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Geological heritage and proposed geosites at the coast of Agaete (NW of Gran Canaria Island)

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ABSTRACT

In this research project, four geosites have been proposed on the coast of the municipality of Agaete (NW of Gran Canaria). From north to south, these are: Punta Gorda, La Caleta-Bco. de Agaete, Puerto de Las Nieves y La Laja del Risco. These geosites are protected by the Maritime-Terrestrial Public Domain and in a protected area of 200 m inland. Volcanic and sedimentary materials, morphologies and structures from different geological formations have been defined corresponding to various geological eras from the Miocene until present day. They present local significance and could potentially present importance in an insular scale. Their characterization will permit a better management, geoconservation and promote geoturism in these coastal areas. It is a pioneer approach for the geological heritage of this locality.

Thanks to the bibliography, cartography and fieldwork data obtained, the descriptive documentation was filled in following the methodology from the Inventory of Places with Geological Interest (Inventario de Lugares de Interés Geológico; IELIG) from the Spanish Geological Survey (García-Cortés *et al.*, 2018) to calculate the value of interest for each of the geosites using a parametric method. These interests are scientific, educational and touristic-recreational. Again, the values of deterioration susceptibility and risk were calculated, based on their principal interest, which allowed the establishment of protection and management strategies for each of the geosites.

Keywords: geological heritage, geosite, geodiversity, coast, Agaete

RESUMEN

En este trabajo se proponen cuatro lugares de interés geológico (LIG) en la costa del municipio de Agaete (NO de Gran Canaria). Estos LIG se encuentran protegidos dentro del Dominio Público Marítimo-Terrestre (DPMT) y en la Zona de Servidumbre de Protección de 200 m tierra adentro. Los LIG propuestos, de norte a sur, son: Punta Gorda, La Caleta-Bco. de Agaete, Puerto de Las Nieves y La Laja del Risco. En ellos se han definido materiales, morfologías y estructuras, volcánicas y sedimentarias, pertenecientes a diferentes formaciones geológicas desde el Mioceno hasta la actualidad. Estos tienen importancia municipal y, potencialmente insular, y su futura valorización permitirá su catalogación como LIG para la mejor gestión, geoconservación y fomento del geoturismo en estos espacios costeros. Aunque se han realizado varios proyectos de investigación sobre patrimonio geológico en la isla de Gran Canaria, este es el primer trabajo de patrimonio geológico que se realiza en este municipio.

Gracias a la bibliografía y cartografía recopiladas y a los datos obtenidos en las salidas de campo, se han cumplimentado las fichas descriptivas contenidas en el documento metodológico del Inventario de Lugares de Interés Geológico (IELIG) del Instituto Geológico y Minero de España (García-Cortés *et al.*, 2018) para conocer el valor que tienen para cada interés, siendo estos, científico, educativo y turístico-recreativo, a través de un método paramétrico. También, se han calculado los valores de susceptibilidad y riesgo de degradación, según su interés principal, lo que ha permitido establecer medidas de protección y gestión para cada uno de los LIG.

Palabras Clave: Agaete, costa, geodiversidad, LIG, patrimonio geológico

1 INTRODUCTION

1.1 Geological heritage and geodiversity

The study of geological heritage is a new and recent approach in Earth sciences which shows how important is Earth's geological history. There are various definitions of geological heritage, but the Law 42/2007 of Natural Heritage and Biodiversity, in the Spanish legislation, states that geological heritage is the "*combination of geological natural resources with scientific, cultural and/or educational value, which include geological structures and formations, topography, minerals, rocks, fossils, soils and other geological features which allow us to have knowledge, to study and to interpret: a) the Earth's origin and evolution, b) the processes that have formed it, c) the past and present climates and landscapes and, d) the beginning and the evolution of life on Earth*". The geological heritage in a region is limited to one or more areas named geosites which are "*areas or sites that show one or various characteristics considered of importance for the geological history of a region*" (Carcavilla *et al*., 2007). In the appendix VIII.II, in the Law 42/2007, the geological contexts of Spain which have worldwide relevance are defined, and one of them corresponds to the volcanic edifices and morphologies of the Canary Islands.

Geological heritage is not a renewable resource, and in case of destruction, it cannot be recovered. The geological resources within the geological heritage can be tangible (movable), they can be extracted from their original natural site, conserved and exposed in museums and public or private collections due to their singularity, and intangible (immovable) which appear *in situ* in its place of origin (Jakubowski, 2004). However, some authors express that the movable elements should not be included in the term "geosite" as they are regulated by the Law 16/1985 of Spanish Historical Heritage (Carcavilla *et al*., 2007) and other legislation.

Geological heritage accounts for many disciplines like mineralogy, petrology, palaeontology, geomorphology, stratigraphy and volcanism, amongst others. Many public entities like the Spanish Geological Survey[1], the Society for the Defence of the Geological and Mining Heritage[2] and the Commission for Geological Heritage of the Spanish Geological Society[3] study the geological heritage in Spain. In Europe, the European Association for the Conservation of Geological heritage (ProGeo)[4] has the objective to promote the conservation and preservation of the principal geosites in Europe (Carcavilla *et al*., 2009).

The main goal of the study of geological heritage is to promote geoconservation and geotourism. Therefore, there are three important aspects to work on: inventory, to know the places to consider as geological heritage; assessment and management to promote geoconservation and to avoid the possible deterioration that de area could suffer; and determine strategies for the diffusion of information about these sites. Geoconservation is needed because some geosites or geological elements (fossiliferous outcrops, specific mineral deposits, etc.) are very fragile and vulnerable. Also, it helps local development for country field areas as mentioned in the Law 45/2007 for the sustainable development of the rural environment. There are many projects taking place such as the Global Geosites project which contributes to the development of strategies to protect the geodiversity and the geological heritage all around the world. It is directed by the Geological Sciences International Union, sponsored by UNESCO.

Geodiversity is a crucial factor when defining geosites and geological heritage. Nevertheless, this term has always been used together with biodiversity and it is still little recognized by the public administrations and the society (Carcavilla *et al.*, 2008). This concept has been defined in different ways, the most popular definitions were established by the authors Nieto (2001) and Gray (2004). The first author explains that the geodiversity "*is the number and variety of structures (sedimentary, tectonic, geomorphology, hydrogeology and petrologic) and geological materials (minerals, rocks, fossils and soils) that constitute the substrate of the region, over which are established the actual human activities*" (Nieto, 2001). The second author, Gray (2004), defines geodiversity as "*the natural range of diversity of the geological (rocks, minerals and fossils), geomorphological (landscape shapes) and soil aspects, including their interrelations, properties, interpretations and systems*". Nowadays, the accepted definition, in Spain, is found in the Law 42/2007, where geodiversity is "*the variety of geological elements, including rocks, minerals, fossils, soil, formations and geological units and landscapes which register the Earth's evolution*".

Numerous definitions lack describing the methodology used to study the geodiversity. The components which define de geological diversity of a region need to be analysed and then compared at different sites. The principal aspects used to define the geodiversity of a specific place are the frequency, the distribution and the variety. The frequency is the number of times that a class appears and its dimensions. The variety is the number of classes that can be identified in a region. Finally, the distribution refers to the special layout of the classes (Carcavilla *et al.*, 2007, 2008).

1.2 Background work about geological heritage and Agaete

The study of geological heritage in Spain is quite recent, starting in the 1970s by the Spanish Geological Survey through several research projects. In 1978, the National Inventory of Points of Geological Interest (Carcavilla *et al*., 2009) started due to the necessity of cataloguing the areas which presented geological interest to promote their study, protection and outreach. This project was interrupted in 1986 due to economic problems; however, 9 inventories were done which covered up to 20% of the country's land, which include the Cantábrica Belt, Galicia and Asturias regions (Carcavilla *et al.*, 2007, 2009). It continued as the 1:50,000 National Geological Map and insular geological map 1:25,000 (MAGNA plan). This way, the Spanish Geological Survey, in 1992, publishes the geological map of Gran Canaria 1:100,000 (where 10 geosites are described) and, in 1990, the geological maps of the municipalities. Specifically, in the geological map of Agaete (1:25,000) there are no geosites identified compared to the geological map of Vecindad de Enfrente (1:25,000) where the Llanos Blancos – Andén Verde (Punta de las Arenas) geosite was defined. This geosite contains ancient aeolic deposits (aeolianites) and the stacking of volcanic lavas from the Miocene forming the cliffs. The geological cartography of the island of Gran Canariashows the geological descriptions of materials, morphologies and structures present in the island (Balcells *et al*., 1990, 1992; Barrera *et al*., 1990). Other projects about geological heritage at national and international levels have been carried out recently such as, for example, the characterization and management of the dinosaur tracksites in La Rioja, Spain (Fuertes-Gutiérrez *et al.*, 2016) or the characterization and valuation of geological heritage in Brazil (Mansur and de Souza, 2011).

The geology of the northwest coast of the island of Gran Canaria, where Agaete municipality is located – the coast of our study area (Figure 1) – has been analysed very little in general due to the access which slows down fieldwork and research activities. Nevertheless, some research works have been carried out, in the region of Agaete, about elements which present high scientific interest such as the marine terraces and the tsunami deposits (Meco *et al.*, 2002; Pérez-Torrado *et al*., 2006; Paris *et al.*, 2018), the recent Holocene volcanic eruptions (Rodríguez-González *et al*., 2009, 2012), lapilli tuffs used in quarries of aboriginal millstones (Mangas *et al*., 2008) or the mineralization of zeolites in the Miocene basalts (Rodríguez *et al*., 2012). On the other hand, the southern part of the coast of Agaete belongs to a protected area, the Natural Park of Tamadaba (PGO, 2004).

1.3 Objective

The main research objective of this work is to define geosites at the coast of the municipality of Agaete, limited within the Coastal Public Domain and in the protection zone of 200 m inland from the nearshore (Law 2/2013). Thus, the characterization of the most representative geological elements of the coast, which make up the geological history of the region is done, and a value is assigned to them. Based on this, management and conservation measures are established, and dissemination strategies are used to make public the geology of the area and promote sustainable developing strategies in the zone.

The coast of Agaete shows numerous cliffs incised by ravines which serve to see the geological diversity, representative for the geological construction of the island during the Miocene period until present day. Thus, volcanic and sedimentary materials and morphologies, both marine and terrestrial, have been originated by different geological processes which allow us to interpret part of the geological history of the island. To reach this aim the following specific objectives need to be carried out:

a) Carry out a geological exploration in the coast of Agaete, identifying materials and geomorphologies, doing drawings and taking pictures.
b) Carry out a survey to a group of experts whom have worked in the area and prioritize the geosites they propose using the methodology of IELIG-2018 document (García-Cortés *et al.*, 2018).
c) Determine the coastal geosites from fieldwork and surveys.
d) Do a geological characterization for each geosite with the descriptive card (IELIG 2018).
e) Put in value the scientific, touristic-recreative and educational interests with a parametric method.
f) Evaluate the vulnerability and protection priority for each of the geological elements of each geosite with a parametric method.
g) Write up suggestions for the diffusion of information, conservation and exploitation of the geosites
h) Present the results in geological congress and produce publications.

