

Final Report

Commercial name of analysed material: Piedra Paloma

Requested by: Piedra Paloma S.L.

January 2011

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RESULTS

Denomination (UNE-EN 12440)	Term
Petrographic denomination:	Oosparite, Oolitic limestone
Commercial denomination:	Piedra Paloma

Physical characteristics according to UNE-EN Natural Stone standard tests	Mean value
Water absorption at atmospheric pressure (UNE-EN 13755) (%):	4,4 ± 0,1
Apparent and real density, and open and total porosity (UNE-EN 1936):	
Apparent density (Kg/m ³):	2379 ± 10
Real density (Kg/m ³):	2734 ± 19
Open porosity (%):	11,4 ± 0,2
Total porosity (%):	15,3 ± 0,7
Flexural strength under concentrated load (UNE-EN 12372):	
Mean value (MPa):	13,8
Standard deviation (MPa):	0,8
Low expected value (MPa):	12,17
Uniaxial compressive strength (UNE-EN 1926) (MPa):	98,8 ± 16,7
Breaking load at dowel hole (UNE-EN 13364) (N):	1100 ± 200
Abrasion resistance (UNE-EN 1341; Annex C) (mm):	24,9 ± 0,4
Rupture energy (UNE-EN 14158) (J):	1,2 ± 0,3
Slip resistance (UNE-EN 14231)	
Wet conditions	63,8 ± 3,9
Dry conditions	64,0 ± 1,1
Water absorption coefficient by capillarity (UNE-EN 1925) C (g/m ² s ^{0,5}):	27,0 ± 3,6

(1 MPa = 10.2 Kg/cm²)



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RESULTS

Durability characteristics according to UNE-EN Natural Stone Standard tests	Mean value
Frost resistance. Technological test (UNE-EN 13271)	
Flexural strength under concentrated load (UNE-EN 12372) after 48 freeze-thaw cycles :	14,6 ± 0,8
Weight loss (%):	0,03
Variation of flexural strength under concentrated load after freeze-thaw cycles (%):	6
Visual appearance of tested samples	No alteration is observed. Evaluation: 0
Resistance to ageing by thermal shock (UNE-EN 14066)	
Weight loss (%):	0,02
Visual appearance of tested samples:	No alteration is observed. Evaluation: 0

(1 MPa = 10.2 Kg/cm²)



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ANNEX I. PETROGRAPHIC DESCRIPTION

Natural stone test methods. Petrographic description UNE-EN 12407

Denomination:

Oolitic limestone

Oosparite (Folk classification, which is included in the UNE-EN 12407 standard).

Macroscopic description:

Structure: Homogenous.

Grain size: Medium, poorly sorted. Allochems range from 0,5 mm to few centimetres.

Colour: White (N9, after The Rock-Color Chart, Geological Society of America, ed. 1984)

Microscopic description:

Texture: Piedra Paloma contains ooliths, ooids, lumps and limeclasts and oncolites. This stone also presents foraminifers and fossil fragments of echinoderms (mainly plates), molluscs and bryozoans. Interparticle porosity is abundant. The calcite cement in this stone consists of microcrystalline blocky and also macrocrystalline rim, which is mainly associated to plates of echinoderms.

Mineralogical composition:

Main components: Calcite (~98 %).

Minor component: Quartz (~2 %).



