Geoheritage, Geoparks and Geotourism

Elena Mateo
Jesús Martínez-Frías
Juana Vegas *Editors*

# Lanzarote and Chinijo Islands Geopark: From Earth to Space

Springer

# Geoheritage, Geoparks and Geotourism

## Conservation and Management Series

Spectacular geo-morphological landscapes and regions with special geological features or mining sites are becoming increasingly recognized as critical areas to protect and conserve for the unique geoscientific aspects they represent and as places to enjoy and learn about the science and history of our planet. More and more national and international stakeholders are engaged in projects related to "Geoheritage", "Geo-conservation", "Geoparks" and "Geotourism"; and are positively influencing the general perception of modern Earth Sciences. Most notably, "Geoparks" have proven to be excellent tools to educate the public about Earth Sciences; and they are also important areas for recreation and significant sustainable economic development through geotourism. In order to develop further the understanding of Earth Sciences in general and to elucidate the importance of Earth Sciences for Society, the "Geoheritage, Geoparks and Geotourism Conservation and Management Series" has been launched together with its sister "GeoGuides" series. Projects developed in partnership with UNESCO, World Heritage and Global Geoparks Networks, IUGS and IGU, as well as with the 'Earth Science Matters' Foundation will be considered for publication. This series aims to provide a place for in-depth presentations of developmental and management issues related to Geoheritage and Geotourism in existing and potential Geoparks. Individually authored monographs as well as edited volumes and conference proceedings are welcome; and this book series is considered to be complementary to the Springer-Journal "Geoheritage".

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# Foreword

When together with my family I visited the breathtaking island of Lanzarote first in the year 1994, we summarized our personal key impressions as follows: permanent strong passat winds, harsh volcanic and desert-like landscapes, massive lava flows and caves contrasting with the blue ocean and black, partly white sandy beaches, cactuses, rare palm trees, beautiful architectural houses (mostly—apart from rare terrible hotel complexes) and spirited communities … spirited by César Manrique (Cabrera) and his holistic understanding of landscapes, the earth's history, culture and human development.

In my understanding, that could be, respecting the 'brand-new' biosphere reserve (and some protected nature parks), an exemplary 'Geopark'—a term, a structure, a philosophy, that did not exist in 1994, but has started slowly growing in the minds of some geo-enthusiasts some 30 years ago.

A few geologists, palaeontologists, geographers and environmental planners recognized that conservation and development of significant geological and geomorphic sites and landscapes could provide a fundamental educational tool in our quest for understanding Earth, planets and life, as well as providing a promotional tool for sustainable regional development through 'geotourism'.

Earth science communication can be difficult, with explanations of complex geodynamic underground or surface processes and the use of scientific terminology often confusing those we want to take with us on a journey to understand and respect our restless planet. While science communication in general can be demanding, it is a prerequisite to convince people, decision-makers, the public at large, by providing up-to-date scientific knowledge on how to maintain and develop our environment in a sustainable way—and sometimes to reduce mistrust towards science experts, as well as partly a bias towards industry and tourism.

To cut a long story short: A wonderful tool to approach these challenging goals with respect to Earth sciences is today a 'Geopark'.

The 1984 inauguration of the *Parc Géologique de Haute Provence* in France, initiated by Guy Martini, set the stage for individual followers. Establishing geo-related inventories and assessing the geoscientific value of sites started in the late 1980s and under the leadership of John Cowie (UK), geoscientists of the UNESCO-IUGS-IGCP community began in 1989 to compile and identify, country by country, the most important sites, in order to establish a *Global Indicative List of Geological Sites* (GILGES).

The highly ambitious and commendable challenge of Cowie to compile a worldwide list of the most important geosites remained incomplete; it was later taken up under the guidance of Bill Wimbledon by the then active IUGS Working Group *Geosites*, aiming mainly at conservation, and a successor project of the *European Association for the Conservation of Geological Heritage* (ProGEO).

Apart from these inventory works, a significant global societal breakthrough in Geoheritage was reached through the 1991 *Digne Declaration on the Rights of the Memory of the Earth*. ProGEO's Working Group, under the leadership of Guy Martini, highlighted the global value of geology, geodiversity and geoconservation for the society.

Taking all these activities and undertakings into account, UNESCO's former Division of Earth Sciences, under my directorship, explored since 1994 the possibilities to create a global network of selected, geoheritage-related territories by offering its international umbrella for the numerous existing, but diverse national efforts in promoting the knowledge of the Earth. At the 30th International Geological Congress (Beijing 1996), a UNESCO workshop on 'Geological Heritage and Geosites/Geoparks' was organized by me and Mechtild Rössler (UNESCO, World Heritage Centre), Paul Dingwall (New Zealand) and Zhao Xun (China, Secretary General of the 30th IGC): An innovative—but sometimes perceived as too popular and 'unscientific'—initiative was therefore on its way.

Today, *Geoparks*, as a new international 'brand', are best defined through the criteria and guidelines of the *UNESCO Global Geoparks* designation that forms since November 2015 one part of UNESCO's *International Geoscience and Geoparks Programme* (*IGGP*).

One of the general principles of the Geoparks concept is, apart from education and conservation, the focus on sustainable development, including sites that represent landscape elements rather than small geological outcrops. This landscape approach is integrating biotic and abiotic Earth heritage conservation and underpins that geoconservation and geological heritage implicitly express the importance of earth history to our cultural heritage.

Managers and Earth scientists engaged in Geoparks are strengthening dialogue with planners, economists, and many others, in seeking to sustain and develop the world's life-support systems for the benefit of present and future generations.

National and (internationally recognized) global geoparks provide important lessons by touring to high rising cliffs and deep caves and the treasure troves of the Earth. Each of the geoparks is different, like the landscapes they represent, each opens a window to new exciting experiences in the world around us or below our feet. Thus, the Geoparks are contributing to today's huge challenges 'Climate Change', 'Disaster Risk Reduction', 'Clean Water', 'Sustainable Energy' and 'Health'.

Also on and around Lanzarote spectacular geomorphologic landscapes representing the 15 Ma history of volcanic landforms with catastrophic eruptions, and regions with special erosion, sedimentological or palaeontological features, quarries or engineering and salt-mining sites are becoming increasingly recognized as critical areas to conserve the unique geoscientific aspects they represent as well as places to enjoy and learn about the nature and history of our planet (and our planetary system), as well as the architectural and cultural development of humankind.

Treasures of Lanzarote and the Chinijo Islands are providing 'windows to a hidden world' in the anchialines, in the volcanic caves on land or the submarine slopes of this volcanic edifice in the Atlantic Ocean.

I certainly hope that this book will have a double effect: firstly, increase the public motivation within Lanzarote to explore the intimate integration of biotic and abiotic features with the island's history and culture; secondly, make the international community curious to gain more and direct information on the natural treasures of this wonderful island(s).

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Wolfgang Eder
Geoscience Centre, University of Göttingen

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# Introduction. Lanzarote, a Unique Geopark

Cayetano Guillén and Elena Mateo

**Abstract**

The island of Lanzarote is a place that represents brittle insular areas with high environmental values, where a coexistence between preservation and the controlled and responsible use of the local heritage has been achieved. Since April 2015, Lanzarote and the group of islands and islets part of the Chinijo Islands, have been part of the European Geopark Network. Such recognition of the islands as a Geopark, has been an essential tool to strengthen local strategies and value the local geological and geomorphological heritage. In addition, it has also been key when it comes to continuing to contribute to the traditional and sustainable use of the islands, favouring coexistence models. In these past three years, the set of actions promoted or supported from the Geopark, have logically unfolded in order to lead to a plan of action that is adapted, participative, efficient when it comes to resources, and that has acted as a unifying agent. The basis of the sustainable development strategy that is the foundation of this unique Geopark is set on these.

**Keywords**

Geopark • Lanzarote • Geoconservation • Geotourism • Participation • Environmental awareness

**Abbreviations**

| | |
|---|---|
| IELIG | Spanish Inventory of Places of Geological Interest |
| IGME | Spanish Geological Survey |
| CACT | Art, Culture and Tourism Centres |
| FEADER | European Agricultural Fund for Rural Development |
| IGEO | Institute of Geosciences |

## 1 Introduction

Since April 2015, the island of Lanzarote and the Chinijo Islands, are part of the European Geoparks Network. The motivations that led to this candidature were diverse and were based on the uniqueness of the geological features that this small group of islands has. The approximately 14 million years of geological history of Lanzarote, its insular nature and the active nature of its volcanism, have resulted in a complex mosaic of geological features in which it is possible to enjoy the forms, processes and materials associated with recent volcanism, along with some of the best examples of geomorphological processes derived from the natural dismantling of the reliefs generated in volcanic oceanic islands.

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The lack of vegetation and the exceptional conservation of its geosites, make this Geopark a unique place to research volcanic processes and exogenous dynamics in arid environments.

Since the recognition of Lanzarote and Chinijo Islands as a Geopark, from the Cabildo of Lanzarote actions have been strengthened to ensure its geodiversity, as well as all other actions and initiatives aimed at evaluating and disseminating this natural legacy. During these past three years, all these actions have been logically carried out resulting in a work plan that is adapted, efficient in resources, involved and unified. The foundations of the sustainable development strategy that supports the existence of this unique Geopark are based on it.

## 2 The Challenge of Local Geoconservation

In general terms, it can be stated that the developing possibilities of a society will depend on the geological characteristics of a territory; the location and characteristics of its buildings, the infrastructures, its agricultural and technological development, etc. But geology is also a determining factor that influences the local culture, the way in which the population has to relate to their environment, to adapt to the characteristics of the territory in which they live and to try to "live together" in harmony. The result of this interaction and influence is a set of natural and cultural landscapes that today represent one of the main assets on which the economy of these islands is based.

In this sense, geoconservation must include all those actions aimed at maintaining and preserving the intrinsic values of the geosites but also those others aimed to guarantee the importance that these spaces have in the local culture and landscape. Therefore, guaranteeing the preservation of the values of our geological heritage means contributing to the preservation of a very relevant part of the cultural identity and the local natural heritage, while guaranteeing the survival of essential elements for the future planning of strategies or sustainable endogenous development initiatives, based on the enhancement of this type of resources.

From the hand of the first initiatives to try to achieve the recognition of the geological and geomorphological singularities of this territory, as well as the different initiatives that were being carried out on the island with a view to the proposal of sustainable endogenous development strategies, the need arose to improve the level of knowledge of this type of natural heritage on a local scale. For this reason, and with the aim of improving the management and preservation of the geological heritage of Lanzarote and the Chinijo Islands, important efforts were initiated to deepen the knowledge of the location, characterisation and relevance of the unique geological features of these island spaces, from which to establish the basis to propose the different lines of work that are currently being developed from the Geopark itself.

In this context, the initial inventory of geosites was drawn up. A multidisciplinary team consisting of Spanish Geological Survey and University of La Laguna personnel, participated in the arrangements. The result of this work is the identification and initial characterisation of 68 spaces of very different nature, located both on the island of Lanzarote and the Chinijo Islands, or even being part of the abrasion platform that borders them and serves as nexus between these insular spaces (the Geopark currently has 19 submarine geosites that in some cases constitute the extension of those that exist on the earth's surface). For the completion of the list, the Spanish Inventory of Places of Geological Interest (IELIG) methodology was used, methodology elaborated by the Spanish Geological Survey (IGME) (García Cortés et al. 2014).

Among the group of Geosites that accompanied this candidacy, undoubtedly, the most emblematic elements are associated with the set of volcanic cones generated during the eruption of Timanfaya, which took place in Lanzarote between 1730 and 1736 and which nowadays it is still historically the most important eruptive event developed in the Canary Islands, whose materials came to cover a fifth of its surface emerged from Lanzarote (Romero 2003). This eruption is undoubtedly one of the main geological values of the island, as well as one of its most iconic and recognisable landscape icons. However, the singularity of the Lanzarote and Chinijo Islands UNESCO Global Geopark lies in the interaction of volcanic processes with active processes such as the movement of sands or coastal dynamics, very present in the local landscape and with great reflection on the territory.

## 3 Keys to Manage Geological Heritage

The geological heritage as well as being a necessary and useful resource for the development of our modern society, is a fundamental tool so that upon studying it, we can establish and interpret the events that occurred in the past, thousands or millions of years ago (Mateo Mederos 2015). From its analysis it is possible to study the history of the Earth, its evolution and the history of mankind.

In addition, it serves as a support to the biodiversity of our planet being its determining characteristics for a large number of animal and plant species of our ecosystems. It is understandable, therefore, that a sustainable and correct management of this resource must be carried out without endangering the continuity of these natural registers. But on the other hand, we must also accept that the geological heritage has to be enjoyed and used by all, as far as possible

(Mateo Mederos 2015). In this sense, it does not matter how many conservation and investment policies aimed at preserving and protecting heritage we have, if the population is not made aware and if they are not allowed to enjoy its benefits, geological heritage management will become a titanic task and often, even a pointless one (Mateo Mederos 2015). Therefore, it must be understood that good management of geological heritage lies not only in protecting and preserving, but also in making everyone aware and allowing for this heritage to be enjoyed.

The island of Lanzarote is a very representative place of fragile insular spaces and high environmental content in which this coexistence between the preservation and the responsible and controlled use of local heritage has been possible. It is an island where that types of initiatives have been developing for decades. Faced with more restrictive models, prevailing in nearby islands, Lanzarote has always opted for more transgressor models of preservation.

A unique example is Ruta de los Volcanes within the Timanfaya National Park. It is a stretch of about 14 km of asphalt road (which would be unthinkable with our current legislation) that is introduced into the inside of the national park passing between unique geological elements (hornitos, caves, aa lava flow, alignments of cones, etc.). That is to say, a space of great interest for text book morphologies that can be seen and for being part of one of the most interesting eruptions in the world for its duration and extension, from 1730 to 1736. The layout of the road blends in with the surroundings and it is not possible to observe more than 50 m of paved road in any section of it. It is visited by a large number of tourists who access it by bus and are not allowed to get off at any time during the tour, thus safeguarding the uncontrolled incursion of people in this very fragile environment. Ruta de Los Volcanes, was managed by artist César Manrique and by Jesús Soto in 1968, and thanks to it, it is possible for many visitors from all over Europe, especially from the United Kingdom, Ireland, the Spanish mainland and Germany to have contact with it and be aware of the value and intensity of these recent volcanic processes. It is also a valuable argument for residents to understand why it is necessary to protect this territory, the heritage of all Lanzarote residents, an important part of its history also responsible for the current island morphology. Therefore, the management of geological heritage must seek a balance, which is not always easy, between preservation of values for future generations and the use of this important resource for enjoyment, culture and even economic development (Mateo Mederos 2015).

Currently, the work carried out for decades by Jesus Soto and Cesar Manrique is a legacy of incalculable value for the island of Lanzarote and the Canary Islands in general. In addition to its undeniable artistic value, the set of works made by them in the geography of the island represent an important part of the most representative iconography of the Canary Islands. These are spaces of high environmental value, adapted, accessible and thematizsed to enhance or improve a natural heritage that is already rich. The work of both artists consciously establishes the foundations of a model of territorial management and coexistence with nature that is maintained to this day and that has had, and continues to have a wide social dimension. This joint work encompasses spaces capable of contributing to the worth of the natural resource it belongs to. Places that help get to know better the spaces and structures they are a part of. Sometimes platforms from which to better understand the geological history of Lanzarote also, in all cases, an important source of resources for the island. These are tools for the respectful and controlled approach of tourists and local population to the natural heritage, eminently geological and geomorphological that houses the island.

A representative part of the work of both artists is currently integrated into the network of Art, Culture and Tourism Centres (CACT) of the Cabildo of Lanzarote. These public capital centres are currently set put as one of the major economic engines of the island. All the benefits obtained through them reverts to finance local public policies, promoted both by the Cabildo of Lanzarote and by the different Town Halls in which these enclaves are located.

These unique spaces perfectly combine Art and Nature through interventions based on sustainability criteria that have had an enormous impact on the way of understanding architecture and interventions on the territory all around the island. At present, there are nine centres part of this network, eight of them with a clear link to the geological heritage of Lanzarote;

## 3.1 Cueva de Los Verdes

It is a natural volcanic cavity of relevant beauty and uniqueness. Its formation is linked to the eruptive episode that gave rise to Volcán de La Corona. Its vaults and corridors are part of the main volcanic tube that was generated during this eruption. From time immemorial, it was used as shelter for the local population and livestock. Sometimes a fortress or a hideout, to protect them from the many dangers that the coasts of Lanzarote were faced with during the sixteenth and seventeenth centuries, sometimes pirates, other times corsairs and slavers.

From the nineteenth century onward, the beauty of this space began to become apparent to travellers and naturalists of the time. The uniqueness of its forms of detail together with the impact of its dimensions, made a visit to Cueva de los Verdes a must for any expedition that ventured to the good knowledge and enjoyment of the north of the island. The magnificent work carried out by Soto and Manrique enhanced their features, introducing elements that contribute to highlighting their natural values (lighting, controlled accessibility), contributing, in addition, the possibility of new uses that have converted their main vault into one of the most important cultural features of the geography on the island.

### 3.2 Jameos del Agua

It was the first CACT designed and made by César Manrique, and is, for many, the paradigm of its aesthetic ideology: the harmony between nature and artistic creation. Jameos del Agua is an extension to the sea of the main volcanic tube of La Corona, the same one in which, upstream, Cueva de Los Verdes is located. The partial collapse of part of the roofs of this tube gave rise to the appearance of unique natural spaces. These are set up as the natural entrance to an underground volcanic world, tremendously complex and, in the case of La Corona, unusually large. The important flow of lava concentrated here, ran downhill entering the sea through an underwater segment that leaves from this place and that is known as "Túnel de la Atlántida". This enormous volcanic tube is the dwelling place of insular endemism (*Munidopsis polimorpha*) and a space that contributes to popularise and give meaning to the word "Jameo", one of the many geomorphological terms that since the Canary Islands has been extended to many other regions. This underground world was reinterpreted and shaped by Manrique to create an iconic space that would act as a standard in a way to understand nature and its coexistence with humans. Currently Jameos del Agua is the physical headquarters of Casa de Los Volcanes, as well as the Lanzarote and Chinijo Islands UNESCO Global Geopark, two initiatives that reflect the same commitment of the island's society and its institutions to continue betting on preservation, improvement of knowledge and the sustainable use of its natural resources.

### 3.3 Jardín de Cactus

It is part of the last major intervention César Manrique did in Lanzarote, aimed at transforming an ancient quarry of pyroclastic into a place that could be visited. At present, Jardín de Cactus hosts around 4500 specimens of 450 different species grouped from 13 cactus families that have arrived from five continents. Among the vertical forms that predominate among the cactus are the remains of the old chimneys that fed this ancient volcano. The multiple shades of green of these plants colour the old quarry walls where the different levels or strata generated during the rhythmic pulses of this eruption are still visible today. A small mill on one of its banks, consciously preserved, reminds visitors of the importance of relief for the use of wind, frequent and tireless, used for grinding in agricultural crops many years ago.

### 3.4 Mirador del Río

Is open on the same cornice that crowns the Risco de Famara. A window on the cliff from which to observe the narrow stretch of water that separates Lanzarote from the closest islands of the Chinijo Archipelago. A salt water "river" seen from here under the same perspective that birds enjoy. A watchtower suspended in the air from which to enjoy one of the most beautiful landscapes in the Canary Islands. Some of the oldest stories in the geological history of the island started on the cliff walls. In front of the cliff, the clear profiles of a more recent volcanism, of colours and morphologies that recall the important role of water in the volcanism of these islands. On both banks of the river, we can see examples of the efforts made by people to adapt to a difficult, extremely arid territory, looking for sustenance and subsistence in the sea. That's why here we find Salinas del Río, the oldest in the Canary Islands, at the foot of the Risco, where the cliff stops to become a beach.

El Mirador is another great effort by Manrique and Soto —in this case with the collaboration of architect Eduardo Cáceres—to generate a respectful, accessible and safe space, from which to enjoy this natural context without distorting it. The materialisation of this space for enjoyment was a boast of technical planning, given the characteristics of the chosen enclave.

### 3.5 Monumento al Campesino

Lifted on part of the lava flows belonging to the lavas field created by the historical eruptions of Lanzarote, it is a public acknowledgment of César Manrique to the effort of the men and women of the Lanzarote countryside who faced the most adverse conditions to give life to the territory. Capable people who were able to harvest "in the volcano", builders of unique cultural landscapes. Creators of the "geria" and, in general, of the cultivation systems under the "sands" that cover Lanzarote. In some volcanic cases, pyroclastic of very small size, locally called "rofe", originating in the multiple eruptive centres of Timanfaya. Its sands protect and provide humidity to the local vineyard, but also to tubers, fruit trees or vegetables that grow better thanks to the water contribution of this superficial layer of sands. A model that is also used, from the beaches of Famara to the south of Arrecife, under a continuous mantle of organogenic sands. A whitish layer that improves the albedo of the soil and promotes, an artisanal agriculture. Like in the rest of the sanded areas on the island, of highlighted heroic features, in which popular knowledge has given place to exclusive productions and cultural and unique practices.

### 3.6 International Museum of Contemporary Art Castle of San José

This old fortress, erected between 1776 and 1779 by order of King Carlos III, stands on a small coastal cliff in the vicinity of Arrecife.

Its walls of perfect masonry show some of the most resistant materials from nearby quarries. Volcanic stone of ocher shades that perfectly blend with this old military construction in the landscape of the area. Its uniqueness and location motivated Manrique to convince the island's authorities of the suitability of this building to house a cultural space of reference, a space for Contemporary Art, of marked international vocation and in a physical context of marked contrast. In order to nurture it, the Lanzarote artist launched the First International Plastic Arts Contest with works by Picasso, Tàpies, Miró, Mompó, Millares, Zóbel, among others, which were the germ of one of the largest collections of abstract art of the second half of the twentieth Century in the Canary Islands.

### 3.7 Museo Atlántico

Barely twelve metres deep, facing the south coast of Lanzarote, the Bay of Las Coloradas hosts a unique exhibition space. Two thousand five hundred square metres of its seabed act as the perfect stage from which unique pieces emerge that intend to reflect the contemporary nature of the islands and the constant questions posed to society in general about the use of natural resources and the sustainability of many of our daily activities. The set of these pieces has been built with neutral Ph materials, so they are intended to be especially respectful with the environment in which they are inserted.

### 3.8 Montañas del Fuego

This is the name under which a singular part of the volcanic massifs generated during the eruption of Timanfaya (1730–1736) is known. They are part of the National Park and, among other reliefs, houses Islote de Hilario. This place was chosen by Manrique to hold an integrated infrastructure that was able to facilitate and enrich the visit to the Park. This natural viewpoint daily hosts innumerable demonstrations of the energy that, in the form of heat, continues to reside in the heart of these volcanoes. Evaporation of water as small natural geysers continue to surprise visitors. This same heat is used to "cook" in a lookout-restaurant, also the work of Manrique, whose views can be a great culmination to a guided tour of the Volcanoes Route of Timanfaya National Park.

## 4 Networking; Recognition, Research, Planning and Performance

Currently, Lanzarote is a mature, dynamic and sensitive community regarding environmental issues. It is an island with an important tradition in the efficient and respectful management of its natural elements. A rich and equally fragile territory whose society is aware of the singularities of its heritage and the importance of its preservation and value. Engaged people and institutions that ensure in the coming years valid efforts that guarantee the consolidation of the Geopark and its objectives on the island, as unique elements of a complete model of sustainable and long-lasting socio-environmental development.

For decades on the island there have been initiatives to enhance the important natural and cultural heritage that together have contributed to forge the island's own identity. These initiatives have conditioned the internal and external image the island has in the Canary Islands, as well as the perception that the population of Lanzarote has of itself. To date, the relationship of the local population with its surroundings has been especially respectful, close, conscious and, in a certain way, conditioned. In this sense, Lanzarote—space and population—has magnificent examples of sustainable models of coexistence and responsible occupation of the territory; unique natural landscapes of jable, lava and volcano, but also of gerias, aljibes and gavias (different methods to manage water), of a unique dryland culture, lived and socially built by the people of the island, one generation after another.

In this sense, the recognition of the island and the whole of the Chinijo Archipelago as a Geopark provides a fundamental tool for the strengthening of local strategies to value and preserve local geological and geomorphological heritage, as well as the traditional and sustainable uses of the insular territory, favouring these models of coexistence and promoting the development of new strategies of valorisation of local geodiversity.

In spite of the evident predominance in the landscape of the island of its geological features, knowledge regarding this topic is not always appropriate. In this sense, a high sensitivity towards the environment, is palpable among the inhabitants of Lanzarote and La Graciosa. However, this does not always imply an adequate knowledge of the natural heritage that these islands harbour, and sometimes the local geological heritage is the least known aspect of the territory. This reality has marked the working strategies of the Geopark in the short term. The success of its development has taken place, to a large extent, by means of a real involvement of the different local agents. Over the last few years, these agents have been consolidating themselves as key players in the process of building a solid long-term work strategy, with which they identify and feel they are jointly responsible for. Since the recognition of Lanzarote and the whole Chinijo Islands as a Geopark in 2015, great efforts have been made to consolidate a project of all, built in a collaborative manner and in which local administration, scientific community and citizens can converge and progress in search of a better future reality in the matter of geo-conservation and responsible use. Despite the young age of this initiative, there are already many synergies and collaborations that have made this a successful project, adapted to the local needs and expectations, which represents and is nourished by the contributions of the different agents of the island whose involvement takes on special importance during the design, programming and execution of the different activities that have been carried out to date.

Over time, these collaborations, initially temporary, have been consolidated, giving rise to permanent links, associable to the achievement of close work objectives. A clear example of social and institutional involvement is the programming of activities developed in recent years in which the work of dissemination and awareness from a participatory perspective have been acquiring increasing importance. Some of these group achievements are exposed below, in part, in recognition of those behind them. All of them are developed within one of the main lines of work with which the Geopark currently counts and which are also described below:

## 4.1 Geo-Conservation and Awareness Increase of Local Geodiversity

The preservation of the local geodiversity and the promotion of the improvement of its awareness is one of the basic objectives of the set of territories belonging to the Global Geoparks Network. The recognition of the geological singularities that are associated with these spaces is in itself the most important initiative in Europe to promote the conservation of its geodiversity.

The term geo-conservation includes those actions aimed at maintaining and preserving the intrinsic values of geosites. Currently, it is a fundamental tool on which the proper management of the geological heritage must be based, since actions of environmental awareness or endogenous development that do not guarantee the preservation of the natural values on which it is based, should not be promoted.

Although the recognition of a territory as Geopark does not imply the implementation of new figures of protection of the territory that favour the conservation of its geodiversity, good part of the island spaces of Lanzarote and the Chinijo Islands are under one of the multiple categories of protection provided by the Public Administrations with competences in this matter. Of all of them, due to its clear geological vocation, the Volcanoes Natural Park stands out, which is also adjacent to the Timanfaya National Park and with a set of Natural Monuments of great territorial singularity and landscape relevance. Currently, all these spaces have a regulation that acts as an effective tool to contribute to local geo-conservation. In the case of the Parque Natural de los Volcanes, its specific regulations document is in the process of being approved, so this space continues to be governed by the precepts indicated by Insular Management Plan of Lanzarote, approved in the year 1991 (Mateo Mederos 2015).

In general, the Legislation regarding territory of the Autonomous Community of the Canary Islands is quite protectionist with the geodiversity of the Archipelago. The body of this regulatory framework is made up of two reference standards for the protection of the local geological heritage (Mateo Mederos 2015):

- Law 4/1999, of March 15, on the Historical Heritage of the Canary Islands. It is a legal text that constitutes a basic instrument for the protection of paleontological goods of the Canary Islands. According to this Law, the paleontological heritage of the islands is defined as the set of “property and movable assets that contain representative elements of the evolution of living beings, as well as the geological and paleo-environmental components of culture.” This Law provides for the protection of this part of the natural patrimony are the Registry of Assets of Cultural Interest, the Inventory of Movable Assets, and specifically, the Municipal Paleontological Letters. Paleontological Zone is applied to paleontological sites of interest. Following the precepts of this Law, up to date in Lanzarote, ten records have been initiated for the declaration as Assets of Cultural Interest, in the Paleontological Zone category with the same number of associated paleontological sites (Mateo Mederos 2015).
- Legislative Decree 1/2000, of May 8, by which the Revised Text of the Laws of Ordination of the Territory of the Canary Islands and of Natural Spaces of the Canary Islands is approved. This Decree establishes the general juridical regime of the Natural Spaces and of the

different planning instruments of the Protected Natural Spaces. Specifically, article 48 addresses "The Protection of Natural Spaces and declaration as such" and establishes the power to declare spaces as protected when a series of requirements are met. Among them are some closely related, or that make direct reference to the geological heritage and the geodiversity of the Islands:

- Housing geomorphological structures representative of island geology, in good condition.
- To shape a rural or wild landscape of great beauty or cultural, ethnographic, agricultural, historical, archaeological value, or that includes unique and characteristic elements within the general landscape.
- Contain paleontological deposits of scientific interest.
- Contain natural elements that stand out for their rarity or uniqueness or have special scientific interest.

Since the recognition of Lanzarote and the Chinijo Islands as a Geopark, there are several initiatives and research projects that have been supported or promoted by the Geopark to improve the knowledge, in general, of the geological heritage of these islands and the geodiversity associated with it. Among them, it is worth mentioning the *study for the recognition and inventory of the Geosites* on the island spaces. This initiative, basic during the process of recognising these islands as a geopark, continues to be active at present, so that this work is ongoing to date, to expand and improve the existing inventory and serve as a diagnostic tool and evaluation of the elements already included in this inventory. This work, carried out under the umbrella of an institutional agreement between the Cabildo of Lanzarote (promoting entity of the Geopark), IGME and the University of La Laguna, has served to provide the basis for knowledge necessary for future initiatives of geo-conservation, awareness and value enhancement. In parallel to the development of these inventory works, the assessment of the state of conservation of the inventoried sites has been made, identifying those that need some type of intervention or action that guarantees their short-term preservation.

An example of an intervention for conservation that has been carried out on the island of Lanzarote after its recognition as Geopark is Caldera del Cuervo (LIG: LZ28, Timanfaya Cones). Caldera del Cuervo is a place where a series of special and unique events converge. It is the first building formed during the eruption of 1730–1736, in particular and according to the documentary chronicles, from September 1, 1730. In addition, it has a first-class landscape quality and therefore is chosen as a place of visit by large amount of tourists freely, by organised groups and by a large number of advertising productions as a natural set. On the other hand is an area in which there is a large amount of lithic material containing olivine xenoliths inside, which has made it be one of the most punished areas by furtive extraction of olivine for years, causing a significant impact on its slopes (Guillén et al. 2015).

This volcanic cone required a direct action for the restoration of its backs and crater, as well as for the recovery of the topographic features associated with its immediate surroundings. Once the impacts were analysed, work was done dismantling roads on the slopes of the volcanic cone, relocating the removed volcanic materials, following to recover its natural and original appearance as far as possible.

The main objective of these interventions was to stop the anthropogenic erosion processes and recover the original profiles as much as possible, erasing the negative impacts generated by public use (Guillén et al. 2015). The set of these actions was possible thanks to a public investment from the European Agricultural Fund for Rural Development (FEADER) and the own funds of the Cabildo of Lanzarote.

## 4.2 Environmental Awareness and Participation for the Preservation of the Geological Heritage

The main set of actions that have been developed since the recognition of the Lanzarote and the Chinijo Islands as a Geopark have been aimed at raising awareness among the local population regarding environmental sustainability, as well as promoting the active participation of the citizenship in the preservation of the geodiversity of these territories. Some of the most significant activities associated with this line of work are developed linked to the programming that is established each year for the "European Week of Geoparks". This event takes place simultaneously in the set of existing geoparks in Europe. Each year these territories use this context to bring citizens closer to the values associated with their geodiversity and the cultural heritage that is generated from human activities in these spaces. Most of the activities programmed in this context have a marked educational and informative character. The aim is to raise awareness among the population about the value of this type of territorial resources, their natural singularity and their worth when it comes to proposing viable strategies for sustainable economic development models where geotourism and educational activities take on special relevance (Fig. 1). This initiative has been held in Lanzarote since its recognition as Geopark and is currently one of the environmental theme events that have the best reception on the island.

The programme of the first European Geoparks Week, held in Lanzarote in 2015, has a wide range of contents ranging from thematic exhibitions on the Geopark and the local geodiversity, to the development of routes, specialised talks and scientific debates. For this edition it is worth

**Fig. 1** European week of geoparks. Example of educational activity realized with school population in Lanzarote

highlighting the first exhibition held in Lanzarote about the Spanish Geoparks that have existed up to now. This is the first travelling exhibition promoted from the Geopark that was rotating around the island through the different exhibition spaces existing in its municipalities. The contents tried to approach, in a graphic and documentary way, the main features and singularities of Spanish Geoparks, paying special attention to the two Canarian representatives; El Hierro and Lanzarote.

One of the main novelties introduced in the programme of the second Week of the European Geoparks is the screening of the documentary "*La Cultura del Volcán*". Its production takes a wide archaeological, historical and ethnographic work, aiming to rescue the memory and knowledge are associated to the coexistence with the volcanoes and to the productive management of these spaces.

As in the case of the Week of the European Geoparks, since 2015 each spring Lanzarote hosts the *Geolodía*. This informative activity has its roots in the province of Teruel in 2005, with the aim of bringing the geosciences and the geologist's profession closer to society. From 2011 a Geolodía by province takes place on the second weekend of May, being currently an initiative supported by the Geological Society of Spain, the Spanish Association for the Teaching of Earth Sciences and the Geological and Mining Institute of Spain. Since the recognition of Lanzarote and the Chinijo Islands as a Geopark, the main activity associated with this day has been a field activity in which the attendees can learn from the hand of geosciences professionals about some of the most unique places of geological interest. Since 2015, these groups visits have been carried out in geological contexts that give rise to landscapes of special beauty, such as Caldera del Cuervo (Fig. 2), the organogenic sands of El Jable and the volcanic alignment of Gayo and the spectacular Risco de Famara.

To date, the relevant informative activity that has been promoted the most since the Geopark is the "Geological Heritage Days". Since 2015, it has been held on three occasions, addressing as central issues other topics of special importance in the local geodiversity and in the singularities of Lanzarote and the Chinijo Islands. This context has also served the purpose of bringing together the local population of geoscientists and prestigious popularisers on the Islands, as well as institutions and research centres linked to geosciences in the Canary Islands.

**Fig. 2** Geolodía. Activity of awareness with local population and tourists. Example of interpretive itinerary in Caldera del Cuervo

Both the approach of the topics to be dealt with during these days, as well as the activities associated with them, arise in a collaborative manner among the set of entities and institutions participating in them. This has allowed each year to maintain a product adapted to the concerns and themes of local interest that translates into a growing number of attendees. The first edition served as an excellent context to publicise the main singularities that had justified the recognition of this territory as a Geopark. An approach to its outstanding and unique geological heritage, which was addressed thanks to the collaboration of the Geological and Mining Institute of Spain and the University of La Laguna. This collaboration has been maintained to date, being the basis that enables it. In successive years, its positive acceptance has justified it being transferred to the last quarter of the year to become a magnificent activity for the annual closure of activities promoted by the Geopark.

During 2016, the theme chosen for this conference revolved around underwater geodiversity. A unique feature of this territory, as well as one of the fundamental factors that help to understand the surface associated with the Geopark itself. In most cases, these are features totally unknown to the public that contribute to the geomorphological complexity of the island's volcanic spaces, where a large part of the subaerial processes have a clear prolongation under the water. At present, the set of underwater geosites of these islands has a great potential for the development of geotourism activities. On the island of Lanzarote, many of these spaces have been acting for decades as unbeatable scenarios for sport tourism activities.

The main objective of the last of these days was to publicise the different experiences developed at a local level for the dissemination of the geological values and wealth of Lanzarote and the Chinijo Islands. This constituted a good context to present to the citizenship the latest initiatives developed in the Geopark in terms of dissemination and that since 2015 have been implemented sequentially, providing sufficient alternatives for an adequate understanding and enjoyment of the high geological value spaces to visit (Table 1).

**Field Geology, Geo-Routes and Guided Interpretive Routes.** Since 2015, one of the strategies of awareness and active training aimed at the citizens and the different local agents has been the guided itineraries in the field. In this sense, during these three years, these routes have had very

**Table 1** Topics addressed during the Geological Heritage Days held in Lanzarote (elaborated by the author)

| | | | | |
|---|---|---|---|---|
| 2015 | Geological heritage of Lanzarote and the Chinijo Islands | Geological heritage and geoparks | Dr. Ángel García Cortés | IGME |
| | | Lanzarote and Chinijo Islands geopark | Elena Mateo Mederos | Environmental area of the Cabildo of Lanzarote |
| | | The geological values of Lanzarote and the Chinijo Islands | Dra. Inés Galindo Jiménez | IGME |
| | | Lanzarote and Chinijo Islands geosites | Dra. Juana Vegas Salamanca | IGME |
| | | Geology of the ten essential geosites in Lanzarote and the Chinijo Islands | Dra. Carmen Romero Ruíz | La Laguna University |
| 2016 | Underwater geodiversity in Lanzarote and the Chinijo Islands | Introduction to the underwater geological heritage | Lic. Gonzalo Díaz Rodríguez | IGME |
| | | Ecosystems associated with the underwater gea | Dr. Juan Carlos Rubio Campos | IGME |
| | | Paleoclimate and variations in sea level in the quaternary period | Dra. Juana Vegas Salamanca | IGME |
| | | Lava under water | Dra. Inés Galindo Jiménez | IGME |
| 2017 | Geotourism for Lanzarote | Los Ajaches: at the heart of an ancient volcano | Dra. Juana Vegas Salamanca | IGME |
| | | Famara: among valleys and volcanoes | Dra. Inés Galindo Jiménez | IGME |
| | | The eruption of Volcán de La Corona | Dra. Nieves Sánchez Jiménez | IGME |
| | | Volcanoes with history | Dra. Carmen Romero Ruíz | La Laguna University |
| | | El Jable: sand between the volcanoes | Lic. Gonzalo Díaz Rodríguez | IGME |

different user profiles, always obtaining great results of active participation and a very good valuation of activity. This model of training activity has been used to do small training actions aimed at tourism professionals on the island, tour guides, technicians and hospitality professionals belonging to CACT dependent on the Cabildo of the island, professionals of heritage interpretation and the environment as well as citizens in general. This type of activity has involved a wide range of geosciences professionals, with different academic profiles and research trajectory, who have been able to transmit, the characteristic features of the local geodiversity. This type of collective activities have given rise to intimate moments of collective learning, participated by default and always thematised and very experiential. Among the results obtained with these activities there is a clear improvement in individual knowledge of the local geological heritage. An increase in the collective awareness towards the exclusivity of the forms and materials that give rise to the landscapes of the islands and that are decisive in the current model of coexistence with the environment.

The set of these visits are organised temporarily giving rise to a programming throughout the year. Depending on the context in which they are made and the target audience, these thematic itineraries are named differently, such as “Geoparqueando” or “Geolorutas” (Fig. 3). To date, there are many spaces visited, always trying to combine the enhancement of emblematic spaces within the geological heritage of the islands, with the recognition and dissemination of other territorial contexts normally less known but equally relevant for their uniqueness.

During these past few years, the Geopark has made a special effort to bring the geological heritage to the school community of Lanzarote. Since 2014, an adequate collaborative context has been created with schools on the island. This has allowed for training and awareness activities aimed at students of very different ages and educational contexts.

**Fig. 3** Geoparqueando; example of thematic itinerary with local population in Lanzarote

Among them, the most important ones, due to their repercussion and number of participants, are those carried out with the different unitary rural schools of the island. Together these activities respond to a main objective, show students the geological, geomorphological and landscape values of the territory in which they live. To value the "next" geodiversity, the one they have in their immediate environment, on which they develop their lives. This is intended to raise awareness of the importance of these places, as well as the need to actively contribute to the preservation of them. In many cases it is the students themselves who become promoters of conservation actions, motivating and involving other people in them.

In this programme of activities aimed at raising awareness about the importance of this "Geology near Home", actions are also included for the students of secondary education centres on the island. Among them, it is worth noting for its impact on students, a set of visits to unique geological sites located in the vicinity of their educational centres. Some of these most important thematic visits were those made to the cultural landscape of La Geria, to the Tinamala quarries or to "Túnel de la Atlántida".

## 5 Training Actions for Tourist Guides and Active Tourism Professionals

During the past two years the Geopark has promoted training activities aimed at improving the knowledge that tourism professionals on the island can have about the geological features and values that the Geopark treasures. The most outstanding of these actions have been the following courses;

- Volcanology Course for Tourist Guides (2016). This course took place at the Assembly Hall of the Cabildo of Lanzarote and covered basic concepts and processes of vulcanology and aspects linked to the genesis, evolution and eruption of magmas and also the compositional diversity of volcanic rocks. There was also time to study the products of volcanic eruptions such as lava and pyroclastic and to analyse a fundamental issue such as hazards and volcanic risk. The course was specially designed for tour guides and also for professionals linked to environmental education. Within the framework of this course, several field trips were made to study local volcanism, where the participants themselves develop their professional activity with thousands of tourists every year.

- Course "Planetary Guide of Lanzarote" (2017). The aim of this course was to make known the importance of the island of Lanzarote as a representative space for the geological features of other planetary contexts, as well as to contribute to the study of astrobiology. This training course was aimed at tourist guides on the island who can use the knowledge acquired to create themed products around this subject. It is a pioneering initiative in Spain that had the collaboration of the Institute of Geosciences (IGEO), the Joint Institute of the Higher Centre for Scientific Research and the Complutense University of Madrid.
- The Creation of a Web Page in 2016, the Cabildo of Lanzarote launched a web site to publicise the Lanzarote and Chinijo Islands UNESCO Global Geopark (www.geoparquelanzarote.org). This page, intended to bring the content and characteristics of the Geopark to the world of digital communication, nowadays used by the majority of the population. It is a space open to different profiles, in which through different sections you can find information about this seal of UNESCO, as well as all the geological and volcanological information related to Lanzarote and the Chinijo Islands. The web includes a calendar with news and outstanding events carried out by the Geopark through this programme, and a section named 'Geology' with 'geosites' to know the 68 geosites of the Geopark, separated by categories.

## 5.1 Geotourism and Value Enhancement of the Geological and Geomorphological Heritage

One of the fundamental principles on which the declaration of a territory as a Geopark is based on is the creation of a socio-economic and cultural development project at a local scale, based on the enhancement of its Geological Heritage (Carcavilla and García 2014). In general, these actions aimed at enhancing the geodiversity of the territory, have a very important educational and informative component, which justifies their implementation. Disseminating is an essential action that contributes enormously to guarantee the survival of the geological heritage in the long term, as well as the models of traditional coexistence of society with these singular spaces (Mateo Mederos 2015).

One of the first actions promoted from the geopark to value and transmit its geological heritage among the local population and tourists on the island was four *self-guided trails, themed according to their geodiversity.*

Each of them has fifteen interpretive panels to appreciate a large number of geosites. Each of these panels is adapted to the standard profile of visitors to these places. The aim is to teach users some of the basic values of these heritage traits, helping them to discover some of the defining essence of our territory and its landscapes. Each of these paths runs along old paths, used from time immemorial for access, or simply to facilitate transport and communications between different spaces. This has great added value for visitors since each of these four routes has a significant amount of interpretative contents linked to the cultural and ethnographic heritage of the island. The incorporation of these elements into the interpretative discourse of the itineraries leads to an integrating product, capable of enhancing the importance of the geodiversity of these places through a broader approach, in which references to other types of heritage traits linked to the landscapes are constant (Guillén et al. 2015). On the other hand, although the final objective of this project was merely informative, it is also part of an explicit geo-conservation measure, since the existence of these panels along the different paths makes visitors tend to follow them, avoiding them from wandering through highly fragile sectors (Mateo Mederos 2015). The start panels of these trails include information regarding the general characteristics of the visitable spaces, their natural relevance and protection categories, as well as the current regulations that guarantee their preservation, from which possible sanctions can be derived if breached.

The installation of these interpretive panels has been accompanied by the cleaning, conditioning and recovery of the traditional roads in which they settle and their surroundings, as well as the edition of a small field guide.

These first four themed trails are intended to be the first of many that can be consolidated as they can be incorporated new routes to the Insular Trails Network. Nowadays, hiking is a booming activity on the islands that demands specific infrastructures and services. The hiking activity gathers daily a huge number of people who see in this environment the best way to know the secrets of our territory in depth, to enjoy their natural treasures and their people. Especially during the last few years, this has ceased to be exclusively a recreational-sporting activity associated with tourism. Each year the number of residents that use these roads increases to enjoy their leisure time outdoors. For these reasons, the empowerment of these roads as tools for the dissemination of local geodiversity and for the promotion of geo-conservation has become a specific line of work within the efforts that are annually carried out by the Cabildo of the island itself.

As an example, the first "Lava Roads" are followed; themed trails for the dissemination of geodiversity and the preservation of the geological heritage of Lanzarote:

- The Gayo Way. It crosses part of the Famara Massif, showing an environment of unique landscapes, the result of the complex relationship maintained in this part of the island by volcanic activity and erosive processes. It is a path of marked contrasts that mixes some of the best examples of the Strombolian volcanism of Lanzarote. This is an area also characterised by the presence of large ravines that open on the Risco de Famara, allowing unbeatable views of the island of La Graciosa and the rest of the islets that make up the Chinijo Islands. The presence of human activity is a constant in the landscape. The availability of water in the area facilitated the consolidation of nearby population centres, as well as the cultivation of an important agricultural area that is partially still in use today.
- The Road of Caldera del Cuervo. It is a low difficulty circular itinerary. It has an estimate completion time of no more than an hour and a half for a 3000 m long route, with hardly any slopes. Its layout allows for a comfortable visit to the first volcano built during the eruption of Timanfaya (1730–1736). Its central crater erupted on September 1, 1730, giving rise to the most important volcanic eruption in the history of the Canary Islands, which would forever change the landscape of Lanzarote. It is an unbeatable example of the type of volcanoes that can be found in the archipelago; simple craters, of relatively small dimensions that are only capable of erupting once, giving rise to simple and yet spectacular constructions.
- El Camino de Montaña Colorada. As in the set of these thematic paths, its difficulty is low, with an approximate duration of an hour and a half and a length of approximately 4000 m. Its layout allows for a comfortable visit to one of the last volcanoes created during the eruption of Timanfaya (1730–1736). Its central crater erupted in 1736, forming part of the most important volcanic eruption in the history of the Canary Islands.
- El Camino de Caldera Blanca (or "Los Islotes"). It is a route itinerary close to 5400 m in length that can be done in approximately two hours. The road represents an unbeatable platform for knowledge and enjoyment of the lava landscapes generated by the eruption of Timanfaya, the most important for its duration and volume of materials emitted from all those that occurred in the Canary Islands in historical times (Romero 2003). This low difficulty path is formed inside the Parque Natural de Los Volcanes, included within the Canary Network of Protected Natural Spaces. The layout of this road crosses the sea of lava created during this eruption, very unique environments, representative of the diversity of materials and forms that are associated with this eruptive episode. Part of the road borders ancient "islets", which correspond to elevated terrain. They are areas not covered by the historical lavas of the island, which allowed the continuity of life after this great eruption. Among these islets are those of La Caldera, Caldera Blanca and Risco Quebrado, all of them old volcanic constructions built from explosive dynamics. Its whitish and ocher shades protrude from the sea of lava, generating one of the most beautiful volcanic landscapes in the centre of Lanzarote.

Despite the fact that the number of people who dare to enter the territory of these islands on foot is increasingly numerous, most visitors who choose Lanzarote for the enjoyment of their time of rest, maintain somewhat more sedentary habits. Most of these visitors also rent a car, seeking to enjoy this territory in a comfortable and autonomous way. The good conditions of the road network of the island, together with its relatively small dimensions, have favoured the consolidation of this tourism model. Thinking about this profile of visitors and the local population that chooses this same model for the enjoyment of their own territory during their leisure time, the Cabildo of Lanzarote, through the Geopark, has promoted the design and edition of five GeoRutas by car. With them, it is intended to provide visitors with educational/informative material, rigorous and entertaining, designed to provide user-friendly information, with graphic material, to facilitate the experience. Each of these thematic itineraries have been designed with contents by a group of specialists, within the framework of an institutional agreement between the main Local Administration of the Island and IGME (Galindo, Vegas et al. 2017).

The result of this effort is the edition of a first edition of 2500 field guides that address five different and complementary GeoRutas proposals, which favour the knowledge of local geodiversity;

- The Eruption of Volcán de la Corona. This proposal covers the northern part of the island to show us the outcrops and products resulting from the eruption of La Corona volcano, which took place approximately 25,000 years ago. This GeoRuta is intended to help discover, among other enclaves, the peculiarities of the Cueva de los Verdes, the Caletón Blanco, the Peñas de

Tao, the buried cone of Órzola, Casa de los Volcanes and Jameos del Agua, habitat of blind crabs Munidopsis polymorpha (Sánchez 2017).

- El Jable: Sand between Volcanoes. El Jable geosite acquires a special relevance in the context of this GeoRuta. This proposal is developed by the contact area between the Famara massif and the central volcanic field, housing a continuous sand cord that, like a mantle, superficially covering a strip of the island that extends from the beaches of Famara, to Playa Honda and Arrecife, helping to nourish these last beaches with sand (Díaz 2017).
- Famara: Between valleys and volcanoes. The Guanapay volcano, the San José Vega, Valle de Temisa, Mirador de Haría, Guinate and el Río, Jardín de Cactus and Volcán de la Corona, are the places that invite us to visit this part of the island. This geo-route can be done throughout the year, although it is recommended on "clear days when the clouds are not stagnant in Risco de Famara" to enjoy the wonderful views at their best (Galindo 2017).
- Ajaches: in the heart of an ancient volcano, submerging visitors in the east Natural Monument. Fraile ravine, Las Casitas, Mirador de Femés, Papagayo and Mujeres beaches, Marina de Ajaches platform and Punta del Águila, are the places of greatest interest from the tourist point of view, in this outstanding visit. In addition, the ornithological richness of the area, declared a Special Bird Protection Zone (Vegas 2017).
- Volcanoes with history, finally, dedicated to the historical eruptions of the island: Timanfaya (1730–1736) and Tao-Chinero-Tinguatón (1824), proposing a journey "of between five and six hours", which takes us from the César Manrique Foundation to La Geria, passing through Monumento al Campesino, Timanfaya, Pico Partido, the Echadero de los Camellos, El Golfo, Los Hervideros and Salinas de Janubio (Romero 2017).

Currently, all of this material is in the process of translation into several languages and its content is available for free to download at www.geoparquelanzarote.org. The publication of the set of these GeoRutas coincided with the celebration of the thirty anniversary of the start-up of Casa de los Volcanes, as well as with the International Year of Sustainable Tourism for Development.

To help achieve the dissemination objectives this material was intended for, these GeoRutas were equipped with interpretive tables in several languages that are located in key places within the route of these itineraries. These are highly visited spaces, easily accessible by car, from which you can see some of the most relevant interpretative elements within the set of proposed content for each route.

The last of the interpretive products published by the Geopark is the *Guide of the Anchialine Ecosystems of Jameos del Agua*. Submitted at the end of 2017, this material is available for free download—online—in the publications section of the Lanzarote and Chinijo Islands UNESCO Global Geopark. For 125 years, more than 50 scientists have visited Jameos del Agua. This publication aims to collect the exploration and research carried out to date, in addition to new contributions. This work represents three generations of scientists dedicated to underground biology.

In the context of Los Jameos del Agua, Túnel de la Atlántida is considered the longest submerged lava conduit in the world. In its 1700 m the existence of 32 estigobios (organisms that develop their life inside caves) of La Corona volcanic tube, has been identified. Three of them endemic; 21 crustaceans; and 11 annelids (segmented cylindrical worms), most of which are unique to the flooded sections of the volcanic tube (Fig. 4).

For a better management, its authors have divided the publication into four chapters: Geological origin of La Corona Volcanic Tube and the Anchialine Ecosystems of Lanzarote; Introduction to Underground Biology; Lanzarote Anchialine Fauna; and Ecology of the Volcanic Tube of La Corona.

This publication is made by a multidisciplinary team, consisting of different profile researchers and graphic professionals. Its completion was supported by the European Union, through the FEADER, as well as the Ministry of the Environment and the Government of the Canary Islands.

## 6 Conclusion

There is no doubt that our island being declared a UNESCO Global Geopark, has resulted in the high spirits of our society when it comes to the preservation, use, research and exposure of our geological heritage. This has been done from a committed, responsible and respectful standpoint toward those natural values that led to the appointment granted by UNESCO. However, everything we have just described must continue on in the short, mid and long term in order to strengthen the structure and composition of the Geopark.

The next immediate challenge is the first revalidation or audit taking place in 2019, that will provide a description of the management situation and the continuation of the Geopark as part of the UNESCO Global Geoparks Network. Subsequently, in two years' time, we will open the doors of the new Casa de los Volcanes that will be used as meeting point to find out everything related to the Geopark and that will offer innovative and cutting edge exhibition elements. Lastly, once the new facilities are in operation, we will work to provide better conditions and installations for research on the islands.

**Fig. 4** Scientists and secundary school students

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# Part I

# From Earth

# Geological and Geographical Setting of Lanzarote and Chinijo Islands UNESCO Global Geopark

Nieves Sánchez, Carmen Romero, Juana Vegas, and Inés Galindo

**Abstract**

Lanzarote and Chinijo Islands UNESCO Global Geopark (UGG) presents a long geological history dating back to the Oligocene, where several constructive and destructive geological processes have taken place up to nowadays. Lanzarote has been built almost only from basaltic materials, grouped in three stages of volcanic construction, one submarine and two subaerial. During the first phase, Oligocene in age, the basement of the island is constructed, constituted by submarine volcanic materials, plutonic rocks and sediments. During the Mio-Pliocene and the Pleistocene-Holocene there were two stages of subaerial volcanic activity separated by an eruptive hiatus of at least 2.5 Ma when the ancient Mio-Pliocene volcanic structures were continuously eroded to model their original morphologies, giving place to different sedimentary deposits, with an important presence of aeolian sands throughout the islands and beaches in the coastal areas. In more recent times, two historical eruptions have occurred in Lanzarote Island, in 1730–36 and in 1824, indeed causing a great impact in the landscape and life of the inhabitants something that remains until now.

**Keywords**

Volcanic materials • Sedimentary environments • Aeolian deposits • Historical eruptions

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## 1 Situation

The Canary Archipelago is constituted by seven main islands (from East to West: Lanzarote, Fuerteventura, Gran Canaria, Tenerife, El Hierro, La Gomera and La Palma) and several islets and seamounts, all of volcanic origin. It is located between 27° 37′N and 29° 25′N, and between 13° 20′W and 18° 10′W, around 100 km far from the northwestern African coast, in the Atlantic Ocean. It covers an area of 7450 km$^2$ and extends around 500 km in an E–W direction and 200 km in a N–S direction (Fig. 1). Lanzarote and its Chinijo Archipelago are the northern and westernmost ones of the Canaries, located between 27° 38′ and 27° 51′N and 17° 53′ and 18° 09′W (Fig. 1).

Lanzarote, with an area of 845 km$^2$ and a maximum height of 671 m asl, has an abrupt relief in the northern and southern sectors and a gentler one in the central part. Five islets towards the north of Lanzarote compose the Chinijo Archipelago: La Graciosa, Alegranza, Montaña Clara, Roque del Oeste and Roque del Este. Their areas and maximum heights are shown in Table 1.

All the islands can be considered as real mountains, whose shape and height depends on several factors, such as the age of the forming materials, type and evolution of the constituting volcanic structures, geological setting and morphology, past and present climate conditions, or the different morphoclimatic evolution of every island. Although the palaeoclimatic evolution is common for all of them, the combination of the different orographic characteristics of each insular edifice together with structural factors (age, volume and altitude of the volcanic structures, height differences, location, orientation and type of materials with respect to erosive dismantling) give as a result the high and medium mountain reliefs of the central and western islands, whose altitudes are above 1500 m asl, as well as the low mountain reliefs of the islands of Fuerteventura, Lanzarote and its islets, whose altitude is under 900 m asl (Martínez de Pisón and Quirantes 1990).


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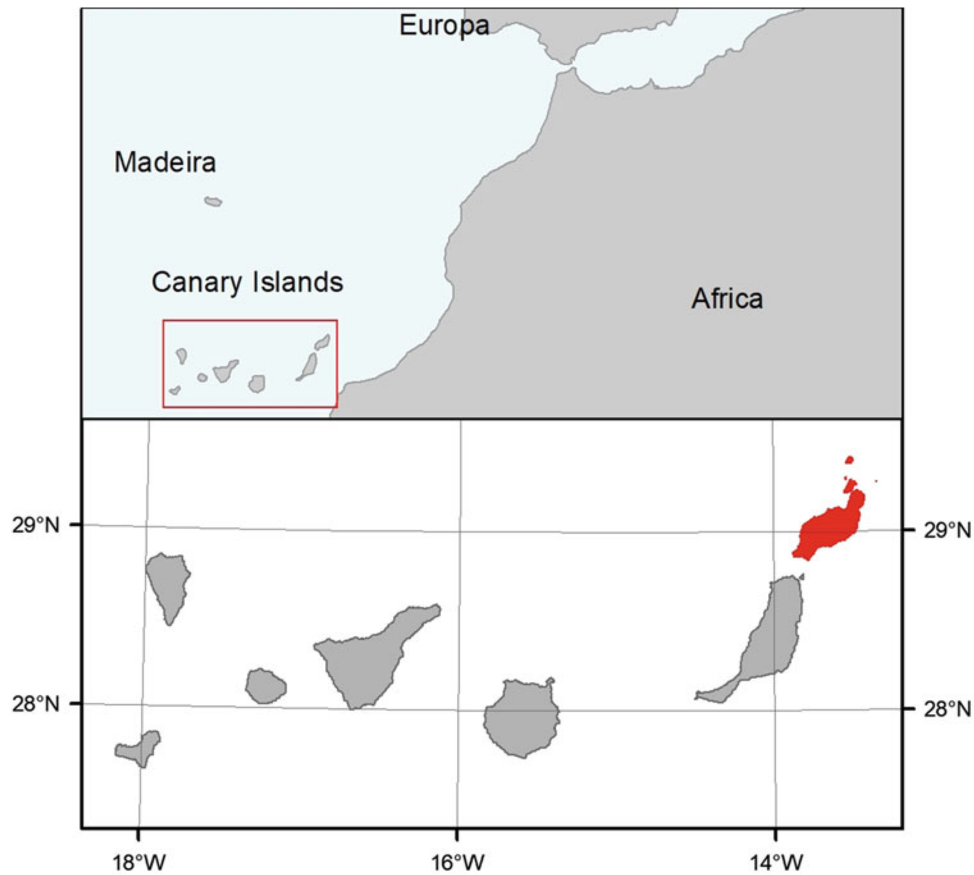


**Fig. 1** Geographical situation of Lanzarote (in red) and Chinijo Islands UNESCO Global Geopark

**Table 1** Areas and maximum heights of the Chinijo Archipelago islets

| | Graciosa | Alegranza | Montaña Clara | Roque del Este | Roque del Oeste |
|---|---|---|---|---|---|
| Area ($km^2$) | 29.05 | 10.3 | 1.48 | 0.06 | 0.02 |
| Max. Height (m) | 266 | 289 | 256 | 84 | 41 |

*Source* ISTAC (2018)

In the first group of the western and central islands prevail the high altitudes and great differences in height, and are characterized by the presence of deep gullies, sometimes narrow and steep, with abrupt and broad polylobulated heads showing, in some occasions, old incisions with a lower base level to the current ones. However, in the islands with low altitude the ramp-shaped reliefs prevail, with well-developed dune beaches and aeolian fields spreading at the foot of old reliefs with smoother gullies and sloped interfluvial zones, sometimes reduced to narrow and entrenched interfluvial areas with shape of “knives”.

The Canary Archipelago is under the effects of a cold oceanic current, a cold bifurcation of the Golf Current becoming detached when reaching the Azores, which carries cold water from northern to lower latitudes making the surface of the sea have notably lower temperatures in reference to those corresponding to its latitude. This fact, combined with the particular regional atmospheric dynamics characterised by the predominance of the trade winds, determines that the latter, during its passing over the Atlantic and in contact with the Canary cold current allow the stratification of the atmosphere in two layers: a superficial one, wet and cool, and another higher up, warm and dry, separated by a mass of stratocumulus (called “sea of clouds”), whose inferior level coincides with the temperature inversion round 1500 m height.

This way, the role played by the orography in the atmospheric dynamic is essential. The islands of higher elevation act as a genuine barrier against the route of air masses and make the latter have higher pluviometric rates, ranging between 300 and 600 mm per year, and a sea of clouds presence in the windward sides. On the other hand, in the islands with lower altitude, such as Fuerteventura and Lanzarote, the humidity and rainfall inputs are very low, and occasional, with a rainfall average lower than 100 mm depending in almost an exclusive manner on the appearance of oceanic disturbances caused by unattached depressions coming from the southern flank of the Polar Front, leading Northeast–Southwest.

The acute orographic contrast between the central and western islands in relation to the eastern ones, adding to it the climatic dynamics and the stratification of the atmosphere, causes the climatic conditions in the eastern islands to be of a semiarid environment, and the erosive processes are common in these areas. In Lanzarote island dominates thus a semiarid environment and, according to the State Meteorological Agency's (AEMET) data, http://www.aemet.es/es/serviciosclimaticos/datosclimatologicos/valoresclimatologicos?l=C029O), the average annual temperature remains steady around 21 °C, ranging between 17 °C in the first months of the year and 24 °C in summer. The clouds related to the trade winds usually gather in the northwest area, generally being the south area warmer and less cloudy. The average rainfalls do not exceed annual levels of 140 mm, therefore, very scarce and basically concentrated in winter, showing very high year-on-year ratings and periods of high rainfall concentration. This way, against periods of practically no rainfall in many cases, the total of precipitations falls within a few hours. The rainwater temperature is usually between 18 and 23 °C.

## 2 Background of Research in Lanzarote

The Canary Islands have been of interest from the naturalist, geographic and geological point of view from the 16th century when the greatest naturalists started their voyages around the known world to study it. Thus, the Italian engineer Leonardo Torriani carried out the first observations and descriptions on the island of Lanzarote in 1590, whilst visiting the island upon the order of Philip II to make a report on the defensive system in the Archipelago. After him, other geologists, geographers, and naturalists came to visit the islands such as, Alexander von Humboldt towards the end of the 18th century, Leopold von Buch at the beginning of the 19th century or Georg Hartung in the mid of the same century and the Spanish Eduardo Hernández Pacheco at the beginning of the 20th century, whom studied and described the island of Lanzarote and its islets. The first chronostratigraphical chart of the island was drawn by the Department of Marine Chemistry and Geochemistry and the Lucas Mallada Institute under the CSIC in the 1960s, under the leadership of José María Fúster (Fúster et al. 1968). All this proves the uniqueness of the Canary Archipelago and specifically of Lanzarote and Chinijo Archipelago.

## 3 Geodynamic Context

The Canary Islands are located within the African tectonic plate over a dormant continental margin, in an intraplate geodynamic setting, developed over a Jurassic lithosphere (150–180 Ma) whose age has been estimated on the basis of the magnetic anomalies studied on the ocean floor (Hayes and Rabinowitz 1975; Verhoef et al. 1991; Roest et al. 1992). The basement of these islands consists of oceanic crust (Dañobeitia 1980; Banda et al. 1981; Uchupi et al. 1981).

The Canary Archipelago is within an area of Jurassic magnetic calm and it is confined within magnetic isochrones dated in 156 Ma, isochrone M25, and 170 Ma, isochrone S1 (Fig. 2), suggesting the creation of the oceanic crust, where the islands currently rest, during the Jurassic South Atlantic opening process (Hayes and Rabinowitz 1975; Verhoef et al. 1991; Roest et al. 1992). It consists of large separated volcanic edifices whose area above water is the top of a piling made out of submarine materials, which as a whole can reach more than 4–5 km altitude.

The Canary Islands were formed in a first phase by a stacking of submarine volcanic materials at the end of the Cretaceous (Robertson and Stillman 1979; Watkins and Hoppe 1979), followed by a stage of subaerial material emission 20–30 Ma ago (Abdel-Monem et al. 1971; Coello et al. 1992; Cantagrel et al. 1993; Balogh et al. 1999), which was mainly formed by means of effusive eruptive mechanisms although many volcanic edifices have also been the product of hydromagmatic and explosive volcanism.

## 4 Geology of Lanzarote and Chinijo Islands

Lanzarote has been built with almost exclusively basaltic materials, grouped in three stages of volcanic construction: one submarine phase and two subaerial ones. During the first stage corresponding to Oligocene in age, the basement of the island was built being made up of submarine volcanic materials, sedimentary and plutonic rocks. During the Mio-Pliocene and the Pleistocene-Holocene two stages of subaerial volcanic activity were developed that are separated indeed by an eruptive quiet period of at least 2.5 Ma, during which the old Mio-Pliocene's volcanic structures suffered a continuous erosion, thereby shaping them to their original form. Figure 3 depicts a simplified geological map of Lanzarote and Chinijo Archipelago

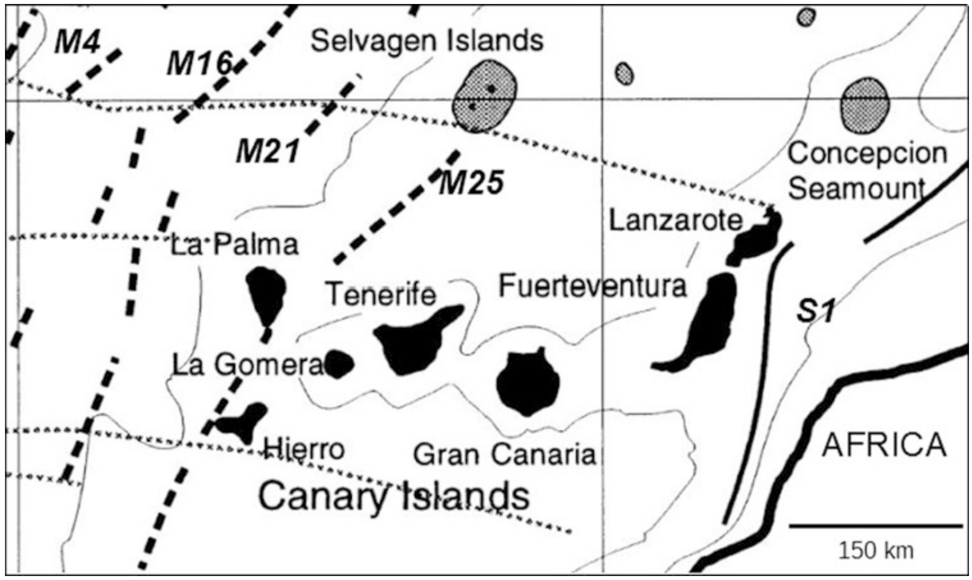


**Fig. 2** Tectonic framework of the Canary Islands (modified from Ye et al. 1999). The volcanic islands are displayed in black and the submarine hills in light grey. The dotted lines depict the prolongation of the transforming faults in the Atlantic Ridge and the dashed lines represented the isochrones of the ocean floor magnetic anomalies: M4, M16, M21, M25 and S1

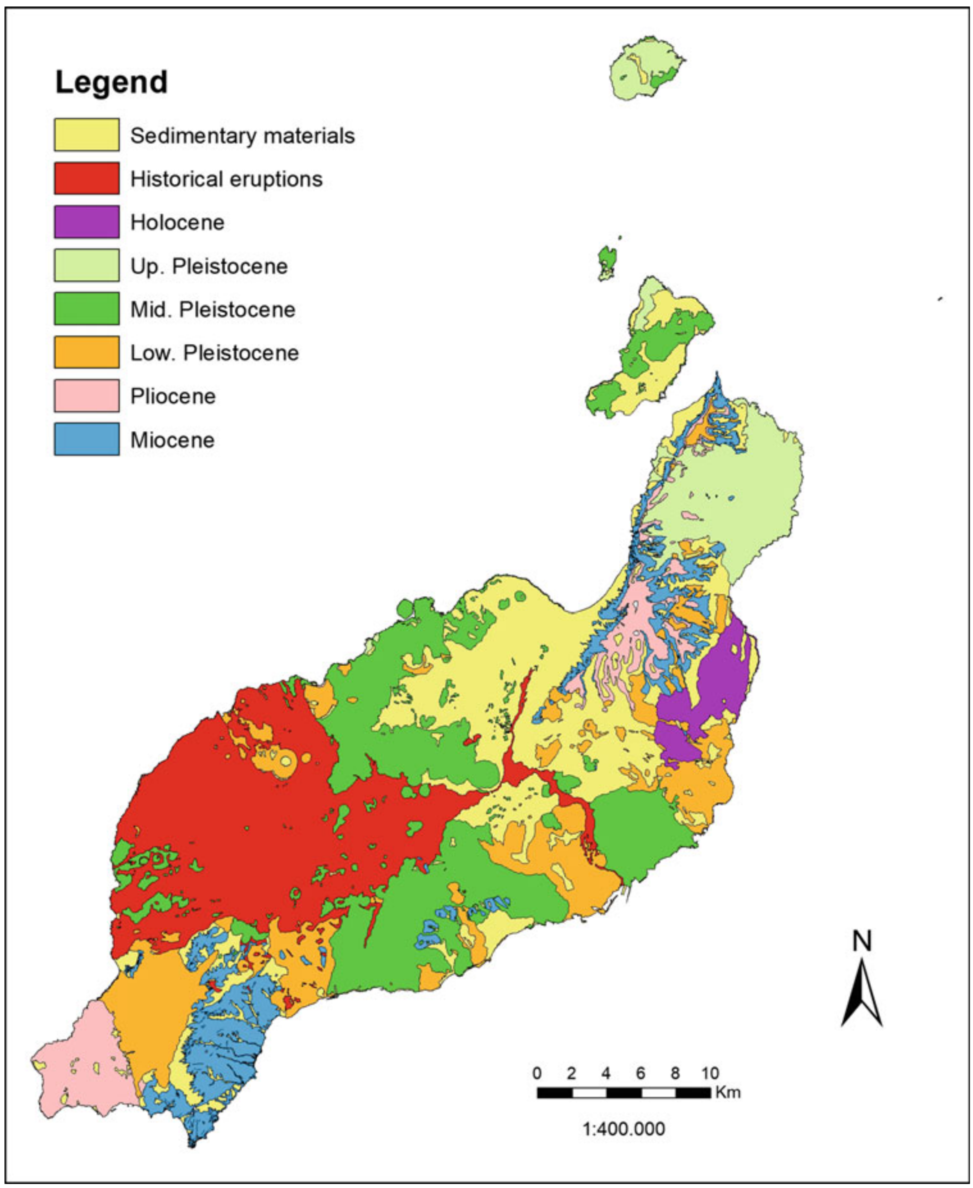


**Fig. 3** Simplified chronostratigraphic map of Lanzarote and Chinijo Archipelago modified from the continuous digital mapping carried out by the Spanish Geological Survey (IGME) at scale 1:25,000 (Bellido Mulas et al. 2008). Any further information (legend, references, metadata and various mapping services) can be accessed at the following Web address: http://info.igme.es/cartografiadigital/geologica/geodezona.aspx?Id=Z2910&language=es

## 4.1 The Beginning of the Lanzarote Island

The emerged volcanic edifice lays on a basement whose structure and features are known by a geothermal borehole that was drilled in the island as deep as about 2702 m (Sánchez Guzmán and Abad 1986). This study revealed that the base of Lanzarote's stratigraphic record is made of sedimentary materials, mainly clay and clay marls finely stratified and plenty of marine microfossils from the middle-upper Palaeocene that have been interpreted as an oceanic basement lifting of around 4 or 5 km.

The first volcanic materials of Lanzarote Island rest over this deep oceanic deposits and started to be formed at the end of the Eocene or beginning of the Oligocene that correspond to the underwater growth phase of Lanzarote. Therefore, it is the oldest geological unit in the island, consisting in a rock set of sedimentary, volcanic and plutonic rocks, crossed by a dense network of subvertical dykes that sometime makes up between the 90 and 100% of the host rock.

## 4.2 The Ancient Volcanic Edifices

The first subaerial stage started around 15 Ma ago, with emission pulses of different importance and length, separated by stages of quiet eruptive periods, which are prolonged until 3.8 Ma (Coello et al. 1992; Carracedo and Badiola 1993; Carracedo et al. 2002). This stage is characterised by the emission of large volumes of basaltic materials, piling up to finally build large volcanic edifices such as Ajaches and Famara (Fig. 4), or minor sets, as the ones found in Tías (Carracedo and Badiola 1993).

This volcanic stage represent the period of greatest subaerial growth showing the maximum eruptive rates, for the construction of the insular block, around 0.01–0.02 $km^3$/ky (Coello et al. 1992). Volcanic edifices from this period were built from a complex tabular lava and basaltic pyroclastic sequence, smoothly and generally dipping towards the SE and ESE, with very isolated outcrops of differentiated trachybasaltic and trachytic rocks.