2 STUDY AREA

2.1 Geographic location

The Canary Islands are an archipelago made up of seven volcanic islands associated to a hotspot, with various islets and seamounts located northwest off the African coast, in the Atlantic Ocean, between 27ºN and 30ºN. The island of Gran Canaria is found in the centre of the archipelago (28º 00'N, 15º 35'W) and is the third largest island (1540 km^2). It is practically circular with a diameter measuring 45 km and an altitude of 1949 m above sea level (Pico de las Nieves). Its morphology has permitted a network of ravines to be formed and preserved since the Miocene period. The study area is the coast of Agaete located NW of the island of Gran Canaria (Figure 1).

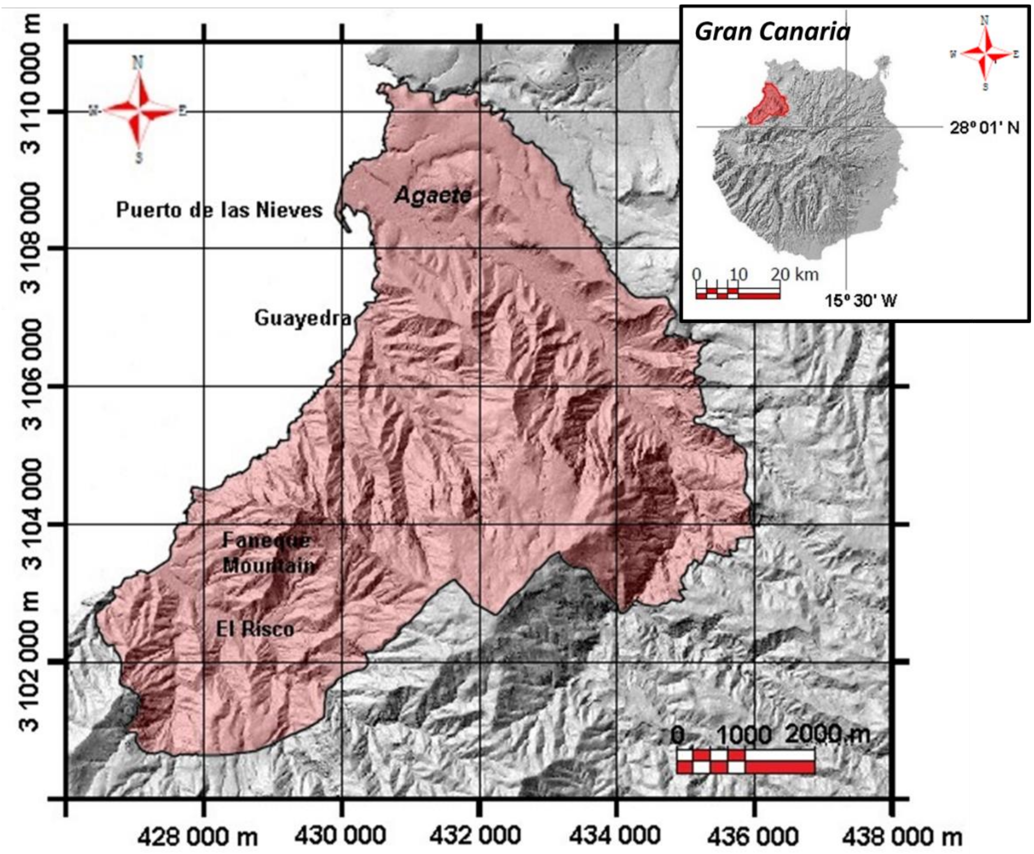


Figure 1. Situation map of the municipality of Agaete. Agaete is marked in red on the map of the island of Gran Canaria. (TNTmips).

The municipality of Agaete has a small surface of 45.49 km^2, an abrupt orography from the coastal area up to 1500 m in the Macizo de Tamadaba. In the municipality of Agaete, there are three principal hydrographic basins: El Risco, Guayedra and Agaete, the first two are located inside the Natural Park of Tamadaba. This littoral area is uninhabited, instead the Valley of Agaete is where most of the population is situated.

The coast of Agaete has 11.74 km in longitude, from the Juncal ravine (N), adjoining the municipality of Gáldar, until the Cuervo beach (S), adjoining with the municipality of Artenara. The coast has plenty of cliffs of more than 100 m in altitude, with gulfs and caps of decametric dimensions. On the other hand, the study area is found inside the limit from the intertidal zone to 200 m inland. The climate in this area is coastal desert, with rainfall reaching 200 l/m^2 in the villages of El Risco and Agaete, the mean annual temperature is 20ºC, but in the Pinar de Tamadaba the mean temperature is 16ºC during winter (PGO, 2004). This arid climate produces limited vegetation and the rock outcrops can be easily studied.

2.2 Geological context of the canarian archipelago and of Gran Canaria Island

The Canarian archipelago is considered volcanically active and each one of its islands, except La Gomera, have holocene volcanism. They are situated in African oceanic lithosphere of about 170 million years of age and they were formed thanks to a constant source of magma (hotspot) during the last 142 Ma (Bogaard, 2013). The hotspot has changed its position throughout time due to the mantle anomalies and the movement of the tectonic plate which caused volcanic activity in a shifting manner: 142 Ma ago it took place to the south of the archipelago, then moved northward about 68 Ma ago and the last 34 Ma in the present Canary Islands (Boogard, 2013). The growth of the volcanic intraplate oceanic islands, such as the Canaries, has taken place in various stages following the model suggested by Walker (1990) for the Hawaiian Islands. The order of these stages is the following: submarine, emergent, shield-building, alkaline declining, erosional, rejuvenation, atoll and guyot.

The island of Gran Canaria starts to form in the Mid-Miocene about 14.5 Ma ago, the submerged materials (marine and emerging stages of the Hawaiian model) do not appear over the surface, so they have not been studied. The subaerial construction of the island is divided in many phases clearly differentiated which are: in shield, alkaline descent, erosive and volcanic rejuvenation. Within these phases, specific formations have developed based on the composition of the materials and morphologies. So, the shield-building stage of Gran Canaria is characteristic of the effusive emission of hundreds of ultramafic, mafic and intermediate lava flows (basanites, basalts and trachybasalts) from 14.5-14.1 Ma which make up the Basaltic Formation (Figure 2), corresponding to the first volcanic cycle (Balcells *et al*., 1992; Schmincke and Sumita, 2010). These materials are predominantly located west of the island with some isolated outcrops in Arguineguín (SE) (Figure 2). Next, the formation and collapse of the Caldera de Tejeda takes place, and this caldera was active between 14.1-8.3 Ma, including the Mogán (14.1-13.3 Ma, Trachy-ryolitic Formation) and Fataga (13.3-8.3 Ma, Fonolitic Formation) formations. The main materials of this phase are the trachytic-riolitic and trachyphonolitic ignimbrites and lava flows (Balcells *et al*., 1992; Schmincke and Sumita, 2010; Carracedo and Troll, 2016). During this stage, many structures were formed in the caldera central zones such as the cone-sheet complex, domes and dykes (12.8 -7.3 Ma).

After the Caldera de Tejeda event, a period of volcanic inactivity establishes in the island (7.3-5.3 Ma) where the processes of erosion and sedimentation produce a network of ravines very incised on the topography of the island and the sedimentation of detrital material (Las Palmas Detritial Formation) concluding the first formation cycle of the island (Balcells *et al*., 1992; Schmincke and Sumita, 2010; Carracedo and Troll, 2016).

Subsequently, the volcanic rejuvenation stage starts (5.5 Ma-present day). It is made up of two main phases, the formation of the Roque Nublo stratovolcano and the Post-Roque Nublo phase (Figure 2). In the first one (5.5-2.8 Ma), the Roque Nublo stratovolcano was formed in the centre of the island produced lava flows and ignimbrites with ultramaphic to intermediate geochemical compositions. Thus, the materials emitted from this volcano were basaltic and basanitic and, immediately, trachytic and phonolitic. The second one started 3.5 Ma years ago with basaltic eruption all along the NW-SE rift, flowing towards the NE of Gran Canaria, and strombolian monogenetic volcanoes which emitted lava flows and fall deposits (Balcells *et al.*, 1992; Schmincke and Sumita, 2010; Carracedo and Troll, 2016).

Lastly, the recent volcanism stage starts in the Holocene in the Post-Roque Nublo phase, the materials emitted are basanitic and nephelitic (Figure 2). 23 eruptions took place during this period produced by strombolian cones and phreatomagmatic calderas aligned NW-SE. The most recent eruption is from the Bandama volcano dated of 1970±70 years (Rodríguez-González *et al.*, 2008, 2012).

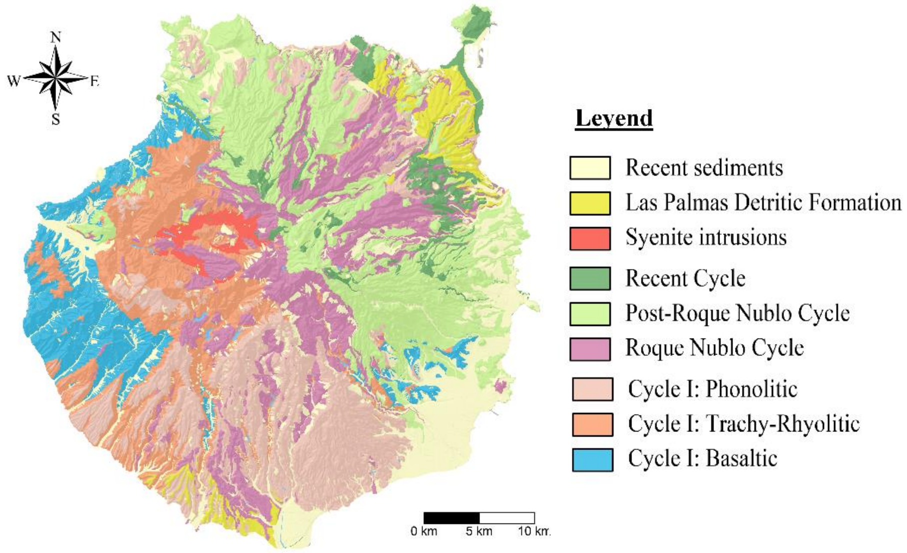


Figure 2. Geological map of Gran Canaria (modified from Bellido-Mulas & Pineda-Velasco, 2008).