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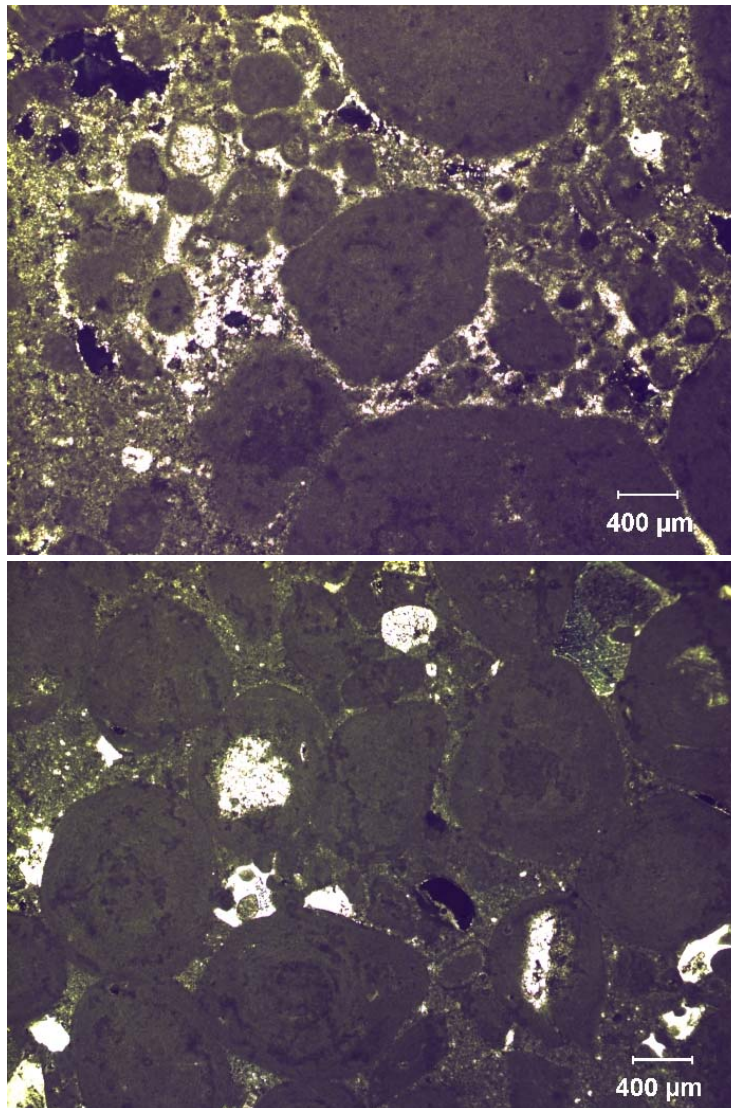


Figure. Thin section microphotographs showing stone texture (Polarization Optical Microscopy, crossed polarizers).



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ANNEX II. PHYSICAL CHARACTERISTICS

Natural stone test methods. Water absorption at atmospheric pressure EN 13755: 2002

Six samples were used in the form of 70 mm cubes. Water absorption coefficient, Cabs, is defined as the ratio of absorbed water (difference between the weight of the saturated and the dried sample) and dried sample. The absorption of water at atmospheric pressure is expressed as weight percentage (%):

Water absorption coefficient, Cabs: $4,4 \pm 0,1$ %

Table. Results of analyzed samples.

Ref.	Weight of the dried specimen (g)	Weight of the specimen after immersion (g)	Water absorption (%)
1	816,73	854,15	4,58
2	827,01	862,48	4,29
3	832,61	870,54	4,56
4	811,44	847,11	4,40
5	809,31	844,76	4,38
6	819,90	854,52	4,22



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Natural stone test methods. Apparent and real density, and open and total porosity
UNE-EN 1936:1999

Six samples were used in the form of 50 mm cubes. Dried samples were weighed and placed in a vacuum chamber at 20 ± 7 mbar pressure controlled by a vacuum manometer. Three steps of the test of 24 hours each were carried out. During the first step, trapped air was eliminated from the porous systems. In the second step, distilled water was slowly introduced until samples were completely covered. In the last cycle, atmospheric pressure was re-established and the saturated weight was obtained. Saturated samples were placed on balance pan to record the hydrostatic weight. Open porosity was calculated from dry, saturated and hydrostatic weights.

Total porosity includes open and closed porosities and was calculated from the relationship between apparent and real densities. Apparent density is defined as the relation between dried weight and bulk volume including total porosity, whereas real density is defined as the ratio of sample mass to solid volume.

Table. Results of analysed samples.