**Fig. 4** Lava pile in the massif of Famara. Reddish palaeosoils interbedded with lava are frequent

## 4.3 Quaternary Volcanic Phase

The second subaerial phase comprises the recent activity in the island developed during the Quaternary marked by generating vast lava fields covering the materials from the previous phase and by presenting most of the volcanic vents aligned. This stage begins around 2 Ma and goes on throughout the Quaternary until now. The eruptions at this stage occur over Lanzarote, affecting the old massifs as well as the central part of the island, though clearly discordant with the materials from the previous subaerial phase and following structural patterns well defined, in NE–SW and ENE–WSW direction. The islets of Chinijo Archipelago are mainly developed during the Pleistocene and are essentially made of basalts and basanites originated by hydromagmatic eruptions (Fig. 5).

This second stage is characterised by a volcanic activity roughly continuous until present, with eruptive rates much lower than the previous volcanic period, and with values in the range of 0.013–0.027 $km^3$/ky. It is characterised by the emission of lavas of great alkaline nature, which later developed into basaltic magma having a decrease in the alkalinity, to finish emitting olivine basalts of tholeiitic nature (Carracedo and Badiola 1993).

During the last period two important historical eruptions are identified: The eruption of Timanfaya which took place from 1730 to 1736 (Fig. 6) and the triple eruption of 1824 resulting in the formation of Tao, Nuevo del Fuego, and

**Fig. 5** Hydromagmatic volcano of Montaña Amarilla (Yellow Mountain). La Graciosa island (Chinijo archipelago)

**Fig. 6** Volcanic field of Timanfaya from the 1730–1736 eruption. Lanzarote Island

Tinguatón volcanoes (Fig. 7). Both of them are multiple vents of fissured nature which in Timanfaya's case results in a complex eruptive set due to the combination of multiple monogenetic volcanic constructions along a main fracture of great longitudinal development (Romero 1991). In the 1824 eruption, a lineal eruptive system is built with three separated eruptive vents of very small scale (Romero 1997).

Although Lanzarote has hosted only two historical eruptions, it is however where the greatest scale and magnitude eruptive processes have taken place in contrast to the other islands throughout the historical period (Romero 2003). Taking into account the total number of eruptive days (79% of the total active eruptive days) as well as the surface covered by volcanic materials (73% of the total affected area by the historical eruptions in the Archipelago), it is therefore the island within the Canaries where historical volcanism shows the biggest entity and where the impact on the relief, society and insular landscape has been greater. This historical eruptive phase is also very relevant because it is the only Global Geosite of international relevance (García-Cortés 2008) that the island of Lanzarote has, with reference "*VC007, Parque Nacional de Timanfaya*", from the total of 215 Global Geosites granted to the Spanish State and established by Law 42/2007 in the Natural Heritage and Biodiversity Act.

## 4.4 Sedimentary Deposits

Throughout the geological record of Lanzarote and the Chinijo Islands intensive erosive episodes have taken place which have been interfered with the volcanic processes giving place to some diverse landscapes, formations and sedimentary materials, where global climate changes can be inferred. The presence of numerous palaeontological sites at different sedimentary records are related to sea-level changes (Meco 2008; Meco et al. 2007; Zazo et al. 2002), and climate and environmental conditions (Lomoschitz et al. 2016). They are also proxies of the environmental and erosive phases in the area (Martín-González et al. 2018). Moreover, the dismantling of the large Miocene volcanic edifices and their erosion, either of aeolian or marine origin, have given place to the formation of great cliffs such as the ones in Famara where the lava pile has been covered by detrital deposits (Fig. 8), marine terraces like in Papagayo area in

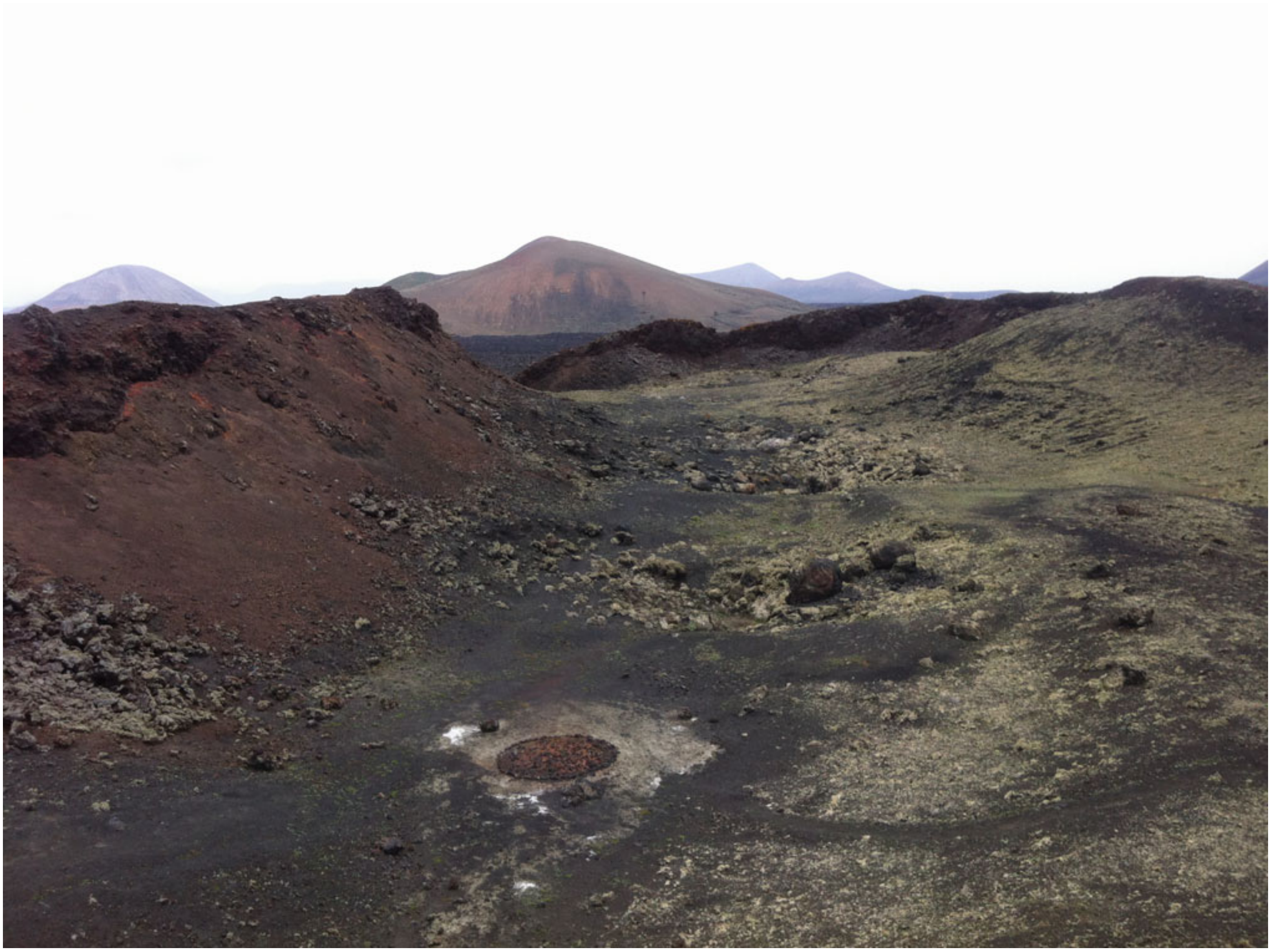

**Fig. 7** Elongated crater from the Tinguatón volcano created during the 1824 eruption. Lanzarote Island

the SW of the island, fluvial valleys, alluvial and colluvial fans, palaeosols, calcretes and dunes, favoured by the intense wind sweeping across the islands, such as in the Jable (Fig. 9).

Aeolic dynamics has had a great influence in the provenance of sediments that can nowadays be found in this UNESCO Global Geopark, also showing a coexistence of erosion and sedimentation with volcanic processes. Thus, dune and beach deposits can be found covered by lava flows and/or pyroclastic rocks, and vice versa, from the upper Pliocene up to nowadays.

One of the most remarkable sedimentary deposits belonging to this aeolic dynamics in Lanzarote is the sandy corridor known as El Jable that crosses the island from north to south, from the area called Caleta de Famara in the North of the island to Playa Honda-Arrecife in the South. The sedimentary sequence found in this area corresponds to an alternation of deposits that have been interpreted as warm and wet climates from the end of the Pliocene to the present times (Ortiz et al. 2006).

In the Jable del Medio site, there are large sand outcrops following the same N–S direction found in the northeast area of Lanzarote, reaching a thickness of more than 22 m that corresponds to dune fields from the Upper Pleistocene, which spread along the NE coastline of the island.

Fluvial processes have also influenced the landscape of the Lanzarote and Chinijo Islands UNESCO Global Geopark. Hydrographical networks are developed in ancient

**Fig. 8** The Famara cliff shows the basaltic lava pile covered by detrital fans (fan deltas). Northeast Lanzarote Island

volcanic edifices of Famara and Ajaches. Thus, fluvial valleys transformed into endorheic basins can be observed due to the appearance of volcanic edifices in its layout which prevented the usual fluvial dynamic from transforming them into closed drainage basins, such as La Vega de San José or the Femés valley, where environmental changes of the last glacial-interglacial cycles are also documented (Von Suchodoletz et al. 2008, 2010).

**Fig. 9** Aeolian corridor of El Jable covered by sands. In the background, alluvial fans are covering Famara palaeocliff. Lanzarote Island

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# Geoheritage Inventory of the Lanzarote and Chinijo Islands UNESCO Global Geopark

Inés Galindo, Juana Vegas, Carmen Romero, Miguel Llorente, Esther Martín-González, Juan C. Rubio, Gonzalo A. Díaz, José Mangas, Elena Mateo, and Nieves Sánchez

**Abstract**

Lanzarote and Chinijo Islands are part of the Canary archipelago situated in the Atlantic Ocean and they have been included into the UNESCO Global Geopark network since 2015. The formation and evolution of Lanzarote and Chinijo Islands can be understood through the visit of 82 geosites, included in eight geological frameworks, which are representative of the geology and geodiversity of a volcanic oceanic island in a semiarid climate. Most geosites are of international or national relevance, but this Geopark has representative and unique geosites where more than 20% of them are included in the "Recent volcanism of Timanfaya (Lanzarote)" geosite of the Global Geosites Project that is the global inventory of Earth's geoheritage (ProGeo and IUGS-UNESCO). The new inventory supposes a change in the limits of the geopark, which would now extend from the sea floor to the emerged parts of the island of Lanzarote and Chinijo Islands. Most of the geosites are well preserved since they are located in Natural Protected Areas. However, a first approach to their geoconservation status allows us to identify some problems such as furtive extraction of rocks and fossils, urban and tourist pressure, and extractive activities or natural processes that have supposed, in some few cases, the irreversible loss of their geoheritage.

**Keywords**

Inventory • Geosite • Geopark • Geoheritage • Assessment

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## 1 Introduction

The main stage into the Geoheritage consist in an inventory of geosites, since it is the first step necessary to identify and know the geosites for their management (Carcavilla et al. 2009; García-Cortés et al. 2014; Brilha 2016). The geoheritage inventory of Lanzarote and Chinijo Islands has the aim of value and select geological sites of interest (geosites) that show the most valuable and representative sites useful for education and geotourism into this UNESCO Global Geopark (UGG). Conservation and outreach require a systematic geoheritage inventory at UGG scale.


E. Mateo et al. (eds.), *Lanzarote and Chinijo Islands Geopark: From Earth to Space*, Geoheritage, Geoparks and Geotourism, https://doi.org/10.1007/978-3-030-13130-2_3

The first inventory of Lanzarote and Chinijo Islands was carried out in 2013 to apply for a candidacy of the UGG that included 63 geosites, being 19 of them submarine geosites (Galindo et al. 2015). This UGG has recognized Geoheritage of international relevance as a requirement to be a new member. Timanfaya Historic eruptions are included into the Global Geosite VC007 "Recent Volcanism of Timanfaya (Lanzarote)" that is part of the Global Geosites inventory for Spain (Garcia-Cortés et al. 2008), a global inventory of the Earth's geological heritage (IUGS project had the support of ProGEO, IUCN and UNESCO), and it is representative of the "Volcanic morphologies and edifices from the Canary Islands" nº 14 geological framework for Spain (Barrera 2009). Most of the island covered by the eruption of Timanfaya has been protected and it is included in the Timanfaya National Park (Decree 2615/1974) and in the Volcanoes Natural Park (Law 12/1987, of the Natural protected areas in the Canaries Government).

We present here the results of a recent detailed geoheritage inventory of Lanzarote and Chinijo Islands that has allow defining the geological frameworks in the UGG, to include new geosites and to have a first approach about their conservation status.

## 2 Methodology

This geoheritage inventory followed the methodological approach implemented by the Spanish National Inventory of Sites of Geological Interest (IELIG in Spanish) proposed by García-Cortés et al. (2014), but also including specific criteria for selecting and valuing geosites at a UGG scale. In this way, the model of inventory followed in this research has differed in regard to superficial and submarine geosites. In the first case, a high degree of scientific knowledge of the territory has made it possible to carry out a systematic inventory, which starts from the classification of the geological units into geological frameworks to obtain the most representative geosites of the geodiversity within this UGG. In the case of submarine geosites, due to the poor knowledge of underwater geology, we made an advanced reconnaissance inventory type.

### 2.1 Selection of Geosites

Systematic geoheritage inventories base their method on carrying out a classification of the geological record of the studied area. Thus, several geological frameworks have been considered that encompass representative geological elements and processes, which together illustrate the geological evolution of the UGG since the Miocene to nowadays. In order to characterize each geosite, we compiled previous information from scientific papers and books, excursion guides, maps, geo-routes, aerial photos, natural protected areas legislation and regulations, and others. Selection of submarine geosites were made by interviews with expert divers in the area and diving books from Lanzarote and Chinijo Islands (Galindo et al. in this volume).

Field and diving campaigns were carried out since 2013 to improve the characterization of preliminary geosites, their edges for mapping and their current conservation state. The information collected for each geosite has been summarised in technical forms (Table 1). Technical specifications include the name of the geosite, an evaluative comment, criteria used for their selection, access itinerary description and an specific map. A section with references about the geology of the site and several photos illustrating general or detailed aspects are also included. Finally, a qualitative assessment has been carried out.

### 2.2 Name of the Geosite

The system used in this inventory to denominate the geosites follows the proposal of Vegas et al. (2011) which suggests establishing a formal name made by three topics that include: (i) the description of the main geological interest, (ii) a geographical reference (reference to the name of the geographical location where its place name is located) and (iii) the age of the geological element (always referred to a Period of the Chronostratigraphic International Chart). Once the denomination of the geosite is recognized, an alphanumeric identification code is established. It is an important issue for geoheritage management (Geoheritage Inventory data base and mapping, and Geographical Information System associated to the inventory). In the Lanzarote and Chinijo Islands´ inventory, a four-digit code has been used that consist of two capital letters indicating the island where each geosite is located (LZ, GR, MC, AL and RE for Lanzarote, La Graciosa, Montaña Clara, Alegranza and Roque del Este, respectively), and two sequential numbers. Those geosites considered as submerged in the current Geopark inventory, previously referred as MR for 'marine' (Galindo et al. 2015), have been renamed and their code has been changed to the one related to the island flank where they are located. The ones that include several islands have been assigned to Lanzarote.

### 2.3 Most Remarkable Geological Features

All geosites' technical sheets include the evaluative comment that includes the most remarkable geological features that motivate and justify its inclusion in the inventory. Each geosite has been selected by a unique main geological

**Table 1** Example of technical sheet of the inventory of geosites of Lanzarote and Chinijo Islands UGG

| Geosite technical sheet I | | | | |
|---|---|---|---|---|
| Name of the site | LZ35 El Golfo Pleistocene hydromagmatic volcano | | | |
| Most remarkable geological features and the main geological interest of this geosite | A Surtseyan edifice where wet and dry pyroclastic flows can be observed with abundant pyroclastic structures and coastal erosive processes. The eruption of El Golfo started with the emission of wet basaltic pyroclastic flows which evolved towards the end of the eruption to drier phases. This edifice was generated as a result of the continuous collapsing of eruptive columns, which ended up forming a tuff cone. Typical elements of hydromagmatic eruptions can be found in the deposits such as, accretionary lapilli, cross-stratifications, dunes and antidunes, channels, etc. Numerous joints and faults can also be observed. Subsequently, the dismantling of almost half of the edifice took place due to coastal erosion followed by a Strombolian eruption whose pyroclastic and lava flows covered part of the hydromagmatic edifice. El Golfo has currently an inner lagoon of greenish water colour caused by algae, previously isolated from the sea by a gravel barrier, known as Los Clicos lagoon (Laguna de los Clicos or el Charco Verde, in Spanish local name).<br>This geosite has a volcanological main interest and geomorphological and stratigraphical secondary interests also occur. It is a geosite of high scenery value due to the fact that its pyroclastic deposits present an alteration of their original colour caused by the palagonisation processes, giving it the current yellow colour, and affecting entire deposits.<br>Getting close to the area is forbidden due to high fragility of this lagoon and visitors can be damaged by a high rock fall occurrence | | | |
| Criteria for selection | Representativeness | | | X |
| | Location type | | | |
| | Scientific knowledge | | | X |
| | Conservation status | | | X |
| | Viewing conditions | | | X |
| | Rarity | | | X |
| | Geological diversity | | | X |
| | Scenery | | | X |
| | Scientific content/use | | | X |
| | Didactic content/didactic use | | | X |
| | Potential for recreational and outdoor activities | | | X |
| | Links with other natural or cultural assets | | | X |
| Location | Province: Las Palmas | | Municipality: Yaiza | |
| | Spot(s): El Golfo—Laguna de los Clicos | | | |
| | Coordinates (UTM, WGS84) | X: 614174,73 | Y: 3205922,6 | Spindle: 28R |
| | In the event of being advisable to maintain the **confidentiality** of the site, by concealing its coordinates, please mark it with a cross (x) | | | ☐ |
| Access itinerary description | From Arrecife drive towards Yaiza and from there, towards to Playa Blanca. Shortly after there is a roundabout, take the exit indicating the little village of El Golfo, there is a parking in the area. Walk up a path, which takes you to a viewpoint. The south access is currently closed due to risk of rock fall | | | |

(continued)

**Table 1** (continued)

| Geosite technical sheet I | |
|---|---|
| Name of the site | LZ35 El Golfo Pleistocene hydromagmatic volcano |
| Map |   |

(continued)

**Table 1** (continued)

| Geosite technical sheet II | |
|---|---|
| Photograph (s) |  Fig. 1. General view of El Golfo, with Los Clicos lagoon separated from the sea by a coastal sand and gravel berm. 2015  Fig. 2. Details of the surface erosive processes over pyroclastic deposits. 2015 |
| References | Anguita, F., Márquez, A., Castiñeiras, P., Hernan, F., 2002. Los volcanes de Canarias. Guía Geológica e Itinerarios. Ed. Rueda. Madrid, 240 pp.<br>Araña, V., Carracedo, J.C., 1979. Los volcanes de las islas canarias, II. Lanzarote y Fuerteventura. Editorial Rueda, Madrid, 176 pp.<br>Downes, H., Day, S., 2013. Field Class to Lanzarote. Department of Earth and Planetary Sciences, University of London, Field guide, 14 pp.<br>Fuster, J.M., Cendrero, A., Gastesi, P., Ibarróla, E., Ruiz, J.L., 1968. Geología y volcanología de las islas Canarias: Tenerife. Instituto 'Lucas Mallada', CSIC, Madrid, 218 pp.<br>Galindo, I., Romero, M.C., Sánchez, N., Morales, J.M., 2016. Quantitative volcanic susceptibility analysis of Lanzarote and Chinijo Islands based on kernel density estimation via a linear diffusion process. Scientific reports, 6, 27381, https://doi.org/10.1038/srep27381.<br>Hansen, A., Pérez-Torrado, F., 2005. The island and its territory: volcanism in Lanzarote. Sixth international conference on Geomorphology. Field trip guide C-1, 33 pp. |

(continued)

**Table 1** (continued)

| Geosite technical sheet II | |
|---|---|
| | IGME, 2004. Mapa geológico de España Escala 1:25.000. Hoja y Memoria nº 1.081 II. Yaiza. 96 pp.<br>IGME, 2005. Mapa geológico de España Escala 1:100.000. Hoja y Memoria nº 88. Isla de Lanzarote. 79 pp.<br>Marinoni, L. B., Pasquarè, G., 1994. Tectonic evolution of the emergent part of a volcanic ocean island: Lanzarote, Canary Islands. Tectonophysics, 239, 1–4, 111–137.<br>Marti, J., Colombo, F., 1990. Estratigrafía, sedimentología y mecanismos eruptivos del edificio hidromagmático de El Golfo (Lanzarote). Boletín Geológico y Minero, 101, 4, 560–579.<br>Pedrazzi, D., Martí J., Geyer A., 2013. Stratigraphy, sedimentology and eruptive mechanisms in the tuff cone of El Golfo (Lanzarote, Canary Islands). Bulletin of Volcanology, 75, 740.<br>Rodríguez-Pascua, M.A., Sánchez, N., Perucha, M.A., Galindo, I., Pérez-López, R., Romero, C., 2016. A proposal of a Hydromagmatic Explosivity Index (HEI) using liquefaction structures. An example in El Golfo volcano (Lanzarote, Canary Islands, Spain). IX Congreso Geológico de España. Geo-Temas, 16, 1, 629–632.<br>Rodríguez-Pascua, M.A., Sánchez, N., Pérez-López, R., Perucha, M.A., Galindo, I., Romero, C., 2016. Caracterización espacial de la deformación frágil en las islas de Tenerife y Lanzarote (Islas Canarias, España). IX Congreso Geológico de España. Geo-Temas, 16 (1), 69–72.<br>Romero, C., 2003. El relieve de Lanzarote. Cabildo de Lanzarote. Rubicón, 242 pp. |
| Qualitative geoheritage assessment | |
| Scientific value | High |
| Susceptibility of degradation | Medium |
| Protection priority | Medium |
| Observations | This geosite is exposed to coastal erosive processes and frequent rock fall occurrence. Los Clicos lagoon is very fragile and vulnerable due to natural processes and visitors. It is recommended monitoring the active geological processes, visitors' access in the parking area and the access paths to the viewpoints |

interest and some of them have several secondary geological interest. On the basis of the geology of the studied area, and the geological frameworks identified in Lanzarote and Chinijo Islands we have selected eight disciplines of geological interest: volcanology, petrology, geomorphology, stratigraphy, sedimentology, tectonics, hydrogeology and palaeontology. Sedimentological interest includes palaeoclimatology and palaeogeography features, and the geomorphologic interest also includes geological hazards. The volcanological interest is not included as type of interest in the Spanish Inventory of Sites of Geological Interest (IELIG), however, the geological features in the area of study has made it necessary to differentiate this specific type of geological interest.

## 2.4 Criteria for Geosite Selection

The technical sheet allows documented and catalogued those criteria that justify the selection of geosites, such as scientific knowledge, representativeness, rarity, type or locality of reference, state of conservation, protection status and legislation, conditions for observation, geological diversity, scenery, scientific-didactic-touristic content and use, and presence of other natural or cultural assets.

## 2.5 Geographical Location and Mapping of Geosites

The geographical location provides the necessary data to be able to locate geosites and includes data related to: province, municipality, area; coordinate system, X and Y coordinates, spindle. There is a section in case of fragile and vulnerable mineral and fossil sites that indicate to maintain the confidentiality about the location, to ensure their geoconservation. A detailed description of the recommended access itinerary is also included. As Lanzarote and Chinijo Islands UGG have several natural protected areas, it is indicated if it is necessary to request a permission for access.

Mapping of geosites was done using software ArcGIS 9.3 by ESRI© and data was georeferenced in UTM 28 N-WGS84. Geosites have been mapped by polygons, so the X and Y coordinates detailed here make references to the coordinates of the polygon centroid. In the case of submarine geosites, no municipality has been assigned, except when they have an emerged area. The used base map is a combination of the orthophoto and the LIDAR based on 5 m mesh size Digital Terrain Model (Centro Nacional Información Geográfica, http://pnoa.ign.es/coberturalidar). Bathymetric data are provided by REDMIC (Dirección General de Sostenibilidad de la Costa y el Mar, Ministerio de Agricultura,

**Table 2** Classification of the main geological frameworks identified in Lanzarote and Chinijo Islands UGG. It is included representative geosites of all geological frameworks

| Geological framework of Lanzarote and Chinijo Islands UGG | Main geological interest representative of each geological frameworks | Code | Geosite denomination |
|---|---|---|---|
| Mio-Pliocene shield volcanism | Stratigraphical | LZ60 | Miocene intraformational unconformities of Ajaches |
| | Tectonic | LZ39 | Pleistocene graben of Femés valley |
| | Volcanological | LZ02 | Mio-Pliocene volcano-stratigraphic sequence of Famara cliff |
| | | LZ03 | Miocene buried volcanic cone of Órzola |
| | | LZ55 | Mio-Pliocene eroded submerged dikes at El Rubicón coast |
| Quaternary volcanism | Stratigraphical | AL03 | Pleistocene volcano-stratigraphic sequence of Trocadero-El Veril |
| | Geomorphological | LZ19 | Historical kipuka of La Caldereta |
| | Volcanological | AL01 | Pleistocene aa lava flows of Malpais del Norte |
| | | AL02 | Pleistocene hydromagmatic volcano of La Caldera |
| | | GR03 | Pleistocene hydromagmatic volcano of Montaña Amarilla |
| | | LZ05 | Pleistocene cone and lava flows with erratic blocks of La Corona |
| | | LZ06 | Pleistocene volcanic tube of La Corona-Atlántida |
| | | LZ10 | Pleistocene hydromagmatic cones of El Cuchillo-Mosta-Montaña Cavera |
| | | LZ17 | Pleistocene pyroclastic deposits of Tinamala volcano |
| | | LZ22 | Pleistocene pseudocraters of Los Ancones |
| | | LZ35 | Pleistocene hydromagmatic volcano of El Golfo |
| | | LZ51 | Pleistocene hydromagmatic volcano of Montaña Halcones |
| | | LZ53 | Holocene feeder dykes at Jardín de Cactus |
| | | LZ61 | Pleistocene tuff cone of Caldera Blanca |
| | | MC01 | Pleistocene feeder dyke of the Montaña Clara hydromagmatic volcano |
| Historical eruptions | Geomorphological | LZ56 | Historical hornito of Manto de la Virgen |
| | Tectonic | LZ32 | Historical volcanic alignment of Calderas Quemadas |
| | Volcanological | LZ21 | Historical volcano-stratigraphic sequence at Monumento al Campesino |
| | | LZ23 | Historical volcano of Chinero |
| | | LZ24 | Historical chasms at Tinguatón volcano |
| | | LZ25 | Historical geothermal manifestations at Islote de Hilario |
| | | LZ26 | Historical volcanic complex and lava channel of Pico Partido-Montaña Señalo |
| | | LZ27 | Historical lavas of Timanfaya |
| | | LZ28 | Historical volcano of Caldera del Cuervo |
| | | LZ29 | |

(continued)

**Table 2** (continued)

| Geological framework of Lanzarote and Chinijo Islands UGG | Main geological interest representative of each geological frameworks | Code | Geosite denomination |
|---|---|---|---|
| | | | Historical lava tube of Cueva de Los Naturalistas |
| | | LZ30 | Historical lavas at Cesar Manrique Foundation |
| | | LZ31 | Historical volcanic complex of Montaña Rajada |
| | | LZ33 | Historical spatter cones of Echadero de Los Camellos |
| | | LZ34 | Historical volcano of Corazoncillo |
| | | LZ36 | Historical volcanic ashes field of La Geria |
| | | LZ43 | Historical lava lake and volcanic bombs of Montaña Colorada volcano |
| | | LZ62 | Historical volcanic complex of Macizo del Fuego |
| Aeolian | Estratigraphical | LZ20 | Pleistocene buried palaeodunes of Lomos de San Andrés y Camacho |
| | Sedimentological | GR07 | Holocene beach-dunes system of Las Conchas-Montaña Bermeja |
| | | LZ09 | Quaternary aeolian sands aisle of El Jable |
| | | LZ14 | Pleistocene aeolian dunes of Jable del Medio |
| Fluvial and gravitational | Geomorphological | GR02 | Quaternary badlands in the Los Conejos ravine |
| | | LZ07 | Pleistocene hanging valleys of Famara |
| | | LZ08 | Pleistocene U-shape valley of Temisa |
| | | LZ12 | Pleistocene detritic fans and glacis of the Las Laderas palaeocliff |
| | | LZ16 | Pleistocene beheaded endorheic valley of la Vega de San José |
| | | LZ59 | Historical rotational landslide at Fenauso valley |
| | Petrological | LZ18 | Quaternary caliche crust on Montaña Tinache volcano |
| | Volcanological | LZ13 | Quaternary structural valley of Tenegüime |
| Littoral | Geomorphological | AL05 | Holocene littoral cave of Jameo de Alegranza |
| | | GR01 | Quaternary coastal mophologies of Los Resbalajes |
| | | LZ04 | Historical coastal salt farms of El Rio |
| | | LZ38 | Historical littoral lagoon of Salinas del Janubio |
| | | LZ41 | Pliocene marine platform of Papagayo |
| | | LZ46 | Holocene littoral cave of Jameo de Guatiza |
| | | LZ63 | Quaternary coves and enclosed beaches of Papagayo |
| | | LZ64 | Quaternary natural littoral pools of Los Placeres |
| | Hydrogeological | GR06 | Artesian upwelling of Caleta del Aguardiente |
| | Sedimentological | GR05 | Holocene coastal lagoon of El Salado |
| | | LZ40 | Pleistocene tsunamite of Piedra Alta |
| | | LZ52 | Quaternary sands of Caletón Blanco |
| | Sedimentological | LZ54 | Historical beach and berm at Playa del Cochino |
| | Volcanological | LZ37 | Historical littoral erosive processes on Timanfaya lavas at Los Hervideros |

(continued)

**Table 2** (continued)

| Geological framework of Lanzarote and Chinijo Islands UGG | Main geological interest representative of each geological frameworks | Code | Geosite denomination |
|---|---|---|---|
| Submarine | Geomorphological | AL04 | Submerged fluvial erosive morphologies of Puerto Viejo |
| | | LZ48 | Pleistocene erosive morphologies on Puerto del Carmen submerged lavas |
| | | LZ65 | Marine insular platform |
| | | LZ66 | Northwest insular submarine ramp |
| | | LZ67 | Southeast insular submarine ramp |
| | | RE01 | Quaternary submerged littoral tunnel of Roque del Este |
| | Sedimentological | GR04 | Quaternary submerged sand littoral bars of El Rio and Rio of Montaña Clara |
| | | LZ44 | Sandy bottoms with *Cymodocea nodosa* meadows of Arrieta and Punta Mujeres |
| | Volcanological | LZ45 | Holocene lava delta of Charco del Palo |
| | | LZ47 | Pleistocene lava delta of Costa Teguise |
| | | LZ49 | Quaternary submerged volcano of Las Bajas |
| | | LZ50 | Pleistocene reef on the lava delta of la Marina de Arrecife |
| | | MC02 | Pleistocene dykes of Las Gerardias |
| Paleontological Sites | Paleontological | LZ01 | Mio-Pliocene paleontological zone of Órzola |
| | | LZ11 | Pleistocene paleontological deposit of La Santa |
| | | LZ15 | Pleistocene paleontological deposits of Timbaiba |
| | | LZ42 | Mio-Pliocene paleontological deposits of Ajaches |
| | | LZ57 | Quaternary paleontological deposit of Fuente de Gayo |
| | | LZ58 | Mio-Pliocene paleontological deposit of Barranco del Valle |

Alimentación y Medio Ambiente, coastal areas at 1 m resolution; Instituto Español de Oceanografía, 50 m resolution) and the Instituto Hidrográfico de la Marina (100 m resolution). The final Geosites Map of Lanzarote and Chinijo Islands UGG has been made at a scale 1:25,000.

## 2.6 Geoheritage Assessment

Once the geosites has been selected, their assessment and conservation status has been assigned because this is one of the steps necessary for geoconservation and management strategy of Lanzarote and Chinijo Island UGG. According to Carcavilla et al. (2007) the assessment of a geosite is based on three basic items: (1) Not every geological element has heritage value, (2) those geological elements having heritage value (scientific, educational or touristic values) are not always equally interesting, and (3) it is possible to define some parameters or criteria which allow us to estimate heritage value.

In the geosites technical sheet a final section has been included dedicated to the geosite qualitative assessment (Table 1). Thus, each one of them has been assessed taking into account three types of criteria within a qualitative scale: (1) the intrinsic (scientific) value, (2) the susceptibility of degradation and (3) the priority for protection.

# 3 Geological Frameworks of Lanzarote and Chinijo Islands UGG

All geosites are included in eight geological frameworks that are representative of the geology and geodiversity of Lanzarote and Chinijo Islands UGG (Table 2) referred to a volcanic oceanic island as: Mio-Pliocene shield volcanism, Quaternary volcanism, historical volcanism, paleontological sites, Aeolian deposits and forms, fluvial and gravitational environments, littoral and submarine actual processes and deposits. Due to the volcanic origin of this UGG, most geosites are included in the historical eruptions and Quaternary volcanism frameworks (17 and 15 geosites, respectively). The fact of being insular areas with a submarine area selected in the territory of the UGG also explain the relative abundance of submarine and littoral geosites (13 and 14 geosites). The other geological frameworks identified are represented by less than the 10% of total geosites. The geological frameworks are briefly described below because geology of the islands can be consulted in Sánchez et al. (this volume).

### 3.1 Mio-Pliocene Shield Volcanoes

The beginning of the construction of the island of Lanzarote dates back to the late Eocene or early Oligocene, when main shield volcanoes were formed (Famara and Ajaches). First subaerial stage was characterized by the emission of a large amounts of basaltic materials (mainly lava flows and tuff cones) and the tectonic processes involved (e.g. lava piles, dyke intrusion, normal faults) building the shield of the Lanzarote island.

### 3.2 Quaternary Volcanism

After shield volcanoes were eroded, a new period of volcanic activity started during the Quaternary, being mainly located in the central area of Lanzarote and along the Chinijo Islands. Some eruptions occurred discordantly over the eroded old massifs. This post-erosional eruptive phase is dominated by fissural eruptions of mainly basaltic composition, but also by hydromagmatic Surtseyan type eruptions in coastal areas forming tuff cones and tuff rings such as Los Cuervos, Montaña Amarilla and Cavera volcanoes. Some of these eruptions changed from hydromagmatic to magmatic phases in the final stages. This framework covers volcano-stratigraphic sequences, landforms, pyroclastic structures as well as feeder-dykes.

### 3.3 Historical Eruptions

The last volcanic episodes in Lanzarote are the eruptions occurred between 1730 and 1736, which originated the Timanfaya volcanic field and the Tao-Chinero-Tinguatón eruptions in 1824. This framework incorporates all volcanological and morphological features related with these eruptions. A great part of the deposits issued during both eruptions are well preserved since they are included in protected landscapes and natural areas (National Park and Natural Park). These eruptions, especially Timanfaya's one, have had great implications for life and inhabitants on the island and caused important and drastic changes in the landscape.

### 3.4 Aeolian Processes, Landforms and Deposits in Oceanic Volcanic Island Environment

The wind and Aeolian processes have played a determinant role since the early subaerial stage of the islands and still shape the current landscape. Aeolian deposits of this UGG are frequent between volcanic deposits as an evidence of the continuous interaction between volcanic and sedimentary construction of the island. Sands, from organic origin (mainly shells and calcareous algae fragments) are transported by oceanic currents from offshore to backshore environments of emerged areas. Once above intertidal level, sands is blown by the wind feeding beaches and dune fields.

### 3.5 Processes, Landforms and Deposits of Littoral Volcanic Island

Coastal areas of volcanic islands are characterized by the presence of geological and geomorphological features that reveal the constant interferences between volcanic and marine sedimentation constructive processes and destructive erosional events. Lanzarote and Chinijo Islands UGG has exceptional geosites belonging to this framework where sedimentary deposits related to coastal processes as beaches, blocky bars of high energy storms or even tsunamis (tsunamites). However, in those areas where coastal erosion prevails there are representative examples of cliffs, abrasion platforms, littoral lagoons, pools, aquifers and caves.

### 3.6 Landforms and Deposits of Fluvial and Gravitational Processes of Oceanic Volcanic Island

The action of rain during Pleistocene humid stages, alternate with draught and arid periods scarce but torrential precipitation in this UGG due to main climate changes occurred at this latitude give rise to a fluvial and mass processes. Examples of ephemeral rivers, gullies, deep V-shaped valleys and their evolution to U-shaped valleys are very frequent over Famara and Ajaches ancient shield volcanoes. Volcano-tectonic events can also considerably affect rivers and whatersheds due to have numerous examples of valleys turned into an endorheic basin after the closure of its drainage network by cones or volcanic deposits as in Vega de

San José geosite and gullies can be formed along an exposed fault surface. Hanging valleys and a historical rotational landslide with typical hummocky surface are also represented in the inventory in Famara cliffs.

### 3.7 Processes and Morphologies over Submarine Platform of Oceanic Islands

Submerged areas of volcanic oceanic islands usually have not a well developed submarine platform. In the case of Lanzarote and Chinijo Islands UGG a prominent submarine platform was developed that has been influenced by global sea level variations since their origin. Under the sea level there are "processes and morphologies of the submarine insular edifice" that include the biggest structures like the marine platform and the submarine ramps, as well as other structures related with volcanic, sedimentary and erosive processes. They comprise lava deltas with hyaloclastites and pillow lavas, eroded dyke swarms, monogenetic volcanoes, sand bars, sandy floors, potholes etc. Most of these geological elements have been originated over surface conditions in the past but nowadays they are submerged due to the rise of sea level during the Holocene.

### 3.8 Neogene Palaeontological Sites in Oceanic Islands

The presence of paleontological deposits is usually linked to sediments accumulated in valleys, alluvial fans, ravines, palaeosoils, dunes and coastal areas. As a result of the isolation conditions of the islands, they have assumed a fundamental importance in the history of biology, showing unique evolutionary paths represented in several endemism and other key fossils, which allows us to understand the past climates in the islands.

## 4 Lanzarote and Chinijo Islands Geosites for a UGG

A total of 82 geosites were included in the Lanzarote and Chinijo Islands UGG inventory: 67 in Lanzarote, 7 in La Graciosa, 5 in Alegranza, 2 in Montaña Clara and 1 in Roque del Este (Fig. 1, Table 2). Nearly half of the geosites have a main volcanological interest (46%), followed by geosites of geomorphological and sedimentological interest (27 and 11% respectively). Only few geosites have palaeontological, stratigraphical, tectonic, petrological or hydrogeological main interest. Most of them are relevant at a national and international level (32 and 31, respectively), and only 19 are relevant at a regional level.

## 5 Geosites Susceptibility and Vulnerability

We have identified several geosites that have suffered irreversible damages due to the plunder and vandalism done by local residents, tourists and collectors. The palaeontological site of Órzola (LZ01) is an example of the damage on geoheritage due to looting, due to the publication of the exact location of outcrops where paleontological sites are in scientific papers, trail guides, books, etc. (Figure 2). One of the sites with fossil bird eggs is almost without specimens, being the rest of the outcrop completely destroyed, with pits, wastes and tip. This palaeontological geosite in particular is not preserved. The difficult access has allowed preservation of other outcrops, although they are extremely vulnerable and none of them have physical protection.

However, the plundering is not limited to fossils. Olivine aggregates, pahoehoe lava flows, lapillis, bombs, lava drops, stafilites, etc. are still collected mainly by visitors.

Another example of injuries on geoheritage is The lava tube of Cueva de Los Naturalistas (LZ29) which has been gradually disappearing during the last decades by looting the numerous stalactites and stalagmites of lava (stafilites) that covered its roof and its floor, and of which practically there are only testimonial elements. This has led to the irretrievable loss of one of its most significant and rare geomorphological elements of this inventory.

The urban pressure in the islands has also resulted in loss of geoheritage. La Santa (LZ11) is a very poorly preserved geosite, and can almost be considered gone because it has been damaged by human infrastructure related to hotel facilities and occupation of the La Santa islet. In addition, since the deposit is along the coast, active littoral dynamics of this sector has also influenced on its deterioration. In this case, it is important to highlight that some authors suggest that, although the geosite is

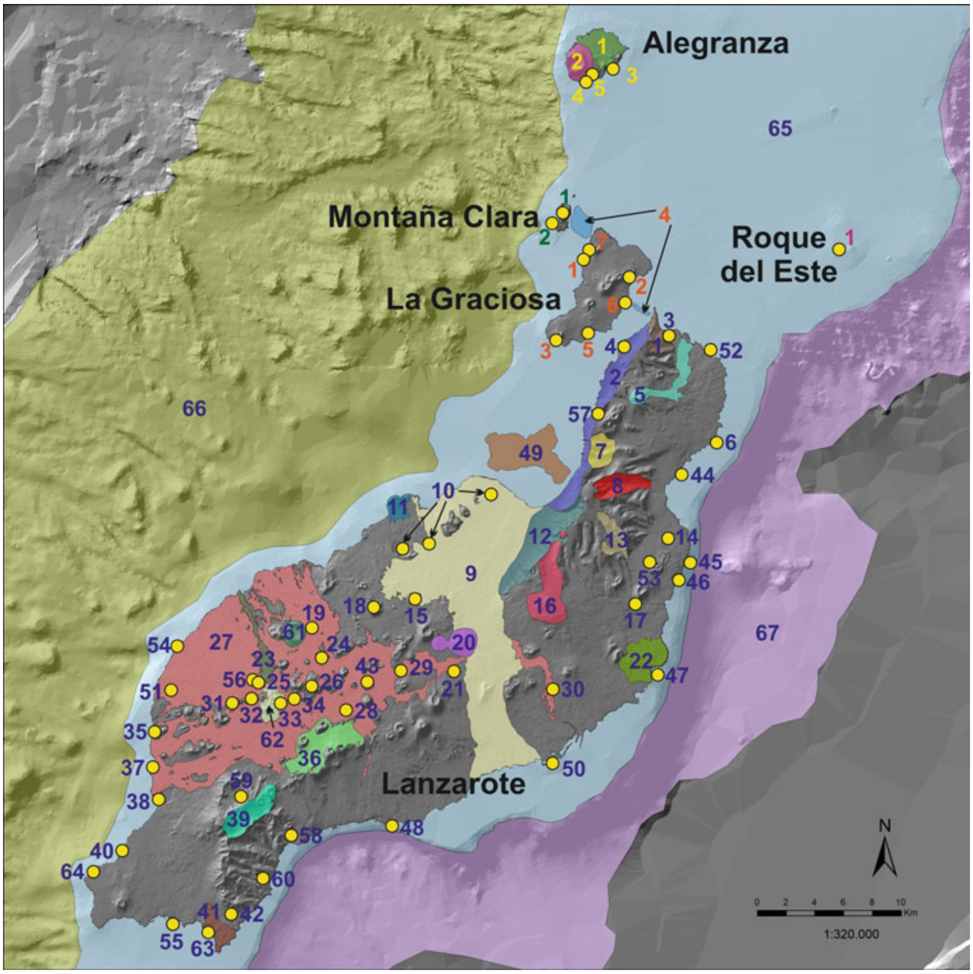


**Fig. 1** Geosites of Lanzarote (numbers in blue) and Chinijo Islands UNESCO Global Geopark (Alegranza´s geosites: numbers in yellow; Montaña Clara´s geosites: numbers in green, La Graciosa´s geosites: numbers in orange and Roque del Este´s geosite has a number in red). Geosites are mapped with different colours except for those with a surface less than 2 $km^2$ that are represented at this scale with a yellow dot

practically lost or has completely disappeared, it must be included in the inventory since its geological context is still important (Salazar et al. 2017).

The uncontrolled public usage has generated an important impact in some volcanic areas. In a large part of the surface of the Caldera del Cuervo (LZ28) and its surroundings, visitors have caused a significant impact on the slopes of the cone and in the lavas of its surroundings (Fig. 2), losing also part of its values as a consequence of the furtive extraction of olivine nodules (Dóniz-Páez et al. 2012). Aware of this problem, the Cabildo de Lanzarote carried out a set of geo-conservation actions in 2014 aimed at curbing the high erosive processes of the cone flank and minimising the impact of the massive influx of visitors, by regularising the external slopes of the volcano and the design of a self-guided interpretive itinerary that acts as a channel for the flow of visitors (Guillén et al. 2015).

Pico Partido (LZ26) has also quite degraded areas; some of them have even irreversibly lost part of their geoheritage (Dóniz-Páez et al. 2012). In this area, there is a lava channel, which used to present beautiful lava, drops, roped-lavas, and extremely thin pahoehoe lava layers that sadly get broken when stepped on (Fig. 2).

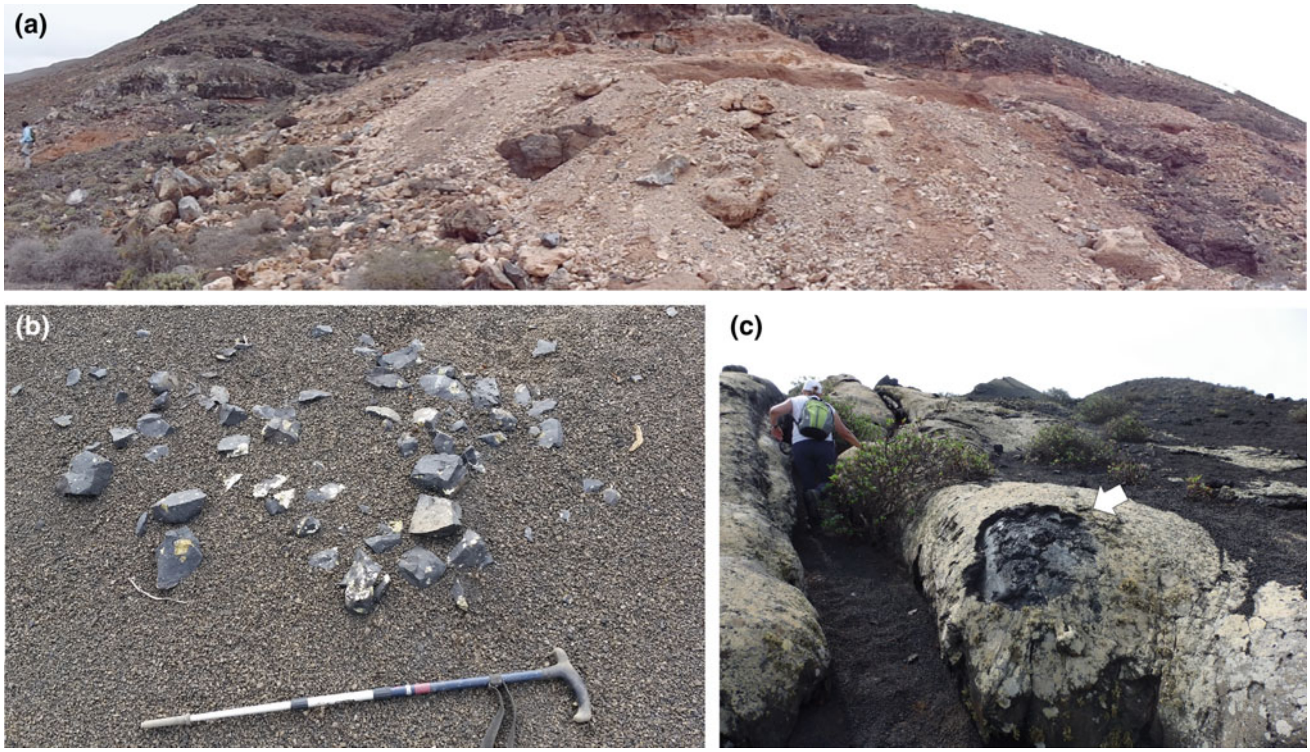


**Fig. 2** **a** Órzola geosite of paleontological interest that are completely damaged by looting and plundering. **b** olivine xenoliths destroyed by visitors. **c** A lava channel eroded and broken when visitors stepped on. Lanzarote and Chinijo Islands UNESCO Global Geopark

Recent inspections to the area show that the lava drops are now very rare and have their tips broken; In addition, the thin pahoehoe lava layers are full of holes having their smooth surface completely destroyed. This area is inside the Los Volcanes Natural Park, but the lack of a ranger's service makes it difficult to avoid tourist and locals to climb up the volcano, and hence spoil and break its geological features. In this sense, the impact of uncontrolled hiking in fragile structures, such as cinder cones and pahoehoe lava flows, should be analysed.

Other activities leading to the decline of geosites are extractive activities. In the palaeodunes of Lomos de San Andrés and Camacho (LZ20) the exploitation of the lapilli that covers the sand dunes has greatly influenced the susceptibility to a degrading state due to anthropogenic causes. The impact of the exploitation of lapilli over the palaeodunes is very high and they are modifying the value and integrity of the geosite putting its disappearance at risk. However, it is also true that thanks to extractive activities it has been possible to discover the origin of these aeolian morphologies that were buried under volcanic lapilli.

Active geological processes also affect the conservation of geosites. For example, littoral dynamics influence the modification of the cliff morphologies, such as the erosion of the cliff baseline, which favours rock falls.

## 6 Boundary of the Unesco Global Geopark for Lanzarote and Chinijo Islands

Once the islands of Lanzarote and Chinijo became part of the UGG in 2015, the scientific team started to revise and improve the previous Geoheritage Inventory according to UGG assessor's comments during the assessment process. The new and improved inventory of Lanzarote and Chinijo Islands now includes several modifications to the current inventory of the Geopark (Galindo et al. 2015). New geosites have been incorporated: 2 in Alegranza, 4 in La Graciosa and 18 in Lanzarote.

Two of the new geosites that are representatives of the flanks of the volcanic edifice in Lanzarote (LZ66 and LZ67) are out of the current boundary of the Geopark (Fig. 3). For this reason, we propose to expand it towards the edge between the submarine talus and the abyssal seafloor (Fig. 3). This boundary follows a geomorphological criteria also coherent with the geological context of a volcanic oceanic island.

The current boundary of the UNESCO Global Geopark covers an area of approximately 2,500 $km^2$, of which 866 $km^2$ are emerged that includes the island of Lanzarote and the Chinijo Archipelago (Galindo et al. 2015). The new

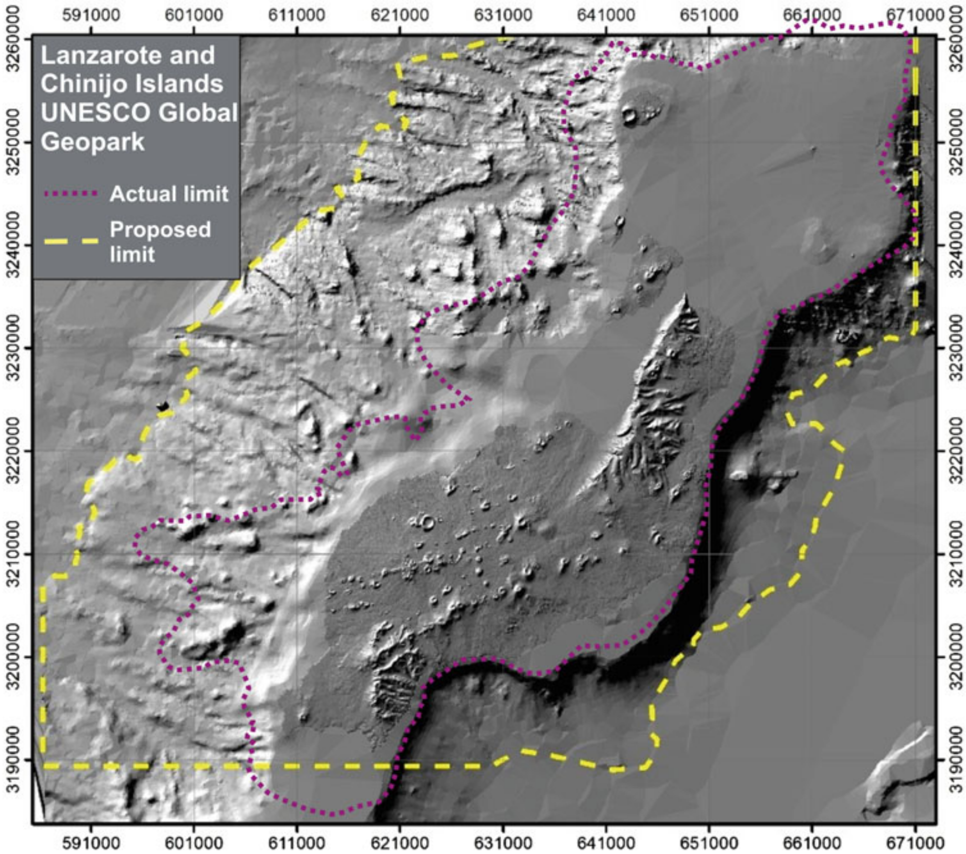


**Fig. 3** Current (dotted purple line) and proposed (dashed yellow line) boundaries within the Lanzarote and Chinijo and Islands UGG

proposed boundary suppose an increase of the surface of nearly 1900 $km^2$.

## 7 Conclusions

Volcanic oceanic islands are the summit of hug volcanic edifices that are built from the ocean floor to the surface. The geological study that has given rise to a geoheritage inventory for the UNESCO Global Geopark has included both the submarine and the emerged part of Lanzarote and Chinijo Islands. Thus, the 82 selected geosites are representatives of the geological history and geodiversity of this UGG and the are unique to understand the evolution of this Atlantic volcanic island.

The scale of geoheritage inventories, the geological frameworks and the level of significance (international, national, regional and local) of each geosite are the driving force used to define the boundary of this UGG.

In this inventory, the methodology used has been adapted for a UGG including not only emerged sites but also submerged geosites. Final geoheritage inventory has been used for management, according to the inspirational principles of the UGG as geoconservation, education and geotourism for sustainable development involving local communities.

Although the main scientific interest is the volcanological, other natural processes that modelate landscape of the islands are represented such as, aeolian and coastal processes and others. Life evolution in the islands is also considered within the palaeontological geosites. 82 Geosites are representatives of four Focus Areas included in UGG as "Natural Resources, Geological Hazards, Climate Change and Geoconservation".

The status of geoconservation of geosites is high in general because most of them are protected by different legal figures (natural protected areas: Timanfaya National Park; Biosphere Reserve of Lanzarote; 2 Natural Parks; 1 Integral Natural Reserves; 2 Scientific Protected Sites; 5 Natural Monuments; 2 Protected Landscapes; 1 Marine Reserve; among other cultural protected areas); and due to the implementation of European Chart of sustainable tourism. Nevertheless, high touristic pressure together the existence of Resorts in coastal areas of palaeontological interest, the increase of uncontrolled hiking and trekking activities over fragile and vulnerable geosites, as well as the collection of geological elements (fossils, minerals and rocks) must be controlled by local management authorities of this UGG and natural protected areas.

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# Historic Volcanic Landforms Diversity on Lanzarote

Carmen Romero, Nieves Sánchez, Juana Vegas, and Inés Galindo

The island of Lanzarote once was the flattest and one of the most plentiful when it came to grains and cattle, so that the other islands were helped and could share this abundance. But now, after the five-year raging volcano, the island is left with mountainous parts and mostly devastated, either by the fire of the volcano that burned a third of the land or by the many stones and sand erupted by the volcano, which burst on the first day of September 1730 with a large earth tremor and so much noise, that even on the island of Canaria, 40 leagues away, caused so much horror that many religious people, unaware of the cause of such tremor, went around preaching penance (…). Five different mouths vomited many stones and rocks, broken into large pieces with loud bursts in mid air, and so much sand that flooded the whole island, to the point that by midday it blocked the light and glare of the sun, leaving dwellers illuminated with artificial light, and covering thirteen places leaving the houses buried under it as they are today. Different rivers of fire scattered through the earth that burned and consumed ten spots and their land, the best and most fertile, which make up the third part of the island, leaving them unfit forever, because the earth remained and is preserved as the scum of the burnt iron (…). Finally, on April 16, 1736, God raised his hand to put an end to so much punishment and the volcano was extinguished, and then the inhabitants began to return to their homeland, although not all of them to their homes and places because they were burnt by fire or were covered with sand.

Translation of D. Juan Francisco Guillen, Bishop of the Canary Islands. 1744

**Abstract**

The inventory of the Lanzarote and Chinijo Islands UNESCO Global Geopark (UGG) includes 82 geosites, out of which 17 are linked to the deposits associated with the eruptions of Timanfaya, that took place between 1730 and 1736, and Chinero and Tinguatón eruption, which occurred in 1824. The volcanic field originated during these two historical events occupies a 210 km$^2$ area, which represents 25% of the island surface, and is formed by numerous lava flows and large-scale volcanic lineaments. This volcanic field contains more than 30 cones that show numerous and valuable tectonic, structural, volcanological and geomorphological features that are enhanced by their favorable state of conservation. All of them are included in protected sectors that contribute to its dissemination and conservation. In this chapter, the detailed geological study of the Geosites associated with the historical volcanism of Lanzarote is carried out, a general overview of the main geological landmarks of the evolution of both eruptions. The study of the cones that make up the volcanic field shows that the temporary-space variations of the eruptive styles, the architecture of the resulting volcanoes, as well as their geochemical and tectonic features, represent an excellent example of the complexity of monogenetic volcanism of intraplate oceanic islands.

**Keywords**

Timanfaya eruption • 1824 eruption • Geosite • UNESCO Global Geopark • Lanzarote

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## 1 Introduction

The UNESCO Global Geoparks in volcanic territories around the World highlight the geological features linked to volcanism and play a substantial role in geo-hazard education (Moufti and Németh 2016a). Some authors point out that the identification of geosites must not only be based on their scientific value, but that the importance these places have for local communities must also be taken into account (Moufti and Németh 2016b). From this point of view, the volcanic areas that shelter volcanic structures of historical eruptions are exceptionally good places to develop sustainable tourism strategies, design environmental education and awareness initiatives and their geo-preservation, since they are usually places that draw the interest of both, the local population and visitors of nearby tourist areas (Erfurt-Cooper 2011; Alessio and De Lucia 2017).

This connection between volcanism, society and culture is a reference on the Lanzarote and Chinijo Islands UGG and is a unique opportunity to outreach volcanic processes, their dangers, geohazards and impact, showing the speed at which volcanism can transform a geographical space, on a human scale. The volcanoes created by the historical eruptions of Lanzarote, have been used to promote the island, which boils down to visual aesthetic landscapes associated with the human impact they have undergone. However, these landscapes have excellent examples that help promote, at different levels, the knowledge of the basaltic eruptive processes characteristic of oceanic intraplate islands. They can also be used as a very effective tool in the awareness of volcanic hazards in active areas with low eruptive frequency such as the Canary Islands. In this sense, the opportunities offered by the historic volcanic areas of Lanzarote are endless, given the wide variety of geological landscapes, their excellent degree of preservation, the easy access and the high quality tourist facilities.

The geological and scientific value of the deposits, outcrops and areas covered by the historical volcanic eruptions of Lanzarote, have been established and integrated into one only Global Geosite denominated “Recent Volcanism of Timanfaya (Lanzarote)” (Reference Code: CV007) in the Global Geosites inventory of international relevance of

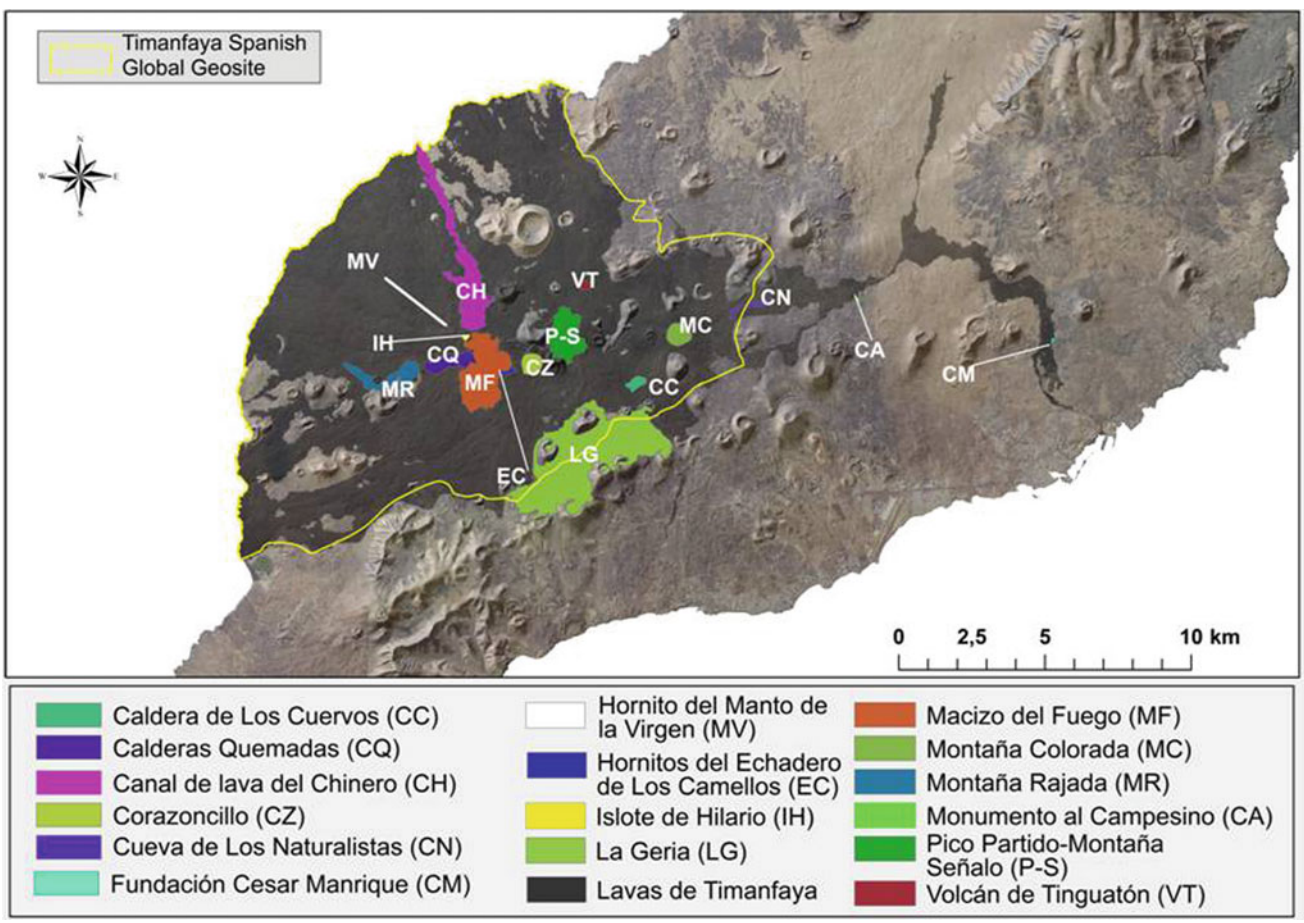


**Fig. 1** The Timanfaya Spanish Global Geosite and geosites representatives of the historic eruptions at regional scale of Lanzarote and Chinijo Islands UNESCO Global Geopark

Spain, developed by the Geological Survey of Spain (IGME). This Global Geosite is part of the Spanish geological framenwork No. 14, which represents the “Volcanic buildings and morphologies of the Canary Islands”. For the definition of the Geosite CV007, the methodology of the Global Geosites project, a global inventory of geoheritage (IUGS-UNESCO) (García-Cortés 2008), has been followed, according to which geological frameworks are chosen in each country on the basis of their special significance in the global geological record. In each of these geological frameworks, the most representative and illustrative geosites are selected. A framework is understood as a grouping of features and geological elements that have the same origin, meaning or that have been originated by similar processes, and that show unique features of the geological evolution of the Earth (García-Cortés 2008).

However, in terms of management and conservation and, above all, the outreach of geoheritage of Timanfaya eruption, it is necessary to have a rigorous inventory at more detailed scales than those considered in the definition of international Global Geosites (Vegas et al. 2015; Galindo et al. this volume). Therefore, the declaration of the Lanzarote and Chinijo Islands UNESCO Global Geopark has allowed for this Global Geosite to have 17 geosites at regional scale for the UGG (Galindo et al. this volume) (Fig. 1).

This chapter presents a brief summary of the first detailed study of the values of the geological heritage of the central volcanic field of the island of Lanzarote linked to the development of the historic eruptions of Timanfaya (1730–1736) and Chinero and Tinguatón (1824). It is an area characterised by the presence of complex monogenetic volcanic lineaments in the central-western sector of the island, and by an extensive lava field that originates from them. This lava field occupies the old valleys of the inland part of the island (Romero 1991b; De León 2000) and extends west reaching the sea and covering more than 22 km of coastline. This study shows that the volcanic deposits and outcrops of the historic volcanoes of Lanzarote, have significant and international relevant geoheritage with main interest on volcanic, geomorphological, petrologic and tectonic values that can be seen at different scales.

## 2 Volcanic Setting

The Canary Islands comprise an active volcanic archipelago with a total of 17 volcanic episodes documented dating back to the beginning of the conquest of the islands in 1402, to present (Romero and references herein), involving only the islands of La Palma, El Hierro, Tenerife and Lanzarote, with a covered area of >250 km$^2$. They correspond to relatively short-term volcanic events (52 days) and scarce covered area (average values around 5 km$^2$). The total number of buildings is approximately 50, although the number of emission centres is well over 350, since practically all eruptions have a fissured structure, with fractures ranging from 500 m to almost 17 km in length. These are eruptions of mafic magmas and generally basaltic composition, with the emission of high temperature fluid magmas, low rates of volcanic explosiveness (usually with VEI of 2 and 3), eruptive dynamisms that vary from Hawaiian to violent strombolian and which may occasionally had water/magma contact phases or develop in underwater environments.

Between the beginning of the 18th century and the first quarter of the 19th century, the Canary Islands experienced a period of greater frequency of eruptions; in a period of about 120 years, 8 of the 17 historical eruptions occurred (1704–1705, 1706, 1712, 1730–36, 1777, 1793, 1798 and 1824). Three of them (1704–1705, 1730–36 and 1824) correspond to multiple fissure episodes developed from highly developed eruptive fractures; Two of these three episodes took place in the central-western area of the island of Lanzarote: the eruption of Timanfaya (1730–1736), located in a fissure of about 16.5 km in length, partially developed in the southwestern submerged flank of the island (Galindo et al. 2016); and the eruptions of Tao, Chinero and Tinguatón volcanoes (1824), of almost 14 km in length. However, the size of both eruptions is quite different.

Timanfaya is the most important eruption that occurred in the Canary Islands in historical times. This volcanic episode represents 79% of the total number of days with volcanic activity in the archipelago, and 73% of the total area affected by historical eruptions in the archipelago (Romero 1991a). The active period of the rest of the historical volcanoes in the Canary Islands ranges between 10 days of the eruption of Chinyero in 1909 in Tenerife, and almost 5 months (145 days) of the eruptive event in Isla del Hierro in 2011/2012. Timanfaya lasted 14 times more than the eruption in 2011/2012 and 205 times more than the Chinyero Volcano, which makes it the longest eruption of all since the time of the conquest of the islands. The total volume of material emitted estimated during the Timanfaya eruption ranges between 3 and 5 km$^3$ (Carracedo and Badiola 1991; Sharma 2005), corresponding to >1.5 km$^3$ DRE (“Dense Rock Equivalent” or total volume of materials emitted) (Becerril et al. 2017). The magnitude of this eruption has been classified as grade 6, based on the DRE (Sobradelo et al. 2011), with between 2 and 4° more than the rest of the historical volcanic episodes of the Canary Islands. The Volcanic Explosivity Index—VEI—of this eruption has been estimated at 4 (Galindo et al. 2014).

Its long duration makes it one of the basaltic eruptions with the largest active period in the world, even higher than the Laki eruption in 1783 in Iceland, which took over 8 months—June 8, 1783 to February 7 of 1784—(Thordarson and Self 1993) and is only topped by the eruption of Pu'u O'o in Kilauea, Hawaii, which began on January 3, 1983 (Heliker and Mattox 2003) and remains active in 2018.

This is, at the same time, one of the largest basaltic fissure eruptions in historical times, only topped by the eruptions of the Eldgja, the 932 and the Laki, in 1783, in Iceland (Carracedo 2014) and by Pu'u O'o, in Hawaii (Heliker and Mattox 2003). Timanfaya is, in short, one of the best examples of high-volume basaltic fissure eruption in an oceanic intraplate context.

During the eruption of Timanfaya, more than 200 emission centres opened and some 30 volcanic cones were built, some of which are grouped forming volcanic buildings of a certain complexity (Romero 1991a). The description of this study shows an overview of this. The morphological variety of the volcanic field cones is very high, there are cones of cinder, slag and spatter, showing sometimes complex volcanic stratigraphies, resulting from eruptive phases of magmatic dynamics that can alternate with short phases of water/magma contact. From these vents a multitude of lava flows were emitted to cover practically a quarter of the island surface and eruptive columns were formed that dispersed their ashes throughout the island of Lanzarote and in the north and centre of Fuerteventura (Romero 2003), with effects that reach the Pyrenees mountain range, located thousands of kilometres away from Lanzarote (Hevia et al. 2018). Glass analysis indicate that 45 Mt of S02 was injected into the upper troposphere-lower stratosphere via 12–16-km-high eruption plumes and that over half this amount was released during the first year of activity (Sharma 2005). A study of proxy climatic records and historical records suggest that Lanzarote's 1730–1736 eruption had a marked environmental and atmospheric impact on the northern hemisphere, affecting all of Europe (Sharma 2005).

During the almost six years that the eruption of Timanfaya lasted, the eruptive phenomena were not continuous. In fact, the eruption can be decomposed into temporary discontinuous activity phases, which led to the construction of independent volcanic buildings or the result of overlapping events at the same point. The historical records from the first year of the eruption, from September 1, 1730 to August 31, 1731, show that throughout that year the volcanic activity comprises a total of 205 days, and that 160 days correspond to stages of eruptive calm. This means 56% of active days during the first year (Romero 2003). Some authors suggest that the eruption of Timanfaya occurred in five phases, most of them with the development of several volcanic episodes, with differences regarding its duration and intensity (Carracedo et al. 1990, 1992).

The eruption of Timanfaya constitutes a volcanic area of apparent volcanological, morphological and structural simplicity, since its elements revolve around a main direction fracture ENE–WSW (N80E). However, the data provided by eyewitnesses of the eruption, show that during the first 5 months the eruption progressed from a perpendicular fracture to the main one, from the SE to the NW. Subsequently, the activity focused on the main fracture and moved along to the SW. From there, it spread sequentially in ENE direction, until reaching the end of the eruption in its most northeastern section and in the vicinity of the first emitting centre (Carracedo 2014). The eruption was actually fed by a diffuse fissure system, with local tendencies NE–SW, NW–SE and EW, since many of the cones are located in stepped fractures of NE–SW direction or articulate their main elements in orthogonal directions to the N80E (Romero 1991a, 1991b).

Instead, during the eruption of 1824, three small fissures between 400 and 750 m long were formed, distributed along the main fracture, with the opening of more than 30 vents. The eruptive activity was located in an ENE–WSW direction fracture, in a sub-parallel arrangement, although somewhat further north, than that generated during the previous eruption. The volcanic assemblages of Tao volcano (31st July–1st August), Chinero volcano (29th September–4th October) and Tinguatón volcano (16–17th October) are located along it. The formation sequence of these volcanoes shows a progression of the fracture similar to that of Timanfaya, although in a single direction. Despite the brevity of the magmatic phases of these eruptions (Rumeu de Armas and Araña 1982; Araña 1982), the most significant event of this triple eruption is the emission, more or less calm, of brackish water at high temperatures through the eruptive channels of the Tao and Tinguatón volcanoes.

The lavas and pyroclastics emitted in Timanfaya cover a wide compositional range that varies from basanites to tholeiitic magma series (Carracedo et al. 1992). Another outstanding feature of the eruption of 1730–1736 is the chemical evolution of the magma throughout; during the first phase, nepheline basanites were generated, which evolved towards alkaline basalts, to become, from the II phase, tholeiitic olivine (Carracedo et al. 1992; Carracedo 2014). This chemical change is related to a somerization process in the magmatic source, possibly controlled by local tectonics. All the lavas are of primitive composition (almost primary) and in them, the xenoliths of different nature are very frequent, with diverse origins that go from metamorphic to sedimentary, organic or purely magmatic (Carmona et al. 2009). The xenoliths of igneous nature, mostly peridotites, have a mantle provenance and have been studied by Neumann et al. (1995, 2000) or Schmincke et al. (1998) among others. The sedimentary xenoliths have been analysed by Araña and Bustillo (1992), Bustillo et al. (1994), Aparicio et al. (2006) and Carmona et al. (2009).

The eruption of 1824 emitted one of the most alkaline and volatile rich magmas of all those identified on the island (Gómez-Ulla et al. 2015). The lavas emitted from the different vents of 1824 do not show significant petrological and geochemical changes; its unique mineralogical peculiarity is the presence of an orthopyroxene in the de-mixing phase and the high proportion of dunitic and sedimentary xenoniths in the Tinguatón lava flows (Araña 1982).

