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Geotechnical Study of the Aptian Limestone of the Kef Region, Northwestern Tunisia: Evaluation for Industrial Use

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Abstract

This study aims to the initial characterization of Aptian sedimentary limestones in the Kef region located in the North-West of Tunisia in order to use in industrial fields. The limestone samples were collected from three outcrops respectively named Jebel Jerissa, Jebel Hmeima and Jebel Harraba. A geochemical characterization highlights a variation of the weight percentage (wt%) as follows: CaO (53 - 55), MgO (0.04 - 0.28), Al_2O_3 (0.07 - 0.51), Fe_2O_3 (0.41 - 2.87), and a loss on ignition (41.62 - 43.35). The other oxides (K_2O, SO_3, Na_2O) are in trace amounts. Mineralogical analysis revealed that limestones contain more than 95% of calcite and the clay impurities are the minor phases detected. Petrographic study showed that these limestones are packestone-wakestone type. The hardness of Aptian limestones crosses the upper limit of the hard domain. Geotechnical tests reveal a Dry Micro Deval (MDS) coefficient varying from 23% to 33%, a Wet Micro Deval (MDH) coefficient with values oscillating around 26% to 36%, a Los Angeles coefficient (LA) about 25% against a value of the compressive strength ranging from 593 Kg/cm^2 to 866 Kg/cm^2. The gravimetric tests highlighted a flexural strength value from 106 Kg/cm^2 at 208 Kg/cm^2, while the ultrasonic coefficient oscillates from 4876 m/s to 5233 m/s, indicating the low porosity of these limestone (0.5% to 1%). The density recorded an average value of 2.50 g/cm^3. The various properties studied have proved that the limestone studied can be used in various industrial fields such steel industry, aggregate, cement industry and marble.

Keywords

Aptian Limestone, Geotechnical Properties, Geochemical Properties, Industrial Use

1. Introduction

Since the works of [1] and his successors, mainly most of them [2] [3] and [4], particular attention has been paid to the series of central and northern Tunisia of the Algerian-Tunisian borders. These series show impressive sedimentary accumulations during the Aptian-Albian periods. [2] describes the Aptian succession exceeding 2200 m thick at the Algerian-Tunisian borders. Impressive calcareous series [5] appears similar throughout the area, such as the "Limestones of Serdj" which have been deposited in certain sectors. These carbonate series belong to a vast platform that extended throughout Central Tunisia [6] and a large part of Northern Tunisia (Slata, Djerissa, Hameïma, Harraba, Boulahnèche...). We selected three study sites in the Kef area: the Hameïma, Djerissa and Harraba deposits, which will be the subject of a petrographic and geotechnical study. This area are located between 35˚15' to the south and 36˚8' to the north and meridians 8˚47' to the east and 8˚18' to the west (**Figure 1**), belongs to the topographic set of Upper Tell [7] marked by a limestone and marl-limestone geological substratum. Despite the number of studies launched in the extreme north Western Tunisia [8] [9], physicochemical and geotechnical characterization of Aptian limestones and their behavior remain unknown. The Aptian limestones

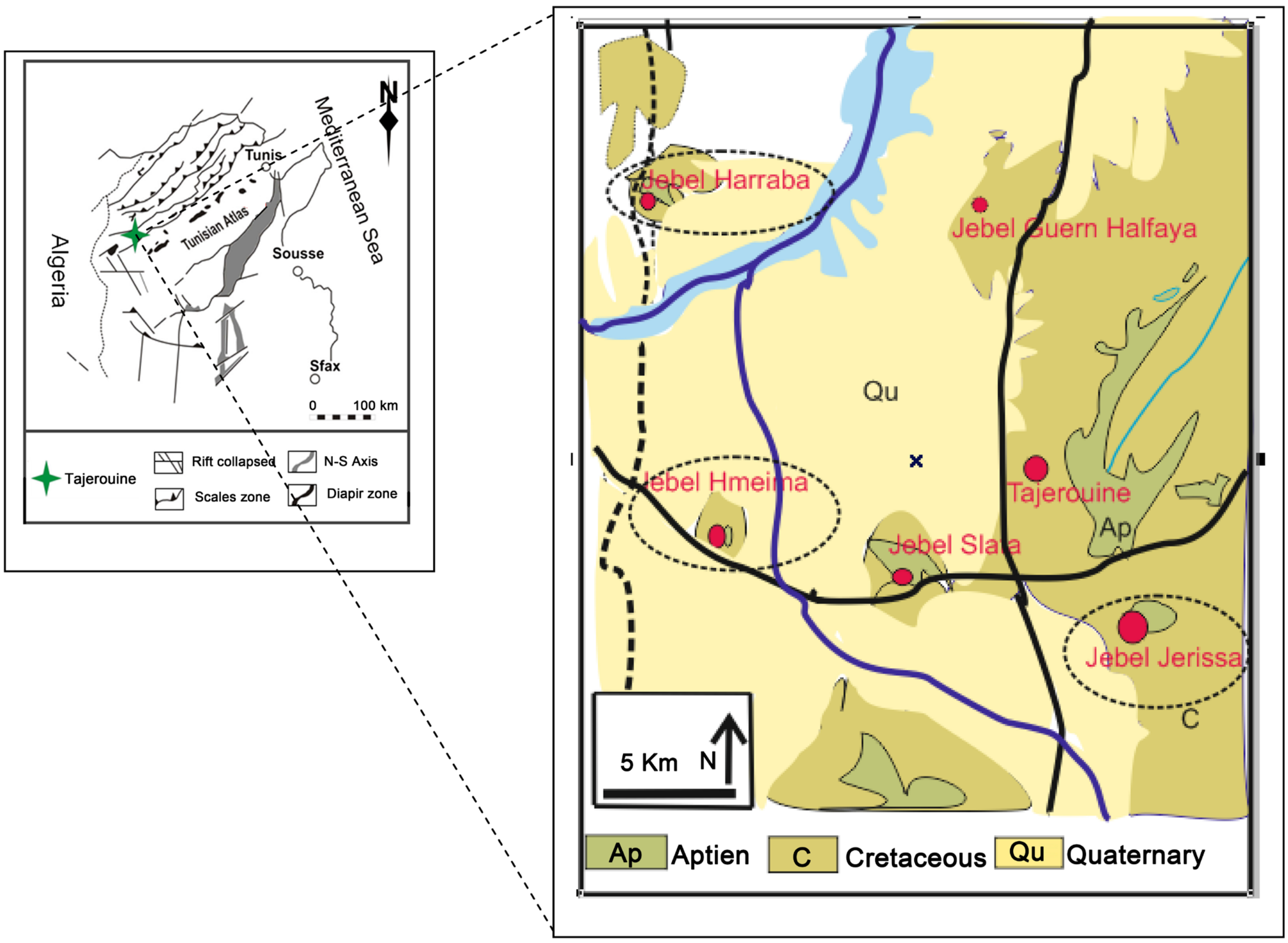

Figure 1. Location of the study area.

of the Kef area have been studied for possible use in the industrial field. The study was carried out on forty-five samples taken from the blackish gray limestone deposit of Hmeima, the deposit of Jebel Harraba and the massif of Jerissa (Figure 2).