Ref.	Apparent density (kg/m^3)	Open porosity (%)
1	2389	11,23
2	2364	11,74
3	2392	11,22
4	2372	11,68
5	2375	11,19
6	2380	11,59

Apparent density: $2379 \pm 10 \text{ Kg/m}^3$

Real density: $2734 \pm 19 \text{ Kg/m}^3$

Open porosity: $11,4 \pm 0,2 \%$

Total porosity: $15,3 \pm 0,7 \%$



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Natural stone test methods. Compressive strength UNE-EN 1926:1999.

The uniaxial compressive strength test is used to determine the maximum value of stress attained before failure, which is measured as force per unit area. Nine dried samples were used in the form of 70 mm cubes. The uniaxial compressive strength test was carried out using the Ibertest MEH-2000 H/FIB-50 machine with a load rate of 0,36 kN/s.

Table. Dimension (L and I), cross-sectional area, maximum value of breaking load and stress attained before failure of the analysed samples.

Ref.	L (mm)	I (mm)	Area (mm ²)	Breaking load (kN)	Comp. Stren. (MPa)
1	70,57	71,31	5032,35	679,50	135,03
2	69,79	72,93	5089,78	368,20	72,34
3	69,81	72,40	5054,24	483,00	95,56
4	69,73	71,94	5016,38	466,40	92,98
5	69,84	71,09	4964,93	437,00	88,02
6	69,43	71,72	4979,52	484,50	97,30
7	69,41	71,40	4955,87	493,8	99,64
8	69,75	72,11	5029,67	518,9	103,17
9	70,36	71,73	5046,92	529,4	104,90

Compression strength: 98,8 ± 16,7 MPa

For the calculation of the lower expected value (E) a logarithmic normal distribution is assumed. The lower expected value (E) corresponds to the 5% quantile of a logarithmic normal distribution for a confidence level of 75%. E is calculated as follows:

$$E = e^{(\bar{X}_{ln} - k_s \cdot s_{ln})}$$

where \bar{X}_{ln} is the logarithmic mean and s_{ln} is the logarithmic standard deviation.

Lower expected value: 68,57 MPa



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Natural stone test methods. Flexural strength under concentrated load UNE-EN 12372:1999

Ten dried samples were used to determinate the flexural strength of samples, each measuring 200x75x30 mm. The sample was supported on two knife edges which were 180 mm apart. Another knife edge, which were placed in the center of the sample, were loaded onto the sample at a rate of 0,25 MPa/s.

Table. Width of the specimen adjacent to the plane of fracture (b), thickness of the specimen adjacent to the plane of fracture (h), breaking load and flexural strength.

Ref.	b (mm)	h (mm)	Breaking load (kN)	Flexural strength (MPa)
1	69,93	30,82	3,327	13,52
2	69,48	29,44	3,161	14,17
3	69,40	29,58	3,134	13,93
4	71,44	29,11	3,246	14,48
5	69,37	29,67	3,264	14,43
6	69,55	29,67	2,947	13,00
7	69,77	30,85	3,098	12,60
8	69,84	30,93	3,302	13,34
9	69,69	30,57	3,164	13,12
10	69,76	29,72	3,481	15,25

Mean value of the flexural strenght: 13,8 MPa

Standard deviation: 0,8 MPa

For the calculation of the lower expected value (E) a logarithmic normal distribution is assumed. The lower expected value (E) corresponds to the 5% quantile of a logarithmic normal distribution for a confidence level of 75%. E is calculated as follows:

$$E = e^{(\bar{x}_{ln} - k_s \cdot s_{ln})}$$

where \bar{x}_{ln} is the logarithmic mean and s_{ln} is the logarithmic standard deviation.

Lower expected value: 12,17 MPa



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Determination of abrasion resistance UNE-EN 1341:2002, Annex C (Slabs of natural stone for external paving. Requirements and test methods)

Abrasion resistance is determined using a test which abrades the upper face of sample with an abrasive material (corundum) applied to a rotating abrasion wheel under controlled conditions. Abrasion resistance is estimated by means of the size of the groove produced in the specimen. The characterization was realised over six samples, each measuring 200 x 200x30 mm.