The consequences of this prolonged volcanism in the landscape, economy, settlement and population were important and could have been established based on the events documented in contemporary accounts (Romero 1997). Only over the course of the Timanfaya eruption, some thirty hamlets were destroyed, leaving numerous infrastructures buried under the accumulations of ash (De León and Perera 1996) whose locations have been identified in a recent study by De León (2008). Only one human victim is recorded (Cazorla León 2003) although the eruption had important demographic consequences (Quintana Andrés and De León 1997) since, according to contemporary chronicles, about five months after the eruption had started, almost 44% of the island population, coming to consider the evacuation of Lanzarote (Romero 1997) at the peaks of eruptive intensity.

Economically, the damage was significant since not only the harvests during the years of the eruption were lost, but also numerous hay lofts and part of the systems to gather and store water (it was vital on an island with the weather conditions Lanzarote has (Sánchez et al. this volume)), as well as a good part of the pastures and of the cattle hut. The economic losses linked to the disappearance of grain, which kept a good part of the population of the Canary Islands, and the problems posed by emigration, with the possibility of abandoning the island leaving it at the mercy of pirates and Berbers, were the main causes that motivated the intervention of the authorities, both insular and regional, during the first months of the eruption (Romero 2003). So much so, that a commission was even appointed specifically to manage the volcanic crisis, promulgating a Royal Decree by the Royal Audience of the Canary Islands, with more than a dozen provisions, which were intended to alleviate as much as possible the inhabitants and keep the island under the control of the authorities (Romero 1997).

The territorial impact of the eruption of 1824 was significantly lower, as two of the three volcanic buildings developed within the Timanfaya volcanic field. The collective memory of the previous eruption caused people to alarm, but also allowed for a much more effective management of the crisis by the local authorities (Romero et al. 2015).

The high value of the natural heritage of these places is reflect in the diversity of territorial protection figures, both at regionally and nationally levels, with the intention to ensure their preservation. Part of the territory affected by these two historic volcanic episodes of Lanzarote was declared a National Park in 1974, the third in Spain at that time (Decree 2615/1974), with a reserve area that accounts for almost 90% of the park's surface. The National Park of Timanfaya (PNT) is the only one of the network of Spanish National Parks whose objective is the preservation of geological and geomorphological elements. The PNT can be partially crossed through the El Volcán Route that runs through its interior and allows the observation of its most emblematic volcanic landscapes.

Different sectors or certain volcanic structures of both eruptions are also included in other figures of regional protection (Law 12/1994 of Natural Areas of the Canary Islands, of December 19th), such as the Volcanoes Natural Park, which protects the habitats of lava and lapilli fields of 1730–36; the Protected Landscape of La Geria, whose purpose is the protection of the traditional agrarian landscape developed in the area of greater accumulation of dispersed ash from Timanfaya and historical age of the Canarian Archipelago and which has an undeniable historical, cultural, ethnographic and agricultural value; the Natural Monument of Montañas del Fuego, the main nucleus of the eruption of 1730–1736, and of Los Naturalistas Cave (Law 12/1987, of June 19th), a volcanic tube of lava flows from the eruption of Timanfaya, representative of the insular volcanic caves. In 1993, UNESCO granted the island the classification of Reserve of the Biosphere, also being a Special Protection Area for Birds (1994). All these figures of protection determine that most of the territories occupied by the eruptions of 1730–36 and 1824 are currently protected, except for the lava flows of Timanfaya that went from Mozaga towards Caleta de Famara and Arrecife and the Tao Volcano, highly deteriorated by human activities, corresponding to the first of the three events of 1824 (Fig. 2).

The island of Lanzarote is an international tourist destination, mainly oriented to "sun and beach" tourism, having received a total of 767,768 foreign tourists between January and March 2018 (Centro de Datos, Lanzarote 2018). The Island has been considered a role model as an international tourist destination in the protection of natural heritage (Araña 2013), since it has excellent infrastructures, the Art, Culture and Tourism Centres (CACTS), promoted by the Cabildo of Lanzarote, located in sites of special natural interest, can be used to value and disseminate their Geology. Two of them are in the area covered by the historical eruptions of the island, the Visitor and Interpretation Centre of the Timanfaya National Park and The Art, Culture and Tourism Centre of Montañas del Fuego, located inside the PNT, which is a main focus of tourism, as it can be seen judging by the influx of visitors, about 308,979 between the months of January–March 2018 (Centro de Datos, Lanzarote 2018), being the most visited tourist centre in Lanzarote and

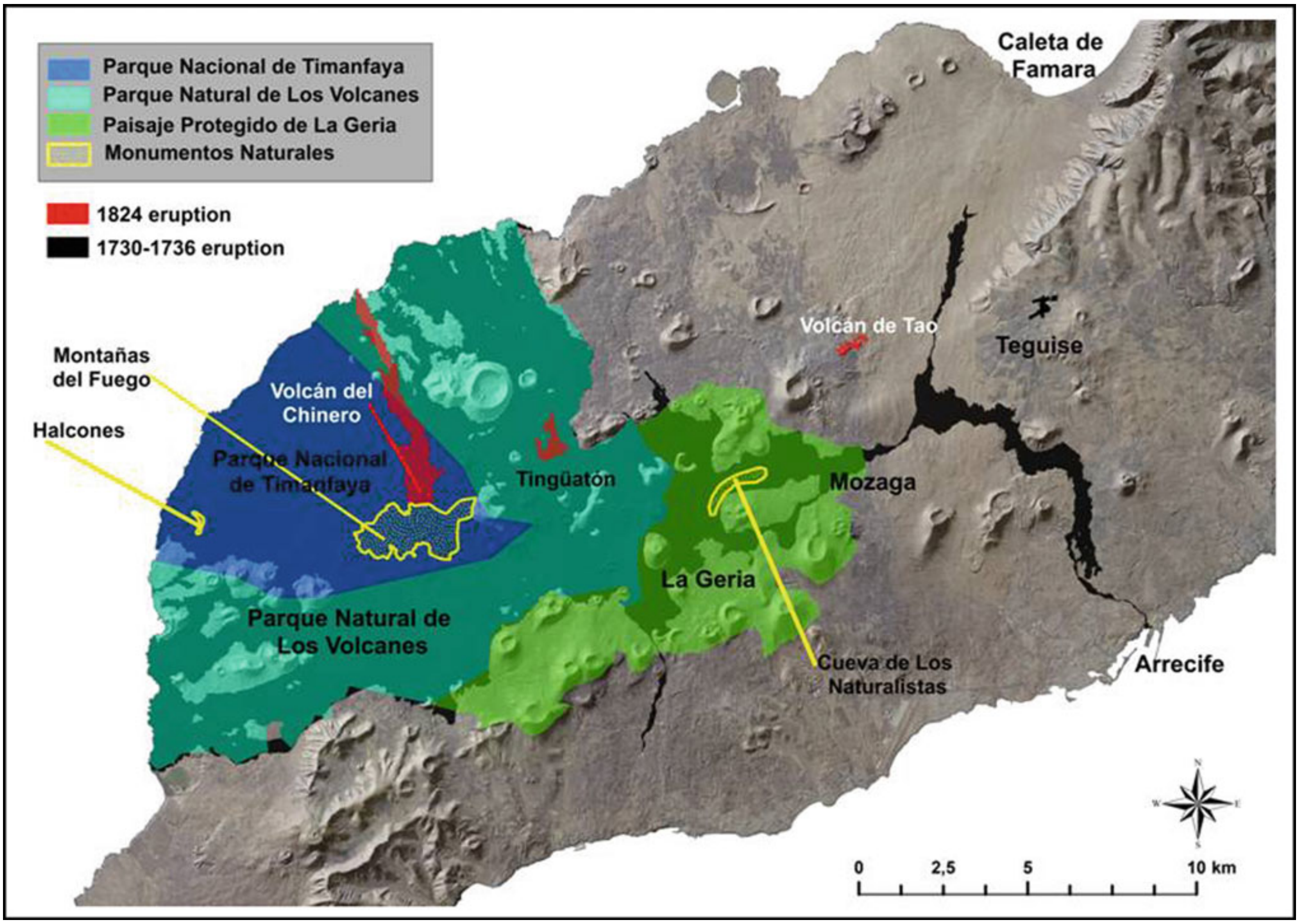


**Fig. 2** Protected natural areas including volcanic materials and structures from the 1730–1736 and 1824 eruptions. Lanzarote Island

practically hosting 40% of foreign visitors on the island. Timanfaya is, therefore, one of the most visited volcanic tourism destinations in Spain and in the world, with more than 1,703,000 visitors a year (Centro de Datos, Lanzarote 2016).

## 3 Geosites in the Historical Volcanism Framework

The historical volcanism framework of the Lanzarote and Chinijo Islands UGG includes 17 geosites (Galindo et al. this volume, Fig. 2) that reflect and exhibit the main aspects associated with the volcanological, geomorphological, chronostratigraphical, petrological and structural features of the eruptions of 1730–1736 and 1824.

These geosites have been grouped into several categories, according to the age of the volcanic manifestations and according to the features of the most outstanding geological elements (Table 1). Thus, of the 17 selected gesoites, 15 correspond to the eruption of Timanfaya and only 2 to the eruption of 1824. On the other hand, 6 geosites are associated with volcanological, morphological, stratigraphic or petrological features of certain isolated volcanic cones; 4 have been selected for the particular way in which some buildings are grouped, with tectonic and structural features; another 4 show the high morphological variability associated with the lava flows; 2 are linked to aspects derived from the dispersion of the ashes during the Timanfaya eruption; and, finally, 1 of them is associated with the presence of superficial thermal anomalies of a residual nature.

The eruptive activity along the set of fractures of the eruptive system of Timanfaya resulted in the construction of cones that, for the most part, appear grouped, overlapping, and at other times as isolated volcanoes, arranged following the structural plot that defines the eruption of 1730–1736. The selection of Geosites within the Lanzarote and the Chinijo Islands UNESCO Global Geopark covers the different eruptive phases, which allows the monitoring through them of the complete chronology of the Timanfaya eruption (Table 2).

It is significant that most geosites in Lanzarote and the Chinijo Islands UGG are located in Timanfaya sectors. But in addition, it should be noted that some of them show traits

**Table 1** Geosites in the areas of the eruptions of 1730–1736 and 1824 in Lanzarote Island

| Eruption | Geological element | Code | Geosite name | Interest | Relevance |
|---|---|---|---|---|---|
| 1730–36 | Isolated cone | LZ28 | Historical volcano of Caldera de Los Cuervos | Volcanic<br>Geomorphological | International |
| | | LZ34 | Historical volcano of Corazoncillo | Volcanic<br>Geomorphological | International |
| | | LZ43 | Historical lava lake and volcanic bombs of Montaña Colorada volcano | Volcanic<br>Geomorphological | International |
| | | LZ31 | Historical volcanic complex of Montaña Rajada | Volcanic<br>Geomorphological | International |
| | Monogenetic volcanic complex | LZ32 | Historical volcanic alignment of Calderas Quemadas | Tectonic<br>Volcanic<br>Geomorphological | International |
| | | LZ26 | Historical volcanic complex and lava channel of Pico Partido-Montaña Señalo | Volcanic<br>Geomorphological<br>Tectonic<br>Petrological | International |
| | | LZ62 | Historical volcanic complex of Macizo del Fuego | Volcanic<br>Geomorphological<br>Tectonic<br>Petrological | International |
| | | LZ33 | Historical spatter cones of Echadero de Los Camellos | Volcanic<br>Geomorphological<br>Tectonic | International |
| | Dispersion pyroclastic deposits | LZ36 | Historical volcanic ashes field of La Geria | Volcanic<br>Geomorphological<br>Estratigraphic | International |
| | | LZ21 | Historical volcano-stratigraphic sequence at Monumento al Campesino | Volcanic<br>Geomorphological<br>Estratigraphic | Regional |
| | Lava flow field | LZ27 | Historical lavas of Timanfaya | Volcanic<br>Geomorphological | International |
| | | LZ56 | Historical hornito of Manto de la Virgen | Volcanic<br>Geomorphological | International |
| | | LZ29 | Historical lava tube of Cueva de Los Naturalistas | Volcanic<br>Geomorphological | International |
| | | LZ30 | Historical lavas at César Manrique Fundation | Volcanic<br>Geomorphological<br>Estratigraphic | International |
| | Kipuka con anomalías térmicas | LZ25 | Historical geothermal manifestations at Islote de Hilario | Volcanic<br>(geotérmico)<br>Geomorphological | International |
| 1824 | Isolated cone | LZ23 | Historical volcano of Chinero | Volcanic<br>Geomorphological | International |
| | | LZ24 | Historical chasms at Tinguatón volcano | Volcanic<br>Geomorphological | International |

that are unique in the world, not including similar examples described in the world scientific literature (for example: “chasms of the devil”, historical chasms at Tinguatón volcano).

Only two of these 17 Geosites (LZ21 and LZ30) are outside the boundaries of the Timanfaya Global Geosite (Fig. 2), although both are part of a tourist reference infrastructure on the island. On the one hand, the Art, Culture and Tourism Centre of Monumento al Campesino, the Cabildo Insular of Lanzarote and, on the other hand, Casa del Volcán of the César Manrique Foundation, both designed by artist César Manrique.

**Table 2** Eruptive phases suggested by Carracedo and Badiola (1991) for the Timanfaya eruption and geosites arranged according to them. Lanzarote and Chinijo Islands UNESCO Global Geopark

| Phase | Eruptive centre | Eruption dates | Geosites |
|---|---|---|---|
| I | Caldera de los Cuervos<br>Pico Partido volcano<br>Caldera de Santa Catalina | 1–19 September<br>10 October 1730–1 January 1731<br>10–31 October 1731 | LZ28, LZ26, LZ27, LZ36 |
| II | Montaña del Señalo | March–June 1731 | LZ26, LZ27, LZ36 |
| III | Volcán el Quemado<br>Rajada Mountain and Caldera Rajada<br>Calderas Quemadas | June? 1731<br>July? 1731<br>December 1731 to January 1732 | LZ27, LZ31, LZ32 |
| IV | Montañas del Fuego | 1732? to 1736? | LZ25, LZ33, LZ56, LZ62 |
| V | Montaña de Las Nueces<br>Montaña Colorada | Early 1733 to 16 April 1736<br>2? April to 16 April 1736 | LZ21, LZ30, LZ27, LZ29, LZ36, LZ43 |

## 3.1 Geosites Associated with Individual Volcanic Cones

Of the almost 30 cones built during the Timanfaya eruption, only ten correspond to isolated buildings. These are small volume volcanoes that fit well within what is currently considered monogenetic volcanism (Németh and Kereszturi 2015), although their volcanic structures and facies may present some complexity. Not all of them, therefore, belong to what Corazzato and Tibaldi (2006) have defined as simple cones. Three of them have been selected, one belonging to the I phase (Caldera de los Cuervos, LZ28), another one to III (Montaña Rajada, LZ34), and another one to V (Montaña Colorada, LZ43). Although its specific formation date is uncertain, following authors such as Hernández-Pacheco (1910), Pallarés (2007) and Romero (2003), we have included in this group of Timanfaya the Corazoncillo volcano (LZ34), considered by Carracedo and Badiola (1991) as a building of dubious assignment to Timanfaya.

### 3.1.1 Caldera de Los Cuervos

The location of the first Timanfaya volcano has been widely controversial, given the imprecision of chronicles that talk about the Timanfaya eruption and the loss of geographical references of the previous areas. Currently, it is considered that the cone generated by the first eruption of Timanfaya, developed between September 1 and 19, 1730, is Caldera de Los Cuervos (LZ28) (Carracedo and Badiola 1991; Carracedo et al. 1992). The location of this and other volcanoes of the I phase of the eruption in a NW–SE direction fracture, with migration of the activity from the SE to the NW, forces us to consider a tectonic scheme in Timanfaya not linked to a single fracture ENE–WSW. Structurally, this explains the existence of volcanic cones isolated and located outside the main fracture of Timanfaya. The materials emitted from this emitting centre are basanites, being representative of the type of magma that characterised the first phases of the eruption (Gómez-Ulla et al. 2017). One of the geological attractions of Caldera de los Cuervos is the abundance of mantle peridotite xenoliths included among the materials emitted by the eruption.

It is a cone of spatter agglutinates, slightly elongated in the E–W direction, about 70 m visible in height, which has been completely surrounded by the lavas of subsequent eruptive phases, so it initially had to be larger in size. This fact explains why the deepest point of its crater is almost 10 m below the apparent base of the cone (Romero 1991a; Kervyn et al. 2012).

The spatters were emitted from a wide and unique crater and accumulated as originally hot liquid pyroclastic, clumping on landing, giving rise to a deposit in which the contour is not always well defined. For some authors (Sumner et al. 2005), these traits are indicative of high temperatures and high emission rates during their placement and are associated with the existence of Hawaiian lava fountains disposed along a fracture of about 350 m in length. In some sectors of the crater's internal slopes, the traces of complete package landslides can be observed along basal spatter layers, which act as a lubricant and gave rise to syn-eruptive collapsing processes inside the crater. The entire lower sector of the north-western inner slopes is covered by a patina of lava that seems to indicate the accumulation of it inside the crater. It was precisely the sudden eviction of this lava pool that caused the partial collapse of the northern wall and its transfer as an erratic block through the lava flows until it was about 200 m from the opening gate (Fig. 3a, b). This block constitutes one of the essential elements that have been considered when placing this cone in the first eruptive phase of Timanfaya (Carracedo and Badiola 1991).

### 3.1.2 Volcán del Corazoncillo

Both the name of the Volcano of the Corazoncillo (LZ34) ("Little Heart", in English) coming from a creeping species of the island's endemic flora (*Lotus lancerottensis*) adapted


**Fig. 3** Overview of Volcán de La Caldera de Los Cuervos (**a** and **b**) and Caldera del Corazoncillo (**c** and **d**). The name *Caldera* (crater) is common in the Canary Islands

to karst landscapes and volcanic ash—, like the spectacular golden mustard shades of its materials—which makes it stand out remarkably on the range of greys, reds and blacks that dominate the landscape—turn this cone into one of the most spectacular, photographed and admired volcano by the visitors of Timanfaya. The perspective from El Volcán Route is spectacular (Fig. 3d).

El Corazoncillo volcano is an annular cone about 113 m high that has a unique vast central crater—nearly 500 m in diameter by 170 m depth—of funnel morphology (Fig. 3c).

The deepest point of this crater is more than 100 m below the outer base of the cone.

It constitutes an apparently Strombolian volcanic cone, whose external slopes are made up of lapilli and ash, while the internal slopes of the crater are rich in spatter agglutinates. The widening and deepening of the Volcán del Corazoncillo crater seems to be due to the existence of highly explosive eruptive phases of strombolian violent or phreatomagmatic. For some authors, the abnormally large size of craters of many volcanic buildings in Lanzarote has been attributed to the widespread occurrence of hydromagmatic activity (Carracedo et al. 1992). Numerous lithic pieces on the backs of nearby Pleistocene islets and their previous name—Fuencaliente, in English hot water springs—(Hernández-Pacheco 1910) seems to show phases of water/magma contact during the eruption.

### 3.1.3 Montaña Colorada

The volcanic set of Montaña Colorada, LZ43, corresponds to the last volcanic building constructed during the eruption of 1730–1736, probably formed in only 15 days (Carracedo 2014). Located in the northeastern end of the fracture, it constitutes an isolated volcanic complex formed by a cone of slag and lapilli of about 110 m high and 700 m of basal diameter, a lapilli field that surrounds the building and a karst landscape, which occupies an approximate surface of 11 $km^2$ and extends towards the NW, NE and S.

The Montaña Colorada volcano is a building of annular features with a circular crater about 300 m in diameter, whose bottom is barely 34 m below its summit. The most outstanding aspect of this cone is the presence of a lava lake solidified inside the crater (Fig. 4b), constituted by lavas of morphology “aa” covered with spatter, and perforated in its central sector by an explosive funnel. There are also large and dense basaltic lava blocks, with diameters between 1 and 6.8 m (Fig. 4a), located at distances of between 500 and 1000 m from the emitting centre (Romero 1991a). During the eruption, the lava lake overflowed several times leading to the initial formation of important pahoehoe type, some of them with obvious clastogenic features, to emit in its final phases more viscous type “aa” lava and generate the appearance of deep annular cracks that led to its partial collapse (Romero 1991a) The cone shows a wide variety of pyroclastic materials, ranging from spatter, slag, lapilli (sometimes with reticulite textures), peridotite xenolites and large blocks. Semple (2001) and Semple and Kobs-Nawotniak (2015) suggest that the formation of the blocks was the result of a transient explosion of the initial lava pool that occupied the vent, with eruptive velocities of the order of 70–100 m/s. The location energy of these large blocks also favoured the formation of small impact craters, visible even in the lapilli field surrounding the volcanic building. An excellent example of the variation of eruptive styles throughout the active period, observed through its deposits, varying from the Hawaiian style, with high and ongoing eruptive rates fed by lava fountains, to more explosive Strombolian styles (Semple and Kobs-Nawotniak (2015), strombolian violent, by self vent shutter, and even phreatomagmatic, by a water/magma contact phase.

### 3.1.4 Montaña Rajada

Montaña Rajada (LZ31) is one of the largest isolated volcanic buildings in the whole eruptive area of Timanfaya (Fig. 4d). With a height of 150 m, the cone is arranged along an ENE–WSW direction fracture of about 600 m in length, which is visible through the alignment of its four craters, and which prolongs the fracture towards the WSW, the main fracture that organises the Calderas Quemadas alignment. It is a spatter cone, slag and lapilli of complex architecture and eruptive history characterised by the succession of phases of differentiated dynamics, with Hawaiian lava fountains and lakes that gave rise to accumulations of spatter and fragmented lavas, and strombolian explosions that built a small slag cone nested in the main crater, eccentric arrangement. There are abundant spheroidal volcanic bombs with xenoliths of sedimentary origin associated to this cone.

On the southwestern flank of the cone, several emission centres open showing morphological variations associated with changes in eruptive behaviour as a function of their relative height. Those located at the highest level are funnel craters of an explosive type, while those located at their base acted as exclusively effusive operating centres. From these basal airs, abundant pahoehoe type lava flows were emitted, giving rise to the formation of a volcanic tube, that conserves its ceiling only in some sections near the cone, and that turns downwards in a channel of lava of 100 m of width and about 10 m of depth until it reached a length of about 3 km (Fig. 4c). It is a channel with important changes in the volume of the flow of drained lava, since from its edges secondary pahoehoe flows were emitted that managed to reach the coast, located more than 6 km from its source.

Montaña Rajada is an excellent example of the spectrum of eruptive processes and changes in eruptive dynamics, both in time and space, produced in many other Timanfaya cones, generated by changes in magma emission and migration activity rates. The possibilities to observe of all these features are excellent because there is a road that runs along its flank, penetrates into the main crater, and ends practically at its top, so that through it you can also get a view of the tube-channel and the associated pahoehoe lava field. It is highly educational, because it can be used to appreciate the complexity that individual monogenetic

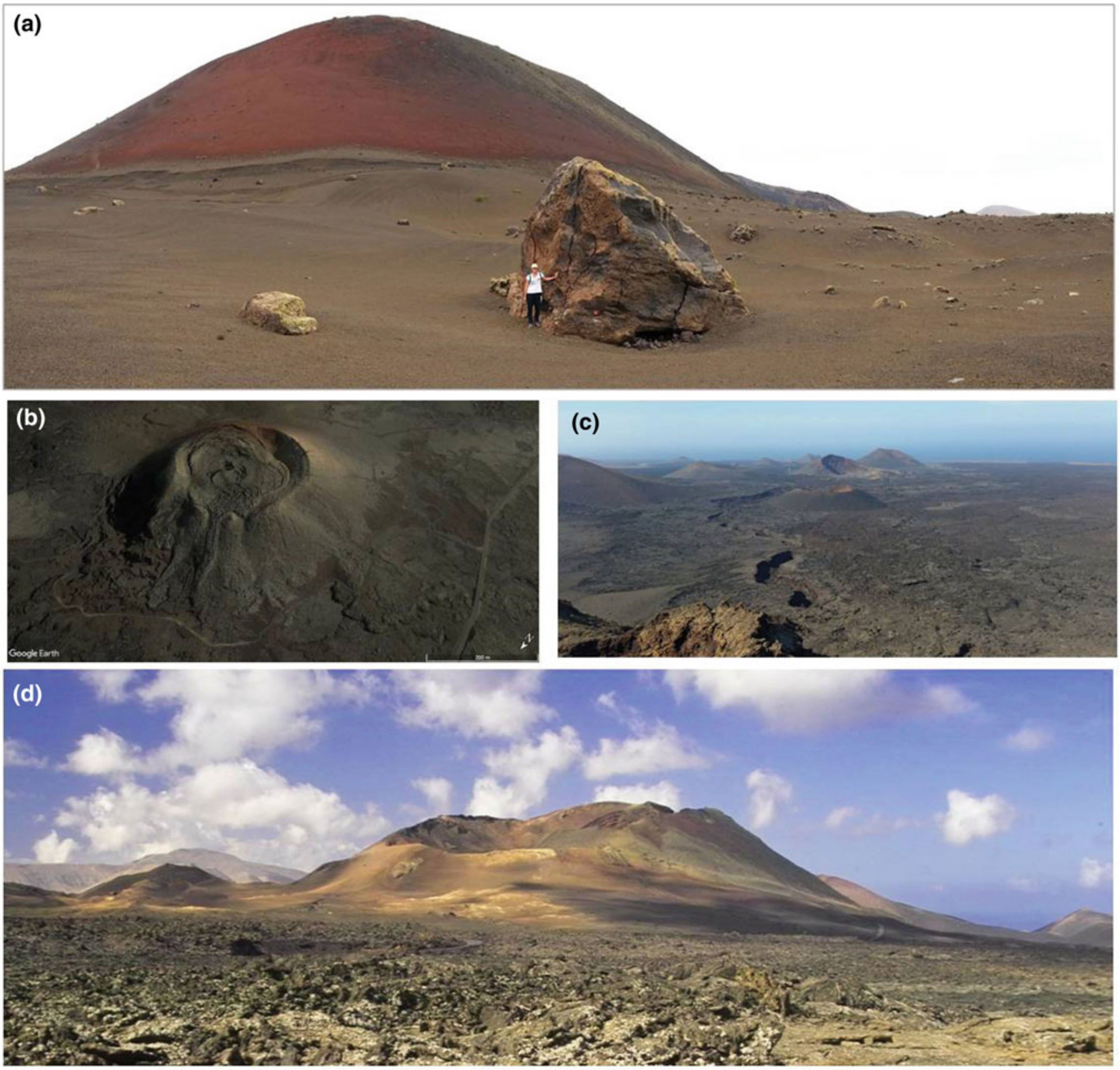

**Fig. 4** Overview of the volcanoes de La Montaña Colorada (**a** and **b**), with the large blocks emitted during its eruption, and lava channel (**c**) and Montaña Rajada cone (**d**). Lanzarote Island

eruptions can have which amount to only one phase of the construction of the entire eruptive system of Timanfaya.

## 3.2 Geosites Associated with GS Monogenetic Volcanic Complexes

The particular mode of association and grouping of the craters and cones that make up the eruptive system of Timanfaya, as well as the morphometric and volcano-tectonic features that characterise them, allow us to establish two different morphological categories that, from less to greater volcano-morphological and structural complexity, are complex alignments and volcanic groupings. The first correspond to small volcanic chains formed from the grouping of several monogenetic buildings around linear fractures. These are very compact and composed of attached cones, imbricated and even overlapping, with no eruptive spacing between them. This type of articulation of volcanoes has been defined as "monogenetic volcanic alignments" (Romero 1991a, 1991b), or as "mixed-type cones" (Corazzato and Tibaldi 2006). The complex volcanic groupings, named by Romero (1991a) as volcanic agglomerations, configure the main scenarios of the Timanfaya eruption, representing the focal points of greater concentration and survival of volcanic activity. They are complex buildings associated to the crossing places of the main volcanic fractures, and where these are arranged forming a relatively dense mesh (Romero 1991a). These are compact eruptive assemblages—the result of the overlap and juxtaposition of cones and craters—, irregular and high. The amalgam of cones and craters is such that only in certain points of these constructions it is possible to individualise some volcanoes and these in no case become available as autonomous elements. These complex buildings were constructed from several dozens of emission points, of clustered arrangement. They have major craters of eminently explosive behaviour and funnel morphology, located in the core of the structure and eruptive mouths and fissures of mixed or effusive behaviour, located at their base and always at lower altitudes than the previous ones (Romero 1991a). From these basal emission centres, the largest surface water flows of all Timanfaya were emitted. Despite their significant morphological complexity, these groups of cones and craters were built in association with a unique feeding system, generated from a deep source that reached the surface through multiple simultaneous eruptive foci. These phases could be separated by short time intervals, but never with the necessary time—established in decades (Connor et al. 1997)—for the solidification of the feeding duct. Therefore, despite its structural and volcano-morphological complexity, this type of architecture can also be considered as a monogenetic construction (Németh et al. 2001).

### 3.2.1 Calderas Quemadas

Among the volcanic groupings of Timanfaya is the alignment of monogenetic volcanoes of Calderas Quemadas (LZ32), 1.5 km in length, following the main direction of the eruptive fracture of 1730–1736 (Fig. 5a). This alignment is formed by four slag cones, with very similar morphometric features, with heights between 40 and 80 m, basal diameters between 300 and 400 m and crater depths between 33 and 65 m. They constitute cones of annular architecture, with one or several funnel-shaped main craters and basal effusive fissures, which are the start of abundant pahoehoe-type lava flows. All of them have deposits made up of lapilli, scoria and spatter agglutinates, and occasionally the presence of abundant volcanic bombs of more than one meter in diameter (Galindo et al. 2013). These deposits appear interwoven with each other, showing the synchronous construction of the different cones, and the overlap in some cases by activity migration along the fracture. The use of a single feeding system allows to define this grouping as monogenetic. The high morphological homogeneity and its marked linear arrangement make this set of cones one of the most representative and expressive landscapes of the Timanfaya fissure eruption. It is also one of the areas of the Timanfaya National Park where there are important geothermal anomalies. An added value is that one of the modules of the Geophysics laboratory of La Casa de Los Volcanes is located in this sector, with numerous instruments for geophysical and geochemical research in the area.

### 3.2.2 Pico Partido Volcano and Montaña del Señalo Volcano

The monogenetic volcanic group complex of Pico Partido-Montaña del Señalo (LZ26) is one of the most active points of the eruptive fissure that articulates the different emission centres of the 1730–36 eruption. It is one of the areas with the highest number of vents per km$^2$ of the entire eruption, with 30 vents in an area of less than 1 km$^2$. It constitutes a compact eruptive group of about 165 m high, formed by the overlap and juxtaposition of cones and craters formed in different phases (Pico Partido in Phase I and Señalo in Phase II). The grouping shows an irregular plant architecture, with an open arc arrangement to the NE that results from the articulation of its eruptive centres around two different fractures, the NW–SE direction that characterised the first phase of the eruption and the ENE–WSW through which the eruptive activity was developed from phase II. The grouping of elements is set up around two juxtaposed and partially overlapping buildings that do not get to form a group as clear and compact as Montañas de Fuego.

Among all the elements of Pico Partido-Montaña del Señalo the magnificent and most spectacular agglomerates of olivine of the Canary Islands stand out, the border of peripheral secondary mouths, through which an important part of the emission of lava flows took place and the spectacular lava channel formed by the drainage of a lava lake (Fig. 5b). This channel is located in a sudden change of slope and shows a sinuous route, with widths between 1 and 10 m, along a 450 m route, that gets lost under the lava flows towards the base of the cone. With a width of between 1 and 10 m, the edges of the channel consist of smooth flows of overflowing pahoehoe sheets and their walls show multiple flow marks that indicate the unstable flow of the lava during their formation. A recent study associates the morphology of this pahoehoe lava channel with the dynamics and rheology of the lava flow, obtaining average flow velocities of approximately 8 ms$^{-1}$ (Woodcock and Harris 2006).

### 3.2.3 Montañas del Fuego

Montañas del Fuego (LZ62) are the most compact volcanic complex of the existing cones in Timanfaya, which rises between 206 and 260 m above the surrounding base level and has a surface area of just over 2.6 km$^2$ (Fig. 5c). This

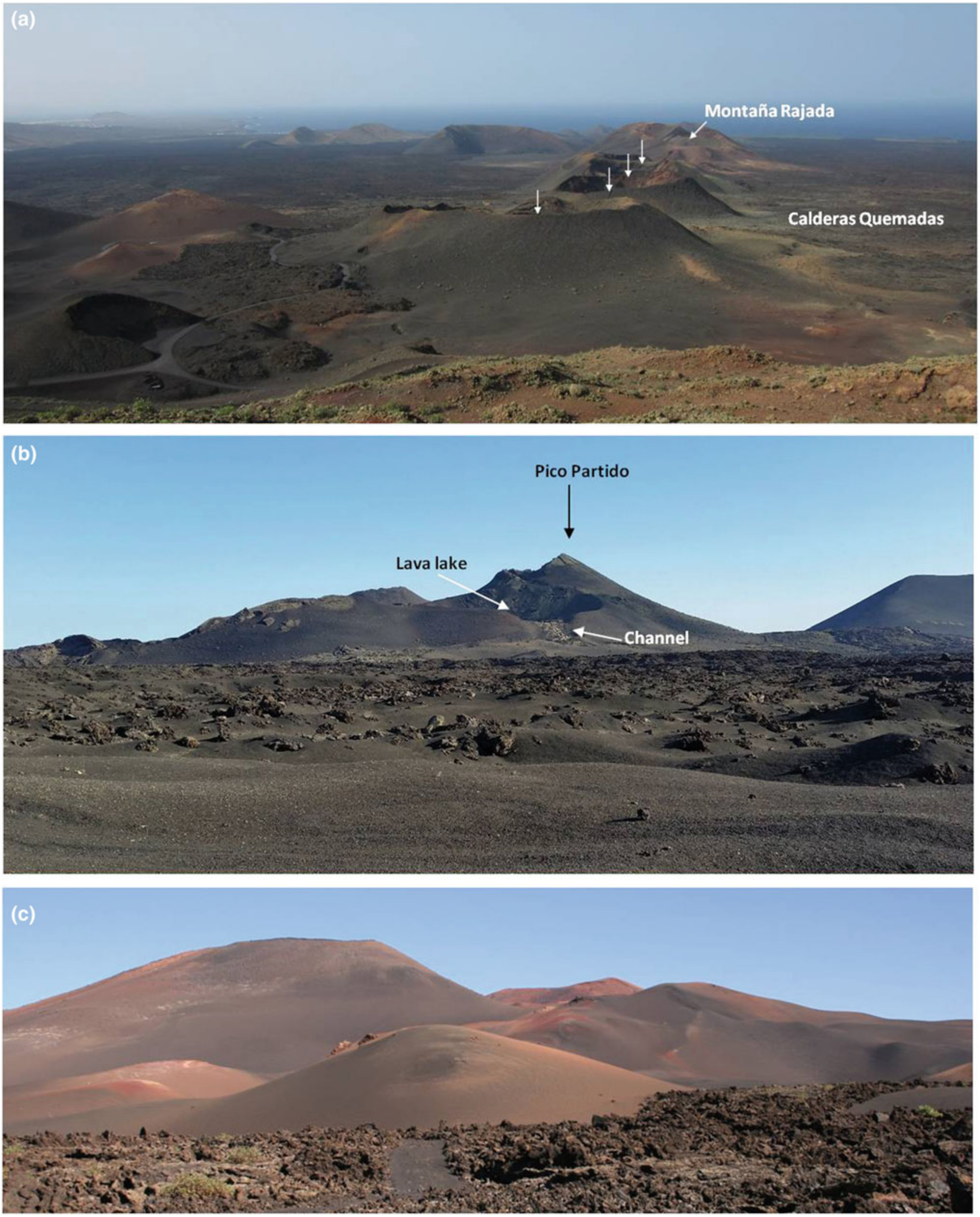


**Fig. 5** Volcanic groupings of the Timanfaya eruption: Calderas Quemadas (**a**), the white arrows mark the main alignment vents. Panoramic view of Pico Partido from the north (**b**), and Montañas del Fuego from the south (**c**)

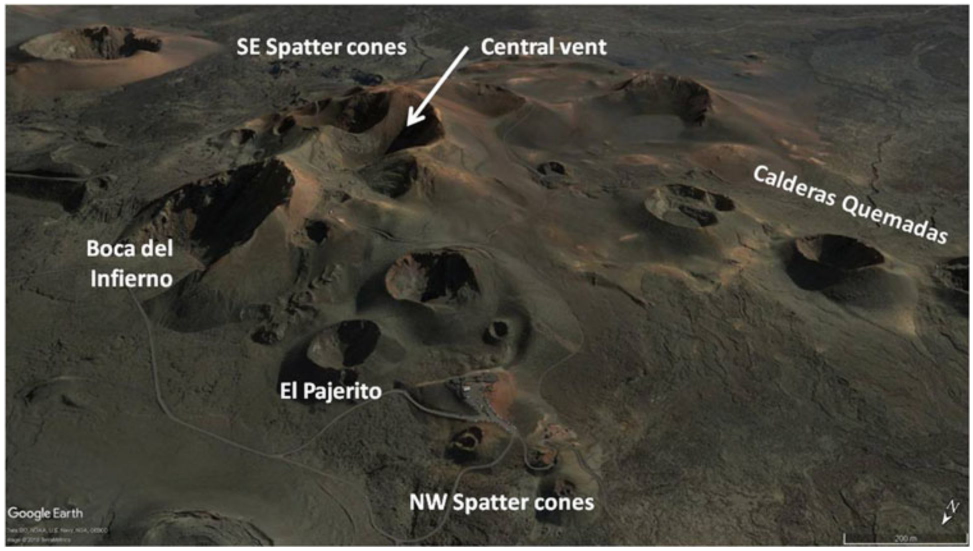


**Fig. 6** Aerial view of Montañas del Fuego volcanoes through a main fissure. Lanzarote Island

sector forms the central core of the Timanfaya eruption, where activity remained concentrated for a longer period of time (Carracedo and Badiola 1991; Romero 1991a, 1991b, 2013; Carracedo 2014), presenting some 20 emission centres per km$^2$.

The emission centres are aligned, both practically perpendicular to the direction of the main eruptive fissure, and directly on it, forming a complex irregular group that goes in two directions. While its central area has wide and deep vents—between 250 and almost 400 m in diameter and more than 130 m deep—towards its periphery it is possible to distinguish some buildings attached or partially imbricated, but which appear as relatively autonomous cones (Fig. 6). That is the case, for example, of the great horseshoe volcano of Boca del Infierno, or the small spatter cone of the Pajerito Volcano. Towards the northwestern and southeastern basal area the group of Montañas del Fuego shows numerous secondary mouths, with abundant pahoehoe type flows. The entire casting of these morphologies that runs along the western lava ramps until reaching the sea has its starting point in one of these sets of secondary mouths and spatter cones, although its downhill drainage is eminently underground (Romero et al. 2008). Over the lava flows, there are also numerous tower-shaped *hornitos*, marking these priority routes of stable underground flows.

One of the most outstanding aspects of this volcanic grouping is the presence of numerous ENE–WSW direction fractures, and less commonly NS, which affect the centre and periphery of the structure and generate breaching of the cones (Tibaldi), crater collapses and occasional fault escarpments. As noted by Corazzato and Tibaldi (2006) in Etna, also in Timanfaya the breaching processes coincide with the weakest sectors of the cones, with the direction of the maximum tension applied to their flanks, by bulging magma or by the propagation of the fracture. The direction fractures ENE–WSW coincide, in Timanfaya, with the main feeding system of the magma throughout the eruption; N–S fractures can be explained considering local control.

### 3.2.4 Echadero de Los Camellos Spatter Cones

At the south-eastern base of Montañas del Fuego, the Spatter Cones of Echadero de Los Camellos (LZ33), constitute a set of smaller, more compact unique constructions, of higher morphological and structural complexity of the Timanfaya eruption (Romero et al. 2007). It is a set that is peripheral to the main core of the eruption of Timanfaya, Montañas de Fuego, linked to the emission of low viscosity magmas and gas content and high temperatures. Formed by spatter agglutinates, these constructions are associated with the formation of very active lava fountains that mark the degassing points of secondary fissures with marked effusive behaviour.

The most striking feature of this grouping of *hornitos* is the existence of a system of fractures of circular tracing that follow WNW–ESE, N–SW and N–S directions. These fractures break the northern back of the spatter cones cluster of the Cachalla Echadero, to the point of generating faults with visible jumps of up to 15 m, giving rise to the formation on the lavas of blocks and slag cones arranged in marked steps that progressively sink to the north. They mark a subsidence sector between the *hornitos* and the south-eastern back of Montañas del Fuego, associated with the massive drainage of lava (Romero et al. 2007).

## 3.3 Geosites Associated with Ash Dispersion Areas

One of the most devastating effects of the long eruption of Timanfaya was caused by the accumulation of ash and lapilli. Although the current tephra accumulations are conserved only in areas close to Timanfaya where the deposits were more powerful, historical records have allowed mapping the sectors covered by ash during the first months of activity (Romero 1991b). The ashes were distributed over a wide area that affected the entire central-eastern sector of the island. At the end of the eruption, the areas covered by the fall of tephra extended from the north of the island of Lanzarote, up to 90 km inland in Fuerteventura (Romero 1991a). A recent study shows that the dispersion pyroclastic layer of Timanfaya affects practically the entire island, and has been trapped, covered by later sedimentary materials, in the valleys that extend south of Famara, in the central area of Los Ajaches and in some sectors near the eastern coast of the centre of the island, so that it can be used as a tephro-chronological control (Criado et al. 2013).

Due to the N–NNE direction and the persistence of the trade winds typical of the island, the preferred area of tephra accumulation is located towards the southeastern sector of the eruptive fissure. The deposits of these zones consist mainly of heterometric deposit sequences, generally with major juveniles and minor lithics and crystals (Galindo et al. 2014). Among the numerous layers of lapilli, we have identified frequent levels with Pele's hairs and tears, indicative of basaltic effusive eruptions of low viscosity and with high emission rates and in sectors located between 6 and 7 km from the nearest Timanfaya vents (Fig. 7b and d). This type of pyroclastic originates by deformation of the lavas in threads during its trajectory in the air and under the effect of the wind. Less frequently, there are also levels of very fine ash and Pyroclastic Density Current (Fig. 7b), which prove the development of much more energetic, phreatomagmatic eruptions (Galindo et al. 2014). These levels of ash could be related to the formation of certain volcanoes from eruptive columns higher than usual in Timanfaya and rich in drops of condensed water, which distributed tephra in the sectors of the north-east and southwestern section of the eruptive fissure. In fact, in the historical records, the formation of this type of columns is commented: "… from its orifices escaping masses of a thick smoke that extends throughout the island, accompanied by a large amount of slag, sand and ash all around, seeing drops of water fall from all areas in the form of rain…" (cronicle by the Priest of Yaiza, in Romero 1997).

In the extensive areas covered by dispersed pyroclasts, two Geosites have been selected, one that includes the best preserved area of preferential accumulation of the pyroclastic, located towards the SW of the main fissure and a stratigraphic sequence with distal pyroclast located in Mozaga, at distances between 8 and 10 km from the vents of phase I.

### 3.3.1 La Geria Historic Volcanic Ash Field

It is the largest field of mafic pyroclast dispersed by wind of all the Canary Islands, in surface and in thickness, since we have measured maximum visible potencies of pyroclasts in situ around 5–6 m in the vicinity of Montaña Diama. However, the pyroclasts have been remobilised after being deposited and their current power is not even, since the maximum powers are located inside the craters of the volcanoes prior to the eruption and in the flatter areas, with averages between 3 and 5 m, on the high slopes of these cones have been practically swept under the wind.

In this extensive lapilli field, one of the most beautiful rural landscapes with the greatest cultural, ethnographic and agricultural value of the Canary Islands is developed (Special Plan for the Protected Landscape of La Geria 2013) (Fig. 7a). Emerged from the 1730–36 eruptions, peasant activity in the area began before the eruption ended, as there are historical references that it was already in operation in the year 1731, with excellent results for the means recorded in that sector in previous stages (Quintana Andrés 2005). The beneficial use of the lapilli layer on agriculture was already known on the island since earlier times, since in 1592 the military engineer for Felipe II, Leonardo Torriani, refers to this use in the north of the island, near Volcán de La Corona (Torriani 1978). The primitive soil cultivated before 1730, was already almost exhausted by overexploitation (Quintana Andrés 2005) and was renewed with the fall of pyroclastic. Taking advantage of the properties of the lapilli, which prevents erosion, retains atmospheric humidity during the night and prevents evapotranspiration during the day, farmers dug holes to find the underlying soil and planted vines, fruit and other products inside it. These holes are currently referred to as gerias (Fig. 7c). To minimise the effect of the wind, so frequent on the island, in the upper part of each geria, stone semicircular walls were built as protective barriers, according to the direction of the prevailing winds (Fig. 7e). Depending on the thickness of the pyroclastic layer, the depths and diameters of each hole change, being larger the greater the thickness of the lapilli. Thus, as the thickness decreases the holes become smaller and smaller, although in counterpart the number per surface increases.

The easy access of La Geria, with a road that crosses it all the way, the imposing perspectives on the volcanic cones of Timanfaya, as well as the existence of numerous restaurants and wine cellars of excellent quality turn this area into one of the of best tourist and gastronomic attractions of all those linked to the eruption of Timanfaya.


**Fig. 7** Protected Landscape of La Geria (**a**). In situ dispersion deposits with ash levels and two lower brown levels containing hair (**b**). Model of the lidar terrain, where the innumerable holes of crops in gerias can be seen (infrastructure of spatial data of the Canary Islands, IDE Canarias) (**c**). Deposits with Pele hair (**d**). Vine crops in gerias (**e**). Lanzarote Island

### 3.3.2 Monumento al Campesino

The historical volcano-stratigraphic sequence of Monumento al Campesino (LZ21) is located inside one of the Tourist Centres of the Cabildo of Lanzarote, conceived in 1968 by César Manrique and dedicated to traditional crafts on the field. Inside the building there is a restaurant where the lava flows distal from the Timanfaya eruption that reached the port of Arrecife, probably around 1733 (Pallarés 2007) have been preserved as decorative elements. In the main dining room, built in an old quarry, the section of a 1.10 m long pahoehoe cast showing the horizontal base of it can be seen. It is worth noting, the exit corridor, whose flat roof is the base of the casting, and where there are several glazed areas that show the existing stratigraphic sequence and make possible the journey through the geological history of this area. The sequence is made up of a wall by Pleistocene pyroclasts, transformed in their upper levels into a brown soil on which the pyroclasts of the Aeolian dispersion of Timanfaya and the subsequent casting of 1733 are supported. The pyroclasts correspond to the 1st phase of the eruption, according to the distribution of tephra obtained from contemporary historical records, and it can be deduced that in this area a layer of about 40 cm is deposited 11 km from the emitting centre.

## 3.4 Geosites Associated with Lava Flows

The "sea of lava" of Timanfaya, in local terms, constitutes an immense desert of black lava that is lost in the horizon from the centre of the island reaching the sea. The historical records refer to 35 hamlets affected by the lavas only during the first 8 months of the eruption (Romero 1991a).

### 3.4.1 Lava Field of Timanfaya

This extensive lava field of Timanfaya lava (LZ27) consists of numerous superimposed and juxtaposed lava flows that extend from the eruptive fissure of 1730 in practically all directions, with maximum lengths of 22 km and visible thicknesses that vary between 1 and 18 m. In some sectors, the lava forms stacks that reach between 30 and 50 m (Ortiz et al. 1986), although data from a survey conducted near the eruptive fissure and that crosses the island to about 2.7 km depth, indicates values of around 37 m (Sánchez-Guzman and Abad 1986).

The spatial configuration of this extensive lava field varies according to the preferred drainage area of the flows and the pre-eruptive topography. Towards the west of the eruptive fissure the lavas, which initially followed the route of some small valleys (Romero 2003), ended up filling them and forming large lava ramps that descend from practically 300 m of altitude to the sea (Fig. 8a). The absence of outstanding topographic obstacles determined the formation of a lava field of great spatial continuity. It is an almost inaccessible sector, in which there is only one path that connects the line of cones with the sea and another one that runs along its coastline, both located inside the PNT.

Towards the east, north and south of the main eruptive fissure, the lava ran confined by the inter-volcanic depressions between the Pleistocene volcanic alignments (Fig. 8b), only partially filling them (Romero 2003). Thus apparent lava arms were formed which, in reality, are constituted by stacks of lava flows, not always belonging to the same eruptive phases. The observation of these last lava flows can be carried out through the multiple roads that cross the central area of the island and that cross the lavas in numerous stretches, all of them cross the interior of the Parque Natural de Los Volcanes and the Protected Landscape of La Geria.

The complexity of the "sea of lava" of Timanfaya Lava Field determines that, although many lava flows appear directly connected to their emission points, most of them are separated from their source areas, by superposition of flows emitted in later stages or by forming castings of extruded fronts and lateral levees.

In this extensive lava field it is possible to observe the full range of surface morphologies associated with pahoehoe and aa lava effusions, with all surface configurations of the transition between both types. For its characterisation, the "morphotype" concept defined by Murcia et al. (2014), which refers to the recognisable and distinctive characteristics of the surface morphology of a lava flow after solidification, and that is used similarly to that of sedimentary facies. In Timanfaya there are flows with the typical configurations of the "pahoehoe" and "aa" lava, although the morphotypes are also the result of the gradual transition between both categories: shelly, hummocky, slabby, rubbly-pahoehoe, platy, cauliflower, rubbly—"aa", lava ball "aa", and blocky (Fig. 9a–d). The study of these morphotypes could give us an idea of the intrinsic and extrinsic parameters of the site, the rheology and the behaviour of dominant flows, as well as its link with other lava structures (Murcia et al. 2014). The pahoehoe morphotypes are predominant around the main eruptive fissure and in the lava arms that travel from the cones of Montaña de Las Nueces and Montaña Colorada through the interior valleys on lands of $<2°$ and go towards the northeast, towards Mozaga, Caleta of Famara and Arrecife; here the scarce slope has favoured the formation by inflation of extensive fields of Sheet pahoehoe lava, with numerous tumuliform structures, micro-tubes and volcanic tubes (Fig. 10). The range of morphologies associated with pahoehoe flows is also wide in

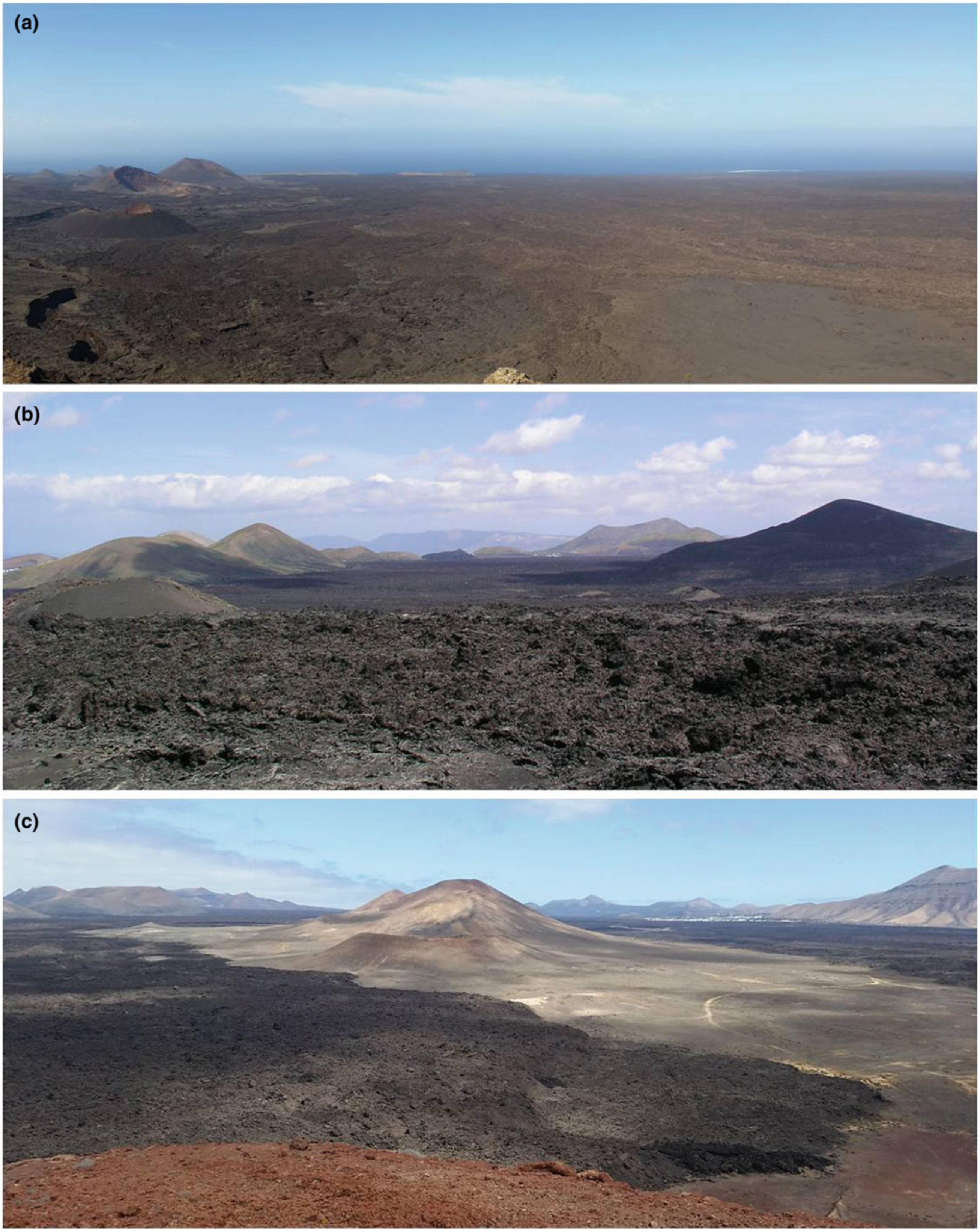


**Fig. 8** Timanfaya lava flows in the extensive lava field. Field of lava of the western ramps (**a**). Lava crossing the depressions of the centre of the island (**b**). Distal lava flows, close to the coast south of Montañas del Fuego (**c**)


**Fig. 9** Typical lava morphotypes in Timanfaya. Morphological changes of pahoehoe lava in Timanfaya (**a**). Slabby pahoehoe (**b**), aa lava flow (**c**) and lava ball (**d**)

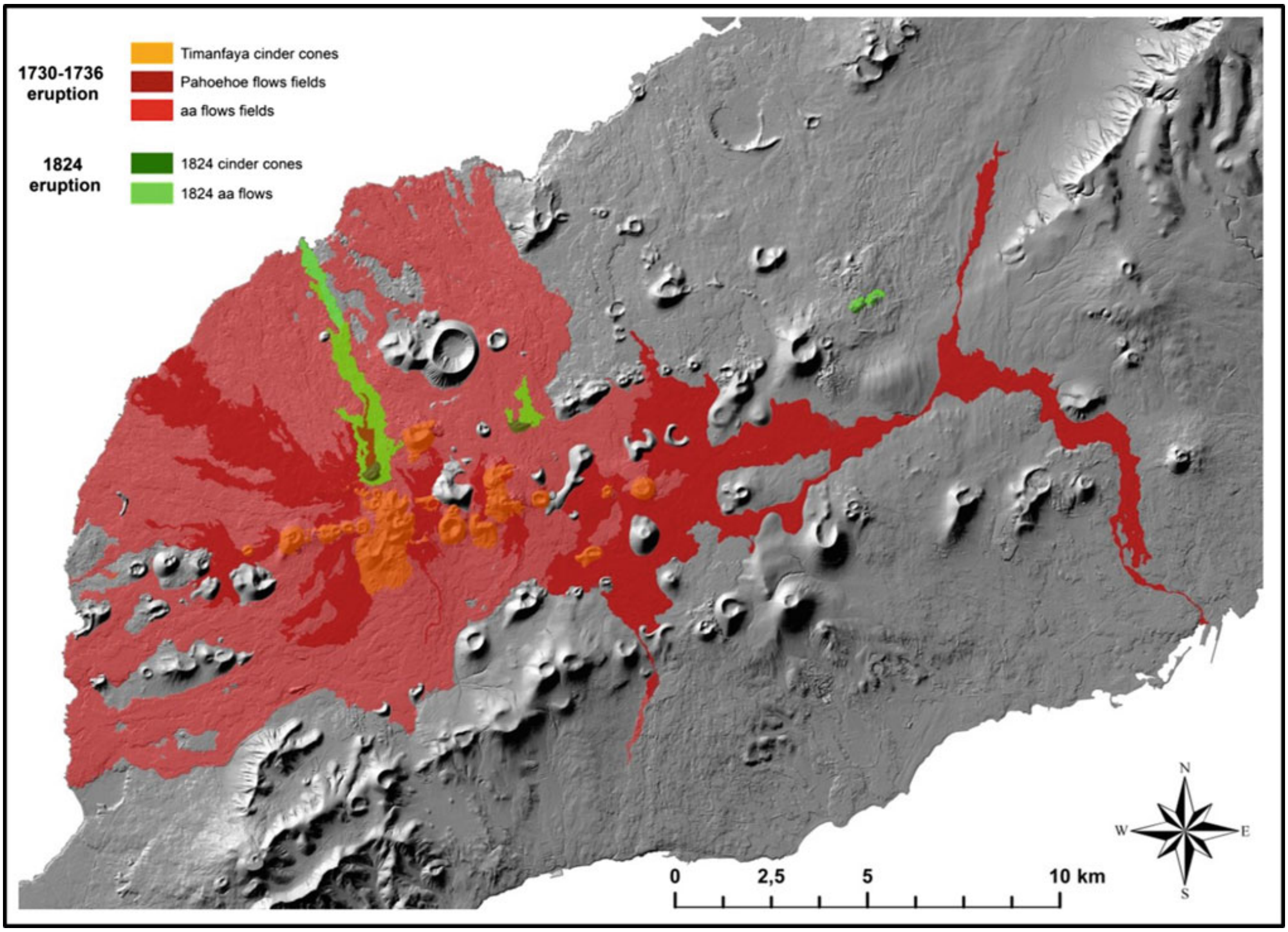


**Fig. 10** Pahoehoe sheet flow and lava flow predominant areas with "aa" direction in the sea of lava of Timanfaya

the central area of the western ramps, where these types of flows develop from the emission centres until reaching the sea.

However, most of the area covered by the 1730–36 lava shows morphologies that move more or less gradually from the pahoehoe to the "aa" as they move towards the sea, being very abundant in distal areas close to the littoral lava ball flows (Figs. 8c and 9d). The roads that cross the centre of the island towards the sea allow an excellent observation and monitoring of these morphological changes.

In these lava fields there are also frequent structures such as lava channels, mounds and mega-tubes, volcanic tubes and microtubes, jameos, lava terraces, lava cascades, rafted mound, erratic block, lateral and frontal levées—initial, accretionary, rubble and overflow levees—, pressure rigges, large acretionary lava ball, and *hornitos*.

The tumular structures that characterise the pahoehoe lava of the western ramps are especially striking. In them it is possible to observe unusually long tumuli, with long axial cracks, which reach between 10 and 12 m wide and up to 400 m long. This type of lava morphologies are not frequent (Walker 1991; Anderson et al. 1999) and are associated with inflation processes produced during the drainage of well-established and topographically confined lava tubes. Its wavy layout coincides with the sinuosity of the underlying lava tube (Orr et al. 2015).

### 3.4.2 Manto de la Virgen

The *hornitos* are equally significant of the dynamics generated during the placement of the lava. They are small structures that never exceed 15 m in height, and are made up of lumps of solidified lava, configuring themselves as small towers of great verticality and open craters, more or less cylindrical, of remarkable depth. The hornito of the Manto de la Virgen, located in the margin of the highway of Ruta de los Volcanes of Timanfaya, is one of the most emblematic buildings of this type in the National Park of Timanfaya. It is a 13 m high *hornito*, formed by degassing processes of underground lava flows. During these emissions, fragments of hot and very hot lava are dragged out and welded together as they fall. This means that it corresponds to a volcanic construction without a root, since it is not directly connected with the magmatic feeding system of the eruption, but with the existence of stable underground drainage pipes.

### 3.4.3 Los Naturalistas Cave

Within the sea of lava of Timanfaya, the Geosites of the volcanic tube of Cueva de Los Naturalistas (LZ29) and the lava of the César Manrique Foundation House Museum stand out for their singularity, good exposure and rarity. Los Naturalistas Cave (LZ29) is a volcanic tube that formed in the pahoehoe castings emitted from Montaña de Las Nueces (Solana et al. 2004), corresponding to the last phases of the Timanfaya eruption. The tube was described for the first time by Hernández-Pacheco (1910) and topographed by Martín and Díaz (1984). It has an approximate NO–SE direction and has an uninterrupted route of about 1640 m in length, although it extends many more metres through "jameos" obstructed by debris but seen on the surface of the lava flows, the underground galleries show elliptical sections with heights of up to 8 m and widths of up to 20 m for which traffic is quite comfortable.

This tube has a high degree of conservation and a wide range of structures characteristic of this type of volcanic caves. Its most outstanding element is the existence of spectacular and delicate stalactites and stalagmites (the best preserved in the Canary Islands), which reach up to 50 and 20 cm respectively, being sometimes connected to each other. The stalactites are tubular elements of between 0.4 and 0.6 mm that in many cases are hollow inside and are formed by lava re-melting inside a tube from temperatures estimated at 1070–1100 °C (Allred and Allred 1998). The gases accumulated inside a tube, and its mixing with external air, can raise the temperature enough to melt the roof rock, which then drips like re-melted lava. These stalactites sometimes appear forming structures of tubular lava drops twisted on themselves, as a consequence of the tensions generated during their consolidation or by the violent currents of hot gases inside the cave (Balázs 1974); this peculiar type of stalactite has received the name of helictitas (Larson 1991) and they are very abundant in Cueva de los Naturalistas. Lava stalagmites are formed by the accumulation of lava drops under lava stalactites. On the side walls of the cave there are morphologies associated with the remelting of the lava, constituted by layers of vitreous bright surfaces, designated as glazes (Larson 1993) and other types of shapes generated by lava dripping as lava runners (Larson 1993). On the wall projections (grooves, cornices, or platforms) the lava runners can end up in agglomerations of lava drops similar to small deltas.

Although the Los Naturalistas Cave is part of a protected landscape and is well preserved as a whole the lack of visitors control has meant that during the past decades, fragile and delicate stalactites and lava stalagmites that covered its roof and its floor have been gradually disappearing. There is barely any trace of them in the galleries of greater access and practically only testimonial elements remain. This has meant the loss of part of its most significant morphological elements and with a very high geological value, since there are no similar morphologies in other volcanic areas of Spain.

### 3.4.4 César Manrique Foundation

The César Manrique Foundation (LZ30) is located in Casa del Volcán, which was built in 1968 in the same lava of the Timanfaya eruption that formed Los Naturalistas Cave, although in distal sectors. It is sheet pahoehoe lava, with a great profusion of small volcanic tubes and spectacular morphologies on the surface. During the construction of the House-Museum, the large underground cavities of the lava, with open ceilings as "jameos", were used, for the construction of rooms connected through tunnels dug into the rock. Although the genesis of these cavities, arranged in the form of large bubbles, is still not well established, it is likely that they were formed by explosive processes produced by the sudden escape of water vapor from the base of the lava flows.

This house was built by artist César Manrique, making the most of the structure and internal morphology of the lava, where the bond between the construction and nature stands out, combining volcano and architecture in a relationship of mutual respect. Originally thought of as the artist's residence, in which he lived for a period of 20 years, it is currently a museum dedicated to the preservation and dissemination of his work that always took into account the geological environment. In fact, this author wrote in 1987: "All my painting is volcanology and geology in its basic foundation".

## 3.5 Geosites Associated with Sectors with Geothermal Anomalies

Timanfaya contains three sectors with marked surface thermal anomalies, most of which have surface temperatures that exceed 100 °C. Timanfaya is considered, therefore, an example of geothermal field HDR (hot dry rock) with very high surface temperatures (Arnoso et al. 2001).

### 3.5.1 Islote de Hilario

Islote de Hilario (LZ25) constitutes a kipuka, surrounded by lava and covered by pyroclastic from the 1730–1736 eruption, where the thermal anomalies reach the highest values of Timanfaya, and in the Canary Islands. The temperatures registered on the surface are around 100–180 °C, and are able to reach more than 600 °C at only 5 m of depth (Carracedo 2014). The source of heat in this area has been modelled as a magmatic intrusion, hypothetically cylindrical, with a radius of 200 ± 100 m, located 4 ± 1 km deep and with a surface temperature of 850 ± 100 °C (Arnoso et al. 2001), corresponding to a residual chamber of the Timanfaya eruption.

The survival of this thermal anomaly has favoured both its traditional use by the inhabitants of the island, as well as its current tourist exploitation. At the top of Islote de Hilario, in 1970, César Manrique designed tourist facilities where the main element is fire, following three basic premises for his work: integration of the work in the volcanic landscape, adequacy of the place for quality tourism respecting the environment and use of a modern artistic aesthetic. It was Manrique's idea and his collaborator's, Jesús Soto, to use the heat of the earth to generate artificial geysers by introducing cold water into soundings, using cracks and crevices to introduce plants and cause their spontaneous combustion, and to build a well of about 6 m deep, which channeled the heat from the foundations of the building to the outside, to be used as a natural furnace. These elements are still used today as a demonstration to tourists of the latent heat existing under the surface of Timanfaya, in an environment of very high aesthetic and scenic qualities. Islote de Hilario has thus become the tourist centre that allows visits to Timanfaya. From here starts a route, Ruta del Volcán, designed to show visitors the most emblematic areas of the eruption, and designed to cause the least visual impact, without damaging the geological structures that are covered. This site is a magnificent example of combine tourist exploitation with the preservation of nature.

## 3.6 Geosites of the 1824 Eruption

Just 80 years after the end of the eruption of Timanfaya, small earthquakes began to be felt on the island, which increased in intensity and frequency, being accompanied during the last days of July 1824 by tremor, underground noises and surface cracks. The eruption began on July 31, 1824, less than 1.5 km from the capital of the island. It ended three months later, on October 24 of that year. There is a complete record of the eruption, carried out as a diary, by Captain D. Ginés de Castro y Alvarez, the person in charge of volcanic crisis management (Romero et al. 2015). While the Tao volcano was located in the northeastern sector of the fissure, outside the Timanfaya influence area, the last two episodes, Chinero and Tinguatón, were located directly on the lava and between the cones created during the Timanfaya eruption.

### 3.6.1 Chinero Volcano

The historic eruption of Chinero, LZ23, corresponds to the second eruptive episode (September 29th–October 5th), located at a distance of about 14 km from the Tao Volcano. The eruption was located in a sector where there was a kipuka of Timanfaya with superficial thermal anomalies, similar to those that currently characterise Islote de Hilario (Romero 1991a). It is the only volcanic entirely magmatic manifestation of this triple eruptive episode and of strombolian dynamics. During this time, the largest volcanic group was built, with sufficient lava to generate flows of lava, which after travelling for 7 km, managed to reach the sea. It constitutes a slag cone 61 m high and slightly elliptical, that adapts to the existence of two craters aligned in ENE–WSW direction.

The cone of an old quarry in the northern sector, whose materials were used for the construction of the Islote de Hilario Restaurant and the Volcanoes Route, currently restored, prevents the morphological features associated with the lava emission point from being established. However, the conservation in this flank of two slag fragments of the back, of arched disposition, facing each other, allows identifying a large horseshoe crater open to the north. In fact, part of this sector of the building was transferred by the flows generating large erratic blocks in the areas near the lava flows. Many of these blocks show spectacular basal patches of very fluid lavas, which indicate their immersion in liquid lava during transport.

The entire southwest arch of the crater is crossed by large cracks that extend from its summit and affect the southern back; part of these large cracks are arranged in arched steps towards the interior of the crater, evidencing its collapse as a result of the drainage of the lava.

The most outstanding element is a winding channel of 6.5 km of route that shows a wide range of surface lava morphologies of pahoehoe type and its transition to castings aa (rubly and slabby pahoehoe, lava ball) (Fig. 11a). Inside and in the erratic blocks it is possible to observe lava marks that indicate changes in the volume of lava drained throughout the active period (Fig. 11b). At the edge of the channel, there are also overflow morphologies caused by sudden changes in the emission rate during the eruption. It is a representative place of the formation of lava channels and the evolution of these over time.

### 3.6.2 Tinguatón Volcano

The Tinguatón volcano is the result of the last event of the triple volcanic eruption of 1824, located directly above the lava flows of 1730–36, in the middle section of the eruptive fissure, between the volcanoes of Tao and Chinero, of which it appears separated 9 and 4 km, respectively.

An exceptional witness of the eruption, the mayor D. Ginés de Castro and Álvarez, at the request of the Regent of the Royal Audience of the Canary Islands, describes in detail the main phenomena occurred throughout the active period in the municipal minutes of the City of Teguise (Romero

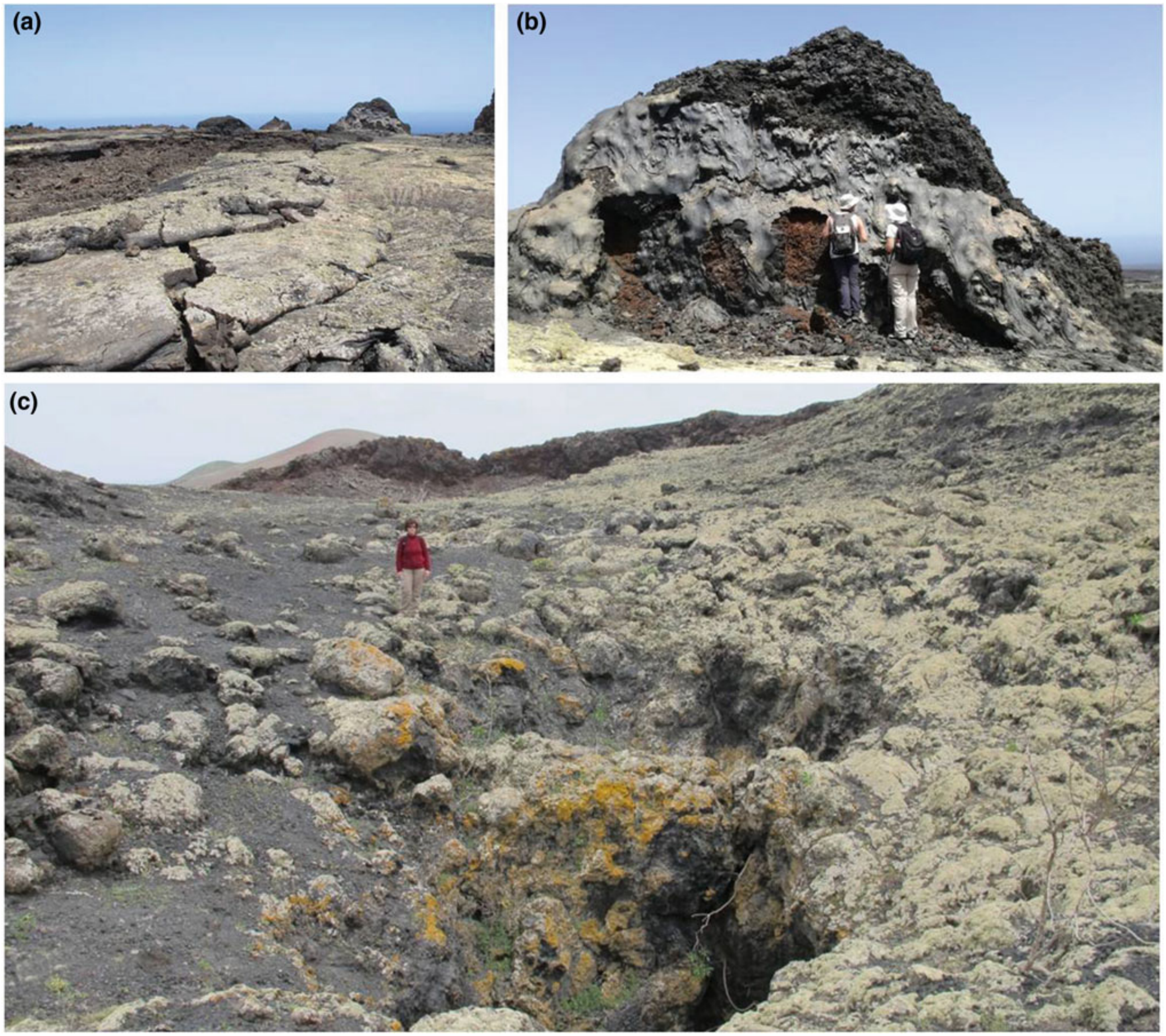


**Fig. 11** Lava channel of the Chinero volcano—second phase of 1824—(**a**), and rafted mound with lava marks located on its edges and in the vicinity of the emitting vent of the eruption (**b**). Simas of the devil of the volcano of Tinguatón (**c**)

et al. 2015). The eruption had two phases of differentiated activity. One of a purely magmatic nature of only one day (16–17 October, 1824), during which a spatter cone with marked fissural features was built, from which three short lava tongues, barely 1, were emitted 2 km maximum length. In the first hours of day 17, eruptive activity decreased and the main crater filled with water; at 11 a.m. was formed "… such a large, thick and terrible column of dense smoke, black and frightful, that by its thickness and elevation is not able to have voices with which to explain it, much less its violence and noise…", indicative of water contact with magma. The water "with a lot of sand and ash… was thrown out in four parts forming four waterfalls…" and resulting in the formation of small ravines on the north side of the cone, the accumulation of water inside the crater so much pressure on the walls of the crater that it managed to open a notch in the north flank of the cone, allowing it to pour impetuously on the castings. However, the most original forms are associated with the emission of water in the form of jets of some tens of metres of height produced between October 18 and 24: "… from the centre of the caldera… you can see those sleeves of water, which they have called sparkles, whose shape is cone-shaped and whose colour is ash… It was a spark that was level with the highest mountain, another one that did not rise so much and left before it went down, a hundred left, while many others came down… and similar to the shape of a cypress, there was a body of water capable of flooding everyone looking…". This process caused the cleaning of the interior of the volcanic chimneys and resulted in the formation of several wells with vertical layout and smooth rock walls, with widths of 9 and 13 m at the outlet and depths between 6 and 99 m (Serrantes and Pena Muiño 2013). They constitute the deepest volcanic chasms of the Canary Islands. There is no eruption in the international scientific literature with an eruptive behaviour similar to that of Tinguatón.

