis.

2.4.6 Petrographic Examination

For petrographic examinations, thirty-seven hard rock samples were used to investigate the mineralogical variation of limestones. The thin sections were cut and polished in the central laboratory of GSE.

For mineralogical characteristics, the modal analysis of thin sections was used. It’s the method of determining the petrography of rocks by counting the various minerals thereby determining the mineralogical composition and therefore the percentage of crystal formation of varied minerals present in the samples of each rock type (Jethro et al., 2014). According to Jethro et al., (2014), “Percentage Mineral Composition” can be calculated using (eq.1).

$$C_m = \frac{T_m}{T_{tm}} x100 \text{ T.................... (eq.1)}$$

Where, C_m = Percentage mineral composition (%); T_m = Total number of count for a mineral, and T_{tm} = Total number of count for the entire mineral.

Thin-section observation allows for a description to be made of the petrographic aspects and classification of the stones (Brilli, Giustini, & Kadıoğlu, 2018). Accordingly, each thin section was viewed under a petrographic plane polarizing microscope. They are prepared for the study of the relative abundance of the sparite and micrite cement, fossils, and diagenetic features.

The classification scheme of Dunham (1962) and Folk (1962) have been applied for the carbonate rock naming. Textures, fabrics, crystal boundary shapes and grain size features were observed, providing descriptive parameters for the characterization of the kinds of carbonate (Dunham, 1962; Wright, 1992; Brilli et al., 2018).

3. Results And Discussion

Properties such as ultrasonic pulse velocity, dry density, specific gravity, effective porosity, water absorption, and volume of voids as well as mechanical properties like compressive strength and other aggregate tests of limestone play a vital role in its geotechnical characteristics (Alqahtani, Seif, & Sedek, 2013).

According to ERA-STS-2002, it is recommended to reject if the ACV (%) exceeds a value of 29% for road construction work. Therefore, based on the result shown in Table 1; the ACV of the limestone aggregate from samples #47 and #86 indicated a bit above the limit of ERA-STS.

The results of UPV for the limestone samples from the study area range from 2940 m/s to 5370 m/s while the highest values were recorded for sample #37 and the least values were from sample # 86 and with an average value of 4859 m/s (Table 1). The values were in good agreement with the compressive strength, degree of weathering, and rifting of samples.

Table 1. Results for different engineering properties of limestone

Rock Type	Sample	F_I (%)	E_I (%)	W_a (%)	E_p (%)	D_d (kg/m^3)	S_d (kg/m^3)	U_w (kN/m^3)	S_g	U_{pv} (m/s)	UCS (Mpa)	S_o Na_2So_4 (%)	AIV (%)	ACV (%)	TFV(
Siliceous Calcareous Dolomite	24	25	13	1.57	3.86	2524.1	2587.6	24.8	2.55	5020	116.5	3.6	11.7	26.3	157.1
	63	26	7	0.36	0.96	2697.5	2709.9	26.5	2.70	4650	90.0	1.0	13.0	27.3	137.8
	90	21	6	1.88	4.97	2616.8	2649.3	25.7	2.60	4730	102.5	6.1	13.1	26.6	130.4
	84	21	5	1.49	3.88	2618.7	2664.0	25.7	2.63	4050	82.5	8.1	13.6	30.4	120.1
Dolomatized bio intra sparitic Limestone	2	19	14	0.35	0.90	2627.6	2654.4	25.8	2.65	5290	100.0	7.2	12.1	28.3	143.0
	48	19	5	3.01	7.56	2527.5	2609.1	24.8	2.53	4240	76.5	5.2	15.8	28.0	130.2
	60	15	10	0.54	1.37	2626.8	2700.7	25.8	2.69	4700	110.5	5.7	9.4	28.9	168.3
	10	32	9	0.28	0.75	2672.9	2684.1	26.2	2.68	5020	82.0	2.7	12.7	29.6	131.7
Dolomatized bio intra micritic Limestone	49	21	13	0.17	0.46	2705.1	2717.1	26.5	2.71	5130	99.0	1.0	10.7	31.0	152.3
	50	26	14	2.87	7.42	2553.8	2589.2	25.1	2.52	3920	115.5	3.1	10.8	28.3	160.2
	4	26	19	0.17	0.44	2636.9	2648.9	25.9	2.64	5300	72.0	1.6	13.0	30.0	130.0
	77	24	9	0.32	0.87	2669.1	2657.6	26.2	2.65	4730	55.5	2.4	14.5	31.1	110.1
	71	17	9	3.75	8.99	2452.1	2599.9	24.1	2.51	3960	60.5	6.9	15.2	29.4	109.9
	42	21	8	0.34	0.92	2738.4	2753.8	26.9	2.75	5330	60.5	1.4	15.1	30.5	107.2
Dolomatized bio oo spary Limestone	47	24	8	0.29	0.83	2742.6	2789.1	26.9	2.78	4970	41.0	6.2	15.1	34.1	97.0
	72	30	10	0.32	0.83	2645.6	2697.3	26.0	2.69	4820	76.5	3.2	12.1	30.4	134.4
	99	29	6	1.71	4.23	2607.1	2785.6	25.6	2.74	5110	100.0	3.0	13.1	27.6	139.9
	34	26	7	0.41	1.12	2683.1	2672.2	5.0	2.66	4930	91.5	2.8	13.8	27.5	130.0
Siliceous bio pel micritic Limestone	58	30	4	0.45	1.26	2762.1	2768.8	27.1	2.76	5050	54.0	2.0	15.2	30.2	108.0
	70	22	9	0.27	0.69	2643.2	2694.6	25.9	2.69	5120	78.0	3.0	12.1	29.8	137.1
	7	32	9	0.33	0.88	2689.1	2725.2	26.4	2.72	5240	68.0	1.4	13.5	30.3	120.7
	37	23	12	0.22	0.61	2698.7	2686.8	26.5	2.68	5370	73.0	2.4	12.3	30.1	137.3
	29	11	19	0.38	1.02	2639.8	2603.8	25.9	2.59	5290	87.0	4.7	15.3	27.5	116.3
	67	22	13	0.28	0.68	2564.6	2596.2	25.2	2.59	5290	108.0	2.1	12.6	26.4	154.3
Bio intra spary Limestone	59	18	6	1.53	3.80	2476.7	2499.6	24.3	2.46	4740	110.0	8.9	13.8	27.5	130.0
	19	28	6	0.40	1.09	2712.6	2686.2	26.6	2.68	5120	74.0	0.6	13.4	30.2	141.4
	17	13	7	0.90	2.37	2644.4	2671.6	25.9	2.65	5280	39.0	3.5	16.7	31.7	94.2
	46	18	5	0.43	1.16	2715.2	2727.9	26.6	2.72	5040	145.0	1.3	8.4	27.5	212.8
	16	35	8	1.65	4.11	2538.6	2636.7	24.9	2.60	4880	68.0	3.0	13.2	30.3	139.9
Bio intra micritic Limestone	13	22	7	1.71	4.41	2550.8	2567.5	25.0	2.53	4590	48.5	7.4	15.1	32.2	102.1
	82	38	12	1.52	3.83	2604.2	2041.3	19.2	2.68	4730	85.5	2.4	11.3	31.3	140.9
	78	27	11	0.33	0.86	2625.0	2670.8	25.8	2.66	4990	87.0	1.5	12.9	28.3	133.8
	40	37	18	0.45	1.20	2741.4	2821.1	26.9	2.81	5060	61.5	1.5	14.6	30.6	110.6
	25	25	13	0.47	1.28	2754.6	2765.0	27.0	2.66	5170	122.5	2.7	11.1	27.2	164.7
	28	31	13	0.24	0.66	2604.2	2041.3	20.0	2.71	5140	180.5	2.6	9.7	24.5	177.1
	32	29	10	0.79	2.02	2585.9	2624.9	25.4	2.61	4850	72.0	3.3	12.4	31.5	127.8
	86	21	6	5.73	13.75	2366.5	2467.9	23.2	2.34	2940	20.5	14.2	19.9	33.3	75.7
Minimum		11	4	0.17	0.44	2366.5	2041.3	19.2	2.34	2940	20.5	0.6	8.4	24.5	75.7
Maximum		38	19	5.73	13.75	2761.1	2821.1	27.1	2.81	5370	180.5	14.2	19.9	34.1	212.8
Mean		24	10	1.02	2.60	2628.7	2634.2	24.9	2.64	4859	84.2	3.8	13.2	29.3	132.8
Standard deviation		6.3	3.9	1.2	2.9	88.9	162.4	3.8	0.1	494.9	30.4	2.8	2.2	2.1	25.6