2.3 Brief description of the geological context of the coast of Agaete

The coast of the municipality of Agaete is mainly covered by basalts corresponding to the Miocene Basaltic Formation (Figure 3). There are also present volcanic materials from the plio-quaternary Roque Nublo and Post-Roque Nublo phases to the north of the coast from the Guayedra ravine. The most abundant materials in this coast are the ancient basalts stacked subhorizontally which are very altered. They contain miocene basic and trachybasalt dykes. Corresponding to the first volcanic cycle, there is an intrusive dome located in the Juncal ravine mouth which penetrates through the basalts, related to the Phonolitic Formation (Balcells *et al.*, 1990).

The lava flows of the Post-Roque Nublo cycle are deposited on top of the basaltic lavas and some outcrops are alternately disposed with alluvial deposits of sand, gravel and clay, for example, the Planchón de Guayedra or in the cliffs of Puerto de las Nieves beach (Figure 3). Belonging to the Post-Roque Nublo cycle, there are cones made up of dispersion pyroclastic materials like lapilli, bombs and scoria (Balcells *et al.*, 1990).

In the Agaete ravine, a lava flow related to the Holocene eruption of Los Berrazales volcano is fit into the ravine (Figure 3). This lava flow is of type “aa” scoria, black-coloured basanite (Balcells *et al.*, 1990) which has been used for the construction of the artificial tidal pools of Agaete (Las Salinas).

Northwards, there are tsunami deposits which lie over the lavas from the Post-Roque Nublo cycle at Llanos de Turmán; there are 4 more outcrops going inland. The tsunamites were produced by a gravitational landslide from the Güímar Valley (Giachetti *et al.*, 2011;

Paris *et al.*, 2018), east of Tenerife, dated about 800.000-years BP (Mid Pleistocene). Their thicknesses vary from 1-5 m, contain from angular to spherical small stones and fossils, heterogeneous made up of volcanic material mainly (basalts from the Miocene and plio-quaternary and felsic rocks) with beachrock, paleosoils and gravels. The matrix contains coarse sand and volcanic gravel with carbonates (caliche). Based on the parameters of size, nature of rock and morphology, two sources of conglomerate material have been determined, one related to beach deposits and the other one to alluvial material. The fossil content is very high and assorted but mostly fragmented, and they correspond to molluscs from the Pleistocene period, in the interglacial period, when the temperature of the water was warmer (Meco *et al.*, 2006; Pérez-Torrado *et al*, 2006). These materials and structures are represented in the geological map (Figure 3 and Table 1) of the coast of Agaete.

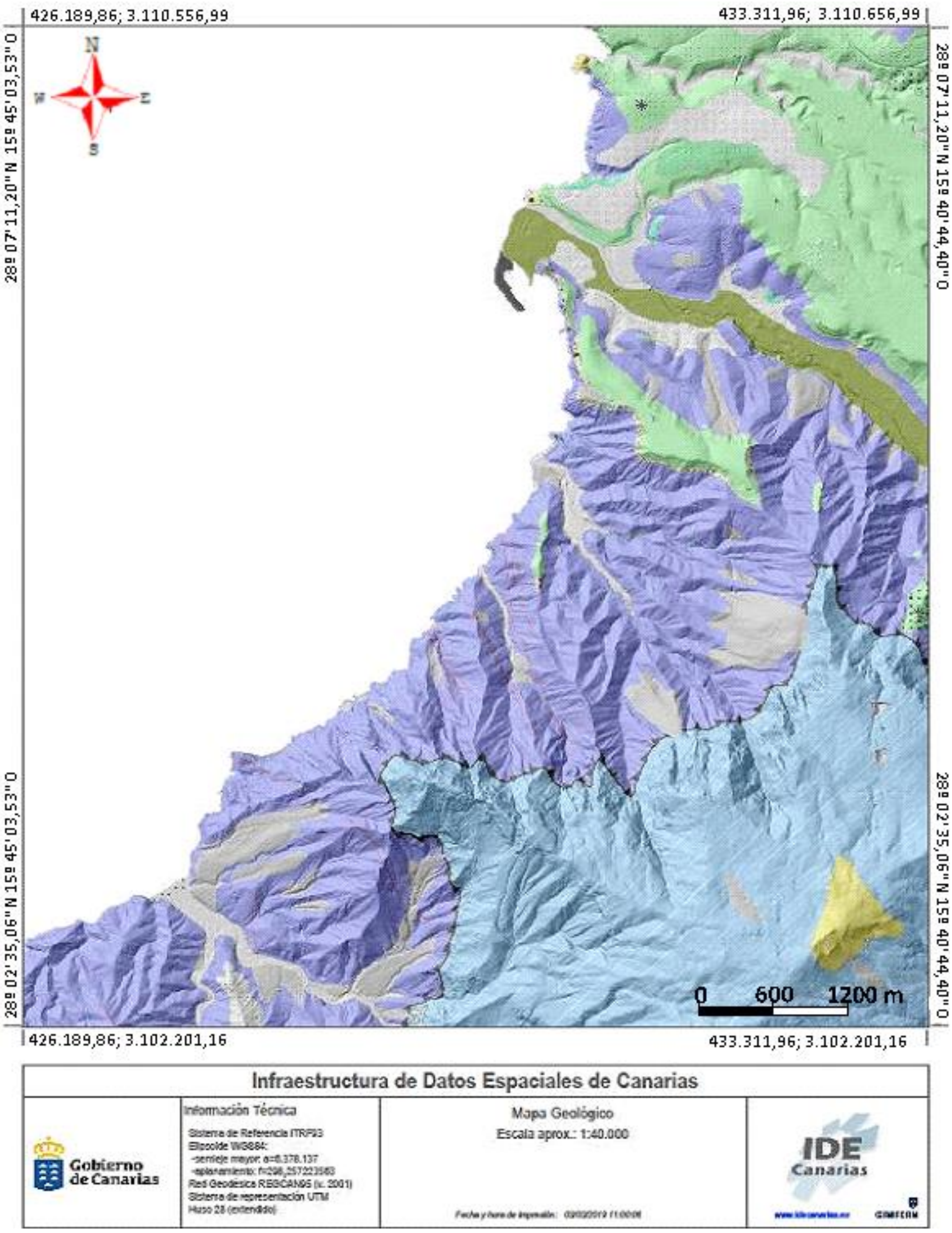


Figure 3. Geological map of the coast of municipality Agaete and inside zones [5].

Table 1. Legend of the Agaete geological map of Figure 3 [5].

	Structures, contacts and fractures		Dispersion pyroclasts
	Centre of emission without crater		Fluvio-marine deposits with gravel and fossils
	Direction and dip		Tephra and pyroclastic cones (lapilli, scoria and bombs, and olivinic-piroxenic basaltic and basanitic pyroclasts)
	Contact by discordance		Nephelitic-basanitic, basanitic and basaltic olivinic-piroxenic lavas. Tephrites
	Caldera boundary edge fault		**Roque Nublo cycle and Las Palmas Detrital Formation**
	Holocene and quaternary sedimentary deposits		Torrential and alluvial conglomerate deposits (gravel, sand, silt and clay).
	Beach and sand deposits (grey or fossiliferous) and sand with gravel, sometimes, with dunes associated.		**First volcanic cycle** *Fonolitic formation*
	Alluvial-colluvial deposits		Phonolitic, phonolitic-nephelitic and, sometimes, peralkaline trachyte lavas
	Actual alluvial deposits of ravines and valleys		Domes, dome-dykes and phonolitic intrusions
	Eolic fossiliferous sand deposits		*Trachytic-riolitic formation*
	Slope washout deposits, sometimes with fossiliferous sand deposits, dejection cones with eolic insertions, glacis-cone of trachytic-phonolitic composition		Altered hydrothermal deposits, green yellow (azulejos) in ignimbrites and riolothic-trachytic lava flows
	Recent volcanic cycle		
	Basanitic lavas		Ignimbrites and peralkaline riolithic-trachytic lava flows
	Post-Roque Nublo cycle		*Basaltic formation*
	Gravitational sliding deposits		Basaltic olivinic and olivinic-piroxenic lavas with trachyte. Hawaiites, banmoreites and mugearites.

3 METHODOLOGY

The methodology used to define the geosites in the coast of Agaete follows the steps of the National Inventory of Places with Geological Interest (Inventario Español de Lugares de Interés Geológico; IELIG), from the Spanish Geological Service (García-Cortés *et al.*, 2018)

Firstly, bibliographic information and documentation about the study area were gathered to be able to know the geological elements defined, about cultural, historical and natural heritage and about the natural protected areas. The published information was obtained from the MAGNA geological cartography of the island of Gran Canaria and of the sections of Agaete and Vecindad de Enfrente, scientific articles, publications from the IGME, legislation which allow the establishment of geosites and other webpages such as the IDE Canarias[5] for the topography, the use of land and the distribution of the area. On the other hand, the webpages of the geoparks of Lanzarote and the archipelago of Chinijo[6] and of El Hierro[7], allowed us to compare the geosites defined with the ones of the coast of Agaete. Again, a working scale was chosen, according to the IELIG, the geosites will have local relevance.

Secondly, a group of experts was chosen to which their collaboration was requested to contribute with information about geological heritage present in the coast of Agaete. The experts came from different areas of study related to earth sciences such as regional geology, hydrogeology, geography, oceanography, paleobotanic, stratigraphy, tectonics, sedimentology, petrology and geochemistry, amongst others. In addition, we contacted with archaeologists, public officials, politicians related to heritage and environmental departments. This way, a more generalized view of the area is appreciated which provide more representation in the study area.

Thirdly, a survey, made up of two parts, was sent to them through the email provided by my tutor. The first questionnaire was divided into three blocks: the first one studies the geoconservation, the second one looks for possible geosites in the island of Gran Canaria and the third one studies the knowledge of the expert (Vegas and Galindo, 2018). This questionnaire was sent the 6th February with a deadline during mid-March, with one-month period to complete and confirm their participation. When the first part of the survey was received from most of the experts, the second questionnaire was sent where the proposed geosites by the experts had to be evaluated by themselves and give their opinion. This second questionnaire was sent the 8th April with a deadline before Easter Holidays. The surveys used came from the IELIG 2014 version, updated to the IELIG 2018.

During this period, fieldwork was carried out to visit the study area. The transport was arranged by car to the study area and then, the coast was examined in detail looking for the structures, geomorphologies, materials (rocks, minerals, soils) which were going to be studied. Many photographs have been taken at various scales, from the structures and geomorphologies to mineral scale, and volcano-stratigraphic schemes were made. Once the area was visited, four possible geosites were localized. For those four geosites, descriptive documentation was filled in, containing information about their geological characteristics, mineral and fossil content, structures, geomorphologies, paleontological sites and other data relevant for the definition of the geosites. Some of the sections were not completed because they did not correspond to the geosite.