These morphologies are locally called "chasms of the devil", because they are considered the very entrance to hell, and are the result of one of the most curious volcanic processes of historical eruptions (Fig. 11c). The abundant emission of brackish water during the eruption, reveals the existence of not very deep water that explains the development of phreatomagmatic phases of different intensity during the historical eruptions of Lanzarote.

## 4 Worth and Heritage of Timanfaya

The existence of geological elements closely interrelated to each other at different scales (of international, national, regional and local interest) is one of the most significant elements of the Timanfaya volcanic field (Vegas et al. 2015). The high volume emitted during the eruption of Timanfaya and the fact that it was developed in one of the islands of greater geologic antiquity of the Canary Islands and in its most western area, are key elements regarding the origin of the Canary Islands. In fact, Timanfaya is one of the best expressions of historical fissural basaltic volcanism in the Canary Islands. The ubiquity of the recent volcanism in the Canary Islands, as well as the high volume of material emitted during the historical eruptions of Lanzarote, represents one of the inconsistencies of regional geology in the interpretation of the volcanism of the islands as a result of the traditional model of proposed hotspot by Wilson in 1963 (Anguita and Hernán 2000). The majority of the authors locate the Canarian hotspot in the western islands of El Hierro and La Palma (Carracedo et al. 1998), which would not explain the location and volume of material emitted during the Timanfaya eruption in Lanzarote, which is the easternmost island and is located about 500 km away from this supposed location (Anguita and Hernán 2000). This fact has determined the appearance of a new model (Hoernle and Schmincke 1993), "blod type", whose mechanism would allow the development of the Timanfaya eruption, or its explanation by convection in the mantle (King 2007; Gurenko et al. 2010). This eruption is therefore one of the key elements in the definition of a new international hotspot model, of great importance in the genesis of the Canary Islands, and therefore, with a clear interest not only internationally but also locally and internationally.

On the other hand, the wide variety and frequency of olivine xenoliths associated with the emission of materials of a different nature over a relatively short period of time, and in already established chronological sequences, makes Timanfaya a place of petrological and geochemical interest worldwide, because they allow the acquisition of data about the generation mechanisms, the processes of partial melting of the mantle, the transfer and rise of magmas in sectors of oceanic intraplate. Similarly, the abundance of sedimentary xenoliths provides valuable information about the rocks that form the Jurassic crust under the island.

Although, Timanfaya is associated with the existence of a single feeding system, when the eruption is observed in its entirety, the high volume of material emitted throughout the eruption is outside the spectrum of typically monogenetic volcanoes established by Németh et al. (2001). Timanfaya could fit into the category of grouped monogenetic volcanism (Németh et al. 2001). This high volume, anomalous in the historical volcanism, could also be related, to a certain extent, with the phases of activity that characterised the first subaerial stages of construction of the insular shields of the Canary Islands.

At a regional and local level, we must add the high degree of preservation of volcanic forms and products emitted in historical times. Lanzarote shows a semi-arid climate that allows the conservation of volcanic forms without major modifications for extended periods of time. The rocky substrate has a fresh aspect in Timanfaya, characterised by the absence of soils and the presence of a thin vegetable covert, reduced practically to communities of a lichen nature. In these sectors, the presence of forms associated with degradation processes is unimportant and very local, with direct volcanic forms predominating. This fact, linked to the ease of access of the outcrops and the good observation conditions practically throughout the year, has an impact on the excellent quality of the same and allows the development of activities associated with research, education and dissemination throughout the year.

Timanfaya is an exceptional volcanic field, since it constitutes a volcanic territory with a high historical and cultural burden that derives from the history of the eruption itself. It is also an excellent example of the role that volcanism plays as a reorganiser of the geographical space. During the eruption of Timanfaya, the transformations of the original landscape were overwhelming, since both the ash and the lava flows occupied not only extensive area, but were also ongoing, destroying the best agricultural plains of the island. In Lanzarote, the historical volcanism seriously transformed almost a quarter of the island's surface, creating a complete chain of monogenetic volcanoes, from which castings were emitted destroying entire valleys with ashes that rendered large areas useless and extended beyond the limits of the island itself (Romero 1991a). During this eruption there was a radical change of both the natural and human landscape of the island, to the point of transforming the systems of agricultural use (Quintana Andrés 2005), and even power relations and the political and economic role that Lanzarote played at that time in the whole of the Canarian Archipelago (Romero 2003). The impact of these eruptions on the island ecosystem, economy, demography (Quintana Andrés and De León 1997), ethnography, culture and landscape of Lanzarote was very high and radically changed the history of the island. The adaptation of the island society to new living conditions is an example of resilience in the face of the use of the most productive area of the island. Its high natural, cultural, educational and even aesthetic values make Timanfaya one of the unique volcanic territories on a world scale, constituting an exceptionally good example in order to explain the impact, and even management problems, caused by long-lasting fissile monogenetic eruptions.

The identification of geosites associated with historical eruptions outside the limits of the national park (Galindo et al. this volume) is allowing to diversify the places of tourist interest and offer other alternatives of use to those offered by the PNT. Since the creation of the PNT, Timanfaya is one of the most visited places in Lanzarote and in recent years the massive influx of visitors has surpassed the load capacity established in its Master Plan for Use and Management (Perán and Escribano 2005; Szeliánszky 2004).

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# Evaluation of Geoconservation in Geosites of Palaeontological Interest from Lanzarote and Chinijo Islands UNESCO Global Geopark

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**Abstract**

The volcanic origin of Lanzarote and the islets located to the north and their relatively young age does not allow an extensive paleontological record, which does not exceed the upper Miocene (around 7 Ma). However, the fact of being oceanic volcanic islands defines the urgent need to preserve the few paleontological sites that allows us to reconstruct the evolution of the Paleobiodiversity of the Canary archipelago. In this chapter a review of the legal framework that protects the paleontological heritage of the Canary Islands is made, considering the main figures of protection and the management that has been carried out on them up to this moment. In addition, a brief description of the marine and terrestrial geosites of paleontological interest of the UNESCO Global Geopark of Lanzarote and Chinijo Islands is added, emphasizing its state of conservation and the risks of loss that these geosites present.

**Keywords**

Paleontological heritage • Legal framework • Paleontological geosites • Conservation

## 1 Introduction

The paleontological deposits and the fossil record of the Canary Islands are very important information resources because they are testimony of the settlement of the islands by the flora and fauna, and they allow us to know how the process of evolution and extinction of the species has evolved (Castillo et al. 1996). Likewise, the formation of some deposits and the fossils that they contain empowers us to establish how global climate changes have affected the archipelago and its immediate surroundings during the last few million years (Ortiz et al. 2006; Meco et al. 2008). In addition, the stratigraphic relationship of some fossiliferous sedimentary formations with the volcanic formations allows us to reconstruct the main geological events that occurred in the formation of some islands and their evolution (De la Nuez et al. 1998).

In Lanzarote and Chinijo Islands UNESCO Global Geopark, 10 geosites of paleontological interest have been proposed according to their scientific value (Galindo et al. this volume). Some of these fossiliferous sites reflect the global climatic changes that have occurred during the last million years of the planet's history, as it's the case of the changes in sea level, generating fossil beaches or large deposits of wind sands. In other cases, the sites preserve fossils of extinct vertebrate and terrestrial invertebrate species millions or thousands of years ago. In one way or another, the life story of Lanzarote is written in these fossiliferous sites, although, as in many other places, this story is composed of chapters, some of which are incomplete or even deleted.

The need to preserve and protect the "best chapters of the Earth Planet's book" is indisputable among the scientific

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community. However, it is not easy to transmit this concern to the political administrators and managers of the territory, so that the conservation process continues to be parsimonious, due to the lack of specific legislation and the slowness of administrative procedures, delaying in time the declaration as Protected Areas. Meanwhile, important geosites disappear without leaving a trace under urban development, especially in the littoral and coastal zone. This chapter aims to record the state of conservation of the paleontological heritage of Lanzarote and Chinijo Islands UGG, not only of the sites chosen as geosites, but everywhere in general.

## 2 Legal Framework

If we look at the origin and nature of paleontological objects, fossils and deposits, their protection should be framed within the legislation referring to Natural Heritage, since they are natural objects not created by the action of humans. To be strictly correct, the regulations on cultural heritage should only refer to heritage elements that are the result of human activity, and fossils are not (Díaz-Martínez et al. 2013). However, there are some fossil species with undoubted cultural value due to their relationship with human evolution and activity. Therefore, the paleontological heritage should be regarded as a natural heritage, although in some cases it may have cultural interest of an archaeological and/or anthropological nature.

This duality has caused the paleontological heritage to be considered in Spain as part of the historical or cultural heritage, especially when establishing its protection regime (Delvene et al. 2018). Thus, Spanish Historical Heritage Law 13/1985, and several of the subsequent regional laws, considers the Paleontological Heritage as a part of the Archaeological Heritage, with the definition "being part of the Archaeological Heritage the geological and paleontological elements related to the history of the man and his origins and background". However, the inclusion of paleontological assets within the Historical Heritage presents some problems, such as the identification of the same with those objects and activities related exclusively to the action of humans, and not with him as a biological or natural being. This would explain the disparity of criteria (regarding the inclusion or not of the paleontological assets in the Historical Heritage) that can be seen in the different documents or regulations elaborated at the regional level.

The paleontological heritage of a region can be understood as constituted by its fossil record, formed by the set of fossiliferous sites and by the fossils contained in them, or deposited in collections (Castillo et al. 1999; Meléndez and Molina 2001). The regulation of the legal regime for the protection of paleontological goods in the Canary Islands is framed by Law 4/1999, of 15 March, on the Historical Heritage of the Canary Islands, and is the responsibility of the Canary islands Government and subsidiary of the Island Councils. According to this law, the paleontological patrimony of the islands is defined as the set "of movable and immovable assets that contain representative elements of the evolution of living beings, as well as with the geological and paleoenvironmental components of culture. The most relevant goods must be declared of cultural interest or catalogued, according to their value. Sites or places with a fossil record of irreplaceable or exceptional materials related to chronology or paleoenvironment are considered relevant". The protection instruments foreseen are: Register of Assets of Cultural Interest (ACI, BIC in Spanish), Inventory of Movable Property and, specifically, Municipal Paleontological Letters. In the case of paleontological sites declared Assets of Cultural Interest, the figure of Paleontological Zone will be applied (p.e., Matas Blancas Site in Fuerteventura island; Fig. 1a).

The other law, which allows the protection of paleontological deposits, is the Law of Soil and Protected Natural Spaces of Canary Islands (Law 4/2017, of July 13) under the figure of Natural Monuments, among which foundations of protection is the fact of containing paleontological sites of scientific interest, so that the real dimension would be specifically collected. The law does not prohibit the collection and commerce of paleontological remains, so that effective protection is subject to the conservation rules of the different plans of use and management.

Another law to be taken into account in the Canary Islands is the Coastal Law (Law 22/1988, of July 28), since many of the deposits are in the area of public domain that regulates such legislation, 100 m from the low-water line, where it controls the extraction of aggregates and the dumping of debris.

National Law 42/2007, and its modification in Law 33/2015 of Natural Heritage and Biodiversity, comes to develop a series of aspects that have been historically demanded by the community of Spanish paleobiologists and paleontologists. It explicitly states in article 34 that "Natural Monuments will also be considered singular and monumental trees, geological formations, paleontological and mineralogical sites, stratotypes and other geological elements that have a special interest in the singularity or importance of its scientific, cultural or landscape values". However, this state law has not been transposed to the Canarian legislation, so the movable property and paleontological outcrops continue to be part of the Historical Heritage, and its conservation and preservation must be assumed by the current legislation, as it happens in the rest of the autonomous communities with their own historical heritage legislation.


**Fig. 1** **a** Assets of cultural interest of Matas Blancas (Fuerteventura island), outcrop with *Persististrombus latus* shells. **b** Fossil beach between Caleta de Sebo and Playa Franceses (La Graciosa island)

## 3 Management of Paleontological Sites

The management in the Canary Islands of the palaeontological legacy, which derives from its consideration as Historical Heritage, is the responsibility of the General Directorate of Cultural Heritage of the Canary Islands, with some functions transferred to the Island Councils, as representatives of the autonomous administration on each island. Management as a Natural Heritage is the responsibility of the Ministry of Territorial Policy, which delegates to the Island Councils as representatives of the regional administration on each island. On the other hand, the management of movable heritage (fossils) is only contemplated specifically in the legislation on Historical Heritage, while the management of paleontological sites is contemplated in the Historical Heritage law and in that of Natural Areas.

With reference to the first, there are only seven sites declared as an Asset of Cultural Interest between all the islands of the archipelago (Martín-González et al. 2009):

Barranco de los Encantados, La Guirra and Matas Blancas sites in Fuerteventura, Bujero del Silo and Puntallana sites in La Gomera, and Punta Negra and Playa del Búnker sites in Tenerife. In theory, paleontological deposits associated with archaeological sites that are inventoried or in some of the effective protection figures should also be protected, although the reality is different. In 1989 a Catalogue-Inventory of the paleontological sites of the islands was elaborated, financed by Canary Islands government, of which only the ones from the western islands is published: Tenerife, La Palma, La Gomera and El Hierro (García-Talavera et al. 1989). Theoretically it would have been the first step for the effective protection of the same, especially those indicated in this catalogue as very threatened. However, one of the deposits has already disappeared due to the construction of Los Cristianos harbour; there was another declared as an Asset of Cultural Interest, which has now been buried by a seafront, and the others have no conservation norms.

Natural Areas Law of the Canary Islands (currently included in Law 4/2017) declares a total of 114 Protected Natural Areas which, together with four National Parks, form the Natural Areas Network of the region. Out of these, 15 include among their foundations of protection the existence in their interior of paleontological deposits of scientific interest. In all of them, the paleontological deposits form only a small part of the area and of the natural values to be protected. Up to this moment there is no paleontological site collected as such, although the Natural Monument of Ajuy, in Fuerteventura Island, covers the entire surface of the homonymous paleontological site, and the Natural Monument of Los Ajaches (Lanzarote Island) does the same with the paleontological area of Papagayo beach. Regarding the general level of protection that this law provides to the Paleontological Heritage of the Canary Islands, it can be stated that, out of the 49 sites catalogued in the Western Islands by García-Talavera et al. (1989) 38.7% are within a Protected Natural Area. However, out of the 13 sites considered most important by these authors, and in need of immediate protection, only 5 are included as protected areas.

Lanzarote is one of the islands that has a greater and extensive paleontological geoheritage providing us information on the geological and evolutionary history of the archipelago from the Miocene to the Holocene. Aware of this importance, the Lanzarote council, Lanzarote Town Council and Las Palmas de Gran Canaria University, together with the University Foundation of Las Palmas de Gran Canaria, signed a collaboration agreement in 2001, in order to write a report on the paleontological sites of the islands of Lanzarote and La Graciosa, to initiate the procedure of declaration of Asset of Cultural Interest. The result of this analysis was manifested in the initiation of declaration files for ten deposits, almost all of them started in 2003.

For La Graciosa, the largest of the Chinijo Islands, two Assets of Cultural Interest were proposed, the northern fringe from the Llanos de Majapalomas to the Vallichuelo site and the western fringe from the Playa de las Conchas to the Playa de la Cocina sites, including the Baja del Salado. Thus, almost its entire extension is a large paleontological site, where both marine and terrestrial sites arise, with a large number of fossil species. For this reason, it is striking that the deposits of the south coast, where the only two little villages in the island are located, have been left out of the proposed protection area, precisely between the Playa de Franceses and Caleta de Sebo (Fig. 1b), and between this town and Pedro Barba, perhaps the best preserved on the island, and with an extraordinary scientific importance (Castillo et al. 1999, 2002; García-Talavera 2003).

In Lanzarote, the proposed paleontological sites belong to different ages and typologies, both terrestrial and marine. The oldest is the Órzola site, belonging to the Pliocene period, and whose importance we will later develop as a geosite of the UGG. Associated with the volcanic deposits of the I Series of Lanzarote (Coello et al. 1992) is an old coastline located approximately 40–50 m above the current sea level, with an age between four and nine million years, which extends from Punta del Garajao and Punta del Papagayo, on the east coast of the island, to the Salinas del Janubio (Zazo et al. 2002), on the west coast of the island. Of marine origin also, but more recent in the time, is the deposit of La Santa, another paleontological site selected as a geosite.

The remaining sites proposed for its declaration as an Asset of Cultural Interest with the category of Palaeontological Zone (Meco 2003) are terrestrial: Guinate, Timbaiba, Tiagua and Guatisea. The first two have also been included in the Lanzarote and Chinijo Islands Geopark geosites inventory (Galindo et al., this volume). The other two deposits (Tiagua and Guatisea) are palaeodunes formed during the Pleistocene, which are crowned by paleosols, and where there are fossil traces of hymenoptera and terrestrial gastropods shells such as *Hemycicla sarcostoma*, *Theba geminata* or *Rumina decollata*, well known fossil dunes of the Pleistocene and Holocene of the Eastern Canary Islands (Meco et al. 1997).

## 4 Geosites of Paleontological Interest in the Lanzarote and Chinijo Islands UNESCO Global Geopark

The geosites of paleontological interest of the Lanzarote and Chinijo Islands UNESCO Global Geopark can be grouped according to several criteria: age, type of deposit, type of fossils, etc. In this section, to establish an order at the time of describing them, we will group the different geosites in those related to terrestrial deposits, first, and coastal deposits, in second place, making a brief description of each of the sets and their conservation status.

## 4.1 Terrestrial Paleontological Geosites

In this group the deposits of the Miocene-Pliocene paleontological area of Órzola would be integrated, the Pleistocene aeolian dunes of Jable del Medio and Timbaiba, and the palaeosoil of Gayo, and the buried dunes of Lomos de Camacho and San Andrés, although the main value of this last geosite is the geomorphological (Fig. 2).

From all of them, the oldest is that of Órzola site, with three deposits located in Valle Grande, Valle Chico and Fuente de Gusa. The deposits of highly cemented sand dunes (calcarenites) those are stratigraphically located between basaltic lava flows dating from 3.78 to 4.3 Ma (Lomoschitz et al. 2016). In these deposits, fossil remains of large eggs attributed to extinct non-flying land-bird species have been found, which were initially assigned to two groups of ratites: some belonging to the genus *Struthio* and others related to the elephant birds (*Aepyornis*) (Rothe 1964; Sauer and Rothe 1972). Subsequently, another hypothesis was postulated suggesting that they might be large-scale seabirds of the order Odontopterygiformes (García-Talavera 1990). Complete molds and egg fragments of a terrestrial tortoise attributed by Hutterer et al. (1997) to an indeterminate species of the genus *Geochelone*, a group that presents an enormous radiation in the archipelago with four extinct species. Fuente de Gusa outcrop also includes the first known snake fossil of the archipelago, a vertebra of a species of the Boidae family cited by Barahona et al. (1998). In addition, Órzola has been defined as type locality and stratum type of four new species of terrestrial gastropod molluscs (Gittenberger and Ripken 1985) whose specific names derive from Órzola, the northest village in the island (*Pupoides orzolae*, *Theba orzolae*, *Leptaxis orzolae* and *Canariella orzolae*).

The Pleistocene dunes of the Lomos de San Andres and Camacho are covered by volcanic materials from a recent and nearby eruption. These dunes are made up of fine-grained organogenic aeolian sands that in some areas are more than 22 m thick, as is the case of the Jable del

**Fig. 2** Terrestrial geosites of Lanzarote and Chinijo islands UNESCO Global Geopark. **a** Valle Chico (zone Paleontological of Órzola). **b** Fossil dunes in Jable del Medio (Mala). **c** *Rebuffoichnus* fossils in Timbaiba geosite. **d** Land snails in Gayo paleosoil (northern of Lanzarote island)

Medio dunes coming from the dune fields generated by the sands that remained on the platforms of abrasion during regressive stages of sea level. The sands are lightly cemented by carbonates and have structures of crossed stratifications of aeolian type.

In the profile of the dunes different paleosols can be identified that have been analyzed and dated by several authors through the racemization of amino acids and radiometric dates C14 in order to study the palaeoclimatic changes of the Quaternary, fundamentally those that occurred during the last 50,000 years (Ortiz et al. 2006; Yanes et al. 2013). However, thermoluminescence dating has yielded an age of 130,000 years (Bouab 2001), in the case of the dunes of El Jable del Medio.

From the point of view of the fossiliferous content and its conservation, the most relevant geosite is Timbaiba, a volcanic cone of horseshoe morphology, formed during a fissure eruption in the Middle Pleistocene (Romero 2003), and built on a Plio-Pleistocene aeolian palaeodune. One of the most characteristic fossils of this deposit is the thousands of fossil traces in the shape of a thimble of different species of Hymenoptera and Coleoptera of the genus *Rebuffoichnus* (Genise et al 2013), erroneously known as *anthophora* nests. Numerous terrestrial gastropod shells of the species *Hemycicla sarcostoma*, *Theba geminata* or *Rumina decollata* are also found. In addition, bone remains and eggs have appear from the extinct shearwater *Puffinus holei*, a species originally described in southern Fuerteventura (Walker et al. 1990), as well as from the rodent *Malpaisomys insularis* Hutterer et al. (1988), extinct during the Holocene (Rando et al. 2008).

Finally, in the northwest of Lanzarote we find the last site of this group, Gayo, formed by two paleosols. The lower one, which has been dated in 23.5 ka (Yanes et al. 2013), contains abundant fossil shells of terrestrial gastropods (*Hemicycla flavistoma*, *Theba geminata*, *Monilearia monilifera* and the slug *Cryptella canariensis*), one of them new for science belonging to the genere *Theba*. In the upper paleosol, the presence of shell remains of the fossil shearwater *Puffinus holeae* stands out, dating from 2.1 to 2.7 ka, which represents the most recent age for this fossil endemic species, as well as suggesting that its extinction might be associated with the beginning of the aboriginal occupation. The chemical analysis of the composition of the shells of the gastropods reflects changes in climatic conditions during the Pleistocene-Holocene transition, so that about 20 ka climatic conditions might have been more arid, causing the drying of the flora and leading to extinction of the *Theba* species (still to be described), while towards the end of the Holocene there would be more humidity and warmer temperatures.

Regarding their conservation status, Órzola and Timbaiba sites have opened a file for their declaration as an Asset of Cultural Interest in the Paleontological Zone category by the Canary Islands Government since 2004, a statement that even after 14 years it is not firm. In addition, Órzola and Gayo are included in the protected area of the Chinijo Archipelago Natural Park of the Network of Protected Natural Areas of the Canary Islands. In the case of the dunes of Lomos Camacho and San Andrés and Jable del Medio, they are located in areas where quarries for sand extraction are allowed. Thus, they are under a serious risk of deterioration and even disappearance.

The state of conservation of these deposits is uneven, being good in the case of Gayo and Órzola, especially the deposits of Valle Chico and Fuente de Gusa due to the difficulty of access. However, the dunes that are found in the quarries for extracting aggregates from Lomo Camacho and San Andrés and from Jable del Medio, have the risk of disappearing if this activity is not controlled. Finally, in the case of Timbaiba, the dumping of rubble and the possible construction of an automobile circuit are its main problems for its preservation.

## 4.2 Littoral Paleontological Geosites

As with the terrestrial palaeontological geosites, we also find different chronologies, from the Mio-Pliocene deposits of Ajaches and El Valle ravine, to the Upper Pleistocene deposits of La Santa and Piedra Alta (Fig. 3). In the southeast corner of Lanzarote, to the south of the steep reliefs of Los Ajaches and above the current coastal cliffs, there is a wide platform of marine abrasion formed during the upper Miocene, which has an average altitude 40 m asl. A fluvial network of dendritic character has been built over it, in the mouth of which beaches of organogenic sands and climbing dunes have been formed and are very frequented by tourism. In the cliffs the rocks belonging to the Miocene building of Ajaches can be seen (Coello et al. 1992), being frequent the stacks of lava flows separated by paleosols and important unconformities.

On the abrasion platform and in disagreement with the basaltic materials of the Ajaches Formation, dated between 14.5 and 13.5 Ma (Carracedo et al. 2002), a sequence of biogenic sandstones and marine conglomerates with frequent rounded basaltic cobblestones were deposited, outcropping along the coast from Punta de Papagayo to Playa Quemada. According to Zazo et al. (2002) in this area up to 12 transgressive episodes can be identified from 2 to 65 m asl, six of them of Quaternary age and the rest belonging to the Mio-Pliocene. These levels contain fossils of marine species typical of tropical waters (Meco et al. 2007; Martín González et al. 2018), among which the species of gastropod mollusk *Persististrombus coronatus* stands out, together with other species of marked chronostratigraphic interest, such as *Ancilla glandiformis* and *Nerita martiniana*.


**Fig. 3** Marine geosites of Lanzarote and Chinijo islands UNESCO Global Geopark. **a** Fossil beach level in Los Ajaches Paleontological zone. **b** Fossil of marine sedimentary environment in Piedra Alta deposit. **c** La Santa geosite

La Santa paleontological site is formed by fragmented coastal marine deposits (sandstones and cemented gravels) that made up an old coastline and contains abundant fossils characteristic of tropical waters (including the hermatypic coral *Siderastraea radians*) corresponding to the marine isotope stage 5e (MIS5e, approximately 125 ka) (Meco 2003; Muhs et al. 2014). This is the northernmost locality in the Atlantic where this species of coral is located, which marks the climatic change of more pronounced warm character of the Upper Pleistocene, as well as a higher sea level than at present. In addition, there are many fossils of gastropods, bivalves, echinoderms, and rhodoliths that are mostly fragmented, and whose association also corresponds to the presence of tropical waters. Another singularity of this place is La Santa islet, formed by the remains of a basaltic lava flow of cursive type, that is surrounded by beach boulders.

On the west coast of the island, in the area known as Los Charcones, the Piedra Alta deposit, also of Pleistocene age, has been described. It consists in a conglomeratic level with boulders cemented by fossiliferous limestones located at 16–18 m asl, which has been interpreted as a tsunami deposit (Meco 2003). The origin of this tsunami is believed to be related to a mega-slip that had occurred about 480 ka (Muhs et al. 2014). The fossils that can be observed in this deposit correspond to molluscs indicative of the supramareal and intertidal zone, such as those of the genus Cursive and Saccostrea, which appear together with fragments of infralitoral corals (*Madracis pharensis*). There are also circalittoral gastropods in perfect preservation, and other minuscule species. Thus, the deposit displays a mixture of deep species with shallow coastal species, typical of the outcrops produced by high energy events, such as tsunamis.

The geosite of Los Ajaches is declared a Natural Monument by the legislation on protected natural areas of the Canary Islands and is declared as an Important Birds Area (IBA), according to the directive Habitat 79/409/CEE on the conservation of wild birds. Like the Santa, the geosites of the Ajaches platform and the Mio-Pliocene sites that it contains, have a file opened for their declaration as an Asset of Cultural Interest in the Paleontological Zone category since July 2004. On the other hand, the LIG of Barranco del Valle and Piedra Alta are not included in any protection figure.

The figures of protection in Los Ajaches and the difficulty accessing this area, as also happens in the case of Piedra Alta, has successfully contributed to the conservation of both geosites. Unlike it happens in the case of La Santa or Barranco del Valle where the construction of tourist-sports facilities has caused an important deterioration of the paleontological zone and the notorious depletion of the fossils. Another case is that of the Barranco del Valle where the installation of a livestock activity has generated a significant deterioration of the soil due to the continuous passage of the animals and the dumping of waste materials.

## 5 Discussion and Conclusions

The data presented highlights the extraordinary importance of the paleontological geoheritage of the Lanzarote and Chinijo Islands UNESCO Global Geopark, confirming the great diversity of sedimentary deposits and unique fossil sites that make up the basic tools for the reconstruction of the evolutionary history, both biological and geological, of the Canary archipelago. However, the situation of protection for this natural heritage does not seem to be correlated with its scientific, cultural, and social importance, with only ten paleontological sites with the opening of a declaration as an Asset of Cultural Interest under the category of Paleontological Zone that remain open after 10 years, although we are in a volcanic and insular territory, where some sites are the only witnesses of the past.

Despite this small number, these paleontological sites are not even well studied and valued (Martín-González et al. 2009). In the reports or dossiers of proposal for them to be declared as an Asset of Cultural Interest, a patrimonial valuation is needed in greater depth, where reference should be made to the assessment criteria (scientific, educative, cultural or economic) considered to justify the protection of a given deposit although these criteria were already used, even before the entry into force of the current legislation on the Historical Heritage of the Canary Islands. These documents also lack from a section describing the risks of deterioration and the conservation measures that should be developed. In this way, most of the paleontological sites mentioned have a total abandonment, without any type of signaling indicating their status, without peripheral protection zones, or, more seriously, they are affected by the dumping of rubbish and debris, tourist constructions, recreational activities, depletion, etc.

Lanzarote has a population density of 172 inhabitants/km$^2$ distributed unequally in its almost 846 km$^2$. Thus, for example, as in most of our planet, the greatest concentration occurs on the coast, with some tourist centres having been massively developed in the last 30 years. This has caused important urban pressure resulting in the disappearance of some coastal deposits, as it is the case of El Berrugo site in the town of Playa Blanca, close to the Palaeontological Zone of Los Ajaches. This site has been studied by several specialists constituting one of the best examples of the Upper Pleistocene of the eastern islands (Meco 2003). The same end can happen in the case of La Santa site, if it continues with its urban development, and indirectly, from the fossil dune deposits by the extraction of aggregates necessary for the construction of tourist developments and the annexed infrastructures. The choice of some of the paleontological geosites of the Lanzarote and Chinijo Islands UNESCO Global Geopark as geosites will undoubtedly contribute to improve their state of conservation and, at the same time, may serve as a revulsive for their better knowledge.

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# Geoheritage in the Shallow Submarine Slopes of an Oceanic Volcanic Edifice: A New Option for Diving Geotourism

Inés Galindo, Carmen Romero, Miguel Llorente, Juan C. Rubio, Gonzalo A. Díaz, Nieves Sánchez, Esther Martín-González, José Mangas, and Juana Vegas

**Abstract**

Volcanic oceanic islands are large buildings that grow from the ocean floor up to their highest peaks above sea level. It is estimated that only a small part of the volcanic edifices emerge above sea level, leaving almost 90% of the volcanic structure submerged. The geology of this submerged area is mainly known from indirect geophysical studies, general and detail mapping, bathymetry, and some drill holes and different types of dredges and humanned–unhumanned submersibles. However, this information is quite poor for geoheritage studies since it does not allow a geological classification of the environment, their genesis and geoheritage value. Hence, direct observation in inner platform and coastal zones has become essential to identify submerged geological structures, rocks, sediments, pyroclastic deposits and morphologies that could be considered as part of a geoheritage inventory. In fact, underwater there are unique and representative geological elements, which in many cases are visited by divers who do not know their significance and value, since their main objective is to observe the fauna and submarine scenery. Therefore, the identification and enhancement of underwater shallow geological heritage is crucial for the development of one of the emerging resources, underwater and diving geotourism. This study contributes to the knowledge of the shallow submarine geology of Lanzarote and Chinijo Islands UNESCO Global Geopark and highlights the existence of fifteen geosites suitable for the implementation of sustainable submarine geotourism.

**Keywords**

Submarine geoheritage • Diving • Volcanism • Geomorphology • Geotourism

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## 1 Introduction

Marine geology has been widely developed since the scientific expedition carried out by the ship HMS Challenger between 1872 and 1876, whose mission was to collect oceanographic data on currents, marine life, temperature, marine chemistry and the geology of the seafloor (Corfield 2003). Since then, the technology associated with the study of underwater geology has greatly advanced, resulting in achieving a better knowledge of the marine environment.


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Nowadays, marine geology can be studied using direct methods, which allow us to obtain information from the observation and analysis of outcrops, and indirect methods, which interpret geology based on geophysical data from geodetic, gravimetric, seismic, magnetic and acoustic studies.

The geology of the submarine platform and talus of Lanzarote and Chinijo Islands UNESCO Global Geopark (UGG) is mainly known through indirect studies. The first research about the submerged part of Lanzarote tried to explain the structure of the crust under the island (Banda et al. 1981). Subsequently, obtaining bathymetries of the submarine flanks of Lanzarote Island have allowed the study of large landslides (Acosta 2003; Acosta et al. 2003; Martín Serrano 2005; Cuñarro et al. 2014). In 2005, the geomorphological map of Spain and the continental margin was published at a scale of 1:1,000,000 (Martín Serrano 2005), including Lanzarote along with all other islands of the Canary Archipelago. More recently, the interpretation of the bathymetry from a geological and/or geomorphological point of view has allowed the study of the volcanic tube extension of La Corona under the sea (Carracedo et al. 2003; Martínez et al. 2016), the geomorphological map of the submarine flanks at scale 1:25,000, the Quaternary Map which includes volcanic lava flows under the sea, or the discovery of a submerged volcano near the coast of Famara (Martín et al. 2014, 2015). All of them are excellent examples concerning the knowledge of this UGG's marine geology. In addition, the identification of submarine volcanic cones and alignments has also been carried out in order to estimate the volcanic susceptibility of the insular edifice (Galindo et al. 2016) and a brief description of the preliminary results of the submarine geosites has been recently published (Galindo et al. 2017). On the other hand, there is information about the underwater landscape of Lanzarote in the dive guide of the Lanzarote Man and Biosphere Reserve (Boyra et al. 2011) and from the Chinijo Islands (Ministerio de Agricultura, Pesca y Alimentación 2003).

In this paper we review the shallow submarine geology of Lanzarote and Chinijo Islands UGG and go into detail about the awareness of the geology of both, partially or completely submerged, geosites, with the aim of improving this knowledge. In addition, we explore the possibilities of launching out a tourist package of submarine geology that includes new scientific information for the public use value on the underwater geology and landscapes of these volcanic oceanic islands and, at the same time, upgrading the tourist experience in the UGG.

## 2 Underwater Shallow Geosites of the Lanzarote and Chinijo Islands UGG

The submarine geological attractions of this UGG could include 8 underwater geosites and 10 littoral geosites defined in the inventory (Galindo et al. in this volume) that are partially submerged (Fig. 1, Table 1). These geosites are suitable for subaquatic activities such as snorkeling, scuba diving, submarine scooter tours or even excursions in a touristic submarine. These geosites are located mainly in Lanzarote (11), but also in La Graciosa (3), Alegranza (2), Montaña Clara (1) and Roque del Este (1) islets. Below we describe the selected geosites with regard to their main geological interest.

### 2.1 Geosites of Volcanological Interest

Most of the selected underwater geosites are mainly of volcanological interest (39%). These geosites are representative of Miocene to Quaternary hydromagmatic and magmatic eruptions, as well as of the emplacement of lava flows in subaerial and submerged environments. It also includes magmatic intrusion processes in the deep part of a shield volcano and in the shallow environment of a monogenetic volcanic edifice.

#### 2.1.1 Montaña Amarilla (Geosite GR03)

Montaña Amarilla is a Pleistocene volcanic edifice with underwater hydromagmatic facies at the base and Strombolian materials on the top. It is located in the southeast tip of La Graciosa (Fig. 1). Sea erosion along with the coastal and aeolic dynamic have given place to the formation of a small sandy bay. The geosite includes the subaerial volcanic edifice as well as its prolongation under the sea where cinerite and lapilli tuff of intense yellow colour, laminated and banded, are of spectacular beauty (Fig. 2a). Pyroclastic surges and structures typical of Surtseyan eruptions such as slumps, parallel lamination, cross-bedding, deformation structures, volcanic bombs or accretionary lapilli can be observed. This geosite presents a large diversity of geological processes and morphologies where, besides the deposits of hydromagmatic origin, it can be observed other types of rocks and structures, such as a lava which reached the sea and spread in subaquatic conditions forming pillow lavas, a littoral platform, cliffs, beach-rocks, aeolianites, necks, tafoni, rockfalls, arches, etc. Furthermore, sedimentary

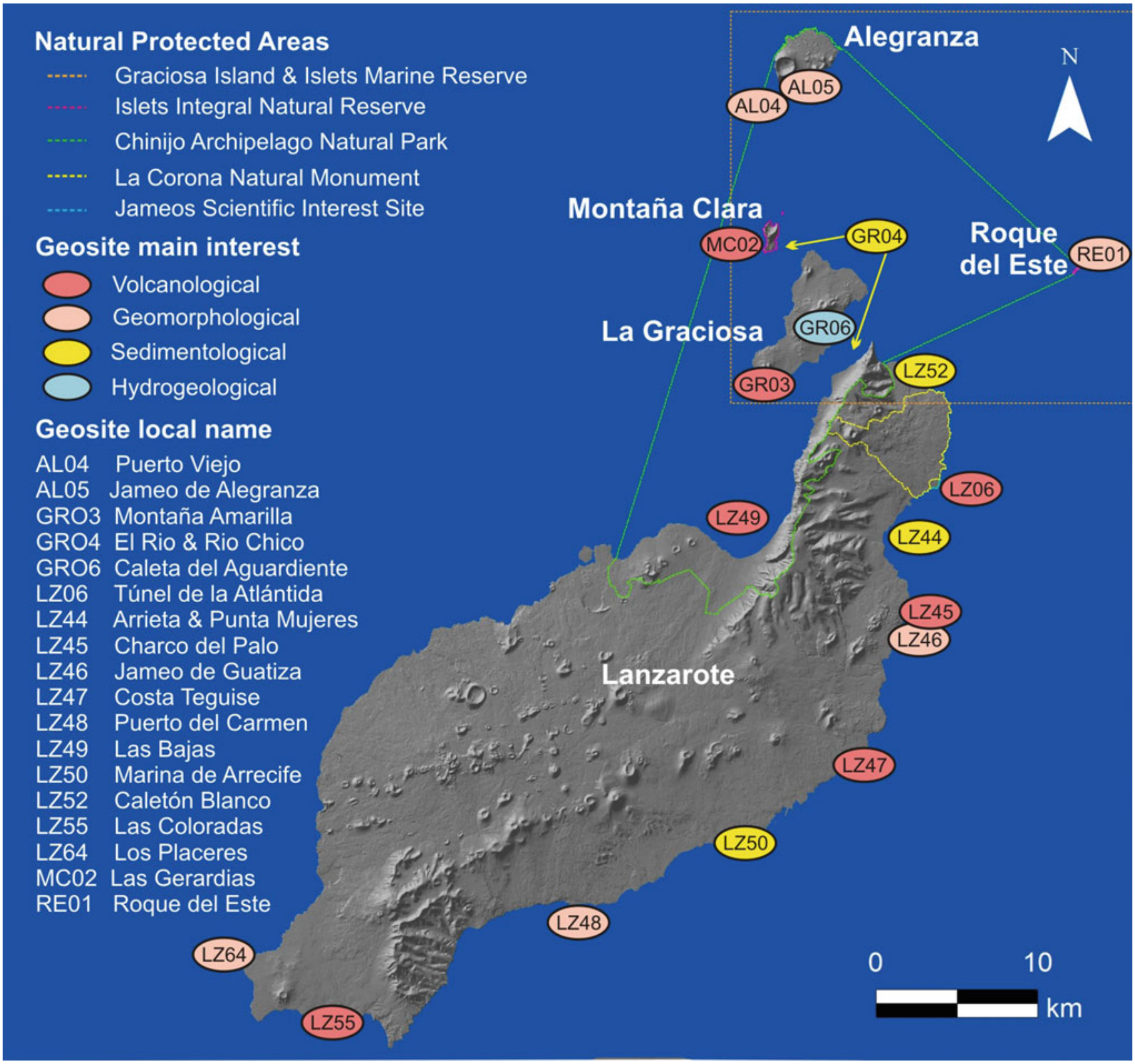


**Fig. 1** Location of marine geosites in Lanzarote and Chinijo Islands UGG. Natural protected areas are also indicated

structures can be observed such as current ripples visible from backshore to offshore. This geosite is of volcanological interest, since it relevance allows us to understand the construction process of a volcano with water-magma in a coastal environment. However, it is also an example of the exogenous processes (erosion and sedimentation) complexity in volcanic islands' coasts. The potential of coastal and submarine tourism in this area is already being exploited since it is a very calm bay, so it would only require to facilitate tourists with the geological interpretation of the submarine and subaerial landscapes. This geosite is part of the Graciosa Island and Islets Marine Reserve (GIIMR) and the Chinijo Archipelago Natural Park (CANP). Thus, it is necessary a permit for scuba diving activities, but no for snorkelling in the beach area.

### 2.1.2 Las Bajas (Geosite LZ49)

The volcano and the issued lava flows named *Las Bajas* are also located in the CANP (Fig. 1), to the northwest of Lanzarote Island, close to the Famara beach surroundings ca. 700 m far from the present coastline. The volcanic edifice and the lava flows are undersea except for some remnants of the summit that still resist the onslaught of the waves, tides and currents. A geomorphological study (Martín et al. 2014,

**Table 1** General aspects of underwater geosites in Lanzarote and Chinijo Islands UGG

| Main geological interest | Id | Local name | Description | NPA | Touristic activities | Scuba diving restrictions |
|---|---|---|---|---|---|---|
| Volcanological | GR03[a] | Montaña Amarilla | Hydrovolcanic pyroclastic deposits | MR, NP | Snorkling Scuba diving | Needs authorisation |
| | LZ49 | Las Bajas | Submerged strombolian volcano and lava flows | NP | Scuba diving | Needs authorisation |
| | LZ06[a] | Túnel de La Atlántida | Submerged lava tube | NM, SIS | Only scientific activities | Forbidden |
| | LZ45 | Charco del Palo | Collapsed lava delta | | Scuba diving | No |
| | LZ47 | Costa Teguise | Eroded lava delta | | Scuba diving | No |
| | LZ55[a] | El Rubicón | Dikes cutting the old shield volcano | | Snorkling Scuba diving | No |
| | MC02 | Las Gerardias | Feeder dikes as habitat for corals | MR, NP | Only scientific activities | Forbidden |
| Geomorphological | LZ64[a] | Los Placeres | Actual littoral platform and erosive morphologies | | Snorkling | No |
| | LZ48 | Puerto del Carmen | Littoral morphologies in a submerged lava flow | | Snorkling Scuba diving | No |
| | LZ46[a] | Jameo de Guatiza | Littoral cave excavated in a lava flow | | Snorkling Scuba diving | No |
| | AL05[a] | Jameo de Alegranza | Partially submerged littoral cave excavated though a fracture | MR, NP | Snorkling Scuba diving | Needs authorization |
| | RE01[a] | Roque del Este | Submerged littoral tunnel excavated in pyroclastic hydromagmatic deposits following a dike wall | MR, NP, INR | Only scientific activities | Forbidden |
| | AL04 | Puerto Viejo | Submerged ravines and littoral erosive morphologies | MR, NP | Scuba diving | Needs authorisation |
| Sedimentological | LZ44 | Arrieta and Punta Mujeres | Unconsolidated sandstones | MR | Snorkling Scuba diving | Needs authorisation |
| | LZ52[a] | Caletón Blanco | Sand dunes over pahoehoe lava flows | MR | Snorkling Scuba diving | Needs authorisation |
| | GR04 | El Rio and Rio de Montaña Clara | Submerged remnant of tombolos and sand bars | MR, NP | Scuba diving | El Rio: needs authorisation. Rio de Montaña Clara: forbidden |
| | LZ50[a] | Marina de Arrecife | Beach rock and actual beach over an eroded submerged lava flow | | Snorkling Scuba diving | No |
| Hydro-geological | GR06[a] | Caleta del Aguardiente | Intermareal water spring | MR, NP | Snorkling Scuba diving | Needs authorisation |

[a]Partially submerged; NPA: Natural Protected Areas (data from http://www.gobiernodecanarias.org/politicaterritorial/temas/espaciosnaturales/informacion/lanzarote/); MR: Marine Reserve; INR: Integral Natural Reserve; NP: Natural Park; NM: Natural Monument; SIS: Scientific Interest Site


**Fig. 2** **a** Parallel stratification of submarine hydromagmatic pyroclastic deposits in *Montaña Amarilla*; **b** Subaerial remnants (basaltic dike and pyroclastic deposits) of the submerged Las Bajas volcano. Famara cliff in the background; **c** Entrance to the *Túnel de la Atlántida* lava tube at the *Jameos del Agua* tourist centre

2015) reveals an elliptical cone with a maximum axis trending NE–SW and an abrasion platform at the summit area. From the cone, two lava flows were issued to the northwest displaying typical subaerial morphologies like pressure ridges and a lava channel flanked by 1 km long levees. A submarine survey showed that the subaerial outcrops are made of welded basaltic pyroclasts and feeder dikes (Fig. 2b). The present submarine lava flows were formed in a subaerial environment, as there are no pillow structures or associated hyaloclastites in the lava flows suggesting that this volcano was formed at surface and, possibly, during the Last Glacial Maximum (Upper Pleistocene), and it was later partially submerged during the Holocene. Probably, the upper part was eroded, since what is seen over sea level is the core of a cinder cone. Thus, this geosite has a palaeoclimatological and volcanological interest. This zone is usually dangerous for diving and recreational activities due to the presence of strong currents.

### 2.1.3 Túnel de La Atlántida (Geosite LZ06)

21,000 years BP, when sea level was almost 110 m below the current levels (Last Glaciar Stage), La Corona volcano's eruption took place (Carracedo et al. 2003) in the northern side of Lanzarote (Fig. 1). During this eruption, large amounts of highly fluid lava flows were ejected where a huge volcanic tube was developed, of more than 7.8 km in length (1.7 km submerged), along with a series of smaller tubes at different levels and variable diameters, between 2 and 30 m (Martínez et al. 2016). From them on, sea level has risen leaving one part of this tube underwater (Carracedo et al. 2003), which is known as the Atlántida Tunnel. Thus, inside the submerged section, besides the typical structures of a volcanic tube (cornices, terraces, lava staphylites and drops and other lava morphologies), a 20 m high sand dune can be seen formed by the entry of sediments in the cave and carbonate precipitations, for instance, calcite and sulphate like gypsum (Martínez et al. 2016). The main interest of this geosite is volcanological. However, it has important geomorphologic and palaeoclimatic implications too. One of the entrances to the Atlátida Tunnel is located in the eastern end of the tourist centre of Los Jameos del Agua (Fig. 2c), in the surroundings of La Corona Natural Monument. Owing to the fragility of the tube fauna, it was declared Site of Scientific Interest (Los Jameos Scientific Interest Site), so access is limited to scientific expeditions upon request for permission.

### 2.1.4 Charco Del Palo (Geosite LZ45)

The basaltic lavas from the Holocene eruption of La Caldera de Guatiza, in the NE of the island, form a progressive lava delta (Fig. 1), which rest on an aeolanite field from the Upper Pleistocene. These lava flows display typical structures formed close to the coastline so on the surface they have ropy flow structure, whereas in cross section columnar and radial joints can be seen (Fig. 3a). The surface of the lava is in some areas covered with boulders fields, and the deeper it gets, morphologies probably related to hyaloclastites and pillow lavas can be observed. In the distal zone, lavas are dipping almost horizontally, increasing up to 20° towards the upper side of the deposits. The most brecciated zones of the lava flows have been eroded, giving place to arches, caves, tunnels, columns, etc. Some of the tunnels have collapsed, whereas others are very well preserved. In some areas, open fractures can be observed, of up to 2 m wide, trending roughly parallel to the current coastline. Something that could be related to the instability processes of the lava deltas, usually culminating in the collapse of the most distal zone. Among the lavas, sandy bodies with bioturbation and sedimentary structures (ripples) can be observed. They can be accessed either by boat or from the shore.

### 2.1.5 Costa Teguise (Geosite LZ47)

Located in the eastern coast of Lanzarote, Costa Teguise (Fig. 1) is one of the most popular tourist resorts area. There, a lava delta has been discovered by bathymetric maps as well as subaerial volcanic deposits, which confirm that it was formed during the Middle Pleistocene (IGME 2004). The delta surface is dipping smoothly seawards down to 10–12 m depth, displaying a very steep slope down to around 30–50 m depth. The maximum extension from the coastline is around 1.6 km. The shallower lavas exhibit columnar jointing that suggest a subaerial emplacement, although further from the coast, the erosion of the lava delta allows to observe a thick pillow lava sequence (Fig. 3b) indicating a submarine emplacement. In the distal area, the pillow lava flows are dipping up to 45º. In some places along the distal and steepest part of the lava delta, rock falls have occurred, having the sandy bottom now covered with blocks and boulders. On the coastal area in this sector, a Holocene littoral platform can be observed which has conglomeratic deposits overlaying a fossiliferous sandstone. This delta is an example of the transition between superficial and submarine lava flows. It can be easily accessed from land as well as by boat from Costa Teguise harbour.

### 2.1.6 El Rubicón (Geosite LZ55)

In the tourist centre coast of Playa Blanca, south of Lanzarote (Fig. 1), there is a castle called *Castillo de Las Coloradas*, which is the only defensive construction in all the insular southern coast. It was built in 1741 to defend the area from corsairs and Berber pirates, whose incursions in the island used to occur very frequently between the 16th and 18th centuries (Pinto de la Rosa 1996). The castle was set on fire in 1749 during an Algerian attack, yet the tower was rebuilt during the reign of Charles III, in 1769, as it states on the tombstone above the castle's door. In the cliff as well as at the bottom of the bay where the castle was erected, at only 6 metres deep, it can be observed the dikes where the magma made its way up to the surface more than 10 Ma ago crossing the Miocene rocks from the Ajaches Old Massif. The differential erosion has left exposed this dense network of dikes, highlighting over the sandy floor and displaying the skeleton of this ancient edifice (Fig. 3c). Different features related to dikes can be observed in this place such as chilled margins, columnar joints, bands with concentration of vesicles, segmentation and excellent crosscutting sections between dikes. The underwater sighting conditions of the magmatic dikes and the sea landscape are superb as they display a contrast between the dark dikes emerging from the seafloor and the whitish sandy seafloor. The area can be access from the coastline or by boat, even whilst snorkelling or scuba diving. From a boat, the cliff dikes can be observed and also the ones located at the end of the bay when the sea is calm, since it has crystal-clear waters.

### 2.1.7 Las Gerardias (Geosite MC02)

Las Gerardias is located on the south-western submerged flank of Montaña Clara islet, inside the GIIMR and the CANP (Fig. 1). It is a system of submerged feeder dikes trending NE–SW associated with the formation of the hydromagmatic Pleistocene edifice that constitutes the islet. These dikes are vertical like walls of great development, some extending from the sandy seafloor, about 65 m deep up to 27 m below sea level. These vertical walls constitute inverted reliefs, moulded by the erosion of the hydromagmatic pyroclasts in which they were intruded. The orientation of these dykes with respect to the sun generate shady

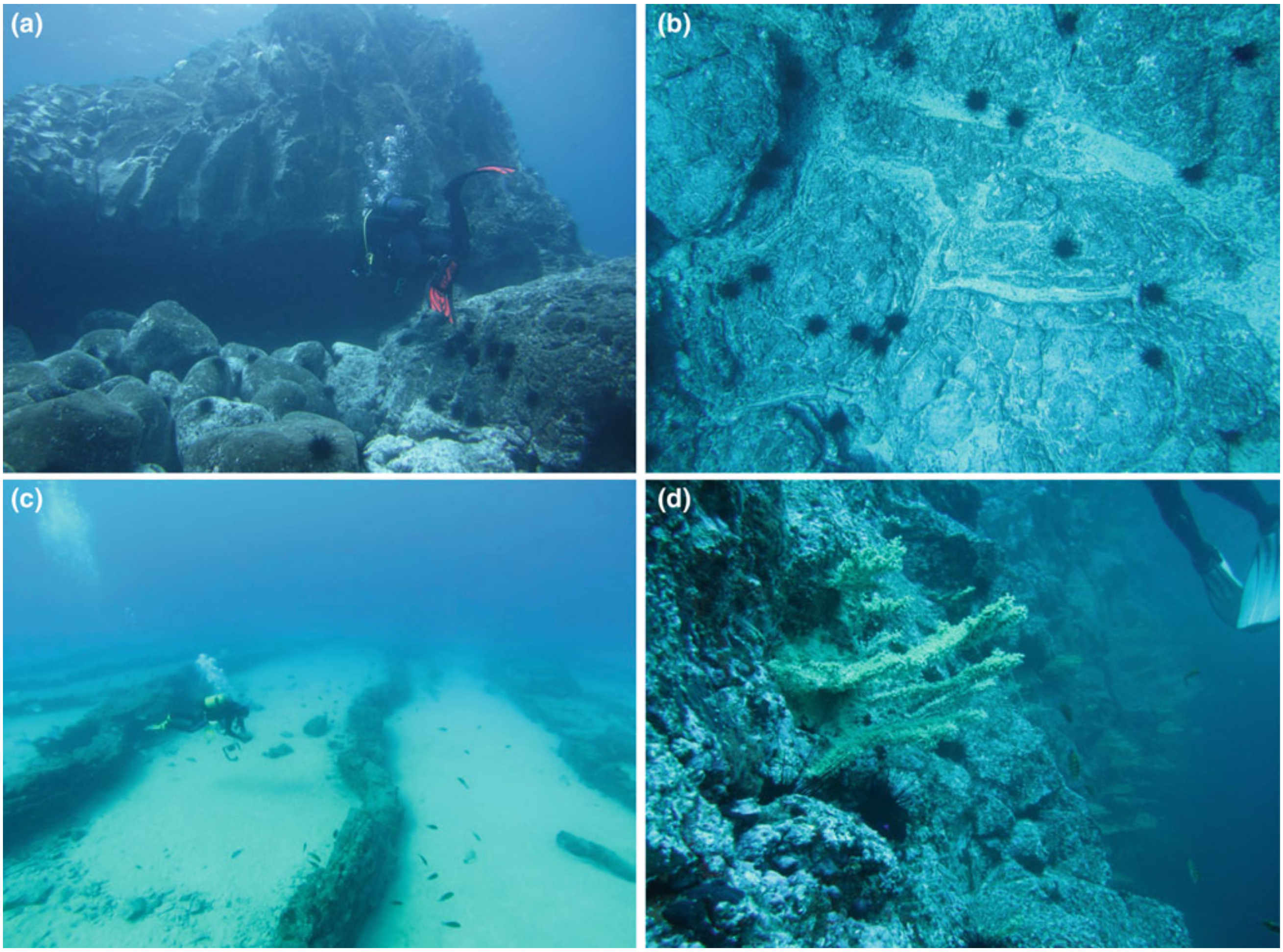


**Fig. 3** **a** Columnar joints in basaltic subaerial lavas and current rounded blocks in the Charco del Palo geosite; **b** Pillow lavas from Costa Teguise; **c** Dikes cutting the old volcanic shield and sandy seafloor in El Rubicón geosite; **d** Corals growing perpendicularly to a basaltic dike wall in Las Gerardias

areas which, along with the productivity of the waters and the opening to the dominant currents, make these rocky structures an ideal habitat to host a community of corals that are usually found at greater depth, the anthozoa *Gerardia savaglia*. *Gerardias* are a type of anthozoan zoantario cnidario able to develop skeleton, which is characterized by growth rings that give information about coral age and, even palaeoceanographic conditions. Here, it is concentrated the highest density of these corals located at a lower depth than usual. Diving slightly separated from the rock wall allows to observe clearly the columnar disjunction in the dike, and how the coral grows in the shelter of these columns, projecting in a perpendicular way to the vertical fracturing (Fig. 3d) to take advantage of the ascending and descending water flows loaded with nutrients. This geosite also emphasizes the importance of the subvertical dikes that constitute the rocky habitat.

## 2.2 Geosites of Geomorphological Interest

The Geosites with main geomorphological interest constitute 33% of the total in the studied area. They are related to the formation of marine platforms and different types of coastal erosive morphologies, as well as some morphology associated with intertidal and supratidal processes.

### 2.2.1 Los Placeres (Geosite LZ64)

The south western coast of Lanzarote is characterized by cliffs of approximately 20 m high excavated on lava flows of Pliocene age. During low tide a narrow platform, usually less than 100 m wide, can be observed at the base of the cliff. At Los Placeres, during low tide, giant potholes and littoral pools, up to a depth of −2 m, are scattered over the platform (Fig. 4a) which were formed due to the erosion of heavy swells passing through the cracks of columnar joins in the lava flow.

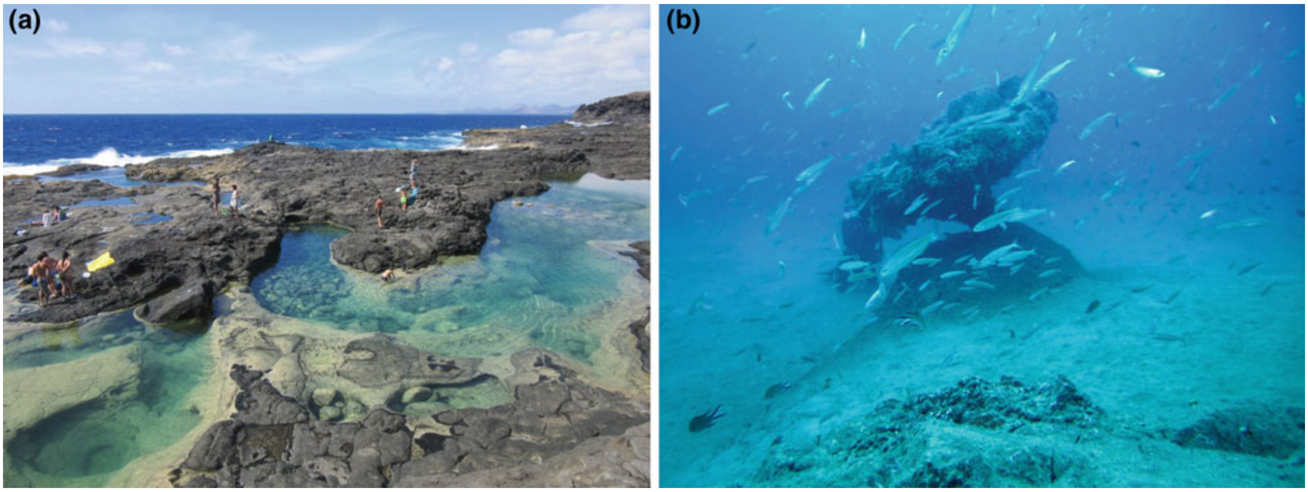


**Fig. 4** **a** Littoral natural pools and potholes in Los Placeres geosite; **b** Mushroom-shape monolith developed in the submerged lava flows of Puerto del Carmen

Boulders and cobbles inside the fractures acted as a natural abrasive, progressively enlarging the fractures and forming the potholes. Littoral caves can be also seen at the base of the cliff, with their bottom covered by rounded boulders. It is common to find puddles furthest from the intertidal zone that have been exposed to evaporation processes, frequently containing brines and accumulation of cubic halite crystals. This geosite is of great beauty, except for the parking area found close to an abandoned edifice that disrupts the landscape. On this site it is only recommended to practise snorkelling with low tide and the sea completely calm, as it may be very dangerous because of tidal regime and the waves that may suddenly and powerfully climb up the platform.

### 2.2.2 Puerto Del Carmen (Geosite LZ48)

The littoral zone of Puerto del Carmen in the central-eastern coast of Lanzarote (Fig. 1) is one of the main tourist areas in Lanzarote. The submareal area is formed here by a marine platform developed on submerged subaerial lavas where the coastal erosion, when the sea level was lower, modelled the lava flows giving rise to a great diversity of forms frequently visited by divers. Highlights include large underwater caves, erosive tubes and mushroom-shape monoliths (Fig. 4b). There are examples of the different stages of these monoliths formation: (1) differentiating erosion of the lava breccia located at the top and base of the lava flow; (2) erosion through columnar joints causing the fall of lava columns; and (3) lava monolith. In the front of the lavas, there are detachments partially buried in the sandy seafloor. The main interest of this geosite is geomorphological due to the well preserved erosive morphologies and the possibility of observing all stages of mushroom-shape monolith formation, from the first stages of erosion of the flows to their complete detachment.

### 2.2.3 Jameo de Guatiza (Geosite LZ46)

The Jameo de Guatiza, located in the northeast coast of Lanzarote (Fig. 1), is a representative example of littoral erosive forms typical of low rocky cliffs carved in Holocene basaltic lava flows of aa-type. These flows are usually made of two brecciated levels, located at the top and the base, and a massive central area with columnar joints. The waves eroded the base of the lava, undercutting the cliff and causing the collapse of the upper part. In this case, marine erosion has formed an elongated littoral cave in Holocene lavas, of approximately 25 m long, which connects the cliff cave entrance with a circular collapsed opening on the lava surface of around 20 m in diameter (Fig. 5a). On surface, a circular pool, partially filled with seawater, can be observed detached from the cliff, filled with rounded cobbles and boulders. A clastic size selection is observed in the tunnel towards the sea. Friction marks caused by the rubbing of the clasts with the rocky bottom in the passage can be seen. These stretch marks might have been due to the dragging of boulders by the marine dynamics (currents, waves and tides). The submarine access is very simple and very shallow from the sea, this area is less well-known to tourists though.

### 2.2.4 Jameo de Alegranza (Geosite AL05)

On the southeast coast of Alegranza islet the Jameo de Alegranza is located (Figs. 1, 5c), a littoral cave excavated in the Upper Pleistocene hydromagmatic deposits of La Caldera volcano flanks, partially flooded by seawater. The cave is longer than 100 m, between 4 and 14 m wide and around 8 m high. The tunnel-shape is due to the existence of a fracture that can be observed along the roof of the cave (Fig. 5b). The bathymetry shows a 400 m submarine scarp that can be interpreted as the prolongation of this fracture, suggesting that the cave was formed by preferential erosion

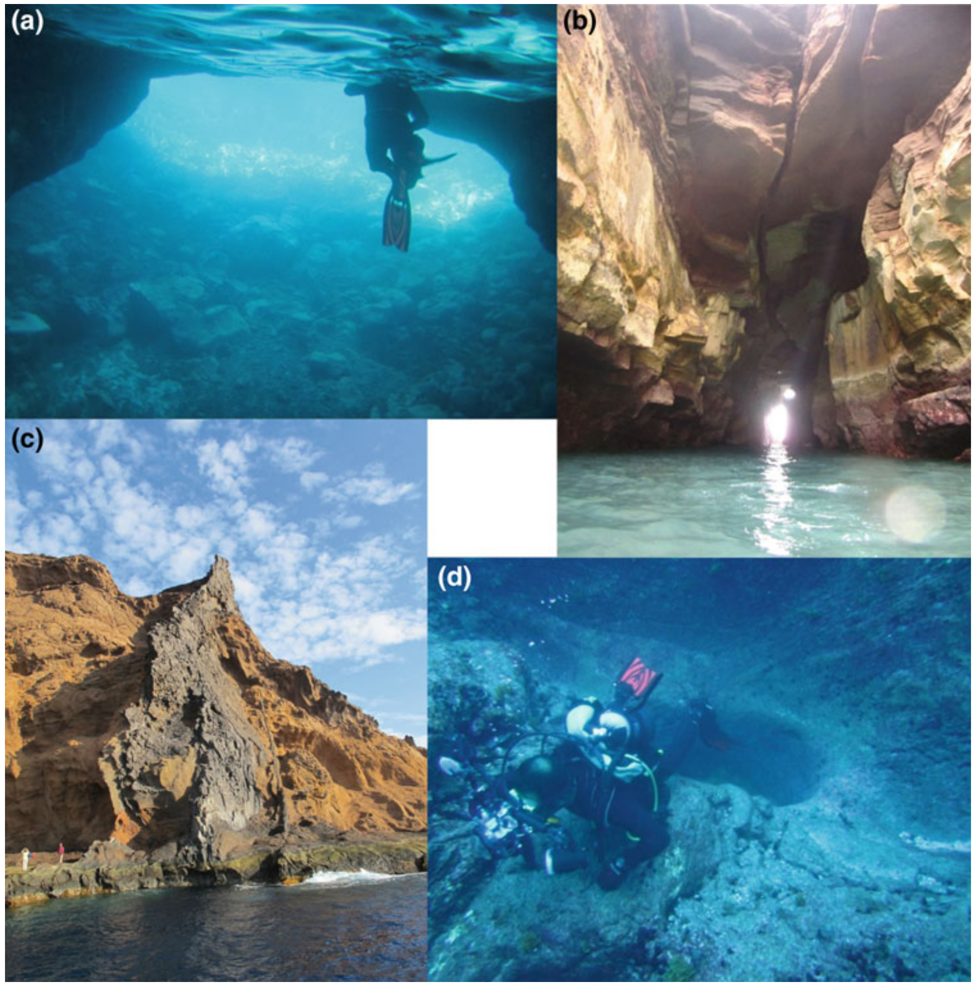


**Fig. 5** **a** Zone of the erosive littoral cave of Jameo de Guatiza close to the inland pool (in the background); **b** Erosive littoral cave of Jameo de Alegranza excavated along a fracture that can be observed in the roof; **c** Dike that favoured the formation of a littoral tunnel by differential erosion in Roque del Este that is actually underwater; **d** Giant pothole inside the Roque del Este tunnel

through the fracture. The roof of the cave displays partial collapses in some areas, whose fallen blocks can be seen at the bottom. However, at about 66 m from the entrance, the roof is completely open to the surface along approx. 36 m. This geosite is of geomorphologic interest and it is a representative example of littoral cave formations mainly by the wave power eroding a fracture. Additional interest is found in the hydromagmatic deposits (cineritic and lapilli tuff) of La Caldera volcano with parallel stratification, abundant accretionary lapilli and structures of deformation by impact of lithic projectiles. It can be access from the coast and by boat, swimming, snorkelling or scuba diving although the risk of the cave collapse should be assessed. This geosite is included in both the GIIMR and the CANP.

### 2.2.5 Roque Del Este (Geosites RE01)

Roque del Este islet is the north easternmost territory of the Canary Islands (Figs. 1, 5c). It is a greatly eroded hydromagmatic volcano, so much so that it even shows its internal structure, including some feeder dikes (Fig. 5c). In depth, one of these dikes constitutes the wall of an underwater tunnel about 100 m long that entirely crosses the islet in a NNE direction. The basaltic dike is more resistant to erosion than the soft pyroclastic ones, so the volcanic deposits have been eroded giving place to the formation of the tunnel. From the south entrance, the base of the tunnel shows several morphologies typical of surface water erosion such giant potholes (Fig. 5d). The dimensions of the potholes in the northern side of the tunnel are of the order of 2–3 m in diameter with a similar depth. All these features suggest that the tunnel was eroded at surface during the falling of sea level (marine regression) and later on, it was flooded in raise stages (marine transgression). The main interest of this geosite is geomorphological, but also palaeoenvironmental as well as biological, since life inside the tunnel is also exceptional. This geosite is in the GIIMR and the CANP, also protected by the Islets Integral Natural Reserve being forbidden the access except for scientific purposes.

### 2.2.6 Puerto Viejo (Geosite AL04)

This geosite is located in the southern submerged flank of Caldera de Alegranza hydromagmatic edifice, in the framework of the GIIMR and the CANP (Fig. 1). Sedimentary structures as parallel stratification and cross bedding, bombs, lithic fragments, impact pits, bomb sags and other features typical from this type of eruptions with magma-water interaction can be observed. However, the main interest found in it is that an ancient network of ravines crosses the whole area; in which large potholes formed by rock abrasion can be seen (Fig. 6a). Sediments (usually rounded cobbles) are frequently found into the potholes. These underwater geomorphologies are related to the tidal and erosive processes of backshore suggesting that sea level was lower than the current one when the Caldera de Alegranza was formed, since potholes are also found on offshore submerged lava flows. In fact, the same erosive features can be observed in the superficial flanks of the Caldera (Fig. 6b). Moreover, hydromagmatic pyroclastic deposits have been eroded displaying mushroom-shapes typical from littoral environments. It can only be accessed by boat.

## 2.3 Geosites of Sedimentological Interest

They constitute only 22% of the studied geosites and allow us to observe sedimentary outcrops with particular sedimentary structures in detrital seafloor, or to study the dynamics of sedimentation and erosion processes on the coastal zones.

### 2.3.1 Arrieta and Punta Mujeres (Geosite LZ44)

"Sebadal" is the local name for a seagrass meadow of *Cymodocea nodosa*, a marine phaneronogam plant belonging to the Cymodoceaceae family. Numerous marine plants, known in the Canaries as *sebadales*, which often harbour nurseries to various species of marine juveniles until their adulthood, hence their ecological importance. Thus, Arrieta and Punta Mujeres geosite have been selected as representative of this habitat (Fig. 1). This specie's favourite substrate is made of sediments found in shallow calm waters, in this case coarse sands mainly made of shell fragments and corallinaceae algae meshes (bioclastic components), and with some rock and mineral fragments of volcanic origin and basaltic composition (terrigenous components). In this part of Lanzarote island, the subtidal sands are shifted towards intertidal areas by the marine dynamic of currents, tides and swells, and from there, the wind blows them to supratidal zones giving place to little dunes (necks and foredunes) and aeolian bedforms. In these sandy beds, sedimentary structures can be observed (ripples of symmetric swells and asymmetric currents) and little conical mounds in the clearings of the marine plant meadows which are related to current bioturbation processes caused by tub warms, annelids (Fig. 7a). Here, it can be easily seen the mud-mounds caused by the gallery cleaning effect of the ichnites, a fossilised footprint, found in the fossil records. It may be accessed by boat.

### 2.3.2 Caletón Blanco (Geosite LZ52)

The severely eroded Miocene shield volcano in the north of Lanzarote is partially covered by basaltic lava flows of Holocene eruptions reaching the sea and expanded over the insular area. Around Caletón Blanco, mafic lava flows are black in colour and covered by cream coloured sandy bars mainly formed by red corallinaceae algae meshes and shell fragments. At this area, sand is dragged by swells and oceanic currents towards the coastline, where they are shifted inland by the wind. In Caletón Blanco beach, a lava platform has been formed where among depressed areas and

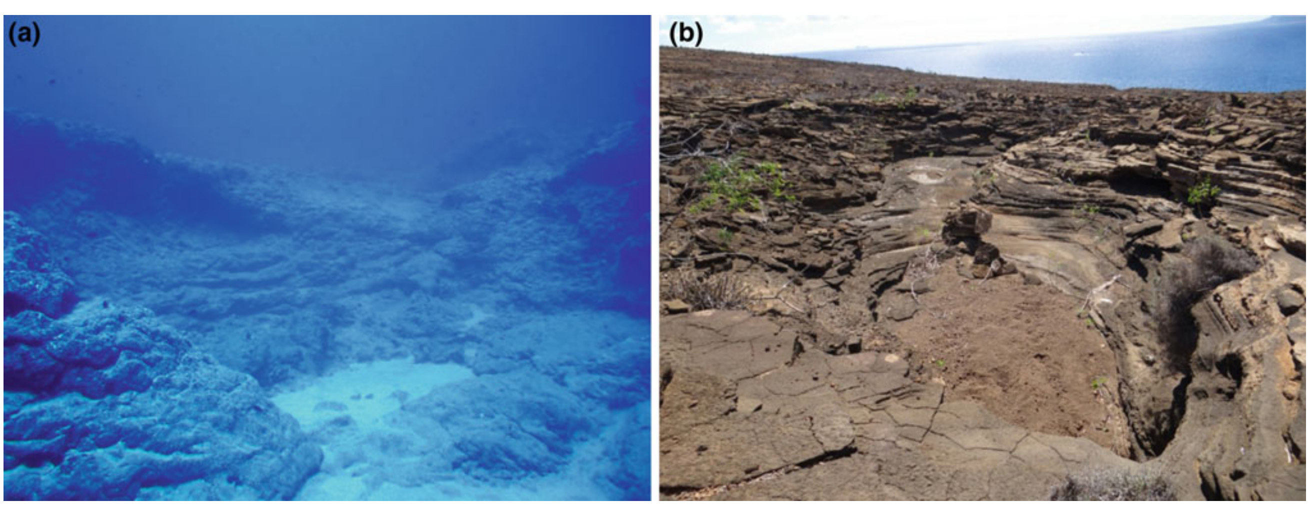


**Fig. 6** Erosive morphologies of ravines and potholes in the Caldera de Alegranza south-eastern flanks underwater (**a**) and at surface (**b**)


**Fig. 7** **a** Sandy sea bottom cover by a seagrass meadow of *Cymodocea nodosa*; **b** Cross-stratification in sand dunes of El Rio; **c** Panoramic view of Caletón Blanco geosite showing the contrast between black lava flows and light-cream bioclastic sands; **d** View of the El Reducto beach in La Marina de Arrecife Resort Area; **e** Water spring in the Caleta del Aguardiente

sands have been accumulating. During low tide, shallow natural pools are exposed, very suitable for going snorkelling (Fig. 7c), although scuba diving can also be done in the deepest areas accessing by boat, as not only in the coastal area but also in the subtidal. The main interest of this geosite is the sedimentary processes of an active beach-dune system, in subtidal zones as well as in intertidal and supratidal ones, but also due to variated lava morphologies. The geosite is in the GIIMR, and therefore authorisation is required for scuba diving.