Table. Groove lengths of the analysed samples.

Ref.	h (mm)
1	25,73
2	24,78
3	24,54
4	24,71
5	24,78
6	24,88

Abrasion resistance: $24,9 \pm 0,4$ mm



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**Natural stone test methods. Slip resistance by means of the pendulum tester
 UNE-EN 14231: 2004**

Six samples, each measuring 200x200x30 mm, were used to characterise the slip resistance of both wet and dry stone surfaces. In each surface, two measurements were carried out, one in normal direction and other in the perpendicular direction. Slip resistance is estimated by means of the pendulum tester, which measured the frictional resistance between a rubber slider mounted on the end of a pendulum arm and the test surface. Slip resistance is expressed as USRV units (Unpolished Slip Resistance Value).

Table. Unpolished Slip Resistance Values (USRV) of the analysed samples.

Ref.	USRV (dry conditions)			USRV (wet conditions)		
1	70	65	64	61	63	61
	64	62	62	63	63	63
2	68	64	63	57	56	56
	63	61	61	58	57	56
3	70	66	65	66	67	67
	64	63	62	65	64	64
4	68	65	64	64	66	65
	64	64	63	65	65	65
5	66	65	63	65	66	65
	65	64	63	66	67	67
6	66	63	61	67	67	67
	62	61	60	67	68	68

Slip resistance in dry conditions: $64,06 \pm 1,06$ USRV

Slip resistance in wet conditions: $63,81 \pm 3,86$ USRV



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Natural stone test methods. Rupture energy UNE-EN 14158:2004

Six samples, each measuring 200 x 200 x 30 mm, were used to characterise the rupture energy. The distance at which a steel ball of 1 Kg falls was increasing in intervals of 5 cm until the moment of specimen rupture. The rupture energy, W(J), was calculated as follows:

$$W(J) = m(\text{Kg}) \cdot g \cdot h \text{ (m)},$$

where m is ball weight, g is the gravitational constant (9,806m/s²) y h is height of fall. The value of height of fall is equivalent to the impact strength (previous test method UNE 22-189-85) when the stone thinness is 30mm and the ball weight is 1 Kg.

Table. Height of fall and rupture energy of the analysed samples.

Ref.	Height (cm)	Rupture energy (J)
1	10	0,98
2	15	1,47
3	15	1,47
4	15	1,47
5	10	0,98
6	10	0,98

Rupture energy: 1,2 ± 0,3 J



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Natural stone test methods. Determination of water absorption coefficient by capillarity: UNE-EN 1325:1999

Six samples were used in the form of 70 mm cubes and distilled water was used. Clean and dry samples were introduced vertically in a container. The water was added until it covered 2mm of the sample height and this level was maintained constant during the test. The absorbed water, as a function of time, was recorded during the test. The time intervals used were short at the beginning and longer later on. The results were plotted as absorbed water per area of the sample throughout imbibition occurs versus square root of time (Figure). With this kind of representation, the capillary imbibition kinetics shows two parts: a first part that defines water absorption, and a second part defining the saturation part. The slope of the curve during water absorption is the water absorption coefficient by capillarity, C ($\text{g}/\text{m}^2\text{s}^{0,5}$).

Table. Dimensions and water absorption coefficients by capillarity of the analysed samples.