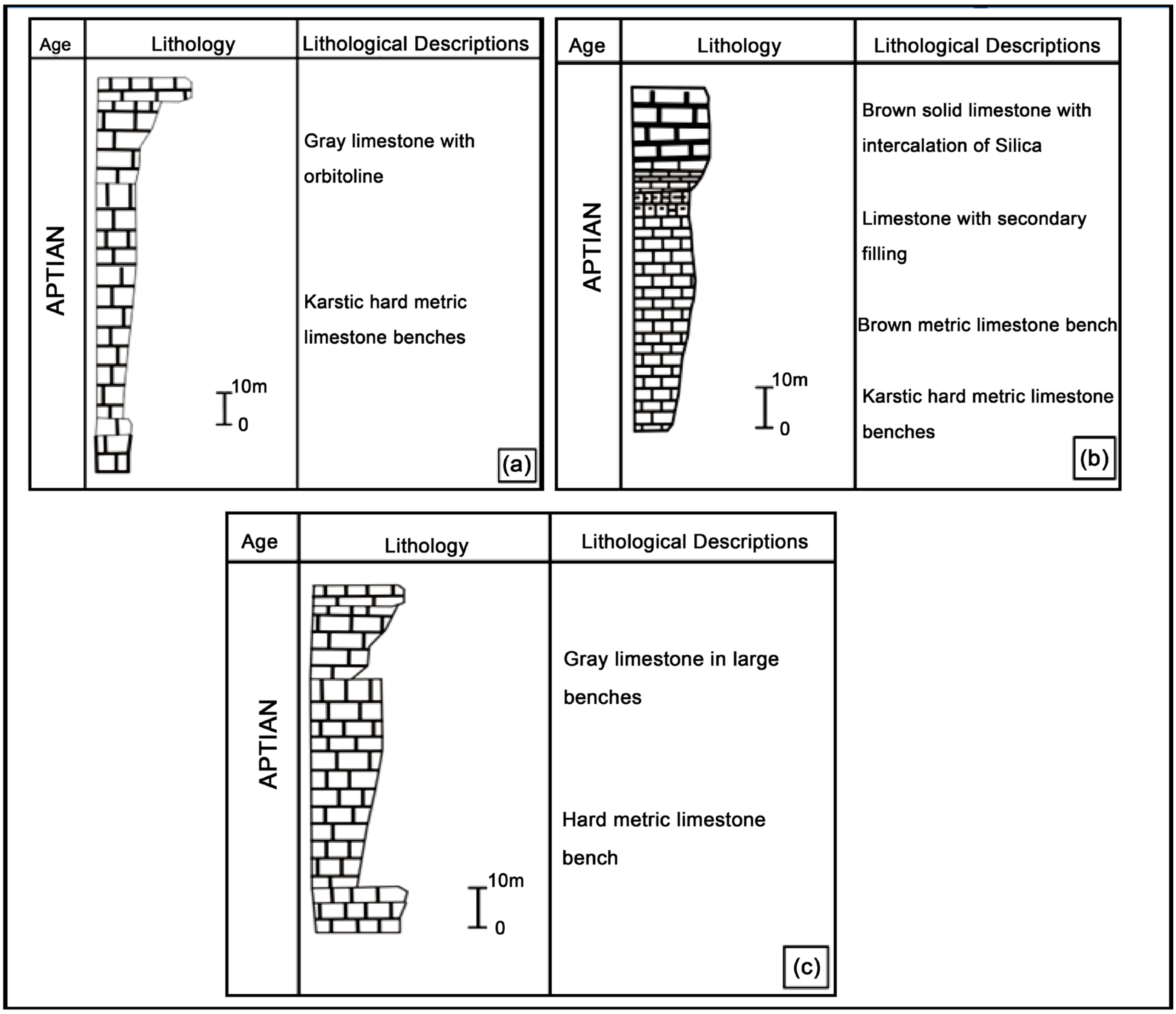

Figure 2. Stratigraphical description of J. Hmeima (a), Harraba (b) and Jerissa (c).

2. Materials and Methods

The available methods for sustainability study are described in Figure 3.

The chemical analysis of the major elements of the useful materials was assayed using the Atomic Absorption Spectrometry technique, which applied to the determination of the content of a sample in CaO, MgO, Al_2O_3, MgO, Fe_2O_3, Na_2O and K_2O. Sulfates were determined by conventional dosage and the gravimetric method for evaluating the weight loss of material after firing at 1000˚C. The mineralogical analysis was performed using an X-ray diffraction device based on the diffraction of a monochromatic X-ray beam according to Bragg's

