GEOLOGICAL CHARACTERIZATION OF LAPILLI IN GRAN CANARIA ISLAND, A RAW MATERIAL USED AS A GAS GRANULAR FILTER

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ABSTRACT
Lapilli is a pyroclastic material ejected by volcanoes (2-64 mm of grain size). Lapillis from recent strombolian eruptions of Gran Canaria have been used as a granular filter for removing fine dust particles from gases and for heat exchange as well. The geological characteristics of these lapillis are: A) They come from ultrabasic geochemical composition magmas (<45% content of SiO_2, and >3% of Na_2O+K_2O); B) Petrologic features indicate lapillis are mainly basanitic and nephelinitic in composition; C) Lapilli textures varies from holohyaline (100% of volcanic glass) to hypocrystalline (glass plus crystals), are black, slightly welded and very vesicular, consequently they have high porosity and permeability; D) The most interesting lapillis to be used as granular filters are of Upper Quaternary age (< 300,000 years) because of their low weathering and cohesiveness; E) Calculated reserves of this material in Gran Canaria are large, up to 350 million m^3, but many of the recent volcanic cones are located in natural places protected by Law. However, the local demand of lapilli as raw material of granular filters (<100 m^3/year) could be satisfied with quarries now available.

INTRODUCTION
The control of gas emissions that contain solid particles is a problem that occurs at present in different urban locations, and mainly in industrial areas since the volumes of gases emitted are high. With the object of reducing the negative environmental effects of these emissions the two fundamental solutions that have been proposed are cleaning the contaminating gases (particle filtering) and gas cooling (heat recuperation).
In this sense since the 90's there has been a development of a series of prototypes of "multipurpose filters". Among these it is the heat exchange filter designed by Jaraiz et al (1991) [1] which cleans contaminating gases and recuperates heat in one device without the need of additional equipment. The later evolution of these prototypes has incorporated lapilli successfully (volcanic fragments with sizes of between 64mm and 2mm, Fischer 1961[2]) from Bandama volcano (Gran Canaria), as a granular volcanic material used forming a fixed filter bed (Socorro et al 2000a[3] and 2000b[4]).
The main objective of this work is to define the principal geological characteristics (volcanic, petrographic, geochemical, physical and texture) of lapilli used experimentally in granular filters, since these parameter had not been taken into account in experimental work previously quoted.

To carry out this investigation pyroclastic have been collected from the Pico de Bandama volcano and from another four volcanic cones with similar geological characteristics and which are representative of the Island of Gran Canaria: La Isleta-Montaña El Vigia (LI), Monte Lentiscal (ML), Montañón Negro (MN) and La Calderilla (LC) (Fig.1) The structures that were selected are distributed in the North East sector of the Island and belong to the main quaternary volcanic groups of the Recent magmatic cycle in Gran Canaria being less than 300,000 years old (Upper Pleistocene-Holocene).

