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THE ISLAND AND ITS TERRITORY: VOLCANISM IN LANZAROTE

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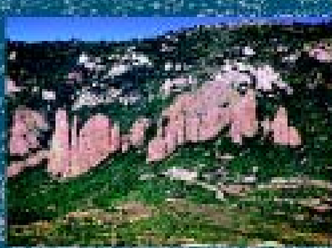

FIELD TRIP GUIDE

C-1

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Lanzarote is an island of volcanic origin situated at the easternmost point of the Canary Island Archipelago. Its tectonic position is an intra-plate area located on the North African plate that encompasses both the oceanic and the continental crusts. Situated perhaps right on the transition between the two, Lanzarote is one of the oldest of the Canary Islands and it is in a state of post-erosive growth. (Fig. 1)

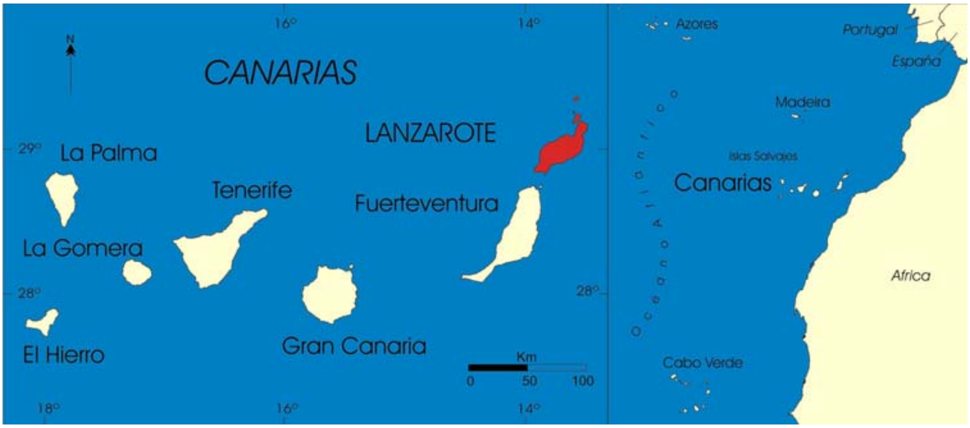

Figure 1.- Position map of Lanzarote and the Canary Islands

1. Intra-plate oceanic islands

The evolution of an oceanic island of volcanic origin is a dynamic competition between the processes of construction (magma activity) and destruction (erosion and gravitational landslides). Very few signs of this competition can be seen in the above sea level areas of these islands, while most of the information is probably located on the submerged slopes. So, although the visible part of the island edifices is by far the most widely studied and best known part, it is not the most important in either volume or from the point of view of geological interest. In the context of Plate Tectonics, volcanic islands can be situated in one of 4 different scenarios:

- Over or in the proximities of ridges (e.g. Iceland)
- Over or in the proximities of transforming faults (e.g. Azores)
- Intra-plate islands (e.g. Hawaii, Canaries)
- Arc of islands in subduction zones (e.g. Aleutians, Marianas).

Compared with the other scenarios, arcs of islands produce more volcanoes and volcanoes with far more explosive mechanisms. Most current volcanic activity, however, is concentrated in islands associated with the other scenarios, especially in an intra-plate context, which has enhanced our knowledge of how they evolve. Hence, the descriptions presented below focus on these intra-plate volcanic islands. Although all volcanic islands situated within lithospheric plates show similar patterns of origin and development, they also show certain differences, due fundamentally to the characteristics of the oceanic crust they form over, the speed of the lithospheric plate and the vigour and fertility of the hot spot that generates and feeds them.

2. Geo-dynamic framework of the Canary island Archipelago

The Canary Archipelago is made up of 7 islands (Fuerteventura, Lanzarote, Gran Canaria, Tenerife, La Gomera, La Palma and El Hierro), 4 islets (Lobos to the N of Fuerteventura, and La Graciosa, Montaña Clara and Alegranza to the N of Lanzarote), several rocks (small erosive remains of different kinds) and a large number of sea mounts.

The islands are located in the proximity of the margin of the NW African continental shelf, classified as "passive" in the framework of Plate Tectonics. The shortest distance to the coast of Africa is about 100 km, between the island of Fuerteventura and Cape Juby. Both geo-physical studies and the nature of the xenoliths found on all the islands however, suggests an oceanic type crust below the islands, although it does have a vast layer of continental sediments (as much as 10 km thick) in the proximities of Fuerteventura and Lanzarote. The exact age of this oceanic crust is unknown, as almost the entire archipelago is located in a zone of magnetic calm. The first recognisable anomaly (M_{25}, 155 million years), situated to the W of Tenerife, is indicative, in very general terms, of the Early Jurassic Period, that is, built in the first stages of the aperture of the South Atlantic.

Bathymetric data of the ocean floor around the Canary Islands give figures of between 3000-4000 m, getting progressively deeper as one moves W. Hence, each island is the summit of a separate and gargantuan volcanic edifice over 4-5 km high, except for the case of Fuerteventura-Lanzarote, which are separated by a strait of water less then 40 metres deep.

3. Age of the Canary Islands

Although the exact time that volcanic activity first started in the Canary Islands is still not known, the data seems to place this date in the Late Cretassic – Early Tertiary Period. Submarine growth and the development of intrusive complexes have been studied in great detail in the magnificent outcrops to be found on the islands of Fuerteventura, La Gomera and La Palma (known as "Basal Complexes"). The mere fact that these formations exist on the surface (only repeated on the island of Maio, Cape Verde) indicates the perseverance of the magma intrusions over long periods of time in a single area. Although dating on these formations is highly complex, as they are heavily weathered and show a certain degree of metamorphism, they do suggest that these grow older as one moves from La Palma to Fuerteventura.

There are over 500 radiometric datings for the sub-aerial stage of growth, taken from all over the Canary Islands, making it one of the most widely studied areas in the world. The age of the oldest volcanic formations of each island (Table I) shows a general progression of ages in the archipelago that goes from E to W, with Fuerteventura as the oldest island (≈ 22 m.yrs.), while the youngest islands, La Palma and El Hierro are at the other end of the scale (< 2 m.yrs.). On the other hand, all the islands, except for La Gomera, have experienced volcanic activity over the last one million years, although the activity itself has varied enormously from one island to another. For example, while the whole of the southern half of La Palma was constructed over the last 125,000 years, an emerged surface area of some 220 km^2 and 125 km^3 of material expelled, the emerged volume of expelled volcanic matter in Gran Canaria is less than 2 km^3.

Dating of the sub-aerial volcanic formations also shows that there have been long periods of inactivity (*gaps*) between periods of volcanic activity, except for the islands of La Palma and El Hierro. This fact, together with the persistence of volcanic activity at both extremes of the archipelago (volcanism in recorded history in Lanzarote and La Palma) has been used as an argument against a possible hot spot origin. But these periods of inactivity followed by rejuvenation are characteristic of almost all hot spot volcanic islands, whose origins are due to distensible force fields (with volcanism) alternating with compressive force fields (with inactivity) that islands come across in their drift across the lithosphere.

Table I.- Age (in million years) of the main volcanic activity phases in the Canary Islands

Fase	El Hierro	La Palma	La Gomera	Tenerife	Gran Canaria	Lanzarote	Fuerteventura
Escudo	1,2 - 0	2 - 0	9,5 - 4	12 - 4	14,5 - 8	15,5 - 5	22 - 11,8
Rejuvenecimiento	-----	-----	inactivo	3 - 0	5,5 - 0	3,7 - 0	5,1 - 0

4. The relief of the Canary Islands

The relief of the Canary Islands is a faithful reflection of the evolutionary state that each of the islands has reached. Hence, one striking fact is that the higher peaks are to be found in the westernmost islands (the highest point is the Peak of Mt. Teide on the island of Tenerife, with a height of 3,718 m), despite the fact that these islands rest on far deeper ocean beds than the easternmost islands.

In general terms, one can see that whereas there is a predominance of erosive relief with just a few volcanic touches in the easternmost islands, in the westernmost islands, volcanic relief provides the basic structure and dominates the landscape. The main geo-morphological features of the former group of islands are: ravines with a wide cross section profile and gentle slopes, convex and “knife edge” dividing ridges, accumulation glacis, fields of lava and pyroclasts that are extremely weathered and/or transformed into soils, long sandy beaches, sand dunes and sea levels above current ones, etc. In the westernmost islands, the main features are: narrow, erosive ravines with steep slopes, countless structural ravines between lava flows, lava fields and pyroclasts with almost no sign of weathering, a large number of volcanic cones almost without any signs of erosion forming lines (ridges in the local terminology), strato-volcanoes, large amphitheatres as a consequence of giant gravitational land slides, etc. The exceptions to this trend are the islands of Lanzarote and La Gomera.