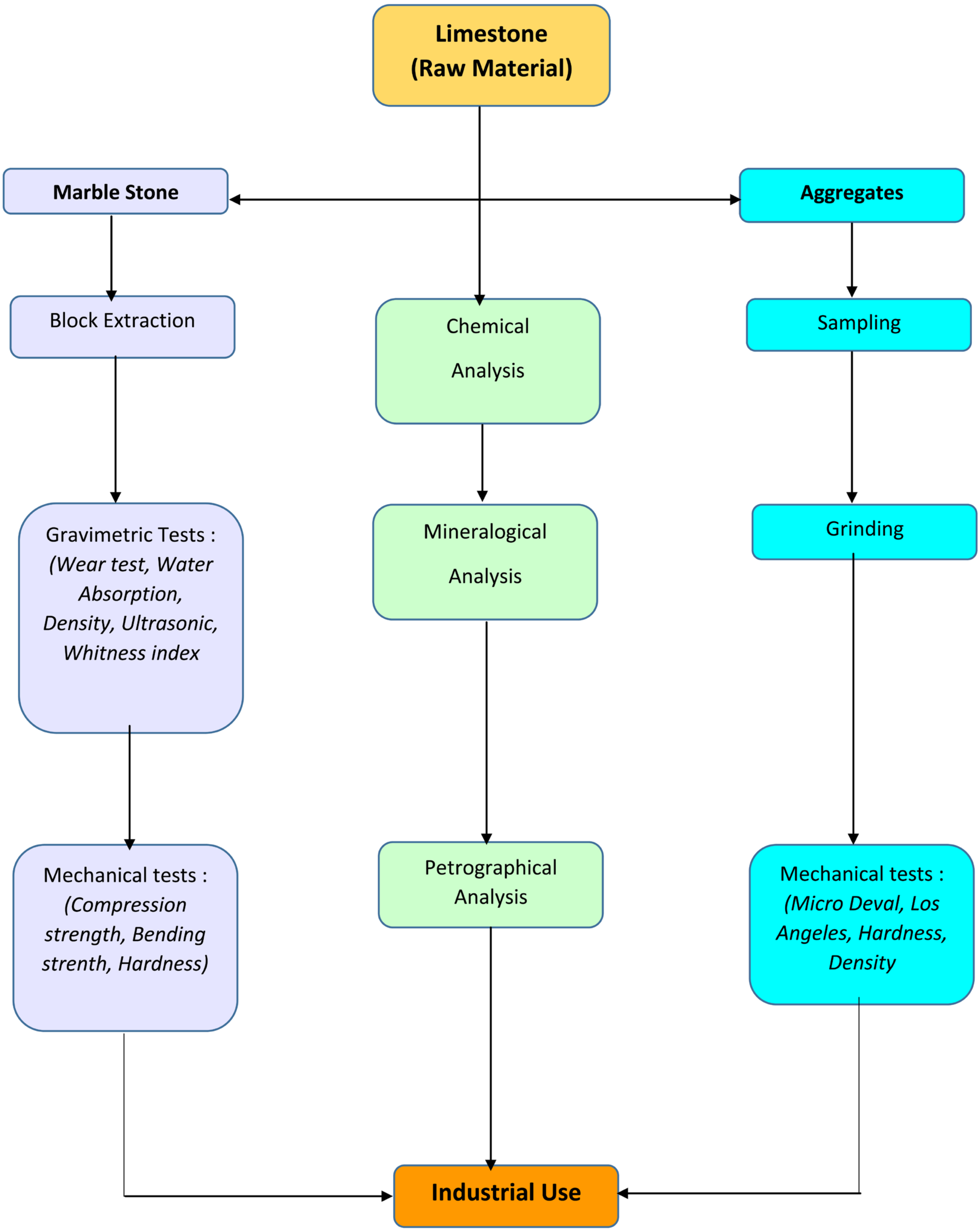

Figure 3. Methodology for limestone's study.

law. An X-ray diffraction analysis was performed on all samples of total limestone based on the use of a Philips X'Pert PRO diffractometer (CuKa, λ = 0.154056 nm, 2θ Range 3˚ - 60˚). Gravimetric testing of marble stone began with the sampling and extraction of blocks. Different block were extracted according to specimens with well-defined dimensions (Table 1).

Table 1. Dimensions of test specimens for marble stones.

	Shape of the test piece	Dimension (cm)	Number of tested pieces
Compression test	Cube	7 × 7 × 7	3
Bending test	Plate	22 × 10 × 5	3
Wear test	Plate	10 × 10 × 3	3
Water absorption test	Cube	7 × 7 × 7	5
Impact test	Plate	20 × 20 × 3	3
Real density	Cube	7 × 7 × 7	3
Apparent density	Cube	7 × 7 × 7	3
Ultrasonic testing	Prism	7 × 7 × 28	3
Porosity test	Cube	7 × 7 × 7	3

The compression strength test was carried out according to [10]. It's consists of the measurement of the resistance of the rock to crushing by progressively applying the pressure up to the break of the specimen. The test was carried out by a hydraulic press. The bending test was carried out according to [11] and consists of the measurement of the resistance of the rock to loads when it is placed above a vacuum when we applied load with an effort of 0.2 N/mm^2 per second. The real density determines the degree of compactness of the rock. The impact strength was determined according to the standard [12] and consisted in dropping a ball that weighs 1 kg attached to a wire. This mass will be released at different heights until the specimen breaks. The resistance of abrasion was achieved according to standard [13] and consists in determining the length of the print produced on the specimen by the edge of a metal disc rotating under specified conditions in the presence of abrasive material. The porosity test was carried out according to the standard [14] and aims to know the ratio of the voids in a rock. The Apparent and real densities was carried out according to standard [14]. The test samples used are dried before use at a temperature of 80 ˚C to a constant weight. The ultrasonic test is carried out in accordance with the requirements of [15]. The result defines the propagation velocity of a sonic wave across the rock.

For aggregate tests, sampling was carried out according to [16], which applies to all aggregates used for civil engineering (concrete, asphalt, surface coatings, etc.). To comply with the rules of sampling a corridor divider was used. The Los Angeles test was carried out in accordance with standard [17] and aims to determine the resistance to fragmentation of a sample of aggregate. It consists on measuring the amount of element less than 1.6 mm produced by subjecting the material to a series of friction shocks in the Los Angeles apparatus which consist of a cylinder measured inside (508 ± 5) mm and has a diameter of (711 ± 5 mm) and is manufactured with a 12 mm thick sheet. The Micro Deval test defines the wear resistance of a granulate sample according to [18]. The Micro-Deval abrasion test is a test of fine aggregate to determine abrasion loss in the presence of water and an abrasive charge. The Micro Deval apparatus consists of a number of test cylinders having a diameter of (200 ± 1) mm and an inside length of (154 ± 1) mm, watertight and laid on two horizontal supports driven by a motor rotating (100 ± 5) rpm. The stainless steel balls used have a diameter of 10 ± 0.5 mm. The tests can be carried out dry or wet. The density and absorption coefficient are determined by the pycnometer method for aggregates in accordance with [19]. The petrographic study of limestones was based on the two facies description nomenclatures, combining the nature of the constituents of the rock: cement, matrix and porous space [20] with the percentage of elements represented by (Mudstone: < 5% allochems, wackestone: >5% allochems, packstone and grainstone: Allochems joined) [21]. This study is carried out at laboratory and consists essentially of the observation by means of a Zeiss Axiosskop 40 microscope using polarized light. The interpretation of the micro facies identified was done through thin sections.