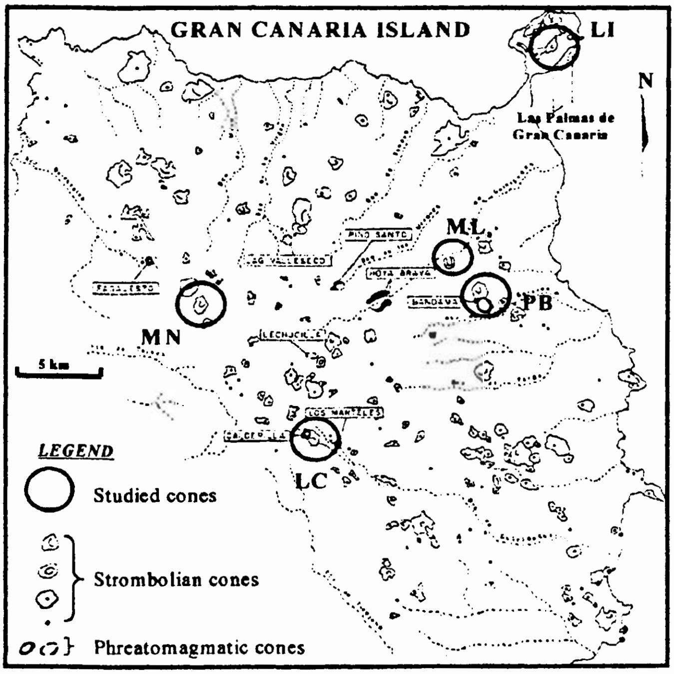

Fig. 1. Volcanic emission centres associated with the Recent magmatic cycle of Gran Canaria (modified from ITGE 1992[5]). The circles indicate the five volcanic cones samples for this work: LI: La Isleta, Montaña el Vigía; ML: Monte Lentiscal; PB: Pico Bandama; MN: Montañón Negro and LC: La Calderilla.

The lapillis samples were later analysed in the laboratory, using different geological and physic-chemical techniques. Determining their characteristics will be fundamental in laboratory experiments dealing with the filtering of contaminating gases using lapilli and will serve as a scientific base in any future exploitation of this natural resource, and in the case of industrial use of this for filtering purposes.

NATURAL CHARACTERISTICS OF GRAN CANARIAN LAPILLI

Geological Setting

The Island of Gran Canaria is situated in the centre of the Canarian Archipelago, and its growth was the result of various magmatic stages, or cycles, over the course of more than 15 m.a. (i.e. million years). The first phase was the result of volcanic submarine eruptions (> 14.5 m.a.); later a volcanic shield stage took place in Cycle I or Ancient cycle (Miocene age between 14.5 and 8.5 m.a.). The following was an erosive stage (between 8.5 and 5.3 m.a.);

after a volcanic rejuvenation stage occurred, that is Cycle II or Roque Nublo cycle (Pliocene age between 5.3 and 2.9 m.a.); and Cycle III or Recent cycle was the latest (Plio-Quaternary age, between 2.9 and the present) (Fuster et al., 1968[6]; Mc Dougall and Schmincke,1976[7]; ITGE, 1992[5]; Pérez-Torrado et al; 1995[8]). The volume of emission related to cycles II and III is noticeably less than Cycle I, supposedly due to the magma source being exhausted in Gran Canaria. The distribution of material emitted in cycles II and III is situated towards zones in the centre north of the island, which indicate a migratory tendency of the emission conducts towards the NE.

Volcanic eruptions in the Recent cycle with ages of less than 300,000 years (Figs. 1 and 2) are studied in this work. Essentially they formed volcanic structures that emitted lava flows and pyroclastic materials of variable composition between ultrabasic and intermediate (volcanic rocks with concentrations of SiO_2 of between 45 and 63% and Na_2O+K_2O of between 3 and 15%). The volcanic cones are aligned through certain structural guidelines NW–SE and NE – SW, these are repeated in other islands of the Canarian Archipelago. These volcanic structures are quite well preserved and show little or no superficial alteration depending on when they were formed and the geographical location where they are found. Therefore volcanoes from the Holocene age (< 10.000 years) and those localized in areas with semi arid climatic conditions are well preserved, whilst those of the Upper Pleistocene (between 300.000 and 10.000 years) and those situated in more humid areas are found to be less well preserved. Although the majority of these cones were formed in the Recent cycle through eruptive strombolian processes (low or moderated explosive force), there are examples of more explosive force occurring due to the interaction of water magma (subterranean water), this caused the creation of phreatomagmatic structures, for example the Bandama caldera (Fig 2), Los Marteles, Hondo de Fagagesto, etc., Fig 1). Given that the recent volcanic eruptions in Gran Canaria are dated between 2,000 and 3,000 years from the present (Mangas et al., 2002[9]), we can confirm that volcanic activity associated with the rejuvenation phase in this island has not yet finished.

Fig. 2. Volcanic group of Pico de Bandama (on the right) of strombolian origin and the Bandama caldera (on the left) formed by strombolian and phreatomagmatic eruptions plus the final collapse of the structure. We can observe bands of pyroclastic material on these structures. These bands accumulated during different eruptive phases.