In Lanzarote, the recorded eruption of Timanfaya (1730-36) covered some 200 km^2 with its lavas, almost a ¼ of the total surface area of the island, forming a predominantly structural volcanic relief in these parts of the island, laying over the previously aged relief of the land. This has led to continual confusion, with Lanzarote often being classified as the most active island in the archipelago. When the volume of material expelled from the volcano during this eruption is calculated however, between 3-5 km^3, the conclusion drawn is that an eruption of this size could only cover so much area on an island that had previously been extremely flat. That is, before the eruption of Timanfaya, Lanzarote must have exhibited the typical features of a highly mature island, dominated by erosive forms and processes.

Structural volcanic relief can scarcely be seen in La Gomera and almost the entire landscape of the island has been sculpted by erosive processes. This fact can be immediately explained by a glance at the radiometric data on the island, which show an almost total absence of volcanic activity in the last 4 million years of its evolution (there are only two datings of lava with an age of around 2 million years). That is, La Gomera is immersed in a period of volcanic inactivity, from which it could awaken in the geological future to enter a phase of rejuvenation, as the easternmost islands already have.

On the other hand, the submarine relief around the islands, recently studied by several different oceanographic ships, show that there are ample island shelves around the islands of Lanzarote, Fuerteventura, Gran Canaria, La Gomera and certain sectors of Tenerife (the sectors of the oldest volcanoes of its shield-building phase), whereas this shelf has scarcely developed around the islands of La Palma and El Hierro. Major gravitational slide deposits have also been found, with very little pelagic sediment cover over them (El Hierro, La Palma and Tenerife), whereas the slide deposits from the easternmost islands have later been covered by sediment, which sometimes make them impossible to locate accurately.

To round off this over-view of the current evolution of volcanic activity in the area of the Canary Islands, in 1998, the oceanographic vessel “Charles Darwin” “photographed” a group of submarine volcanoes with its sonar, some 70 km SW of the island of El Hierro, on a sea bed 3,800 m deep. These volcanoes, named Las Hijas by their discoverers seem to be in a phase of volcanic activity and they follow the progression direction of the hot spot, which could turn them into the next islands to form part of the archipelago in the geological future. The largest of these volcanoes is 1,600 metres high and 20 km across its base.

5. Lanzarote, an old island renown for its young volcanoes

Forming part of the Canary Island Archipelago, the island of Lanzarote is known throughout the world as the “island of the volcanoes”, which, along with its climate, are undoubtedly its main tourist attraction. The idea that is generally held of the island is that it is a land that has only recently been created by Nature, a view that is more than justified by the “historic memory” of the eruption that occurred between 1730 and 1736 and by the ample area that is covered by volcanic lava and ash (one quarter of the island). It is strange, however, to discover that Lanzarote, along with its “big sister” Fuerteventura, is really one of the oldest islands of the Canary Archipelago.

The volcanic events that have occurred over the last 21,000 years, first in the north with the eruption of the La Corona volcano and later in the centre of the island, with the eruption of Timanfaya, caused a rejuvenating make-over on an island that was aged and worn down by erosion, an island with little volcanic activity in the upper Pleistocene, dominated by highly evolved forms of relief in the two mountain chains, like open valleys, rolling hills, areas with no sharp contrasts, erosion-accumulation glacis and a large number of isolated volcanoes, many of which were affected by crusts of saltpetre and radial gullies, rugged coastlines and coasts in the form of gulfs, remains of former beaches above the present sea level, etc. Hence, the old lives side by side with the new in the Lanzarote relief; rocks that emerged millions of years ago next to newly formed ones, forms moulded and sculpted by erosion over time with structural forms manufactured by young volcanism in weeks, months or a mere few years of activity.

The physiography of the island is simple; it has two mountain massifs, one in the South (Ajaches) and the other in the North (Famara), with the territories created by volcanic activity over the last 0.8 million years between and partially surrounding them. These volcanic lands are low-lying with very little topographical contrast, with rows of volcanic cones from different times of the mid and early Pleistocene that follow the structural patterns of the NE quadrant.

6. Lanzarote in the Canary Island Archipelago.

The Canary Island Archipelago is located off the North West coast of the African continent in the Atlantic Ocean, one hundred kilometres from Puntal de La Entallada, on the neighbouring island of Fuerteventura, at its nearest point. The shortest distance from Lanzarote to the African coast is 130 Km if we take Cape Juby, but if we follow the line of latitude and measure the distance to Sidi Ifni, then the distance is 320 km from Punta de Las Escamas.

The Canary Island Archipelago is made up of eight islands and several islets, laid out, in general terms, from East to West. Lanzarote and its islets are at the northernmost and easternmost extreme of the archipelago, with Fuerteventura, Gran Canaria, Tenerife, La Gomera, La Palma and El Hierro to the west. As we have seen, the age of the islands decreases as we move west, with Fuerteventura as the oldest island (22 million years for the first rocks to emerge above sea level) and El Hierro the youngest, with a mere 1 million years. Table 2 shows the location, surface area, altitude and number of rock fingers per island.

Table 2. Canary Island relief data.

Location, surface area, altitude and number of rock fingers per island.						
Island	**Localization (en el Archipielago)**	**SURFACE**		**Altitude maximum**	**ROQUES**	
		(Km)	**%**		**Number**	**Surface (m^2)**
CANARIAS:	-	7.447	100%	3.718	600	767.325
Lanzarote	Oriental	846	11%	671	10	52.997
Fuerteventura	Oriental	1.660	22%	807	4	19.787
Gran Canaria	Central	1.560	21%	1.950	95	122.026
Tenerife	Central	2.034	27%	3.718	200	213.835
La Gomera	Occidental	370	5%	1.484	49	65.375
La Palma	Occidental	708	10%	2.423	102	162.093
El Hierro	Occidental	269	4%	1.501	140	131.212
Source: INSTITUTO GEOGRAFICO NACIONAL. Elaboration:INSTITUTO CANARIO DE ESTADÍSTICA (ISTAC). "Anuario Estadístico de Canarias.						

7. Lanzarote and Fuerteventura

Although they have been worn down in both height and surface area by erosion, Lanzarote and Fuerteventura are still great mountains if we consider the fact that they rise from the ocean floor, where they rest on the ocean crust at a depth of 2,500 m. But the depth of the sea between the two islands reaches a mere 40 m in La Bocaina strait. Hence, Lanzarote and Fuerteventura really form a single enormous volcanic edifice running NNE to SSW (35º N) along a possible fracture line parallel to the African coast. In the Canary Islands, this fault, over which the islands were born and developed, is known as the "*African Fault*" (Ancochea et al 1992; 1996).

As the sea between the two is so shallow, a mere 18,000 years ago, when the ices of the last great ice age stretched further than they do now and, therefore, the sea level was 70 to 120 lower than today's level, Lanzarote and Fuerteventura, together with the Chinijo Archipelago and the islet of Lobos, made up a single large island, approximately 200 km long and with a surface area of approximately 5,000 km^2.

As we can see in Table 2, Lanzarote, with a surface area of 846 km^2 is the fourth largest of the islands, contributing 11% of the regional surface area (half the contribution of Fuerteventura and very close to the 10% contribution made by La Palma) (Hansen Machin, A. 2002 a and b). Concerning the height, with the exception of the islets, Lanzarote is the lowest of the islands, with a mere 671 m at the highest point, Las Peñas del Chache, in the former Famara massif, whereas Fuerteventura reaches a height of 807 m at Pico de La Zarza, in the former Jandia massif.

The fact that these are low-lying islands in comparison with the other Canary Islands is not only due to a lesser growth of the original volcanic structures, it is also due to the time that has transpired since their construction, about 22 million years ago for Fuerteventura and 14.5 million years ago for Lanzarote. Although the processes of their construction did not occur at the same time for the two islands, erosion has had millions of years to wear down the islands, reducing their surface area and evacuating the material they were made of down to the submarine slopes and abyssal depths of the surrounding ocean. As they are older and have been exposed for a much longer time, it is understandable that Lanzarote and Fuerteventura have been turned into peneplains, with weathered relief and smoothed topography. And, following the same logic, they have broad submerged island shelves as a consequence of the long and constant retreat of the coastline.

This lack of height is also a conditioning factor with regard to the aridity of the island, as the lack of rainfall (no more than 200 mm at any point of the island) is related to the fact that the relief of the two islands is almost incapable of provoking orographic precipitations, or of collecting horizontal rain, events that are common in the rest of the Canary Islands because of their greater height. For the same reason, average annual temperatures are in the range of 19º-22º C, which, in the other islands, is only true of the areas below 300 m above sea level

8. Geological evolution of Lanzarote

As with all the Canary Islands, and like all volcanic oceanic islands, Lanzarote has been through a succession of stages of eruptive activity in which the island has grown from the accumulation of volcanic material and structures (Abdel-Monem, A. at al, 1971). Between stages of growth, there have been periods of inactivity, when the island has been worn down, loosing height, volume and area to erosion.