Variance	39.7	15.0	1.4	8.4	7899.2	26369.1	14.1	0.0	244974.3	927.1	7.9	4.7	4.4	656.9

Note: ACV: Aggregate Crushing Value; $D_{d:}$ Dry Density; E_I: Elongation Index; $E_{p:}$ Effective porosity; F_I: Flakiness Index; LAAV: Los Angles Abrasion Value; $S_{d:}$ Saturated Density; $S_{g:}$ Specific Gravity; $S_{o:}$ Soundness; TPFV: Ten percent fine Value; U_{PV}: Ultrasonic Pulse Velocity; UCS: Uniaxial compressive strength; $U_{w:}$ Unit Weight; Vv: Volume of voids; $W_{a:}$ Water Absorption

Regarding water absorption values, the cube samples have water absorption values ranging from 0.2- 5.7 % with an average value of 1.02% (Table 1). However, the minimum value of the water absorption was determined for the dolomitized biointramicritic limestone (Sample #4 and 49) which is dense and fine-grained while the maximum water absorption was recorded from biointramicritic limestone (#86).

The water absorption and specific gravity of aggregates are important properties that are required for the design of concrete and bituminous mixes. The amount of water that an aggregate can absorb tends to be a wonderful indicator of the strength or weakness of the aggregate. Strong aggregates will have an awfully low absorption below 1%. An aggregate with high moisture absorption isn't likely to be a suitable road-building material. Generally, less absorptive aggregates often tend to be more resistant to mechanical forces and wetting. The appropriate limit of water absorption generally ranges from 1-5%. However, lightweight aggregates have higher water absorption values usually from 5-20%. Water absorption values range from 0.1 to about 2.0 percent for aggregates particularly utilized in road surfacing. Thus, all the samples within the current study satisfy this requirement except sample #86.

The specific gravity of the limestone samples ranges from 2.34-2.81 and the average specific gravity for the limestone in the study area is 2.64. The specific gravity of aggregates normally utilized in pavement construction ranges from about 2.5-2.9. The minimum value of 2.34 was obtained for sample ML 86 (biointramicritic limestone) and the maximum value (2.81) was obtained for sample #40 which is also biointramicritic limestone.

The dry densities of the samples vary from 2366.5-2762.1(kg/m^3) and the average value of dry density is 2634.2 (kg/m^3) for the limestone in the study area. The lowest value is from sample ML 86 (biointramicritic limestone) and the highest one is from sample ML 58 (siliceous biopelmicritic limestone). There is no significant variability among the values concerning the dry density. Although the strength of high-density limestone (sample ML 58) is relatively high, the natural discontinuities made the rock mass weak.

Effective porosity is defined as the ratio of the volume of voids (V_v) to bulk volume (V_{bulk}) of the cubes multiplied by 100, expressed in percentage (eq.2).

$$EffectivePorosity\ (\%) = \left(\frac{V_v}{V_{bulk}} * 100 \right). \qquad \text{(eq.2)}$$

The limestone of the study area was evaluated and the minimum and maximum effective porosity is 0.44% for sample no #4 from dolomitized biointramicritic Limestone and 13.75% for sample no #86 from biointramicritic Limestone respectively.

About 89% of the total studied samples have effective porosity not exceeding 5%. It is widely understood that diagenetic processes play a key role in controlling porosity and permeability within limestone (Alqahtani et al., 2013). Petrographical analyses of the remaining samples indicate that the diagenetic processes increase the total porosity of the studied limestone.

Table 2. Permissible Limits of AIV, ACV, LAAV, TPFV, FI, and Soundness (Na_2So_4) for pavement applications (Ethiopian Roads Authority Standard Technical Specification (ERA-STS), 2002)

Engineering Parameters	Purpose	Standards Applied
AIV (max.) 45%	Crushed stone unbound road base course	BS 882:1992
AIV (max.) 30%	Bituminous bound surfacing or wearing course	BS 882:1992
ACV (max.) 29%	Crushed stone unbound road base course	ERA-STS-2002
ACV (max.) 25%	Bituminous bound surfacing or wearing course	ERA-Pavement Design Manual Volume I-2002
LAAV (Max) 35%	Crushed stone unbound road base course	ERA-STS-2002
LAAV (Max) 30%	Bituminous bound surfacing or wearing course	ERA STS 2013 Clouse 6303[b] (ii)
TPFV (Min) 110%	Crushed stone unbound road base course	ERA STS 2013 Clouse 8404[d] Table 5204/2
TPFV (Min) 100	Bituminous bound surfacing or wearing course	ERA STS 2013 Clouse 6303[b] (ii) Table 6303/9, 6303/12
FI (Max) 30%	Crushed stone unbound road base course	ERA STS 2013 Clouse 5204[b]
FI (Max) 20%	Bituminous bound surfacing or wearing course	PD 6682-1:2003 Recommend FI_{20} of BS EN 12620
Soundness (Na_2So_4) (Max) 10% for fine aggregate	Crushed stone unbound road base course	ERA STS 2013 Clouse 8402 [C] (i) and AASHTO M80, Table 2
Soundness (Na_2So_4) (Max) 10% for fine aggregate	Bituminous bound surfacing or wearing course	ERA STS 2013 Clouse 6303[b] (ii)

Generally, better aggregate surface texture and higher angularity lead to a good aggregate-cement bond and good particle interlock, both of which help in achieving good compressive strength properties. However, flakey aggregate has less strength than cubical aggregate and doesn't create the dense matrix that well-graded cubic aggregate can do, and it'll provide less texture when used in the surface dressing. E.g. Granular sub-base with a high proportion of flakey aggregate tends to segregate and be difficult to compact. Moreover, Flakey chippings do not create the surface texture that a cubic or angular chipping can produce. Flaky particles are more easily stripped from bitumen seals. In flakiness study, it involves investigating the lithological causes, as distinct from the crushing induced, causes of flakiness. The flakiness index of the limestone aggregate in the study area ranges from 11- 38%, and the elongation index ranges from 4-19%. The maximum and minimum flakiness index values were from sample #82 and #29, respectively. However, the maximum for the elongation index was from samples #4 and #29 whereas the minimum values were from sample #58. In this study, fortunately, most samples satisfy the requirements for road base course (Table 2).