Once the geosites were defined, it continued with the valuation looking for the principal interest for each of the geosites, as in scientific, educational and/or touristic-recreative importance. This way, it could be established which one of the geosites had the highest value and how it must be managed to be able to boost that characteristic. Moreover, values of deterioration susceptibility and deterioration risk were calculated, both for natural and anthropogenic causes. So, protection, conservation and dissemination strategies can be used to present the geosite. The valuation guideline follows the IELIG 2018 (García-Cortés *et al*, 2018) which is the most updated version.

Finally, the geosites were delimited and located so they could be integrated under the protection of natural geological heritage. The cartographic presentation of the geosites depends on the surface it occupies. The programme used to do both the geographical location of the island of Gran Canaria and of the municipality of Agaete (Figure 1), together with the cartography (Figure 9) was the TNTmips software. The coordinate system used for the situation map of Gran Canaria was geographic coordinates and the coordinate system for the municipality of Agaete was the UTM system.

4 RESULTS

According to the results obtained from the surveys distributed to the group of experts and the fieldwork to recognize, explore and evaluate the coast of the municipality of Agaete, four geosites have been proposed. These are the dome of Punta Gorda and its surroundings, the area from the beach of La Caleta to the Salinas of Agaete; the cliff from Roque de las Nieves to the Dedo de Dios in Puerto de las Nieves; and the cliff from the Planchón de Guayedra to Risco Faneque called Laja del Risco due to the observation point from which the whole coast of Agaete can be seen and where the immensity of the cliffs can be appreciated. This selection was done using the methodology explained in the previous section.

4.1 Survey results

For this study area, even though it is a small area, the surveys were sent to 64 experts to whom we asked for their collaboration. However, only 11 of them were able to participate, the rest of them dismissed their participation because they had little knowledge about the geology of the study area, or they were not able to complete it in time or they lacked interest. Therefore, only a total number of 11 experts decided to participate voluntarily, most of them being geologists (Figure 4A). 46% of the experts were working in the University of las Palmas de Gran Canaria (Figure 4B).

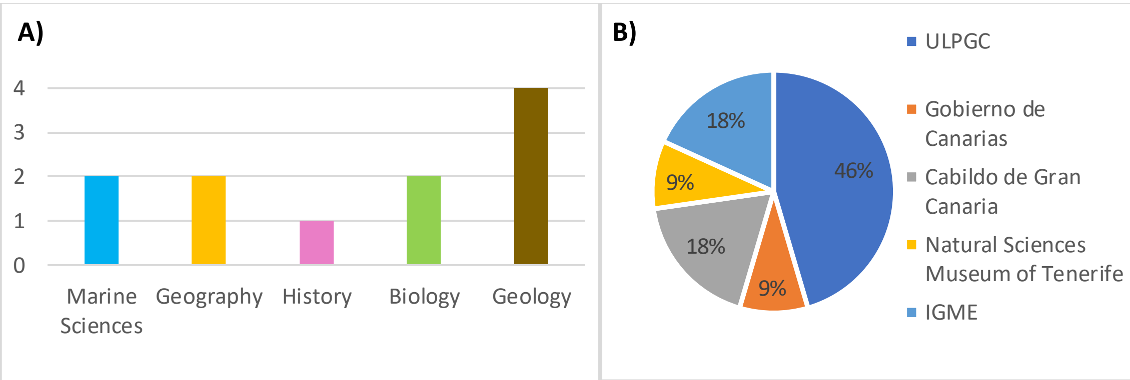


Figure 4. A) Experts' studies (bachelor o specialism). B) Organization in which the experts work.

For the first round of the survey, the data was processed so it could be sent again to the experts on the second round. The first section of the survey referred to the geoconservation theme. As for the importance of geological heritage from a general perspective, an 80% of the experts said that it was very important, in comparison to 20% which thought it had an average importance. For the coast of Agaete, half of the experts said that the geological heritage was very important, again compared with 20% whom thought it had average importance.

Comparing the relevance of the geological heritage of the possible geosites of Agaete with the rest of the geological heritage at national and regional levels, most of the experts coincided that those geosites presented a higher relevance, but only in specific cases. Finally, the value of the geological heritage is an important factor in the economic development obtaining a high-medium importance. Within this section, the experts had to name 10 places which they thought had importance as geological heritage in the island (Table 1A) and those places in the coast of Agaete which had geological interest (Table 1B).

Table 2. A) Ten sites which have geological interest and potential for geological heritage in the island of Gran Canaria. B) Sites that have geological interest in the coast of Agaete.

A) Sites with geological interest in Gran Canaria	Votes
Caldera of Tejeda (Cone Sheet)	9
Caldera of Bandama	7
Dunas of Maspalomas	6
La Isleta	4
Beach of las Canteras and barra	4
Las Palmas Detritic Formation	4
Macizo of Guguy	3
Cuenca of Tirajana	3
Roque Nublo	3
Fataga ravine	2

B) Sites with geological interest in Agaete	Votes
Juncal ravine – Punta Gorda	6
Faneque cliffs	6
Llanos del Turmán – La Caleta	3
Maipez – tsunami deposits	3
Agaete ravine	3
Guayedra	3
Dedo de Dios – Puerto de las Nieves	2
Macizo de Tamadaba	2
Risco de Agaete	2

The table 2A has absence of possible sites with geological interest belonging to the coast of Agaete. Some of these sites coincide with the Points of Geological Interest established in the geological map 1:100.000 of the island of Gran Canaria (Ballcels *et al.*, 1992) as part of the geological heritage of the island and the inventory of natural heritage of the island of Gran Canaria (Vegas and Galindo, 2018). The table 2B names those sites in the coast of Agaete which present geological interest, chosen by the experts.

The purpose of the second part of the survey was that the experts gave their opinion about the geosites proposed for the coast of Agaete. Therefore, they had to give a score for each one of the geosites with values of 0, 5, 10, 15 and 20 based on the importance or characteristics to study, recognize and interpret the origin and evolution of the geology of the coast of Agaete. Seven answers were received for this last part, most of them agreed with the data collected in the fieldwork.

4.2 Study and characterization of the geosites with the descriptive documentation

The approaches for the geosites were studied and the scores were received from each one of the experts and, with the information obtained from the fieldwork, four geosites could be established in the coast of Agaete. Some of them were combined due to the proximity between them. Descriptive cards were filled in for the geological characterization of the proposed geosites, considering the IELIG 2018 document, the geological information of our fieldwork, the geological publications and MAGNA cartography such as Balcells *et al*. (1990, 1992) and Barrera *et al*. (1990). Most of the sections were completed except for the following: 16) Description of the deformation processes; 18) Description of the hydrogeology and the Descriptive card for museums and collections as the geosites proposed lacked these features.

The geological domain of this research, according to GEODE, is Canary Islands and the geotectonic unit corresponds to Gran Canaria. According to the law 42/2007, the geological context to which they belong is the volcanic edifices and morphologies of the Canary Islands and the geological unit is the volcanic systems. The age the geological materials at all the geosites ranges from the Mid-Miocene until Holocene and present day.

4.2.1 Punta Gorda Geosite

The Punta Gorda geosite is located at the northern coast of Agaete (Figure 9), has an area of 151,811 m^2 and it has various components which have an important value (Figure 5). The principal geological elements of this site have petrologic and geochemistry interest, as a secondary interest the geomorphology stands out. In addition, the non-geological interest is the archaeologic potential it presents.

The geological components of this geosite are the following: the presence of the miocene phonolitic dome of Punta Gorda that penetrates into the miocene basaltic lava flows (Figure 5B), the quaternary – lower pleistocene – pyroclastic cone of Morisca Mountain (Figure 5A), the stroked hillsides (badlands) and the cliffs formed due to the erosion caused by the sea over the miocene basaltic stacking. Historically and culturally, there is an aborigine cave called Cueva del Moro in the hillside of the pyroclastic cone at Llanos de la Morisca (Figure 5F). These altered pyroclasts contain calcium carbonate, iron oxides and hydroxides (brownish neoformation minerals) in their cavities and fractures. Also, there are beaches containing coarse sand, gravel and fallen blocks due to the coastal dynamics of the area and gravity, respectively.

The miocene pahoehoe basalts have a blackish colour, are very altered and relatively thin lava flows, forming subhorizontal stacking dipping towards inland. These lava flows develop vitreous and porphytric textures, and the phenocrysts are olivine and clinopyroxene, mainly. The endogenous phonolitic dome is a greenish cupuliform body which is very eroded due to the marine abrasion and intrudes into the miocene basalts giving place to a volcanic breccia on the border (Figure 5C). In addition, the dome core is massive, but displays columnar disjunction due to fast cooling. On the other hand, the phonolitic rock presents aphanitic texture and microcrystals of clinopyroxene and feldspar, and bigger pieces of basaltic xenoliths (Figure 5D) There is presence of macrostructures such as a dyke located next to the dome, at the edge of the breccia, which has also columnar disjunction in both the centre and the borders, also very fractured. The quaternary pyroclastic cone is composed of altered dispersion pyroclasts such as bombs, lapilli and scoria (Figure 5E) with brownish colours due to iron oxides and hydroxides, and whitish thin layers of calcium carbonate in fissures and holes.