The <u>first stage of activity</u> was submarine volcanism. This geological unit does not well up to the surface of Lanzarote, but soundings taken down to a depth of 2,700 m in the area of Timanfaya to explore the possibilities of harnessing geo-thermal energy, reveal its subterranean structure (Sanchez Guzman, J. and Abad, J. 1986). At the base, it found the oceanic basement, where submarine sediments (limestone, marls, clays, etc.) were found from the African continental slope containing marine micro-fauna from the Lower and Middle Palaeocene (65 – 55 million years ago). Over these, from a depth of 2,598 m, there are piles of submarine pyroclasts and lavas (pillow-lavas and hyaloclastites) that have built up on the sea beds since the Mid Oligocene (35-28 million years ago). This is when the volcanic construction of this submarine edifice started and after countless eruptions, it reached the surface of the sea. This phase of activity must have been located in what is now the centre-south of Lanzarote and there are no signs of it anywhere on the island today, but it is the basement on which the island rests. On other islands of the Canary Island Archipelago, like neighbouring Fuerteventura, La Palma and La Gomera, this geological unit is hundreds of metres above the current sea level, forming part of the topography of the islands, known by the general name of Basal Complex. This first cycle of volcanic activity was followed by a long period of inactivity.

After a period of calm, <u>the volcanic activity started up again in the area that is currently occupied by the Los Ajaches Massif,</u> in the south of the island. Although the time line varies a little from one author to another and depending on the system used for establishing it, the emissions from this first sub-aerial cycle seem to have occurred very quickly, in a single episode between 14.5 and 13.5 million years ago, with very large volumes of lava and very frequent eruptions, forming a shield-type volcanic edifice (Rodriguez Badiola, E. et al, 1994), which was the “original Lanzarote” for the next two million years; the primitive island, the island of “Los Ajaches” (fig. 2.1).

There is no geological discontinuity in the Los Ajaches volcanic macro-structure that would indicate periods of rest from the volcanic activity during this first cycle. On the contrary, they appear to have been continuous emissions issuing volumes of basalt rock that would have covered a larger area and reached a greater height than those we see today. Some authors have suggested the possibility that this was a contemporary edifice that was juxtaposed to the volcanic shield that formed the North of Fuerteventura, something that does not seem very likely.

Once the shield-island of Los Ajaches had been constructed, and after some three million years of eruptive inactivity, during which the island started to be eroded away (fig. 2.2), <u>the volcanic activity shifted north east, re-appearing in the area now covered by the Famara Massif</u> about 10.2 million years ago (fig. 2.3).

Unlike Los Ajaches, the volcanic structure of Famara was constructed in three stages separated by erosive gaps, which can be distinguished in the current scarps of the massif by the geological anomalies characterised by the presence of former soils or areas of erosion. Less and less volume of material was emitted in each successive phase (Carracedo Gomez, J.C. and Rodriguez Badiola, E. (1993). The lower unit is formed by an accumulation of very powerful basalt lava flows covering a large area, having been expelled between 10.2 and 8.3 million years ago. In the intermediate unit, there are frequently cones and mantles of pyroclasts thrown out between 6.7 and 5.3 million years ago, overlying the lava flows The upper unit was emitted from 3.9 to 3.8 million years ago and it is comprised, above all of sometimes very powerful basalt extrusions that fill in the incipient ravines gouged out in the period of eruptive calm between the intermediate and the upper unit.

Altogether, the eruptive activity in Famara will have lasted some 6.4 million years, although it would not have been continuous. The resulting structure would have been a mega “ridge” type volcanic edifice, similar to the volcanic macro-structures of Cumbre Vieja, in La Palma, Esperanza-Pedro Gil in Tenerife or El Hierro. These kinds of structures, like the shield type structures, are characteristic of young oceanic islands, which is why they are presently active in the westernmost and youngest part of the Canary Archipelago.

The “ridge-island” of Famara arose from a “structural axis” or “rift”, that is, from the existence of a series of fissures in the oceanic crust with a preferential orientation of 35º N, which was harnessed by the magmatism to inject its materials. The resulting mega-form was a longitudinal “range” with the highest peaks nearer the geometric centre, coinciding in the vertical plane with the warren of fissure chimneys or dykes, with slopes on either side like a pitched roof.

<u>At the same time as the intermediate stage of Famara, volcanism appeared in the area that is now the village of Tias</u> (fig. 2.4). Around this area, there are remains of lava flows and basalt emission centres that are 6 million years old. Although they never managed to construct any large edifices, these emissions occurred in the span between the two already formed islands, creating the first land bridge between the two: Famara to the north that was still active and Los Ajaches to the south, which was already in an advanced stage of erosion. The lava flows from the Tias volcanoes ran down the lower north east and western slopes of Los Ajaches, which are now in discordance with the Janubio area. This is when the island of Lanzarote appeared for the first time, with an elongated shape running from NE to SW, although it was morphologically a long way from the island of today. The materials and structures described above are, for geologists the Series I or the First Cycle of sub-aerial volcanic activity.

At the end of the eruptions of the Tias Volcano, and when volcanic activity fell dormant in Famara too, a period of erosive decline began that lasted at least 2.5 million years. (fig. 2.5). The erosion dug deep into the Ajaches shield, which had already been severely reduced by over six million years of wear, while the surface area of the Famara ridge, probably affected by a gigantic landslide down to the west, was quickly reduced in size by the abrasive action of the sea, gradually building up a massive cliff from the action of constantly crashing onto the scar of the landslide. The continuation of these cliffs to the south, passing north of Tias and Yaiza around Los Ajaches before heading south east, formed the coast line which was gradually sculpted until the eruptions started again in the Quaternary Period. This arch shape or gulf is a frequent feature of the windward coasts of the more evolved islands, as can be seen from the Famara massif itself, or the Jandia massif on the neighbouring island of Fuerteventura.

<u>The volcanic activity entered a Second Cycle of eruptions</u> building emission centres especially on the peripheral edges of the aged massifs of Famara and Los Ajaches (fig. 2.6). The Teguise group of volcanoes arose to the south of Famara, including La Montaña de Guanapay, which raised the relief in the area and poured its lavas down towards the east coast, masking the demolished southern and south eastern slopes of the massif. The activity was more evenly spread in Los Ajaches: the solitary volcano of Montaña Roja appeared to the south, with its lavas spreading over a former marine bed raised between 50 m and 20 m above the present sea level, forming a great lava platform around the island; the Caldera Riscada group of volcanoes covered the north-east slopes of the massif with its material and, later one, the La Atalaya de Femes volcano spilled its lavas on the western and southern slopes, creating an ample malpais, or badlands. These two groups of volcanoes on the periphery of the former massifs constitute Series II and, as we have seen, date from the Lower Quaternary Period.