Ref.	L (mm)	l (mm)	h (mm)	Water absorption coefficient C ($\text{g}/\text{m}^2\text{s}^{0,5}$)
1	70,45	70,91	71,58	22,1
2	69,81	69,66	73,09	30,6
3	70,79	70,38	71,37	23,7
4	70,86	70,44	71,12	26,7
5	69,34	69,91	70,83	30,9
6	70,68	70,42	70,98	28,1

Water absorption coefficient by capillarity: $C = 27,0 \pm 3,6 \text{ g}/\text{m}^2\text{s}^{0,5}$

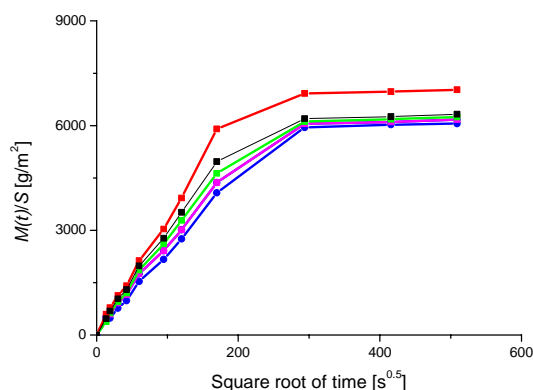


Figure. Weight of absorbed water per unit area, $W(t)/S$ versus square root of time of the analysed all samples.



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Natural stone test methods. Breaking load at dowel hole: UNE-EN 13364:2002¹

This test consists of applying a force in a direction perpendicular to the face of a specimen through a dowel previously placed in a hole drilled in one of its sides and measuring the breaking load of the specimen. Three samples, each measuring 200 x 200 x 30 mm, were used to characterise the breaking load at dowel hole. In center of the stone edges, cylindrical holes of 5 mm of diameter and 30 mm of depth were preformed. The dowels were placed inside the holes and fixed using a mortar (type CEM I 52,2 R, according to EN 197-1 recommendations). A force in a direction perpendicular to the face of a specimen was applied to breaking load of the specimen (F). The distance from the hole wall to the face where fracture occurs, d_1 , and the maximum distance of the centre of the hole to the fracture edge on the face, b_A , were also measured (Figure).

Sample	Hole identification number	Breaking load, F (K)	Maximum distance, b_A (mm)	Distance from the hole wall fracture, d_1 (mm)
1	1	1040	41,84	13,0
	2	1100	35,80	13,0
	3	1160	36,31	13,7
	4	1310	34,62	12,5
2	5	870	32,90	13,5
	6	1050	39,99	12,7
	7	990	38,42	13,5
	8	1110	39,85	13,9
3	9	890	41,69	13,1
	10	1360	40,17	13,3

Breaking load at dowel hole: 1100 N

Standard deviation: 200N

¹ This test was carried out in the Technological Institute of Ornamental Rocks and Building Materials (El Instituto Tecnológico de Rocas Ornamentales y Materiales de Construcción, ITROMAC) since the Applied Petrology Laboratory does not have the equipment necessary for its implementation according to UNE-EN 13364 test method.



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For the calculation of the lower expected value (E) a logarithmic normal distribution is assumed. The lower expected value (E) corresponds to the 5% quantile of a logarithmic normal distribution for a confidence level of 75%. E is calculated as follows:

$$E = e^{(\bar{x}_{ln} - k_S \cdot s_{ln})}$$

where \bar{X}_{ln} is the logarithmic mean and s_{ln} is the logarithmic standard deviation.

Lower expected value: 797 N

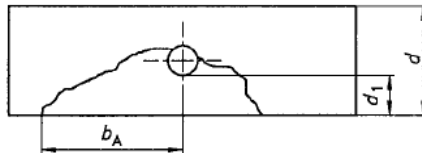


Figure. Sketch diagram indicating the distance from the hole wall to the face where fracture occurs, d_1 ; the maximum distance of the centre of the hole to the fracture edge on the face, b_A ; and the sample thickness, d .



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ANNEX III. DURABILITY

Natural stone test methods. Resistance to frost UNE-EN 12371:2001

The frost resistance of natural stone was determined by a test comprising cycles of freezing in air and thawing in water. The frost resistance was estimated by the variation of the flexural strength and weight and through a visual inspection.