#### 2.3.3 El Rio and Rio de Montaña Clara (Geosite GR04)

Two linear sandwaves have been identified in the sea channels located between Lanzarote and La Graciosa (El Rio channel), and between the latter and Montaña Clara (Rio de Montaña Clara channel) (Fig. 1), between −30 and −15 m depth. These sedimentary deposits are perpendicular to the present sea circulation in these channels and join the coast of the islands trending N45°W. These rocky outcrops rise, in both channels; about five metres from the sandy bottom and have around 1.5 km in length. Direct observation shows that they are formed by a coarse-grained calcarenite with parallel stratification at the base and cross stratification at the top (Fig. 7b). A great diversity of erosive forms typical of littoral areas (columns, arches, bridges, tafoni, mushroom-shapes and potholes) suggests that the sandy bar was exposed in the past to a littoral environment. These deposits were also intensely bored by a *lithofagus* bivalve from intertidal areas battered by the waves. We interpret these features as littoral sandwaves formed perpendicularly to the dominant sea currents and these deposits were eroded when the sea level was around −15 to 30 m below the current one. These submarine structures could have evolved to tombolos with sandwaves and sheets that joined the islands of Lanzarote, La Graciosa and Montaña Clara. They were submerged gradually during a later transgressive period, and at present, the remains of the bars are full of rock shelters that harbour a large amount of fauna. For all these reasons, scuba diving is spectacular here; however, it is only accessible by boat. Both areas are included in the GIIMR and the CANP, yet in the zone of Rio de Montaña Clara recreational diving is not permitted.

#### 2.3.4 Marina de Arrecife (Geosites LZ50)

On the capital of Lanzarote, a coastal area of natural and cultural interest (ethnographical, historical, ecological, geological, and biological) can be found known as la Marina de Arrecife (Fig. 1). This geosite includes part of La Marina and spreads on the coast from Reducto beach (Fig. 7d) in the south to Charco de San Ginés in the north, prolonging towards the sea like a littoral shelf. This submerged platform has a curved shape related to a lava delta formed more than 700 ky BP. However, on the current coastline, lavas show hexagonal columnar joints suggesting that there the emplacement of lavas was subaerial and that sea level was lower when they were issued. Along the coast of Arrecife some outcrops of beachrocks can be found over the eroded surface of the lava flows. This deposit was exploited to extract calcarenite blocks for the construction of Las Bolas Bridge. The low slope of the coast makes the oscillation of the tide here very remarkable, where large surfaces are exposed at low tide. Currently, it forms a shallow marine shelf dotted with puddles and rocky islets that protects the coast from waves and ocean currents. This natural shelter propitiated the construction of a port and the transfer of the island capital from Teguise to Arrecife in 1847. In the area close to the coastline, protected from the currents, snorkelling is highly recommended, as besides the abundant marine fauna, the formation of ripples on the sand can be observed on the cradling waves.

### 2.4 Geosites of Hydrogeological Interest

Only a geosite with hydrogeological interest has been found and represents a current example of island aquifers discharge into seawaters at coastal zone.

#### 2.4.1 Caleta Del Aguardiente (Geosite GR06)

In La Graciosa the only geosite of hydrogeological interest included in the inventory of Lanzarote and Chinijo Island UNESCO Global Geopark can be found. Throughout the islet east coast (Fig. 1), in the intertidal area, there are volcanic rock ledges along with small sandy deposit locally known as Las Caletas. In this environment on the sandy marine floor the release of fluid liquids forming bubbles, yet in Caleta del Aguardiente (Firewater Cove) is where this process is much more spectacular. Here, during high tide, snorkelling is a must to observe the bubbling on the sandy seafloor. However, during low tide, cold brackish waters are visible, bubbling and generating artesian springs giving the impression that the water is boiling (Fig. 7e), hence its place name. Water pressure is strong enough to rise several decimetres during low tide. These water spring areas are usually related to previous fractures in the substrate. Furthermore, in intertidal and supratidal areas there are also beachrock deposits, paleosoils and aeolianites, along with current sand sheets and dunes. The Aguardiente cove is located in the GIIMR and the CANP, and authorisation is needed for scuba diving. Nevertheless, geological features can be observed by either direct observation during low tides or snorkelling during high tides.

## 3 Discussion and Conclusions

Few UNESCO Global Geoparks have tourist activities in coastal and submerged areas, such as Cabo de Gata UGG in Southeast Spain (http://guiadelparque.com/rutas/ruta-submarina/) or Azores Islands UGG in Portugal (Lima et al. 2013; http://dive.visitazores.com/en/divespots/baixa-da-vila-nova). However, these activities are mainly focused on the biological or ecological aspects and also consider the geology as a static landscape where life develops. This is also the case of some marine Protected Areas and Marine National Parks where it is necessary to improve the geological interpretation for visitors

(Orrú et al. 2005). In Lanzarote and Chinijo Islands UGG, there are already submarine routes within the framework of the Man and Biosphere Reserve (Boyra et al. 2011), some of them coinciding with the location of geosites. They are mainly focused on the observation of underwater life, although they point out the existence of some geomorphologies of interest. In this work, we provide for the first time information about the geology of eighteen geosites located in the shallow marine slopes of Lanzarote and Chinijo Islands UGG.

Underwater geosites include geological attractions associated to igneous and sedimentary rocks and morphologies, together with volcano-tectonic and sedimentary structures, and diverse volcanic and erosive morphology in mainly sandy bottoms, volcanic cliffs and marine platforms. This first study provides new information about the shallow submarine geology of Lanzarote and the transition between the subaerial and submarine environments. Most of the morphology included in the geosites is formed at surface near or on the coast, and are currently submerged due to changes in sea level during the Quaternary period. Thus, part of this geoheritage includes morphologies formed in different environments from the current ones. This recognition study shows that a deeper analysis of some of this underwater geosites and the determination of their age could help to infer the location of sea level in different ages and to better understand the geological evolution, palaeogeography, palaeoceanography and palaeoclimatology of the islands, with implications in the North Atlantic area. The observed features and genetic processes might contribute to understand the geological history of this UGG.

The analysis of the selected eighteen geosites from the Geopark inventory shows that eleven of them are included within natural protected areas (Fig. 1). In three of them (LZ06, MC02 and RE01), access is allowed only for researching, thus, they have been discarded for submarine touristic purposes. Las Bajas geosite (LZ49) is neither recommended since the area is usually subject to strong currents. However, for this last geosite, the story of a "hidden volcano" can be explained from a viewpoint located on top of the cliff of Famara from where the subaerial part of the edifice can be observed (Galindo et al. 2017).

Out of the remaining geosites, eight are in Natural Protected Areas where scuba diving is subject to the expedition of an authorisation, while the other seven are not under use restrictions and can be accessed in a relatively simple manner. The control of access in the protected geosites should as a result avoid overloading these spaces, whilst maintaining their good state of conservation and improving the scuba diving experience. Thereby, in the Lanzarote and Chinijo Islands UNESCO Global Geopark there are fifteen geosites that constitute really good options for diving geotourism and could be used for a sustainable submarine geotourism through different types of activities such as swimming, snorkelling, scuba diving, submarine scooter tours or submarine safaris. All these tourist offers already exist in Lanzarote but no information about the geology of the visited area, nor the geoheritage, is provided to visitors.

Diving geotourism constitutes a realistic option to improve divers' experience in the island, since Lanzarote is a consolidated tourist destination for diving as shown by statistics (Cabildo de Lanzarote-Centro de Datos 2018), available since 2014, proving that the number of authorised diving centres in Lanzarote has increased from 19 in 2013 to 35 in 2017, being currently the island with the largest offer of this type in the Canary Islands. This is consistent with the gradual increase of the number of tourists who have done diving in Lanzarote, from 96,165 in 2014 to 176,644 in 2017, being 5–7% of the total number of tourists visiting the island. The profile of this kind of tourism is of the affluent type, since they are usually middle-aged people with income slightly higher than the rest of tourists. Most of them (87%) get a good or very good impression of Lanzarote, valuing the activity in almost 9 points out of 10. This profile of diving tourism is very specific. Most tourists could reach this UGG touristic offer if we consider that in ten geosites one can enjoy the geology simply by snorkelling without being necessary to have great swimming skills or even scuba diving licence.

As a first step, it is important to adapt the geological information to different types of visitors through geoheritage interpretation techniques and disseminate it among diving guides, diving centres or tourist information sites. Brochures could also be published including coastal and submarine geology of the UGG as a dynamic process, also explaining the formation of the rocks and forms and the implication that they have in the geological evolution of a volcanic oceanic island. This does not mean that the biotic factor has less importance, but should be presented as an added value together with historical, cultural and other information allowing to have a holistic approach of the area. As suggested by Orrú et al. (2005) the purpose is to make visitors have a better knowledge of the submarine world beyond the living organisms. On the other hand, before promoting sustainable geotourism, it is essential to establish monitoring and controlling mechanisms such as carrying capacity studies or the periodical analysis of the geosites use and susceptibility towards degradation, in order to ensure the protection of the geoheritage. Hazards related to rock falls in the access to the immersion areas as well as related to currents and waves should be evaluated before publicising any geosite as geotourism sites. In addition, it should be recommended to users to check carefully the tides schedule and sea conditions before immersions.

As a conclusion, the fantastic and unique landscapes of fifteen submarine geosites located in the shallow seawaters of Lanzarote and Chinijo Islands UGG are magnificent sites to discover and enjoy the geology of a volcanic island. Moreover, the constructive and destructive processes that take place during their evolution and some aspects of global change also can be interpreted. Next steps for the UGG management would be: (1) to elaborate brochures, online resources, geological guides and routes as well as organise courses for getting across submarine geology knowledge, (2) improve protection of submarine geoheritage, and (3) to implement a sustainable submarine geotourism package to add value to the tourism experience in Lanzarote and Chinijo UGG.

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# Geoconservation and Geotourism in the Lanzarote and Chinijo Islands UNESCO Global Geopark

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**Abstract**

Lanzarote is a well-established tourist destination with numerous geosites located in tourist centers on the island, such as seven Art, Culture and Tourism Centers, the Timanfaya National Park, Cesar Manrique's Foundation and some tourist attractions like Los Hervideros cliff, Salinas del Janubio or El Golfo volcano. Although these places are visited mainly for their spectacular scenery and performance, until now, there was a lack of geological information and interpretation about those emblematic natural sites. Thus, the Lanzarote and Chinijo Islands UNESCO Global Geopark has developed a geoconservation strategy by promoting sustainable geotourism. The main aims of this strategy are to improve the knowledge of the geological elements present in tourist areas as well as to widen the touristic offer by promoting less known geosites and alternative geo-routes. In order to improve the outreach of geology and the tourist experience through the understanding of geoheritage that underlies the volcanic landscape, two actions have been implemented: 17 interpretative panels for Lanzarote and La Graciosa Islands, and 5 geo-routes by car in Lanzarote. The interpretative panels and the geo-route brochures guide visitors through the geology of the UGG, including some aspects of historical, cultural and natural interest. The geo-routes themes selected, go from the formation of ancient volcanic massifs to quaternary eruptions and sedimentary processes. Interpretative panels, road guides and brochures are meant to promote a more sustainable alternative to the prevailing "sun and beach" tourism on the islands. Carrying out these actions, this UNESCO Global Geopark improves its outreach information, and in turn upgrades tourist infrastructures, trying to draw the attention of tourists who come to the islands for other reasons than its Geology.

**Keywords**

Geoconservation • Geoheritage • Outreach • Geotourism • Geo-routes

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## 1 Geoconservation Through Geotourism in Lanzarote and Chinijo Islands UGG

One of the "Top 10 Focus Areas" of UNESCO Global Geoparks (UGG) is Geoconservation. According to this, UGG are territories that use the concept of sustainability, assess the geoheritage of international relevance and recognize the need to protect it (Torabi Farnaso et al. 2011; http://www.unesco.org). The geosites defined in Lanzarote and Chinijo Islands UGG are protected by local, regional and national laws as well as management authorities, in cooperation with the corresponding agencies, which allow for the necessary conservation and maintenance of these geosites


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(Galindo et al. in this volume). According to the UGG, the term geotourism recognizes that it deals with tourism, through the promotion of geoheritage, and it entails a sustainable development of the local community in which it is implemented, with a regard for their culture, traditions and customs, without interfering in their daily life-styles (http://www.unesco.org/new/en/natural-sciences/environment/earth-sciences/unesco-global-geoparks/).

One of the aims that geoconservation has, is the use, denominated as public use, of geoheritage committing to ensuring preservation and protection. Many conservation organisations see tourism as one of the sectors with the greatest potential to connect conservation to economic development (International Union for Conservation of Nature—IUCN). Public use is generally carried out through outreach, education and geotourism, which are key to the mid and long-term conservation of the geological heritage. However, we must not forget that geotourism should never has the use of geosites before conservation.

To value and effectively protect the geoheritage, it is necessary for society and the people who live and visit UGG to understand the values of geology. The sentence written by an anonymous U.S. National Park Service ranger in the USA said: “Through interpretation, understanding; through understanding, appreciation; through appreciation, protection”. Only in this way and according to Ham (2007, 2014) will the recognition and value of the geoheritage become a true guarantee of conservation and learning process goes further than simple contemplation and enjoyment (Carcavilla et al. 2009).

There is no doubt that travelling and appreciating natural landscapes and geological phenomena continues to grow as a niche area in tourism (Newsome and Dowling 2010; Stueve et al. 2002; Dowling 2011; Newsome et al. 2012). Geotourism, through UGG network, and geosites in protected areas and other recognised geological elements, are now quickly spreading around the world as a form of tourism where the primary focus is on geosites (Dowling and Newsome 2006; Newsome and Dowling 2010). In 1995, Thomas Hose defined primarily the Geotourism concept (Hose 1995) and in 2000, the same author redefined its definition as “the provision of interpretative facilities and services to promote the value and societal benefit of geologic and geomorphologic sites and their materials, and ensure their conservation, for the use of students, tourists and other users”.

As a fundamental axis for a sustainable territorial development strategy, based on outreach, education, conservation and geotourism, the Lanzarote and Chinijo Islands UGG was declared in 2015. Within the framework of the activities carried out since its declaration, 17 interpretive panels have been installed in three languages (Spanish, English and German) in the geosites most relevant to geotourism and five self-guided interpretative geo-routes have been created to be used by car, as a means to discover the geoheritage of the UGG. The creation of this new infrastructure aims to provide output and new products to the growing demand for a type of tourism other than sun and beach in certain areas of the Canary Islands (Díaz et al. 2013; Hernández and Santana 2010; Galindo et al. 2015), thus diversifying the tourist offer through geotourism, which ultimately contributes to encouraging awareness and a conservative attitude for our visitors.

## 2 Visitors Analysis and Relationships with Geoheritage

Free-choice environmental learning experiences are also identified as an important aspect of environmental education and geotourism. This type of experience focuses on the fact that learning about a topic is largely down to those directly involved (Ballantyne et al. 2007). Such learning and outreach opportunities, which are found in ecotourism and nature-based tourism experiences, also play an important role in educating and influencing environmentally-friendly behavior, geological knowledge, and the conservation intentions of individuals part of large groups (Ballantyne and Packer 2005). Weaver (2005) discussed that “effective interpretation can have a “transformative” effect by inducing a deeper understanding and a more ethical and environmentalist ethos among participants”. The observations and experiences that visitors have on site have an influence on their awareness, as well as on their understanding and knowledge regarding environmental and geological issues (Ballantyne et al. 2007) especially for visitors of UGG.

In the case of geotourism in the Lanzarote and Chinijo Islands UGG there are three essential aspects that have been thoroughly analysed before initiating the design of the infrastructures: 1—type of public and visitors to this UGG, 2—method used for communication, and 3—place chosen for the location of the route stops and interpretative tables within the UGG.

Public opinion is essential and also a priority, because the information given will vary depending on it, as well as the method, language and the techniques used. The method of heritage interpretation is essential (Tilden 1957; Ham and Weiler 2002). The methods to be used are not the same to design, for example, a panel, a field guide or a guided tour. Each target public has a particular preference for a type of material, although the available economic resources have also conditioned this choice. The choice of location is also key, because of accessibility, the ownership of the place where the interpretative tables will be installed or also depending on its aesthetic component, even if they are geosites of high scientific value. Likewise, geosites of extraordinary scientific interest are ruled out if they are either geologically complex or vulnerable to visits.

Lanzarote and Chinijo Islands UNESCO Global Geopark is one of the main tourist destinations in the Canary Islands, bringing 3,146,117 visitors in 2017 (Source: Canary Islands Statistics Institute and Data Centre of the Cabildo of Lanzarote), contributing to the upward trend of tourism in Spain. Outside this figure, foreign visitors account for 91.7% (2,885,483 visitors), the engine of the island's economy. Considering the same year, by country of origin, 1,452,141 visitors come from the United Kingdom, followed by German (474,587 people) and, thirdly, Spain (261,734 people); Ireland has 266,773 more English-speaking tourists. In addition to the Spanish-speaking tourism we must add the population of the UGG, who should be involved in its sustainable development, 145,084 inhabitants in 2016 and a density of 171 inhabitants/km$^2$ (Source: National Institute of Statistics of Spain). For all these reasons, the geotourism strategy is focused on two main axis: local population and national visitors whose language is Spanish, and foreign visitors, where English speakers are a majority. Therefore, from the Geopark it was decided for the texts on the panels to be in these three languages: English, German and Spanish.

To adapt to the needs and particularities of tourism in Lanzarote, self-guided geo-routes have been designed to be done by car, the most commonly used means of transport by visitors on the islands. The mobile fleet of Lanzarote is 125,137 vehicles (data from 2017, Canary Islands Statistics Institute). On the island, there are at least 8 large car rental companies, where their main demand is rental for tourists.

## 3 Panels or Interpretative Tables

Lanzarote has a rich and diverse geology as it is a volcanic island greater than 15 Ma. The always present volcanism, has interacted with the erosive and sedimentary processes leading to a great variety of unique and spectacular landscapes in an oceanic insular area, that result in internationally relevant geosites (Galindo et al. in this volume). The Lanzarote and Chinijo Islands UGG tries to spread its geoheritage through geotourism as one of the main objectives of the UGG network. In 2016, one of the actions carried out was the preparation of 17 interpretative panels in three languages (Table 1). With regard to visitors, it is both a matter of providing new information for those interested in nature tourism, and of capturing the attention of those who visit the island for its climate, culture and gastronomy. Although visitors to Lanzarote do not generally choose this destination because of the UGG, the idea is for them to discover its geological values, through the interpretation of the volcanic landscape, and enjoy its spectacular geoheritage.

### 3.1 Selection and Location of Interpretative Tables

The location of the interpretative tables was predefined by the management of the UGG and meets the following criteria: (1) located on public land to avoid conflicts with landowners, (2) interpretation of geosites of the geoheritage inventory of the UGG, (3) location in strategic tourist places with (4) minimal impact on the natural environment, avoiding geosites exposed to mass visits, to prevent risk of geoheritage degradation.

The places selected for the location of these tables were visited to determine their access and their exact location by GPS. Photographs and maps were made, in order to decide the geological elements that would be interpreted at each point. All the interpretative tables will be located in accessible areas, in or very close to car parks (ports, campsites, viewpoints, parking lots) and, generally, in the most visited geosites due to their high tourist value according to the assessment (Galindo et al. volume).

### 3.2 Format of the Interpretative Panels

The format of the panels is similar (Fig. 1), since it must comply with the provisions of the Canary Government Order of June 30, 1998, regulating the types of signals and their use in relation to Protected Natural Areas. The measurements of each panel are 119 × 105 cm and the information is distributed in two columns, 14 and 105 cm wide. In a first 7-cm high strip figure, in two lines, the category of natural protection, the name of it and on the right the official UGG logo. Then, another 7-cm high strip separated by a line appears with the name of the corresponding geosite. In the column on the left, all the logos of the entities involved are placed, the Cabildo of Lanzarote first of all. The column on the right is intended to contain the main information.

### 3.3 Texts

It is the main means used to transmit information about an object, although all specialists agree that they are not easy to create (Ham 2014; Morales 2001). Institutionalised signage in Canaries is very strict, however, to overcome these difficulties the texts on the panels have three categories:

(1) Titles, which draw attention to a particular process or geological element. The introduction is the only part of the panel that many of the visitors will read; for this

**Table 1** Interpretative panels of the geoheritage of the Lanzarote and Chinijo Islands UNESCO Global Geopark

| Location | Name | Theme | Protected Natural Area |
|---|---|---|---|
| Papagayo Camping site | When the tide goes out | Sea miocene abrasion platform above sea level | Los Ajaches Natural Monument |
| Playa Mujeres beach | A young beach among ancient rocks | Formation of an embedded beach | |
| Las Casitas de Femés | A hole that gathers sediments | Formation of a graben and evolution as an endorheic valley | |
| El Golfo volcano | The history of a volcano that emerged at the edge of the sea | Origin and evolution of the El Golfo volcano | Los Volcanes Natural Park |
| Los Hervideros | Lava flows that ruffle the sea and make the water sigh | The Timanfaya lava flows reach the sea and its erosion to forming a cliff | |
| Pico Partido volcano | An overflowing crater | Lava channel formation and lava lake | |
| Echadero de los camellos | At the heart of Timanfaya | Types of volcanoes in Timanfaya | |
| Guinate viewpoint | Lava cascades trying to get to the sea | Formation and evolution of the Famara cliff | Chinijo Archipelago Natural Park |
| La Graciosa port | Geosites of La Graciosa | Brief explanation of La Graciosa´s geosites | |
| La Graciosa Camping site | Shelter from the sea | Fossil beaches and a coastal lagoon | |
| Puerto de Órzola | Islets with impressive geological features. Also under the sea! | Geosites in the Chinijo Islands | |
| Playa de Famara | Famara cliff. A permanent struggle between land and sea | Active processes in the cliff of Famara | |
| Haría viewpoint | The cliff that guards a volcano | Angular unconformity located in the cliff, submerged volcano and entrance of marine sands to the island | |
| El valle de Temisa viewpoint | An ancient valley witness to climate change | Formation of U-shaped valleys in ancient volcanic massifs | |
| Salinas de Janubio salt pans | The perfect combination: sea water, sun, wind and *salineros* | Formation of Laguna del Janubio coastal lagoon and its use for salt crops | Site of Scientific Interest of El Janubio |
| Pantalanes de Arrecife | A current and a fossil beach | Formation of a fossil beach on a lava platform, its use in architecture and the current Reducto beach | – |
| El Charco lagoon | A natural port influenced by the tides | Underwater lava delta and its use to build the Arrecife port | – |

reason, the classic recommendations of Heritage Interpretation techniques have been followed (Ham 1992, 2014). As an example, the title “Lava flows that ruffle the sea and make the water sigh” from the Los Hervideros panel, refers to a geosite where the sea has eroded one of Timanfaya’s historical flows, in turn creating a cliff where the waves sneak through several erosive caves, causing a great rumble.

(2) Text with messages. So that the texts have an impact on visitors. They are brief, concise and rigorous in geological terms, without any technical language. They develop a single strong idea that corresponds to what visitors observe on the panels. The same text is translated into the three languages, accompanied by the corresponding iconography.

(3) Accompanying text of the graphic images. They follow the pattern of the photo or object, which are brief explanations that facilitate the understanding of the images. When accompanied by graphic images, such as 3D geological diagrams, they can indicate their age, composition, rock type or type of geomorphological element.

## 3.4 Maps

It is an exhibiting technique in itself, especially if it is accompanied by drawings or photographs (Ham 2014). The panels designed for the UGG, when maps are included, are always complementary to the main graphic images. There are two key types: (1) Maps to locate visitors. Easy to understand,

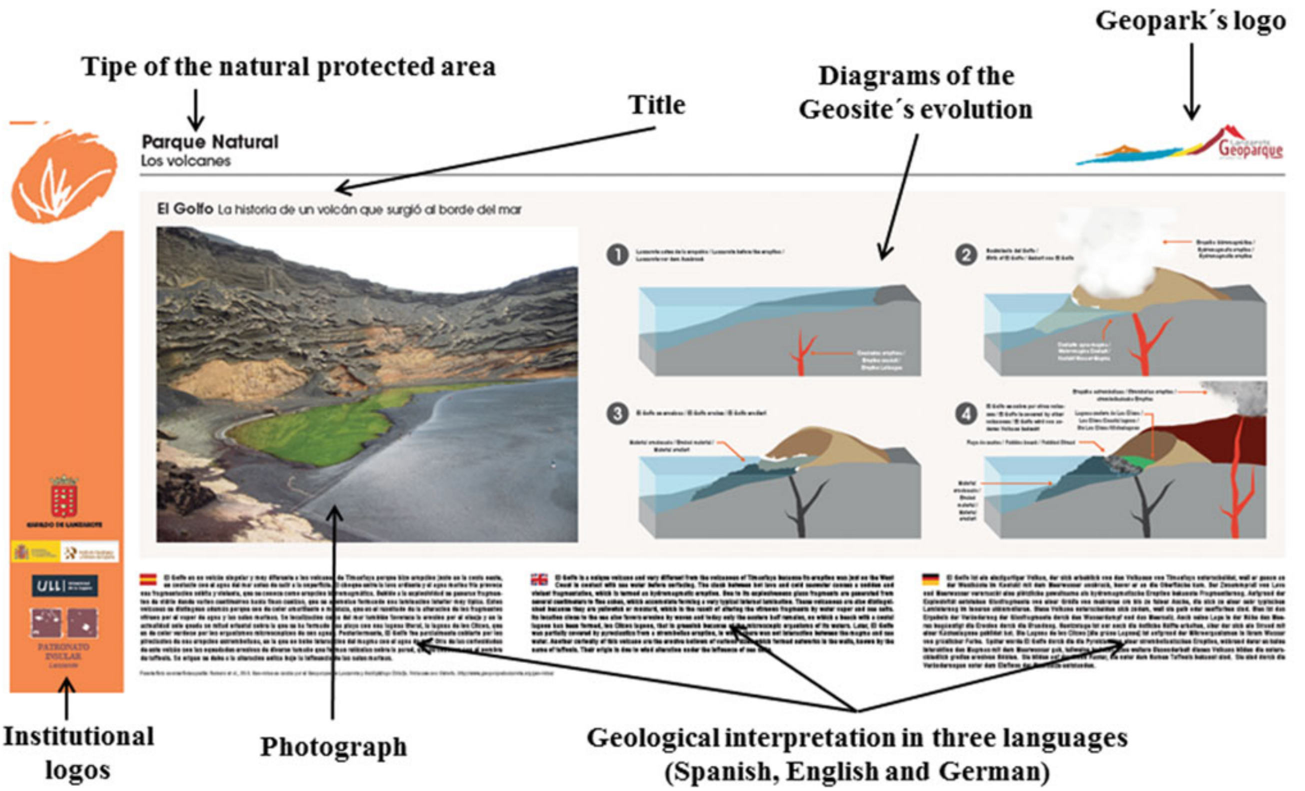


**Fig. 1** Format of the interpretive panels of the Lanzarote and Chinijo Islands UNESCO Global Geopark. Origin and evolution of the El Golfo volcano is explained

they facilitate access to geosites; (2) Maps whose function is to transmit the geology and the message of the panel. Maps are created with ESRI ArcGIS 9.3.1 (http://www.esri.es/es/productos/arcgis/). We used the LIDAR based Digital Terrain Model with 5-m mesh size (National Geographic Information Centre, http://pnoa.ign.es/coberturalidar), the analysis of orthophotos and vertical aerial photographs at scale 1:5000 and 1:18,000, respectively.

### 3.5 Photography

The panels on many occasions include high quality photographs, since it is a documented source that, when chosen correctly, is self-explanatory (Fig. 2). They have been chosen because they offer extended visual information about a part of the geosite that is shown in the panels and are very useful when looking for a reference in the real world and to introduce visitors to the graphic images of geological content.

### 3.6 Graphic Images

Diagrams of geological evolution have been created, which include a time sequence of the geological processes that have occurred in the past, up until the current situation of the geosites. It has unique educational values, since they are one of the best tools to explain active geological processes that have occurred in the past and that do not manifest themselves in the present. The sequence of diagrams allows for a simple and quick visual reconstruction that explains geological concepts and the time scale of events that may seem abstract to the general public at first glance.

## 4 Trails and Geo-Routes by Car

The UGG has also opted for the design of itineraries to interpret and outreach its geoheritage, which can be considered as one of the most effective means for the dissemination of the values of the UGG network, education and sustainable tourism, since they develop alongside the geosites that are interpreted and are a vital experience for visitors. Each geo-route follows the principles and methodology of heritage interpretation, which is the art of revealing the meaning of the natural, cultural or historical legacy in situ, to the public who visits these places in their time off (Tilden 1957; Morales et al. 2000; Association for the Interpretation of Heritage http://www.interpretaciondelpatrimonio.com). One of the best ways for geoheritage outreach is field trips

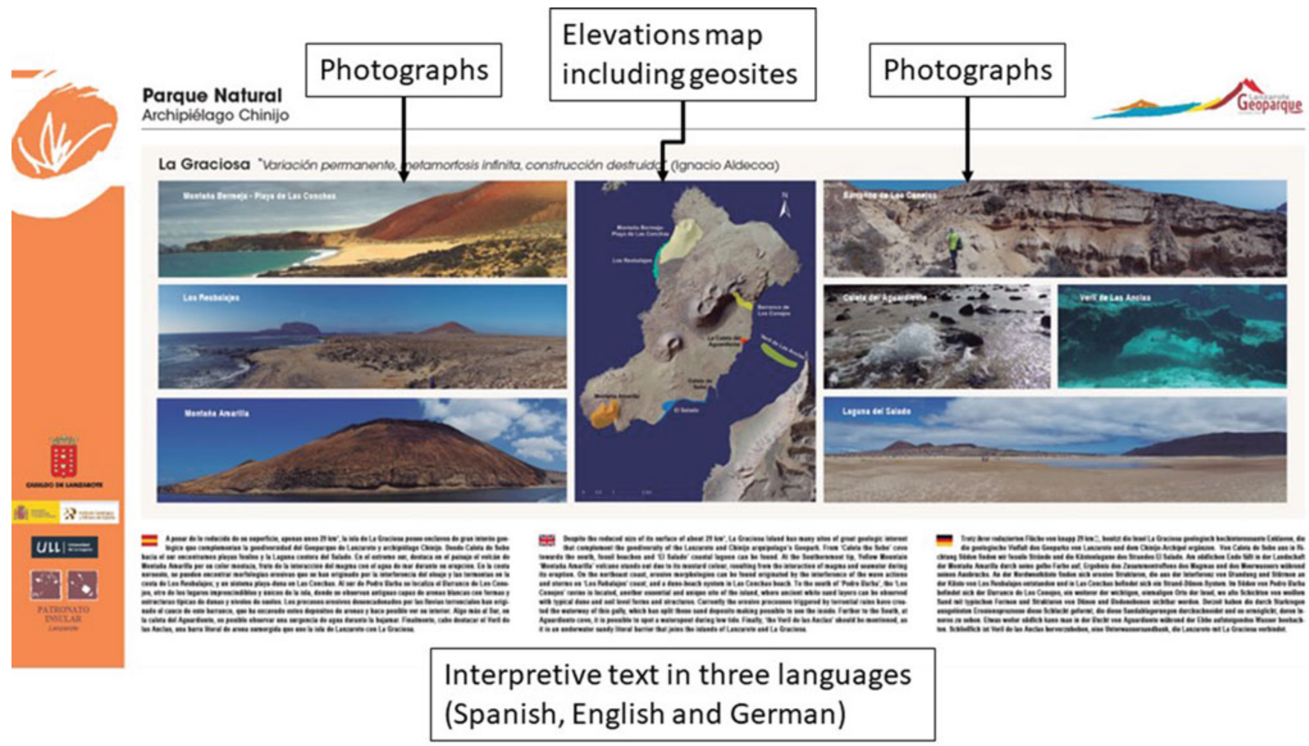


**Fig. 2** Example of panels based on photographs. The location of this table in the Port of La Graciosa, point of entry on the island, illustrates the geosites that can be visited

guided by a group of scientists (Garofano 2014) or by nature guides specialised in interpreting geology.

Interpretative itineraries are routes for the general public that take place in a specific environment (natural, urban, rural, maritime, technological, etc.) in which they are interpreted or explained, with the support of complementary interpretive means (guide interpreter, brochures, panels, posters, augmented reality, etc.), the elements that shape this space and its characteristics and relationships, as well as the importance of the conservation of its heritage values (Tilden 1957; Guerra 1998). In addition, the itineraries designed to be done by car, are routes made in a natural and rural environment, self-guided with the support of brochures, in which the elements of the geoheritage of Lanzarote and Chinijo Islands UGG with their characteristics and relationships are interpreted. Furthermore, they have highlighted the importance of their geoconservation, avoiding stops in geosites common in these types of visits, always conveying a message of respect for nature and especially for rocks, minerals and fossils.

The itineraries by car are designed to help make the most of the various tourist infrastructures that already exist in the geosites of the island (Art, Culture and Tourism Centres of the Cabildo of Lanzarote called CACTS and Timanfaya National Park), although they also include geosites that have been unknown to the general public to date, such as the El Jable sandy area or the volcanic cliff of Famara and, therefore, remain outside the usual tourist circuits, thus contributing to the diversification of island tourism.

## 4.1 Design

The five geo-routes have been designed making the most of the main road network, secondary roads and some tracks, taking into account accessibility, safety and condition of the road, as well as the possibility of stopping when travelling by car. The estimated duration of each geo-route ranges between 4 and 7 h, and it is always possible to do each of them in a day. All the stops are accessible with a passenger car, although in some cases the possibility of taking a dirt road, for more detailed stops, is available. In the cases where an off-road vehicle is necessary, it is duly specified in the corresponding booklet.

All routes avoid passing through vulnerable geosite areas. There are stops designed to observe specific elements of a geosite, geosites in the distance and others included in the visit of interpretation centers (CACT, Art, Culture and Tourism Centres of the Cabildo of Lanzarote), the César Manrique Foundation and other museums in the UGG.

Another condition for the development of the five geo-routes is that they are thematic according to the

**Table 2** Title, location and general theme of the five self-guided geo-routes by car in the Lanzarote and Chinijo Islands UNESCO Global Geopark

| Title | Area | Theme |
|---|---|---|
| Los Ajaches: in the heart of an ancient volcano | South | Formation and evolution of the ancient Ajaches volcanic massif |
| Famara: among valleys and volcanoes | Northeast | Formation and evolution of the Ancient Famara Massif |
| The eruption of La Corona volcano | Northwest | Eruption of La Corona volcano 21,000 years ago |
| Volcanoes with history | Southwest | Volcanic eruption of the Timanfaya (1730–1736) |
| El Jable: sand among volcanoes | Central | Marine sand system that goes by wind across Lanzarote from north to south and its interaction with quaternary volcanism |

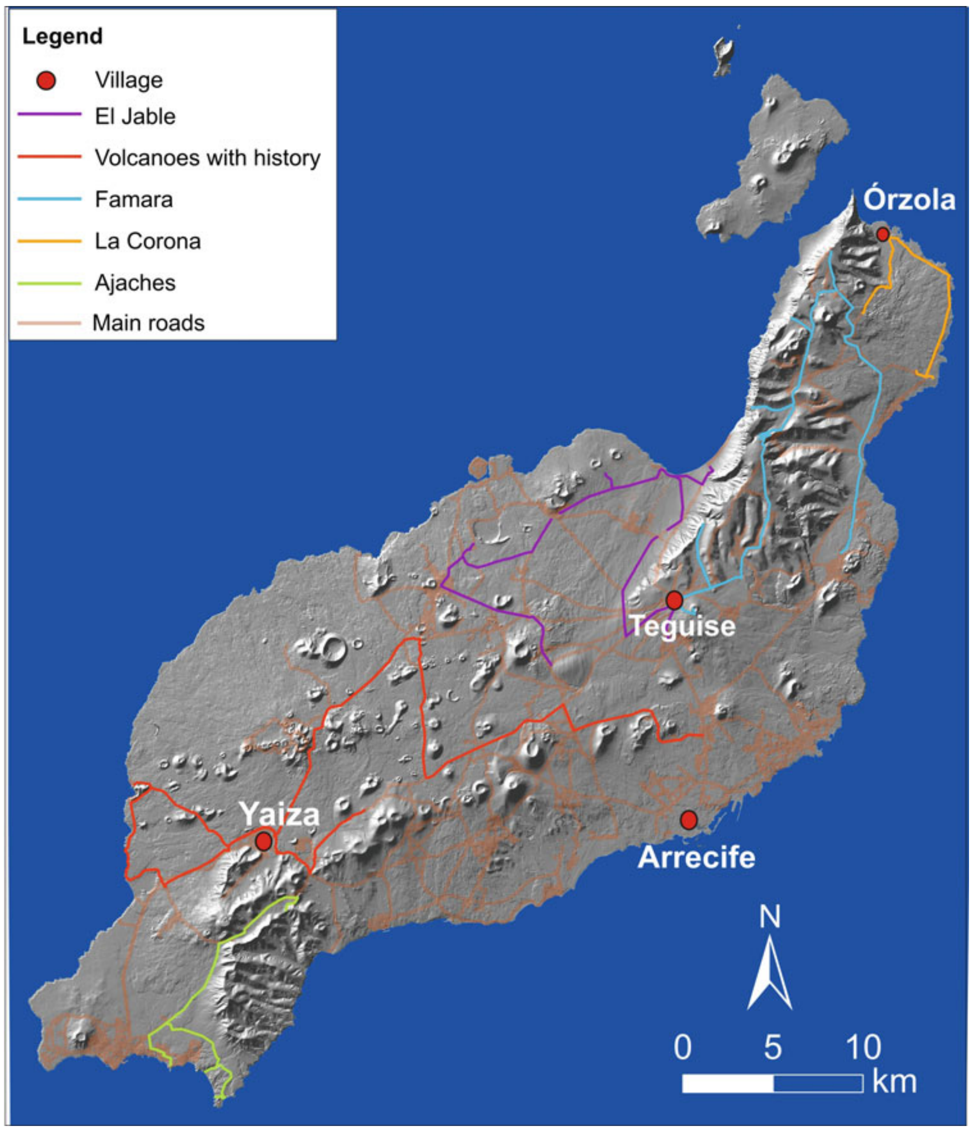


**Fig. 3** Location of the geo-routes by car through the UNESCO Global Geopark of Lanzarote and Chinijo Islands

geological frameworks of Lanzarote. They focus on the ancient volcanic massifs of Ajaches (Vegas et al. 2016) and Famara (Galindo et al. 2016), the Upper Pleistocene eruptions of the La Corona volcano (Sánchez et al. 2016), the historical volcanism de Timanfaya (Romero et al. 2016) and deposits with sedimentary sands of El Jable (Díaz et al. 2017) (Table 2 and Fig. 3). For further information regarding these routes, there is a free download available from the Geopark website (http://www.geoparquelanzarote.org/).

### 4.2 Format of the Brochures

Brochures are the ideal way to support self-guided routes (Guerra 2000). In this case, we have used informative and non-technical language that the general public can understand, considering a person with hardly any knowledge in Geology. In this way, basic principles are introduced about the geological processes that make each of the places visited unique. In addition to explaining the geosites that are included in the routes, they also contain explanations of other interesting geological, historical, cultural and natural aspects throughout the route. So far, they have been published in Spanish, but they will be translated into English and German, which are the main languages spoken by foreign visitors.

The interpretative brochures of the geo-routes (Fig. 4) are 16-pages long, with a standard A5 size, printed on paper. They are arranged as follows: (1) cover and back cover, (2) introduction of the geo-route and the UGG, (3) location, details about the start of each stop, as well as the roads and crossings that visitors must follow, and (4) a series of stops where the interpretation of geosites is backed with the support of maps, texts, photographs and diagrams.

#### 4.2.1 Cover and Back Cover

The common structure of the covers is divided into: (1) title of the geo-route, which draws the visitor's attention to a particular geological process or element (Table 2, Fig. 3); (2) cover photo, high quality, of one geosite that is covered in the geo-routes; (3) UGG logo; and (4) authors. The back covers contain: (1) graphic image, which is usually a reproduction of old engravings, with the name of its author; (2) the UGG logo and a text; (3) explanatory text of the cover photo.

#### 4.2.2 Introduction to the Geo-Route and the Geopark

The first page has a simple explanation text with the geology covered in the routes, with a brief time line of events and what the geological theme of the suggested stops is. It goes along with a simplified colour map that corresponds to the main geological units of the UGG for a better understanding


**Fig. 4** Left: Front cover of one of the leaflets of the geo-routes by car. Right: Detail of one of the stops on the brochures which includes photography and geological diagrams with the evolution of processes that originate the visited geosite. The texts are very brief and do not use technicalities

of the territory. This page always ends with a text box that explains the basic objectives of the UGG.

#### 4.2.3 Suggested Route

On self-guided routes, it is essential that the itinerary be clear to visitors, through maps and a series of basic recommendations. The text of the brochures indicates where the geo-route begins and ends, and the estimated time to complete it. It also includes a color map to locate visitors, indicating the roads and the location of the stops. They have been designed on a grey relief background, easy to understand and superimposed with colours indicating the situation of the geosites that are visited.

#### 4.2.4 Stops

The stops consist of several blocks of text, the main one is generally used for information about the geosite that is visited. The texts are divided into four categories: (1) titles of the stops, which are suggestive and inspiring to draw attention to the geological element of each stop; (2) location text, which explains how to get to each stop and where to park the vehicles; (3) text with brief, simple, concise and rigorous messages, which develop a single main idea that corresponds to what visitors can see from the viewpoint at each stop; and (4) Explanatory text of the graphic images.

All the stops include high quality photographs, since it is a documentary source that offers extended visual information about a part of the geosite, allowing for geographical location of the stop, used as a reference in the real world. Some of the stops also contain cartographic elements, avoiding geological cartography because it is more complex. User-friendly maps have been used to facilitate access to the stops, using as a topographic basis, as in the explanatory panels.

Diagrams of geological evolution have only been used in stops that deal with a geological element where it is necessary to interpret the processes that originated it, with a block sequence in 3D (Fig. 4). These diagrams are essential because they are used to answer many questions that visitors may ask.

#### 4.2.5 Back Cover

The brochures end with a back cover with a common design. It includes a representative photograph of the geo-route, the logos of the institutions involved in the information contained in the brochures and the list of authors, with their professional affiliation.

## 5 Conclusions

Geotourism is presented on the Lanzarote and Chinijo Islands UNESCO Global Geopark as an alternative sustainable territorial development that guarantees the conservation of geoheritage through education and interpretation. With the installation of 17 interpretative panels and five geo-routes to be done by car, it is intended to contribute to the outreach of the geoheritage of this UGG, improving the knowledge the local population has regarding their environment and the experience of almost 3 million tourists that go to this destination. In both cases there is not always a clear interest in geology, but there is an appreciation of a fantastic volcanic landscape. To facilitate an explanation about the formation and the geological processes that build them is to help satisfy one of the concerns human beings have, curiosity.

The interpretative panels and the geo-routes to be done by car, go through the geosites with the highest tourist value of this UGG (Galindo et al. 2014). These tourist infrastructures are shown as a means of effectively disseminating the geoheritage and its interaction with other natural and cultural values that make this tourist destination a unique place for visitors. The proposed stops and viewpoints chosen to locate the panels cover a great variety of elements and geological processes representative of the formation of these islands as a basis of the territory and of the environment, biodiversity, traditional trades and the culture of the Lanzarote and Chinijo Islands UGG. The infrastructure generated opens a wide range of possibilities and can be used by local tourist guides, with the possibility for tourist agencies to incorporate the new itineraries created to be offered to visitors, thus expanding the offer of nature tourism and contributing to the outreach of its geoheritage. From the UGG it is necessary to create quality geotourism, that satisfies visitors and that at the same time provides basic geological knowledge.

Governments and public administrations must guarantee the protection of geoheritage through the enactment of laws and regulations that recognise the value of geological heritage. However, the greatest challenge for geoconservation is society's awareness when it comes to respect and preservation of the geoheritage by means of educational and tourism activities that guarantee its conservation. Only then, shall the geoconservation be a real fact.

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# Lanzarote and Chinijo Islands: An Anchialine UNESCO Global Geopark

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**Abstract**

The Lanzarote and Chinijo Islands UNESCO Global Geopark hosts one of the most extensive and diverse volcanic anchialine ecosystems in the world, consisting of water bodies with marine origin that penetrated inland through coastal crevicular systems. Marine infiltration is facilitated by the low rainfall and the permeability of the coastal terrains. Best known for Túnel de la Atlántida, Lanzarote has other types of anchialine habitats, such as pools, lakes, and even hand-made wells, all of them interconnected with the crevicular system. So far, 39 endemic stygobitic species of crustacean, annelids, and platyhelminthes have been described in the island. Some of them belong to lineages previously interpreted as Tethyan vicariant relicts because they belong in ancient groups restricted to caves situated in areas along the coastline of the ancient Tethys Sea, such as Mexico, Bahamas or Western Australia. Others, instead, have clear affinities with deep-sea lineages, suggesting that their ancestors might have dispersed into the island from surrounding deep-sea environments. In overall, while the anchialine habitats of Lanzarote are relatively small in comparison to other regions, the presence of so many species with such a diverse origin have puzzled zoologists and biogeographers throughout the 20th century, who have regarded the island as a model to understand the origin and evolution of similar groups in other areas of the world. The anchialine habitats in Lanzarote are subject to intense recreational use and the island itself is a major touristic destination. However, geologist and biologist working in the local government offices, as well as in UNESCO Global Geopark and Biosphere Reserve Institutions have started close collaborations with the touristic centers and independent scientist from several universities and research centers around the world with the goal of implementing novel conservation policies based on the results of state-of-art research. This strategy will ensure not only a better understanding of the anchialine ecosystems in the island in the near future, but also its long-term preservation.

**Keywords**

Anchialine • Stygofauna • Evolutionary biology • Lanzarote • Cave fauna

## 1 What Anchialine Ecosystems Are?

Anchialine ecosystems consist of tidally influenced subterranean water bodies with marine origin, often located within crevicular and cavernous karst and volcanic terrains, extending inland to the limit of the seawater penetration (Bishop et al. 2015). The term derives from the Greek word *anchialos* or 'near the sea', and it was coined to describe pools with brackish or marine waters hosting assemblages of 'red shrimp' never found elsewhere in marine or freshwater environments (Holthuis 1963). Given their tidal fluctuations, these pools were assumed to have subterranean connections with the surrounding marine and inland waters. After cave diving techniques were revolutionized scientists, investigations in several of these pools showed that they represented entrances to extensive underwater labyrinths, many of which contain both hydrological and faunistic components fitting

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original 'anchialine' definition by Holthuis (Sket and Iliffe 1980; Iliffe et al. 1984b). Despite both geological and geographical differences, cave diving explorations consistently revealed caves with comparable hydrology that hosted assemblages of extraordinary animals. Among these animals, mostly crustaceans, were the new class Remipedia (Yager 1981), the new peracaridan order Mictacea (Bowman et al. 1985), the new copepod order Platicopioida (Fosshagen and Iliffe 1985), as well as several new families, genera, and numerous new species (Fosshagen and Iliffe 1991, 1998; Sterrer and Iliffe 1982; Huys 1996; Huys and Iliffe 1998). Nowadays, anchialine ecosystems are the focus of multidisciplinary integrative research from a variety of scientific fields, including microbiology, ecology, and hydrology (Wicks and Humphreys 2011).

Anchialine systems are more often found in karstic limestone throughout tropical localities and typically contain both freshwater and marine water layers (Brankovits et al. 2017). The most extensive anchialine systems are described from the Yucatán Peninsula (México), being the largest anchialine cave the Sistema Ox Bel Ha (Quintana Roo) with more than 270 km of surveyed passages interconnect with hundreds of entrance pools (Coke 2012). Other geographical areas with large karstic anchialine systems are the Bahamas, Bermuda, and the Balkan Peninsula. Anchialine systems are also present in volcanic terrains although they are less common and mostly restricted to island locations, such as the Canary Islands, Galapagos, Ascension, Hawaii, and Iceland (Iliffe and Kornicker 2009). Anchialine habitats in these locations are found in the form of lava tubes, tectonic faults, and lava rock pools (Iliffe 1992). Lava tubes are the most extensive of these three forms, and they are originated during eruptions of fluid basaltic lava in which the slow-moving surface is cooled forming a drain that favors the progression of the lava flow inside for distances ranging from few meters to several kilometers. Once the eruption ceases, the hollow drain becomes the lava tube (Dragoni et al. 1995). Typically, lava tubes are formed above the sea level, flowing towards lower elevations until the lava reaches the coastline and is suddenly cooled by the surrounding marine waters, preventing the tube from progressing any further. The longest anchialine lava tubes of the world are located in the Canary Islands, but they have also been reported in Hawaii and Galapagos archipelagos (Kensley and Williams 1986; Figueroa and Hoefel 2008; Martínez et al. 2016). Anchialine volcanic tectonic faults are better described in the Galapagos, where they are known as 'grietas' or faults (Iliffe 1992). These faults are formed when a crustal block moves up or down with respect to a neighbor along a nearly vertical fracture, producing series of high cliffs and deep fissures (Simkin 1984). Those fissures close to the coastline may extend below the sea level and contain anchialine pools. Finally, lava rock pools occur in low-lying terrain near the coastline, where highly uneven and irregular lava flows have left behind low spots, cracks or gas pockets that extend below the sea level. Anchialine lava pools are an iconic anchialine habitat in the Hawaiian archipelago (Brock and Bailey-Brock 1998).

## 2 Lanzarote and Chinijo Islands: An Anchialine UNESCO Global Geopark

Lanzarote harbors the most extensive anchialine ecosystem in the Eastern Atlantic and one of the most extensive volcanic anchialine habitats in the world. The presence of this ecosystem in Lanzarote is a consequence of the marine infiltration through the coastline, which is favored by the low annual rainfall as well as the high permeability of the volcanic materials along the coastline. These two features are intimately related to the geological history of the island (Martínez et al. 2016) (Fig. 1).

The arid climate of Lanzarote is favored by its low altitude. The highest mountains of the island are Los Ajaches and Famara massifs, which today consist of dry and highly eroded ridges reaching 560 and 671 m high respectively. However, they looked very differently during their infancy, 14.5–3.8 years ago, when geologist think that they were higher than 4000 m and capable to collect the moisture carried by the trade winds (Carracedo and Badiola 1993). The precipitation resulting from this moisture facilitated the growth of laurel forests, and also infiltrated the volcanic rocks forming a relatively shallow aquifer, thicker in the interior of the island and tapering towards the coastline. However, as erosional processes reduced Los Ajaches and Famara massifs, they progressively lost their capability to capture of trade-wind precipitation. Eventually, the mountains laid below the trade-winds moist layer, bringing as a consequence a dramatic reduction of the rainfall and the aridification of the island (Machín and Pérez-Torrado 2005). The dry climate favored the overall shrinking of the freshwater aquifer, which was progressively replaced by marine waters infiltrated through the coastline (Custodio 1992).

The permeability of the volcanic materials in the coastal lowlands depends on the presence of porous volcanic rocks, as well as crevices and lava tubes, which produce a network of interconnected void spaces that can be occupied by the infiltrating marine waters. The precise extension and distribution of this crevicular system in Lanzarote remains unknown, but it is most likely non-homogeneous and concentrated in certain areas along the coastline depending on the nature and composition of the volcanic terrains, which varied during different eruptions and across different areas (Carracedo and Badiola 1993). Most anchialine habitats in Lanzarote are known from Malpaís de la Corona (Fig. 2a), a stark, jagged lava field on the northern tip of the island originated from eruptions of La

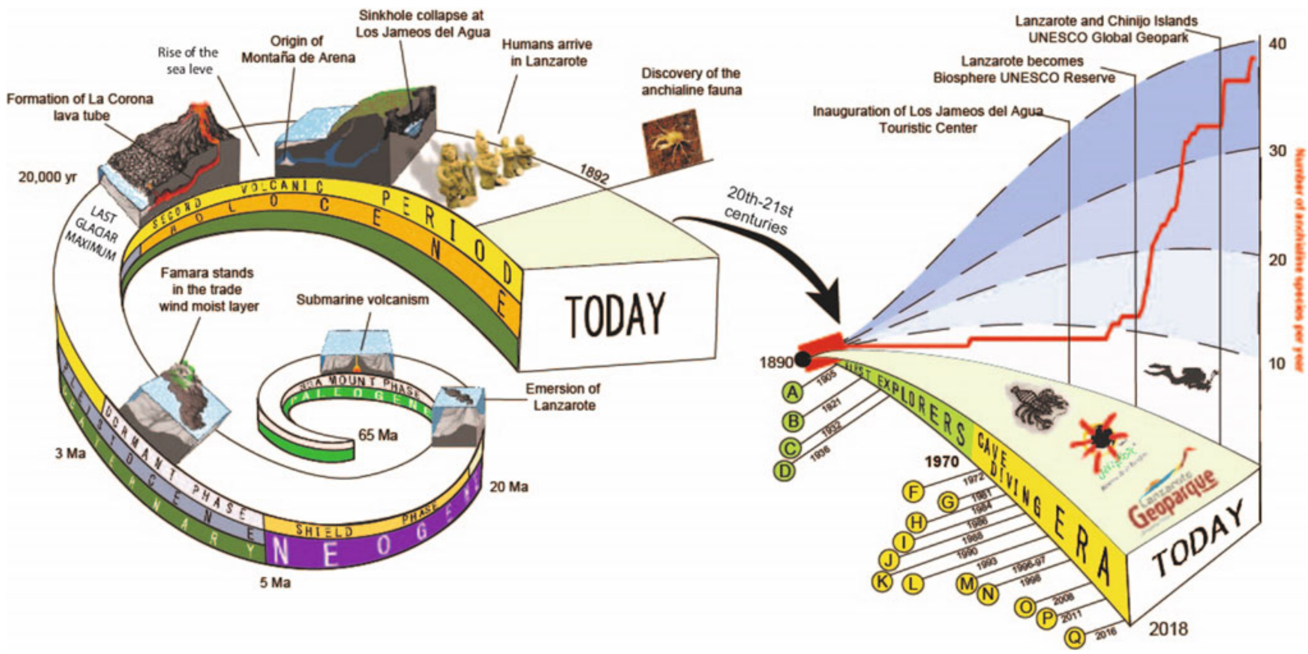


**Fig. 1** Timeline showing the major events on the history of Lanzarote and its anchialine ecosystems. The main events are highlighted on both timelines, corresponding the whole geological history of the islands (left) and the 20th and 21st centuries (right). A. Studies of the morphology of *Munidopsis polymorpha* by Calman. B. Studies on the anatomy of the reduced eyes of *Munidopsis polymorpha* by Harms. C. Description of mysid crustacean *Heteromysoides cotti*. D. Monograph of the ecology of Los Jameos del Agua lake by Fage and Monod. F. First dive in Túnel de la Atlántida by Hermanos Guerra. G. Italian "Mondo Somerso" and Spanish 1st STD Expeditions. H. Description of remipede *Morlockia ondinae*, and first ecological studies at Montaña de Arena. I. The GLPS/FFS-SCB Expedition reaches the end of Túnel de la Atlántida, studies in wells by Wilkens and collaborators. J. Revista GEO Cave Diving Expedition reaches the end of Túnel de la Atlántida, first studies in Montaña Bermeja anchialine pools. K. Ecological studies on the biology of *Munidopsis polymorpha*. L. Discovery of Charcos de Luis in Caletón Blanco. M. Discovery of the interstitial fauna at Los Jameos del Agua. N. Discovery of several cave copepods. O. Atlantida Cave Diving Expedition and Discovery of *Morlockia atlantida* and *Meganerilla cesari*. P. 1st International Workshop to Cave and Anchialine Meiofauna and discovery of *Megadrilus pelagicus*

Corona Volcano. The low altitude and the high permeability of the volcanic materials in this area favors marine infiltration at least 500 m inland. The most remarkable geological feature of the Malpaís de la Corona is La Corona lava tube, which traverses the lava field over 6.2 km in southeasterly direction, continuing for an additional 1.6 km into the Atlantic Ocean beyond the present coastline of the island, and ending at a maximum depth of 64 m (Carracedo et al. 2003). The cave was primarily formed from the eruption of a lateral vent off La Corona Volcano, although the complex morphology of the cave and the presence of upper and lower sections suggests that several volcanic episodes were involved during speleogenesis (Jantschke et al. 1994). Age estimates based on potassium-argon radiometric methods dated the formation of La Corona lava tube to the last glacial maximum (21,000 ± 6500 years), when the sea level was approximately 50–100 m lower than today (Church et al. 2001). These estimates suggest that the lava tube was formed under subaerial conditions across La Corona lava field until the lava flow was abruptly stopped by the sudden cooling consequence of its contact with the Atlantic Ocean. Flooding of La Corona lava tube occurred more recently, after the last glacial maxima, when the sea level rose to its present position (Carracedo et al. 2003) (Fig. 2e).

La Corona lava tube is divided into several sections by secondary collapses or 'jameos', although only three of them lead to anchialine section (Carracedo et al. 2003). The most inland of these sections is known as Cueva de Los Lagos, which consists of a sinkhole opening 600 m from the coastline and leading to a partially flooded passageway that ends in a short sump (Martínez et al. 2016). Downstream, this sump is separated by an artificial collapse from the second section, known as Los Jameos del Agua, which includes a partially illuminated, tidal lake integrated into a tourist center (Wilkens and Parzefall 1974) (Fig. 2f, g). The third anchialine section, known as Túnel de la Atlántida, is also accessed from a pool in the touristic center, from which a 1.6 km-long, completely submerge passageway extends under the seafloor without any conspicuous connection to the overlying ocean. Túnel de la Atlántida ends abruptly at a maximum depth of 64 m and it represents the longest flooded lava tube in the world.

Other geological features that allow human access to the anchialine subterranean waters are the so-called anchialine

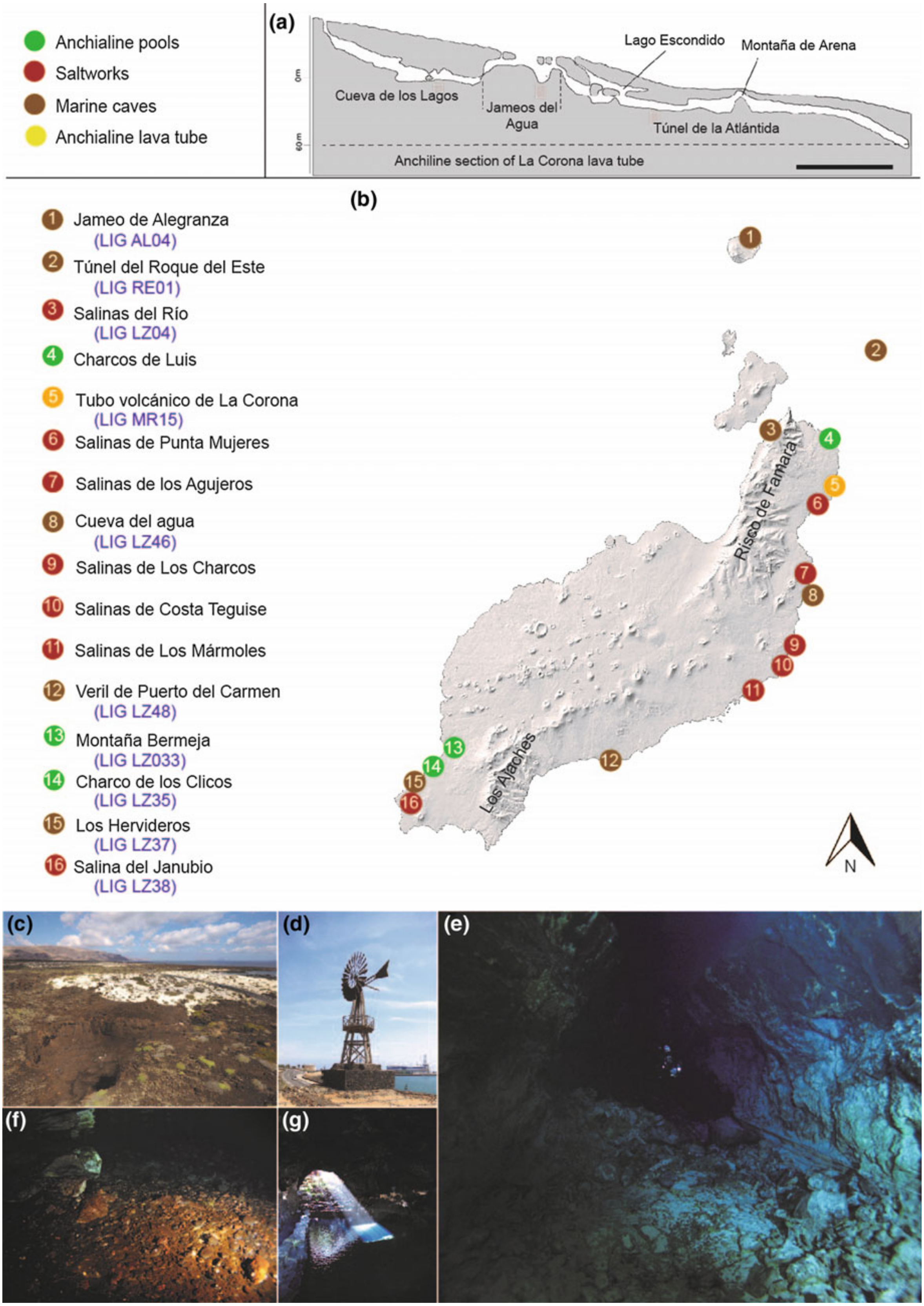


**Fig. 2** Anchialine and marine subterranean localities known in Lanzarote. **a** Profile schematic representation of the anchialine sections of La Corona lava tube. The vertical axis is not scaled in relation to the horizontal one. **b** Distribution of anchialine and marine caves, wells and pools in Lanzarote and the Chinijo Islands. The numbers refer to the localities listed on the left. The colours indicated different types of habitats. **c** Aerial view of Charcos de Luis. **d** Abandoned anchialine well in Puerto de los Mármoles. **e** Cave diver hovering in Túnel de la Atlántida, ca. 250 m from the entrance. **f** Underwater image of Los Jameos del Agua lake, showing the brown carpet of benthic diatoms and high densities of *Munidopsis polymorpha*. **g** Los Jameos del Agua lake photographed early in the morning, when sunlight beams illuminate the Western part of the lake

pools. They consist of small depressions that extend beyond the level of the subterranean anchialine waters exposing a comparatively small water body to the surface. The pools are indirectly connected to the sea thorough crevices and fluctuate with the tides. Main anchialine pools in Lanzarote are Charcos de Luis, near Caletón Blanco, and Montaña Bermeja pools, near Los Hervideros (Huys 1988; Wilkens et al. 1993). They both consist of comparatively small, rocky depressions situated near abandoned cinder mines, and therefore it is not currently known if they are natural or manmade. The lagoon at the beach in El Golfo, known as Charco de los Clicos, could represent an additional anchialine habitat. However, this hypersaline lake shows minimal tidal fluctuations and its water composition differs substantially from that of the ocean. The high concentrations of microscopic algae, mainly diatoms and dinoflagellates, give the Charco de los Clicos an intense green color (Luque and Medina 1997).

A third type of anchialine environment in Lanzarote is represented by manmade wells, which were hand dug between the 15th and 19th centuries along the coastline of the island in order to pump subterranean waters into saltpans for salt production (Luengo 1994). Most of these wells are relatively small, ranging between 2–3 m in diameter and averaging 10 m in depth. Since construction, many of these wells have been destroyed, and those that remain are mostly abandoned. Active wells can be found in Salinas del Janubio, Salinas de El Río, as well as around the towns of Costa Teguise, Guatiza, Los Cocoteros (Fig. 2d), and Punta Mujeres (Wilkens et al. 1986).

## 3 The Life Hidden Amongst the Lavas: A Story of Discoveries

There are 39 stygobitic species (aquatic cave specialists) in Lanzarote, including 27 crustaceans, 11 annelids, and two flatworms (Martínez and Gonzalez 2018) (Fig. 3).

Twenty-eight of them are restricted to the flooded sections of La Corona lava tube, whereas the remaining 12 occur in anchialine wells or pools. Non-stygobitic, marine species are found in certain anchialine ecosystems, being more common in anchialine pools and Los Jameos del Agua anchialine lake, where the presence of light and higher trophic resources facilitate their settlement (Martínez et al. 2009). The main most relevant anchialine environments known in Lanzarote are summarized in Table 1.

### 3.1 First Discoveries: The Fauna of Los Jameos Anchialine Lake

The earliest discoveries of anchialine endemic species in Lanzarote were made by European researchers who investigated Los Jameos del Agua during short visits (Martínez et al. 2016). The first stygobite discovered by the European scientist was the squat lobster *Munidopsis polymorpha* (Fig. 3 k). However, these lobsters were known long before by the inhabitants of the north of Lanzarote, who called them 'grillos blancos' (white crickets) (Fig. 1). Today, *Munidopsis polymorpha* is very popular amongst locals and tourists and it has been chosen as the animal symbol of the island under the vernacular name of 'jameíto' in reference to the high densities that it exhibits in Los Jameos del Agua lake. *Munidopsis polymorpha* was formally described by zoologist Karl Koelbel from the Natural History Museum of Vienna (Austria) in 1892 from samples collected by Oskar Simony (Koelbel 1892). During his early description, Koelbel already highlighted the remarkable adaptations of *Munidopsis polymorpha* to the darkness of the cave and its similarity with certain deep-sea forms. This resemblance was studied in higher details by zoologists Jürgen Harms (University of Marburg, Germany) and William Calman (University College of Dundee, Scotland) (Calman 1904; von Harms 1921). This last author also described the crustacean mysid *Heteromysoides cotti* (Fig. 3h), named British explorer and zoologist Hugh Cott who collected the types series (Calman 1932). Observations from these works were summarized together with an ecological description of Los Jameos del Agua lake in a monograph published in 1936 by zoologists Louis Fage and Théodore Monod from the Muséum National d'Histoire Naturelle de Paris (Fage and Monod 1936).

The discoveries continued in the late 1960s with the contributions by German zoologists Horst Wilkens and Jakob Parzefall (University of Hamburg). Although most of their research focused on the biology and behavior of *Munidopsis polymorpha* and the ecology of Los Jameos del Agua lake (Wilkens 1970; Wilkens and Parzefall 1974; Parzefall and Wilkens 1975; Wilkens et al. 1990), they also discovered several new cave species as a result of their sampling effort. Their discoveries include isopod *Curassanthura canariensis*, ostracod *Humphreysella wilkensi*, copepod *Neoechinophora karaytugi*, and scale worm *Gesiella jameensis* (Hartmann 1985; Pettibone 1985; Wägele 1985; Huys 1996). Our knowledge on the fauna of Los Jameos del Agua was completed by Spanish zoologist Jorge Núñez and his team (Universidad de La Laguna), who discovered the annelids *Fauveliopsis jameoaquensis*, *Leptonerilla diatomeophaga*, *Macrochaeta* n. sp. and *Mesonerilla* n. sp. in the cinder deposits of the lake (Núñez et al. 1997).

Los Jameos del Agua lake (Fig. 2g) is the only anchialine section in La Corona lava tube that receives sunlight indirectly. The light intensity varies across the lake and during different day hours, but still ensures primary production by pelagic microscopic algae and a dense bed of benthic diatoms (Brito et al. 2009). This primary production sustains comparatively dense populations of animals and allows the coexistence of stygobitic species and typically marine forms

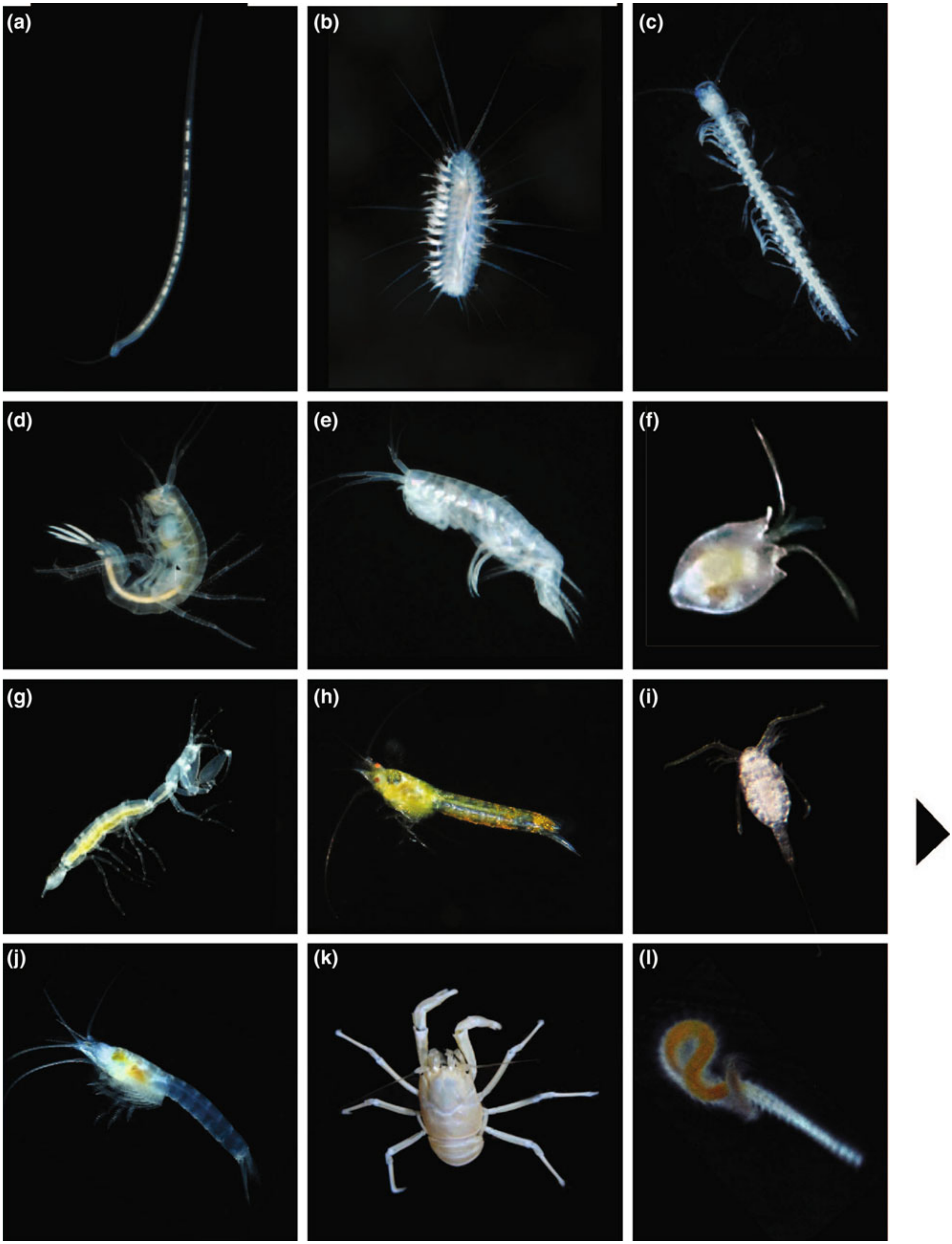


**Fig. 3** Stygobitic animals inhabiting La Corona lava tube. **a** Protodrilid annelid *Megadrilus pelagicus*. **b** Scale worm annelid *Gesiella jameensis*. **c** Remipede *Morlockia ondinae*. **d** Amphipod crustacean *Hadzia acutus*. **e** Amphipod crustacean *Spelaeonicippe buchi*. **f** Ostracod crustacean *Humphreysella* sp. **g** Isopod crustacean *Curassanthura canariensis*. **h** Mysid crustacean *Heteromysoides cotti*. **i** Copepod crustacean *Palpophria aestheta*. **j** Undescribed mysid crustacean *Burrimysis* n. sp. **k** Squat lobster *Munidopsis polymorpha*. **l** Undescribed annelid spionid *Prionospio* n. sp

**Table 1** Summary of the most important localities regarding the presence of anchialine and marine subterranean fauna in Lanzarote

| Anchialine/marine sites | Geosite | Geopark code | Category | Stygobitic species |
|---|---|---|---|---|
| Famara freshwater mines | Valles colgados de Famara | Lz07 | Freshwater mines | – |
| Charco de los Clicos | El Golfo | Lz35 | Lagoon, maybe anchialine | – |
| Charcos de Montana Bermeja | – | – | Anchialine pool | 3 |
| marine caves at Los Hervideros | Los Hervideros | Lz37 | Marine cave | – |
| Tunel de la Atlantida | Tubo volcanico de la Corona—Tunel de la Atlantida | Lz06 | Flood anchialine lava tube | 33 |
| Jameos del Agua | Tubo volcanico de la Corona—Tunel de la Atlantida | Lz06 | Lake in anchialine lava tube | 13 |
| Cueva de los Lagos | Tubo volcanico de la Corona—Tunel de la Atlantida | Lz06 | Partially flood anchialine lava tube | 16 |
| Charcos de Luis | Caleton Blanco | MR04 | Anchialine pool | 3 |
| Salinas del Rio | Salinas del Rio | Lz04 | Wells | – |
| Jameo de Alegranza | Jameo de Alegranza | AL04 | Marine cave | – |
| Tunel del Roque del Este | Tunel del Roque del Este | RE01 | Marine cave | – |
| La Catedral | Veril de Puerto del Carmen | Lz47 | Marine cave | – |
| Cueva de las Gambas | Veril de Puerto del Carmen | Lz47 | Marine cave | – |
| Cueva del Agua | Cueva del Agua | Lz46 | Marine cave | – |
| marine caves | Charco del Palo—Puerto Moro | Lz45 | Marine cave | – |
| Salinas de Janubia | Salinas de Janubia | Lz38 | Wells | – |
| Salinas de los Agujeros (Los Cocoteros) | – | – | Wells | 2 |
| Salinas de los Mármoles | – | – | Wells | 3 |
| Salinas de Costa Teguise | – | – | Wells | – |
| Salinas de Punta Mujeres | – | – | Wells | 2 |
| Salinas de los Charcos (Guatiza) | – | – | Wells | – |

The name of the geosite that hosts them is indicated when applicable, along with the type of habitat and the number of stygobitic species known in each place

that otherwise cannot survive in the dark sections of the cave (Wilkens and Parzefall 1974; Martínez et al. 2009). Dense populations of mysids, copepods, and ostracods swim in the water column, while the macroscopic benthic communities are dominated by the stygobitic squat lobster *Munidopsis polymorpha* and the peanut worm *Bonellia viridis* (Wilkens and Parzefall 1974; Wilkens et al. 1990; Brito et al. 2009). These large animals feed on the microscopic communities that colonized the spaces amongst the cinders, and include diatoms, dinoflagellates, annelids, and crustaceans (Núñez et al. 1997; Worsaae et al. 2009).