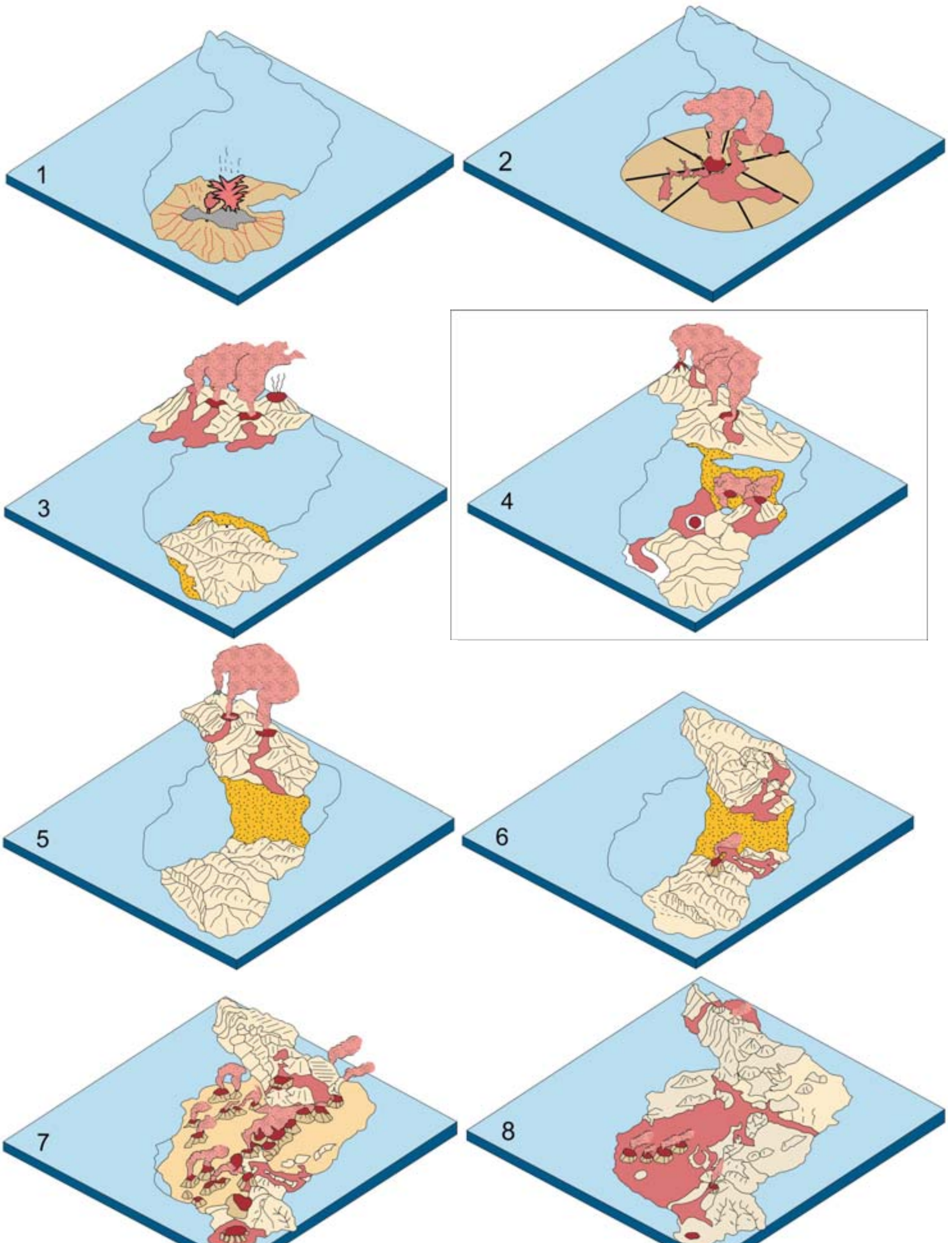

Fig. 2. Volcanological evolution of Lanarote. Carracedo, reworked by A. Hansen and C. Moreno.

Over the last 700,000 years, volcanism has become more fissural in nature so the different emission centres are built along a linear distribution, or in a chan running north-east – south-west (NE-SW), especially between the two former massifs, hence transforming the old coast line and gaining more land for the surface area of the island (fig. 2.7). This way, a whole chain of volcanoes were built, running from La Atalaya volcano in the west of Los Ajaches to Las Caldereatas de Mala, to the east of Famara. Apart from this chain which shows the greatest longitudinal and topographic continuity, there are volcanoes scattered almost all over the centre-western half of the island, forming continuous or discontinuous rows of volcanoes like the Soo row in Famara cove or the one running from Montaña de Tao to Montaña del Chinero in the centre of the island.

The volcanic activity remains fissural (fig. 2.8). The historic eruptions of 1730 to 1736 and the eruption of 1824 occurred along fissures running in the same direction, indicating the presence of a volcanic rift characterised by the low frequency of its eruptions, which, together with the wide strip it affects, is creating a rift with low morphological resolution. The result of this long process of evolution reveals the geological map of Lanzarote to us (fig. 3), in which we can see the area covered by the rocks of each series of eruptions and how they fit into the territory.

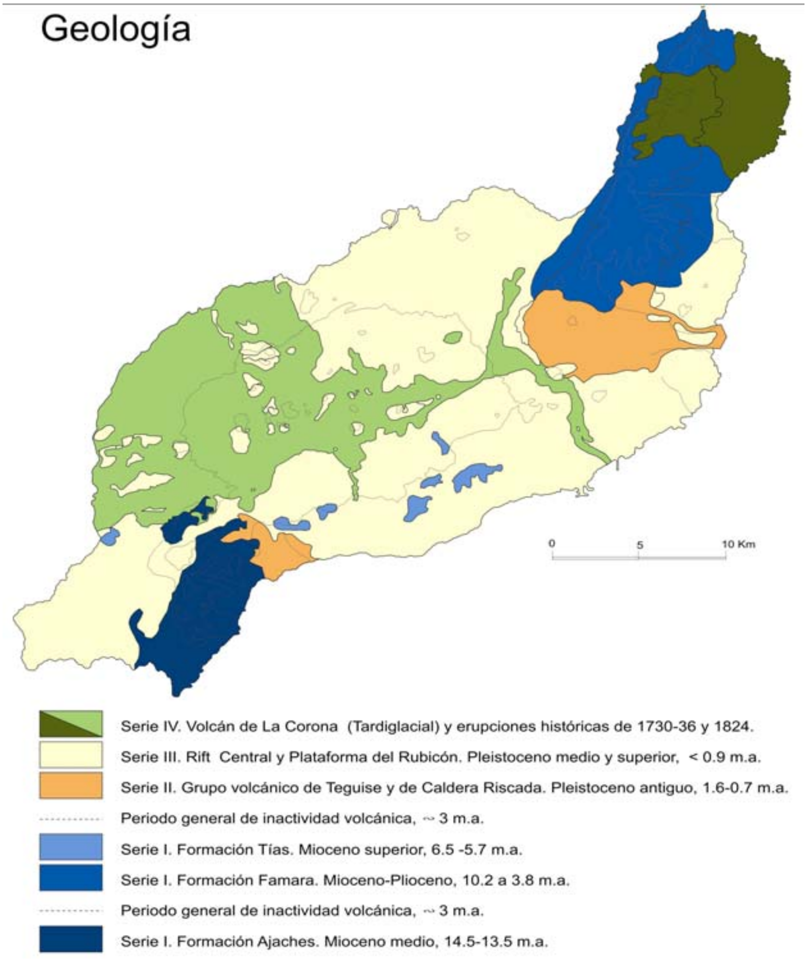

Fig. 3. Geological Map of Lanzarote. Simplified by A. Hansen and C. Moreno

9. Major units of relief in Lanzarote

An analysis of the Lanzarote relief reveals several morphologically distinguishable units of territory. These are the result of the original volcanic structures and of how they have evolved over the period of time they have been moulded by natural agents. Over this period of erosion, the climate has been changeable, sculpting the relief with a range of different processes, and by the ocean rising eustatically to flood the coasts, creating beaches and cliffs that are now fossils, before retreating to leave broad littoral platforms behind and allowing the lavas to spread down to the depths that are now covered by water.

Fig 4 shows a simplified form of the geomorphological map of Lanzarote, but it does give us an approach to the major units of the Island relief. Below, we will show which fragments of the island territory make up these units and what they are like.

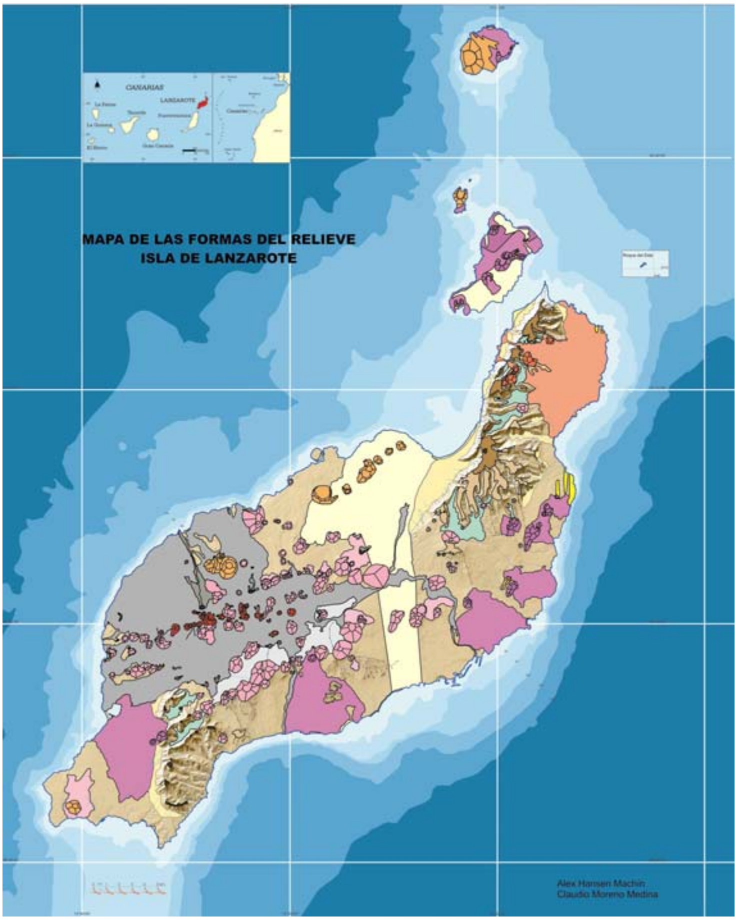

Fig. 4. Simplified geo-morphological map by A. Hansen and C. Moreno.

The former volcanic massifs

In the Canary islands, the term "volcanic massif" is used for those topographical features that, once built as complex rift, shield or strato-volcano type volcanic structures, have been transformed by erosion into derivative and declining forms in which the original structures have almost completely disappeared (only the piles and intrusions remain as such), and the recent volcanism has provoked occasional processes of interference and rejuvenation in the landscape. Geographic studies of the Lanzarote relief have been conducted by A. Hansen Machin (2002 a-b) and by C. Romero (1987 and 2003).