The most recent volcanic structures in Gran Canaria and related deposits are made up of pyroclastic material of different sizes (bombs and blocks >64 mm, lapilli between 2-64 mm, coarse ash between 2 and 1/16mm and fine ash <1/64: classification by Fisher 1961[2]) (Fig 3). These materials are created by the solidification of magma fragment surfaces, which in turn contain glass and rocks formed in the magma chamber or fragments of host rocks. The shape of the pyroclastic deposits is related to transport depositing mechanisms which have intervened in the accumulation process. Pyroclastic deposits of ash fall where the material falls around the eruptive centre due to gravity, pyroclastic flows where particles move at high velocity in a laminar flow and surges in turbulent flow. Each eruptive phase creates a layer of fragmentary material with homogenous physic-chemical characteristics. The pyroclasts are distributed according to their size, density and the fￏrce of the eruption. The heavier and larger pyroclasts being closer to the structures (blocks and scoria) and the finer and less heavy (lapilli and ash) in areas further away.

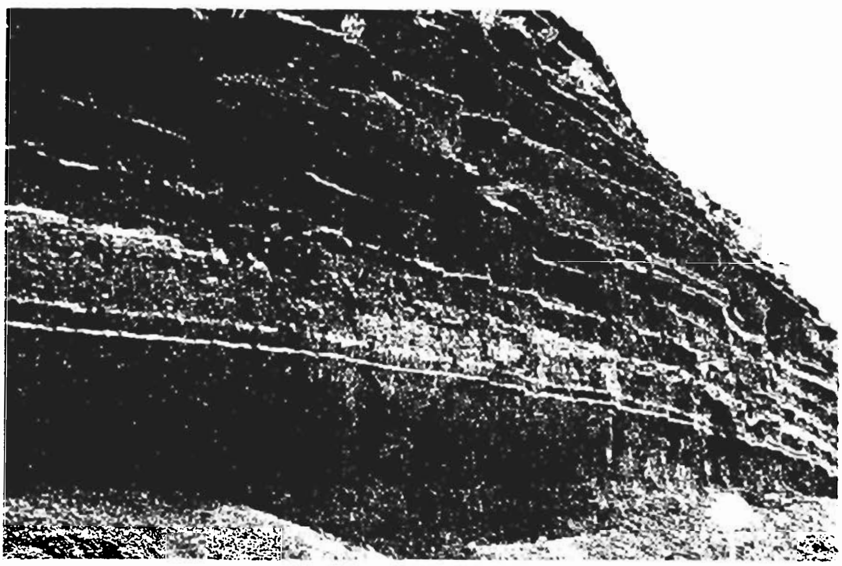

Fig. 3. Detail of the volcanic cone Pico de Bandama. A pyroclastic deposit can be observed in bands with variable grain size (lapilli and scoria), different colours correspond to the different eruptive phases of the volcano.

From the perspective of economic geology, lapilli and other natural fragmentary materials are abundant raw materials. They have been traditionally exploited in the Canaries due to their being easy to find and cheap. Generally, these materials have been used as aggregates (for roads and concrete elements) and in agriculture (to cover earth surfaces) and in industry (manufacture of building blocks and bricks). If we analyse the abundance of this resource in Gran Canaria, we can point out that there are 118 recent volcanic cones (Fig.1) with an estimated lapilli reserve of some 357.9 million in m^3 (ITGE,1986)[10]. Nevertheless many of these cones are found in nature reserves protected by law and this limits the number of cones that can be mined to only 53, with potential reserves of 110.7 million m^3. Therefore the ITGE (1986)[10] recommends Montaña del Capitan (Northern zone, Galdar) with reserves of 9 million m^3, Montaña Blanca with 3.2 million m^3 (Northern zone, Arucas) and Santidad, Cuatro Puertas, Cuevas Blancas and Montaña, Jinamar with 6.5 million m^3 (Western zone, Telde) as exploitable.