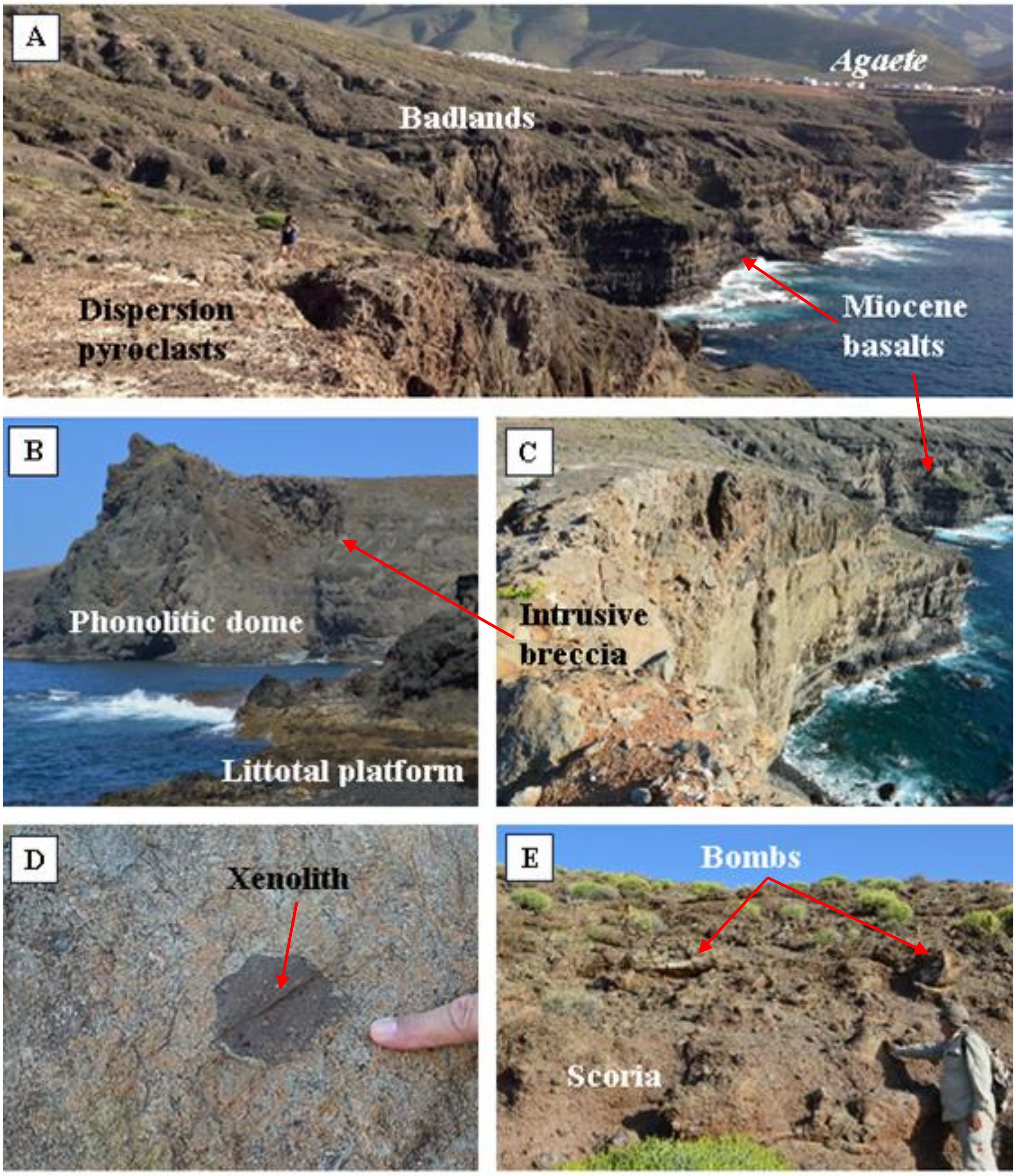


Figure 5. A) Miocene basaltic stacking and pyroclastic cone of Morisca Mountain with badlands. B) Phonolotic dome of Punta Gorda. C) intrusive breccia at the dome. D) Xenolith in the phonolitic rock. E) Dispersion pyroclasts. F) Cueva del Moro.

4.2.2 La Caleta – Agaete ravine Geosite

La Caleta-Agaete ravine geosite is situated in the north-centre of the coast of Agaete (Figure 9), occupies 148,821 m^2 and it contains numerous geological materials, geomorphologies and structures which represent a part of the geological history of the island. So, this geosite presents the most geodiversity of all the geosites defined in this research. The main interest is geological history, together with other secondary interests such as stratigraphy, geomorphology, palaeontology and mineralogy. As a non-geological interest, it has mining and industrial elements (old arid quarry to build the port).

Firstly, the miocene pahoehoe basalts are also present as part of the cliff (Figure 6A), as the geosite of Punta Gorda, with the same characteristics, however, geodes and fractures with secondary minerals can be seen in lava flows of the intertidal zone and cliffs. Within this stacking, there are two subvertical basic dykes with thicknesses less than 1 m and vitreous borders. In general, the basaltic lavas contain phenocrysts of iddingstized olivine and pyroxene and show porphytric textures with a microcrystalline matrix with olivine, clinopyroxene and Fe–Ti oxides. Other microstructures present in the basalts are the geodes and cracks filled with crystals of zeolites and calcium carbonate.

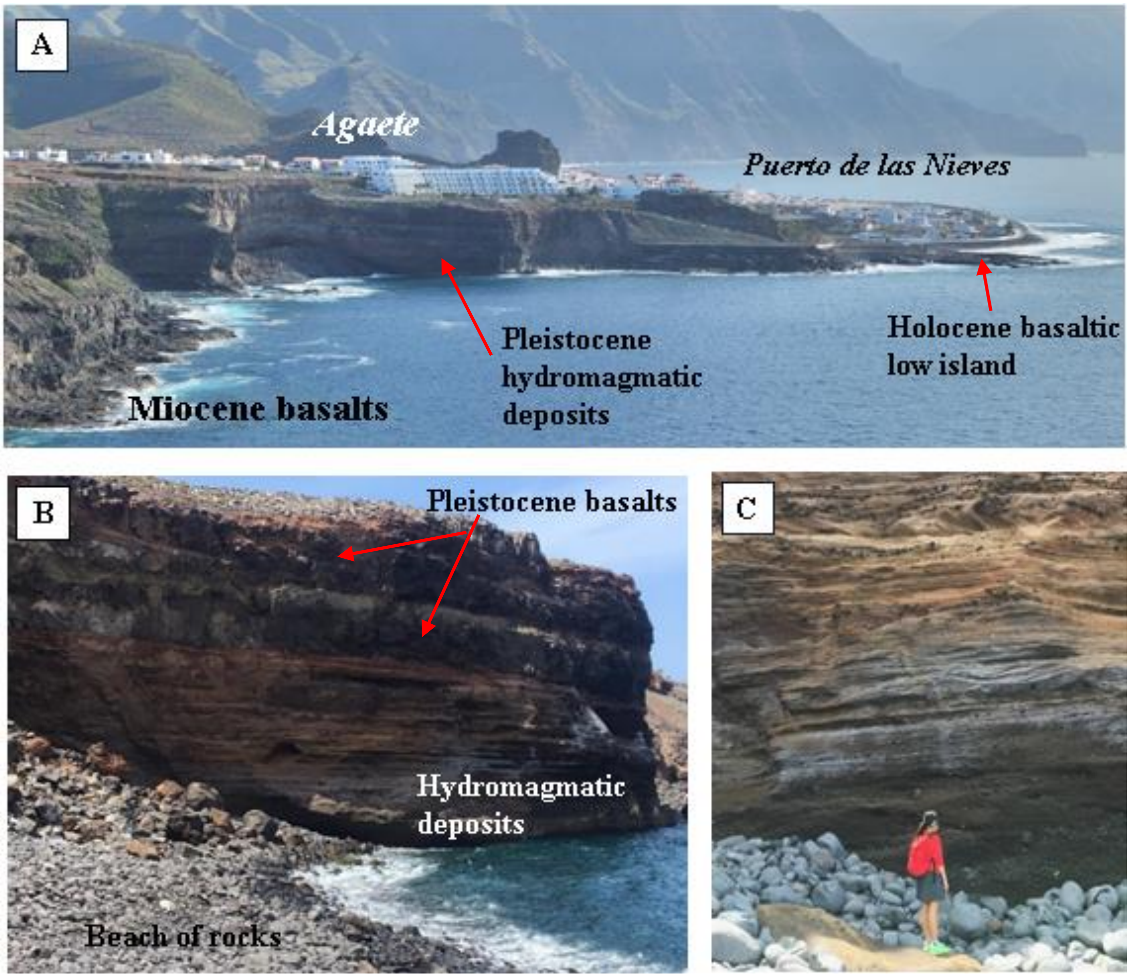
Then, the nephelinitic, basanitic and tephritic lavas corresponding to the Post-Roque Nublo cycle are made up of olivine microcrystals and have very aphanitic with some scoria present in the top and bottom of the lava flow which originate in some places at the cliff and the marine platform (Figure 6B). The stacking is very thick, each of the flow separated from the other by an almagre (interbedded reddish pyroclasts), but the coastal scarp is made up of only one lava flow with columnar disjunction.

Located under the lava flow of the Post-Roque Nublo cycle, there are hydromagmatic deposits which have been formed due to the interaction of magma from a very vigorous volcanic eruption with seawater. These deposits are quite thick and are made up of very thin material interleaved with coarse material, meaning the alternation of very vigorous eruptions with more gentle ones. It is constructed by very thin layers which have parallel stratification and cross-lamination (Figure 6 B and C).

Situated on top of the plio-quaternary lava flows, dated in 1,75 Ma (Pérez-Torrado *et al.*, 2006), in the area of Llanos de Turmán, the tsumani deposits are located which were caused by a gravitational landslide from the Valley of Güímar (east of Tenerife). They have been studied by several authors which have classified them as marine terraces (Meco *et al.*, 2002) produced by the ascent and descent of the sea level and, then, they were classified as tsunami deposits (Pérez-Torrado *et al.*, 2006; Paris *et al.*, 2018), based on the data collected from stratigraphic, sedimentologic and geomorphologic measures. There are various outcrops throughout the Agaete ravine, but only the one at Llanos de Turmán is going to be studied. It is located at 41 m above sea level, has a thickness of about 2 m, is heterometric containing mainly small angular rocks and some subrounded and fossils, is heterogeneous as it is made up of volcanic material (miocene and plio-quaternary basalts and miocene felsic rocks), beachrock, paleosols and gravel with a high sorting, its matrix is composed of coarse sand and volcanic gravel cemented with carbonates (Figure 6E). The fauna present comes from the Pliocene and Pleistocene periods (some of them are said to belong to the Tirreniense age); these include molluscs, bivalves and gasteropods. This fauna lived during an interglacial period where the climate was warmer than today; they can be used in paleoclimate studies. Most of the fossils are fragmented (Meco *et al*., 2006; Pérez-Torrado *et al*., 2006). There are two types of sources of the conglomerate material, related to beach deposits and ravine alluvial materials.

After, the lava flow coming from the Los Berrazales eruption (Holocene, around 3000 years BP), channelled through the Agaete ravine, reaches the coast creating a low island with a deltaic shape, corresponding to the recent volcanic cycle of the island of Gran Canaria. These lavas are 'aa' type which originate a scoria type lava flow (Figure 6F), they are also basanitic with vesicles and contain minerals such as olivine and pyroxene (Figure 6G), strong black colour and have columnar disjunction. These lavas have been used to build the tidal pools of Agaete (Copeiro and García, 2006).

Finally, materials from nowadays correspond to ravine deposits made up of blocks, grey sands and heterometric basaltic and phonolitic gravel. These materials are not quite developed. In the actual marine platform, there are passageways formed thanks to the process of erosion produced by the sea (Figure 6D). There are also small structures caused by the movement of pebbles and gravel inside small holes in the platform which is produced by the process of abrasion (coastal kettles). Another structure present which shows how the sea level has decreased throughout geological time is the cascade located at the mouth of the ravine which has about 2 m in height.