The soundness test is meant to review the resistance of aggregates to weathering action, by conducting accelerated weathering test cycles. Porous aggregates subjected to Na_2So_4 solution are likely to disintegrate prematurely. To ascertain the soundness of such aggregates, aggregates of specified sizes are subjected to an accelerated cycle of alternate wetting utilizing a saturated solution of Na_2So_4. The minimum and maximum percentage of losses of Na_2So_4 soundness are 1% and 14% respectively. The minimum values were exhibited by samples (such as #63, #49, #42, #7, #19, and #46) (Table 1). The maximum values were from sample # 86 and the average values for the Harer-Dire Dawa limestone are 4%. According to ERA STS 2013, the loss in weight should not exceed 10 percent for fine aggregate when tested with sodium sulfate. Thus, fortunately, only sample number 86 exceeds the maximum limit, and therefore, most samples are suitable concerning soundness. A relatively lower limit value of Na_2So_4 soundness is set for fine aggregates than coarse aggregates; because there is an interconnection between soundness or weatherability and particle sizes or surface area. The weatherability or soundness increases as particle size decreases or as surface area increases.

Results of the compressive strength value of the limestone samples range from a minimum value of 20.5 MPa to a maximum value of 180.5 Mpa, the limestone in the study area has a mean value of 84 Mpa, thus mainly classified into strong rock according to (Singh & Goel, 2011) and as medium-strong to very strong rocks. It is found that about 89% of the tested samples have a compressive strength of more than 50MPa. Hence, it is safe to say that the compressive strength values of the samples are more than 50Mpa with 95% confidence. The highest compressive strength was recorded for samples ML28 which is from biointramicritic Limestone and the lowest value is for sample ML86 from the same group. The average compressive strength results of the limestones in the study area are satisfactory and accepted results that satisfy the utilization of such rocks as crushed stones for road construction purposes.

The maximum and minimum values for AIV were 20% and 8%, respectively. The maximum value was obtained from sample #86 and the minimum AIV value is obtained from sample #46. The average value for Harer-Dire Dawa limestone is 13.2%. AIV is used as a measure of resistance to sudden impact. Low numerical value means a resistant rock (eq.3).

$$AIV\,(\%) = \left(\frac{Weight\ of\ fines\ passing\ 2.36\ sieve}{Original\ Weight\ of\ Sample} * 100\right). \qquad \text{(eq.3)}$$

AIV's, below 10 are considered as strong, and AIV's above 35 would normally be considered as too weak to be used on road surfaces. Aggregates to be used for wearing course, the AIV shouldn't exceed 30%. For water-bound macadam base courses, the maximum permissible value defined by BS 882:1992 **is 45%. Thus, as far as AIV is concerned, in the current study, all samples satisfy the requirements for road construction (Fig 6 (a)).**

On the other hand, the aggregate crushing value is a value that indicates the ability of an aggregate to resist crushing. The lower the value the stronger the aggregate is i.e. the greater its ability to resist crushing. A value below 10 signifies an exceptionally strong aggregate while above 35 would normally be considered as weak aggregates. Therefore, all the samples in the current study exhibit ACV between 10-35 (Table 1) indicating that they are strong aggregates. The degree of resistance is assessed from fines particles passing BS sieve 2.36 mm which are calculated as the percentage of initial weight. The percentage resulting is taken as a measure of the aggregate crushing value (eq.4).

$$ACV\,(\%) = \left(\frac{Weight\ of\ fines\ passing\ 2.36\ sieve}{Original\ Weight\ of\ Sample} * 100\right). \qquad \text{(eq.4)}$$

The maximum and minimum for the aggregate crushing value (ACV) ranges from 34% to 24% while the maximum ACV value was exhibited by sample no 47 from dolomitized biooospary Limestone and minimum value by sample #28 from biointramicritic Limestone. The mean value of ACV for Harer-Dire Dawa limestone is 29%. According to (Ethiopian Roads Authority Standard Technical Specification (ERA-STS), 2002), the ACV should preferably be less than 25% and in any case less than 29% for road base course (Table 2, Fig 6 (b)).

The principle of the LAAV test is to find the percentage wear due to relative rubbing action between the aggregate and steel balls used as an abrasive charge. A maximum value of 35% and 30% is allowed for road base course and wearing course in Ethiopian conditions (ERA-STS-2002 and ERA-STS-2013). The maximum and minimum LAAV were 31.1% and 18.9% respectively. The maximum value was from sample #86 and the minimum value was from sample #28. Both minimum and maximum values were obtained from the same group of limestone which is biointramicritic Limestone indicating the variation in the result is due to micro-structures and alteration or weathering.

For road sub-base applications, the LAAV shall not exceed 45% when determined following the requirements of (AASHTO T 96-94, 1994). Consequently, in the current study, all samples except sample #86 satisfy the requirement for road sub-base, base course, and bituminous bound surfacing or wearing course (30%), (Table 2 and Fig 6 (c)). Therefore, the aggregate of these limestones will not wear away; abrade too quickly particularly when present in wearing courses and surface treatments.

The results of the XRF analysis show (Fe_2O_3, MgO, CaO, and SiO_2) major oxides that dominate the rock sample in the study area. The XRF analysis of samples from Harer-Dire Dawa revealed an average value of CaO of 49.23% with average levels of MgO 1.71% (Table 3). Calcium oxide (CaO) is the most dominant oxides in all samples of the study area but Silica (SiO_2) is the next dominant.

The microscopic investigations of thirty-seven samples of the Harer limestone indicated the presence of three main components; allochems (grains), matrix (mostly micritic), and cement (spray calcite). The allochems are mainly composed of fossils. These skeletal components are embedded in micritic fine groundmass or cemented by sparitic cement.

Diagenesis processes (compaction, dissolution, cementation, recrystallization, and dolomitization) are of special importance when studying carbonate sediments because these processes modify the texture, structure, and composition of the original sediments (Alqahtani et al., 2013). Consequently, the modifications may greatly affect their mechanical properties.

The relatively higher porosity of the samples may be related to its higher bio-clastic contents. This is indicated in (Fig.7) as the percentages of bio-clastic contents increases, the porosity also increases.