3. Results and Discussion

3.1. Chemical Analysis of Deposits in the Kef Region

Chemical analysis of Aptian limestones in the Kef area is presented in **Table 2**.

Chemical analysis of Aptian limestones (J.Harraba, J.Hmeima and J.Jerissa) showed a similarity in geochemical distribution by recording a percentage of CaO varying from 41% to 43% for all outcrops, a low content of Fe_2O_3 with the exception of Jebel Jerissa (2%), infinitesimal contents for other oxides such as MgO, Na_2O and K_2O. The loss on ignition was 42%, indicating a chemical purity of these limestones. These results are confirmed by the mineralogical analysis (**Figure 4**), where the XRD patterns show a very high content of $CaCO_3$ (with an average of 95.80%) with low impurity contents.

Table 2. Chemical results of the Aptian limestone of the Kef area.

Samples	L.O.I	CaO	Fe_2O_3	SiO_2	Al_2O_3	MgO	Na_2O	K_2O
Har 1	45.30	53.1	0.29	0.95	0.2	0.14	0.01	0.01
Har 2	45.36	52.76	0.26	1.05	0.3	0.25	0.01	0.01
Har 3	45.44	52.34	0.32	1.4	0.23	0.23	0.01	0.03
Har 4	44.56	52.32	0.95	1.6	0.35	0.18	0.02	0.02
Har 5	44.13	53.22	0.82	1.2	0.35	0.24	0.02	0.02
Har 6	44.25	53.15	0.74	1.2	0.35	0.28	0.02	0.01
Har 7	43.03	54.13	0.95	1.23	0.3	0.25	0.08	0.03
Har 8	43.14	54.18	0.84	1.23	0.3	0.28	0.02	0.01
Har 9	43.00	54.25	0.75	1.31	0.36	0.29	0.01	0.03
Har 10	42.53	54.88	0.75	1.14	0.41	0.25	0.01	0.03
Har 11	42.44	54.14	0.92	1.3	0.89	0.25	0.02	0.04
Har 12	42.30	54.2	0.95	1.35	0.87	0.24	0.02	0.07

Continued

Har 13	41.51	54.3	1.5	1.37	0.91	0.31	0.02	0.08
Har 14	41.64	54.15	1.5	1.32	0.95	0.33	0.03	0.08
Har 15	41.64	54.19	1.53	1.35	0.89	0.3	0.02	0.08
Average value	**43.35**	**53.69**	**0.87**	**1.27**	**0.51**	**0.25**	**0.02**	**0.04**
Hme 1	45.19	54	0.1	0.45	0.06	0.1	0.02	0.08
Hme 2	44.42	54.7	0.2	0.19	0.09	0.3	0.02	0.08
Hme3	43.37	55.8	0.24	0.33	0.06	0.1	0.01	0.09
Hme 4	43.19	55.9	0.3	0.21	0.08	0.2	0.03	0.09
Hme 5	44.44	54.6	0.1	0.35	0.07	0.3	0.02	0.12
Hme 6	43.82	55.2	0.11	0.44	0.09	0.2	0.02	0.12
Hme 7	43.12	55.1	0.31	1.1	0.05	0.2	0.02	0.1
Hme 8	43.47	54.2	0.63	1.12	0.06	0.4	0.02	0.1
Hme9	42.18	55.5	0.6	1.11	0.06	0.4	0.01	0.14
Hme 10	42.7	55.3	0.5	1.1	0.07	0.2	0.01	0.12
Hme 11	41.7	55.4	0.5	2.12	0.05	0.1	0.01	0.12
Hme 12	41.29	55.5	0.6	2.15	0.02	0.3	0.01	0.13
Hme 13	41.89	54.8	0.6	2.01	0.05	0.5	0.01	0.14
Hme 14	41.05	55.5	0.6	2.21	0.08	0.4	0.01	0.15
Hme 15	40.9	55.5	0.7	2.15	0.09	0.5	0.01	0.15
Average value	**42.85**	**55.13**	**0.41**	**1.14**	**0.07**	**0.28**	**0.02**	**0.12**
Jer 1	43.64	52.3	2.21	1.57	0.24	0.01	0.01	0.02
Jer 2	44.72	51.4	2.18	1.36	0.22	0.02	0.02	0.08
Jer 3	43.76	51.2	2.11	2.62	0.21	0.02	0.01	0.07
Jer 4	42.77	52.18	2.12	2.61	0.22	0.02	0.01	0.07
Jer 5	43.26	52	1.89	2.55	0.2	0.02	0.02	0.06
Jer 6	40.76	54.22	2.18	2.54	0.21	0.02	0.01	0.06
Jer 7	41.92	53.11	2.13	2.51	0.22	0.05	0.01	0.05
Jer 8	40.66	53.72	2.13	3.12	0.22	0.08	0.01	0.06
Jer 9	41.38	53.2	1.94	3.11	0.23	0.07	0.02	0.05
Jer 10	41.57	52.83	2.17	3.11	0.21	0.04	0.01	0.06
Jer 11	40.22	54	2.31	3.12	0.21	0.07	0.01	0.06
Jer 12	39.62	53.95	1.92	4.13	0.23	0.08	0	0.07
Jer 13	39.54	54.04	2.11	4	0.22	0.02	0.01	0.06
Jer 14	40.04	53.55	1.97	4.16	0.21	0.02	0.01	0.04
Jer 15	40.38	53.14	2.18	3.96	0.21	0.07	0.01	0.05
Average value	**41.62**	**52.99**	**2.10**	**2.96**	**0.22**	**0.04**	**0.01**	**0.06**