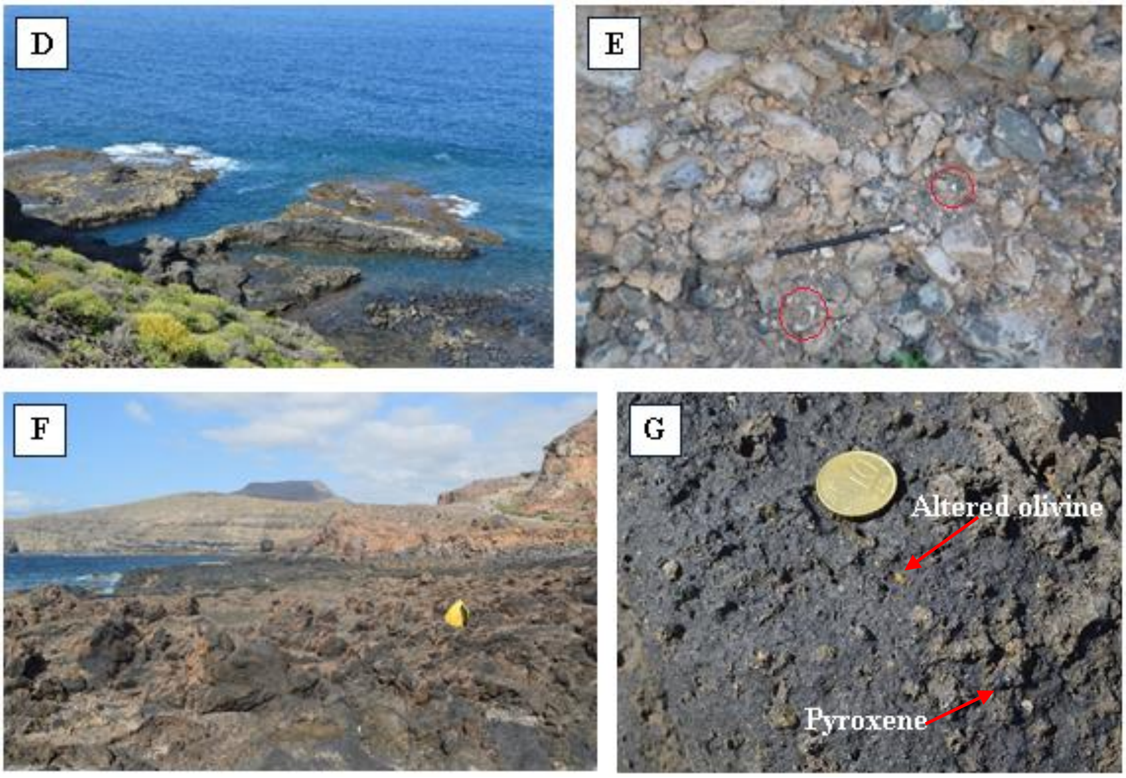


Figure 6. A) Overall view of La Caleta and Llanos del Turmán. B) Hydromagmatic deposits, pleistocene lava flows and altered sediments. C) Hydromagmatic deposits with cross-lamination. D) Erosive passageways and marine platform. E) Tsunamites, with fossils circled in red. F) Holocene lava flow "aa" type. G) Holocene basalt minerals.

4.2.3 Puerto de Las Nieves Geosite

Puerto de las Nieves geosite is in the central part of the coast of Agaete (Figure 9) and has an area of 107,991 m^2. At this geosite, a volcano-stratigraphic column can be appreciated clearly, so the main geological interest would be stratigraphic together with geomorphologic. As a non-geological interest, this area shows historical and cultural elements.

The same way as the other geosites, the miocene basaltic pahoehoe lavas are located at the base of the Puerto de las Nieves' cliff and massive plio-quaternary lavas with some scoria at the base are on top and, in between them, a sedimentary alluvial deposit can be observed (Figures 7A, B and C). Some parts of the Miocene basalts are covered by colluviums. The textures present are porphytric and vesicular, containing cracks and geodes filled with zeolites and calcium carbonates (Figure 7E). The principal phenocrysts in the lava flows are olivine and pyroxene, and olivine altered to iddingsite (Figure 7F).

The lavas corresponding to the mid-Pleistocene period have columnar disjunction and a volcanic breccia with big scorias is present were the sediments and the lava seem to get mixed together (would be a lava front or lateral moraine). The alluvial deposit in between them is made up of sand, gravel and some silt-clay containing rounded, heterometric pieces of various natures (phonolitic, basaltic and vitrofidic tuffs, corresponding to miocene magmatic cycle). Intruding into the miocene basaltic lavas, there are two basaltic dykes (Figure 7G) which have an aphanitic texture and their edges are vitreous.

The beach is made up of small stones, blocks and sands, and a marine volcanic platform appears near to the coastal line. In addition, an erosive remainder of the cliff generated by regression called Dedo de Dios, is a famous geomorphology in the village and it is the Puerto de Las Nieves icon (Figure 7D).

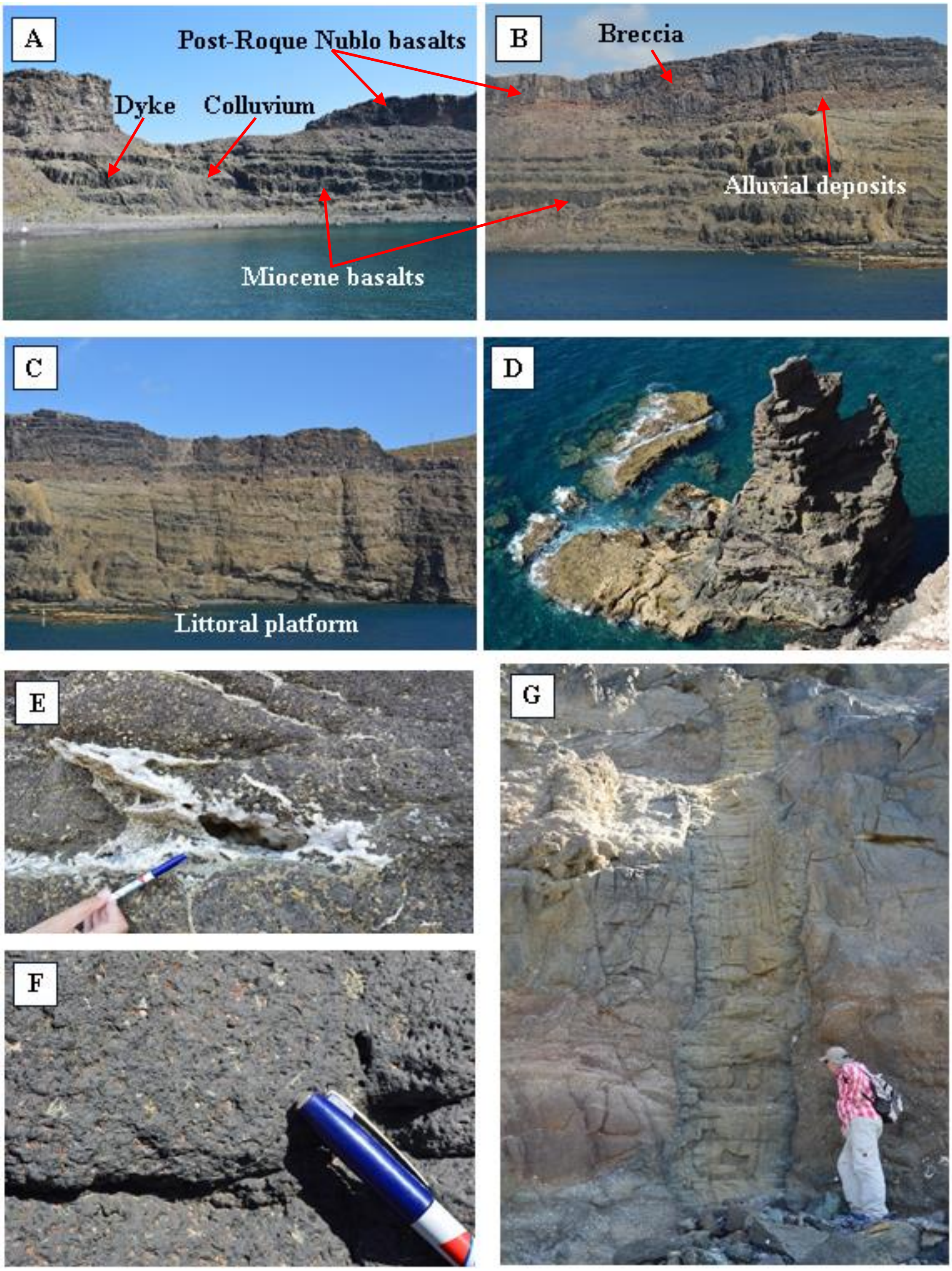


Figure 7. A) Roque de las Nieves, lava stacking and beach of stones. B) Lava stacking, alluvial sediment deposits and volcanic breccia. C) Lava stacking, erosive remainder of the Dedo de Dios and marine platform. D) Dedo de Dios. E) Zeolite geode. F) Miocene basalt minerals. G) Basaltic dyke.

4.2.4 Laja del Risco Geosite

Laja del Risco geosite is located south of the coast of Agaete (Figure 9). This geosite is the largest of all with a total surface of 3,526,056 m^2 and has a geomorphological interest principally, followed by stratigraphic and geological history. Also, thanks to the magnitude of the cliffs, it has a landscape interest (Figure 8A). This geosite is the only one that is located inside a protected area, the Natural Park of Tamadaba and it is also within the Red Natura 2000. It is important to point out the presence of an archaeological site at the Roque de Guayedra where aborigine houses and necropolis areas are located.

This geosite has a main interest in landscape and is visually attractive because it is where the most characteristic littoral geomorphology of the area can be appreciated (Figure 8 A). From this geosite, the entire coast of Agaete can be seen from the dome of Punta Gorda (N) to the beach of El Risco (S) and Punta de las Arenas appears (cap with quaternary aeolianites, colluviums and alluvial deposits) in the municipality of Artenara. The basaltic stacking of hundreds of meters can be appreciated in the lower parts of the cliffs, these lavas are pahoehoe very altered (Figure 8B) with a paleosol deposit (almagre or red ocher) interbedded between them. Felsic ignimbrites and lava flows of the Trachy-ryolitic Formation appear in the high part of the cliff, and they are thicker lavas with light colours. Also, there are various basaltic, trachybasalt and phonolitic dykes spread throughout the cliff's wall intruding into the basalts and trachybasalts. The subvertical cliffs show abundant small ravines, colluviums in the walls and alluvial deposits and blocks fallen by gravity in the coastal zones (Figure 8 A). In addition, beaches of stones in the of Guayedra and El Risco ravines can be distinguished. So, this geosite, contains all the geological history of the coast of Agaete. In a more specific area, the observation point is located at the Laja del Risco which is characterized by the presence of two dykes (Figure 8C) that belong to the first volcanic cycle. One of them is dark basaltic and the other one is clear trachybasaltic, so textures can be compared, minerals and other characteristics. Again, the minerals present in the materials are olivine, pyroxene, Fe-Mn oxides, volcanic glass, zeolites (Figures 8D and E) and calcium carbonates. Finally, an inactive quarry of building materials (aggregates) appears near to the coastal line (Figure 8C).