## 3.2 The Era of Cave Diving: Túnel de la Atlantida

The first dive in Túnel de la Atlántida was performed by the Hermanos Guerra in 1972, who penetrated the first 370 m of the cave using regular open water diving equipment (Oromí and Martín 1990). However, it was during the 1980s when the development of cave diving techniques motivated several international teams to compete to discover the end of the lava tube (Lainez and Pérez-Rijo 1999). The first of these teams integrated the Italian "Mondo Somerso" Expedition, reaching 518 m of penetration in February 1981. They were soon followed by the First Spanish STD Expedition, which explored 861 m in August of that year, discovering Montaña de Arena (see below). Divers from the USA pushed these marks in 1983, when an expedition led by cave diver Sheck Exley reached 1377 and 53 m depth (Exley 1983). A new record was stablished soon after in 1983 by the Second Spanish STD Expedition, whose divers explored 1570 m and stopped only 30 m from the end of the cave due to technical problems. The Second STD Expedition provided the first monograph on the fauna of the cave, and described in detail the so-called Montaña de Arena, a 30 m high sand dune formed approximately 750 m from the entrance by sediments entering the cave through a non-visible crack in the ceiling (García-Valdecasas 1985). The end of the cave at 1618 m was reached in 1986 by the GLPS and FFS-SCB cave diving teams with Belgian and French members (Isler 1987). This record was also equaled by the Spanish GEO Expedition in 1987 (Molinero 1988).

Although the main focus of these expeditions was the exploration of the cave, they brought along fascinating zoological discoveries. The most impressive amongst them was the remipede *Morlockia ondinae* (Fig. 3c), first discovered by bioespeleologist Thomas M. Iliffe in 1983 (Texas A&M University) (Iliffe et al. 1984b), but described by zoologist Antonio García-Valdecasas in 1984 (Museo Nacional de Ciencias Naturales de Madrid) (Garcia-Valdecasas 1984). These and subsequent diving expeditions mainly organized by Iliffe yielded the discovery of additional stygobitic animals including the annelid *Speleobregma lanzaroteum*, thermosbaenacean *Halosbaena fortunata*, ostracods *Humphreysella phalanx* and *Eupolycope pnyx*, and copepod *Enantronia canariensis* (Bertelsen 1983; Bowman and Iliffe 1986; Kornicker and Iliffe 1995; Jaume and Boxshall 1997; Jaume et al. 1999; Koenemann et al. 2009).

These discoveries motivated new expeditions between 2008 and 2017 with the aim to better investigate the fauna of the cave. The main of those were the 2008 Atlantida Cave Diving Expedition led by Prof. Thomas M. Iliffe, and the 1st-international Workshop to Anchialine and Marine Meiofauna 2011 organized by Alejandro Martínez and Katrine Worsaae (University of Copenhagen, Denmark). The surveys of the water column done during these two expeditions led to the description of the new remipede *Morlockia atlantida* (Koenemann et al. 2009), and the annelids *Megadrilus pelagicus* and *Speleonerilla isa* (Martínez et al. 2017; Worsaae et al. in press); as well as the first genetic analyses of annelids *Speleobregma lanzaroteum* and *Gesiella jameensis* (Fig. 3b) (Martínez et al. 2013; Gonzalez et al. 2018a). These expeditions also focused on the fauna at the sediments of Montaña de Arena, leading to the discovered of new species of annelids, crustaceans, and flatworms (Núñez et al. 2009; Worsaae et al. 2009; Gobert et al. 2017).

The total darkness of Túnel de la Atlántida favors the presence of stable water temperature (ca. 18 °C) and lower dissolved oxygen (ca. 3.7–5.7 mg/L) compared to the surrounding ocean (Wilkens et al. 2009). Contrary to other anchialine caves, the water column in Túnel de la Atlántida is poorly stratified, fully marine, and affected by minimal currents due to tidal exchange (Jantschke et al. 1994). These currents produce small fluctuations of the oceanographical parameters with slightly lower salinities and higher oxygen during the low tide (Wilkens et al. 2009). The lack of sunlight prevents photosynthetic activity, and the cave ecosystems is sustained by the particulate organic material introduced through tidal exchange or infiltration across the overlying lava rock (Iliffe et al. 2000; Wilkens et al. 2009). It remains unknown if chemoautotrophic production from low concentrations of dissolved inorganic compounds occur within the dark remote sections of La Corona lava tube, as it has been described in other anchialine systems in the Caribbean (Pohlman 2011; Brankovits et al. 2017). Since particulate organic matter is mostly found in the water column, most of the stygobites are suspension feeding crustaceans (Fig. 3d–f, i, j) or annelids capable of collecting small food particles while swimming (Iliffe et al. 2000). These suspension feeders serve as preys to the remipedes *Morlockia ondinae* and *Morlockia atlantida*, the scale worm *Gesiella jameensis*, and the copepod *Enantronia canariensis*. While remipedes and copepods capture the preys with specialized raptor appendages, *Gesiella jameensis* uses a protruding proboscis armed with two pairs of jaws (Koenemann et al. 2007; Gonzalez et al. 2018b). The claws of the remipedes are connected to venomous glands capable of producing a lethal cocktail of peptidases and putative neurotoxic proteins (von Reumont et al. 2017).

The benthic environments in Túnel de la Atlántida mostly include rock surfaces and patches of lava debris distributed throughout the lava tube (Martínez et al. 2009). These patches superficially resemble interstitial environments but exhibit similar permeability to that found at the surrounding subterranean crevicular environment. Therefore, they do not harbor typical interstitial species but rather a few stygobites in low abundances. The only exception is the dimly illuminate debris near the entrance of the cave, where a comparatively high number of species can be found (Fig. 2f) (Martínez et al. 2016). True interstitial environments are characterized by smaller sized sediment particles, which in La Corona are restricted to Montaña de Arena. The spaces amongst the sediments of the dune harbor a rich fauna which includes typical interstitial groups such as annelids, platyhelminths, gastrotrichs, gnathostomulids, priapulids, and crustaceans (García-Valdecasas 1985; Núñez et al. 2009; Worsaae et al. 2009; Gobert et al. 2017).

## 3.3 Windows to the Underworld: Anchialine Pools and Wells

Anchialine pools and wells in Lanzarote were mainly investigated by two teams: one led by Prof. Jan Stock from the Zoological Museum of Amsterdam (the Netherlands) and the other by Prof. Horst Wilkens from the University of Hamburg (Germany). Both teams mainly focused on crustaceans, and while some of the species they discovered were new to science, such as the copepods *Boxshallia bulbantenulata* and *Stephos canariensis* (Huys 1988; Boxshall et al. 1990); others were already known from La Corona lava tube (Wilkens et al. 1986). The presence of the same species in La Corona lava tube and comparatively distant wells or pools provided first indirect evidence for connectivity among the island's anchialine habitats and laid the foundation for later theories of dispersal between distant caves through the crevicular systems (Wilkens et al. 1986, 1993; Rondé-Broekhuizen and Stock 1987; Sánchez 1991).

Anchialine pools (Fig. 2c) are interesting from an ecological point of view because they harbor particular assemblages of animals, which combine both marine and stygobitic species. These assemblages are dominated by the amphipod *Parhyale multispinosa*, which should be considered as a 'pond specialist' capable of coping with extreme changes in both temperature and salinity while forming permanent populations in the pools (Martínez et al. 2016). True stygobites, such as *Munidopsis polymorpha* (Fig. 3k) and *Burrimysis sp*. (Fig. 3j), are found in some pools specially during nighttime, when they can feed on decomposing organic matter, green algae, and cyanobacteria avoiding the higher temperatures and risk of predation brought by the daylight (Wilkens et al. 1993). The abundant resources in the pools also facilitate the presence of marine intertidal species, including blenny fish, sea stars, crabs, and shrimp. Interestingly, the endangered European eel *Anguilla anguilla* has been spotted several times in Charcos de Luis, at the northern tip of Lanzarote, probably entering the pools from the ocean through subterranean crevices (Wilkens et al. 1993; Martínez and Gonzalez 2018).

Anchialine wells (Fig. 3d) ecologically differ from pools mainly because they are lined by steep walls, which protect the limited water from direct sunlight and the daily extreme temperatures. The bottoms of these wells mostly consist of gravel and mud, but natural or anthropogenic debris is often present. Few stygobites have been found in wells, including the amphipod *Hadzia acutus*, ostracod *Humphreysella wilkensi*, mysid *Heteromysoides cotti*, thermosbaenacean *Halosbaena fortunata*, and squat lobster *Munidopsis polymorpha* (Martínez and Gonzalez 2018). However, while Hadzia acutus has been found among the debris in the bottom of the wells, all the remaining species have only been collected with baited traps, suggesting that they might live in the surrounding crevices and migrate into the wells attracted by the bait (Wilkens et al. 1986).

### 3.4 Exploration of Marine Littoral Caves

Marine caves differ from anchialine caves in having a direct connection with the surrounding ocean, large enough to allow the passage of a diver. Several marine caves in Lanzarote are important from the geological point of view and included amongst the geosites of the Lanzarote and Chinijo Islands UNESCO Global Geopark (Table 1). Ecologically, marine caves can be regarded as ecotones between marine open to subterranean environments representing natural gradients with decreasing incidence of light and presence particulate organic matter from the entrance to the bottom (Gili et al. 1986). This gradient favors the presence of different communities of organisms with typical marine species near the entrance and an increasing amount of cave specialists towards the bottom. Within the Canary Islands, the marine caves in Lanzarote are poorly known compared to those in Gran Canaria, Tenerife, and La Palma (Álvarez et al. 2005; Sangil 2007; Riera et al. 2018), where preliminary research have highlighted the existence of specific communities of the organisms on the walls (Cruz 2002; Martínez et al. 2004; Álvarez et al. 2005), and the sediments (Corberá et al. 2001; Herrera et al. 2016, 2017; Riera et al. 2018), with an increasing number of new species of crustaceans, flatworms, annelids, and kinorhynchs (Riera et al. 2007; Martínez et al. 2013; García-Herrero et al. 2017; Gobert et al. 2017). Since marine caves are directly connected to the ocean, the presence of specific assemblages and cave exclusive species is more likely related to the particular ecological conditions inside the caves, rather than to physical isolation.

## 4 Geological Evolution of Lanzarote and Their Effect on the Endemic Cave Fauna

The anchialine ecosystems of Lanzarote are inhabited by strange creatures, most of them representing unique animal lineages never found in the sea. How these animals arrived and evolved in Lanzarote remains as an open question, which we cannot answer without considering the geological evolution of the island. Many of these stygobitic lineages belong in genera, families, orders or even classes that are restricted to anchialine caves spread thorough broad geographic ranges including Australia, the Caribbean, and the Indopacific (Wilkens et al. 2009). Such disjunct global distribution pattern is shared by different animal groups such as remipedes, thermosbaenaceans, thaumatocyprid ostracods, and spionid annelids (Martínez and Gonzalez 2018). This so-called full Tethyan distribution pattern has been traditionally interpreted as the result of cave colonization by marine shallow water species along the coasts of the Tethys Sea during the Mesozoic, followed by vicariant events driven by plate tectonic and changes in the sea level (Stock 1993; Juan et al. 2010). However, since Lanzarote is only 14.5 Ma and it has never been connected to the coasts of the Tethys (Hou and Li 2018), the discovery in the island of several of these stygobites challenged vicariant theories and drove the search for explanations that include some form of dispersal.

As an alternative, many of the stygobites found in Lanzarote present a clear affinity with groups of animals otherwise exclusively found in the deep-sea (Iliffe et al. 1984b). This includes the annelids *Speleobregma lanzaroteum*, *Fauveliopsis jameoaquensis*, and *Gesiella jameensis*, the squat lobster *Munidopsis polymorpha*, the thaumatocyprid ostracods *Humphreysella wilkensi* and *H. phalanx*, and several species of misophrioid copepods (Kornicker and Sohn 1976; Bertelsen 1983; Pettibone 1985; Ohtsuka et al. 1993; Boxshall and Jaume 1999; Núñez et al. 1997). A deep-sea affinity not necessarily implies deep-sea origin (Boxshall and Jaume 1999; Jaume et al. 2000; Martínez et al. 2013), but phylogenetic analyses have indicated that at least the ancestors for the cave lineages containing the scale worm *Gesiella jameensis* and the squat lobster *Munidopsis polymorpha* originated in the deep sea (Ahyong et al. 2011; Gonzalez et al. 2018a). The details on how the hypothetical deep-sea ancestors of these species reach the island remains speculative. One possibility is that they arrived during the seamount stage, when submarine volcanic activity might have produced vent-like habitats resembling those currently occupied by the deep-sea relatives of these cave species (Macpherson and Segonzac 2005; Parapar et al. 2011; Pettibone 1989). Alternatively, the crevicular system of Lanzarote might extend deep along the island building and provide physical connectivity between the island and the surrounding deep-sea environments (Iliffe 1990). In this scenario, cave colonization might have been facilitated by the ecological similarities between cave and deep-sea environments, both characterized by total darkness, constant temperature, and low oxygen (Danielopol et al. 1996).

## 5 Conservation Challenges and Sustainable Uses of the Anchialine Environments

Anchialine habitats, like many other natural splendors, are highly susceptible to negative anthropogenic impacts. In Lanzarote, the main impact derives from recreational uses of the anchialine environments, but other potentially harmful activities are unregulated animal collections for scientific or expositive purposes, as well as the uncontrolled use of the land especially in the areas nearby the lava field of La Corona.

***Recreational uses***. Anchialine ecosystems in Lanzarote are threaten by unappropriated recreational uses both by locals and tourists. Cueva de Los Lagos is often visited without authorization by small groups of people with an inherent risk both for the environment and the visitors, who often lack the appropriated equipment and training. Vandalism acts and garbage dumped in the passageways, as well as sunscreen and other cosmetic products polluting the anchialine lakes are the undesirable consequences of most of these visits (Martínez et al. 2016). Local authorities have installed different types gates during the years to protect the entrance, but all have been forced open and illegal visits continue (Núñez and Brito 2008a, b).

The touristic center of Los Jameos del Agua has been one the major touristic attractions of Lanzarote since the 1970s and receives thousands of visitors every month (Centro de Datos de Lanzarote 2017). The touristic center protects the anchialine lake from uncontrolled visitation, dumping of trash, and acts of vandalism, but as a counterpart exposes it to other types of anthropogenic threats. These threats mostly revolve around the intentional tossing of coins into the lake by visitors who regard this water body as a natural ‘wishing well’, despite the displayed signs forbidding such activities (Brito et al. 2009). The occasional dropping of random objects, evening musical events, and periodical festivals may also potentially have detrimental effects on these fragile ecosystems. While to date the populations of the endemic species in the lake show no signs of stress, preliminary research has detected very high concentration of heavy metals in the sediments that might eventually carry deadly effects on the fauna (Núñez and Brito 2008a). Additionally, the presence of heavy metals might facilitate the co-selection of antibiotic resistance genes in bacterial communities of the lake, as it has been showed elsewhere (Di Cesare et al. 2016). Scientist are working along with the local authorities and the administration of the touristic center to understand the cumulative effects of all these disturbances and minimizing possible long-lasting effects.

***Collection of cave animals.*** Collections of cave animals with scientific or exposition purposes might have harmful effects on certain the stygobitic population (Núñez and Brito 2008a, b). *Munidopsis polymorpha* and *Morlockia ondinae* are considered endangered and can only be collected after permission granted by the local governments. The collection of other cave species remains unregulated. However, lack of information on biology and life cycles of most of these species complicates the establishment of efficient regulations, which minimize the negative impact over their fragile populations.

***Use of surrounding terrains.*** Any anthropogenic access to terrains surrounding anchialine ecosystems, either for commercialization, construction, agriculture, mineral exploitation, or water resources via bore holes or wells has the potential to introduce contamination, ultimately impacting the underlying anchialine system (Iliffe et al. 1984a). Likewise, due to the interconnectivity between Lanzarote’s anchialine system and the ocean, even activities several kilometers away from the island may have detrimental effects, especially with regards to those contaminants capable of entering the system by tidal pumping. Given that the majority of species living within these habitats have limited distributions and highly specific habitat requirements, any of these activities is likely to have conservation implications.

Many anchialine systems occur in tropical and subtropical areas, such as México, Bahamas, and Bermuda, where the push for development of tourism increased risks derived from land use. Fortunately, Lanzarote has adopted a sustainable touristic development since the 1970s partly due to work of the artist César Manrique, who promoted an integrative touristic model that minimizes the negative impact on the landscape and nature (Pezzi 2013). Furthermore, in the 1990s several areas of Lanzarote, including La Corona lava field and Los Jameos del Agua, were integrated and protected within the Red Canaria de Espacios Protegidos, which regulates human activities and prohibits major alterations in these areas. The efforts for conservation reached a milestone in 1993, when Lanzarote was declared an UNESCO Biosphere Reserve, and in 2015 when it was integrated within the UNESCO Global Geopark of Lanzarote and the Chinijo Islands. Today, these institutions and the local government work along with scientists performing state-of-art biological and geological research that allows the implementation of evidence-based policies, which, amongst many other benefits, will ensure a better understanding of the anchialine ecosystems that ensure its preservation through time.

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# Part II

# To Space

# Volcanic Caves of Lanzarote: A Natural Laboratory for Understanding Volcano-Speleogenetic Processes and Planetary Caves

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**Abstract**

The volcanic island of Lanzarote hosts an impressive variety of cavities formed by different volcanic processes. The presence of well preserved lava fields belonging to historic eruptions and more ancient and weathered quaternary and pliocene terrains and the association with an arid climate provide the unique opportunity of studying volcanic caves at different stages of evolution on the same volcanic island. The different mechanisms of lava tube emplacement can be observed in great detail, from the most recent pyroducts of different sizes formed during the Timanfaya eruption (1730–1736) to the exceptionally voluminous conduits of the Corona volcano, formed during the Last Glacial Maximum and partially submerged by the sea level upraise during the Holocene. In addition, other type of cavities, like explosive and geyser vents, "hornitos" and sinkholes in pyroclastic deposits offer the opportunity to extend the study to other important volcano-speleogenetic processes in different settings. All these cavities are easily accessible and present a variety of morphological, mineralogical, biological and microbiological significances, allowing for a wide range of multidisciplinary studies. The countless analogies with lava tube collapses and other potential volcanic cave features detected on the Moon and Mars also provide an unprecedented research ground that offers hints to solve some open issues in the interpretation of still unresolved planetary cavities. These characteristics make the Lanzarote and Chinijo Islands UNESCO Global Geopark an exceptional case where the protection and scientific outreach has been extended to the volcanic subsurface. In this chapter we offer a review of the current knowledge and existing scientific studies on the volcanic caves of Lanzarote and we discuss future researches and protection issues that need to be addressed in order to fully include this geoheritage in strategic plans of environmental protection.

**Keywords**

Volcanic caves • Lava tubes • Inflation • Planetary geology • Cave minerals • Cave microbiology

## 1 Introduction

The study of volcanic caves in the Canary Archipelago started as early as in the 18th century with the first pioneering speleological explorations in the island of Tenerife (Castro 1779) and continued uninterrupted spreading to the other islands thanks to the interest of travellers, naturalists (Benitez 1909), biologists (Koelbel 1892), geologists (Hartung 1857) and speleological organizations (Oromí and Martín 1990). Several papers and notes have been published about this unique heritage (Hernandes 1998). These researches were focusing not only on speleological, geological and biological aspects, but also on history, anthropology (Hooton 1925; Segura 2016) and architecture (Signorelli et al. 2007).

The island of Lanzarote has been known since early times for the presence of some of the most impressive volcanic

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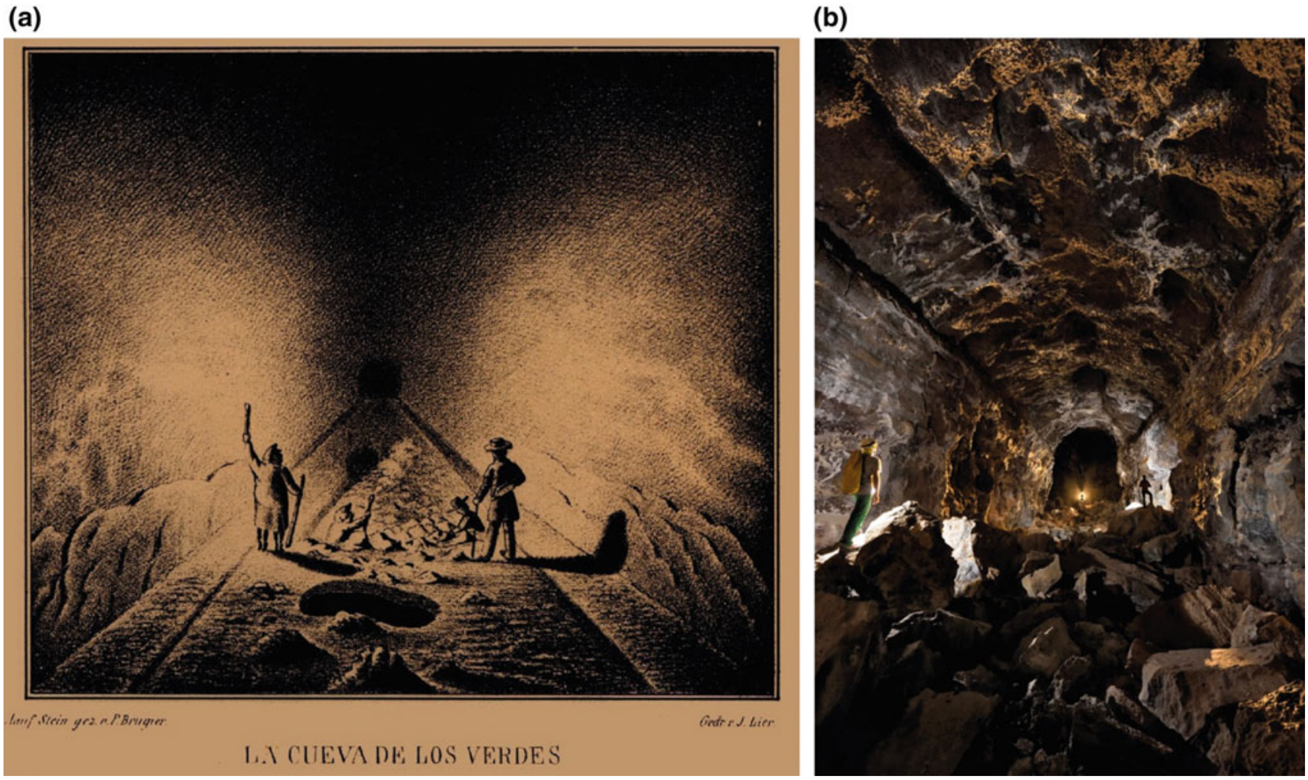


**Fig. 1** The Corona lava tube in images: **a** representation of the conduit section of Cueva de Los Verdes from the Hartung's monography about Lanzarote and Fuerteventura geology "Die geologischen Verhältnisse der Inseln Lanzarote und Fuerteventura" published in 1857, **b** a photo of the National Geographic photographer Robbie Shone of a section of the Corona lava tube between Jameo de las Gentes and Jameo de los Prendes

cavities in the world (Hartung 1857; Hernández-Pacheco 1910), among them the series of sinkholes (called "jameos" in the local language) leading to the giant underground galleries of the Corona lava tube system (Fig. 1) (Montoriol-Pous and De Mier 1969). The cave was used through historic time as burial site and later on as a refuge for the islanders from the incursion of pirates and for the search of water resources (Chil 1876). In the 19th century it became very soon of great interest also for biologists due to the presence of a unique endemic crab (*Munidopsis polymorpha*) in the tidal lagoon inside the Jameo del Agua, the sinkhole closest to the sea (Koelbel 1892).

Despite the large quantity and variety of these early studies, the real extension of the Corona Lava tube system remained unknown until 1961–1962 when two speleological expedition from the GES Club Montañés Barcelonés realized the first topographic survey measuring a total development of 6.1 km and a total vertical displacement of 230 m, being recognized as the longest volcanic cave known in the World at that time (Montoriol-Pous and De Mier 1969). The fame of this cave raised even more after the adaptation for general tourism of the most spectacular sections of the tube, Cueva de Los Verdes (1965) and Jameo del Agua (1978), by the famous artists Jesús Soto and César Manrique (Signorelli et al. 2007). Nevertheless, the submerged section of the Corona lava tube, called Tunnel de la Atlantida, had to wait for other twenty years before American, German, France and Belgian, diving expeditions were able to explore the whole 1.6 km of underwater passages developing up to −64 m below the sea level (Isler 1986; Wilkens et al. 2009).

Aside of the Corona Lava Tube System, the basaltic volcanism characterizing Lanzarote is offering particularly favourable conditions for the formation of pyroducts and other type of volcanic caves in several other regions of the island. The long, high-magnitude, historic eruption of Timanfaya (1730–1736) has allowed the formation of tens of kilometres long aa and pahoehoe highly fluid lava flows with a composition of melanephelinites and basanites indeed hosting several lava tubes (Carracedo et al. 1992), These are varying from few meters up to kilometres in length, and can be shallower (with ceiling thickness of less than 1 m) or deeper (between 5 and 15 m) into the subsurface, depending on the different emplacement processes. Some of these caves have been documented in the recent years, the most important of them is Cueva de Los Naturalistas-Las Palomas (Martín and Díaz 1984; Montoriol-Pous et al. 1991). Nonetheless, most of these tubes are still waiting for a proper survey and documentation, especially in the protected area of the Timanfaya National Park.

Up to know, extracting information from all the publications available and previous registers (Oromı et al. 1989), the number of caves known in Lanzarote is approximately 25, for a total of roughly 25 km of passages (Table 1). However, while the scientific studies have focused on the few major and easy accessible lava tubes (Corona and Naturalistas), the documentation of other cave typologies is rather poor, with few scattered information, and proper scientific research is still missing, as well as topographic survey.

## 2 Types of Volcanic Cavities

Caves in volcanic rocks form through different processes (Kempe 2012), either primary (formed while the lava was flowing and solidifying) or secondary (formed by weathering, erosion, collapses, tectonic events, long after the lava was deposited). The most common primary caves in Lanzarote are lava tubes. A lava tube, or pyroduct, is defined by Halliday (2004) as a "roofed conduits of flowing lava, either active, drained, or plugged". In several cases, especially in the Corona and Timanfaya lava fields, the network of tubes, along with eventual ephemeral vents and secondary flows, is

**Table 1** List of the most important caves known in Lanzarote

| Name | Locality | Typology | Devel. (m) | Depth | Ref. and surveys |
|---|---|---|---|---|---|
| Corona lava tube system | Haría | Lava tube | 8960** | +183/−69 | GES-CMB (Montoriol-Pous and De Mier 1969), Atlantida 1986 (Mendo and Ortega 1988), Vigea (Santagata et al. 2018) |
| Cueva de Los Naturalistas/Las Palomas | Masdache | Lava tube | 1647 | +6/−11 | GIE-UL (Martín and Díaz 1984), GES-CMB (Montoriol-Pous et al. 1991), Vulcanfaya Vertical—Speleo NL 2017 |
| Tizalaya 3 | Masdache | Lava tube | 250 | | GES-CMB (Montoriol-Pous et al. 1991) |
| Cueva Perdida o Escondida | Timanfaya | Lava tube | 1176 | ? | J. L. Martin, unpublished |
| Cueva de Los Pescadores | Timanfaya | Lava tube | 900* | ? | Unpublished (Hernandes 1998) |
| Cueva del Lago de Lava | Timanfaya | Lava tube | 520* | ? | Unpublished (Hernandes 1998) |
| Cueva la Pedrera | Timanfaya | Lava tube | 320 | ? | Unpublished (Hernandes 1998) |
| Cueva Montaña Rajada | Timanfaya | Lava tube | 168 | ? | Unpublished (Hernandes 1998) |
| Cueva sender Mtña. Hdez. | Timanfaya | Lava tube? | 157 | ? | Unpublished (Hernandes 1998) |
| Cueva de Caldera Escondida | Timanfaya | Lava tube? | 150* | ? | Unpublished (Hernandes 1998) |
| Cuevas de La Atalaya | Las Cuevas (Maguez) | In pyroclasts | 900* | ? | Unpublished, mostly artificial |
| Cueva Las Breñas | Las Breñas | Lava tube | 1470 | +22/−14 | Vulcanfaya Vertical—Speleo NL 2017 |
| Covon-Chifletera | El Golfo (Timanfaya) | Lava tube | >500* | ? | Unpublished (Hernandes 1998) |
| Esqueleto-Paso | El Golfo (Timanfaya) | Lava tube | >500* | ? | Unpublished (Hernandes 1998) |
| Cueva Choco | El Golfo | Lava tube | 680 | ? | Unpublished Hernandes 1998) |
| Sima del Pedro Perico | Timanfaya | Volcanic vent | 201 | −31 | Unpublished (Hernandes 1998), Vulcanfaya Vertical—Speleo NL 2018 |
| Sima 1 Tinguaton | Tinajo | Geyser vent | | −29 | CRCE 1976 (unpublished), Vulcanfaya Vertical—Speleo NL 2017 |
| Sima 2 Tinguaton | Tinajo | Geyser vent | 298 | −70 | CRCE 1976 (unpublished), Vulcanfaya Vertical—Speleo NL 2018 |
| Sima 3 Tinguaton | Tinajo | Geyser vent | | −31 | CRCE 1976 (unpublished), Vulcanfaya Vertical—Speleo NL 2018 |
| Cueva Canal de Pico Partido | Tinajo | Lava tube | 99 | +13/−9 | Unpublished (Hernandes 1998), Vulcanfaya Vertical—Speleo NL 2018 |
| Cueva Nazaret | Nazaret | Lava tube | 150* | ? | Unpublished (Smith 2015) |

(continued)

**Table 1** (continued)

| Name | Locality | Typology | Devel. (m) | Depth | Ref. and surveys |
|---|---|---|---|---|---|
| Cuevas de Mozaga | Mozaga | Lava tube | 275 | ? | Unpublished (Hernandes 1998; Oromı et al. 1989; Solana et al. 2004) |
| Cuevas de Tahiche | Tahiche | Lava tube? | 198 | −21 | Unpublished (Hernandes 1998), Vulcanfaya Vertical—Speleo NL 2018 |
| Cueva del lago Nero | Orzola | Lava tube | 150 | ? | Unpublished |
| Cueva de Playa Blanca | Playa Blanca | Modified lava Tube | 125 | −16 | Vulcanfaya Vertical—Speleo NL 2018 |
| Cueva Montana Bermeja | Los Hervideros | Modified lava Tube | 75 | +5/−6, 8 | Vulcan Vertical/Speleo NL 2018 |
| Hornitos de La Perola | Timanfaya | Hornitos | 18 | −21 | Unpublished (Hernandes 1998) |
| Hornitos de Las Clacas | Timanfaya | Hornitos | 35 | −14 | Unpublished (Hernandes 1998) |

**Total development considering the different sections of the tube separated by open jameos
*Only estimated length

responsible for most of the widening, thickening and lengthening of the lava flows through inflationary processes described by Solana et al. (2004) and Calvari and Pinkerton (1998). Lava tubes in Lanzarote have been documented mainly in the lava flows belonging to the quaternary eruption of Serie IV (Timanfaya and Corona), and in few cases in Serie III (Fuster et al. 1968) belonging to the lower Pleistocene (Los Alcones in Isla Graciosa) and late Pliocene (in the area of Playa Blanca and Las Breñas). Most of the lava tubes that certainly existed in older terrain probably collapsed or were filled by more recent lavas and sediments.

In terms of morphologies, most of the preserved lava tubes are slightly sinuous and/or branched tunnels in the near subsurface, sub-parallel to the surface itself. Their cross-sections are usually arched, rounded, elliptical, or keyhole shaped due to accretion of lava to the sidewalls and the downcutting of lava flows into the underlying rocks. Lava tubes typically form in the pahoehoe type of basaltic flows, and less commonly in aa type. At the surface, lava tubes may exhibit peculiar features such as linear to sinuous elongated collapses (which are called *jameos* in Lanzarote, the equivalent of *pukas* in the Hawaii), mostly organized in sinuous chains and sometime with skylight-like overhanging openings.

The lengths of lava tube caves in Lanzarote vary from a few meters up to several kilometres in the case of the Corona system (Table 1). Their width and height vary from 0.5 up to 30 m, developing from few centimetres below the surface up to a depth of few tens of meters (Fig. 2). Lava tubes can present different patterns: (a) single tubes, sinuous or rectilinear (i.e. Cueva del Pico Partido), (b) braided tubes, with bifurcation and joints (i.e. Cueva de Los Naturalista, Cueva Las Breñas) (c) multilevel tubes with different levels connected by lava falls and sinks (i.e. Corona System), (d) a combination of braided tubes on different levels (i.e. some sections of the Corona System).

This range of morphologic variability is due to slightly different processes of formation, controlled mainly by the effusion rate, dip of the flow surface, the underlying paleo-topography, and the composition and related rheology of the lava. The most superficial tubes are formed by "overcrusting" of an open lava channel, e.g., by the coagulation of rafted crustal slabs (some beautiful examples can be observed in Montaña Señalo), the growth of rooted crust from the edges of the lava channel, aggregation of floating crustal rafts, and/or accretion of lava levees to build an arch (a magnificent example is the channel of Pico Partido). Usually overcrusted tubes are small in size, and the roofed sections do not reach more than few tens or maximum hundreds of meters in length and few meters in diameter.

Another type of lava tube is the one formed by shallow inflation, through partial draining of an inflated pahoehoe lava flow. This type of lava tube is usually characterized by a superficial bulge (due to the inflation) along its development, and by an elliptic cross section. The most remarkable examples in Lanzarote are Cueva de Los Naturalistas-Las Palomas (Fig. 2) and several other smaller tubes (like Cueva de Mozaga) from the "*malpais*" de Tizalaya along the Montaña de Las Nueces flow field (Martín and Díaz 1984; Solana et al. 2004). As a result of lava being injected from below under pressure hollow *tumuli* hosting small chambers and short low-ceiling caves can also be associated to this types of tubes.

In addition to the two main lava tube morphotypes, the Corona system has been proposed as a very peculiar example of "deep inflated-entrenched" lava tube formed

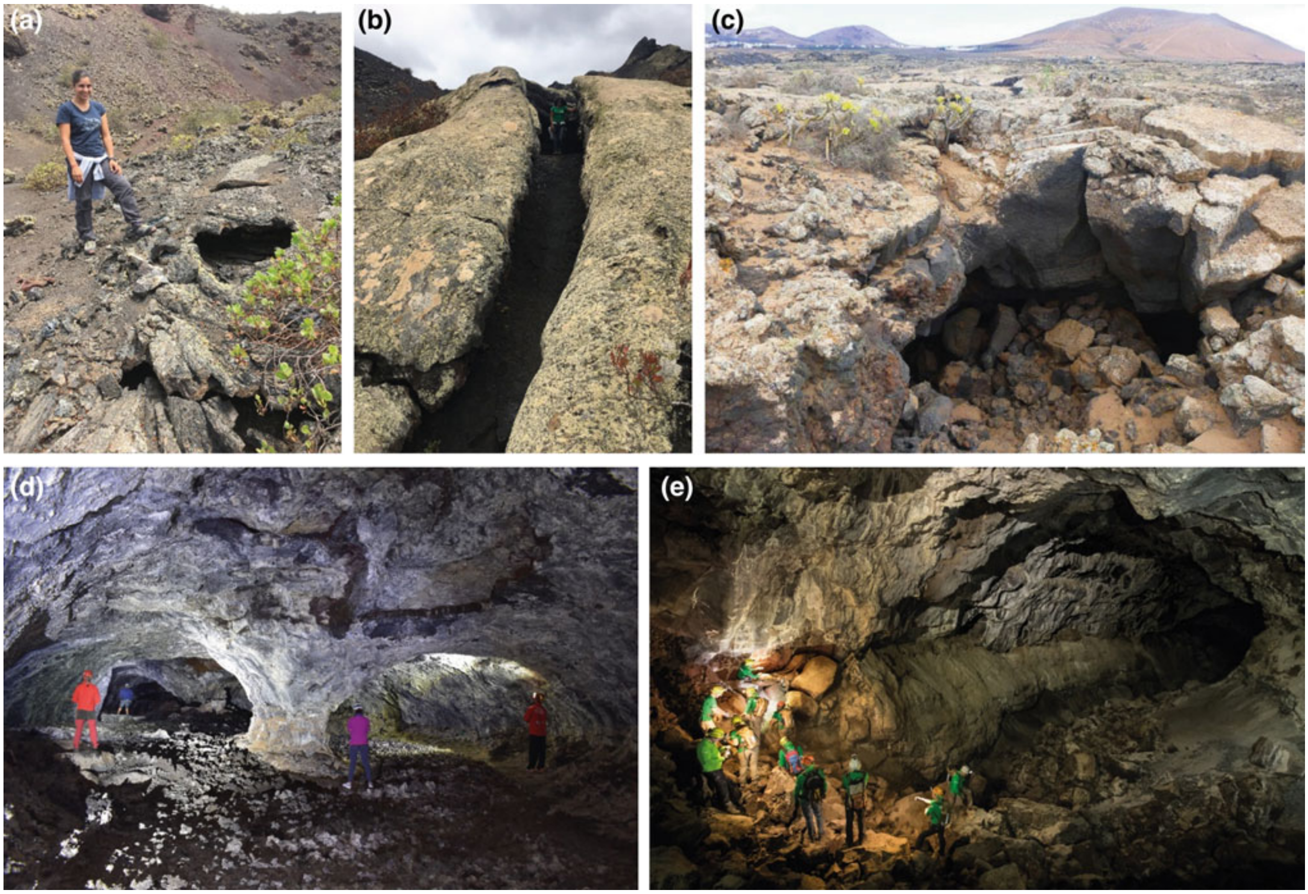

**Fig. 2** Different lava tube morphotypes: **a** a very shallow overcrusted conduit in Montana Senalo (photo Francesco Sauro), **b** the channel of Pico Partido, formed by the accretion of lava leaves on the channel sides (photo Francesco Sauro), **c** the entrance of Cueva Nazaret, a typical tube bulge due to inflation (photo Christopher Binding), **d** braided conduits of Cueva de Los Naturalistas, a shallow inflated tube of important dimensions (photo Juan Pedro Camejo Casanova), **e** the main conduit of the Corona lava tube system (photo Robbie Shone—ESA)

through inflation along deep inception horizons along previous lava flows (Tonello 2017) where, after inflation, the conduit has been enlarged by downward thermic erosion and breakdowns. Previous authors also proposed a mechanism of emplacement along a pre-existing erosional canyon, in order to explain the giant dimensions of this peculiar pyroduct (Carracedo et al. 2003).

Other minor primary caves, still poorly investigated are some characteristic eruptive vents, like those opening on the side of Pico Partido, Montaña de Las Nueces and on the southern side of Montaña Señalo (Fig. 3), as well in several other volcanic cones inside the Timanfaya National Park. Solidified lava and wall collapses probably limit the accessibility of these caves at depth, but detailed explorations and surveys have not been performed so far. The most relevant of this cave is Sima de Pedro Perico, near the village of El Golfo, an open shaft of 18 m of depth leading to a volcanic chimney approximately 200 m long and descending to almost 30 m of depth. Similar to volcanic vents, some hornitos in the area of Timanfaya provide access to subsurface voids cavities, but usually with a very limited extension. Comparable volcanic vent and hornitos conduits have been documented in Hawaii (Kempe 2012) and in Isla Isabela in Galapagos.

Another exceptional type of primary caves are the fissural vents of Tinguatón (that can be classified as a peculiar type of open vertical volcanic conduit), formed first as a fissure feeding strombolian lava fountains at the beginning of the eruption of 1824, and then evolving as geyser vents at the final stage of this historic eruption (Fig. 3). So far very few other examples of accessible geyser vents are known in the World.

Secondary volcanic caves, formed by weathering and erosion, or by tectonic movement, are less common in Lanzarote, but in the recent years some really interesting cavities of this type have been partially explored. The Cueva de Las Breñas, located in the homonymous village, has been mapped for over 1 km (pers. comm. Laurens Smets)

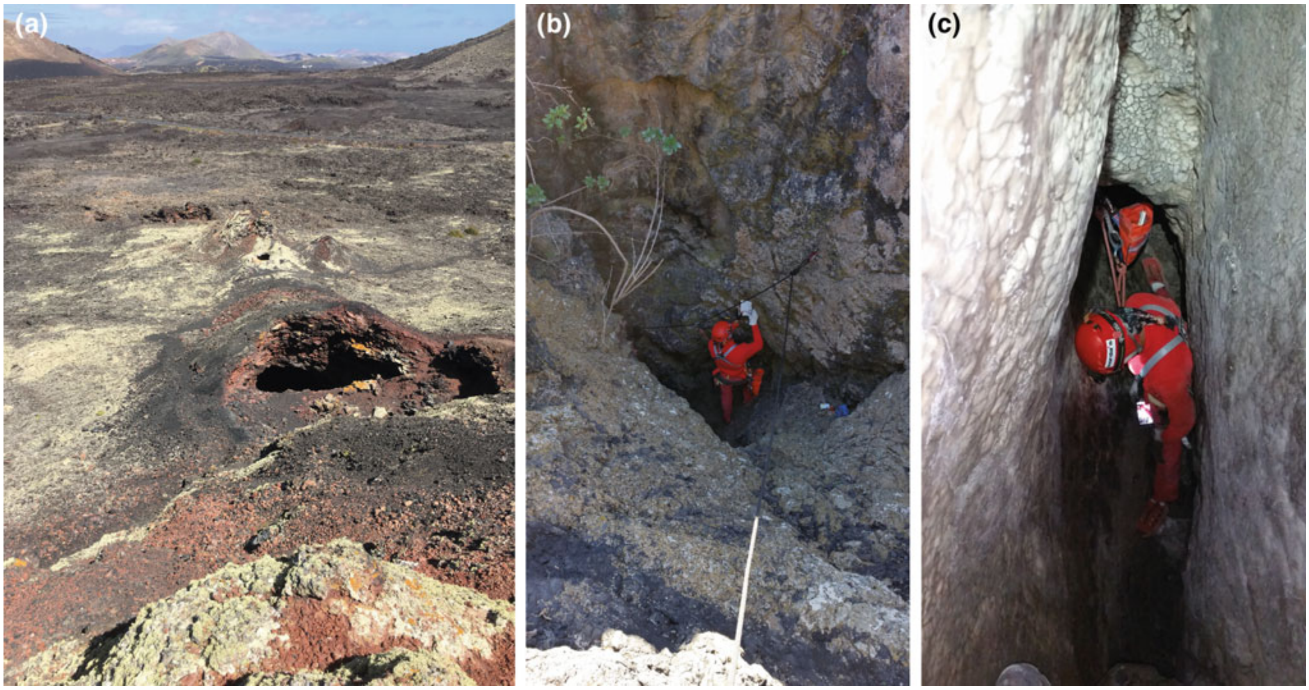


**Fig. 3** Different examples of volcanic vents and volcanic open vertical conduits: **a** a lateral vent with a departing tube on the flanks of Montana de las Nueces (photo Francesco Sauro), **b** one of the main entrances of Tinguatón (photo Lauren Smeths), **c** the Simas de Tinguaton develop along a fracture which is often encrusted by carbonatic speleothems (photo Lauren Smeths)

representing an ancient lava tube, probably formed in the early Pleistocene and deeply modified by water erosion and chemical weathering. Similarly, other caves like Cueva Tahiche and Cueva Playa Blanca, appear as ancient lava tube conduits deeply modified by erosion and sedimentation. Coastal caves represent a first type of secondary origin voids still not well investigated at the present time. Several of them are known along the high basaltic coast of Los Cocoteros and Charco de Palo, some related to wave erosion, while others being originally lava tubes modified by erosional processes (Cueva del Agua). Other similar caves are common in the Chinijo Islands, like the collapsed tube of Los Arcos in the Isla Graciosa and the Jameos de Las Palomas excavated in tuff layers in Alegranza. Close to the village El Golfo in Lanzarote, a recent survey campaign has surveyed the Cueva de Montana Bermeja, a cave that seems related to seawater erosion connected to a pre-existing lava tube conduit.

The second types of caves, still not well studied, that likely have secondary origin, are sinkholes and small cavities developed in pyroclastic deposits (fine volcanic products known as *picón* in Lanzarote). Several ancient pyroclastic edifices from the Pliocene and early Pleistocene presents quickly evolving sinkholes on their flanks due to the presence of unconsolidated material, and some of them give access to short caves usually filled with loose pyroclasts. Some of these collapses are probably very recent and related to hydrological setting perturbed by the opening of quarries extracting *picón* for agricultural purposes on the foot of the volcanic edifices. The most impressive sinkholes of this type can be easily identified on the slopes of Lomo de San Andres near Mozaga and in the area of Los Roferos in the municipality of Teguise (Fig. 4). This type of cavities and their related collapses probably have origin through water piping effects acting during storm events, removing important amount of pyroclasts from below harder substrates. Similar processes have been described for the formation of sinkholes in ashes and pyroclastic terrains in the area of Vesuvio in Italy (Di Santolo et al. 2016; Guarino and Nisio 2012), and could represent potential hazard for constructions and agriculture activities.

This astonishing variety of cave types, both primary and secondary, makes Lanzarote a unique place for the study of speleogenesis in volcanic settings. However, very few of these cavities have been objective of scientific investigation. In the following chapter we provide an overview of the most important and well-known case studies.


**Fig. 4** Sinkholes in pyroclastic terrains in Lomo de San Andres near Mozaga, probably related to piping processes in unconsolidated pyroclasts below a harder substrate. The process could have been induced by hydrological instability caused by a quarry of "picón" on the upper-left side of the image

## 3 Case Studies

### 3.1 The Corona Lava Tube: A Deep Inflated Tube?

The Corona lava tube system is one of the most voluminous pyroducts known on Earth. With sections of the conduit up to 25 m wide and 50 m high, this cave is comparable in terms of volumes only to few other known tubes in the World, like Undara in Queensland (Atkinson et al. 1975), Vidgelmir in Iceland (Wood 1974) and some other pyroducts in Arizona and Utah (Bunnell 2008).

The Corona lava tube has been mapped for the first time by Montoriol-Pous and De Mier (1969) and more recently by a specialized company (VIGEA) through an extensive campaign of laser scanner surveys promoted by the Lanzarote and Chinijo Islands UNESCO Global Geopark

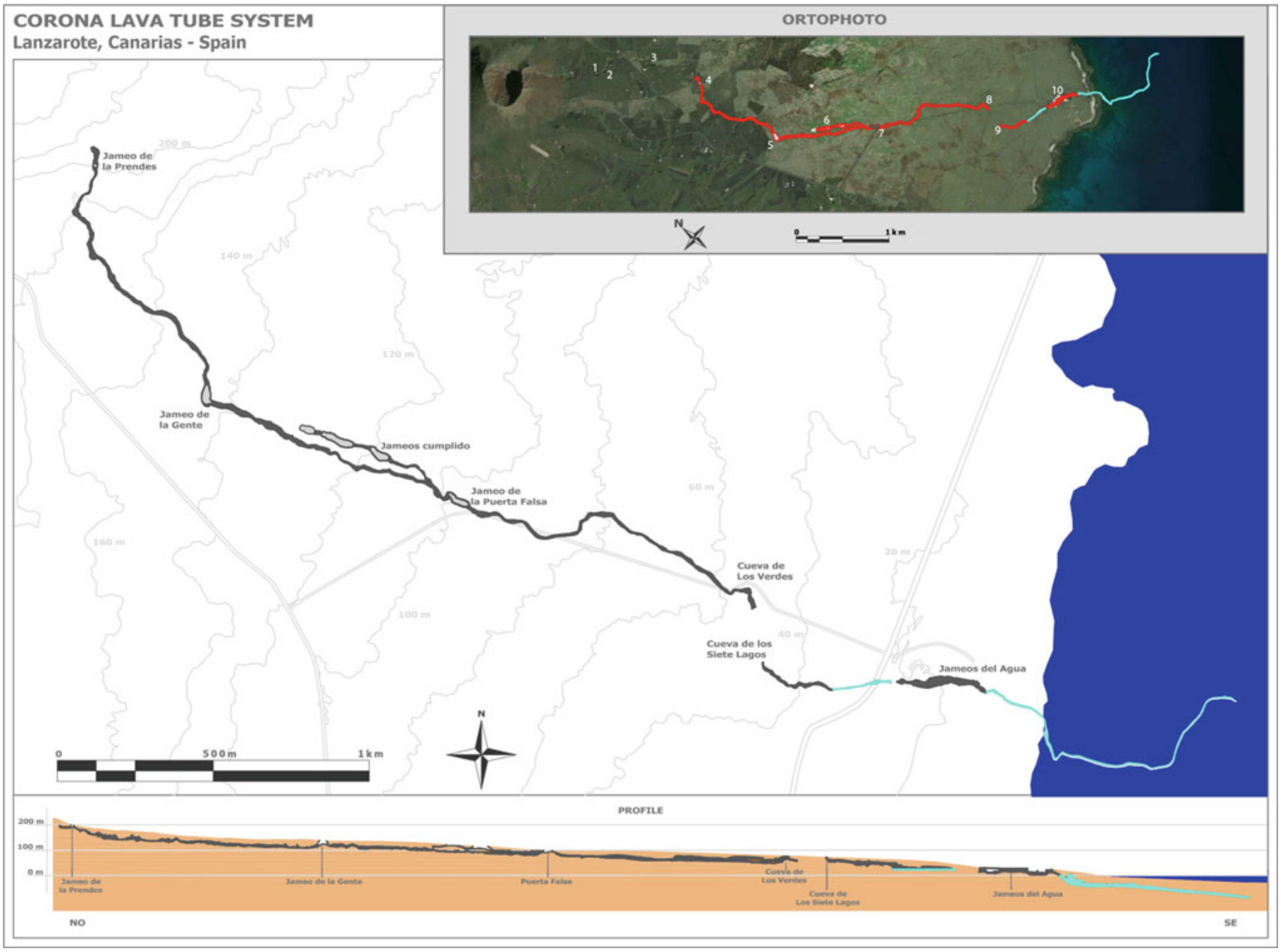


**Fig. 5** Topography of the Corona lava tube system realized with terrestrial laser scanning by the team of Vigea for the Cabildo of Lanzarote, with the support of Leica geosystems. The collapses indicated in the orthophoto are: (1) Jameo de Arriba, (2) Jameo de La Corona, (3) Jameo de Los Lajares, (4) Jameo de los Prendes, (5) Jameo de la Gente, (6) Jameos Cumplidos, (7) Jameo de la Puerta Falsa, (8) Cueva de Los Verdes, (9) Cueva de los Siete Lagos, (10) Jameos del Agua

(Santagata et al. 2018). Now the subterranean sections of the lava tube are completely mapped in 3D with a resolution of few cm, allowing for detailed morphologic studies (Tonello 2017).

The tube starts from a lateral vent on the eastern side of the Corona Volcano, one of the most important volcanic cones of the northern sector of Lanzarote, whose activity has been radiometrically dated to 21 ± 6 ky BP (Carracedo et al. 2003).

From La Corona volcanic edifice to the coastline the lava tube can be followed on the surface through the sinuous alignment of twenty *jameos* (Fig. 5; not all of them directly open on the underground conduit). These collapses already provide a clear hint of the impressive size of the underling tube, being in some cases almost 50 m width (38 m in average) and with a depth ranging between 7 and 16 m (10 m in average). The first eight *jameos* are situated near the volcanic cone of La Corona, among which there are Jameo de Arriba, Jameo de La Corona, the three Jameos de los Lajares and Jameo Largo (Fig. 5). This first series of collapses do not provide access to relevant sections of the underground tube, being mainly plugged by breakdowns. However, during a recent geophysical campaign using geoelectric tomography, Torrese et al. (2018) demonstrated that intact section of the conduit surely exist in between these collapses. The following sinkhole, Jameo de Prendes, is the first one providing direct access to the pyroduct, situated at approximately 15–20 m below the surface. From this entrance it is possible to follow the tube upstream only for few tens of meters ending in a boulder choke, while downstream the gallery descend with a shaft of 15 m to a lower level and continues with bigger dimensions. From here on, the tube continues for 1170 m (1340 m including some upper levels) up to the opening of Jameo de La Gente. To the other side of this sinkhole the tube is again accessible for another segment, 1160 m long (1540 m including the upper level connecting to Jameo Cumplido), joining the surface again at Jameo de la Puerta Falsa. This section also has an upper level, which is interrupted by three other *jameos* (Tacho, Cumplido and Agujerado). Downstream Jameo de la Puerta Falsa the tube continues underground in its longest and most complex segment, leading to the entrance of Cueva de Los Verdes (partially adapted for touristic visits). Higher galleries and canyons, sometime with two or even three superimposed levels, characterize this segment (the planimetric length from Puerta Falsa to Cueva de Los Verdes is of 1290 m, but a total development of 3090 m has been mapped considering all the different levels). Downstream Cueva de Los Verdes the tube is closed by a boulder choke, but few tens of meters from this point a new smaller *jameo*, Cueva Siete Lagos, provide access to the downstream continuation of the conduit. A high canyon gently descends to the sea level, which is finally encountered at approximately 600 m from the coastline. From this point onward a series of seawater lakes occupy the most of the conduit, which ends in a deep sump that has been explored by divers up to a submerged boulder choke. The boulder choke represent the rockpile below the first of the three close sinkholes known as Jameos del Agua, now hosting the Casa de Los Volcanes museum, adapted for tourist visit by Cesar Manrique (Bravo 1964; Signorelli et al. 2007). At the end of the Jameos del Agua cave, another seawater pool provides diving access to the last section of the cave, the wholly submerged Túnel de la Atlántida. This continue underwater maintaining comparable dimensions, and with some superimposed levels, a further 1726 m, where it terminates 64 m below sea level in a cul-de-sac (Isler 1986). The length and depth of the submerged tube is consistent with an origin approximately 21,000 years ago, at a time when the glacial sea level was 100 m lower than today. In this scenario, the cave is assumed to have formed entirely under subaerial conditions, only to be flooded during subsequent post-glacial sea level rise (Carracedo et al. 2003).

Some peculiar morphologic and geologic aspects need to be discussed to understand the primary speleogenesis of this impressive cave (Fig. 6): (1) the entire tube is developed along the interface between two different lava flow sequences marked by the presence of a layer of reddish pyroclasts; (2) the tube tends to acquire a canyon-like cross section toward the sea, developing different superimposed levels in the more distal part (Cueva de Los Verdes and Cueva de los Lagos); (3) the most of the tube is characterized by lateral benches that in some cases are joining and forming the floor of the different levels. Looking at these characters Carracedo et al. (2003) proposed that the tube formed through a lava flow that was channelized along a pre-existing fluvial canyon that had eroded the older lava flows related to Los Helechos (a volcanic event pre-dating Corona). The reddish layer would represent the first explosive phase of the Corona eruption and the Corona lava flow would constitute the

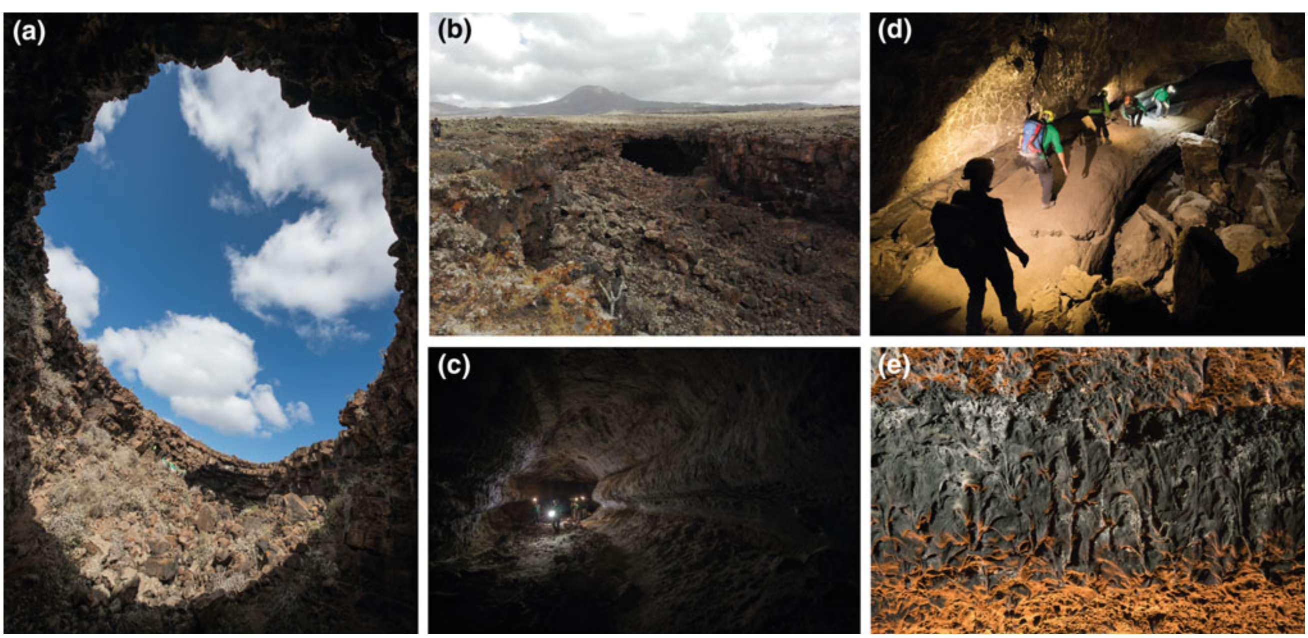


**Fig. 6** Main geological and morphological features characterizing the Corona lava tube system: **a** the entrance of Jameo de la Gente seen from inside show the typical elliptical shape overhanging walls of the lava tube sinkholes (photo Robbie Shone—ESA), **b** the Jameo de la Puerta Falsa with in the foreground the volcanic edifice of La Corona (photo Robbie Shone—ESA), **c** a typical section of the lava tube: it is possible to identify lateral flow ledges testifying different phases of flow inside the tube (photo Luca Ricci—ESA), **d** several passages are characterized by flow ledges on one or both sides of the tunnels (photo Robbie Shone—ESA), **e** lava splash stalactites on the walls of Cueva de Los Verdes (photo Robbie Shone—ESA)

overcrusted roof of the conduit. More recent studies (Tonello 2017) suggest, instead, an inflationary process along the pyroclastic layer between the Los Helechos/Famara older flows and the first one emplaced during the Corona event, but this hypothesis has still to be demonstrated. The deepening of the conduit toward the sea suggests an important back-cutting thermal erosion effect (Kempe 2012), and the presence of several benches clearly indicates that the tube remained active for a long time, with oscillating effusion pulses. Therefore, the Corona system would represent a deep-inflation case, and the tube would have been enlarged and entrenched by more than one, high effusion rate, phases of the eruption. However these hypotheses will need a more detailed research in the future to be fully demonstrated.

The cave is also an extremely important biological hotspot, with several endemic species, especially in the anchialine pools of Cueva Siete Lagos and Jameos del Agua (Wilkens et al. 2009). Moreover, the cave hosts one of the main modules of the Lanzarote Geodynamic Laboratory installed in the tube section between Jameo de la Puerta Falsa and Cueva de Los Verdes and actually managed by the Lanzarote and Chinijo Islands UNESCO Global Geopark together with IGEO (CSIC-UCM). This is one of the most complete underground monitoring stations in the World, providing continuous measurements of the tube stability and of the island deformation through a network of seismographers, water tube clinometers, pendulums, extensometers and gravimeters (Vieira et al. 1991). In addition all the environmental parameters are constantly measured, like temperature of air and rock, airflows, and radon concentration.

Because of the striking analogies between this cave and candidate lava tube collapses detected on Mars and the Moon, since 2016, the Corona cave system has been used by the European Space Agency for the geologic training for astronauts and for testing new exploration and scientific technologies (Bessone et al. 2018; Sauro et al. 2018a).

## 3.2 Cueva de Los Naturalistas/Las Palomas: A Shallow Inflated Tube

The Cueva de Los Naturalistas-Las Palomas has been described for the first time by Hernández-Pacheco (1910) and mapped by Martín and Díaz (1984), Montoriol-Pous et al. (1991), and more recently by Speleo Limburg (NL) and Club Vulcan-Vertical Espeleologias y Barrancos that realized also a 3D map (Fig. 7). It develops for 1.6 km under the *malpais* of Tizalaya, on the north-eastern side of Montaña Juan Bello. With a roof few decimetres to maximum two meters thick, the tube has a sub-horizontal floor and elliptical sections with height varying between 1 and 8 m (mean value 3 m) and widths from about 1 to 20 m (mean value 10 m).

The conduit is braided in some sections, forming lateral braches and two spectacular central columns (Fig. 2d). Very well preserved lava stalactites and stalagmites cover the roof and floor, while lateral benches are absent along the walls. Since benches are associated with a step-wise emptying of a tube, each bench marking a particular level of sustained flow, their absence suggests that drainage occurred in a single episode. The absence of thermic erosional deepening of conduits also supports this hypothesis. Longitudinally, the tube becomes smaller towards both its extremities and is largest about half-way along its length, where it consists of four prominent, bifurcating galleries finally ending on low passages and boulder chokes. The continuation of the conduit, mostly collapsed, can be followed in the surface through a series of sinkholes (Cueva de Los Jameos) up to the village of Mozaga (Cueva de Mozaga). However, along this path the inflated sheet has mainly collapsed during the

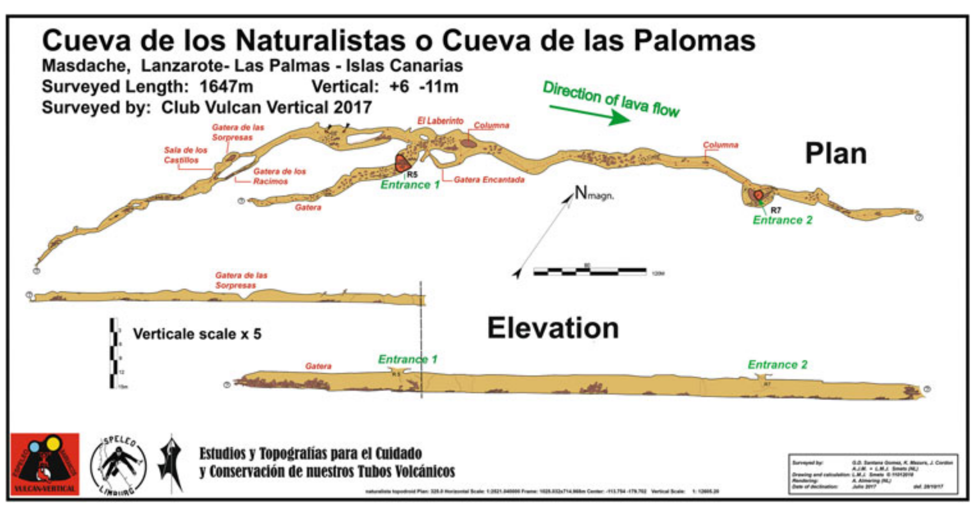


Fig. 7 Topography of Cueva de Los Naturalistas

tube drainage forming peculiar depressions that are filled by the roof slabs themselves, as a deflation effect.

The elliptic and braided conduits, together with the formation of a prominent bulge on the surface along the cave development, all these features suggest that this cave represent a beautiful example of a big size shallow inflated tube (Kempe 2012). The formation was related to one single effusive event where the lava flow was advancing mainly through endogenous growth, with aa sheet inflation below crust slabs of pahoehoe (Solana et al. 2004). The cave and the lava flow surface are very well preserved allowing for an exceptional overview of the process. The presence of gypsum and calcite deposits also offers the possibility to study weathering processes subsequent to the tube emplacement in the last three centuries (Montoriol-Pous et al. 1991). However, a detailed geologic map of the whole Tizalaya lava flow in relation to the subsurface tubes, sinkholes, and hollow tumuli is still missing and could be the objective of a future speleological campaign. The area is under the protection of the law of 12/1987, "Declaración de Espacios Naturales de Canarias" as "Parque Natural de La Geria" and reclassified as Natural Monument through the law 12/1994.

## 3.3 Lava Tubes of the Timanfaya National Park

The Timanfaya National Park covers an area of 51.07 $km^2$ of lava flows and eruptive centres belonging to the seven years long eruption of 1730–1736. The strict protection rules and the dry climate of the island have allowed the preservation of several volcanic caves at almost the original conditions when they were created during the eruptions. Despite this, the subsurface heritage of this area is still mostly undiscovered by the scientific community. Several caves, mostly related to lava tubes and volcanic vents have been explored, and partially mapped, but few scientific publications are available until now (Carracedo et al. 1992; Oromı et al. 1989). The main cave systems are those of the lava tubes of Covon-Chifletera and Esqueleto-Paso, not far from the village El Golfo, characterized by single overcrusted and shallow inflated tubes (Hernandes 1998). Other tubes segments are known in the central part of the park (Fig. 8), and a series of campaigns organized by the National Park authorities in collaboration with the Club Adventure Lanzarote, have mapped a maze system that has been estimated between 12 and 14 km of development, with up to three different levels and several entrances. These preliminary researches suggest that this area could host some of the longest lava tube systems in Europe. Due to the excellent preservation of the lava flows and of the unique variety of tube morphogenetic types, the Timanfaya National Park could represent an exceptional laboratory to understand the speleogenetic processes of the different pyroducts along the evolution of the same eruption. In order to fully understand these environments, several new campaigns performing 3D modelling and more detailed geologic and biologic studies would be desirable for the future.

## 3.4 The Tinguaton Shafts: An Exceptional Example of Open Geyser Vents

The last eruption in the island of Lanzarote has happened between the 31st of July and the 25th of October of 1824, forming the volcanic cones of Tao, Volcan Nuevo and Tinguaton. The peculiarity of this eruption was the formation of a series of aligned geysers in the Tinguaton crater during the last week of the effusive episode (Becerril et al. 2017). This event was described in detail by the priest of Sant Bartolomé, D. Sebastian Perdomo, that observed boiling water emerging from the caldera the 17th of October. When it was possible to get closer to the edifice the scenario was impressive:

> The day 21st, from the crater edge we observed that a deep caldera with a flat floor had been formed; the bottom of the caldera, very flat, was completely flooded by water and sand, except for few emerging sharp rocks, and at the centre and northern side there were two holes close one to each other from which two columns of water were ejected. These two fountains were joining and rising with so much violence as when the firing rocks were expelled, reaching heights of more than 30 m. (…) This water had the colour of lye and is so hot that it looks like boiling, and salty as seawater. (…) The day 22nd the water continued to erupt with the same impetus and direction and the 23rd it stopped and the smoke reduced. Few time after one p.m. the mountain was broken again on the western side and the water re-started to erupt with the same intensity and abundance as before, continuing during the night, with the same direction as before.

The eruption and geyser activity ended the day after, 25th of October, leaving in the Caldera a series of aligned holes, which are now known as the Simas de Tinguatón or Simas del Diablo. These deep fissural abysses were first explored by pioneering expeditions organized by the Comitté Regional Canario de Espeleologia in the early seventies (C. R.C.E. 1976). At that time the deepest of these shafts was descended to −83 m, being the deepest volcanic vertical cave in Spain. Recent 3D surveys performed by the association Vulcan Vertical and Speleo Limburg has mapped all the main passages up to a depth of −64 m, being some deepest passages probably now clogged by fallen rocks (Fig. 9).

The exploration and mapping of these peculiar vents provide the unique possibility of studying geyser conduits from the interior and in great detail. All the *simas* are developed along the same fracture, with some of them merging or splitting in different branches at depth. The maximum depth reached until now is at 260 m a.s.l.