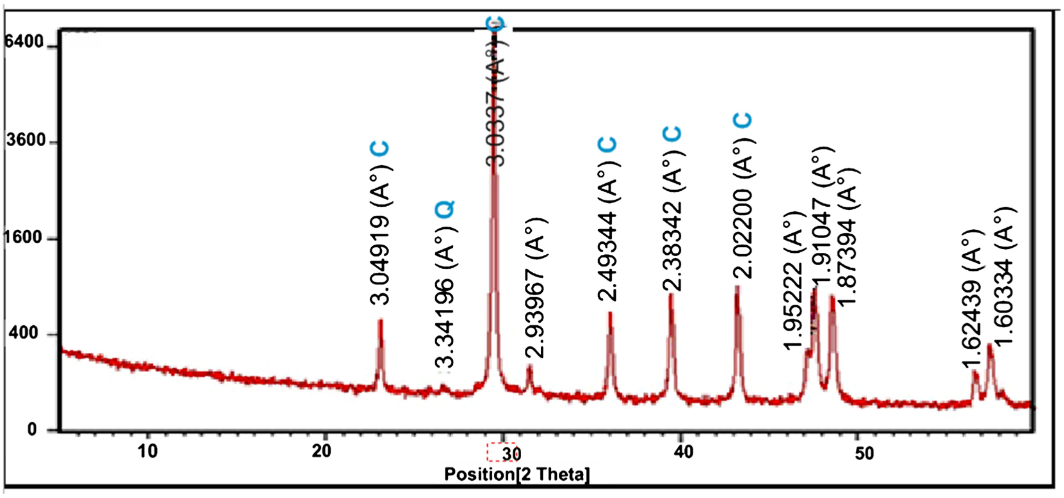

Figure 4. XRD patterns of the Aptian limestone of the Kef region (J.Hmeima).

3.2. Gravimetric Characterization of the Aptian Limestones of the Kef Region

The results of the gravimetric tests of Aptian limestones are presented in Table 3.

Gravimetric tests of Aptian limestones showed an acceptable flexural strength of 200 Kg/cm^2 compared to a compressive strength of around 600 Kg/cm^2 and sometimes greater than 850 Kg/cm^2 (J. Jerissa). The impact wear values were greater than 28.44 mm, while the ultrasonic coefficients oscillate around 5000 m/s, indicating the low porosity of this limestone (0.5%). All samples showed a reduction in strength, probably caused by the cementing material, which in this case is calcite [22]. Other possible explanation is the reduction of surface particle energy [23], or a modification of particle binding due to interstitial pressure in poorly drained samples [24]. Analysis of the whiteness of limestones revealed a whiteness index of 83.22% and a chromatic tendency towards yellow (J. Harraba) or gray (J. Hmeima) or brown (J. Jerissa).

3.3. Mechanical Characterization of Aptian Limestones of the Kef Region

The results of the mechanical tests of Aptian limestones are presented in Table 4.

Aptian limestones in the Kef region have a variable Dry Micro Deval (MDS) coefficient about 32% for the outcrops of Harraba and Hmeima compared to a value of 23% for that of Jerissa. The Wet Micro Deval (MDH) coefficient was around 33% for the Harraba and Hmeima deposits against a lower value for the Jerissa deposit. This is due to the presence of a ferruginous matrix acting as cement. The Los Angeles coefficient (LA) was about 25%. The values of compressive strength have an interesting value for Jerissa limestone (866 Kg/cm^2) compared to the acceptable values for the two others deposits. All limestones studied had an apparent density (MVA) and a Real density (MVR), varying from 2.66 g/cm^3 to 2.67 g/cm^3. The study of the limestone hardness in the Kef area (Figure 5) showed that all Aptian limestone deposits are able to cross the limit of hard field according to [25]. These results were confirmed by [26] who reported a hardness value rating of 7 to 8 and a compressive strength of 662 bars and a specific gravity of 2.54 g/cm^3.

Table 3. Gravimetric result of the Aptian limestone of the Kef region.

Samples	Flexion (bars)	Compression (bars)	Wear (mm)	Water Absorption (%)	Density (g/cm^3)	Ultrasonic (m/s)	Whiteness index
Har 1	200	620	36	0.9	2.46	4918	80.12
Har 2	205	620	37	0.93	2.45	4915	81.11
Har 3	205	630	37	0.92	2.5	4917	81.2
Har 4	210	650	36	0.94	2.5	4910	80.27
Har 5	205	644	36	0.95	2.5	4908	80.24
Har 6	205	680	34	0.14	2.5	4915	80.31
Har 7	212	685	34	0.15	2.5	4905	80.28
Har 8	215	695	33	0.17	2.51	4904	80.1
Har 9	216	700	33	0.2	2.52	4908	80.02
Average value	**208**	**658**	**35**	**0.59**	**2.49**	**4911**	**80.41**
Hme 1	104	540	32	0.9	2.56	4865	79.23
Hme 2	105	550	32	0.94	2.55	4865	72.11
Hme 3	105	570	31	0.95	2.5	4865	73.28
Hme 4	106	570	31	0.94	2.5	4880	73.27
Hme 5	105	590	30	0.94	2.52	4833	73.74
Hme 6	105	600	30	0.95	2.54	4874	73.11
Hme 7	108	610	29	0.95	2.55	4880	73.78
Hme 8	108	620	29	1	2.54	4881	73.33
Hme 9	110	630	29	1	2.55	4882	73.68
Average value	**106**	**586**	**30**	**0.95**	**2.53**	**4870**	**73.95**
Jer 1	200	760	28	0.6	2.5	5230	71.25
Jer 2	200	750	26	0.5	2.5	5235	70.13
Jer 3	201	770	27	0.62	2.5	5215	70.42
Jer 4	201	850	26	0.75	2.5	5250	70
Jer 5	202	810	26	1.05	2.52	5240	70.1
Jer 6	201	860	28	1.14	2.52	5220	70.5
Jer 7	204	940	27	1.35	2.52	5230	70.4
Jer 8	204	950	27	1.6	2.53	5240	70.2
Jer 9	205	990	28	1.6	2.53	5238	70.2
Average value	**202**	**853**	**27**	**1.02**	**2.51**	**5233**	**70.36**

Table 4. Geotechnical test results of limestone from the Kef region.