The geological classification of the different limestone, in this case, is mainly based on carbonate grains. The grains include skeletal and non-skeletal grains. The skeletal grains are bioclast or fossils which were transported, broken, abraded, and still completely preserved shells such as bi-values. However, non-skeletal grains are peloids, ooids, and various coated grains. Plates 1-8 and Fig.5 (a-g) show the results of the photomicrographs and the modal composition of the various samples examined in this work. In the present study, micrite, sparite, intraclasts, ooids, fossils, peloids, clastic quartz, dolomite, and Fe-oxides are the main minerals present (Fig.5 (a-g)). From the results, it can be concluded that ML-29 has the highest percentage composition of micrite content of 60% as compared to sample #17 which is 9%. In the thin section of ML-29, micrite appears dark, featureless, and microcrystalline (plate 1). The matrix is a fine-grained, homogeneous texture, bio-clastic micrite. The slide of sample #17 contains a prominent pressure solution seam with spacing in mm laying in the horizontal direction with large stylolite. Moreover, brownish Fe-oxides staining remains in the pressure solution seam. Pressure solution can increase the dissolution of calcite and is believed to be a significant source for the formation of porosity (Erik, 2010). On the other hand, pressure solution may create conduits for fluids and open migration paths leading to low strength value of the sample. Thus ML-29 has the highest strength value as compared to sample #17. Sample #ML-24 and CL-90 contain the highest percentage of clastic quartz (plate 3) which adds to the high strength value. In these samples, (sample ML-24 and CL-90), the whole matrix is dolomite sparite, and fossils are converted to sparite. The development of a good rhombohedral structure is a typical form of dolomites and uncommon in calcites. Therefore, all these add to the high strength value. On contrary, samples # 84 and 72 contain the least clastic quartz and this adds to the lowest strength values as shown in the modal composition. The slide of sample #72, contain coated grains formed by a series of concentric layers of calcite surrounding a quartz nucleus. Oolites form quartz in the core and concentric calcites (plate 4). The calcite cement in the interparticle pores appears white and the spaces between ooids are filled by sparite. In this oolitic limestone, the Oolitic grains form rounded or spherical morphometry with a smooth surface or small scale roughness and the individual grains are supported by the sparitic matrix. The Mud-support (matrix support) fabric is indicated by grains 'floating' in lime mud (plate 4). Thus, these also contribute to the lowest strength values. The sparite of this sample is both calcite and dolomite.

The fine to medium texture of sample # ML-29 also confirmed the hardness of the rock as indicated in the results of aggregate mechanical properties (Aggregate crushing and aggregate impact values), particularly when compared with the results of sample #17. In addition, limestone sample #17 contains abundant stylolites and matrix support fabric which may make a poor aggregate (Plate 2). Stylolites are irregular, suture-like contacts produced by differential vertical movement under pressure in the presence of solution. They are marked by irregular and interlocking penetration on two sides (plate 2): Columns, pits and tooth-like projections on one side fit into their counterparts on the other side (Erik, 2010). The samples which have stylolites tend to have relatively lower compressive strength (Average value = 81Mpa) when compared to the stylolites free samples (average value = 86Mpa).

On top of this, in sample #86 though there's some clastic quartz, however the Fe-minerals in this sample show oxidation (plate 6). Thus, due to intense oxidation, it shows poor (lowest) strength and aggregate quality as compared to sample #28 (Table 12). But sample #28 (plate 5) has the very best unconfined compressive strength and comparatively lowest AIV and ACV; indicating better rock strength and aggregate quality (AIV and ACV) (Table 12). The good quality may be due to well-cemented grains, the sharpness of grain corners or irregular shape, grain supported fabrics (plate 5), as well as fossils, are filled with larger crystals (coarse) sparitic calcite. The grain-support fabric, are indicated by a little or no mud, close packing of grains, and abundance of carbonate cement in interparticle pores. In plate (8) for instance, the bio-clasts are suspended within the lime mud. Thus, matrix-supported fabric alongside the pressure solution and oxidation contributes to the poor quality of the sample. This means that the knowledge of the petrographic features of rocks is of great importance for the estimation of their engineering behavior.

Generally, materials such as chalcedony, opal, volcanic glass filling vesicles, chert (often associated with limestone), zeolites, olivine, sulfides, and sulfates are undesirable and rocks containing them in concentrations greater than 0.5 to 1.0%, should not be used as aggregates (Blyth & Freiats, 1984). Thus, based on Petrographic examination, sample #84, 90, 63, and 24 contain dolomite crystals above 60% and are potentially susceptible to alkali-carbonate reaction. Moreover, sample #2, and 29 contain chalcedony (from thin section analysis) above 1%. Therefore, they are not suitable for aggregate. However, sulfates (from the XRF test) though present, is a trace in amount or less than 1% in all samples (Table 3).

The limestone samples have a very similar chemical composition and differences in the content of major elements are insignificant (Table 3). MgO, Sio_2, Al_2O_3, Fe_2O_3, and SO_3 are also common mineral impurities that occurred in limestones. Kayaba, Soypak, & Göz, (2018) suggested an equation Eq. (1) about the calculation of chemical homogeneity of the limestone and they stated that if the chemical homogeneity of limestone is greater than >95, the limestone is homogenous.

Chemical homogeneity =100 – [$\%SiO_2 + \%Al_2O_3 + \%Fe_2O_3 + SO_3$] (eq.5)

According to (eq.5) the limestones of Harer-Dire Dawa areas are homogeneous limestone except for sample no 48, 84, 40, 71, 37, 50, 86 which has chemical homogeneity <95% (Table 3). The results of the XRF analysis show four metal oxides (Fe_2O_3, MgO, CaO, and SiO_2) that dominate the rock sample in the study area. The XRF analysis of samples from Harer-Dire Dawa revealed an average value of CaO of 49.23% with average levels of MgO 1.71%. Calcium oxide (CaO) is the most dominant oxides in all samples of the study area but Silica (SiO_2) is the next dominant. Magnesium oxide (MgO) has the highest levels found in samples number 71 and 86. Silicates (SiO_2) have the highest levels at samples #84, 48, 40, 71, 37, 50, and 67. If the Al_2O_3 content is too high, then the aggregate is deemed poor quality (Harris & Chowdhury, 2007). In the current study, this correlation is in good agreement particularly for some engineering properties such as effective porosity and AIV. However, in the current study, the researchers speculate that clay mineralogy may be the most important factor in controlling aggregate durability.