Petrographic and geochemical characteristics of lapillis

The pyroclastic material studied in those selected cones were examined *de visu* and with binocular microscope and they show lapilli grain size and to a lesser amount scoria - bombs and ashes, and they are varied in colour. In Montañón Negro, black coloured lapilli predominate, which indicates their recent origin (Holocene) and the absence of superficial alteration. However, those analysed from Pico Bandama, Monte Lentiscal, Montaña El Vigía and La Calderilla are of black, redish, violet, grey or cream hues. This indicates that they are older and have undergone some type of alteration during their formation. Different pyroclast bands with different sizes and different colouring occur in the same volcanic cone indicating that physic-chemical conditions during the formation of individual bands were different in each eruptive phase (Fig. 3). On the other hand the lapillis that were studied show a glassy nature, with brilliant iridescent or matt hues. They have a vesicle texture characterised by the presence of numerous voids (Fig. 4). These voids are the remains of gas bubbles formed in the magmatic liquid through decompression as they rose to the surface or when the magma is on the exterior. The bubbles have sizes of between 5 μm and 1cm and shapes that vary from rounded, subrounded or completely irregular. In general these voids are interconnected, they appear empty without any mineral filling, the walls between bubbles are very thin. Sometimes chipped edges can be observed, botryoidal, stalactitic or fluidal which indicate that the material was in a plastic state at the moment of its consolidation. Although some pyroclastic fragments have massive aspects, in their interior they are equally vesicular. Also occasionally it is observed that finer particles (ashes) are adhered to external surfaces. Planar or curviplanar surfaces that intersect nearly at right angles (blocky morphology) are also observed. The fragments are usually fragile and break easily when subject to light pressure resulting in concave or convex surfaces. These combinations of characteristics cause this pyroclastic material to have a low density with marked porosity and permeability, we can therefore define it with the term pumice (Heikena and Wohletz,1985[11]).

The shape of the fragmentary particles of lapillis can be defined due to the spherical and rounded shapes as defined by Krumbein and Sloss (1955)[12] and Powers (1953)[13], respectivelly. The spherical form of the pyroclasts that were studied from the five volcanic cones include those between 0.5 and 0.9, these correspond to particles from spherical to ellipsoidal; roundedness is low with values from 0.12 to 0.25 which correspond to angular or very angular particles.

On the other hand within the Bandama volcanic area (Caldera and Pico de Bandama) there also exists more crystalline and dense lapillis, these correspond to xenoliths proceeding from the upper of the earth 's mantel and basic and ultrabasic cumulates and olivine, pyroxene and amphibole megacrysts formed in the magma chamber which have been expelled out to the exterior during the eruption (Mangas et al., 1997)[14].

Fig. 4. Aspect of a subangular lapilli sample from the La Calderilla where interior bubble with rounded and subrounded shapes can be observed. The interbubbles walls are thin. The external surface is massive and shows a fluidal waved morphology.

When lapilli is studied with a petrographic microscope show holohyaline or glassy textures (100% of volcanic glass) or hypocrystalline (glass plus microcrystals and criptocrystals). Volcanic glass occasionally shows a spherulitic morphology and contain crystals (sizes >100 μm), microcrystals (< 100 μm) and criptocristales (<5 μm). These glass particles have polyedric, tabular and acicular shapes. They have been identified optically as olivine, clinopyroxene (augite) and plagioclase, amphibole and Fe-Ti oxides occur in a lesser proportion. The crystals are distributed randomly in the glass with microporphyritic textures, sometimes they are orientated to create fluidal textures.
To characterise from a geochemical point of view the lapillis selected from cones we have performed a geochemical analysis of lavas from studied volcanic cones (Table 1). As a first approximation, the chemical composition of the lava from strombolian volcanoes is similar to associated lapillis.

Table 1. Geochemical analysis of lava from those volcanic cones which are the object of the study (data in oxide %. 1% equivalent to 10.000 p.p.m.)

muestras	SiO_2	TiO_2	Al_2O_3	FeO	Fe_2O_3	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	H_2O
LI	43.63	3.64	13.22	11.14*		0.17	8.56	10.80	3.88	2.29	0.86	
ML	42.10	3.62	13.10	9.20	2.52	0.21	11.11	10.96	3.81	2.00	0.80	0.39
PB	41.75	3.53	10.73	8.22	3.88	0.18	14.73	11.68	2.84	1.1	0.68	0.35
MN	41.72	3.53	12.94	6.95	3.93	0.18	10.20	11.14	5.50	1.96	0.75	0.76
LC	42.20	4	12.40	8.50	4.50	0.17	11.80	11.20	3	1.50	0.75	0.75