Sample	Dry Micro Deval (MDS) %	Wet Micro Deval (MDH)%	Los Angeles (LA)%	Compressive Strength (Rc) Kg/cm^2	Apparent Density (MVA) g/cm^3	Real Density (MVR) g/cm^3
Har 1	33	35	25	625	2.66	2.65
Har 2	32	36	26	615	2.52	2.55
Har 3	34	38	26	620	2.6	2.63
Har 4	35	37	25	650	2.65	2.67
Har 5	34	37	26	645	2.65	2.68
Har 6	34	36	26	685	2.69	2.7
Har 7	33	35	24	685	2.73	2.75
Har 8	32	36	24	697	2.71	2.74
Har 9	32	35	23	700	2.74	2.75
Average value	**33**	**36**	**25**	**658**	**2.66**	**2.68**
Hme 1	31	33	23	550	2.67	2.68
Hme 2	32	34	25	560	2.66	2.67
Hme 3	32	35	26	580	2.66	2.67
Hme 4	31	34	25	590	2.66	2.67
Hme 5	31	33	26	595	2.65	2.66
Hme 6	30	33	26	610	2.65	2.66
Hme 7	29	34	27	615	2.65	2.66
Hme 8	29	33	27	620	2.65	2.66
Hme 9	29	32	27	625	2.66	2.67
Average value	**30**	**33**	**25**	**593**	**2.66**	**2.67**
Jer 1	19	22	22	770	2.64	2.65
Jer 2	20	24	22	755	2.65	2.65
Jer 3	25	26	23	795	2.65	2.65
Jer 4	24	26	23	860	2.64	2.65
Jer 5	24	26	25	825	2.61	2.65
Jer 6	25	26	25	875	2.65	2.65
Jer 7	26	27	24	965	2.65	2.66
Jer 8	26	28	24	970	2.64	2.7
Jer 9	26	29	22	980	2.65	2.71
Average value	**23**	**26**	**23**	**866**	**2.64**	**2.66**

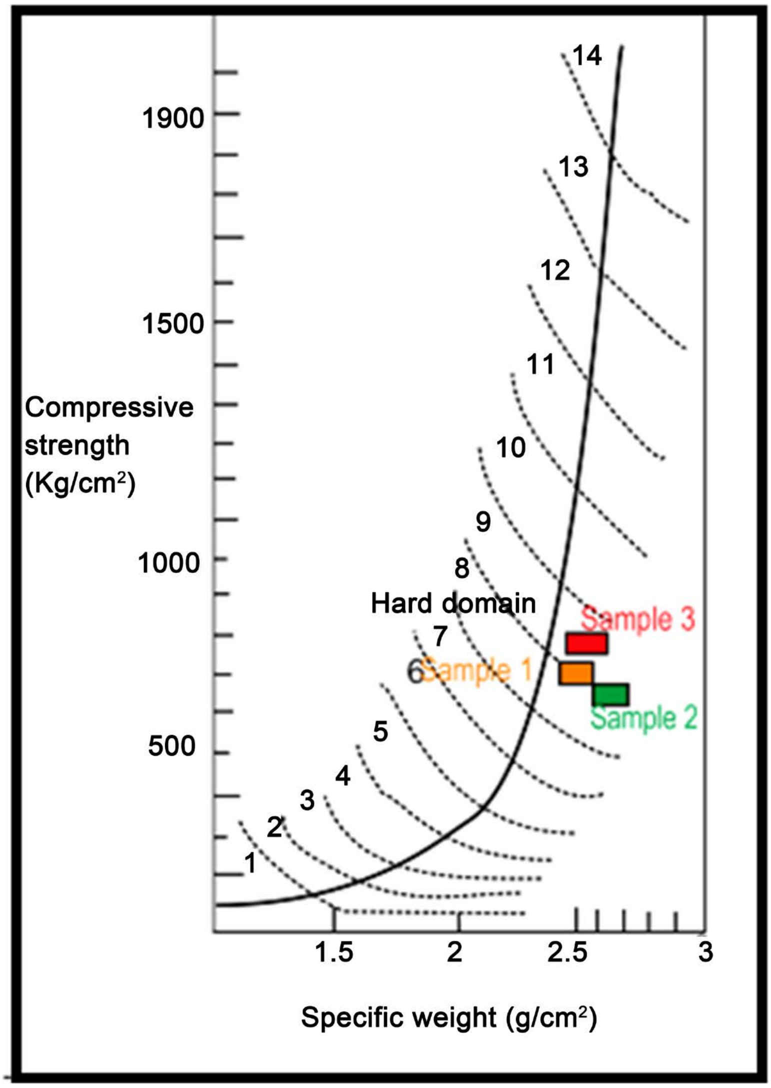

Figure 5. Hardness diagram of the Aptian limestone of the Kef area.

3.4. Petrographic Study

The petrographic examination of thin section representing the facies of the Aptian limestones (**Figure 6**) highlighted ferruginous inclusions in the cement and revealed the existence at least of two distinct phases of filling in karst. The karst affects the last calcareous bed of the Formation Serdj [27]. This bench is a wackestone-packstone limestone with orbitolina type (*Mesorbitolina texana, Paracoskinolina tunisiana and Archaeoalveolina reicheili*), milioles and rudists according to [28] [29]. The uniformity of these facies reveals a homogeneous and continuous sedimentation character. The karstic surface was found in our three study sites: Hameïma, Harraba and Jerissa. Unlike in the last 50 meters of the Serdj Formation of the Harraba deposit, we found ammonites *Mellegueicerasechihaouiae*, as well as poorly preserved *Douvilleiceratidae*. The presence of phosphate forms suggested that they are reworked and highlight an Aptian-Albian line [30].