Table 3. Chemical composition of Harer-Dire Dawa limestones

Identification: Chemical Composition of Limestone						Test type: Complete silicate and sulfate analysis					Rock Type: Limestone	
No of Samples: 37						Test method: ES 1172:2 Equivalent to EN 196:2					Source: Harer-Dire Dawa Area	
S.N	Code	LOI	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	Total Carbonates	Sum	Purity %	Remark
1	7	43.30	1.94	0.40	0.03	50.87	0.48	0.13	92.06	97.15	97.50	XRF
2	16	43.27	1.70	0.32	0.08	51.77	0.13	0.08	92.79	97.35	97.82	XRF
3	48	42.19	4.47	1.23	0.87	40.38	8.80	0.07	93.95	98.01	93.36	XRF
4	72	43.32	1.84	0.43	0.16	50.05	1.60	0.09	93.36	97.49	97.48	XRF
5	77	43.52	2.66	0.56	0.32	49.80	0.45	0.09	90.04	97.40	96.37	XRF
6	84	37.91	9.49	2.53	1.49	43.00	0.28	0.06	77.49	94.76	86.43	XRF
7	60	43.45	3.08	0.53	0.63	49.49	0.78	0.11	90.31	98.07	95.65	XRF
8	17	43.24	2.37	0.77	0.34	52.50	0.12	0.22	93.91	99.56	96.30	Chemical
9	42	43.05	2.71	0.49	0.18	52.41	0.36	0.18	94.25	99.38	96.44	Chemical
10	2	42.47	2.59	0.45	0.14	50.28	0.38	0.09	90.73	96.40	96.73	XRF
11	4	43.33	1.40	0.28	0.01	51.47	0.44	0.10	93.02	97.03	98.21	XRF
12	13	43.30	1.42	0.18	0.01	51.95	0.31	0.09	93.56	97.26	98.30	XRF
13	28	42.11	3.32	0.64	0.29	49.36	0.70	0.09	89.91	96.51	95.66	XRF
14	40	41.66	4.93	0.92	0.55	47.64	0.73	0.10	86.89	96.53	93.50	XRF
15	51	43.10	1.26	0.31	0.30	51.51	0.13	0.08	92.32	96.69	98.05	XRF
16	71	43.55	4.06	1.32	1.07	32.60	15.62	0.08	96.97	98.30	93.47	XRF
17	19	43.26	2.40	0.57	0.10	49.03	1.73	0.10	91.87	97.19	96.83	XRF
18	47	42.57	3.04	0.70	0.24	52.29	0.51	0.14	94.35	99.49	95.88	Chemical
19	70	42.82	2.93	0.49	0.24	52.54	0.32	0.15	94.40	99.49	96.19	Chemical
20	25	42.32	1.46	0.37	0.13	51.33	0.51	0.08	92.95	96.2	97.96	XRF
21	37	40.25	4.71	0.62	0.65	48.32	0.36	0.08	87.20	94.99	93.94	XRF
22	50	42.08	4.68	0.93	0.54	43.79	5.5	0.10	91.85	97.62	93.75	XRF
23	63	41.75	3.06	0.81	0.38	49.92	0.52	0.07	90.43	96.51	95.68	XRF
24	67	41.09	4.32	0.37	0.09	49.46	0.48	0.11	89.53	95.92	95.11	XRF
25	86	40.99	3.89	0.8	0.56	32.96	15.6	0.09	97.57	94.89	94.66	XRF
26	99	42.67	1.47	0.33	0.02	51.82	0.38	0.09	93.49	96.78	98.09	XRF
27	82	42.83	2.93	0.42	0.42	52.38	0.3	0.14	94.07	99.42	96.09	Chemical
28	32	42.15	2.58	0.57	0.24	49.63	0.42	0.15	89.42	95.74	96.46	Chemical
29	49	43.57	1.91	0.53	0.24	50.48	2.36	0.05	94.99	99.14	97.27	Chemical
30	90	43.18	1.69	0.26	0.12	53.78	0.36	0.09	96.70	99.48	97.84	Chemical
31	10	42.68	2.68	0.48	0.11	49.81	0.62	0.11	90.50	96.49	96.62	XRF
32	24	42.84	1.71	0.43	0.32	51.03	0.39	0.08	92.12	96.80	97.46	XRF
33	29	42.61	2.60	0.40	0.16	50.47	0.48	0.11	91.32	96.83	96.73	XRF
34	46	42.39	2.29	0.53	0.29	50.53	0.46	0.12	91.39	96.61	96.77	XRF
35	78	43.05	1.12	0.22	0.01	52.19	0.16	0.08	93.61	96.83	98.57	XRF
36	58	42.14	1.96	0.53	0.48	52.07	0.24	0.12	93.39	97.54	96.91	Chemical
37	34	41.24	2.93	0.68	0.24	52.75	0.36	0.29	94.86	98.49	95.86	Chemical
Mean		**42.47**	**2.85**	**0.61**	**0.33**	**49.23**	**1.71**	**0.11**	**92.10**	**97.31**	**96.11**	

In limestone, porosities change with increasing age and/or burial depth of the sediment (Erik, 2010). As a result, some samples such as #90, 84, 2, 60, 71, 47, 59, 13, and 86 are collected stratigraphically from a higher elevation, which is younger than all the rest obtained from relatively lower stratigraphic sections.

This age difference is a good indicator of limestone quality. The younger rock typically is more poorly cemented and softer, resulting in less durable aggregate (Harris & Chowdhury, 2007).

4. Conclusion

From the achieved results, it could be concluded that there are certain limestones with chemical, physical, and strength properties that are adequate for serving as construction materials for highway pavements. This observation is based on the laboratory-obtained strength and mineralogical properties of these limestones.

The strength is mainly dependent on the presence of rifting since both minimum and maximum values are from the same group. Moreover, significantly different values were obtained for the same samples indicating the effect of rifting. When compared with the maximum permissible limits of standards the measured values of AIV for all varieties of limestone complies with standards values for pavement applications. All samples of dolomitized bio oosparry limestone are excellent for pavement base course. However, the same limestone type was evaluated as good for pavement surfacing course. Siliceous bio pel micritic limestone is also excellent for pavement works. Almost all samples collected except sample #86, 13, and 71 are evaluated as excellent for pavement base course. Under hot weather conditions, frequent contact of the limestone base-course materials with water may cause weathering of these materials (sample #86) and thus have a deleterious effect on the durability and serviceability of highway pavements. In general, the absorption results of the Harer-Dire Dawa limestone showed a very low absorption value and considered advantageous.

Aggregates of Harer-Dire Dawa limestone are more resistant to sudden impact (tough) and fragmentation by abrasion than a continuous gradual load. The average value of the fragmentation resistance (LAAV) and ACV were =23.3 and 29.3, respectively, whereas the average value of the impact resistance (AIV) was =13.2. Therefore, it can be concluded that the Harer-Dire Dawa limestone aggregates will be better suited for the construction of elements subjected to dynamic loads.

In this study, all samples except a sample with the maximum value (#86) satisfy the maximum percentage losses of Na_2So_4 soundness requirement (10%-fine aggregates and 12%-coarse aggregates) for crushed stone unbound road base course, and bituminous bound surfacing or wearing course.

Dolomitic limestones are generally preferred in asphaltic concrete wearing courses since they are generally harder and tend to polish less, thus maintaining their skid-resistance properties longer. Dolomitic limestones also have lower absorption rates and thus lead to the use of lower Bitumen Content in asphaltic concrete mixes.

Last but not least, locally available limestone, although variable in quality and physical properties, can be used in road construction applications by appropriate mining and processing where igneous source aggregate has previously been used. However, the aggregates to be used in road construction, particularly in the wearing course of the pavement should be sufficiently resistant to crushing to withstand the high stresses induced due to heavy traffic wheel loads.

The mechanical properties of the rock are greatly influenced by the composition, fabric (arrangement of intraclasts of skeletons and voids), and the diagenetic processes. Especially Stylolites are the product of intergranular pressures-solution and are pervasive in the studied limestone. The prevalent views are that the presence of stylolites significantly weakens rocks and that they induce a significant mechanical anisotropy. Therefore, the impact of stylolite on strength of limestone can’t be neglected in geotechnical applications, even if the stylolites are closed.

Generally, the results indicate that rocks of the same type in different areas have different physical and mechanical values. This is because of the difference in the geological setting and other physical properties. Thus it can be concluded that changes in texture and mineralogical characteristics due to crystallization, diagenesis, and tectonism appear to affect the engineering properties of the same rocks in different areas.