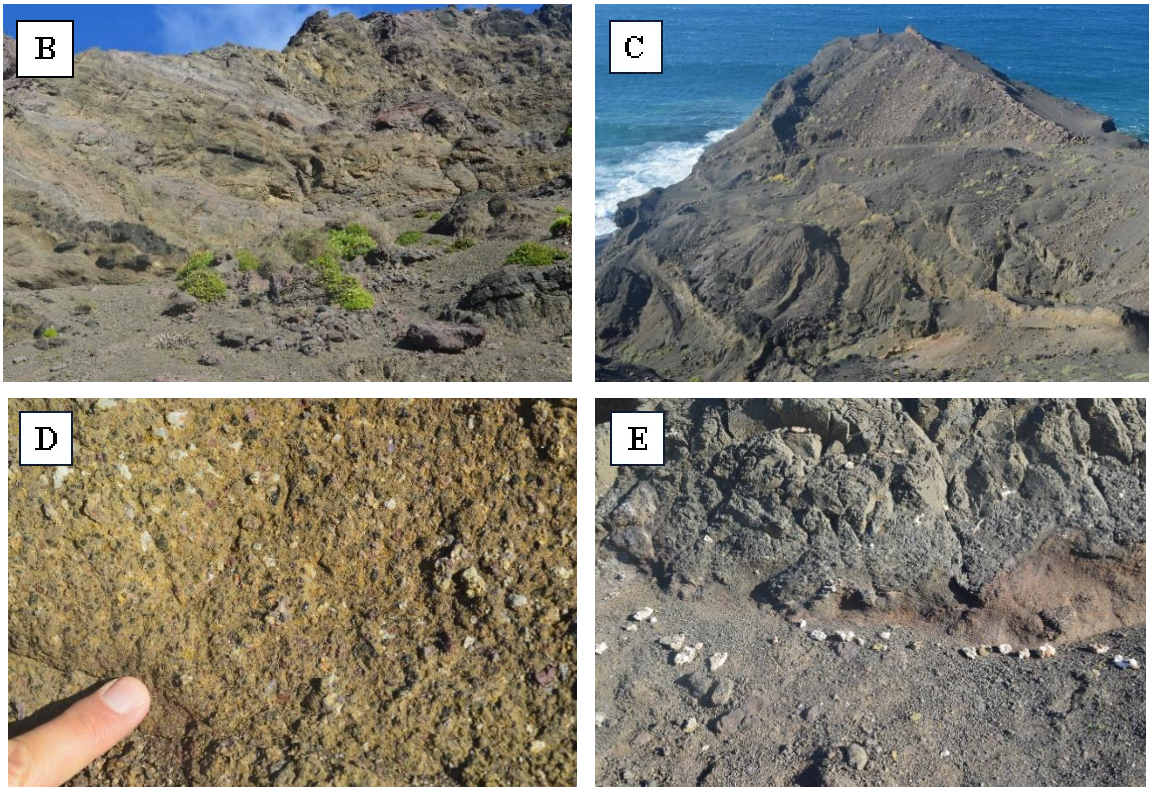


Figure 8. A) Overall view of the north coast of Agaete. B) Altered Miocene basalts. C) Morro de la Laja with two dyes. D) Minerals in altered miocene basalts. E) Remains of a despoiled geode.

Figure 9. Cartography of the final geosites (Source: GRAFCAN, modified with TNTmips).

4.3 Cartography

A cartographic presentation was elaborated for all the geosites (Figure 9). To do so, a geographical information system program, TNTmips, was used to build up the map, using rasters supplied by the GRAFCAN from the IDE Canarias [5]. These rasters were the topographic map at a scale 1:50,000 and the orthophoto at a scale 1:50,000. Using the program, the polygons which contain the geosites were constructed using the topographic map, their areas measured, and their coordinates taken using the centre of the polygon. Then, they were superposed over the satellite image as shown below. For the geosites of la Laja del Risco and Punta Gorda, there are straight edges conforming the polygon because they follow the map's corresponding parallels and meridians.

4.4 Valuation of the proposed geosites

The valuation of the proposed geosites has been carried out using the methodology detailed in the IELIG 2018 document, to look for the main purpose of each of the geosites, if they have a more scientific, educational or touristic-recreative approach. The values of interest obtained for each one of the geosites are shown in the following Table 3. The values higher than 6.65 have a very high interest, the values from 3.33 to 6.65 have a high interest and the values lower than 3.33 have an average interest. The geosites which have a value lower than 1.25 should be reconsidered as a geosite (García-Cortés *et al*, 2018).

Table 3. Values of interest of each one of the LIG.

Geosite	Scientific Interest	Educational interest	Touristic-recreative
Punta Gorda	3.5	3.9	3.8
La Caleta - Agaete ravine	5.6	5.3	4.3
Puerto de las Nieves	3.1	4.4	5.1
Laja del Risco	4.8	4.9	5.1

In general, all the geosites show high importance values for all interests except the geosite of Puerto de las Nieves which has obtained a value of 3.1 out of 10, an average importance, with respect to the values mentioned before. The geosite of Punta Gorda has a high educational interest, followed by the touristic-recreative and, at last, scientific interest. The geosite of La Caleta – Agaete ravine has the highest values of all geosites with the scientific interest (5.6) the most important and the least is the touristic-recreative interest. For both Puerto de las Nieves and Laja del Risco geosites, the touristic-recreative interest is the highest followed by the educational and finally the scientific interests.

And now, the calculated values of deterioration susceptibility and deterioration risk, according to the parametric calculation of the 2018 IELIG official document, are shown below (Tables 4 and 5) for each one of the geosites. The deterioration susceptibility is defined as how easy it is for the geosite to deteriorate; this depends on its size, its vulnerability and fragility. The fragility is related to the characteristics of the area that make it deteriorate easily like lithology. The vulnerability talks about the threats that the geosites are exposed to cause by nature or by human activity. The deterioration risk measures the potential harm that can be produced to the geosite. It combines the deterioration susceptibility with the interest value of the geosite. Depending on the values obtained, the geosites are more susceptible and are more at risk to deteriorate (values higher than 3.5 and 2.5, respectively), have an average value of deterioration susceptibility and risk (1.5 and 1, respectively) or a low deterioration susceptibility and risk (0.75 and 0.5, respectively), based on the 2018 IELIG official document.

Table 4. Values of deterioration susceptibility of the geosites.

	Punta Gorda	La Caleta-Agaete ravine	Puerto de las Nieves	Laja del Risco
Natural	0.38	0.75	0.19	0.13
Anthropic	2.63	21.00	10.88	2.88

Table 5. Values of the deterioration risk of the geosites.

	Punta Gorda	La Caleta-Agaete ravine	Puerto de las Nieves	Laja del Risco
Natural	0.14	0.38	0.08	0.06
Anthropic	0.97	10.59	4.58	1.41

According to the values stated before, the deterioration susceptibility due to natural causes for all the geosites is low (less than 0.75), compared to the values caused by human activity which are quite high (above 2.5). This means that it is more probable that the geosites get deteriorated because of human actions than for nature’s effect, being the highest for the geosite of La Caleta – Agaete ravine (21.00). It is highest because the tsunamites are very fragile and can deteriorate easily by actions such as the force of the wind or collecting fossils from the area by visitors. The values for deterioration risk are quite low for natural causes. On the contrary, they are very high for the anthropic causes. The geosites of La Caleta – Agaete ravine and Puerto de las Nieves are the most affected because they are closer o are in the city nucleus, so they are more exposed to everyday-life human activity.

Considering the prior results, protection measures need to be established for each one of the geosties, especially, for the geosites of La Caleta – Agaete ravine which present elevated values of scientific and educational interests and are more sensitive to the human actions. Hence, the protection measures for this geosite need to be urgent and at a short-term approach. For the geosite of Puerto de las Nieves, the protection established must be at a mid-term approach as it has a high touristic-recreative interest compared to the other two interests. Finally, the protection measures for both geosites of Punta Gorda and Laja del Risco can have long-term measures as they are the least threatened thanks to its distance from the village and their spatial magnitude knowledge of the environment and geological characteristics (surface, access, unknown geological elements and, cultural and scientific publications, among others).

However, it is important to comment on the values obtained deterioration susceptibility and risk caused by anthropic activities at the geosite of La Laja del Risco, comparing them to those obtained for the geosite of Punta Gorda. These values are higher which is contradictory to what it is explained in the methodology used as the values for susceptibility depend on the size of the geosite. The values for La Laja del Risco geosite should be lower because its bigger in comparison to the geosite of Punta Gorda. An explanation for this could be the presence of the road GC–200 crossing through the entire geosites as so for the presence of two small populations, Guayedra and El Risco. Also, due to the possibility of building a carpark next to the entrance of the geosite which could cause extra damage. Another factor which affects the values of susceptibility and risk of deterioration is that it is in a protected area. This means that there are many measures which need to be taken

4.5 Management strategies

The geosites proposed contain representative structures, morphologies and materials of the geological history of the coast of the municipality of Agaete. In each one of them, management measures need to be established. The most important measures that need to be taken is to promote recycling and waste collection for every geosite, especially for those ones which have picnic areas. For both carparks and the picnic areas, litter bins need to be located with the aim to promote waste collection and recycling. Also, the interpretative panels need to be made of materials which are resistant to the marine spray, to the wind, the dust suspended in the atmosphere and the insolation. Other improvements need to take place as explained next.

4.5.1 Access, routes and parking areas

In general, the geosites of Punta Gorda and La Laja del Risco are the only ones which could have the access and the parking areas improved (Figure 10 A and D). The geosites of La Caleta - Agaete ravine and Puerto de las Nieves are located the village's nucleus, so they have good access (Figures 10 B and C). However, for this last geosite, it is preferable to not get close to the cliff as there is danger of detachment, even if a cement wall has been built to support it.

For the geosite of Punta Gorda, a good path is established for the walkers which crosses the farmlands at Morisca Mountain and crosses in front of the indigenous cave of Cueva del Moro (Figure 10 A). This route is low intensity as it takes 30 minutes to complete and the area is quite flat and even, but near the phonolitic dome there is a vertical cliff, so danger signs need to be installed. Also, a route coming from the Juncal ravine can be established. A carpark can be conditioned in the area of Llanos de Turmán, benefiting both geosites of Punta Gorda and La Caleta – Agaete ravine (Figure 10 B).