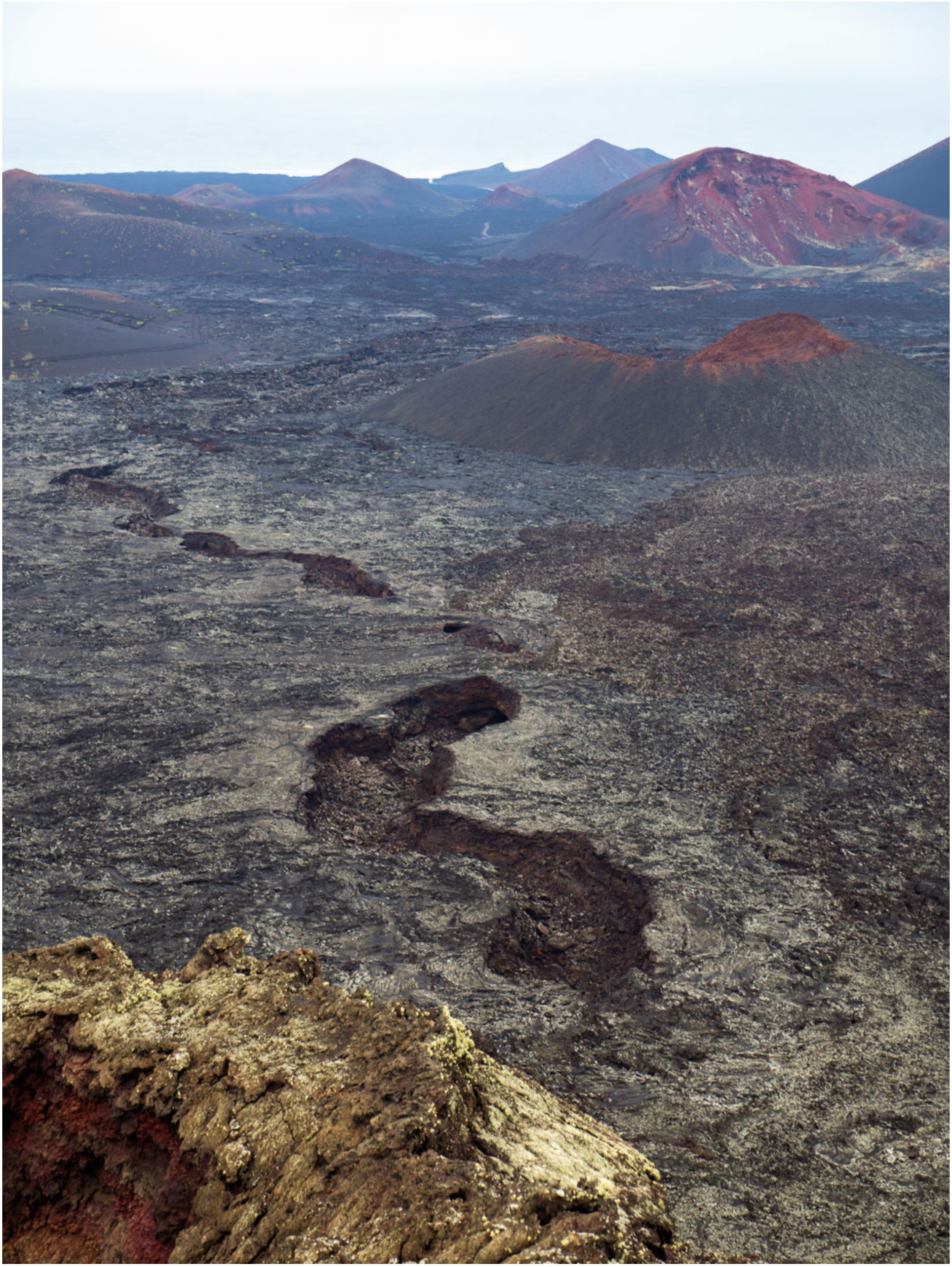

**Fig. 8** Series of lava tube collapses in the National Park of Timanfaya (photo Sirio Sechi—ESA)

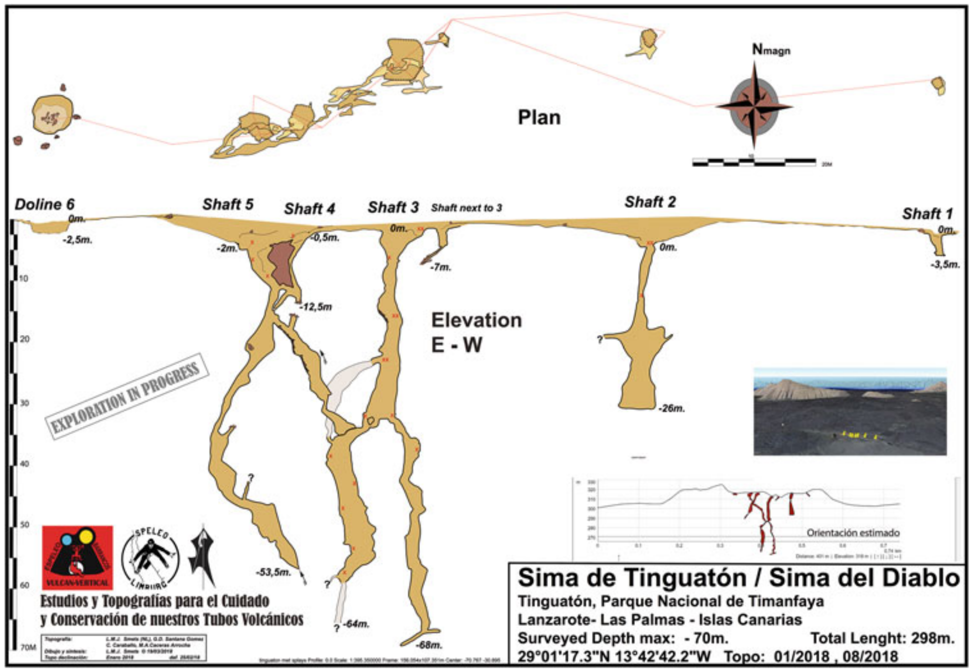


**Fig. 9** Topography of the Simas de Tinguaton

Considering that the origin of the geysers was probably related to seawater infiltration along a volcano-tectonic fracture from the coastline, the potential to extend the exploration deeper is really high. The walls of the shafts are mostly covered by mineralization crusts and some passages are often obstructed by boulders or volcanic bombs that sunk inside the chimneys, which explain the subsequent clogging and re-opening of the geysers described by the direct observation at the time of the eruption. Detailed mineralogical studies have not yet been performed, but a sampling campaign has recently started in the frame of the PANGAEA program of the European Space Agency. Preliminary results show the presence of abundant carbonate crusts (calcite, aragonite, ankerite) and the presence of several types of zeolites related to different thermal environments characterized by the interaction of magma with seawater. Biospeleology and microbiological studies are still missing, as well as a dedicated protection plan for these exceptional cavities and their surroundings.

## 4 Research Potentialities

### 4.1 Planetary Analogies

The several volcano-speleogenetic processes and different case studies that can be observed in the subsurface heritage of Lanzarote represent an excellent analogue for understanding the genesis of cavities and sinkholes in volcanic terrains of other planetary bodies like Mars and the Moon (Hong et al. 2014). The sinkholes chains related to lava tubes—like the several *jameos* of the Corona system (Tonello 2017) and those in the Timanfaya National Park (Fig. 8)—present striking analogies with collapse chains on the volcanic edifices of Arsia and Olympus Mons on Mars (Fig. 10) (Sauro et al. 2018b). The lack of vegetation in Lanzarote allows the study of the relationship between lava flows and underlying pyroducts, allowing a detailed comparison among morphologies, dimensions and volumes of the different volcanic features. In addition the availability of 3D models, thanks to new survey campaigns performed in the last two years will allow in the future morphometric quantitative analysis of these tubes to be compared with planetary counterparts. Not only lava tube could be used as planetary analogue features, but also volcanic vents and secondary caves related to subsequent erosion and weathering, would also be very interesting for these studies. The Tinguaton "geyser" vents would be of interest for making analogies with water-volcanism interactions features on Mars (Cushing 2012).

Because of these reasons, in 2016 the European Space Agency has started in Lanzarote a training program for the European astronauts that involve the visits to the Corona lava tube system and to the Tinguaton site (Sauro et al. 2018a). In addition to that, in November 2017, a technology test campaign with the involvement of four different space agencies, several research institutions and private companies, has been focused on exploration, navigation and mapping in lava tubes with the aim to develop new technologies for future exploration of planetary caves (Bessone et al. 2018).

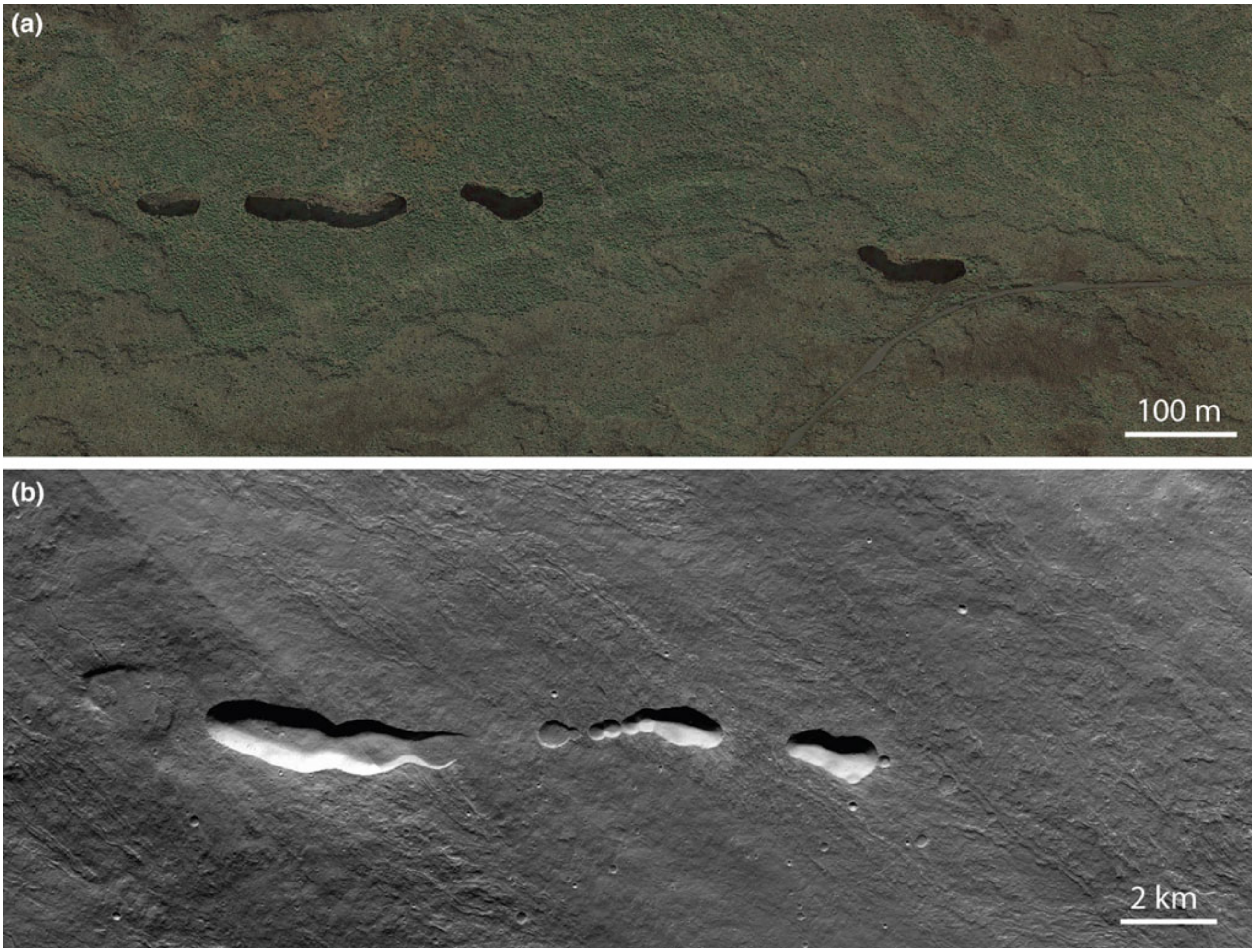


**Fig. 10** Sinkholes of the Corona lava tube systems compared to analogue collapses on the flanks of Olympus Mons on Mars. Note the difference in scale

## 4.2 Biology, Microbiology and Astrobiology

Biospeleological research in Lanzarote has started as early as in the 19th century, with the discovery of the depigmented crab *Munidopsis polimorpha* (Koelbel 1892) in the Jameo del Agua. The anchialine fauna of the Corona lava tube was the focus of several studies in the following decades, and especially in the Seventies, with the discovery of numerous depigmented new species of amphipods, polychaetes, isopods and the first and only remipede up to date known from the eastern Atlantic, *Speleonectes ondinae* (Garcia-Valdecasas 1984). The most recent reviews on the topic (Wilkens et al. 2009) reported 77 species including 37 endemic inhabiting the anchialine sections of the lava tube.

If these aquatic subsurface environments are well known (Iliffe et al. 1984), little information are available on terrestrial cave ecosystems. Oromí (2008) suggested that the aridity of the climate and the scarce soil covering the lavas prevents the existence of the necessary humidity for the development of a true troglobitic fauna. However, several caves have not yet been investigated, and studying the colonization by arthropods of the lava tubes belonging to the historic eruptions would be extremely interesting for understanding how these environments have been colonized by life in a timespan of few centuries (Ashmole et al. 1990, 1992).

Another topic of interest would be related to the study of lichens at cave entrances (Van den Boom 2010), in order to understand the potential presence of new species and their role in cave walls weathering (Stretch and Viles 2002).

Also, the microbiology of the volcanic caves of Lanzarote has never been studied so far. Extensive studies on this topic have been recently published about lava tubes in La Palma and Tenerife (Gonzalez-Pimentel et al. 2018), providing fundamental information on how bacteria have colonized the subsurface in volcanic settings (Riquelme et al. 2015).


**Fig. 11** The ESA astronaut Matthias Maurer and the researchers of the University of Sevilla are extracting and sequencing DNA from biologic material in the Geodynamic Lab module of Cueva de Los Verdes (photo Robbie Shone—ESA)

However the University of Sevilla have just started a microbiological sampling campaigns in the Corona lava tube system (Figs. 11 and 12), with the preliminary results showing the predominance of bacterial halophiles within the Gammaproteobacteria class (Miller et al. 2018), The presence of bacterial communities associated with sulphates like gypsum and halite makes this cave an excellent analogue to what is expected to be found in the Martian subsurface in terms of geochemical environments and potential life forms. These discoveries raise the importance of studying the microbial life in these peculiar environments, with a focus on the astrobiology prospective (Léveillé and Datta 2010).

## 4.3 Secondary Minerals in Volcanic Caves

Caves are peculiar minerogenetic environments, because of the action of specific chemical and geological processes (degassing, solubilization, weathering, karst process, phase change) often associated with biogenic activity (Hill and Forti 1997). Several studies in lava tubes and volcanic vents around the globe have discovered tens of new minerals for science and several cave minerals unique to volcanic environments (Forti 2005). In Lanzarote, few studies has so far dedicated much attention to cave mineralization, being mainly focused on the Corona lava tube system (Montoriol-Pous 1965). Here, calcium sulphate, halite and iron hydroxides are the most common species. Gypsum can form huge deposits with different morphologies (powders, massive, crusts, stalactites, desert roses, cotton like crystal aggregates) probably related to different phases of accumulation (Fig. 12). While the study of Montoriol-Pous (1965) was suggesting an origin of the gypsum as a weathering product of the basalts, following stable isotopes of sulphur from gypsum deposits in the lava tubes within the National Park of Timanfaya (Huerta et al. 2015) and in La Corona (unpublished) have shown that the sulphate ion is probably mainly of marine origin with limited contamination from the sulphate deriving from the basalts. This marine sulphate from sea spray would have been accumulated in the caves by airflows and, possibly, through biological mediation of bacterial communities. This kind of studies would need to be extended to much more caves in the island, and also to peculiar geological environments like the geyser vents of


**Fig. 12** Sampling cotton-like gyspum deposits in Jameo de la Puerta Falsa (photo Robbie Shone—ESA)

Tinguaton, where carbonates dominates due to the hydrothermal activity that characterized these cavities. The opportunities for research in this field are still almost untouched.

## 4.4 Protection and Documentation

Despite speleological research has started in Lanzarote more than one century ago (Hernández-Pacheco 1910), aside of the major features like the Corona system and Cueva de Los Naturalistas, few concerted actions have been taken until now for the protection of the general subsurface heritage involving both speleological associations, research institutions, political organisms and stakeholders. An official register of the known caves is still missing, therefore limiting the possibility of protecting and evaluating the human impact on this invisible side of the island. Cave maps are scattered in different archives, mostly private and unpublished, and the local institutions have no way to use them for environmental protection and planning. Even if the island is mainly protected, with its several "natural spaces" recognized by laws (and with the even more strict regulations in the Timanfaya National Park), a coordinate program aiming in providing tools and information to the public and the institutions is strongly needed in the next years. This effort will need to find a balance between preservation, scientific research, and environmental sustainable speleological tourism. At the moment, even if the access to the most of the caves is theoretically prohibited due to environmental protection, several of them are regularly visited by groups of tourists and improvised speleologists. This has brought to a situation of degrade, especially in some segments of the Corona Lava tubes, like in Cueva de Siete Lagos where several stencils made with chemical varnish have severely damaged the cave walls. It is not easy to efficiently regulate the access to these caves, because of the difficulties of monitoring so many entrances. However, a more responsible and informed involvement of civil society organizations, caving clubs and certified touristic guides, would allow a indirect control on the territory, reporting to the public authorities eventual risks of environmental damages. This policy has been applied with success in several other cases in the world, with a direct involvement of the speleological community by the institutions (Elliott 2012; Watson 1997). The subsurface heritage definitely needs a coordinate action to be protected and investigated.

## 5 Conclusions

Lanzarote offers one of the most various and spectacular geoheritage of volcano and speleogelogical type in the World, allowing the study of different speleogenetic processes, biospeleology, cave microbiology and more. The case studies described in this chapter are ranging from different type of lava tubes, volcanic and geyser vents, secondary caves related to weathering and erosion. Such an abundance and diversity of forms with a so high grade of preservation cannot be found in any other volcanic terrain in Europe, aside of Iceland, and in few other places in the World. The potential for scientific studies, with a focus on the unique analogies with planetary features and astrobiology, is really high and we are certain that the interest of research institutes and space agencies on this topic will increase substantially in the near future. Nevertheless, it is time to develop a strategic plan for the protection of these environments, involving speleological associations, stakeholders and the general public with the final aim to raise awareness on the importance of volcanic caves not only for touristic purposes but mainly for their integration in the Lanzarote and Chinijo Island UNESCO Global Geopark as unique geoheritage and ecosystems.

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# Lanzarote: Mars on Earth

Jesús Martínez-Frías and Elena Mateo

**Abstract**

This chapter analyses the planetary and astrobiological significance of the Lanzarote and Chinijo Islands UNESCO Global Geopark. The peculiarities and volcanic relevance Lanzarote has, along with its excellent preservation, have turned it into a place that is exceptionally similar to Mars (and similar to the Moon in some aspects too). The main points in common between Lanzarote and ancient Mars are included herein (mainly a connection between volcanism and water) and the principal features are outlined from this viewpoint, taking into account that the activities developed can be used as a model for other geoparks globally.

**Keywords**

Lanzarote • Geopark • Mars • Analog • Planetary geology • Astrobiology • Planetary habitability • Geoeducation • Geotourism

**Abbreviations**

| | |
|---|---|
| USGS | United States Geological Survey |
| CSIC-UCM | Consejo Superior de Investigaciones Científicas-Universidad Complutense de Madrid |
| PANGAEA | Planetary Analytical Geological and Astrobiological Exercise for Astronauts |
| IGEO | Instituto de Geociencias |
| ESA | European Space Agency |

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## 1 Introduction

The main aim of this contribution is to provide a general overview of the planetary and astrobiological significance of Lanzarote as a place that is akin to Mars, from several perspectives, mainly science, geo-education and geotourism in the area of the geopark. For decades, there have been unique places on Earth used as support for missions to the Moon and to other planets.

However, Lanzarote is a place like no other. The landscape itself, tells us about something scientific that lays beneath, something that is real and that goes beyond the borders of our planet and allows us to take a look further. For this reason, 5 years ago we started a specific project between the Cabildo of Lanzarote and the Geosciences Institute (IGEO) in order to cover the relevance of the materials and geological processes on the island with this new planetary approach (Martínez-Frías et al. 2016a, b).

It has been divided into five sections:

(1) A first chapter related to planetary geology (habitability, and more specifically its development in Spain), which is the area this contribution is based on, explaining its foundation and evolution,
(2) A second chapter about Mars, especially ancient Mars, with a special focus on the connection between volcanoes and water,
(3) A third section about planetary analogs, explaining what they are and which ones are the most relevant ones in Spain,
(4) A fourth more specific chapter about Lanzarote as an analog, and, lastly,
(5) An example of a "Martian router" in Lanzarote, specifically in the Caldereta-Caldera Blanca area.



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## 2 Planetary Geology

Astrogeology or Planetary Geology, is a discipline that has been promoted in Spain and internationally for more than 30 years. Geological studies related to planetary exploration cover many aspects and cannot be understood at present without considering their inter and trans-disciplinary aspects. Therefore, just as there are astrophysicists, astrochemists or astrobiologists, planetary geologists have called themselves, and continue to refer to themselves as astrogeologists. The Geological Service of the United States has a specific astrogeology research programme (USGS), USGS Astrogeology Research Program, that has been in operation for years. Although there is no specific and standardised definition of astrogeology, one of the best descriptions is the one used by the Arizona State University: an emblematic institution, a pioneer in this line of research. Planetary geology can be defined as:

> the study of the origin, at different scales, evolution and distribution of condensed matter in the universe in the form of planets, satellites, comets, asteroids and particles of different dimensions and genesis. This involves the incorporation and detailed study of data from space probes, comparative analysis of meteorites and cosmic dust, structures and meteorological impact events, laboratory simulations of various planetary processes and also field studies on terrestrial analogs useful to explore and model the geological mechanisms and processes that take place beyond the borders of our planet.

Although this is a broad definition, it doesn't fully portray the work carried out by planetary geologists. Those scientists, just like geologists who work with more traditional terrestrial issues, although benefiting from physics, chemistry, biology and other disciplines in a scientific-technical blend which does not only enrich the Sciences of the Earth and space area, is key for knowledge to evolve in its highest expression. The following issues are some of those included:

- Extraterrestrial matter studies, mainly meteorites.
- Meteor impact and crater research.
- Geological, mineralogical and metallogenic characterisation of terrestrial analogs in order to explore other planets and moons.
- Lab simulations using planetary cameras.
- Direct participation of astrogeologists in planetary missions (i.e. Mars, Pluton).

Institutionally speaking, it's important to keep in mind that planetary geology is a specific subject area officially recognised in the scientific disciplines and sub-disciplines and international fields context of UNESCO (UNESCO code: 2104.04), whose review, rearrangement and updating has been recently proposed. In addition, Planetary Geology is a professional activity officially recognised within the field of geology in Spain.

As stated at the Round Table of the 7th Geological Congress in Spain, planetary geology is currently developing in advanced countries, and in our country, it is gradually covering a broader scope—although slowly—both, in professional areas related to research as well as in education. By simply having a look at major-impact scientific magazines (Nature, Science), we can see how mineralogy or Martian geodynamics studies are more and more in the spotlight.

We, geologists, must be free of hangups and be able to take part in space missions like other specialists from other areas do. It would make no sense for astronomers, astrophysics, chemists and engineers to be responsible for looking into Mars minerals, rocks, geomorphology, geodynamics or geochemistry, or to have to interpret everything that grows there, just like we would not expect for them to do our job either.

In order to do so, a shift in how we view many academic and scientific applications in our country is required. In Spain, we can still see how some of our colleagues see these studies as unusual, or even inadequate, and they see advanced science as science fiction, although it is regarded as normal in other countries. Without a doubt, the studies and activities that take place at the Lanzarote and Chinijo Islands UNESCO Global Geopark, are living proof of the innovative development of advance science in this regard.

Studying analogs, we can:

- understand specific processes taking place in Mars and other planets and moons (mainly from an astrobiological viewpoint, those related to the existence of liquid water in the past);
- determine the geological evolution and the possible overlap of episodes that have different origins;
- establish the environmental and habitability conditions that could have led to the existence of life;
- carry out controlled simulations that can help future crewed missions, and
- test technologies and prototypes of state-of-the-art tools which, can allow us to perform non destructive monitoring and characterisations "in situ".

The planetary analogs are closely linked to geodiversity. Geodiversity can be seen as "the variability of abiotic nature, including lithological elements, as well as tectonic, geomorphological, edaphic, topographic and the physical processes over the face of the earth, seas and oceans, alongside systems created by natural, endogenous and exogenous and anthropic processes that make up the diversity of particles, elements and places." This variability can be qualitatively described with the geodiversity index.

Spain, due to the large variety of processes and materials that are involved in its creation and evolution throughout its geological history, has a considerably high geodiversity index that can be seen in the large number of geologically diverse areas for such a relatively small surface.

On the other hand, our Solar System consists of a wide range of planets and moons with different features; areas with a high geodiversity index stand more chances to have places with potential to be researched and looked into as planetary analogs, hence helping us extrapolate what we learn from them to planetary exploration.

## 3 Mars

Mars is basically a volcanic planet. Around half the size of Earth, it has several volcanoes that surpass the largest volcanoes on our planet. Most of them are in high areas or domes of the Tharsis and Elysium regions. The Tharsis region covers an area of about 4000 km and reaches an altitude of almost 10 km. The three shield volcanoes in this area are aligned: Ascraeus Mons, Pavonis Mons and Arsia Mons. The majestic and gigantic Olympus Mons is a shield volcano, 24 km high and 550 km in diameter that is surrounded by a 6 km high escarpment. It is the largest known volcano in the solar system.

In addition to all this important volcanic activity, all geological data and models indicate that the “red planet” had a watery past, with rivers, lakes, seas and even a gigantic ocean, with a possible hydrological and hydrogeological cycle in a way similar to the terrestrial one. This is not only of great relevance for the purposes of its “geological vitality” and past geodiversity, but also in relation to the multiple aspects linked to its past and present habitability and to everything related to the search for astrobiological life and significance.

Therefore, this evolution from an aqueous Mars to another current, with different geological and atmospheric characteristics, should be taken into account in the study and characterisation of its paleo-environments and in the so-called terrestrial analogues or planetary analogues. And this interaction between Volcanoes and Water makes the Canary Islands in general, and more specifically Lanzarote, an ideal place for this type of research.

## 4 Planetary Analogs

There are currently three fundamental pillars that support research on Mars (including the study of habitability conditions and life search):

- The characterisation of Mars meteorites;
- Space missions to Mars; and
- The identification and characterisation of the so-called analogues of Mars.

No area on Earth is really similar to Mars, not even in the past. But there are certain areas that, due to their uniqueness and geological, geomorphological, mineralogical, geochemical or astrobiological significance, are of great importance in order to understand the processes that take place in the Red Planet, to test prototypes and avant-garde instrumentation, and to interpret its paleo-environments and habitability conditions when it comes to searching for life.

Despite the enormous amount of data obtained thanks to missions to Mars, there is still great ambiguity when interpreting certain features of its surface. Hence the importance of having terrestrial models, based on knowledge of processes taking place on our planet, that allow us to extrapolate to other planetary bodies. For this reason, the Earth has many keys for its exploration and the study of analogues is crucial. Studying analogues is an important planetary sciences field, since it allows in situ work to take place in terrains with characteristics similar to those found in other planetary bodies.

The information resulting from these studies backs up missions of planetary exploration scientifically, in turn providing new characteristics to be researched within the analogues, thus giving feedback to these two pillars of study of the Solar System. Many “sites” of our planet have been used during the past decades as analogues, from Antarctica to Atacama or from Iceland to Mauritania or Australia. In fact, there is already abundant scientific literature, books and even catalogues of analogs of planetary interest (i.e.: CAFE). However, none covers each and every one of the aspects to be investigated, whether they are climatic, volcanic, geomorphological, mineralogical, geochemical, sedimentological, paleo-environmental, etc. They are like the pieces of a puzzle that must be put together, according to the scientific objectives to be addressed.

Planetary analogs are intimately related to geodiversity. Spain has a large internationally recognised geodiversity that includes numerous areas, materials and geological processes throughout the geological evolution of the Iberian Peninsula and both archipelagos (Muñoz et al. 2017). This has resulted in defining and characterising important areas as planetary analogues, mainly for the investigation of Mars, but also the Moon, Europe (Jupiter) or Titan (Saturn).

Of all of them, the main areas studied as analogues of the Red Planet, are: Río Tinto, the hydrothermal and evaporitic system of Jaroso-Sorbas-Cabo de Gata and the Canary Islands (Lanzarote and Tenerife), there being other areas that have been less researched from this perspective, but that have also been used to develop different scientific and instrumentation elements linked to planetary aspects, such as the Gulf of Cádiz, the volcanic area of Calatrava or the evaporitic endorheic zone of Bujaraloz-los Monegros.

## 5 Lanzarote: Geopark and Planetary Analog

A geopark is a territory that contains both a unique geological heritage and a self-development strategy. This entails a series of activities among which are geosciences research, education, cultural heritage, dissemination and other facets that connect multidisciplinary geosciences and society. Geoparks have become one of the main programmes of UNESCO, along with others better known as World Heritage or Biosphere Reserves. Spain, with 12 geoparks, ranks second worldwide after China.

In 2013, The Cabildo of Lanzarote submitted the candidacy of the Lanzarote and Chinijo Islands Geopark. The boundaries of the proposed area cover a total of 2500 $km^2$ that include a submarine platform to the emerged parts of the island of Lanzarote and the islets that make up the Chinijo archipelago. Of the 140 existing geoparks in the world, the Lanzarote and Chinijo Islands is the only one that contemplates the evaluation and characterisation of certain zones as potential planetary analogues for the exploration and geological and astrobiological investigation of Mars (Martínez-Frías et al. 2017). It is also the only one that has a "Corner of Mars" on its official website (http://www.geoparquelanzarote.org). In this context, an agreement was established between the Cabildo of Lanzarote and the Geosciences Institute (CSIC-UCM) in order to address the following aspects:

- Acquisition of new scientific knowledge, from a planetary and astrobiological perspective, based on the relevance of Lanzarote as a Natural Laboratory and analogous potential of Mars.
- Modelling the interaction processes of volcanic rocks with water and its importance in the field of planetary habitability in relation to the past of Mars.
- Establishing pilot areas to monitor and conduct "non-destructive" tests, respecting the environment, both in relation to the current robotic exploration of the different planetary bodies, and, what is even more important, with the future human exploration of the solar system.

All this, considering the following areas and objectives in the Lanzarote and Chinijo Islands UNESCO Global Geopark:

- In hydrothermal volcanic zones, with or without mineralization.
- In volcanic zones of meteoric and/or marine alteration, low temperature.
- In lava tubes.
- In surface areas "volcanic soil" with the possibility to develop atmospheric water absorption processes.
- Morphological analysis of fractures due to thermal differences and/or related to the presence of water.
- Identification and establishment of places and routes of educational interest based on this new data and, if applicable, proposal of new "planetary and astrobiological itineraries".
- Identification of an area near Timafaya (not inside), that can be used to set up a semi-permanent base similar to that of the Hawaii Space Exploration Analog and Simulation (http://hi-seas.org/).
- Availability information products.

So far, a Planetary Guide to Lanzarote has already been set up (Martínez-Frías and Mateo-Mederos 2018) and several Planetary Routes (related to Mars) have been identified (Martínez-Frías and Mateo-Mederos 2016) that complement the effects of science, geo-education, dissemination and geotourism, the already remarkable relevance of Lanzarote. The subjects and aspects in which the importance of the Geopark in relation to the studies of Mars (and also of the Moon) is observed are different.

## 6 Caldereta-Caldera Blanca

The most emblematic and best-known planetary route identified in Lanzarote was Caldereta-Caldera Blanca (Fig. 1). This route is of special interest in order to explain different types of ancient and current volcanic rocks, the evolution of volcanic series in space and time, what the different colours, alterations, textures, flow structures, lava flows represent and also other additional aspects connected to the construction of this type of water-related buildings.

This volcanism-water connection, is especially relevant in aspects related to habitability and life search on Mars, something fundamental from an astrobiological perspective, since it allows us to understand potentially habitable ancient and current environments at different scales, from those strictly related to genesis from volcanic buildings to the current ones represented by furrows and gullies eroding the slopes of said buildings (and associated with the precipitation of other secondary minerals). It is important to bear in mind that Caldera Blanca had already been used as a

**Fig. 1** Caldera Blanca is the most emblematic and best-known planetary route identified in Lanzarote

terrestrial example of a Martian analogue in relation to the possibility of hydrovolcanism on the Red Planet.

As previously mentioned, among the different areas and scientific objectives, the study of lava tubes is one of the aspects given priority to due to their importance in terms of lunar and planetary habitability, not only from a microbial point of view, but also as potential shelters for future semi-permanent bases on our satellite and on Mars.

The initiatives developed in this Lanzarote-Geoscience Institute (IGEO) Cabildo Agreement have been reinforced by the collaborative activities carried out within the framework of the European Space Agency (ESA) programme PANGAEA (Planetary Analytical Geological and Astrobiological Exercise for Astronauts) (http://blogs.esa.int/caves/category/pangaea/; Martínez-Frías 2016a, b). This activity has already been successfully carried out in two editions and is a true milestone in global-level training activities in which Spain, through actions taking place in Lanzarote, is having evident international relevance.

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# Part III

# Living in the Geopark

# Lanzarote: The Landscape and the History Behind the Volcano

José de León Hernández


**Abstract**

In general, the geological aspects of a territory, despite being a determining factor in its own physical constitution, are perceived far from the human reality, distant from historical events that have occurred. This makes sense for territories whose physical support was formed dozens, hundreds of thousands or millions of years ago and whose transformations have undergone a slow process in temporary terms, especially when erosive agents are involved, as a result of various factors, chemical, mechanical, climatic, etc. In those cases, the geology is there, more or less perceptible, but it is however quite alien to us. Another case is that of territories where geological formations, more or less ancient, have been related to important human factors. In those cases, the geological singularities that result from human interaction with them in order to survive, lead to cultural features. In some cases, these factors can have an important historical dimension. We mean, among many other things, the formation of more or less productive soils or wastelands, areas with greater or lesser hydric capacities, the formation of plains or mountain ranges, the greater or lesser exposure to natural disasters (volcanoes, floods, landslides, …), the possibilities for a permanent habitat (tufa or calcareous formations, easy to build caves), or displacements (unevenness, hydrological basins, …). In these circumstances, these geological singularities are due more to their relationship with human development, mainly seen as resources, than their own physical constitution. This fact has led to much of what we understand by culture not only material (agricultural landscapes, habitat, infrastructure, works of art, crafts, …), but also immaterial, linked to the set of beliefs and collective imagination (the affection to a landscape, the coexistence with volcanoes, the sacralisation of mountains, etc.). The enormous wealth and diversity that geology provides the planet with, contributes to a great extent to the enormous richness and variability of cultures. It is true that other factors are equal or more determinant when it comes to the formation of cultures, socio-economic, political or ideological aspects, but these areas are also exposed to those resources, where the geological peculiarities are hidden (mines, strategic places, fertile soils, are usually behind empires, wars or happiness). Nowadays, the revaluation of geology, the socialisation of knowledge that until a few decades ago interested merely solitary characters carrying a hammer, travelling to unusual places, has also turned geology into a not only cultural, but also economic resource. But let's talk about some much more explicit cases, about the important role that geology can play in culture and even in historical processes, as an example that is very close to home. We're talking about the island of Lanzarote and how a geological event, a significant volcanic eruption can, not only, profoundly transform its physical reality, but also its historical and cultural reality (De León Hernández in Lanzarote bajo el Volcán. Los pueblos y el patrimonio edificado sepultados por las erupciones del siglo XVIII. Servicio de Publicaciones Cabildo de Lanzarote. Serie Casa de los Volcanes, Las Palmas, 2008). This can still be seen nowadays in the collective religiosity of the island which revolves around Virgen de los Volcanoes, which replaced the founding saint after the conquest, San Marcial, talks about the relevance that an important geological short-time phenomenon has had on this island. Not only was much of the island buried by lava and ash from the eruptions of the eighteenth and nineteenth centuries (Rumeu and Araña 1982), but also another important part of it was buried by flying sands at different times in history. Between the late 18th Century and first quarter of the 19th, it covered villages, agricultural land and infrastructures shaping a new landscape that, just like areas covered by volcanic sand, is cleverly reused (De León Hernández and Robayna Fernández in El Jable, poblamiento y aprovechamiento en el mundo de los antiguos mahos de Lanzarote y Fuerteventura. III Jornadas de Historia de Lanzarote y Fuerteventura, Tomo II. Puerto del


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Geoheritage, Geoparks and Geotourism, https://doi.org/10.1007/978-3-030-13130-2_11

Rosario, pp 11–107, 1989). Hence how we understand that such circumstances and their consequences on the population, could lead to differentiated and unique types of culture. These new territories, would contribute to generate what we call volcano culture and Jable culture. But in the case of Lanzarote, the emergence of these new territories, not only make up new ecosystems and new cultural patterns, but those changes also had an important historical footprint, in just a few decades. The volcanic eruptions change the social, demographic, economic and political reorganisation of the island, with the emergence of new productive zones, new agricultural systems, new populations and parishes that led to the current political administrative organisation and the development of a new local bourgeoisie, closely linked to the benefits derived from the volcano, especially with the exploitation of the Geria area. But, in addition, the Jable invasions at the beginning of the 19th Century, are also connected to the process of usurpation of lands on the Famara coast, by the new economic sector linked to the barrel and the brandy industry, that strives, at the same time, to be the Capital, finally leading to Arrecife, at the expense of Villa de Teguise (Quintana and De León 2004). The latter case of Jable, seems to have predicted the current situation we are living, how human action can also generate important geological changes, or even climatic, in the short term, with highly significant historical long-term consequences. We can therefore see how, for an island like Lanzarote, geology, culture and history are not that different, they are in fact essential factors to rebuild the past and present of this island. We will now briefly explain the impact volcanic eruptions of the eighteenth century had on the future of Lanzarote, taking a deeper look at the physical and cultural reality that the lavas and ashes covered and at the same time providing information, unknown to date, not only about the people and the land that disappeared, but also the geological reality that was also erased from the map and from people's memories.

**Keywords**
Timanfaya • Eruption • Villages • Archives • Virgin

**Abbreviations**

| | |
|---|---|
| AMC | Archivo del Museo Canario |
| AHPLP | Archivo Histórico Provincial de Las Palmas |
| AML | Archivo Municipal de La Laguna |
| PN | Protocolos Notariales |
| CD | Conventos Desamortizados |
| LFIMT | Libro de Fábrica de la Iglesia Matriz de Teguise |
| FJMA | Fondo José Miguel Alzola |

## 1 The Natural and Cultural Heritage Destroyed by the Volcano

In the eighteenth century the island of Lanzarote experienced one of the most important volcanic events in the recent history of the planet (Carracedo and Rodríguez 1991: 29). For 6 years, almost non-stop, this small island of about 800 $km^2$, was subject to ongoing volcanic eruptions that began on September 1, 1730 (between 9 and 10 at night) and seemed to culminate in April 1736.

> …, which lasted two days and two nights the first time, suffering the fury and rage of a volcano that erupted in a place called Chimanfaya on September 1st of this year between nine and ten at night … (AMC. LFIMT, s/f 1730.)

The consequences of this fact, although not catastrophic in terms of human lives (however undoubtedly did have psychological effects on the population) were tragic in terms of material damage. The "volcano", as the area that today covers a quarter of the island surface is popularly known, before the eruptions, used to be the physical support of a great human, economic, cultural activities, etc.

In a provisional assessment, we can say that it affected more than 2000 people directly (almost half the population of the island), it destroyed and buried about 14 villages and 8 small towns; destroying some 700 houses, more than 1500 cisterns, 3 chapels (such as the still unknown chapel of Our Lady of Candelaria), two prayer rooms, a granary, tahonas, maretas (used to gather rain) and several corrals, bird sheds, eras, etc. It also destroyed some of the best agricultural land, such as Boiajo, Las Vegas de Iseo or Santa Catalina; large cattle meadows like the ones in Fuego Macher and Tegurrame, and the Real de Janubio port, as well as numerous paths.

The largest number of villages were located in the centre of the island. If we exclude mountains, some low hills, numerous aa lava flows and some important ravines, what stands out the most were the relatively flat and fertile spaces that constituted rich meadows associated with the most important villages. The most mentioned towns were Tíngafa, Santa Catalina, Mancha Blanca, Chimanfaya, Chupadero, Peña Palomas, El Rodeo, Maso, Jarretas, Buen Lugar, Masdache (Verneau 1981: 46), Gerias, Guatisea and Testeyna. Other enclaves sometimes mentioned, with a few houses were Maretas, Tenemozana, Masintafe, Iniguadén, Conil, Candelaria, Guimón and El Miradero.

This dramatic event was going to affect powerful families that were part of the clergy, such as the family of the author who wrote the Journal about the eruptions, the priest from Yaiza, Andrés Lorenzo Curbelo, as well as other wealthy people such as Bernabé Gutiérrez de Mancha Blanca, Francisco González Guerra de Santa Catalina, Captain

Roque Luis, Ensign Lucas Gutiérrez. Also, the descendants of Captain D. Luis de Betancur Ayala, who died shortly before the eruptions, they owned several houses, farmhouses and a large amount of land and property in the areas affected.

The consequences on the humble population were even more tragic. They saw their few possessions destroyed. The names of some places refer to marginalised ethnic groups, such as the numerous slaves who lived in that area, like the sallow man named Antón, bought by Bartolomé de Medina, a neighbour of Santa Catalina. Several examples of land that these groups refer to, are: Cueva del Negro in Tíngafa or La Vegueta de la Negra in Mancha Blanca.

The island depopulated, people migrated to other islands, especially to Fuerteventura (De León 2000: 133) and in some cases, to Caracas, Buenos Aires and even the Philippines. (AHPLP, PN, file 2805. Folio 135. 1733)

After the eruptions, some villages grew, like Los Valles, Tajaste and Uga and others were set up, which later became the centre of municipalities, such as Tías, etc. In a few years, the cultivation of large areas of land covered by volcanic sand led to spectacular productive results, doubling the population of the island in about 40 years and the production of wines reached international prestige.

On the other hand, this economic boom promoted a build-up of capital process with large families from the island pushing for the introduction of *barilla* harvesting, resulting in the growth of Puerto de Arrecife. Thus, encouraging a series of political transformations that resulted in the change of capital. Such is the economic impact produced by the eruptions, as the great historian José de Viera y Clavijo says:

> … the horrible volcano … changed the agriculture and commerce on the island. … This result, so feared by locals who saw how the most plentiful part of the island went up in fire, including their cattle and granaries. However, the resulting usury provided by nature compensated for that loss. (Viera 1967: I. 788)

Although we have carried out a broad and thorough study of the physical reality of that land, and what the population did before 1730 (De León y Perera 1996; De León Hernández 2008, 2010) in this article, we will provide a summary of the most important factors of the Historic and Natural Heritage that was lost after the 18th Century volcanoes, like for instance, the significant impact that a recent geological phenomenon has had.

## 2 The Destroyed Land and Natural Resources

Although the previous idea about the area covered by lava and volcanic sand was the existence of numerous good quality land for cultivation. Notwithstanding the truth of this, we would need to top it up with broader and more detailed knowledge that we have about this land.

In terms of suitable land for cultivation, in this area there were some well-known meadows before the eruptions, like the Vegas de Chimanfaya, Santa Catalina, De Iseo, Del Pueblo, Iniguaden, Guagaro, Tingafa, Buen Lugar and Chichirigauso. In the East, the Vegas de Tomaren, Candelaria, Masdache and Testeyna stood out. In the West, there was Boiajo, near Montañas del Fuego, and Vega Nueva de Villaflor. Sometimes, flat areas stood out for their productivity: El Llano de Iniguaden or Llano de las Jarretas. Other times, the name itself refers to that potential productivity, like La Esmeralda, Aguaclara and La Vega Nueva (Fig. 1).

There is an interesting description given by E. Hdez. Pacheco on this area, made in 1909 and found in documents that no longer exist:

> The name of Timanfaya was also used for the plateau on both sides of the old landscape, that is now covered by a sea of lava and that used to be the meadows of Timanfaya, with small villages and houses well-known as the most fertile and productive on the island (Hernández Pacheco 1909: 177; Hernández Pacheco 2002)

There are testimonies that were passed down orally, like Tito Rivera's, a late neighbour from the Tajaste area, talking about the land that was hidden by the lava near the small town of Tíngafa: *That plain used to be called Vega de las Flores, because it was very fertile before the eruptions.*

However, as we have already pointed out, despite the existence of good land for agricultural activity, many parts of the territory covered by the volcanoes of the 18th century were formed by relatively recent aa lava flows landscape. We have found several quotes about that type of land in this area: Malpaís de Santa Catalina, Malpaisito de Luis Cabrera, Malpaís de Mancha Blanca, Malpaís de Las Vacas, Joan Gante, Malpaís de Inaguaden, Guagaro, Las Casas and La Jorqueta.

Despite the predominantly flat nature of this area, it should be noted that in the interior or on the edge of this territory there were numerous mountains, among which were Montaña Blanca de Perdomo, El Rodeo, Ortiz, Mazo, El Miradero, Santa Catalina, Podemosana (Tremesana), Pedro Perico, Bermeja, the Montaña Las Vegas, the current Montaña Negra, the Diama and El Chupadero. Thanks to the toponymy prior to the eruptions, we know some elevations not currently identified or that are known by a different name, such the Montaña de Blas, Lomo de Carlos, near Tíngafa, and Lomo de Pajitos, near Chimanfaya. Many of these mountains played a very important role in the development, advancement and distribution of the lava flows, since they sometimes formed natural obstacles that prevented certain areas and even villages from being covered. We have been able to make a spatial reconstruction of the land prior to the eruptions thanks to these elevations (Fig. 2).

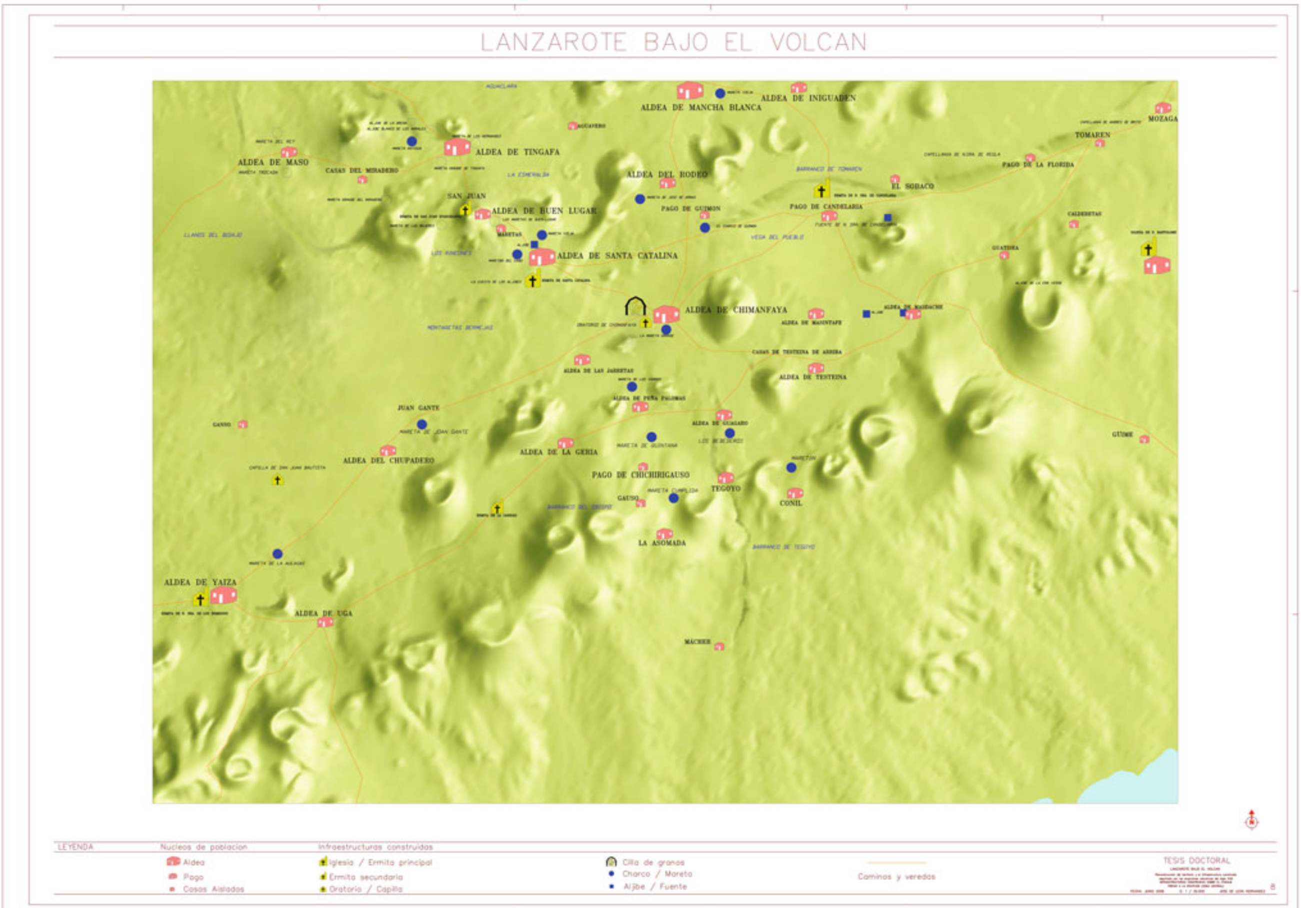


**Fig. 1** Map of shadows of villages buried by eruptions of the volcano

It is necessary to emphasise the existence of some ravines that no longer exist. Sometimes they are associated with villages that nowadays have disappeared, such as Tíngafa, La Geria or Tomaren. Sometimes these ravines are mentioned by some elements that stood out in them or in their surroundings, such as the Negro cave near the ravine in front of Tíngafa, or the ravine called Las Cuevas, bordering on the Vega de Tomaren. Another document mentions the *ravine in a large reservoir in Tingafa* (AHPLP, CD Legajo 44. Fol 448. July 9, 1664). But undoubtedly, we must highlight an important ravine that crossed much of the central area of Lanzarote which played an important role before the eruptions, the ravine of Tomaren. This great ravine which possibly started near the current Rodeo Mountain, crossed between the current Montaña Colorada and Montaña Ortiz, and now crosses where Cueva de las Palomas or Naturalistas is today, and passes where nowadays there is a set of volcanic tubes that reach Mozaga, from there it went to the Jable, dividing into two, to the northeast of Lomo de San Andrés, on one side which is known as the Jable ravine, heading towards Famara and which nowadays is perceptible in the lava language from the 18th century that runs along the old channel, and the Arena ravine, which kept going down Llanos de Maneje to Ubigue, reaching the sea through the current Puerto de los Mármoles.

Several rocks also stood out in that area, such as Peña de los Pastores, which may correspond to small islets next to Peña de Santa Catalina north of Diama, or Las Peñas, near Candelaria before the eruptions. There would also be old coastal cliffs that have now disappeared, old volcanic tubes and Jameos.

From the point of view of strategic resources, we may notice that this area, as it happens with the rest of the island, had very few water resources. These issues were solved with an impressive and specialised human adaptation to extreme arid conditions and with the construction of a large number of artificial deposits or working on seasonal natural pools (tides). In any case, what the documents highlight is the lack of water:

> This Island is small and it lacks water. To such an extent, that water saved from rainfall, in cisterns, tanks and puddles, is used by people and cattle to drink during the year (López de Ulloa, in Morales Padrón 1993: 250)

**Fig. 2** Small islets north of Montaña Diama, which were probably the Peñas of the Pastores

Although there are some inaccurate references to sources in the area, one for Candelaria and another near Tígafa, we believe that there were no natural conditions favourable to the existence of natural water springs. The sources that today exist in this new area, such as Tínga, Ortiz, Montaña Negra, Diama or Los Miraderos (Fuente de Crisanto), would have been formed precisely by the accumulation of volcanic ash after the eruptions on old mountains. The humidity and occasionally the rain, would be absorbed by the deposits of volcanic rock retaining the water and sliding it down some old slopes.

The theory of engineer, Carlos Soler, has recently gone public. There are important accumulations of water under the historical flows, precisely thanks to the existence of old impermeable land, by the action of the incandescent flows on brown floors (flushing), which allowed for the water to accumulate under the lava flows, which would in turn help to avoid fast evaporation. From our research work we have located many areas with a certain impermeability, where seasonal water deposits (puddles and tide puddles) were formed, as well as ravines, pits and depressions of the land, in some very abundant areas, which could support this theory.

The Coast was another area that although practically uninhabited, it could offer important resources, especially for fishermen and farmers, when locating the best meadows for breeding animals. This was a sector of the old territory that was transformed almost in its entirety. When exposed to strong northern sea waves, there were no important ports, except in the south-western sector, the Puerto Real de Janubio, covered by lava and a small one on the north coast, that no longer exists, which is called Cala de Lovos (Torriani 1978). Other economic activities took place in this area, such as salt mines, collecting *orchillas*, etc.

In terms of plant, animal or mineral resources in this area, the document sources provide us with some references:

> On the island of Lanzarote there is a lack of trees, there are only a few small bushes they call tabaibas, … (Abreu Galindo 1977: 58).

There were possibly areas with seasonal pastures, badlands colonised by *tabaibas*, (such as the Malpaís de la

Corona or El Mojón), some types of isolated trees such as wild olive trees, and perhaps a palm grove. The domestic fauna includes goats and sheep. There are many mentions made to corrals, flocks, folds, especially in the coastal areas, which attest to the abundance of goats. (AHPLP, PN L.2801 (II), Fol. 1. 1723).

Although this may seem surprising today, cattle were also abundant, especially in years of good harvests, due to the large cereal production and surplus straw. There were place names such as Malpaís de las Vacas, located near the village of Jarretas or Dehesa de Maso, which was used to graze cows (AHPLP, PN 2797. S/f, September 11 1618). There are numerous mentions of camels. This tenant on the island, arrived with the first Moorish slaves, and was going to revolutionise the concept of space and production. Due to their great resistance, they were an important resource in transportation, communications and in the driving force for land clearing. The horses of the island stood out: *They also have good breeds of Berber horses, and many cheap donkeys.* (Torriani 1978: 46).

Other animals are mentioned in various documents of the sixteenth and seventeenth centuries, such as plenty of chickens, rabbits and shearwaters … (Torriani 1978: 46).

It is necessary to look back at the times we are studying, to see part of the current fauna of the island: black-eye, Egyptian vulture, bustards, various rodents, *corujas*, crows, shrikes, hoopoes, shearwaters, among others. Many of these animals have been an important human resource. There were place names which have now disappeared under the lava flows, such as Hoya de las Lechuzas, Cueva del Gato or Peña Palomas.

Techniques and traditional knowledge related to food resources would also be present in that area, such as fishing with spurge milk, making *gofio de cosco* (slender-leaved ice plant toasted cornmeal), harvesting baby potatoes and locks or hunting shearwaters. Also, in the documents and in the names used prior to the eruptions, mention is made of a certain mineral exploitation: the Tingafa calera, the Toscas loin by Masdache, the Cantos de Guagaro, the La Arena gully or the tide called Los Barros in the Miradero (AHPLP, PN 2798. March 23, 1721).

## 3 The Disappeared Cultural Heritage

There are many archaeological remains of Majos, inhabitants of the islands of Lanzarote and Fuerteventura before the European Conquest, who were buried by the eruptions (Le Canarien 1980: 169) . Those populations occupied this area significantly and the deposits located under the volcanic sands in Masdache, El Taro, Uga and Ortíz are evidence of this. In this last area, we discovered an interesting station of rock inscriptions belonging to two different, and probably connected, alphabets, the Libico-Berber or Amazigh, and another one that we related to some North African variant of Latin. Both inscriptions were made around the beginning of the era (between the 1st century B.C. and the 1st century A. D.). It was in the borders of this area, Castillejo in Montaña de Tenésera, where we first found this type of writing, in 1985.

Also, the names used for the volcanoes refer to aboriginal settlements with names of villages, such as Tíngafa, Chimanfaya, Podemosana, Chichirigauso and Masintafe.

But perhaps the most important references to the population from the area that disappeared, unpublished data up until now, are those related to the villages and homes of the aboriginal population. We have located numerous houses of the *majorera* population of Lanzarote (also known as vault houses), destroyed by lava flows or ash: Casas Hondas de Chimanfaya, Maso, Gauso, Guimón and Tíngafa. Some of them provide us with details about aspects related to the construction of those houses, now covered by lava, like a vault house that was in the village of Maso, called casa jonda, which could be used as a corral. (AHPLP, PN, Leg 2744. F.30r/32v, April 15, 1646).

After the Conquest, the oldest mention made to some of these towns was in 1455 referring to the village (later buried) of Tizalae (Tisalaya), when Alfonso de Cabrera, who became governor of the island under the Portuguese flag, went around the island. It also mentions the villages of Eque and Guihafuso. (Aznar Vallejo 1990: 132).

At the end of the sixteenth and early seventeenth centuries, the village of Iniguadén, later buried, is mentioned. There was an important farmhouse and the temporary residence of the Marquise there (AMC, FBL, Maiorasgo de Lanzarote, 1,568). This farm was owned by different people, until it was acquired and developed by the aforementioned Luís de Betancor Ayala (AHPLP PN 2799. 1722. Date of the testament: 30-1-1772). This important and wealthy area got destroyed in two phases, first by the ashes in the first two years of the eruption and from 1733, it got covered by lava flows.

We must bear in mind the almost complete loss of all written documents prior to that date, due to the fact that most of them were burnt and destroyed by pirate attacks. The first map of the island dates back to this period (Torriani 1978), and it mentions the villages of Hainaguadén and Tenemosana, later buried (Fig. 3).

After the Conquest and throughout the 15th and 16th Centuries and the first third of the 17th Century, the life of the inhabitants on the island was quite tough. Added to the economic hardships due to chronic drought, sporadic plagues and unfair and bloody relations of production and power, were the constant pirate attacks, plundering villages and kidnapping and abducting many inhabitants, leading to constant insecurity.

It was also then when the ethnic base of the local society was set up, composed of some surviving Majos,

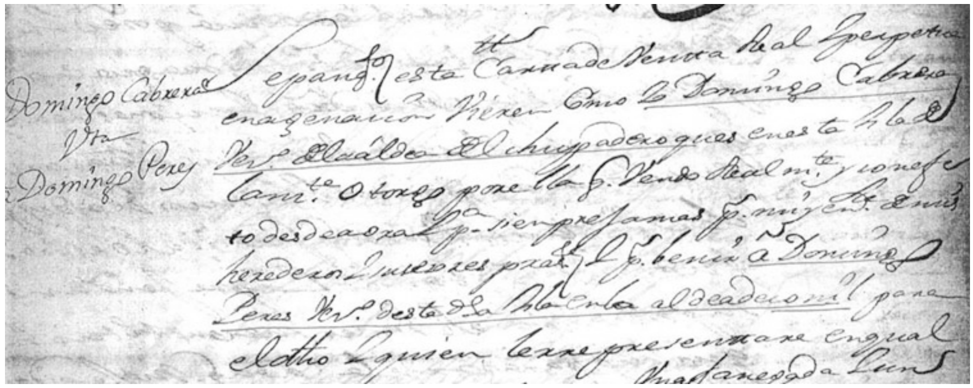

**Fig. 3** Document about the villages that were buried by the lavas

Sub-Saharan slave populations and, above all, Moorish that became a majority in some areas, as well as diverse settlements from European countries (Norman, Castilian, Basque or Portuguese). It is possible that many cultural practices of these communities survived in this area, some related to persecuted activities, such as witchcraft. In the area destroyed by the lava flows, there were places related to witchcraft such as the Revolcadero in Tingafa, and others that are still remembered in Muñique, Soo and El Monte, associated with witches mud holes.

The island made it to the 17th Century with an economy that was based on the production of grains, which were exported to the central islands and Madeira. This activity was to be complemented with some crops for local consumption and especially with livestock. In addition salt and orchilla were to play a key role. This lichen was going to represent one of the most profitable trades of Lanzarote in the 15th and 16th Centuries.

In the early seventeenth century, the first documents that were not destroyed by pirate attacks, began to appear (testaments, buying and selling contracts, …). They mentioned the history of these villages and areas and give us a pretty good idea of what the economy, demography, landscape, infrastructure, political, social and religious aspects of these areas were like.

There are two main sources that tell us about the population centres in that area before the eruptions, Las Sinodales del Obispo Dávila and Cárdenas (Dávila 1737) and the documents of the Archivo de Simancas (Romero Ruiz 1991a; Romero 1997). According to the data provided by the Sinodales, we know that the main population centres that disappeared with the volcanoes were Tíngafa with 64 people, Chimanfaya with 24, Mancha Blanca with 44, Santa Catalina with 42 and Peña Palomas with 18. We have already mentioned that wealthy families lived in those areas before the eruptions. In a study of the economic situation on the island in the first quarter of the eighteenth century, Pedro Quintana Andrés, located a large part of the buyers or sellers on the island in these villages. This can be seen in a growing real estate industry, with plenty of houses, reservoirs, *tahonas*, etc. (Quintana Andrés 1993). Shortly after, almost all those were destroyed by lava and volcanic sand.

The Church had significant property in the area, judging by the taxes on numerous tenants such as the property of La Florida, from the *mareta* of the Church near Montaña Blanca de Perdomo. We have located a significant number of places linked to the Church, such as Montañeta de la Inquisicion, Las Monjas, near Testeina, the land of the Santísimo Sacramento, Candelaria and San Juan.

Many members of the Island's militia were neighbours of these villages, such as Ensign Julio Perdomo de Chimanfaya, Captain Francisco Perdomo de Buen Lugar, Captain Baltasar de Samarín and Captain Roque Luis, of Santa Catalina.

Given the historical information available to us, there is no doubt that this region was witnessing a process of progressive economic predominance when the eruptions started. We can see that there was a concentration of villages in the centre of the island, which would end up totally destroyed years later. This process meant that the most significant buildings on the island and most of the recently set up economic infrastructure, gathered in that area. We can be sure that the eruptions didn't merely cause enormous material losses, but also immaterial ones, especially cultural and emotional, as almost half the population of the island lost practically all their possessions. Take the following description of the state the neighbours of Tíngafa were in, after having lost everything, as an example (AHPLP, PN, Leg 2,805, 147–150, December 1733).

Below, we will make a brief review of the buildings and the most important infrastructure destroyed by the eruptions. First of all, we will take a look at religious buildings.

Up until now, in the different chronicles about the eruptions, three chapels were mentioned as affected by the volcanoes. Santa Catalina and San Juan Evangelista, disappeared under the lava in the first days of the volcanic activity and Caridad in Geria, was buried by tephra and shortly after the eruptions, was *cleared of sand* and it can nowadays be visited in said locality (AHPLP, CD, Leg 45, Expte, 5. S/f, 1736). Our investigation led to the finding of another very important chapel before the eruptions, Nuestra Señora de Candelaria (De León Hernández 1996).

As for the chapel of Santa Catalina, one of the most important ones back then, we do not know when and how it was built. In the documents we work with, the reservoirs of the chapel of Santa Catalina are mentioned, as well as the conflict between neighbours of that area, requesting the creation of the Parish Aid for the Remedios chapel in Yaiza.

Oral tradition helped maintain the memory of the chapel of Santa Catalina alive. Although most of it has been lost, it is striking to see that the town of Santa Catalina and its chapel have remained in the collective memory. We believe that one of the reasons behind this, besides the economic relevance of that village, was its fast and unexpected destruction, due to a sudden change in the direction of the lava flow. According to popular tradition, remains of the chapel covered by lava flows can be seen, although, so far, we have not been able to confirm this fact with our research. There are references to one of the doors of the chapels of San Roque in Tinajo and the beams of a house in Yaiza, which were taken from the old chapel, before being burned and then dragged away by camels.

As for the chapel of San Juan Evangelista, we know exactly when it was built, the people who promoted it and also some furniture and construction elements that it had:

> … We, Juan Gutiérres Nuñes and María de los Reyes, his lawful wife, neighbours of this island of Lanzarote, confirm, as loyal devotees of the glorious San Juan Evangelista, that we have arranged for a chapel to be built for the glorious San Juan, in our home, where our houses are, … Said chapel has been built and its walls are whitewashed … (AHPLP. PN. Leg. 2728. Fol. 241 v.-246r. 2nd August 1625)

But in addition to these two chapels, we have already mentioned that we located a third one, which was not known to have been buried by the lava flows. This was the chapel of Our Lady of Candelaria, some of the most important villages in the area belonged to its jurisdiction (Chimanfaya, Mancha Blanca, Guagaro, Geria, etc.).

The most striking feature of this discovery is that until recently, its location was unknown, or it was taken for granted that it was unknown, from the beginning, in the town of Tías, since that is the patron of that town. Since the end of the 18th Century, it has been the Parish and Municipality of that town. Nowadays, the town of Tías is one of the most important ones on the island, however, it did not exist before the eruptions and its creation and development took place as a consequence of the volcanoes. Some residents of the affected towns founded and built the new chapel of Candelaria in this new place, some 15 km away from the original site of Nuestra Señora de Candelaria.

The importance of this sanctuary is clear as there is a reference that tells us that it was the first place that people headed towards, a few hours after the eruptions started:

> … of white sebada that were taken out of those that were sawed in Chimanfaya in the house of Ensign Julio Perdomo, … by the fire of the volcano and the turbulence that still … hastily they got out of the risk and put themselves in front of the Hermitage of Our Lady of Candelaria and from there they took to saw the village of Masdache (AMC, LFIMT, Year: 1730. S/f.)

According to another document, there is no doubt that the destruction of the above-mentioned chapel dates back to February 1736. That document mentions some of the assets that were contained in that chapel:

> … we have produced and made at our own expense the hermitage of Our Lady of Candelaria paying for its ornaments, image and everything else that was in the mentioned hermit which was destroyed by the fire and the only thing to escape its havoc was the said holy image, the referred ornaments and wood … (AHLP. PN. Leg. 2806. Fol. 215. 10th February 1736).

We have already mentioned the chapel of La Caridad, covered by a rain of volcanic ashes in the middle phase of the eruptions, although it could be recovered, as we can see in some documents from the following years after the eruptions were over.

In addition to these chapels, the priest of Yaiza, Don Andrés Lorenzo Curbelo, mentions a chapel in his Diary, called San Juan Bautista. We also know of a reference to another chapel in Chimanfaya,

With regard to buildings related to economic activities and linked to the church, the most outstanding one was the Cilla used to save and account for the grain, which was built in Chimanfaya on land that was sold in the year 1701 by Miguel López, a neighbour of Tiagua, to the Cabildo Catedralicio (Quintana Andrés 1993 and AHPLP, PN, Leg 1802. Fol. 57v, May 19, 1725). This fact proves the growing importance of the central area of the island in the production of cereals. There was only the Cilla de la Villa Capital and Haría that existed in the North.

This construction was possibly destroyed in the first hours of the eruptions, since reference is made to the burning hay lofts, as we saw in a previous mention, in the village of Chimanfaya and in the first moments of the catastrophe:

> … to be able to distribute the grains of the Cilla de Chimanfaya burned in Lanzarote, and be able to say that her Coxedor wants to be completely satisfied with everything that she has done, having completed the recovery and that the burning of Cilla and other things were not his fault, …. (Hernández Rivero 1991: pp. 94–95)

One of the population's concerns was to save the food reserves. However, during the eruptions, some of the best fertile valleys and farms on the island were lost, as we can see in numerous documents related to the inability to pay fees and taxes:

… for 115 Reales with which it is discharged because they were burned by the fire of the volcano on the day … of September one thousand seventy-five and thirty years at the place of Chimanfaya in pages of the Ensign Julio Perdomo … (AMC. LFIMT. S/f. Year: 1730).

… it should be noticed that the two fanegas of land … were lost with the malpais of the bolcan that flowed over them … (AHPLP-PN-L.2806-F.148-The document was issued in July 1734).

Other elements of the heritage had to do with housing. Sometimes it is specified that they were two-storey houses, which could be a surplus or an upper room, which on the island is called *troja*. Sometimes they mention rooms attached to the house and the attached kilns.

It should be noted that there was a type of construction that was very common in the centuries being researched, called *taro*. It was an enclosure with a circular and vaulted floor. The function of these *taros*, some of which still exist nowadays, was as a warehouse or pantry. In the areas covered by the sands, there are archaeological remains of this type of construction like El Taro, in Testeina. This Taro was located on the property of Domingo Hernández Fajardo, destroyed by the lavas and the sands, the father of Susana Fajardo, wife of the scribe Nicolás Clavijo Álvarez, parents of the famous erudite José Clavijo y Fajardo.

Other buildings highlighted in that territory for their important economic role, were the *tahonas*. We know of some of those buildings that had a large stone wheel to grind grain with. There were several *tahonas* in the most important villages, such as those owned by Bernabé Gutiérrez and Juana Perdomo, who lived in Mancha Blanca and had properties in Chimanfaya also:

… another tahona from his wife during the marriage bought 20 more fanegadas, the houses of his dwelling, another tahona, three cisterns, … , another 2 and a cistern, … (AHPLP. PN. Leg. 2800. Fol. 70v. March 1720)

Also, a large number of eras, fences and bird sheds were related to agricultural activity:

… among the real goods that belong to me are a house in this village of Tíngafa with its kitchen, oven, and other belongings at the entrance of an orchard that has a water tank inside it …. (AHPLP. CD. Leg. 44. Date: 15 May 1693)

There is mention to handcrafted activities. The *blacksmith* from Chimanfaya and *carpenter* from Santa Catalina, are mentioned.

Another one of the infrastructures that were destroyed by the eruptions were those related to livestock activity. An enormous number of corrals are cited in all the affected villages, although, as we have said, there were numerous corrals in the coastal areas, some of which were large enough to handle livestock, called *Gambuesas*. Marks or stripes are also mentioned to delimit and isolate the agricultural grazing areas as well as flocks. “Sises” are often mentioned, a term that has been lost nowadays, except for some names of places. It was small walls to prevent livestock from getting through. The livestock areas were mainly concentrated in coastal areas closest to the sea:

… Know that many see this letter … such as Juan Gopar, neighbour of the Island … I have sold to Sebero Ruiz neighbour of Ysla … a house in Maso that is next to the big house that was owned by Juan de Bonilla the old man and also a corral and entrance and exit in the term of the burned one of Maso. (AHPLP, PN Leg.2724, Year: 1623)

As for communications, there were roads, trails and paths. We can see that Mancha Blanca played an important role as a link between towns in the area, such as Tíngafa, Maso and the North and Northwest Coast with Tinajo, Iguadén, Candelaria, with the Villa in east direction and the Port. Also, Chimanfaya and Candelaria, located in the centre of the island, were very important crossroads.

With regard to water-related infrastructures, we must say that it represented one of the most important material and knowledge-related constructions in this area. Most of the water supplies, for both the inhabitants of the area and for the animals, were made through artificial collectors, huge and expensive hydraulic engineering. In the first historical accounts, the enormous scarcity of water on the island stands out.

The island of Lanzarote has a lack of water, there is nothing except rain, collected in large pools or puddles made by hand or stones. They also collect in wells and keep it for sustenance, and their cattle. (Abreu Galindo 1977: 58)

We believe that there were one or several *maretas* in every town, possibly of communal use and care and in many cases with an outer wall or pavement. One of the most important tasks carried out by the Cabildo, was the maintenance and control of some of them. In addition, there were numerous cisterns and reservoirs: in this area, we have located plenty of these constructions: the Mareta Grande that was in the Cortijo de Chimanfaya, the mareta known as Fuego Mácher, in the northwest coast, the maretas and reservoirs in the Cortijo de Santa Catalina, the mareta of Las Mujeres, near Buen Lugar and Tingafa and the maretón de El Cabo by Santa Catalina. In some documents dating back then, reference is made to Las Maretas, as an inhabited place next to the village of Buen Lugar.

As for water deposits, cisterns, reservoirs, wells, piles, … there are even more mentions made; often for individual sale. Among many others, the cistern of the heirs of Juana Perdomo in Santa Catalina is worth mentioning, the large cistern that was in Tíngafa, a covered and mortar well in Masdache, the white cistern they called Los Morales near Tingafa. In the area that is now known as Los Islotes, is where most of the reservoirs were, such as those of Montaña Bermeja, north of Maso (Fig. 4).

**Fig. 4** Remains of a cistern buried by volcanic ashes

One of the most important clues we have, from an archaeological point of view, to locate any building of the time, buried by the sands, is the location of water deposits. The existence of some semi-buried ones in the areas of Masdache, Geria, South of Diama, Guatisea, Peña Palomas and Chibusque is worth noting.

All this was to succumb to the apocalyptic event, which according to all written references began on September 1, 1730. To illustrate some aspects of life before the eruptions, when there was no suspicion of what was about to happen shortly after, the following quotations are striking, in which houses, water deposits or lands are sold and bought, and which were to disappear under the lava only a few days later:

> … Beatríz de la Concepción, widow of Miguel Ruiz de Armas, neighbour of Tingafa, granted … Juan de Betancor Reyes, neighbour of Mancha Blanca, for him and his, two fanegas (bushels) of worked land in the Pago de Tingafa, which they call Lomo de Carlos, I had them as a legacy from Balthasar de los Reyes Machin, my father … I sold him another two fanegas (bushels) of land with its entrances and exits …. (AHPLP-PN-L.2804-October 1730)

More dramatic is another document, from August 20th, 1730, ten days before the Chimanfaya volcano exploded and about fifteen days before the lavas buried part of the land sold here

> … like Joseph Calleros, a neighbour of the village of Santa Cathalina … I sold Sebastián Cabrera, a neighbour of the same village, honestly and forever … namely a fanegada of Labradia land in the Llano del Boiaso …. (AHPLP. Leg.2804. Fol.85. 20 August 1730)

The situation could not be more dramatic, at first people migrated to other areas of the island, there are cases of clandestine emigration to Fuerteventura, which alarmed the authorities of that island due to the lack of control and the passage of cattle without markings on them. Although they tried to control the exit of the population, as the magnitude and eruptions increased, more exceptional measures were proposed, such as the almost total evacuation of the island, leaving a reserve of 200 or 300 men to guarantee their safety against possible enemy attacks.

On the other hand, with the beginning of the volcanic activity, the church is mobilised with all kinds of masses, processions and prayers, which did not end until the volcanoes extinguished six years later. Some of these prayers and processions were ordered by the bishop for all the islands of the archipelago, to be celebrated on the same day and at the same time:

> For a pound of wax that was used on March 25 of this year (1733) in the mass and general procession that was ordered by his Excellency so that his Majesty … by the intersection of San Pedro de Alcántara extinguishes the volcano. (AMA, FJMA, LFIMT, 1733 and AML, Minutes from the Cabildo de Tenerife)

Not only did the volcanic eruptions destroy a rich and extensive constructed heritage, but they were the cause of the creation of both material and immaterial elements closely linked to the cultural heritage of the island, to the point that the Virgen de los Dolores, (also called Virgin of the Volcanoes), was associated with the “miracle” of the end of the eruptions and became patroness of the island. We have located a document that refers to the founding moment of this new devotion, although the chapel was built many years later:

> In the place of Tinajo … on April 1st, 1735 … and in the name of the other neighbours of this place (de Tinajo) … they said that

> they choose and name as a special protector and Patroness of this place the everlasting Virgin Mother of God and Our Lady with the Most Venerable Title of Los Dolores under that protection and care are placed so that with her power, this most important intercession may reach our Lord God who frees us from this place and its districts from the ruins of the Volcano from which we are threatened …. (AHPLP-PN-Leg.2806-F.61. 1st de April 1735)

Remains of buildings destroyed by lava flows and tephra, and above all the new infrastructure that is built later, taking advantage of these large volcanic areas, for production on volcanic sands, as well as new settlements, roads, etc., bearing witness to the consequences of the catastrophe and the ingenious adaptation of our countrymen to this new ecosystem.