Declarations

Plates 1-8 are available in the Supplementary Files

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Competing Interests

The authors declare no competing interests.

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Figures

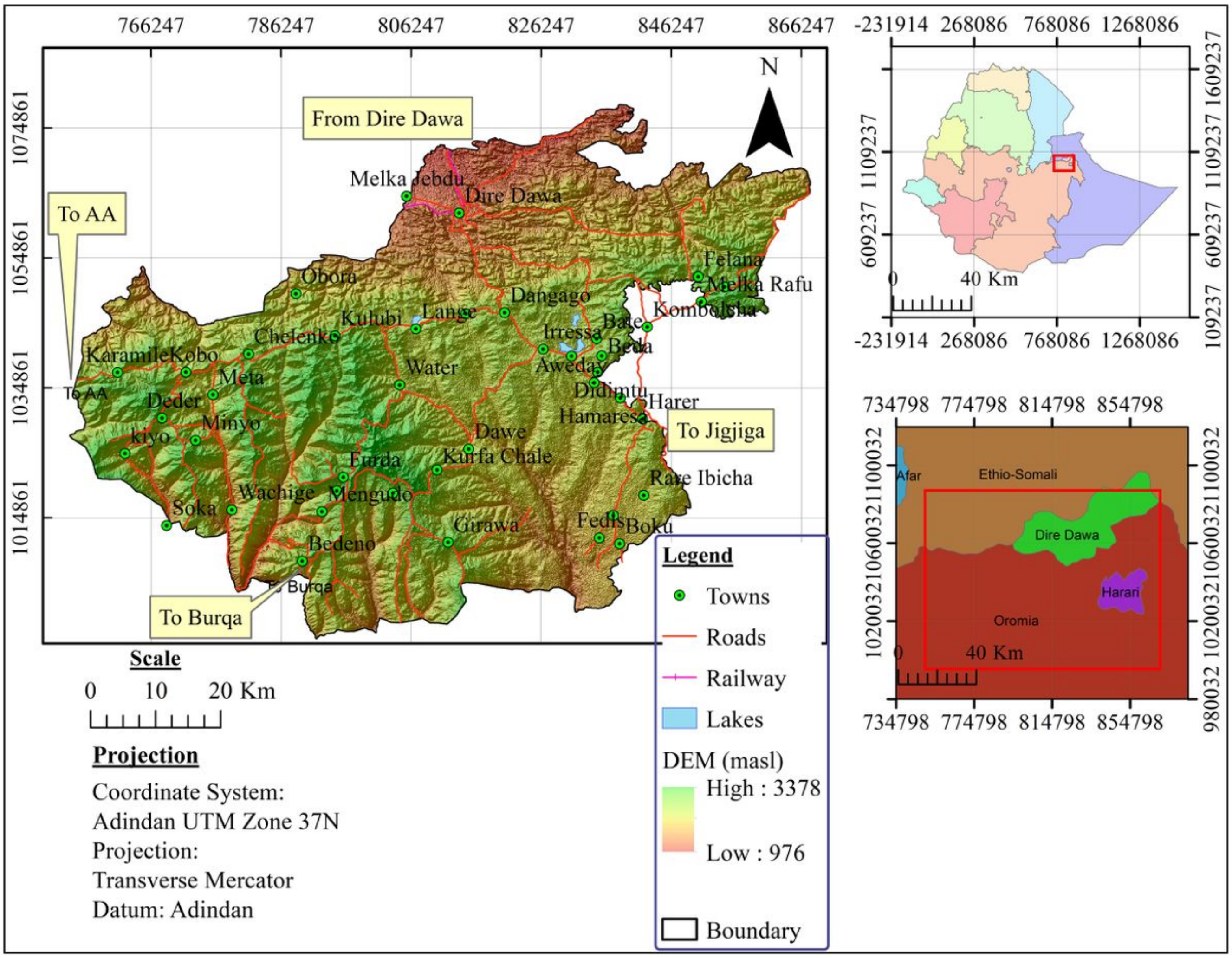

Figure 1

Location map of the study area.

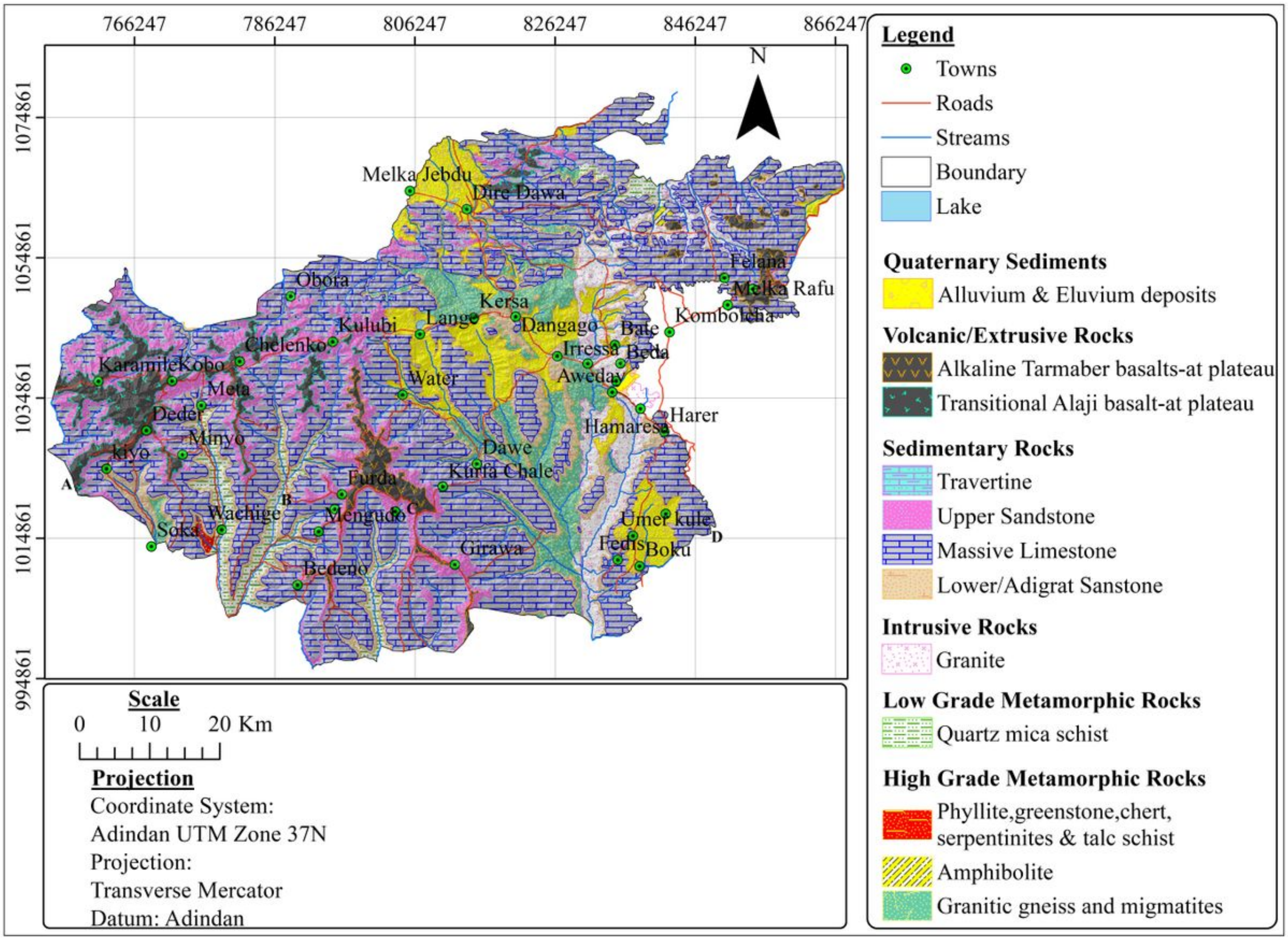

Figure 2

Geological map of the study area.