For the geosite of La Laja del Risco, there are two possible routes to establish for this geosite, maritime and terrestrial routes. The terrestrial route is a little complicated because a carpark should be built, and it would cost a lot of money. Hence, a carpark in the village of El Risco should be conditioned so that the visitors get to the geosite walking or organise shuttle buses from Agaete and/or El Risco to the beginning of the trail. It can be accessed walking through the road, which is a great danger, while in front of the trail there is an area to park the car. This route is only recommended for hiking experts because of the orography and the climatology – the trade winds blows very strong. The maritime route is done by boat to be able to get closer to the cliffs and provide a guided visit explaining the geodiversity and biodiversity characteristics of the area. These visits will depend on the weather, the waves and tides as it has a very high dynamic activity. Both routes could be done within 30 minutes to 1 hour, the terrestrial path has a medium intensity.

4.5.2 Signage

Information panels need to be installed in every geosite at keypoints. These panels should contain cartography, orthophoto, travel recommendations for the geosite, cultural and natural date, geological explanations, general and detail photographs and emergency telephones, among other. Thus firstly, it is necessary to indicate where the carpark is located, especially for the geosites of Punta Gorda and La Laja del Risco.

Secondly, indicating the path that should be followed to see the geosite as some of the geosites can have more than one route to access them. These panel need also to inform of the intensity and time required to do the route so that very young people and elderly stay in the geosites that can access easily, topographical cuts with slopes and the different stops with the basic natural information. This is again, especially for the geosites of Punta Gorda and La Laja del Risco.

Thirdly, interpretative panels need to be situated at each of the important points of interest. For example, in the geosite of Punta Gorda, the panels could be located at the indigenous cave, the dome and the farmlands (Figure 10A I, IV & V); in the geosite of La Caleta – Agaete ravine at the tidal pools, the tsunamites and in an oriel built to watch the volcano-stratigraphic column (Figure 10B, I, II & III); in the geosite of Puerto de las Nieves at the small dock to explain the volcano-stratigraphic column observed on the cliff, as well as the beach's dynamic behaviour (Figure 10C, I & II) and, finally, in the geosite of La Laja del Risco situated in the viewpoint of Morro de La Laja, orientated northwards to observe the north coast and another panel facing south explaining the beach of El Risco and Punta de las Arenas (Figure 10D, I & II), even though is belongs to the municipality of Artenara. Also, for this geosite, information of the weather is essential as it is very windy.

Finally, informative panels of leisure areas must be installed to inform of the areas where they can rest, have a picnic or take photographs of the area.

4.5.3 Leisure areas

As leisure places, picnic areas can be established for the geosites of Punta Gorda and La Caleta – Agaete ravine containing benches and tables (Figures 10 A, III and B, II). These picnic areas will have litter bins and, in the second one, public bathrooms can be built. The geosite of Puerto de las Nieves is next to the port and there are many restaurants and shops for the tourists (Figure 10C). Another aspect which is very important is for the geosite of La Caleta – Agaete ravine is to improve the area for the tsunami deposits as this area was a dumping area. All the waste that has been dumped need to be recollected and transported to a recycling plant.

Another important infrastructure to include in the management measures is the Geological Interpretation Centre in the geosite of Puerto de las Nieves, located in the same building as the Tourist Information Centre. This would provide visitors and tourists general information about the coastal geosites and give them leaflets and guides of each one of the geosites in several languages.

4.5.4 Security measures

All the geosites need to have security and protection measures implanted such as delimitation of the trails for the Punta Gorda and La Laja del Risco geosites and protective fences around the picnic areas in Punta Gorda and La Caleta – Agaete ravine. The oriel located at the geosite of La Caleta – Agaete ravine should be improved to avoid detachment. At the geosite of Puerto de las Nieves, the passage should be restricted due to risk of detachment. Again, signage informing of the potential risks in each one of the geosites should be constructed.

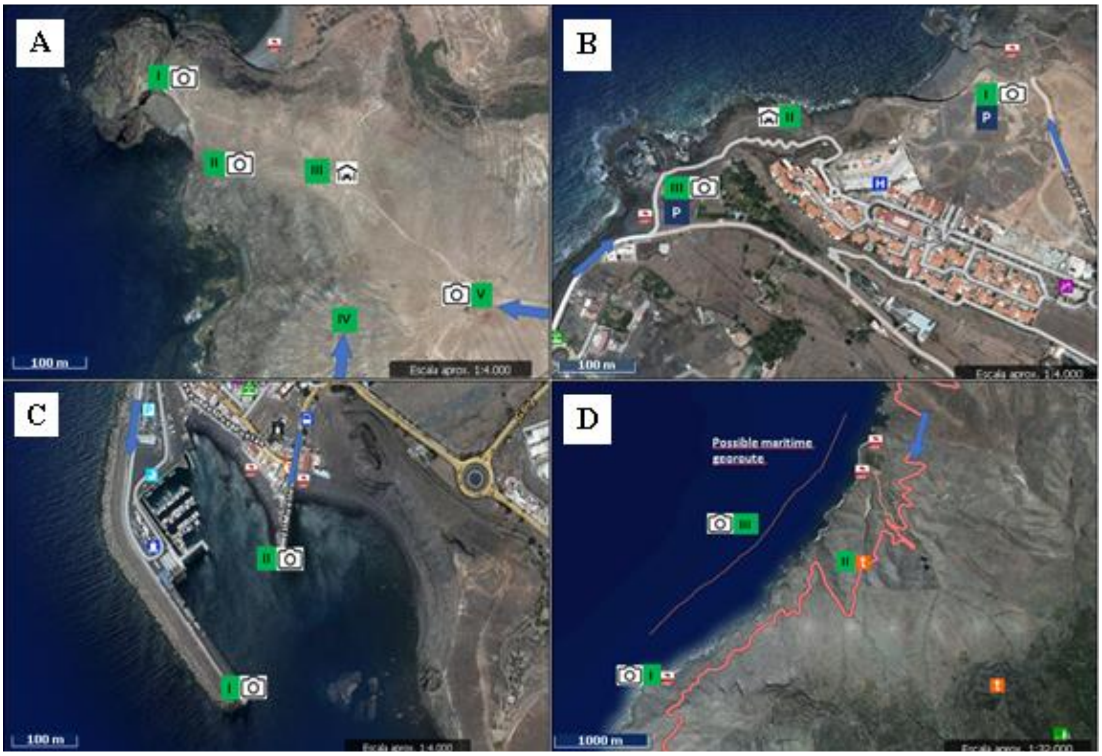


Figure 10. Viewpoints, photographs and picnic areas of each of the geosites. A) Geosite of Punta Gorda. B) Geosites of La Caleta – Agaete ravine. C) Geosite of Puerto de las Nieves. D) Geosite of La Laja del Risco.

5 DISCUSSION

This study is the first one that is done for the coast of Agaete about geological heritage. Nonetheless, at an insular level, other inventories have taken place along the coast of Gran Canaria, more specifically, the coasts of Arucas and Las Palmas de Gran Canaria (Déniz-González and Mangas, 2010 and 2011). In both of those works, four geosites were defined, the same way as for the coast of Agaete with areas smaller than 0,5 km^2 except for the geosite of La Laja del Risco. At a regional level, the geoparks of El Hierro and Lanzarote and the archipelago of Chinijo represent a worldwide geological importance, compared to the geosites defined in the coast of Agaete, which would have a local importance. Finally, at a national level, Spain has very important geosites included in the national geological heritage, as mentioned in law 42/2007, such as the dinosaur tracksites in la Rioja, (Fuertes-Gutiérrez *et al.*, 2016) and the geoparks at Cabo de Gata-Nijar (Almería) and Zumaia-Guipúzcoa (Basque Coast) where the submarine and subaerial areas are protected. However, the geosites defined in the coast of Agaete will only reach a local level of importance. The Gran Canaria Cabildo has commissioned the inventory of the insular geosites to the regional Geological Service (IGME) in Las Palmas de Gran Canaria (Vegas and Galindo, 2018). The Gran Canaria geosite inventory and cataloguing will be the base to define the insular geopark and this geological documentation will serve to submit the UNESCO request.

This work shows that the Final Degree Projects carried out by students of Marine Science Faculty generate enough geological results in coastal and marine zones to be used as future geoconservation and geotourism strategies in littoral areas. The obtained geological data contribute for enlarge geological knowledge which can be used in the management of natural protected areas or for making a request to Public Administration in relation to the conservation of natural heritage new zones.

6 CONCLUSION

The study of geological heritage in Spain is quite recent, starting in 1970s, with the scientific projects carried out by the Spanish Geological Survey. Nowadays, it has a strong support all around the world; there are some projects taking place like Global Geosites which aims to protect and preserve those geosites of great importance and, also, associations such as ProGEO which share the same objective but in the European Union. At a national level, there are other entities together with the Spanish Geological Survey. This work explains the geological heritage and geodiversity of the coast of the municipality of Agaete.

The coast of Agaete is characterized by the cliffs which can reach about 1000 m and they are constituted by miocene basalt stacking; basaltic lava flows with scoria, dispersion pyroclasts and plio-quarternary hydromagmatic deposits lying on top of them and, in the mouth of the Agaete ravine, the holocene lava flow type “aa” form a low-island. Other deposits, structures and geomorphologies found in the coast of Agaete are mafic and felsic dykes and a phonolitic dome intruding through the volcanic staking, the tsunami deposits dated in the mid-pleistocene (800.000 years BP), colluviums, stone beaches and, actual and ancient alluvial materials. All these geological elements need to be conserved for our future generations.

These geological elements have been limited into four geosites following the methodology explained in the 2018 IELIG official document (García-Cortés *et al.*, 2018). These geosites are Punta Gorda, La Caleta – Agaete ravine, Puerto de las Nieves and La Laja del Risco. Based on the calculations carried out, following the 2018 IELIG document, the value of interest of each geosite was calculated. The geosite of Punta Gorda obtained a higher educational interest, the geosite of La Caleta – Agaete ravine had a higher scientific interest, and the geosites of Puerto de las Nieves and Laja del Risco obtained the same value for touristic-recreative interest, higher than the other interests. Being able to know the approach for each of the geosites, can help the calculation for vulnerability, where the geosite of La Caleta – Agaete ravine was the most susceptible and at a higher risk of deterioration due to the wide range of geologic elements it contains and need to be protected urgently. The rest of the geosites had lower vulnerability values so their protection can be at a long-term approach. These geosites are going to be included in the geosites inventory of Gran Canaria and the local, insular and regional administrations should build a Geological Interpretation Centre for the four geosites in Puerto de las Nieves, improve access and signage which present the geological characteristics of this territory, as part of the geological evolution of the island of Gran Canaria.

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