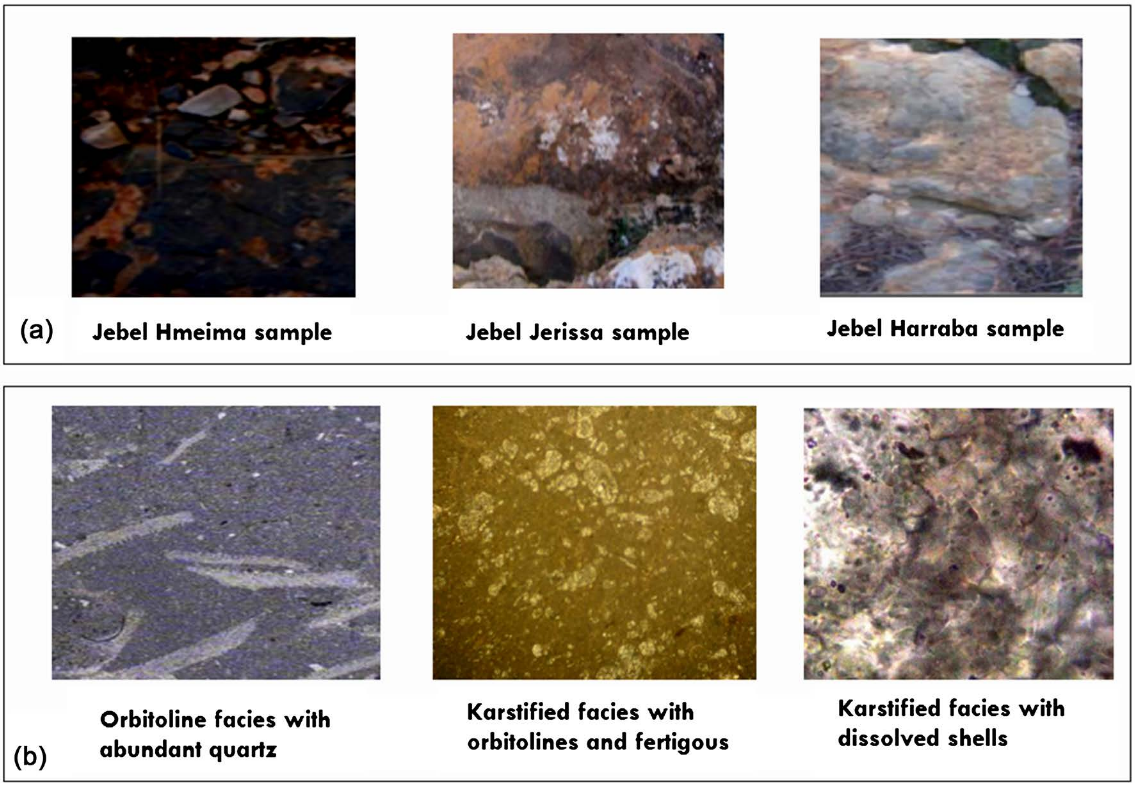

Figure 6. Petrographic facies of the Aptian limestones of the Kef region. (a) Limestone samples; (b) Microscopic Observation of each limestone sample (Grx5).

3.5. Industrial Use of Limestone

3.5.1. Technological Characterization Parameters for Aggregates

The specifications of the aggregates are based on their mechanical strength: Los Angeles and Micro-Deval [31]. The specifications (Table 5) of the aggregates take into account the different fields of use depending on the association with hydraulic hydrocarbon binder [32].

The characteristics of aggregates used in concrete (Table 6), as defined either by [33] [34], rely mainly on their mechanical characteristics such as the Los Angeles, Micro-Deval and the water absorption coefficient.

The cement is generally made from a mixture of limestone and marl fired at a temperature close to 1450˚ C. The product thus formed is in the form of a module called Clinker, which, after fine grinding, will be added with a little addition (gypsum) to provide Portland cement. The quality criteria and permissible limits of the different cement components are shown in Table 6. Aptian Limestones of the Kef region can be used as a basis for the manufacture of cement CPA according Tunisian [35], but a restriction relative to their use for the production of hydraulic lime when their use is conditioned by chemicals corrections. In spite of their lithology, limestones have acceptable brightness index, however, its chromatic tendency towards yellow can play as a limiting factor for industrial use. The effect of oxidation by iron oxides is always felt. The calculation of the silica modulus (MS) and Alumino-ferric (MAF) modulus with the addition of

Table 5. Specifications for road aggregates.

Pavements type 4			
Bituminous concrete		**Top rendering**	
LA	MDH	LA	MDH
25 ≤ LA ≤ 30	20 ≤ MDH ≤ 25	≤25	≤20
Pavements type T3			
Bituminous concrete		**Top rendering**	
LA	MDH	LA	MDH
20 ≤ LA ≤ 25	15 ≤ MDH ≤ 20	≤25	≤20
Pavements type T2			
Bituminous concrete		**Top rendering**	
LA	MDH	LA	MDH
25 ≤ LA ≤ 30	20 ≤ MDH ≤ 25	≤25	≤20
Pavements type T1			
Bituminous concrete		**Top rendering**	
LA	MDH	LA	MDH
25 ≤ LA ≤ 30	20 ≤ MDH ≤ 25	≤25	≤20
Pavements type T0			
Bituminous concrete		**Top rendering**	
LA	MDH	LA	MDH
LA ≤ 25	MDH ≤ 20	≤20	≤10

Table 6. Criteria for the use of aggregates in ordinary concrete and cement.

Concrete						
LA	**MDH**	**Water Absorption**	**Silicic Modulus (MS)**	**Alumino-Ferric modulus (MAF)**		
≤40	≤35	0.5	2.4 < MS < 2.7	1.5 < MAF < 2.5		
CaO	MgO	Al_2O_3	Fe_2O_3	SiO_2		
>51	<2	<1	<1	<6		
White Cement						
MS	MAF	DS				
≥2.4	≤2	≥0.95				
Hydraulic lime						
MS	DS	IH				
≥2.4	≥0.95	0.45 < IH < 1				
Quick lime						
$CaCO_3$	MS	MAF	DS			
>98	≥2.4	≤2	≥0.95			
Portland Cement						
CaO	MgO	Al_2O_3	Fe_2O_3	SiO_2	MS	MAF
>51	<2	<1	<1	<6	2.4 < MS < 2.7	1.5 < MAF < 2.5

the marls of the region give satisfactory results. For the field of concrete the carbonate outcrops find their place despite their inter-variability.

3.5.2. Criteria for Chemical and Agricultural Use of Limestones

Calcium carbonates and lime, derived from limestone, are widely used in agriculture, both as an amendment or soil corrector, as well as in the processing of agricultural products (sugar manufacture), animal, and human feed. The selection criteria for the use of limestone are presented in **Table 7**. For certain uses other criteria are required such as the whiteness at least equal to 85% for the fillers and the compressive strength > 400 Kg/cm^2 for the rocks dedicated to lime.