LI: lava flow from Montaña el Vigía en la Isleta (F.J. Pérez Torrado, pers. com.) * FeO total
ML: lava flow from del Monte Lentiscal (MAGNA, 1992)[5]
PB: lava flow from Pico de Bandama (Mangas et al., 1997)[14]
MN: lava flow from Montañón Negro (MAGNA, 1992)[5]
LC: lava flow from La Calderilla (MAGNA, 1992)[5]

If we analyse the chemical data from Recent cycle eruptions published in the official geological cartography (MAGNA, 1992)[5], the volcanic rocks have variable compositions ranging between ultrabasic and intermediate, that is to say between 39 and 55% of SiO_2 and between 4 and 14% of Na_2O+K_2O. Lava flow materials has been classified according to classification of Le Maitre (1989)[15] as nephelinite, basanite, alkaline basalt, tephrite, tephrite-phonolite and trachibasalt, among others, and these all belong to the magmatic alkaline trend. Now, the samples of lava flows studied in this work (Table 1) indicate that they are quite homogeneous in composition and deal with ultrabasic rocks (< 45% of SiO_2) with concentration of Na_2O+K_2O between 4.5 and 7.5%, thus corresponding to basanite composition, except Montañón Negro which would be nephelinite, and they too have a tendency to the alkaline trend. Besides, lava flows have high total values of MgO, CaO, FeO and TiO_2 and are moderate in Na_2O, K_2O y Al_2O_3. Therefore the magmas that created these volcanic rocks were quite primary, that is to say that they underwent very little magmatic differentiation or fractional crystallization in the hypovolcanic magma chambers. Taking theses characteristics into account, our lapilli have an ultrabasic alkaline composition and can be defined as sideromelane.

Physical and Textural Properties

Lapillis selected from the five volcanic cones have been laboratory tested in diverse ways to determine some physical and textural characteristics, for example their grain-size measurement, density, specific weight and porosity.
Regarding to the analysis of the lapillis grain size, figure 5 and table 2 show the results, that is the grain-size curves of the samples, their principal size values and data of the most common grain-size indices, used in the analysis of aggregates.

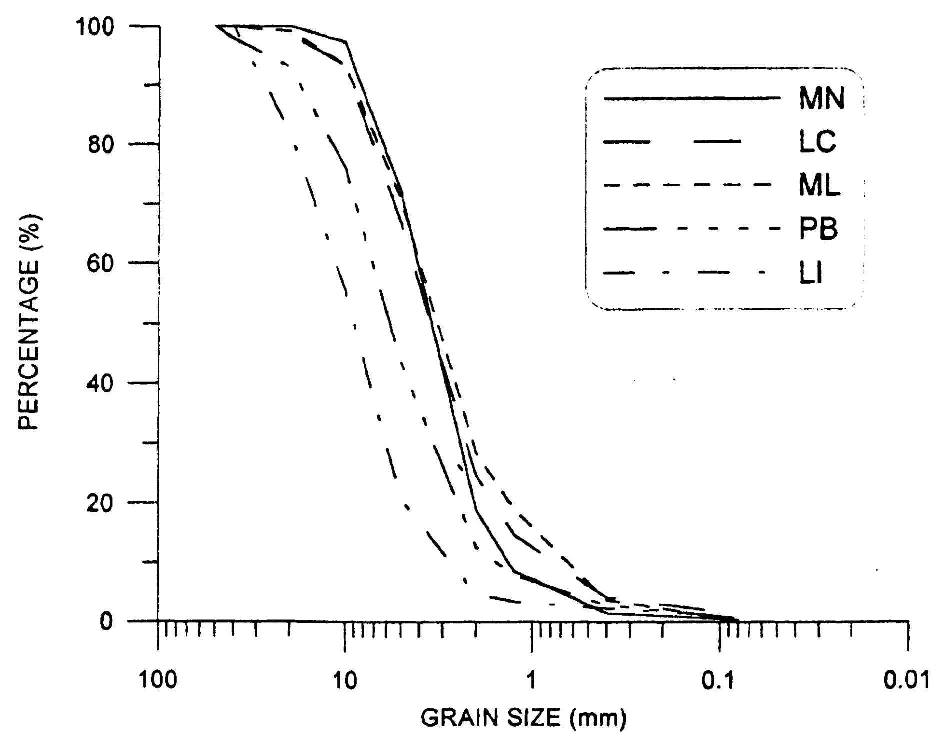

Fig. 5. Grain-size curves of lapillis from the studied volcanic cones.