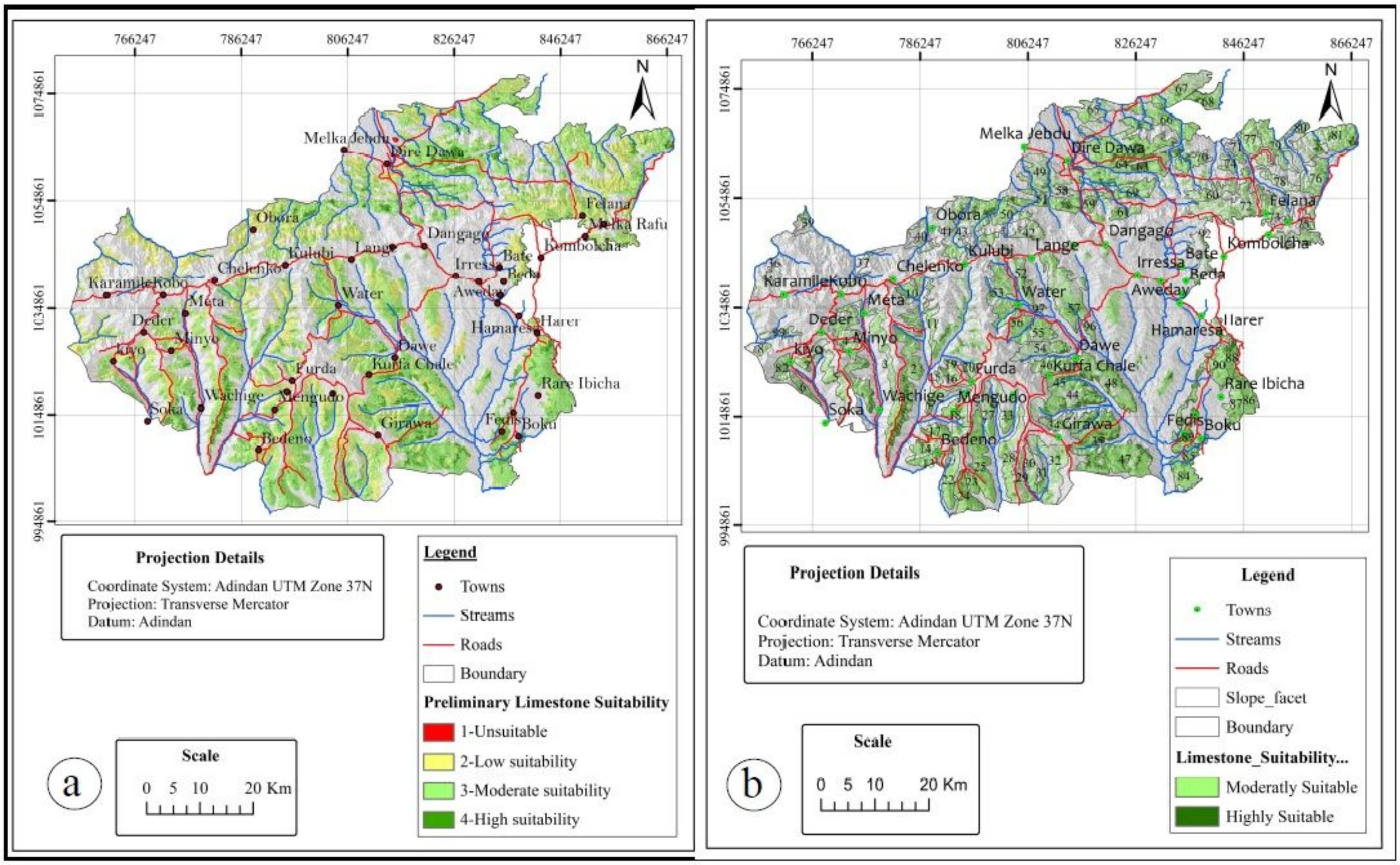

Figure 3

(a) Preliminary quarry site suitability map for all quarry sites in the study area; b) Suitability map for limestone quarry sites in the study area.

Figure 4

a) Red Band Masonry Saw for rock Cube preparation; b) Rock Cubic Specimens.

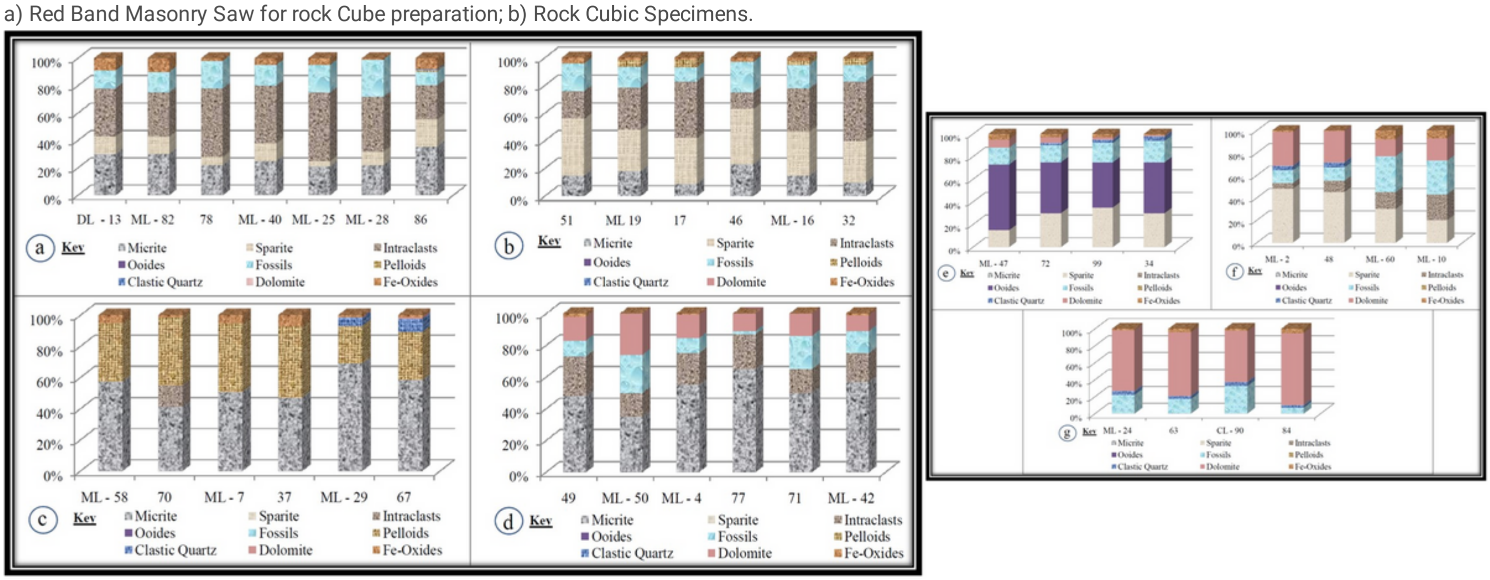

Figure 5

Modal Composition of Rocks Studied by Thin Sections Analysis (a) for biointramicritic limestone (b) for biointraspary limestone (c) for biopelmicritic limestone (d) for dolomitized biointramicritic limestone (e) for dolomitized biooospary limestone (f) for dolomitized biointraspary limestone (g) for calcareous dolomite.