Los Ajaches Massif

Situated in the South, it is the oldest volcanic edifice of the island, so it contains the most evolved rocks and forms in Lanzarote. Its 46.5 km^2 is only a small portion of the original shield structure that has been worn away by time and now accounts for 5.5% of the area of the island (fig. 5).

The base geometry of the massif is triangular, with the western side running along a 10 km mountainous axis running from north to south, from Montaña de la Cinta (436 m) to Montaña de Hacha Grande (560 m), passing through Atalaya de Femes, the highest point of the massif at 608 m, and Morro del Pozo, the second highest point at 571 m. The other physiographic units are articulated by the backbone of this topographic axis that falls off gently to the West: to the north, there are valleys with flat bottoms and sloping sides, and steep ravines on the eastern slopes, with pronounced heads and finger-like drainage systems, especially in the Barranco de La Higuera Ravine, which covers a greater area. This eastern sector is undoubtedly the most rugged topography of the island, with a sheer coastline and no surfaced roads to provide access. The following ravines are to be found from south to north: Barranco de Perdomo; Barranco Parrado; Barranco de Los Haches; Barranco de La Casita; Barranco de La Higuera and Barranco de Naos, disgorges onto Playa de la Arena, on the north eastern boundary of the massif. All these ravines run as sporadic torrents and the drainage channels contain abundant coarse sediments in their flatter sections.

From a geological point of view, Los Ajaches Massif was constructed by a sub-horizontal piling of lava flows and pyroclasts, of a wide compositional diversity, with the presence of alkaline basalt volcanism, essentially basanite (found frequently in Lanzarote, especially in Famara), contrasting with the presence of picrite, trachybasalt and trachyte rich basalts, which are only found in this massif. The original structure that it comes from was an approximately circular volcanic shield, of which, the present massif would only have been the north easternmost sector (Fig.5). This shield-island appeared in a single, very fast sub-aerial eruptive cycle, without any major interruptions, between 14.5 and 13.5 million years ago, in a single event in which the current "positive" polarity of the Earth was reversed. The remains of this activity outcrop all along the south east coast of the island, from Playa Quemada to Punta del Aguila, (where the coastal scarp shows an important network of dykes) and to the south of Yaiza and at Las Salinas del Janubio (Rodriguez Badiola, E.; Veintemillas, S and Carracedo, J.C., 1994).

The Femes and Fena valleys are two highly original morphological pieces: Femes has a pan cross section thanks to the retreat of the slopes, with accumulations of detritus deposits softening the slopes and the bottom filled in by sedimentary material that built up when the valley was cut off by lava from the Caldera Riscada group of volcanoes. Femes scarcely has a valley head, as this was captured by the retreat of the western slope of the massif and, in its place, a defile provides easy north-south passage for the massif. The Fena valley was even more evolved in the retreat of its slopes and head, but the intervention of volcanic activity is even greater. The Miguel Ruiz volcano emerged within the valley, softening the valley bed with its lava and pyroclasts. The lava from La Atalaya volcano later completely flooded the valley floor, flowing from south to north and spilling over Yaiza and Uga. The weathering of these lavas and the endorheic accumulation of sediments completed the processes that sculpted the present morphology of the valley.

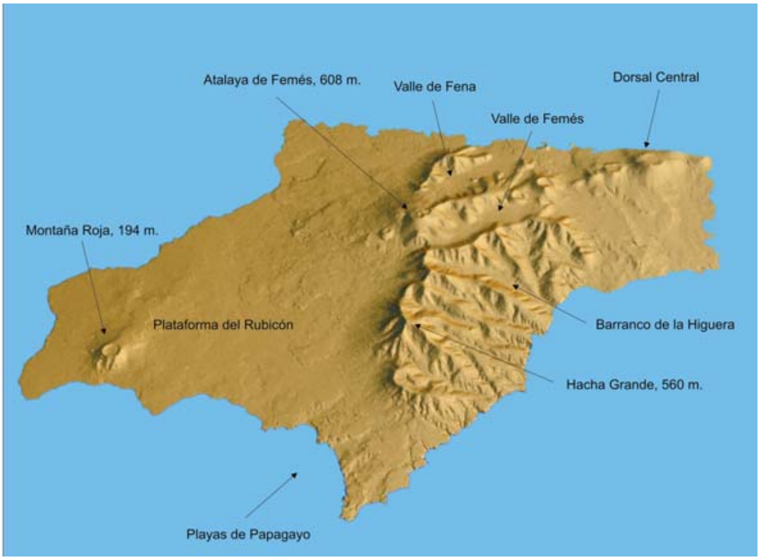

Fig. 5. Shade model of the old Los Ajaches massif and the El Rubicon lava platform, seen from the S.E. A. Hansen and C. Moreno, 1999.

Towards the periphery of the massif, the Ajache Mountains are surrounded to the north, west and south by the lavas that have raised the height of Lanzarote over the last few million years, creating areas of lower altitude. To the north, the material spewed out from the Caldera Riscada group of volcanoes cover and stitch the lower slopes of the massif, while, to the west, the lavas from La Atalaya volcano spill down the slopes (fossilising a former coastal cliff) to the sea. To the south and north west, there are alluvial cones and accumulation glacis that hide the lower part of the steep, rocky slopes that characterise the hills and mountains of Los Ajaches. To the east, the sea is, and always has been, the boundary.

The youngest forms of this unit of the Lanzarote relief are these six Quaternary volcanoes that re-moulded its slopes and valleys. The lava flows form the two La Atalya volcanoes make up malpaises with scoriaceous, but highly weathered surfaces, but which do reveal a large number of volcanic tubes and "*jameos*", or volcanic caverns, for instance around the village of Las Breñas. The distribution of these eruption centres was generated by a new period of volcanic activity that occurred in Lanzarote during the Quaternary Period. This volcanism runs along a N.E.-S.W. axis, which is precisely the same orientation as the groupings of the main cones: the two La Atalaya cones and the three from the Caldera Riscada-Volcan de Miguel Ruiz group. The Montaña Bermeja volcano, further over to the east, seems to indicate the possibility of secondary fractures running in the opposite direction, i.e. N.W.-S.E. This new volcanic rift runs from the Los Ajaches massif to Famara, in the north east of the island.

Photo 1. Highly evolved Fena Valley, in the old Los Ajaches massif.

The Famara Massif

The Famara Massif is in the north of the island, sticking out from the island in a peninsular. It covers an area of approximately 138 km^2, or 15% of the surface area of the island. The massif is approximately rectangular in shape, 22 km long and an average of 9 km wide. Like the entire island, it developed from tectonic-volcanic activity running N.E.-S.W.

Its geological construction distinguishes it clearly from the Los Ajaches Massif. The macro-structure of Famara was constructed in three volcanic stages with intermediate periods of inactivity. These interruptions in the eruptive activity show up in the massif in the form of angular geological discordances, old soils or areas of erosion. Each stage produced a smaller volume of volcanic material, suggesting a progressive attenuation in the magmatic activity.

The base of the present massif has been built by powerful basalt lava flows piling up to cover a large area. These lavas flowed from volcanoes between 10.2 and 8.3 million years ago, during a time when the polarity of the Earth's magnetism was normal, i.e. the same as it is now. The intermediate unit (projected forth between 6.7 and 5.3 million years ago) contains frequent mantles of pyroclasts and cones between the lava flows with reverse polarity magnetism. The upper unit was released during a very short period between 3.9 and 3.8 million years ago, during a normal or positive polarity event and after a pronounced period of eruptive inactivity that allowed time for radial gullies to be cut into the landscape. This is the smallest of the units, in terms of volume, and covers the least area, although the highest peaks were sculpted over this upper unit.

All together, eruptive activity in Famara would have lasted some 6.4 million years, although it would not have been continuous, creating a "rift" type volcanic mega-edifice (Fig. 6). This "rift-island" of Famara was created from a "structural axis" or rift, that is, from a strip of fissures in the oceanic crust running preferentially 35º N , which was used by the Miocene-Pliocene magmatic activity to release volcanic material. This Famara edifice took on an oblong-longitudinal shape with a cross section in which the highest point was at its geometric centre, coinciding in the vertical plane with the network of chimney fissures and dykes, in the form of a two-sided pitched roof. But, there has been major erosive activity: the western half, at least, has been worn down and swallowed up by the sea and by a probable gigantic landslide that would have occurred during its stage of rapid growth.

This unit of relief is the largest mountain mass, in terms of both volume and area, on the island, reaching its maximum height of 678 m in Las Peñas del Chache. The Famara relief is not, however, homogeneous: its long geological and geo-morphological development and the sculpting effects of volcanism in the quaternary period enable us to differentiate several sub-units of relief and major small-scale morphologies. Hence, we can distinguish: the Famara escarpment; the Famara-Guatifay plateaux; the ravines to the east; the valleys and ramps of the south and south east and the areas covered by the lavas and pyroclasts of the Los Helechos-La Quemada group of volcanoes and the more recent La Corona volcano.