Rediscovering this part of the History of Lanzarote and all that human and natural landscape that was buried under the lava and volcanic sands, is what our efforts have consisted of since the middle of 1995 (De León 1998: 442). The written documents prior to the eruptions, the field surveys, and oral information have been, and continue to be, our most important resources to approach this objective and deepen our knowledge, much of it unpublished, which must be returned to the people of the island. In addition, we have considered of great interest, the immense culture that the people of the island have produced from the eruptions, with the reoccupation, uses, techniques and beliefs concerning this new land, what we call the culture of the volcano, that is largely fading away, with the disappearance of the people who made it possible. We are, therefore, faced with the urgency of undertaking and developing a new task based on this new perspective.

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# Lanzarote, César Manrique and the Creation of the Art, Culture and Tourism Centres, 1960–1976

Mario Ferrer Peñate

**Abstract**

Between 1960 and 1976, during the first stage of the development of mass tourism in Spain, the island of Lanzarote experienced the creation of a network of publicly owned spaces in which natural and cultural values intrinsic to the environment were combined, with artistic interventions in various disciplines: architecture, sculpture, design, interior design and landscaping, among others, the Art, Culture and Tourism Centres (CACT). The primary purpose of these centres was to encourage the arrival of visitors from the new tourism industry and thus improve the difficult socio-economic conditions of the population. It was an initiative whose aesthetic leadership was assumed by artist César Manrique, while the political, labour and budget agenda corresponded to the Cabildo of Lanzarote, the main local public institution on the island. In this research, we briefly browse the guidelines of the artistic work of Manrique, already studied greatly through the history of art, to focus on the objectives and dimensions that this programme had from the perspective of public administration and as a pioneering experiment in the combination of tourism, public art and geography. Likewise, some of its social and economic consequences and in the minds of residents and visitors of the island are mentioned.

**Keywords**

History of tourism • History of Lanzarote • History of contemporary art • History of art in Spain • History of the Canary Islands • César Manrique • Tourism • Cultural tourism • Art and tourism • Geology and tourism

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## 1 Lanzarote Before the 1960s

Using a current term within the European framework, Lanzarote symbolised the concept of the outermost region for centuries. Being one of the so-called “minor islands” of an Atlantic archipelago, Lanzarote stood out for showing economic and social development data significantly below the average of a country and a region which is already in arrears compared to the percentages of Western Europe.

Prior to the definitive European conquest of the Canary Islands in the late Middle Ages (they had previously been discovered by navigators of the continent), Lanzarote hosted a small primitive population of North African origin, according to most specialists, although there are various theories on the phases and origin of the settlement among prehistorians. The island became part of the crown of Castile, and then part of Spain as territory of Señorío, which means, that the king yielded his management to a lord, a system that hindered the agricultural and economic development of the population by increasing tax burdens.

In the following centuries, Lanzarote lived in an Atlantic “overseas” context typical of the Old Regime, marked by demographic and financial fragility and under a panorama of piratical insecurity. The volcanic eruptions of the 1730–1736 period, were a defining historical episode, when the lava transformed almost a third of the surface of the island.

The few revenues were based on the countryside, livestock and fishing, along with other small craft activities, resulting in a very basic survival economy. Lanzarote only experienced small stages of prosperity when there was a temporary boom of some local product in European markets (such as orchilla or cochineal), while the base was the export of some cereals, vegetables and fruits, so that the cyclical droughts led to real crisis that were usually solved with emigration as the main social escape valve.

The secular delay of the island was based on various factors such as geographical remoteness, economic weakness, the impact of droughts, emigration, tyranny, illiteracy,



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etc. But one reason stood out above all others, the lack of water. With a rainfall regime similar to that of the nearby Sahara Desert, and without the presence of high mountains, like other Canary Islands, which retained prevailing trade winds in this geographical area, life in Lanzarote was marked by the lack of rain:

> They do not speak of gold or silver or of jewels or other conventional goods dependent on caprice or the glare of judgment, but on the rains in time, on the fields, on the abundant pastures. (Viera and Clavijo 1971)

The arrival of the twentieth century did not bring improvements when it came to the structural problems the island had. The situation in Lanzarote during the beginning of the last century was even tougher than for the capital islands, which only lived situations of economic strength between the aftermath of the world wars and the Spanish Civil War. The Canary Islands is a region with sharp differences between its islands, so much so, that historically there has been a division between larger islands and smaller islands that was not justified in physical geography as well as in socioeconomic, demographic and political geography.

For the purpose of our analysis, it is convenient to bear in mind that in this context, the traditional economy of the island's inhabitants was structured to obtain the maximum possible benefits of the extreme conditions in which they lived and preventing resources from running out, using in many cases ingenious and arduous formulas, not only for the collection and conservation of drinking water but also for their agricultural, livestock or fishing activities. The traditional society was by no means aware of a concept as current as sustainability. However, the natural limitations at the time, led to the sustainable exploitation of natural resources.

The socioeconomic situation Lanzarote was in, began to change at the beginning of the 1960s, coinciding with the improvement of Spain's economic outlook. The Franco dictatorship entered a new phase with its progressive opening, and tourism allowed the country to enter the stage of developmentalism. Following the trend of the rest of the country and what was happening in several areas of Gran Canaria and Tenerife, Lanzarote began to take small steps to establish the new tourism industry.

## 2 Tourism Development Background in Lanzarote

It is worth making a brief mention of the first references that the modern travel industry produced in Lanzarote before the second half of the twentieth century. In this protohistory of tourism the flow of visitors was still very scarce, but it already started to set several aspects regarding the tourist imaginary of the island that we must take into account in this research.

With the Scottish captain and writer George Glas as the most prominent precedent in 1764, in the 19th century there was a growing trend of scientists or naturalists who did stopovers or visits to Tenerife or Gran Canaria during their trips, and, to a lesser extent, to other Islands like Lanzarote. Thus, the Germans Hartung or Haeckel, the Englishmen Stone and Brown or the Frenchmen Verneau and Proust, among many others, published chronicles of their journeys in different types of guides and books. Without delving too much into the payroll and quality of these publications, we do want to draw attention to the routes or points of interest that were established, since they began to clearly indicate certain landmarks of the island: Timanfaya and its fields of lava, the Malpaís de la Corona and the Cueva de los Verdes, the battery area of Bateria del Río.

In the search of singular places or of scientific interest, these pioneers were highlighting some of the most striking geographical features of the island, especially the one related to "the volcano".[1] Subsequently, a tourist imaginary of Lanzarote was shaped, embryonically, a sort of prototypical itinerary of the insular landscape for foreigners who visited the island, but also for locals, who gradually became aware of the new symbolic and economic value of those territories.

In addition to the illustrious travellers, in this primitive phase of the tourist development, Tenerife and Gran Canaria began to welcome a growing flow of Europeans who approached these islands for health reasons. The benign climate of the islands acted as initial claim in the 19th century, before tourism became popular as a purely holiday and leisure industry in the following century. The island of Lanzarote, with poor external communication and at an economic disadvantage, tried to boost its tourist structures, but only managed to do so quite formally, although it did get to provide better port infrastructure.

The slow progress in transport during the first half of the century ran in parallel with the first steps of the new mythology and tourist island iconography. In this process we must bear in mind that soon the informative actions also came from the Canarian authorities and society, eager to achieve new economic branches. The tourist Canarias magazine dedicated several reports to Lanzarote at the beginning of the 20th century and other national or international publications did the same. Among the local initiatives we should highlight the Martínez González (1936a, b, c) tourist brochures of the 1930s or the intense awareness-raising work carried out by the journalist Guillermo Topham, especially as director of the only insular written medium between 1953 and 1970; the weekly Antena.

[1] "Volcán" is the term used in Lanzarote to refer to a surface of historic lava flows. PALLARÉS, A.: Lanzarote place-name dictionary, Ediciones Remotas, Lanzarote, 2014.

Topham highlighted César Manrique significantly, as he was probably the person most interviewed by that newspaper, publishing numerous editorials about the tourist possibilities of the island:

> Few places in the world have such peculiar, original and outstanding features as the land in Lanzarote (…). However, few of us take care of it. We turn our backs on its tangible reality. We refuse to pay attention to such an important thing. Men from different parts of the world have always said so and will keep on saying so during their constant and frequent visits to Lanzarote: 'It's a diamond in the rough'. 'You're missing out on a wealth that is being offered to you and is right in front of you and yet, you pay no attention to it'. And when it comes to that, those regular foreign visitors are right, very right indeed. (Antena 1955)

Indeed, at the beginning of the 1950s, Lanzarote did not have the necessary resources for tourism development. The airport was not only not open to international traffic but it had a dirt runway and the rain used to force it to close, while the only modern accommodation, the Arrecife National Tourism Parador, had been inaugurated in 1950 and had just a dozen beds. The creation of basic infrastructures for the development of tourism was the main strategy of the Cabildo from the arrival to the presidency of the Cabildo of Lanzarote of José Ramírez Cerdá in 1960. Before commenting on this cycle, it seems necessary to highlight this shaky phase of tourism in Lanzarote, the facts that, on the one hand, there was an insular awareness, humble but latent, that tourism could be an outstanding economic branch for the future of the island. On the other hand, many of the places intervened for the creation of the Art, Culture and Tourism Centres had already begun have, a prominent hierarchy in the island's cultural and tourist imaginary.

## 3 The Beginning of Mass Tourism in Spain, the Canary Islands and Lanzarote

From the 1960s, Spain and the Canary Islands undoubtedly chose tourism development. Many factors converged in this way, but we will only point out some of those that we consider most important.

Starting from the international level, the technological advances of the new transports, especially in aviation, allowing for a massive scale of tourist transfers. The travel industry itself implemented organisational improvements, following the footsteps of the Fordist production model, while labour and sociological changes achieved an extension and generalisation of the right to vacations among the growing European working classes. In addition, Western Europe, the natural market of the Canary Islands, deepened in a phase of great economic growth and favoured tourism investments, as it happened, among others, with the paradigmatic "Strauss Law" (Fiscal Law on Aid to Developing Countries promulgated by the Ministry of Treasury of the Federal Republic of Germany).

In Spain, which in the 1950s had managed to return to the main international organisations in the recently opened context of the Cold War, the Franco government restructured its economic policy based on the famous 1959 Ullastres Economic Stabilisation Plan. The dictatorship placed tourism as a priority sector and the successive Development Plans promoted the new industry. Legislation was also enacted by the central government creating the Areas of National Tourist Interest, which allowed access to credit aid more easily. The Canary Islands achieved that category in 1963 and although initially the tourism development had focused on a nuclei of the north of Tenerife and Gran Canaria, it soon went on to more intensive exploitation models in areas south of both islands. Other notable national measures were the convertibility of the peseta in 1961, the liberalisation of foreign investments in 1963 and the creation of the "Hotel credit and aid for tourist buildings" in 1965.

However, in this first phase other islands with great tourist potential such as Lanzarote and Fuerteventura had a considerably slower pace. In fact, we advance that our hypothesis are based on tourist arrivals and hotel beds data. That mass tourism did not really penetrate the two easternmost islands of the Canary Islands until the eighties of the twentieth century, but since the sixties, it did lay the foundations for it: water supply, improvement of external and internal transport, installation of the first modern hotels. The creation of the Art, Culture and Tourism Centres of César Manrique, as an insular cultural tourism offer, part of this planning (Table 1).

## 4 The Cabildo of Lanzarote and the Creation of Basic Structures for the Island

In a context of great precariousness but of significant national economic change, the Cabildo of Lanzarote, as the first public institution on the island (the only one of exclusively insular and local rank, and the one with the largest budget by far) started a programme of actions aimed to improve the socioeconomic conditions of the island, with a special emphasis on modernisation of infrastructures.

One of the most important decisions made by the Cabildo of Lanzarote, with José Ramírez Cerdá as president since 1960, was to create his own construction company: Vias y Obras Insulares. The purpose of this measure was to take charge of projects that had great insular utility but that were often not attractive for the few private companies able to carry them out at that time in Lanzarote and that used to be deserted:

**Table 1** Tourist influx to Lanzarote (1970–1996)

| Año | Turistas |
|---|---|
| 1970 | 14,684 |
| 1972 | 30,120 |
| 1974 | 41,848 |
| 1976 | 52,449 |
| 1978 | 90,446 |
| 1980 | 137,782 |
| 1982 | 150,371 |
| 1984 | 269,389 |
| 1986 | 414,733 |
| 1988 | 713,487 |
| 1990 | 763,936 |
| 1992 | 998,094 |
| 1994 | 1,247,699 |
| 1996 | 1,381,195 |

*Source* Data Centre of the Cabildo of Lanzarote and AENA

> The problem back then was that projects to build new roads for the State were approved, they were put out to tender and no external companies went for them because it wasn't profitable for them to come to the island, and there were no construction companies here either, so money was then lost. (Perdomo Aparició 2017)

Measures like these, along with the arrival in those years of tourism credits, Development Plans or state aid, allowed for many projects to be developed in a short space of time. Among the most strategic ones, we would highlight the asphalting of the airport runway, which previously used to close frequently due to the effects of the rain, and the consolidation of a modern and well-articulated road network. Only in 1964, when the works of the airport were awarded to the Cabildo, 31 million pesetas were allocated to road improvements, the Tourism Centre was created and the new minister of Tourism and Information, Fraga e Iribarne, visited the island to give aid for the creation of Cueva de los Verdes and Jameos del Agua and "a 20-million credit to pave roads of tourist interest" (Martín Hormiga and Perdomo Aparicio 1995).

In addition to these projects, the Vías y Obras team, which was directed by the Cabildo's general foreman, Luis Morales, and which went from having less than a dozen workers to more than three hundred in a few years, also undertook actions in other areas: water supply, construction of the Ciudad Deportiva Sports Complex, maintenance works in the Insular Hospital and buildings of the Cabildo … But soon, the team of José Ramírez Cerdá approved measures to prepare spaces of tourist interest, initially subtly, with the acquisition of land or starting small improvement works, to then move on to more ambitious actions. This line of action would lead to the creation of what later would be called Art, Culture and Tourism Centres.

Several key witnesses of the time, such as Juan Marrero Portugués, director of the Caja Insular de Ahorros de Gran Canaria and a person who was very close to Ramírez, have highlighted the influence of Manrique from the beginning:

> When he started his administration in the Cabildo, in the mind of Pepín [the nick name José Ramírez was known by] there was no tourist reference (…). He was obsessed by clearing the island (…). What was obvious to him was that this clearing, which involved moving stones, would not be done without listening to César's opinion - for purely aesthetic reasons, not for tourism. "I will not move a stone without telling César!" He kept on saying (…). (Marrero Portugués 2017)

A significant step regarding the progress that was being made in terms of planning came with the drafting and approval in 1973 of the first Insular Plan, an innovative instrument of territorial organisation. Despite containing a significant forecast regarding places available at the time, it was a pioneering urban tool of an island nature promoted by the Cabildo de Lanzarote, launched much earlier than the rest of the Canary Islands, and that little more than one decade later had already undergone a strict revision.

Before continuing with the description of the interventions that led to the creation of the CACT, it is important to take a key factor into account: the relationship between José Ramírez and César Manrique. Both of them had a very close friendship since childhood and shared decisive experiences in their youth. Later, with José Ramírez as mayor of Arrecife, he turned to Manrique for advice on various projects for the city, something he did again, more intensely, in his long term period as President of the Cabildo.

It is also important to remember that in addition to the State tourism support programmes and the measures taken by the Cabildo during the mandate of José Ramírez, certain private actions taken, some of them of great importance, were also decisive at this stage, such as the start-up of the dual purification plant or the creation of the first modern hotels. From there on, national companies and especially international companies in the sector began to invest in the island, such as Fred Olsen, who began to bring cruises from 1965.

Lastly, in addition to the structural and economic component, the territorial project in which the CACT were framed, as well as the work that Manrique did, also had a social dimension with respect to the awareness regarding the treatment of landscape and heritage. In 1966, Manrique already stated that the island was "at a crucial moment in its history" and that it had to be "aesthetically saved" (Santana 1993).

## 5 The Art, Culture and Tourism Centres, 1960–1976

Next, we are going to carry out a very brief review of the characteristics of the centres that composed the initial and essential network of the CACT, following the chronological order of their respective inaugurations. A little more emphasis will be placed on the significance of the chosen places and their natural values, although they are only brief descriptions, since they are well-known spaces and, although not much, there is a bibliography available.

### 5.1 La Cueva de los Verdes

Cueva de los Verdes emerged from the volcanic activity of the Corona Volcano, between 15,000 and 18,000 years ago. This spectacular volcanic cone visually dominates the whole northern area of the island and is the protagonist of the Natural Monument of the Malpaís de la Corona, where the underground volcanic tube is located, which also gives rise to Jameos del Agua.

Known since ancient times by the inhabitants of the island, this cave was also used after the European conquest as a refuge, especially during pirate attacks.[2] From the 19th century, it began to draw the interest of scientists more and more, as well as explorers like Georg Hartung, geologist and botanist Karl Von Fritsch or the Spanish scientist Eduardo Hernández Pacheco, among others.

The original idea to intervene in Cueva de los Verdes started in the early 1960s. The President of the Cabildo of Lanzarote, José Juan Ramírez, who was always in contact with Manrique, entrusted the lighting to Jesús Soto, an electrician and inventor who had already developed small visual experiments, who went far beyond the initial commission, investigating lighting patterns with the textures and peculiar shapes of the Cave (Martín Hormiga 2011).

The result of his work, as can be seen today, is magical. Visitors enter the bowels of the earth to observe how the subtle variations of lights, shadows and colours give the space an amazing artistic poetry with enormous dramatic force. The proposed route, perfectly integrated into the environment, masterfully enhances the striking shapes that nature gave to the stone in this spectacular grotto. Once the journey begins, about a kilometre away, visitors to Cueva de los Verdes go through different size paths, from narrow passages to areas of 50 m in height. The Cave has up to three heights in certain points, although the essential route is through two superimposed galleries with vertical interconnections between them (Fig. 1).

Much of the historical relevance of this intervention lies in the fact that its success helped to envision the landscape of the island in a completely new way, opening the door to the arrival of César Manrique and the creation of an exemplary combination of cultural tourism, art and environmental commitment.

### 5.2 Jameos del Agua

After making small contributions in urban areas of Arrecife, the first major work of Manrique in the territory of Lanzarote were the Jameos del Agua, a work where the artist launched the rich syncretism of disciplines (architecture, design, interior design, sculpture, gardening, etc.) that he practiced in his public art spatial interventions.

Originating from the primitive inhabitants of the island, the term 'jameo' refers to the section of underground volcanic tubes that lack a roof and that, therefore, have left part of their structure exposed. The Jameos del Agua correspond to a portion of the great subterranean vault that runs from Volcán de la Corona to the ocean, with a small lake between two jameos that is connected to the nearby sea water.

During the first half of the twentieth century, the space was a place frequented by residents of Lanzarote for excursions and leisure, but it was in a state of semi abandonment and received no specific attention. However, with the new plans of the Cabildo de Lanzarote, well before finishing the adaptation of Cueva de los Verdes, the team of José Ramírez decided to intervene in this unique geological landmark, putting César Manrique at the head of the aesthetic project.

In 1966, the first phase was launched, that of the so-called "Jameo Chico", a complex that a decade later completed its main structure, including the auditorium, which opened in 1977. In any case, the central part of the intervention, "Jameo Grande" and "Jameo de la Cazuela" were under managed by Manrique, who began to lay the foundations of his pairing Art/Nature or Nature/Art, a concept that sums up his commitment to the territory.

The delicate intervention of Jameos del Agua offers an idyllic symbiosis between the intrinsic values of a space and the capacity Manrique had. The artist from Lanzarote brings unusual, graceful and eloquent solutions that enhance the natural beauty of the place, combining the great architectural lines to the details regarding furniture, lighting or gardening. For critic Javier Maderuelo, Jameos del Agua "*can be*

[2]One of the most significant events took place in 1618, when an Algerian fleet of 36 pirate ships led by Tabac Arráez and Solimán, took over the port of Arrecife and attacked the towns on the island. Some people hid in Cueva de Los Verdes, but they were caught after some resistance and 900 locals were imprisoned, the highest figure in the pirate history of the Canary Islands. PAZ SÁNCHEZ, Manuel de: La Piratería en Canarias (Piracy in the Canary Islands), CCPC, Government of the Canary Islands, Cabildo of La Palma and Cabildo of Lanzarote, Santa Cruz de Tenerife, 2009, pp. 40 and 41.

**Fig. 1** Cueva de los Verdes

*considered a pioneering work of the art of postmodernity capable of opening paths to the participation of artists in the recovery and enhancement of elements of nature and landscape, allowing visitors to be aware, through the mechanisms of art, of their intrinsic values and the need to preserve them*" (Maderuelo 2006).

### 5.3 Casa-Museo del Campesino

This centre is made up of a large abstract sculpture made by César Manrique called Monumento a la Fecundidad which is accompanied by a series of buildings from different periods that pay tribute to the island's own architecture. The great value of the centre lies in the fact that it manages to harmonise the recognition of the traditional culture of Lanzarote with the use of modern and avant-garde aesthetic styles.

The complex was located in the so-called Peñas de Tajaste, almost in the geographical centre of Lanzarote. The importance of this place is due to its geological and agricultural symbolism for an island with a strong and peculiar agricultural tradition, since the Monument is located next to two of the most relevant cultivation modalities in the evolution of Lanzarote: towards the area to the east, La Geria, the emblematic space of vineyards on volcanic ash that concentrates the production of wine, and to the west, the wide area of jable (sand), which runs from Famara to the southern beaches, and which has also been used with agricultural purposes for very typical products of Lanzarote.

The mentor and aesthetic leader of the initial intervention of the Casa-Museo del Campesino in 1968 was César Manrique, accompanied by some of his usual collaborators. In Manrique's work on the territory of Lanzarote, not only the political part of the Cabildo's management and the technical coordinators must be highlighted, but also the large team of workers who built the CACT, the technical team (Fig. 2).[3]

Monumento a la Fecundidad is the name of the abstract large sculpture at the start, although it is lightly and intentionally separated from the rest. The work rises on a succession of cylinders, trunks of pyramids or rectangles painted white and taken from old tanks recycled by Manrique. The result is one of the first abstract works made in a public space in the Canary Islands (Castro Morales et al. 2008), which, despite its large size and geometric design, has great dynamic and allegorical power. By its composition and abstraction, the sculpture combines classic avant-garde, such as cubism, with experiments of kinetic art.

In the adjacent architectural constructions of the Casa-Museo del Campesino, the popular housing model of Lanzarote which Manrique was so interested in was used, and that encouraged the development of several initiatives to revalue this type of architecture (Manrique 1974). Nevertheless, this intervention does not reproduce a specific example, but combines various typical elements (balcony, fireplace, decks, eras, wineries, doors, windows, furniture …) and acts with a simplicity and purity that characterises the traditional architecture of the island, by also using the white and green colours for walls and woodwork respectively.

[3]We recommend watching the documentary film Las Manos (Morales 2015). The same director also made a film focused on the artist from Lanzarote: Taro. El eco de Manrique (Morales 2012).

**Fig. 2** Casa-Museo del Campesino

In fact, the whole work, from Manrique's inaugural and central participation, to the lesser contribution of other more recent artist such as Ildefonso Aguilar in 1990, is conceived as a great tribute to the cultural heritage of Lanzarote: agriculture, landscape, ethnography, architecture, crafts, gastronomy.

## 5.4 Restaurant El Diablo—Timanfaya

Declared a National Park in 1974, Timanfaya is an authentic outdoor volcano museum. An area of great scientific value, priceless for geologists and volcanologists, with a surface that has hardly been altered by man. We are facing the result of one of the most violent volcanic processes of the last thousand years, which lasted from 1730 to 1736 (some authors believe that the eruptions ended in 1735).

Following the planning of highlighting the most emblematic spaces of the island and boosting the emerging tourism, the Cabildo of Lanzarote turned its attention to Timanfaya in the sixties. César Manrique, accompanied by several of his collaborators (Eduardo Cáceres, Jesús Soto and Luis Morales, among others), directed the creation of the restaurant El Diablo and the Ruta de los Volcanes under three basic guidelines of his work: integration of the work in nature, adequacy of the place for tourism under strict respect for the environment and use of contemporary artistic styles (Fig. 3).

In 1968, the work began on Ruta de los Volcanes, where in addition to Manrique, the Lanzarote-born author Jesús Soto played a very prominent role. Previously, occasional small excursions were already taking place in several areas and a small picnic area had even been created, so one of the objectives of the Cabildo was to act to regularise and adequately control access to this unique geological space. The paved road of Ruta de los Volcanes that runs through the interior of the National Park is designed to minimise the visual impact on the landscape, resulting in a very careful intervention that manages to mimic the volcanic "epidermis" that surrounds it.

Before the visitor enters Ruta de los Volcanes, the real protagonist of the architectural and special offering is El Diablo (Santana 1997), whose construction in the Islote de Hilario area posed serious technical problems due to the very high subsoil temperatures. Aware of the omnipresent force of the surrounding volcanic landscape, Manrique redesigned effective strategies to integrate the work in the territory, combining the purity of the circular lines with the visual power of the large perfectly carved stone walls. The whole intervention has a marked geological and organic, minimalist and ritual character.

El Diablo restaurant has a circular floor plan and is on one level. Its main facade is a large window with a view to the vast and spectacular surrounding lava fields. The interior decoration is limited and in tune with the volcanic environment (an example of this is the so-called "Dead Garden", a small glazed space located at the centre and where a dry trunk and dromedary skeleton are placed) and only in the bar area we can see details of furniture that reminds of pop

**Fig. 3** El Diablo Restaurant. Montañas del Fuego

aesthetics, with original ornamental twists of common utensils such as pans, being used as lamps.

Next to the restaurant, two curved walls give access to the bathrooms and a third one, closed with a decapitated dome, contains an oven in which the natural heat that comes from the bowels of the earth serves to cook food.

## 5.5 Mirador del Río

Mirador del Río is located 475 m above the sea, on top of the steep walls of the Famara massif, bordering the northernmost limit of Lanzarote, just opposite a group of islets known as the Chinijo Archipelago. It is called "El Río" ("The River") from the strip of sea that separates the islands of Lanzarote and La Graciosa.

Historically, the area stands out for its strategic value, in fact, it was always of military interest and previously, there were old cannons installed. It is an area of great geological wealth, flora and fauna, both terrestrial and marine. In fact, Mirador del Río is inserted in the Famara massif and allows a view of a large part of the Islotes Marine Reserve, some of the largest marine reserves in Europe.

Artistically speaking, this is one of the best examples of Manrique's Art/Nature concept, with a piece of art that is perfectly integrated into the environment through subtle organic and fluid forms, but also including rich aesthetic and scenographer patterns and an implicit message of respect and dialogue with the landscape. In his writings, Manrique documented his almost reverential relationship with nature, something that critics have pointed out as a key factor in understanding his aesthetic postulates: "… *the purpose of his spatial interventions was for man to participate actively in the wonders of Nature itself, promoting a total communication between man and the natural environment*" (Galante 2000).

Manrique's proposals could be changed or modulated during their execution, on site, and discussed with the team of collaborators, especially in technical matters. In the case of Mirador del Río, where important constructive difficulties had to be resolved, architect Eduardo Cáceres and artistic master Jesús Soto once again stood out (Fig. 4).

Mirador del Río begins with a large stone facade in the form of a semicircular amphitheater that rises forming structures similar to the agricultural terraces typical of Lanzarote and giving a solemn appearance that, at the same

**Fig. 4** Mirador del Río

time, camouflages what is hidden on the inside. Passing the entrance door, visitors go through a small winding archway that leads to two larger elliptical halls. This space, flooded with light, enhances the surprise effect and makes gazes focus on the splendid view offered by the large windows. From these rooms you can go to a covered exterior terrace or climb an aesthetic helical staircase to an upper floor, which also gives access to the exterior and where there is a delicate crowning in the form of a glass skylight whose roof is made of stone.

As in other centres, Manrique designed the logo (a bird with a fish in its claws) and inside you can see sculptures and ornamental and floral details of the artist, who developed the typology of the viewpoints during his career, with examples such as Mirador de La Peña in El Hierro. Before his death in 1992, Manrique had various projects related to viewpoints in several islands of the Canary Islands.

## 5.6 Castillo de San José—International Contemporary Art Museum of Lanzarote

Although the purely creative action of César Manrique was much more limited than in other centres promoted by the Cabildo of Lanzarote at this time, the intervention of Castillo de San José and its transformation into the International Contemporary Art Museum of Lanzarote (MIAC) was a successful example of rehabilitation and cultural promotion, two aspects that were also used by an artist who developed an active role as cultural agitator in Lanzarote and the Canary Islands.

The main criteria in the intervention during the 1970s, was the respect for the idiosyncrasy of the building, at the same time that new spaces were built appropriately for museum use. Thus, the original structure was barely modified, but annexed buildings were created, such as the restaurant that faces the seafront, the esplanade of the entrance, the stairs. Despite this, the fortification reveals all its main characteristics as a military stronghold.

Lanzarote was an island especially ravaged by pirates and corsairs for centuries, before and especially after the European conquest, so it has several castles. San Jose's was built between 1771 and 1779, with a capacity for 500 men and with the mission to defend the nearby ports of Naos and Arrecife.

One of the new contributions in the reforms was the large platform that precedes the entrance, which has its corresponding moat and drawbridge. Before that, there is an open-plan area where rofe, stone, gardening and several sculptures are harmoniously combined with the real visual protagonist of the space: the great stone facade of the castle.

The visitor to the museum accesses the drawbridge on the upper floor where the museum's permanent collection is located. At the end of the first level, a delicate and pretty helical staircase goes down to a restaurant with large windows through which you can perfectly see the Arrecife marina. On the left there is a temporary exhibition hall, which usually houses samples of contemporary art. The lower part of the Castle can also be accessed by a lateral stone staircase that winds through a garden area.

Like in other Art, Culture and Tourism Centres, the whole space is accompanied by original or striking decorative details, such as restaurant lamps made with bottles, Manrique's solution to recycle and reuse objects. Also, the gardening and stonework of Castillo de San José is also highly valuable.

In addition to being an artist, Manrique developed an important facet as a cultural promoter. After living in Madrid and New York, once he had definitively settled in Lanzarote, the artist opted to promote cultural activities as a way to energise the local society, as it happened with El Almacén, a pioneer cultural centre in an old house in Arrecife.

The Manrique utopia consisted of enriching the combination of culture and tourism. In fact, CACT was conceived from the beginning to host cultural and artistic activities, as is the case of Cueva de los Verdes or Jameos auditorium, and the MIAC, which regularly organises events (Fig. 5).

The official opening of the museum in 1976 took place with the "I International Visual Arts Competition", one of the most ambitious contemporary art exhibitions that had been held in Spain up until that moment. For the inauguration, the works of great international artists were brought over, artists such as Picasso, Marc Chagall, Francis Bacon, Alberto Giacometti and Henry Moore. The permanent collection of the MIAC stands out as one of the most important ones when it comes to the artistic generation of mid 20th century in Spain (Bonet et al. 2000).

## 5.7 Other Interventions that Manrique Carried Out in the Following Years

In 1976, the artistic activity of César Manrique in the territory of Lanzarote did not stop and the CACT also experienced extensions that have since been completed, especially in the case of Jameos del Agua. Also, the artist from Lanzarote made his Taro de Tahiche (Marchán 1996) home (architecturally very outstanding work and headquarters of the César Manrique Foundation since 1992) and his house in Haría, where he spent his last years and turned into a museum centre recently by his Foundation. He also designed outstanding works in Tenerife, Madrid and

**Fig. 5** Castillo de San José

El Hierro, in addition to planning several interventions that did not see the light. Both the completed works, as well as those that got left in a project phase maintained many of the architectural patterns and aesthetic turns common in an author with a style of "Total Art", as he defined it, which was already very consolidated in the mid-seventies. In addition, Manrique continued with his artistic career in design, graphics, sculpture and especially painting, a discipline he always felt more identified with and to which he dedicated more time in the last stage, before his death in 1992 in a traffic accident.

Two years before his death, in 1990, Manrique premiered a work whose initial project began to take shape in the sixties and which was integrated into the CACT as an outstanding piece of the network: Jardín de Cactus. In addition to hosting hundreds of thousands of visitors annually and being the last major intervention Manrique did in Lanzarote, Jardín de Cactus is considered one of the most outstanding works of public art (Ramírez de Lucas 2000). Again, architecture, landscaping or design go hand in hand in a subtle proposal dedicated to cultural tourism. Focusing on a plant element closely linked to Lanzarote, the cactus, Manrique reconnects contemporary artistic languages with a message of respect paying tribute to local traditions and nature.

But the central object of our analysis is not so much the artistic career of Manrique, which has been studied by several history of art, painting or architecture[4] specialists, as the creation of a spatial intervention model in the landscape, which from the start combined tourism, nature, culture and

[4]Besides the aforementioned bibliography and filmography, in order to take a deeper look at Manrique's work, we recommend reading: Carmona (2006): "César Manrique en los años cincuenta. Consideraciones en torno a la creación de un imaginario plástico", in César Manrique 1950–1957, César Manrique Foundation; Castro Borrego (1985): "Pensar en el paraíso", César Manrique über Kunst und Umwelt, Münchner Volkshoschule Gasteig Kulturzentrum, Munich; Gómez Aguilera (1994): "Arte y naturaleza en la propuesta estética de César Manrique", in Atlántica Internacional, Centro Atlántico de Arte Moderno, nº 8; Gómez Aguilera (2006): "La fábrica del artista moderno. César Manrique en el contexto del arte español (1950–1957)", in César Manrique 1950–1957, César Manrique Foundation; Izquierdo (2000): La obra artística de César Manrique, Cabildo of Lanzarote, Arrecife; Ruiz Gordillo (1995): César Manrique, César Manrique Foundation, Lanzarote; Zamora Cabrera (2009): La artealización de Lanzarote, tesina inédita; VV.AA. (1996): César Manrique. New York, César Manrique Foudation, Lanzarote.

public administration. That model began at the beginning of the 1960s and in 1976 it had already completed its tourist and urban planning objective. In addition, since the mid-seventies we can see the beginning of another different historical moment in certain areas. Locally, a key element of this programme, José Ramírez Cerdá, left the presidency of the Cabildo in 1974, while nationally, there were years of great socio-political transformations within the democratic transition framework.

Financially, it is very important to bear in mind that there was a transcendental change for Lanzarote. Simultaneously, with the fast-paced fall of the fishing industry, mass tourism, which until then was still a secondary sector, experienced a brilliant take-off since the early eighties, to become the central axis of the island's economy. One of the consequences of this phenomenon was that the debate on the impact of mass tourism on the island[5] became more acute, with Manrique as a media focus on the critics of the constructive development that the island experienced since the 1980s.

In 1976, all the CACT centres were in operation, except the Jardín de Cactus, while political, economic and social changes were bringing about a new era. For these reasons, in the next few pages we will focus our analysis on defining the essential guidelines of this initial model, as well as its implications and consequences.

## 6 Characteristics and Repercussions of the Creation of the CACT

### 6.1 Specific Historic Context and Favourable Conditions for Experimentation

Like any outstanding artistic work or socio-economic and political programme with a broad historical impact, we must take into account the moment in which it emerged. Shortly after the Second World War, in the context of the European recovery, the economic, social and technological conditions for the first great development of mass tourism took place, placing the south of the continent as a preferred place for its conversion into a tourist zone due to weather and political reasons. Likewise, favourable circumstances arose in the national and regional context, and the local mechanisms that made this programme possible also materialised in Lanzarote, especially with the key relationship between José Ramírez and César Manrique.

In addition to all these favourable scenarios, both the initial nature of the period in which it took place—the beginning of mass tourism development and the marginal nature of the space where it happened—Lanzarote until then combined the peculiar quality of being a very suitable terrain for experimentation and innovation. As the starting point was so new and primitive, this allowed the main people involved to act with more freedom, before the total implementation of the industry imposed more standardised formulas regarding the cultural and leisure offer for tourism.

### 6.2 Integrating and Innovating Approach

The creation of the CACT within the political ideology of the Cabildo of Lanzarote should be observed as part of a larger project that aimed to modernise the island. It was a multi-sectorial programme (industry, transport, water, urbanism, tourism…) that did not respond to a theoretical planning or a previously designed road map, but was articulated, little by little, around a governmental intentionality to diversify the economy of a society dependent on a very rudimentary primary sector and, above all, of a prosperous fishing industry that contemplated with fear the future of the waters of what was then called the "Canarian-Saharan fishing bank". Indeed, a few years later, the decolonisation of the Spanish Sahara produced a rapid decline of the canning factories and the fishing fleet.

On the very nature of the CACT, it is remarkable that its innovative and mixed nature merged tourism with the geological, landscape, biological or historical intrinsic interest of the enclaves themselves where it was intervened, and with the new contemporary sensibilities in art, architecture, design, landscaping, gardening, public art, etc. One of the great contributions and novelties of these spaces is that they manage to harmoniously combine patterns of different typologies. On the one hand, there are the elements of natural monuments, and on the other hand, classic features of museums and heritage centres and, finally, the creativity of contemporary art and architecture is added. A triple nature—environmental, cultural and artistic—placed at the service of the new tourist economy. Manrique, playing a vital role, and with a certain missionary sense to his work, encouraged the breadth of objectives of these centres. The artist "*arranges a kind of applied arts with the purpose of contributing, through the production of new natures, to "educate", but, above all, to improve the lives of people through the beauty and wellbeing that would show off the total work of art: to contribute to collective happiness*" (Gómez Aguilera 2004).

[5]Regarding this topic, we recommend reading Santa Ana, M., [coordinator], (2004): Paisajes del placer (Pleasure Landscapes), Paisajes de la crisis (Crisis Landscapes), César Manrique Foundation, Lanzarote.

## 6.3 Manrique Style: The Aesthetics and Ethics of Tourism

With a very distinguished previous artistic career in Madrid and New York, especially in painting, but with incursions into other disciplines, the creative capacity of César Manrique allowed him to galvanise aesthetic styles of the avant-garde of his time (informalism, pop art, land art, etc.) and values of the cultural and natural heritage of the island, with a formula that he himself called using the pairing Art/Nature, Nature/Art. Manrique, as artistic and intellectual author of the CACT, has not only left unique pieces of architecture behind, landscaping or design that will go down in the history of art, but also left a legacy that goes beyond the artistic one standing out in a larger field, that of culture, especially in relation to tourism. The CACT must also be observed as a contribution of ideas and innovative approaches around an international debate that has intensified in recent decades, the impact of tourism on society, territory or heritage. In this sense, it is important to note that the creation of a powerful aesthetic of tourism by Manrique, was also accompanied by an awareness of the dangers of mass tourism and the importance of safeguarding the essence of heritage and landscape of Lanzarote. The social and environmental activist Manrique had, was strengthened in the eighties, in accordance with the increase in tourism pressure on the island. It was the moment in which his popular and high-profile facet was highlighted as an environmental symbol, but since the sixties he had been expressing a clear ideology in this regard:

> Soon we will see the light of my book "Architecture of Lanzarote", which is a compilation of what is really interesting in the aspect of a new island, which is at a time in great danger, due mainly to its economic and tourist boom. For this reason, they are beginning a series of anarchic constructions, without the least aesthetic sense, that could spoil, and in fact they are already spoiling, the tourism future of the island, so that when the landscape is damaged, Lanzarote would lose one of its main charms. (Gomez Aguilera 2004)

## 6.4 Revaluation of the Natural and Cultural Heritage

The CACT, catalogued as Cultural Interest for many years, are a legacy of enormous historical, artistic and natural significance for the Canary Islands and especially for Lanzarote, providing it with a new fundamental layer for its cultural history. Along with Manrique, other authors (Jesús Soto, Eduardo Cáceres, Ildefonso Aguilar …) left their mark on centres that were created with auditoriums and multi-purpose rooms to host an ongoing cultural programme (music, performing arts, cultural events, exhibitions …) that had an impact and continues to have an impact on residents and visitors. Initially, they were also conceived to make room for their own gastronomy, which had its roots in local traditions and, in two specific cases, Castillo de San José and Casa-Museo del Campesino, had an unquestionable intention to enhance the historical heritage of the island. On the other hand, one of the significant guidelines of the original actions of the CACT lies in their rehabilitating nature, being erected in certain enclaves of relevant landscape that were degraded or in a state of neglect (Cueva de los Verdes, Jameos del Agua, Mirador del Río, Castillo de San José or Jardín de Cactus) and in danger due to uncontrolled mass growth (Timanfaya). All this contributed to the creation and promotion of a social awareness of the landscape and culture, offering a new story of the island associated with a way of understanding tourism. In short, the creation of the CACT centres has significantly enriched Lanzarote, creating new spaces and rehabilitating natural enclaves that were in danger, and raising awareness among the population.

The creation of the CACT began to reap international awards from very early on. In 1978, the Association of German Tourism Journalists gave the World Prize of Ecology and Tourism to César Manrique; in 1981 it was the World Prize of Ecology from the city of Goslar, in 1989 it was the Europa Nostra Prize, and in 1989 it was named member of the Spanish Committee of the UNESCO Man and Biosphere Programme. The contribution in this organism was key for Lanzarote to be named a Biosphere Reserve in 1993.

## 6.5 Economic Relevance

From its beginnings, especially for the creation of direct employment (administration, construction, maintenance, restoration, gardening, etc.), the CACT demonstrated an enormous economic potential.

The main source of income for the CACT are the entrance fees, which in 2015 were close to 3 million. According to the newspaper El País (Nogueira 2017). That year, in Spain only the Sagrada Familia in Barcelona and the Reina Sofía Museum were able to surpass those figures. Monuments and museums as relevant as the Alhambra, the Prado Museum or the City of Arts, had fewer visitors. Regarding National Parks, Timanfaya is the fourth most visited in Spain (http://www.mapama.gob.es/es/red-parques-nacionales/la-red/gestion/visitantes.aspx). These figures can help us get an idea of the significance the CACT have, although, nevertheless it is necessary to take into account that we are not speaking of a single space but of a network of six centres. The demographic and tourist dimensions of Lanzarote should also be measured in comparison with large capitals, or also taking into account that we are talking about spaces that, as we previously mentioned, mix different typologies, combining characteristics of

**Table 2** Visits to the Art, Culture and Tourism Centres 1982–2016

| Year | Total | Jameos del Agua | Mirador del Rio | Cueva de los Verdes | Montañas del Fuego | Jardín de Cactus | Castillo de San José |
|---|---|---|---|---|---|---|---|
| 1982 | 820,664 | 278,226 | 160,645 | 117,378 | 264,415 | | |
| 1984 | 997,126 | 330,928 | 194,807 | 146,859 | 324,532 | | |
| 1986 | 1,227,058 | 391,852 | 255,924 | 195,386 | 383,896 | | |
| 1988 | 1,567,225 | 478,441 | 292,924 | 267,404 | 528,456 | | |
| 1990 | 1,655,324 | 465,746 | 251,629 | 272,157 | 550,872 | 114,920 | |
| 1992 | 2,103,909 | 564,826 | 324,410 | 348,164 | 702,935 | 163,574 | |
| 1994 | 2,675,785 | 708,415 | 420,721 | 428,189 | 872,050 | 246,410 | |
| 1996 | 2,670,797 | 693,615 | 427,984 | 410,295 | 855,645 | 283,258 | |
| 1998 | 2,805,901 | 754,518 | 419,076 | 402,735 | 933,388 | 296,184 | |
| 2000 | 2,682,704 | 721,733 | 411,177 | 369,411 | 913,442 | 266,941 | |
| 2002 | 2,475,347 | 666,209 | 362,999 | 335,450 | 866,944 | 243,745 | |
| 2004 | 2,561,893 | 702,968 | 374,604 | 358,387 | 889,797 | 236,137 | |
| 2006 | 2,564,883 | 691,029 | 362,506 | 370,127 | 894,220 | 247,001 | |
| 2008 | 2,637,107 | 684,563 | 369,939 | 392,270 | 892,217 | 262,933 | 35,185 |
| 2010 | 2,410,644 | 615,839 | 340,795 | 349,300 | 802,534 | 263,971 | 38,205 |
| 2012 | 2,356,496 | 612,745 | 312,418 | 334,326 | 788,223 | 255,776 | 53,004 |
| 2014 | 2,605,238 | 668,311 | 368,005 | 349,058 | 870,372 | 293,336 | 56,012 |
| 2016[a] | 2,956,322 | 750,552 | 413,626 | 417,755 | 967,914 | 333,000 | 64,423 |

*Source* Data Centre of the Cabildo of Lanzarote

[a]Since 2015 two new centres were opened, La Casa Amarrilla and Museo Atlántico, although their joint visitor numbers added up to less than 10,000 in 2016

natural monuments, with elements of heritage museums or contemporary art centres.

In 2015, the auditing company Deloitte carried out an Analysis and evaluation of the socio-economic contribution of the Art, Culture and Tourism Centres and the figures in the report indicated that in that year the CACT generated 186.7 million euros from its activity, "*… this translates into 231 million GDP, in maintaining 6,624 jobs and 16.2 million in tax returns*." (AAVV 2016). Again, may we remind you that this data must be interpreted within the framework of an island of 145,000 inhabitants to better understand their true influence on the economy and society of Lanzarote.

The promotional and prestigious value that the centres bring to a tourist destination such as Lanzarote is more difficult to calculate. Nevertheless, the impact of the CACT and César Manrique on the image of the island is enormous. The Deloitte report mentions that 44% of tourists who came to Lanzarote in 2015 visited the CACT (Table 2).

## 6.6 Social and Symbolic Impact

The impact of the CACT in the society of Lanzarote, is deep and strong, starting with what we discussed in the previous sections in terms of heritage and economic aspects. Along with the enormous work of revaluation and dissemination of the island's heritage and the promotional value of the CACT for the island's tourism brand, the Art, Culture and Tourism Centres have generated many jobs in recent decades. It is not only about administrating or managing the CACT, but about a whole range of activities that go from transport of tourists to catering and hospitality, through the cultural offer or the products sold in their stores, if we are to only mention a few areas. In addition to the millions of foreign visitors who have passed through these centres, the residents of the island have frequently attended festivals, cultural events and social events that are organised periodically. Following the data of the 2015 Deloitte report, the centres carried out 217 cultural events that year.

The CACT also has an educational department that annually receives thousands of primary and secondary students from the island's education centres. But beyond the extracurricular activities, these centres have played a wide pedagogical role in the social perception of the landscape of Lanzarote. Created just at a time of transition of the island's socioeconomic model, from the primary and fishing sector to the service and tourism sector. These centres and their fast economic and cultural success inevitably became the insular reference with regard to how the landscape was perceived. In César Manrique's studies, the authors agree when pointing out his educational will and the social meaning he gave to contemporary art: "… *he manages, through his spatial works and his ecological discourse, to get the population to identify with the preservation of its heritage and with the benefits of a planned tourism development*." [6]

For all that has been said so far, it makes sense to realise that the impact of the CACT goes deep into the realms of the tourist imagination and the cultural identity of the island. The impact of the centres in the configuration of contemporary collective mentalities of Lanzarote is unquestionable. Even with the high numbers they offer regarding visitors or jobs for a relatively small setting such as Lanzarote, the historical and ideological significance of these spaces on the island's society is probably even greater than the economic one. The great impact of the CACT has been on the minds of the population of the island. Highlighting the educational work Manrique did, the critic and historian Fernando Castro argues that "*it can be said that his true creative work was neither his painting nor the conversion of the island into a work of art, but the education of his fellow citizens.*"[7]

## 7 Conclusions

In an international and national context conducive to the development of tourism and under the presidency of José Ramírez, the Cabildo of Lanzarote began, starting in 1960, to create a network of new infrastructures aimed to favour the economic modernisation of the island. Within that political setting, special mention was made of some pioneering artistic interventions in different natural spaces that were converted into enclaves such as Cueva de los Verdes, Jameos del Agua or Mirador del Río in areas of great tourist interest. It was the time in which a group of personalities, among which artist César Manrique stood out, defined the modern image of the island, creating the symbolic bases of a new economic and social identity of enormous promotional strength for Lanzarote and culturally instilled in the population of the island.

Beyond the purest economic and political planning, what the Cabildo of Lanzarote was developing with the CACT was one of the most original and ambitious cultural public interventions, within its scale, of the second half of the 20th century in Spain. Taking it to an international level, we are facing one of the newest offers of an emerging global industry, mass tourism, and a project that combined currents of contemporary aesthetic and different artistic disciplines, with the vindication and revaluation of the local natural and cultural heritage as a unique and valid element.

[6](González and Hernández 2005).
[7](Castro 2009).

In this sense, the CACT must be understood as a process of cultural experimentation, in the broadest sense of the word, because elements of economics, volcanology, geography, tourism, ecology, cultural identity, and history, among others, were put into play. Even fifty years later, the concepts raised during their creation are as current or even more so than before, and the creation phase of the CACT is still a very valid model to discuss and reflect on regarding the relationships between tourism, nature, culture and society.

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# Lanzarote Saltworks, Symbol of Identity

Juan Antonio Bacallado Betancort

**Abstract**

Lanzarote Saltworks are witnesses of the way islanders (*lanzaroteños*) interacted with their surrounding embracing their geological heritage. They form an essential part of their inhabitants' identity and, make up a significant part of their Historical and Cultural Heritage. The recovery and revaluation of these salt-producing networks rescues the testimony of an era responsible for the socio-economic development of the island.

**Keywords**

Saltworks • Salt pans • Salt ponds • History of lanzarote • Salt • Cultural heritage • Historical heritage • Tourism • Industrial archaeology • Industrial memory • Geology and tourism

## 1 The Productive Cycle of Salt

Common salt or table salt, popularly known as salt, is the commonly used and generalised qualifier of the halite or sodium chloride, whose chemical formulation is NaCl. Salt is an ionic compound formed by a Sodium cation ($Na^+$) and a Chlorine anion ($Cl^-$). The sodium chloride has a crystalline structure with cubic symmetry. In nature, it can be found in a solid or liquid state.

Salt in liquid state is basically associated to ocean and seawaters. However, it is also localised in lakes, lagoons or springs whose salinity has occurred due to their waters passing through halite deposits. Salt concentration in seawater is lower than that in inland waters, but the location of saltworks in very specific sites and with optimal conditions of production, makes this type of saltworks much more productive salt factories, as the raw material is practically inexhaustible, estimating the sea-salt reserves to about 40,000 trillion tons.

Throughout history, the salt productive cycle could be classified as technologically simple, if we consider the low investment in both complex tools and operations to obtain the final product. Nevertheless, and although common operational standards in the process of salt collection can be determined, every saltwork has some features differentiating it from the rest of saltworks. Theses differences are due to the fact that the collection process has as main conditioning its setting in very specific sites, never chosen by humans but by the laws of nature.

The relationship between salt production and specific sites directly conditions all the steps of its cycle, determining its production season, the form the raw material is collected, the way the final product is elaborated, and even the materials and constructive techniques used when building the infrastructures required by the process.

Due to all these circumstances, the salt production cycle is characterised by the man adaptation to the site peculiar features where the saltworks are located. Summarising, it is a constant capacity of the man adaptation to the environment, where from the beginnings the success of salt production was solely based on the man's ability, and thus the knowledge being passed on from generation to generation. This process was only stopped by the emergence of some innovating techniques, which provoked variations in the production cycle (Moreno 2006).

In accordance with the different deposits and technical resources used, throughout history different cultures have developed various technologies for the collection of salt, from which the recollection systems, mining, graduation and ebullition, and the concentration and vaporisation can be distinguished.

Salt cultivation or production comprises four basic elements: seawater which nourishes the saltwork, soil to obtain the necessary mud for the waterlogging of the salt ponds, the fire of the sun which crystallises the salt and the wind that contributes to the evaporation (Marín and Luengo 1994).

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Solar evaporating saltworks are the ones used for the process of seawater brine. These saltworks can be defined as a set of salt ponds, surrounded by stonewalls, whose beds are covered with mud or mixed material, where seawater is stored until its crystallisation. Through a system of water channels, water is pumped into the different areas of brine concentration increasing this way its salinity level. Once the crystallisers or gorges are filled up they are blocked to prevent any more brine from getting in. All saltworks in Spain, the Canarians among them, follow this technology.

In the Canaries, four different types of intensive saltworks can be established, evolving into the new saltwork made of mud covered with stones from which can be confirmed it is an own and genuine invention belonging to the island of Lanzarote, emerging in the late 19th Century:

1. The primitive saltwork on rocks originally pools formed from the high tide, built with stones and cordoned with mud.
2. The old mud salt work whose salt ponds are made of stones and lime mortar and with simple gorges in a row.
3. The old salt work made of lime mortar, similar to the previous one, but mud is substituted by lime mortar, forcing gorges to be built in a smaller size.
4. The new mud-covered-with-stones saltwork, evolving from the old mud one by introducing the stone covering and the complex gorges. The walls of the salt ponds are stone masonry buildings with a mud and stone interior slope for waterlogging. The base of the salt ponds is made of rammed mud (Marín and Luengo 1994).

The evolution of the different types of intensive coastal saltworks results in a great diversity of models, which, in the archipelago's particular case, especially enriches the geography producing shapes of great singularity.

## 2 Fragments of Memory

The saltworks possess themselves and intrinsic natural and cultural interest and value. They are one of the mankind's most beautiful and singular creations made on the coastal edge, offering the spectator a variety of unique landscapes.

> I've always been impressed by the vision of a Saltwork. The ones in Lanzarote have caught my attention for their lineal beauty and glaring coloring; their own personality stands out over the island's landscape.
>
> César Manrique.

The construction of the complex saltworks, the types of tools used, the irrigation systems, its salt collection or because salt producing performance directly depends on the commitment of the man and the annual solar cycle, maintain a parallelism with the agricultural activity. Just like the collective imagination devised new formulas for the use of the resources as for instance, the vineyard pits in La Geria, the islander ingenuity has been able to develop saltworks unique in the world, providing peculiar inventions to increase the production of salt. These activities or geniuses in the different saltworks has been the hard work of past centuries, with lack of technical resources, but with an intelligent adaptation to the different areas in order to make the best out of its productive potential in the most efficient manner.

The current discontinuity with the different traditional models of natural resource management, where the territory was shaped providing in turn value and creating new landscapes, has left oblivious the spectacular creations of the saltworks, which deserve a prominent place as activity in the territory due to its high cultural and architectural interest, being one of the landscape views with greater plastic force of the human ingenuity (Estudio Luengo 2008a, b).

César Manrique advocates, in his intervention in the prologue of The Salt Garden book *"El Jardín de la Sal"*, the need of spreading the salt-producing work as a transcendental aspect of the Canary Islands Cultural Heritage, and trusts that the sustainability of the salt-producing activity can be attained, through certain initiatives, preserving an important aspect of our culture.

> I've always been impressed by the vision of a Saltwork. The ones in Lanzarote have caught my attention for their lineal beauty and glaring coloring; their own personality stands out over the island's landscape.
>
> Lanzarote saltworks amaze me for how well programmed they are, just like the rationalist proposal where the design rule composes the functionality of creativity. In my opinion, the whole saltwork is framed within Mondrian's compositional coordinates, but achieving its integration in the appropriate frame of nature and life.
>
> The culture, tourism, landscape, ecology and practical performance become allies to prevent the saltworks from disappearing and for us to be able to enjoy an activity almost lost, once in the past very important though when ice didn't exist.
>
> The conception of occupied spaces by the saltworks as areas to be protected for everybody's enjoyment, combined from a practical perspective with the necessary economic return to guarantee the continuity of the activity, thus make from many saltworks places of mayor attraction, as well as bringing the exceptional quality of the marine salt within reach. I believe this is the direction that must be taken in the Canaries, of which Lanzarote has set a good example, taking advantage of the natural conditions for the collective enjoyment, and not to hopelessly destroy them for good due to the blindness and hysteria of a few who cannot see further than their pockets.
>
> César Manrique (Marín and Luengo 1994).

## 3 Lanzarote and the Salt

The island of Lanzarote started to form during the Miocene, 15 million years ago, with the appearance of the oldest remains in the Ajaches area in the south and Famara in the north of the island. These two edifices and the set of volcanic craters shape the island's geography which, along with the eruptions historically occurred, create a geological singularity which has given rise to a historical and cultural heritage linked to the collective imagination, product of the necessity of resources to face the harsh natural conditions.

In the Canaries, there are very few written references regarding the use and production of salt in the native culture. It is known that the early population of the island collected it from the natural tide pools, created during hide tide, to preserve fish. The numerous natural salt pans served as single source for salt extraction known until the 15th century.

One of the basic features of the Canary people's idiosyncrasy is their devotion to the sea, a clear example of it can be observed in the island of Lanzarote, where is still current the collection of salt from the natural salt pans spread along the coast. Lanzarote owns, most certainly, the oldest saltworks in the Archipelago. The *"Salinas del Rio*" Saltworks, located in the north of the island, "*Bajo el Risco*" in Famara, a natural salt pan made of mud of which it is believed to have been exploited from Ancient times, and which has been documented in the engineer Leonardo Torriani's maps in 1590 (Marín and Luengo 1994).

The main reason for the existence of Arrecife as primal harbour of the island is due to its location, features, and privileged site as a port area. The provision of reefs located by the coast, giving calm to its waters, along with its especial orography, were the triggers for the port to be developed. From all the Canary coasts, Arrecife stands out as the best natural port. Lanzarote had the need to establish a shipping point and Arrecife soon became the main harbour in the island. Due to this fact, trading in Lanzarote and the other islands begins to settle in El Puerto. Its first infrastructures were built in the 15th century, creating first La Puntilla's settlement. It is in the 19th century, thanks to the commercial activity that had been developing on its coast, when Arrecife becomes the capital of the island of Lanzarote. At the end of the 16th century, after observing the advantages found in the coast of Arrecife, engineer Torriano arranges the construction of a defensive system fortified with a wall, establishing what later would be the main line of defence in the island (Hernández and Barba 1999).

After the Timanfaya volcanic eruptions, between the years 1730 and 1736, the islanders start to grow the grapevine for wine production, but it is the ice plant the product that would mean a before and after in the capital of Lanzarote. Its exportation transforms Arrecife into an important trading and urban landmark, greatly speeding up the development of its docks and town. In the commercial port of Arrecife cochineal insects, onions, pulses, and tobacco are also traded. Salt has its relevance too however, what leads to the highest growth of the town was the development of the fishing industry (Cantero 1982).

The fishery industry played an important role in the socioeconomic growth of Lanzarote. The geostrategic location of Arrecife, situated at a few miles from the fishing ground in the Canary-Saharan Banks, makes the capital an exceptional place for the development of its port. In the 60s, dry salting and dried fish were replaced by tinned food. In Arrecife, there are up to five operational factories: Lloret and Linares, Afersa, Hijos de Ángel Ojeda and Rocar, Conservera Canarias and Frigorsa, and Atunera Canaria (Falero Lemes and Montelongo Franquiz 2000).

In the early 1980s, the fishery industry was the main engine of the island's economy making up to the 70% of its total turnover. Arrecife became home to the first Canary fishing enterprises, making up to the 90% of the Spanish sardine fleet, the most important in Europe and, by extension, in the world. Through this fishing activity there was an intensive operation and usage of the saltworks for the development of the fish, both offshore by means of brine, and onshore for salting.

In Lanzarote, saltworks were abundant, spreading from the north to the south of the island, most of them mainly located in Arrecife town, due to its situation, features, and privileged position as port area. From Lanzarote, salt was exported to the archipelago, and many ships stopping over in the town took advantage of it to trade and load their cargo holds with large quantities of brine for fish preservation during extended periods of time (Saavedra 1993).

It is in the 1960s, and with the change of tourism model, that the salt network in the island begins to decline, linked to the fishing and canning, of such importance for the socioeconomic development of the island, in view of the emerging of new cold techniques and the falling of the catches on the African coast.

## 4 Current Situation of the Saltworks in Lanzarote

From a total of 27 saltworks existing in the island, there are currently only 2 in operation, Janubio Saltworks—*las Salinas de Janubio*, at a 10% of its historical production and Agujeros Salworks—*las Salinas de los Agujeros*, with a current residual production thanks only to the effort of one of its workers. The 8 saltworks left, las Salinas del Río and de

**Table 1** The set of saltworks historically present in the island of Lanzarote

| Saltworks | Municipality | Antiquity | Area ($m^2$) | Annual production (TN) | Current state |
|---|---|---|---|---|---|
| El Río | Haría | 1520 | 106,380 | 600 | Layout remains |
| Órzola | Haría | 1930 | 28,150 | 400 | Layout remains |
| Punta Mujeres | Haría | 1930 | 43,900 | 700 | Disappeared |
| Los Agujeros | Teguise | 1940 | 51,090 | 800 | Recently shut down |
| Tío Joaquín | Teguise | 1930 | 60,540 | 900 | Layout remains |
| El Charco | Teguise | 1920 | 56,000 | 700 | Only mills left |
| El Rostro | Teguise | 1935 | 76,000 | 800 | Disappeared |
| Las Cucharas | Teguise | 1925 | 50,000 | 550 | Only mills left |
| Bastián | Teguise | 1930 | 91,000 | 800 | Only mills left |
| Las Caletas | Teguise | 1935 | 47,690 | 800 | Layout remains |
| Punta Grande | Arrecife | 1920 | 140,000 | 1500 | Disappeared |
| Los Mármoles | Arrecife | 1930 | 66,000 | 900 | Layout remains |
| Puerto Naos I. Tomás Toledo | Arrecife | 1935 | 79,705 | 600 | Layout remains |
| Puerto Naos II. Fuentes | Arrecife | 1935 | | | Layout remains |
| Puerto Naos III. El Herrero | Arrecife | 1935 | | | Layout remains |
| Puerto Naos IV | Arrecife | 1930 | 29,000 | 400 | Disappeared |
| Puerto Naos V | Arrecife | 1920 | 50,000 | 650 | Disappeared |
| Puerto Naos VI | Arrecife | 1920 | 26,700 | 350 | Disappeared |
| Puerto Naos VII | Arrecife | 1930 | 30,000 | 400 | Disappeared |
| Puerto Naos VIII | Arrecife | 1930 | 30,000 | 400 | Disappeared |
| El Islote | Arrecife | 1920 | 10,470 | 200 | Layout remains |
| El Reducto | Arrecife | 1940 | 115,800 | 1300 | Disappeared |
| La Bufona | Arrecife | 1935 | 23,420 | 320 | Layout remains |
| Matagorda | Tías | 1934 | 120,300 | 1400 | Disappeared |
| El Berrugo | Yaiza | 1900 | 50,000 | 550 | Disappeared |
| Janubio | Yaiza | 1910 | 428,640 | 13,000 | Partly operational |
| La Santa | Tinajo | 1920 | 84,000 | 800 | Disappeared |

*Source* Salinas Canarias report (2008a, b)

Órzola in Haría, las Salinas del Tío Joaquín and las Caletas in Teguise, las Salinas de Puerto Naos, los Mármoles, la Bufona and el Islote in Arrecife are in a state of neglect, although they still retain their layouts and important heritage features (Table 1).

## 4.1 Puerto Naos Saltworks. Architectural Ingenuity

The Saltworks in Puerto Naos represent the saltwork of greater architectural interest in Lanzarote and in the Canaries. To understand the importance of this saltwork we must take into account the great need of salt supply. Due to this fact, the closeness of the saltwork was a must. That is why, in order to cut costs and be able to quickly supply great amounts of salt to the boats in the port, it was seen necessary the construction of saltworks in Arrecife. From the 19th century the saltworks started to be built at the entrances and exits of the town, in strategic places close to the coast and, most importantly, with good connections to Puerto de Naos (Clar 1999) (Fig. 1).

The first saltwork in Puerto Naos dates from 1860, being made of mud over a total area of 50 $m^2$. The original site was terraced and walled but, at a later stage, it was refurbished to have a stone lining added. It was built in 1920 making use of stones taken from a salt pond in ruins. Puerto Naos Saltworks are owned by Rafael Perdomo, with an area of 26,700 $m^2$ and with an annual production of approximately 350 tons of salt.

These saltworks were later transferred to Juan Betancort, to finally be acquired in the 1960s by the canning industry Lloret y Linares. In subsequent years, more saltworks were being built in the surrounding areas, like the one named

**Fig. 1** Image of Salinas de Naos. *Source* Compiled by author (2017)

Salinas del Herrero with an area of 31,200 $m^2$, also drawn in 1920 in an unused area. Water for these saltworks was obtained through a well where a hydraulic pump was installed to carry water to the upper salt ponds.

In 1935 the saltworks, las Salinas de Tomas, were built. They also had a regular drawing adapted to the terrain by means of constructing stone terraces. The latter collected seawater by means of three wells and various mills of a wooden structure and sheet-metal multi-blades (Clar 1999).

It is classified in the General Master Plan of Arrecife where the creation of an Ethnographic Park and a Salt Museum has been proposed. It is included in the Protection of Areas and Open Spaces catalogue and has been initiated as a Site of Cultural Interest in the Monument category.

These saltworks offer a very spectacular architectural work. Not only because of their layout and topographic adaptation but also due to its singular and majestic mural work that can reach 5 m high, being the largest saltwork architectural project of all the Canary Islands and one of the most unusual in the world. It constitutes an important open space placed between industrial developments and a landscape breath to San José's Castle one of the patrimonial emblems of the town. El Castillo de San José (Salinas Canarias Report 2008a, b).

### 4.2 Salinas de Janubio. Emblem of the Salt Culture in the Canaries

Las Salinas de Janubio—Janubio's Saltwork, located in the municipality of Yaiza, started to be built in 1895 by Vicente Lleó Benelliure, leaving the property at a later stage to his nephew Jaime Lleó Mira, whom with the collaboration of the family Cerdeña y Ginés Díaz continued its construction until approximately the year 1945.

Its natural origin goes back to the year 1735, when the inner lagoon was formed, due to its pebble range resulting from the coastal erosion of Timanfaya's runs which led to the closing of Puerto Real de Janubio.

These saltworks are the ones of largest size and greatest interest in the Canaries, and if we take into account their important landscape and ecological values, along with their uniqueness and the architectural hydraulic complexity within, it can be considered as one of the most important saltwork ingenuities in the world (Marín and Luengo 1994).

Las Salinas de Janubio is grouped around a lagoon located in a deep terrain, which on its own already worked as a natural saltwork. When producing salt, water is collected via the canals within the lagoon, and is carried upwards by means of mills, which are replaced in the 50s with a

**Fig. 2** Panoramic of Salinas de Janubio. *Source* Compiled by author (2018)

combustion engine for water lifting. The saltwork set continuous to fully adapt to the terrain, surrounded by canals transporting water to the salt ponds. The stonework of their salt ponds and edges, ramps and walls, as a whole, represents a unique landscape of a singular and extraordinary architectural beauty (Fig. 2).

Under Resolution No. 1986/03, dated 12th June 2003, proceedings are initiated for the declaration of Site of Cultural Interest, within the Monument category, in favour of these saltworks, besides being included in another ("Goods of Cultural Interest") BIC file in the category of Paleontological Area. In 2007, due to its historical, landscape, architectural, ethnographic, cultural and ecologic value, they are classified as Site of Scientific Interest, being at the same time a protected natural area, rustic land of natural and coastal protection and a restricted use zone. It is also a zone of environmental awareness. They are declared IBA (places of international importance for conservation), and ZEPA (SPAB—Special Protected Areas for Birds) ZEPA (Nº 98/32885, DE 79/409/CEE). They are part of the NATURA 2000 NETWORK (DE 92/43/CEE). They are integrated in the core area of Lanzarote Biosphere Reserve to ensure their conservation and landscape maintenance as one of the greatest values established in declaration (7th October 1997). Lanzarote and Chinijo Archipelago included as geosite.

The salt and brine marketing in these saltworks were linked to the fishery and the fish salting and canning industry. Janubio's salt was used by the insular non-industrial fleet and by the Basque tune fleet too. Nowadays, its salt is traded throughout the Canary Archipelago.

The Town Hall of Yaiza describes this site as "*A relevant area due to its close relationship to susceptible basaltic lava to be radiometrically treated and therefore single point in the island allowing a radiometric age nearby the fossilliferous marine deposit. Consequently, its interest is stratigraphic and radiometric. The Mio-Pliocene fossilliferous marine deposits are located at above 40 metres high over Miocene basalts, traversed by dikes and low basalts belonging to the Mio-Pliocene transit, and others from the later Pleistocene period*" (Ayto. Yaiza 2017).

Throughout the development of the salt industry, it progressively refines until reaching high performance. Janubio's saltworks play an important role in this development, and are acknowledged at the time thanks to the contributions from one its managers, Víctor Fernández Gopar. Some of the improvements made by Víctor Fernández, born in the village of Las Breñas on 15th June 1844, are the projection of a new system to fill up the salt ponds, and a mixture of mud, brine, and salt to form the surface of these salt ponds and thus

**Fig. 3** Salinas del Río and La Graciosa island. *Source* Art, Culture and Tourism Centres of Lanzarote (Acosta, R.)

speed up the salt conversion time. These inventions attract American engineers, who move to the island to learn more about the working system of these two elements invented by Víctor Fernández.

### 4.3 Salinas Del Río. Biological and Scenic Wealth

The saltworks Las Salinas del Río, also known as Las Salinas de Gusa, are the oldest in the Canaries. They are located inside the Natural Park of Chinijo Archipelago, Bajo el Risco de Famara, which is made up of tabular basalts from the ancient series. The platform where they are located was created by lava flows belonging to La Corona and La Cerca volcanoes, whose lava cascaded down the cliff. The saltwork is composed by detrital material resulting from the cliff erosion and has an inner lagoon protected from the sea by a coastal berm, which favours the concentration and subsequent evaporation of the salt. As the bottom of the lagoon is below sea level, it naturally allows the entry of water during spring tide periods. They were built taking advantage of the mud present in the alluvial lagoon, with high organic content (Fig. 3).

The main interest of these saltworks is of geomorphologic type and secondly, petrologic type. They are characterised by its high historical, cultural, landscape value and its biodiversity, especially birds, crustaceans and algae living in the surrounding areas. Their characteristic reddish colour comes from the community of extremophiles living in the muddy bottom of the salt ponds, which, formed by a branchiopod crustacean called Artemia salina, Archaea, Halobacterium and the cyanobacteria Dunaliella salina, are awaken from between 16 and 18° Baumé.[1]

Classified by the General Master Plan of Haría and ranked as Rustic Land of Natural Protection. Included in the Areas and Open Spaces Protection Catalogue within the Insular Management Scheme of Lanzarote. Found within the Sites of Cultural Importance SCIs—LIC ES7010045 (Chinijo Archipelago). It is also part of the Birds Protection Special Zone within the islets on the north coast of Lanzarote and Famara (Nº 002/64 Directive 79/409/CEE. Included in the Strict Biosphere Reserved Area of Lanzarote. Its declaration includes the recommendation of the saltwork protection as cultural landscape of great value and environmental ecotone of special importance for the biodiversity conservation. Lanzarote and Chinijo Islands UNESCO Global Geopark classified as geosite.

## 5 Conclusions

All the areas comprised within Lanzarote Saltworks, conform an identity symbol for all the islanders called Lanzaroteños. These architectonic masterworks provided value

[1]Antoine Baumé (1728–1804), pharmacist, professor of the School of Chemistry and member of the Science Academy, in 1750 designed the "Baumé Aerometer" in which 1-grade corresponds to a density of 11 g of salt per litre.

to the territory, and meant the first transformation of the coast edge of the island of Lanzarote. For this reason, and with tourism pressure on the coast, it is necessary the recovery of these little pieces of memory which meant so much for the development of the island.

Without memory, the sustainable development is impossible, and an important part of this memory started with the Salt. With the recovery and revaluation of the Saltworks, the importance of the Salt and Lanzarote's Saltworks is regained, paying attention to its Cultural Heritage, Historic, Ethnographic, Ecologic and Architectural value, also rescuing the testimony from an era responsible for the socio economic development of the island.

Within the frame of sustainable development, and in such a vulnerable territory as it is Lanzarote, we must encourage initiatives such as ecotourism and geotourism or an enhancement of the geologic heritage in the island, where it gains in value by visitors as well as by Lanzaroteños themselves. The specificities of the region along with the collective imagination, as well as the multiple advantages of its resources must be shown and given value, all of this with the effort of being a Biosphere Reserve island and UNESCO's Global Geoparks (UGG) and to keep well on track with the Manrique's model of sustainable development in the island.

> Never did my loneliness have mountains, because in your shore beats the infinite heart of salt.
>
> Pedro García Cabrera.

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