The freeze-thaw test was carried out in a freezing chamber. The first step of the test consists in saturating the samples with distilled water. After that, the cycles begin. One cycle consists in three parts: 1) temperature decrease until -8°C for 2 hours (dry conditions); 2) temperature decrease until -12°C for 4 hours (dry conditions); and 3) temperature increase until 20°C for 6 hours (wet conditions and sample water saturation). Samples were subjected to 48 cycles of freeze-thaw. After the completion of the required number of cycles, samples were taking out from the freezing chamber, and dried in an oven (70°C). The specimens were visually inspected, weighted and flexural strength tested in accordance with UNE-EN 12372 standard.

Weight loss: 0.03 %

The visual inspection was realised to the tested samples and evaluated in concordance to the following classification (Table).

Table: Classification of alteration on tested samples

<i>Evaluation</i>	<i>Alteration forms on tested samples</i>
0	No alteration
1	Minimal damage (minimal roundness of corners and edges) that does not affect the integrity of the samples.
2	One or several small cracks ($\leq 0,1$ mm width) or breakdown of small fragments (≤ 10 mm ² fragment surface)
3	One or several small cracks, holes or breakdown of fragments higher than classification number 2
4	Specimen breakdown in two pieces or in large cracks
5	Specimen breakdown in several rock pieces or disintegrated.

The tested samples did not show visual alteration after the freeze-thaw test.



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Tested samples were used to determinate the flexural strength of samples, each measuring 200x75x30 mm according with UNE-EN 12372 standard.

Table. Width of the specimen adjacent to the plane of fracture (b), thickness of the specimen adjacent to the plane of fracture (h), breaking load and flexural strength.

Ref.	b (mm)	h (mm)	Breaking load (kN)	Flexural strength (MPa)
1	69,50	29,56	4,17	15,46
2	69,48	29,76	4,37	15,97
3	69,53	29,78	4,03	14,70
4	69,27	29,81	4,14	15,14
5	69,42	29,33	3,81	14,37
6	69,53	29,48	3,67	13,68
7	71,34	29,80	3,98	14,14
8	69,49	29,63	3,69	13,60
9	69,25	29,75	3,84	14,10
10	69,40	29,64	4,12	15,20

Mean value of the flexural strength: 14,6 MPa

Standard deviation: 0,8 MPa

The tested samples did not decrease their mechanical strength after 48 cycles of freeze-thaw. Although the results showed a slight increase of the mean value of the flexural strength, this variation is included within the limits of the mean value deviation and, therefore, it should not be considered as a rock strength improvement.

Table. Variation of flexural strength under concentrated load by freeze-thaw cycles.

Flexural strength after freeze-thaw test (MPa):	Flexural strength before freeze-thaw test (MPa):	Variation of flexural strength under concentrated load (%):
13,8 ± 0,8	14,6 ± 0,8	+ 6



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Natural stone test methods. Resistance to ageing by thermal shock UNE-EN 14066:2003

Six samples, each measuring 200x200x20 mm, were used to evaluate the resistance to ageing by thermal shock.

Firstly, clean and dry samples were introduced vertically into a container and covered with pure water at a temperature of 20 °C for 4 hours. Secondly, the samples were taken out of the container and introduced into the heating cabinet at 105 °C for 20 hours. The cycle duration was 24 hours, and 20 cycles were carried out. The dry weight loss was calculated at the end of this stage (Table). Finally, the specimens were visually inspected.

Table. Weight loss after ageing by thermal shock test and alteration description of tested samples.

Ref.	Weight of the dried specimen (g)	Weight of the dried specimen after test (g)	Percentage of weight loss (%)	Comments
1	1964,44	1964,04	0,02	No alteration
2	1942,19	1941,85	0,02	No alteration
3	1988,41	1988,01	0,02	No alteration
4	1869,82	1869,46	0,02	No alteration
5	1860,83	1860,46	0,02	No alteration
6	1878,96	1878,61	0,02	No alteration

Percentage of weight loss: 0.02 ± 0.00

The tested samples did not show visual alteration after the thermal shock test (Figure).



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Figure. Comparison of visual appearance of the unaltered sample (or reference sample-left sample) with an altered sample (right sample).