All the carbonate deposits studied are favorable for use in the field of chemistry. Their calcium carbonate content and the chemical composition of all the calcareous deposits reveal an interesting mineralogical purity and homogeneity. The $CaCO_3$ content greatly exceeds 95%. This use is strongly conditioned by the variability of the values recorded which is due to the degree of recrystallization and the limestone porosity in relation to the Grain dimensions which form the carbonated cement.

Table 7. Chemical criteria required according to the use of limestone [32].

		Steel industry			
CaO	MgO	Al_2O_3	Fe_2O_3	SiO_2	
>51	<2	<1	<1	<6	
		Chemical industry			
CaO	MgO	Al_2O_3	Fe_2O_3	SiO_2	S
>50	>1	<0.2	<0.3	ε	<0.1
		Charge			
CaO	MgO	Al_2O_3	Fe_2O_3	SiO_2	
>55		<0.2	<0.2	ε	
		Flue gas treatment			
CaO	MgO	Al_2O_3	Fe_2O_3	SiO_2	
>51	<1.5			<0.1	
		Glassware			
CaO	MgO	Al_2O_3	Fe_2O_3	SiO_2	
>55		<0.7	<0.1	<0.3	
		Calcium carbonate			
CaO	MgO	Al_2O_3	Fe_2O_3	SiO_2	
>55	<0.59	0.045	0.04	0.12	
		Agriculture			
Whiteness	compressive strength				
> 85	>400				

3.5.3. Possibilities of Industrial Use of the Aptian Limestone Deposits of the Kef Area

The use of limestone in marble industry depends on numerous parameters. The degree of importance relative to each technical parameter of the marble stones studied in relation to the various use in the field of construction was presented in Table 8.

The Aptian limestone of the Kef region can be used in various industrial fields such as the marble quarry sector. Since all deposits are favorable for use as a marble stone, a deposit study has objectified the estimation of the volume and dimensions of the blocks (Figure 7) that could be extracted according to the

Table 8. Industrial parameters for use in marble [36].

	Apparent density (g/cm^3)	Water absorption (%)	Compressive strength (bar)	Bending strength (bar)	Shock value (cm)	Wear value (mm)	Ultrasonic (m/s)
Exterior Siding	●●	●●	●●	●●●		●	●●
Interior Siding	●●	●	●	●			●●
Paving Outside	●●	●●	●●	●●	●●●	●●●	●●
Interior Paving and stair Lining	●●	●	●	●●	●●●	●●●	●●
Suspended Staircase	●●	●	●●	●●●	●●●	●●●	●●

●●●: Very important; ●●: Important; ●: Low importance.

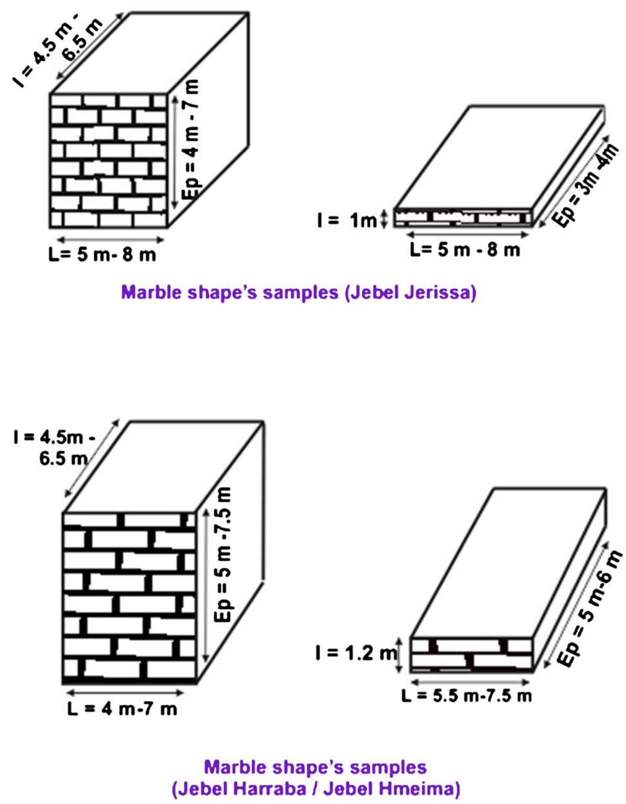

Figure 7. Block Diagram of the dimensions of the marble blocks extracted from the Aptian limestone.

Table 9. Dimensions of marble blocks as a function of fracture index.

	Minimal Thickness (m)	Maximum Thickness (m)	Fracture Index (IF)	L(m)	l(m)	Minimum Volume Vm (m^3)	Maximum Volume VM (m^3)
Hme	1.2	5.5	0.1	7	6.5	54.6	250.25
Har	1.2	5	0.1	7	5.5	46.2	192.5
Jer	0.8	5.5	0.114	8	5	32	220

fracturing density (length, Width, thickness) recorded. [37] suggests that marble does not exist anywhere in Tunisia. However, slightly metamorphosed and/or recrystallized carbonates, giving good polish and good color, were able to impose themselves on the national and international market. The work of these authors was able to distinguish clearly lower gravimetric characteristics for the Eocene limestone of Tunisia (Kesra Marble) with a porosity ranging from 1.6% to 4%, a compressive strength ranging from 450 Kg/cm^2 to 1250 Kg/cm^2 and a water absorption value varying from 0.25% to 1.7%. The extracted blocks can have a volume ranging from 32 m^3 to 250 m^3 (**Table 9**).

4. Conclusion

The study of the carbonate deposits of the Kef region has objectified the Aptian limestones. The calcium carbonate content and the chemical composition of all the calcareous deposits show a very high purity and mineralogical homogeneity. The geotechnical resistance tests showed that limestones are compact and massive. These results are confirmed by gravimetric tests. Despite its lithology described as a pakestone-wakestone limestone, the Aptian limestones of the Kef region have an acceptable whiteness index; however, its chromatic tendency towards yellow may be a limiting factor for industrial use. The effect of oxidation by iron oxides is always felt. The variability of the geotechnical and gravimetric values is due to the degree of recrystallization and to the porosity of the limestones and to the fineness of the grains that form the carbonate cement. The limestones offer a multitude of industrial use in the field of construction (marble, cement, calcium carbonate), in the infrastructure (aggregates) and in the field of chemistry and the siderurgy. This study will help to understand the behavior of Aptian calcareous limestone for different industrial use fields, however more detailed studies should be undertaken and data set is required to launch economic projects.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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