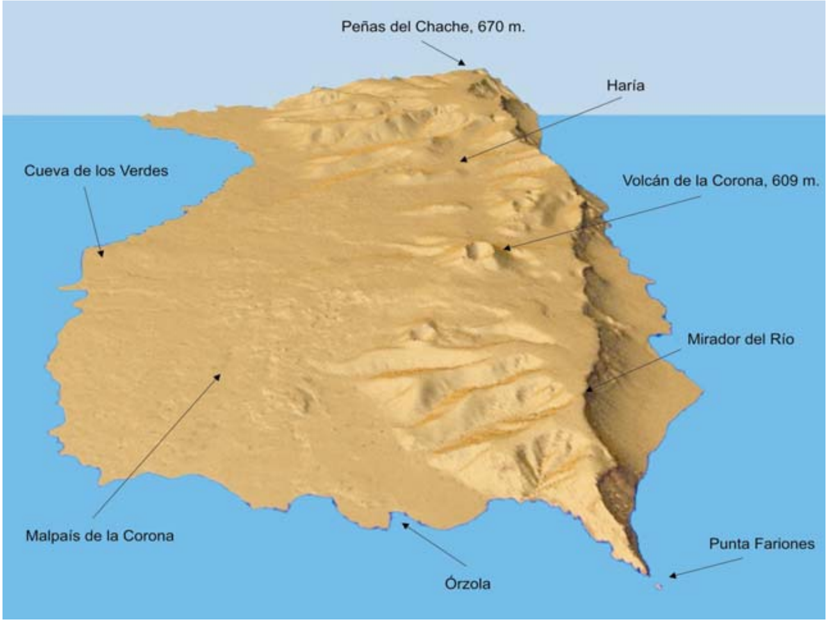

Fig. 6. Shade model of the old Famara Massif, seen from the N.E. A. Hansen and C. Moreno, 1999.

The Famara cliffs

The Famara cliffs run from La Bateria look out point (479 m) in the north, to Morro del Hueso-Montaña de Chimia (381 m) to the south of the massif and west of Teguise, where the final spurs disappear into the central plains of the island. The cliffs are not even: the northern sector falls off in a powerful buttress that leads to Punta Fariones, before running into the sea in two large rock fingers known as Farion de Afuera and Farion de Tierra. In this part of the cliffs, there is a large number of dykes that have been exhumed by the retreat of the cliff. The top part of the cliff is very steep, over 45ª, but the lower slopes are carpeted by an accumulation of detritus that spread over the marine abrasion platform, softening the slopes down to the coastal platform. Water erosion from the rainfall is cutting gullies into these sedimentary formations which open out onto sandy beaches with very flat profiles.

Further south, on both sides of Montaña de Guatifay (448 m), the upper part of the cliff opens up into saddles like the Guinate valley and Las Rositas that have provided passage for streams of lava from the young volcanoes of the Los Helechos - La Corona group. These cascades of lava carpet the tabular morphology of the massif and they have created a small “lower island” called “Bajo Risco”. Hence, the foot of El Risco de Famara in this northern sector is comprised of a platform generated by the accumulation of sediments on the one hand, and by lava on the other.

Photo 2. Famara Cliffs, in the old massif of the same name.

From Bajo Risco Bay to the Barranco de La Poceta ravine, the Famara Cliffs become higher and more vertical. This central section can also be divided into two parts. The northernmost part runs monotonously from Punta del Roque to Los Mariscales, with no platform or colluvions, which only appear as a small area in Los Lomillos. The maximum altitude is reached at Los Risquetes (544 m), Las Mesas (552) and Montaña Aganada (588 m); the southern part of this central sector of El Risco rests on the Caleta de Famara shelf, running from Los Mariscales to the Barranco de La Poceta ravine. The maximum heights of this stretched are reached here: 629 m in El Castillejo, to the west of Las Peñas del Chache. Between these two points is the Barranco de la Poceta ravine, which has been cut almost parallel to the scarp, following the structural network of the dykes. The contact between the steep slopes and the coastal platform occurs by establishing powerful accumulation glacis generated during at least two morpho-climatically different times, which connect the coastal shelf with the sandy beaches of Caleta de Famara.

The southernmost sector of the scarp runs between Barranco de La Poceta ravine and Morro del Hueso, now entirely over the platform wrested from the sea during the volcanic quaternary period. This means that, in this stretch, is not a functional cliff from the point of view of marine abrasion, predominated by gravitational and torrent-related processes. As in the previous stretch, there is a constant presence of accumulation glacis, known with the local place name of Las Laderas. Three incisions cut transversally across this stretch of the escarpment: Barranco de Las Pocetas ravine, Barranco de Maramajo ravine and the gulley that collects the waters from Montaña de Chimia. All three help to break up the lateral continuity of the glacis, contributing alluvial fans to the sediment as a whole. This is the highest point of the entire cliff: 670 m below Peñas del Chache, before gradually loosing height (Ermita de Las Nieves, 608 m, Risco Blanco, 309 m) down to 200 m, where the cliff disappears under the sands of El Jable.

Photo 3. Quaternary-modern day sedimentary formation of El Jable.

The Famara-Guatifay plateaux. Transformed by recent volcanism

From the break in the Famara scarp, the eroded ridge of the original rift runs east. The highest sectors make up flattened areas, flat top hills, tables and plateaux, with broad, hump-backed interfluvials running gently down between open, flat-bottomed ravines.

The southern sector is known as the Famara plateau and the northern sector, the Guatifay plateau, separated by the Haria Valley. Peñas del Chache, at 678 m, and Montaña Aganada, with 539 m., are the highest peaks of the island, the massif and of the Famara plateau, while Montaña de Matos Verdes (496 m), La Mesa (552 m), Gayo (544 m), Guatifay (448 m), Atalaya Chica (443 m) and Bateria (479 m), are the highest points of the Guatifay plateau, the remains of a former continuous structural area.

These plateaux are really “areas of erosion and flattening” as the result of landscape moulding activity during the upper Pliocene and the lower Quaternary. The retreat of the escarpment has reduced their area and is also responsible for capturing the heads of the El Rincon, Los Castillos, Maguez, La Quemada, Guinate and Las Rositas valleys. All these mountain valleys have open profiles and flat bottoms and they hang over more modern incisions, such as those of the Guatifay Plateau with the Vega Chica and Valle Chico valleys, but they have been profoundly modified by the volcanic activity of the Los Helechos-Las Quemadas group, and by the more recent La Corona volcano.

Photo 4. La Corona-Los Helechos Group of Volcanoes and Haria Valley, in the old Famara massif.

The materials from these eruptive centres have modified the drainage network, causing sealing phenomena, filling in the bottoms and lower slopes of the valleys with their lava and pyroclasts, and raising the relief in places with cones of slag along the lines of the N.E.-S.W. fracture. From north east to south west, the volcanoes emerged in the following order: La Quemada (356 m), La Cerca ((454 m), Los Helechos (581 m) and La Quemada de Maguez (422 m). Although these edifices have been associated with a single eruption for many years (Luis, M. and Quitante S, F.,1984), recent articles suggest that the eruption of Los Helechos took place around 91,000 years ago, while La Corona erupted during the height of the last ice age, around 21,600 years ago (Carracedo et al, 2003). The size of this volcanic tube has originated a large number of studies on its genesis and morphology. These include the studies of Bravo, T. (1964b); Mendo, A. and Ortega, L. (1988); Montoriol-Pous, J. and De Mier, J. (1988) and Carracedo et al (2003). Hence, on the table-top peaks of Guatifay, we find landscapes of great morphological interest, where processes of volcanic interference have produced major morphological changes of great importance for both the relief and for man's later use of the land. The Famara plateau, however, has developed without nay recent volcanic interference.

The lava, and to a lesser extent, the pyroclasts from the La Corona group of volcanoes has completely transformed the palaeo-geography of the north-east slopes of the Famara-Guatifay massif. The eruption of the La Corona volcano about 21,000 years ago must have been one of the most spectacular eruptions on Lanzarote. In the early moments of the eruption, the lava flowed towards the Vega Chica valley, falling some 400 m in cascades down the Famara escarpment. But most of the lava from La Quemada de Orzola, La Cerca-Los Helechos-La Quemada de Maguez and, finally, La Corona flowed down the eastern slopes of the massif, fossilising the existing coastal cliff and creating new areas for the island that extended some 2,500 m beyond the former coastline. The platform of lava won from the ocean covered approximately 18 km^2, between Arrieta and Orzola, where there are powerful malpaises with countless surface morphologies. The continuation of the La Cueva de Los Verdes and Jameos del Agua volcanic tube at least 1.6 km below the sea to a depth of 80 m, clearly indicates that this eruption took place when the marine platform was dry land at the height of the last ice age (Fig. 7).