Table 2. Percentages of size division and main index in the studied volcanic cones

	Grain size [(1)] (mm)			Indices [(2)]			
Sample No.	**64 – 2**	**2 – 0.06**	**< 0.06**	**D_{10}**	**D_{50}**	**Cu**	**Cz**
MN-1	81.0	18.8	0.2	1.3	3.1	8.5	0.47
LC-1	74.0	24.8	1.2	0.8	3.2	9.4	0.96
ML-1	71.4	28.4	0.2	0.8	3.3	5.6	1.11
PB-1	87.3	12.1	0.6	105	6.1	3.0	1.52
LI-1	95.3	3.9	0.8	3.2	9.5	1.4	2.25
X	81.8 %	17.6 %	0.6 %	1.52	5.04	5.58	1.26
σn	8.74	8.81	0.38	0.88	2.49	3.07	0.59

(1) The divisions correspond to the three pyroclastic particle sizes. Lapilli: 64-2 mm; Coarse Ash: 2-0.06 mm; and fine ash: < 0.006 mm.

(2) **D_{10}** Effective particle size
D_{50} Median particle size
Cu Uniformity coefficient
Cz Coefficient of curvature

$$Cu = \frac{D_{60}}{D_{10}}$$

$$Cz = \frac{(D_{30})^2}{D_{10} \cdot D_{60}}$$

As can be observed, lapilli size predominates (81.8%) compared to coarse ash (17.6%) and fine ash (0.6%) which are minorities, being always less than 1%. D_{50}= 5.04 and σn= 2.49 indicate that the graduation curves are very well centred around ϕ= 5mm and D_{10}= 1.52 mm indicate that 90% of the grains are larger than this value. The distinction between a uniform and a well graded soil can be defined numerically by the Uniformity coefficient Cu and the coefficient of curvature Cz. Soils with Cu less than 4 are said to be uniform and soils with Cu greater than 4 are well graded. The coefficient of curvature Cz is a measure of symmetry and shape of the gradation curve. For well graded soil, Cz will be between 1 and 3. Data of our samples indicate that lapilli may be uniform to slightly well-graded.
Referring to lapillis density, we will indicate that for rock characterization, three different weight-volume relationships are normally used as shown in table 3. The specific gravity correspond to the solid part of the rock without voids. Ws = solid weight; Vs = Solid Volume. The apparent density normally refers to the whole sample. Total volume (V) intervenes including voids and Ws = solid weight. Real density corresponds to the solid part with inaccessible voids (Vi), whilst V= open voids (accessible) and closed voids (inaccessible).

Table 3. Main weight-volume relationships used to determine the density of basaltic pyroclast. Representative values and reference of their authors.

Parameter		**Representative value**	**Reference**
Specific Gravity	$G = Ws/Vs$	Basalt (x= 27.1) 25.1- 27.2 KN/m³ Basalt (vesicle) 13.5-18.9 KN/m³	Blyth and de Freitas (1984)[16]
Aparent Density	$\rho a = Ws/V$	Lapilli (young) 11.87-12.16 KN/m³ Gran Canaria 7.94-9.51 KN/m³	IGME (1974a)[17] IGME (1974b)[18]
Real Density	$\rho r = Ws/(Vs + Vi)$	Lapilli (young) 12.26-16.38 KN/m³ Gran Canaria 13.24- 15.69 KN/m³	IGME (1974a)[17] IGME (1974b)[18]

With regard to the specific weight of the lapilli, we can consider it as granular material formed by porous particles. Therefore the different unit weights will essentially depend on the unit weight of the solid particles (γs), the dry unit weight (γd) and porosity (n). In addition, depending on water content (ω or Sr) it would have variable humid unit weight values(γ)