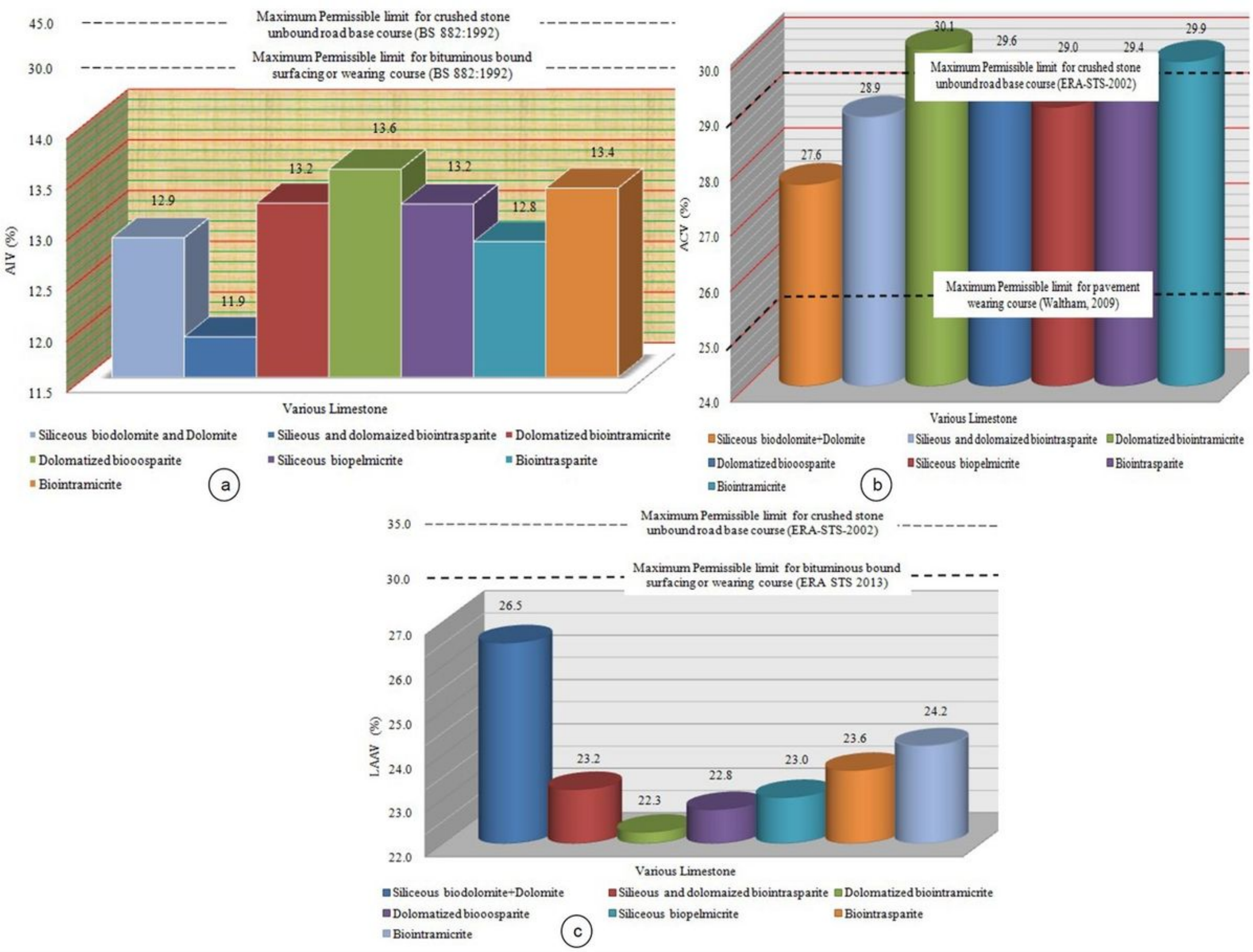

Figure 6

Bar chart showing the comparisons of a) AIV b) ACV c) LAAV for various limestones and comparison against standards.

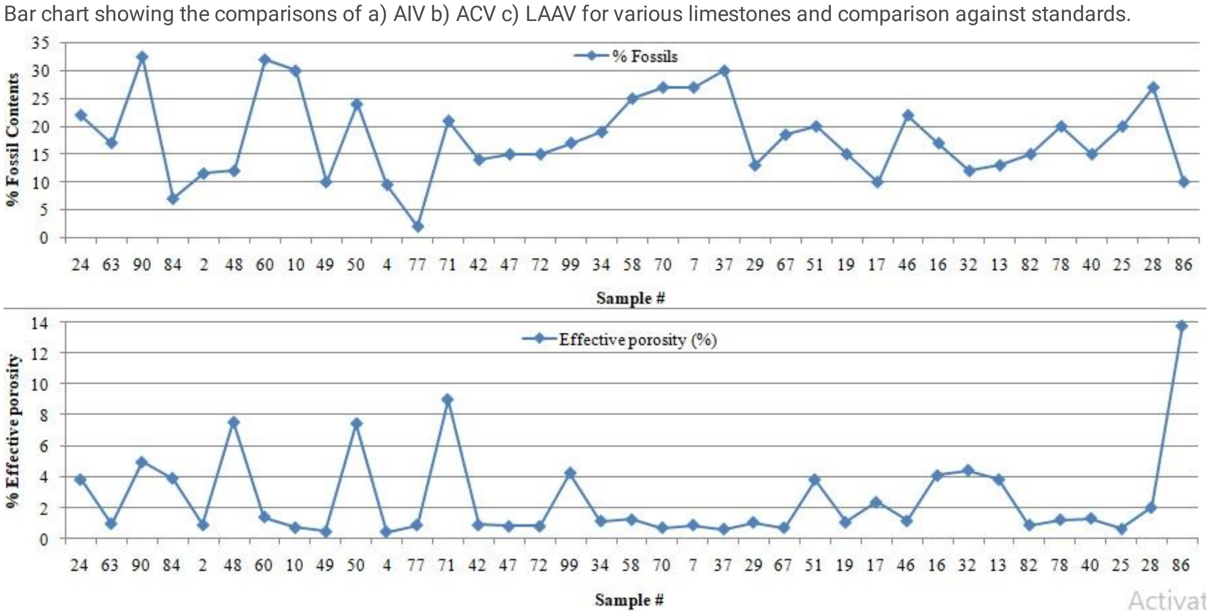

Figure 7

Comparision of the percentages of bioclasts with effective porosity.

Supplementary Files

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