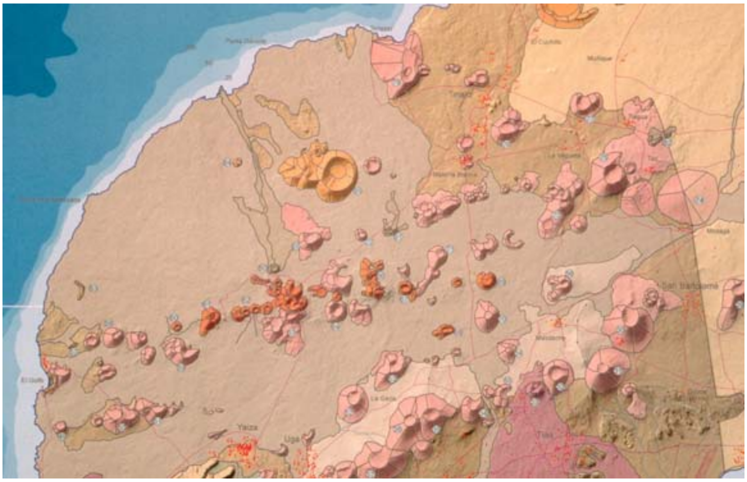

Fig. 7. Map of the Los Helechos, La Quemada and La Corona volcanoes according to J.C. Carracedo et al 2003.

Eastern slopes of Famara

Unlike the Guatifay slopes, rejuvenated by recent volcanism, eroded and moulded forms predominate on the eastern slopes of Famara: a network of U-shaped valleys run down in radial fashion from highly pronounced valley heads on the plateau to the coastal lava platform created by volcanism during the last eruptive cycle on the island. From south to north, these ravines are: Piletas, Teneguime, La Higuera Valley, Barranco de Temisas ravine, Barranco de Chaferis ravine. The bottoms of all these ravines are covered with sediments and the colluvions of both slopes are well developed, especially in the Temisas Valley, causing pan shaped morphologies, although the slopes are, at times, very steep. Outside of the interfluvials, the slopes exceed 20º and they are often over 45º. There were intense morphological transformations at the foot of the eastern slopes of Famara during the mid and upper Pleistocene: the Mala, Guatiz and Guenia calderas enabled the island to grow and spread over abrasion platforms and dune fields that are now fossilised by the material from these eruptions. An ample drainage zone, in turn, has been sealed by these structures that have generated lacustrine obturation deposits.

The valleys and ramps of the south and south east of Famara

At the southern tip of Famara, the relief softens; the slopes are more gentle – between 2º and 15º, most of which are under 10º. The Teguise, Manguia and Vega de San Jose valleys, like the Femes and Fena valleys in Los Ajaches, are highly weathered erosion and accumulation forms. Once again, the phenomena of volcanic interference that we have analysed for several points of Ajaches and Guatifay, explain their formation. But this volcanic interference did not occur in recent times: the southern slopes of the massif were affected by Old Quaternary volcanism, between 1.67 and 0.97 million years ago, during a period of negative polarity of the Earth, thus giving rise, first of all, to the volcanic cones of the Montaña Chimia and Montaña de Guanapay group, to the west and east of Teguise respectively. That is, as happened in the Los Ajaches Massif, quaternary volcanism affected the periphery of Famara to start with, closing valleys and wresting land from the sea.

These volcanoes release large quantities of lava that flowed east, over surfaces with very little inclination, causing them to accumulate in shallow ramps, such as those that descend from

Guanapay, on which the settlement of Teseguite is built. These ramps covered up the lower south eastern slopes of Famara, but they have now become moulded ramps, in areas in which diffuse streams predominate as the surface is very smooth. They have been transformed from structural ramps into glacis-ramps. These valleys, and particularly the ramps, have been profoundly affected by carbonatation processes and the creation of saltpetre and limestone. Beneath the soils, very often stripped bear by a concentrated stream or washed away by a diffuse stream and the effects of the wind, there are continuous white carbonate crusts, which mark a clear limit to agricultural use, or even for the growth of vegetation, but, at the same time, in the past, it has been used as a resource for obtaining lime. Lime ovens abound in the proximities of Teguise, where the saltpetre stone used to be burned to obtain lime for exporting to the westernmost islands up until a few short decades ago.

Quaternary construction units: *the Rubicon lava platform*

The Rubicon platform is the southernmost unit of relief of Lanzarote. It is a practically flat area measuring 53 km^2 that extends the island south west. Its fairly straight east and west coasts run in the same N.W.-S.W. direction as the island's main volcanic structures and alignments, whereas the south coast is divided into three great arcs: from Punta de Papagayo to Punta del Aguila; from here to Punta Limones and from Punta Limones to Punta de La Pechiguera. Some of the best golden sand beaches of the island are to be found in these coastal arcs: Papagayo and Playa Mujeres in the first arc; Playa Blanca in the central arc and Playa de Montaña Roja, with its characteristic volcanic sands, in the third one.

Despite its apparent morphological simplicity, the Rubicon platform guards a more complex geological history. Its base is mainly built from the rocks of the island's first eruptive cycle, released between 14.5 and 13.5 million years ago. Between Punta del Aguila and Punta del Papagayo, there are lava outcrops, sharp points of rock and basalt pyroclasts from Series I, together with more differentiated rock outcrops like trachytes. But this coastal cliff also reveals a large geological discontinuity represented by powerful soils and a dyke swarm that are brushed by an erosion area. The lava from later volcanic series has flowed over this surface, constructing this great lava platform, which, because of its location, is eccentric to the island.

Photo 5. El Rubicon lava platform, a quaternary volcanic unit in the south of Lanzarote.

These lavas, thrown out by the independent Montaña Roja volcano, located to the south of the Platform and perhaps from other volcanoes situated on the southern slopes of the Los Ajaches Massif that are now invisible, flowed over a sea bed situated at between 20 and 50 metres above the present sea level (which can be recognised in the southern slopes of Montaña de La Breña Estesa, on the edge of the Los Ajaches Massif). The Montaña Roja volcano, the age of which is the subject of much debate, although it has been dated at 0.8 million years old, presents some hydro-magmatic features. With a height of 194 m, it has a perfectly circular summit crater that is partially open to the north-north-west, where most of the lava flowed down. These lavas must have covered a far larger area than that of the present platform, as the coasts of the platform are cliffs on all sides, showing a major retreat. Later on, on several occasions, the sea has reached levels above the lowest edges of the platform, making several marine palaeo-levels recognisable, including an abrasion platform situated 6 m above sea level, which is visible in Papagayo, Punta de La Pechiguera and on the west coast.

The northern contact between the platform and the Los Ajaches Massif is hidden by two different morphological phenomena: at the southern and north-easternmost tips, the colluvions deposited by two generations of glacis, generated during the mid and upper Quaternary period, carpet the platform, stitching it to the mountain; the western edge of the massif is, in turn, hidden by the mantle of lava released by the two emission centres situated in La Atalaya de Femes. The lavas from these centres, spreading out like a fan, cover an area of 26 km^2, presenting some very fresh sectors, but, on the west coast, they fell into the sea. On this coast, where the platform meets the central unit of relief of the island, one of the island's largest geological accidents has been created: the Laguna de Janubio, a small, steep-sided bay protected from the open sea. The Miocene lavas from Los Ajaches, covered by those of the Tias edifice, the Pleistocene lavas from La Atalaya de Femes and the lavas from the 1730 eruption, have all converged on the shores of this bay. Used as one of the "ports" of Yaiza until the 17th century, the material from the 1730-1736 eruption helped to modify the dynamic of the shoreline and block up the harbour entrance.

Quaternary units of construction: the island centre, a low-lying rift

Most of the island of Lanzarote stretches between the old volcanic massifs of Famara and Los Ajaches. This is an area of approximately 500 km^2, measuring 32 km long from Janubio bay to Caleta de Famara, and 34 km from Montaña Bermeja on the northern edge of Los Ajaches massif, to La Pared point, on the northern edge of the coastal platform of Mala. The length of this area, measured along the axis of the island, is 24 km. The average width of this geological-geo-morphological unit in its central sector is 20 km, whereas it narrows down to 15 km towards the confluence with the massifs.

Quaternary volcanic activity was responsible for constructing this grand morphological unit from which Lanzarote got its present surface area and morphology (Fúster, J.M., et al, 1966). Prior to the Quaternary, the Tias volcanic edifice was already situated in this area, whose appearance 0.6 million years ago has already been analysed. But, apart from the fact that this was never a very voluminous edifice (material from the edifice only outcrops to the east of Tias, causing some breaks in the slope of the ramps due to differential erosion), marine erosion has had time since then to sculpt a coastline that took the form of a "gulf" before the appearance of volcanic activity in the Quaternary period, running from the Famara scarp to the western slopes of the Los Ajaches Massif. This was the coast and the marine abrasion platform that the materials from quaternary volcanism have conquered to increase the surface area of the island.

At the beginning of the cycle, 1.6 million and 970,000 years ago, the volcanic activity was restricted to the edges of the old massifs, but when the magmatic activity became consolidated around 700,000 years ago, in a N.E.-S.W. band of activity, or "rift", the volcanism started to construct alignments or chains of volcanoes that preferentially follow this structural orientation. The landscape is dominated by the presence of a large number of volcanic cones distributed spatially from the central axis – Montaña de Femes-Mala and Guatiza volcanoes – west, over rolling lands, or flat lands, sometimes covered by malpais between cones, and, on the eastern slopes, by the existence of monotonous ramps with gentle slopes down to the sea, almost without any topographical feature worth mentioning, with evolved soils, saltpetre crusts and the occasional eroded malpais, or *"breña"*..

The lines of volcanic cones are continuous or discontinuous, creating small "ranges" of several juxtaposed cones, or leaving empty spaces between isolated cones. Their height too, varies, as each eruption varies in duration and activity rate. The morphologies range from simple cones to horseshoe shaped cones, elliptical or complex circular shapes, due to the involvement of several cones in the eruptive activity, or due to the presence of multiple outlets. There is enormous variation in their volume and state of conservation, as they vary greatly in age too; the oldest have developed soils and saltpetre crusts on the surface, the consolidation of pyroclasts into welded tuffs, radial gullies, the craters turning into ravines, loss of general mass, colluvions on their slopes; whereas the more modern cones could be confused with eruptions from historic times. These great lines of cones are, of course, polygenic, and their evolutionary sequence can often be seen from stratigraphic data, associated deposits and their state of conservation.

Hydro-volcanic edifices are common in this unit, in which the sea or the water tables have played a direct part in their construction. The fact that the eruptions have taken place on a marine abrasion platform, or close to the sea, has facilitated the entrance of water into the volcanic conduit and an efficient interaction of this water with magma at high temperatures. The result of this would be very powerful explosions, causing particular pyroclast deposits. These deposits are well represented on the El Golfo volcano (152 m.), (Martí, J. and Colombo, F., 1990) and on the El Cuchillo volcano (120 m.), (Aparicio, A.; Araña, V. and Diez Gil, J.L., 1994), the former situated on the west coast and surrounded by lavas from the 1730 eruption, and the latter at the southern end of the Soo volcano group.

Photo 6. El Golfo hydro-magmatic volcano. Central rift.

The most structurally continuous and outstanding of all the alignments as a topographic accident is the one running 45 km from Montaña Roja, in the south of the island, to Las Calderas de Guatiza. But the most continuous part of this chain is the central portion, where 16 great cones are juxtaposed along a distance of 22 km, from Montaña del Mojon (386 m) to Montaña de Tahiche (321 m), with the highest edifices being Montaña Tinasora (503 m), Montaña Guardilama (608 m), the highest of the central sector of the island, Montaña Gaida (562 m), Montaña Blanca (596 m) and Montaña Guatisea (542 m) (Table 3).

Table 3. Length of the alignments of the central unit of Lanzarote.

VOLCANOES LINATION IN THE CENTRE OF LANZAROTE	DIRECCIÓN	KM LONG.
Montaña del Mojón – Las Calderas de Guatiza	N 60º-n 80º	31
Mª de Miguel Ruiz – Lomo de San Andrés	N 55º	18
Mª Bermeja - Mª de Tao	N 60º	21
Mª Quemada - Caldera Quemada	N 80º	16
Mª Bermeja - Mª Tiagua	N 80º	14
Mª Bermeja - Mª Tiagua	N 60º	14

But apart from this major chain that divides the geography of the centre of the island in two, there are a further five volcanic chains at least, in the western part of this chain, as can be seen from the geo-morphological map of Lanzarote (A. Hansen and C. Medina, 1996). All these volcanoes rest on gently sloping ramps that were created before the volcanoes, which, in turn, have been heightened by the material from them. The historic eruptions of 1736 and 1824 occurred over this area, which have rejuvenated this field of volcanoes and made it both denser and more complex. This structure is, therefore a complex one, formed by a band of tectonic-volcanic activity about 10 km wide on average, i.e. a somewhat peculiar rift that seems to maintain a low frequency of eruptions, but a very high rate of emission. This would explain the low resolution appearance of the morphology, compared with the active rifts of the west of the archipelago which are higher because of the higher eruptive frequency, although the rate of emission is far lower, a fact that facilitates their growth in height.

The Timanfaya-Las Montañas del Fuego eruptive system

The centre of the island is an area characterised by a high rate of volcanic activity over the last million years in which it has been created. The extension and spectacular nature of these landscapes and their recent creation has attracted many researchers, so many studies have been conducted on them. These include the following authors: Hernandez Pacheco, E., (1960, 2002); Carracedo Gomez, J.C. and Rodriguez Badiola, E., (1991 a and b) Carracedo, J. C., Rodriguez Badiola, E. and Soler, V., (1992); Romero Ruiz, C. (1991 y 1997). The frequency of the eruptions does not appear to be very high but when eruptions occur, they can last several months or even years, expelling large quantities of fragmentary material - lapilli, cinder, coarse volcanic sand – and lava. This is how the eruption that took place between 1730 and 1736 was, the longest lasting of all the volcanic eruptions in the Canary Island in recorded history and one of the largest eruptions in the world from the point of view of the volume of material expelled; calculated as approximately 3 to 5 km^3. The interesting features of this eruption are its long duration (6 years), in sharp contrast with all the other historic eruptions in Canaries that have only lasted weeks, or a few months), the length of the eruptive fissure – over 13 km - , the diversity of edifices and forms, the toleitic nature of some of its magmas and the system that must have fed it. In 1824, a new, much shorter eruption (31st of July – 24th of October) created the eruptive centres of Volcan Nuevo, Tinguaton and El Clerigo Duarte, which all helped to enrich the already ample inventory of young volcanic forms in Lanzarote. Most of these young spaces are now protected as part of the National Park or the Nature Park. (Figs. 8 and 9).

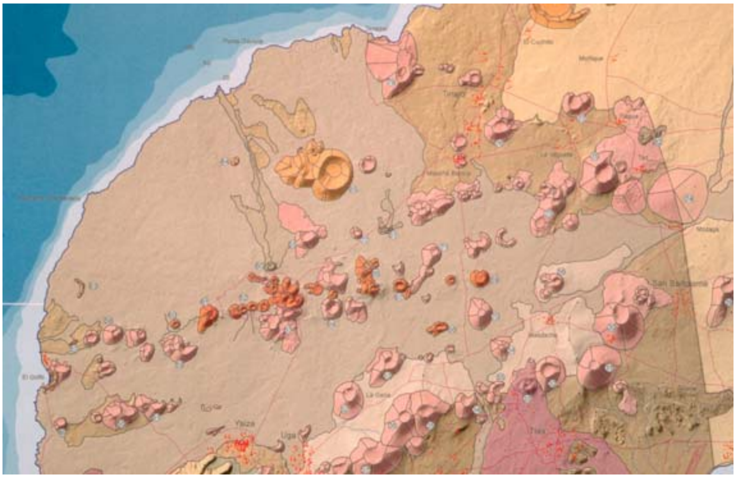

Fig. 8. Reduced Geomorphological Map of Timanfaya. A. Hansen and C. Moreno, 1999.

La Geria: a veiled landscape between the old and the young volcano

Many of the pyroclasts expelled by the 1730-1736 eruptions were carried south and east on the Trade Winds, covering the valleys and mountains there with a layer of coarse volcanic sand, or *"rofe"*, that varies in thickness between a few centimetres and several metres. The recognisable edge of this mantle is situated on the alignment of the central volcanoes, from Montaña del Mojon to Montaña Guatisea. Between these almost continuous lines of Pleistocene cones and their westernmost parallel, from Uga (Montaña Viera) as far as Montaña Tisalaya, to the north east, runs is a broad valley, or "corridor between volcanoes". From the easternmost line, the slopes of the cones and their lava flows created gentle, ramps and rolling hills on which the incision had left little mark.

In was in this valley that the volcanic activity constructed the largest extensions of natural cinder flats, or *"enarenados"* on the island. La Geria covers a total area of 22 km^2 of cinder flats. The oldest volcanoes have a strange appearance two and a half centuries after the eruption: once again their peaks are naked, stripped by the deflation of the wind and the violence of the torrential rains, exhibiting their white carbonated crusts. Their flanks, skirts and ridges are dressed in black and their craters, turned into geometrically striking agricultural "hollows" by the hand of man. The degree of the cover varies from one cone to another, depending on the wind, the position and slope. The nuances of the landscape are particular too. The western boundary of this valley is constrained by the surface of historic lavas. The lavas of Las Nueces volcano cover almost the entire lava space. These lavas penetrate into the valley, crossing this to the Tegollo pass, where they spill down towards the east coast, while covering more area to the north, surrounding the old Montaña de Juan Bello volcano with pahoehoe lavas in the malpaises they call Volcan del Islote, Juan Bello and Volcan de Mazdache.

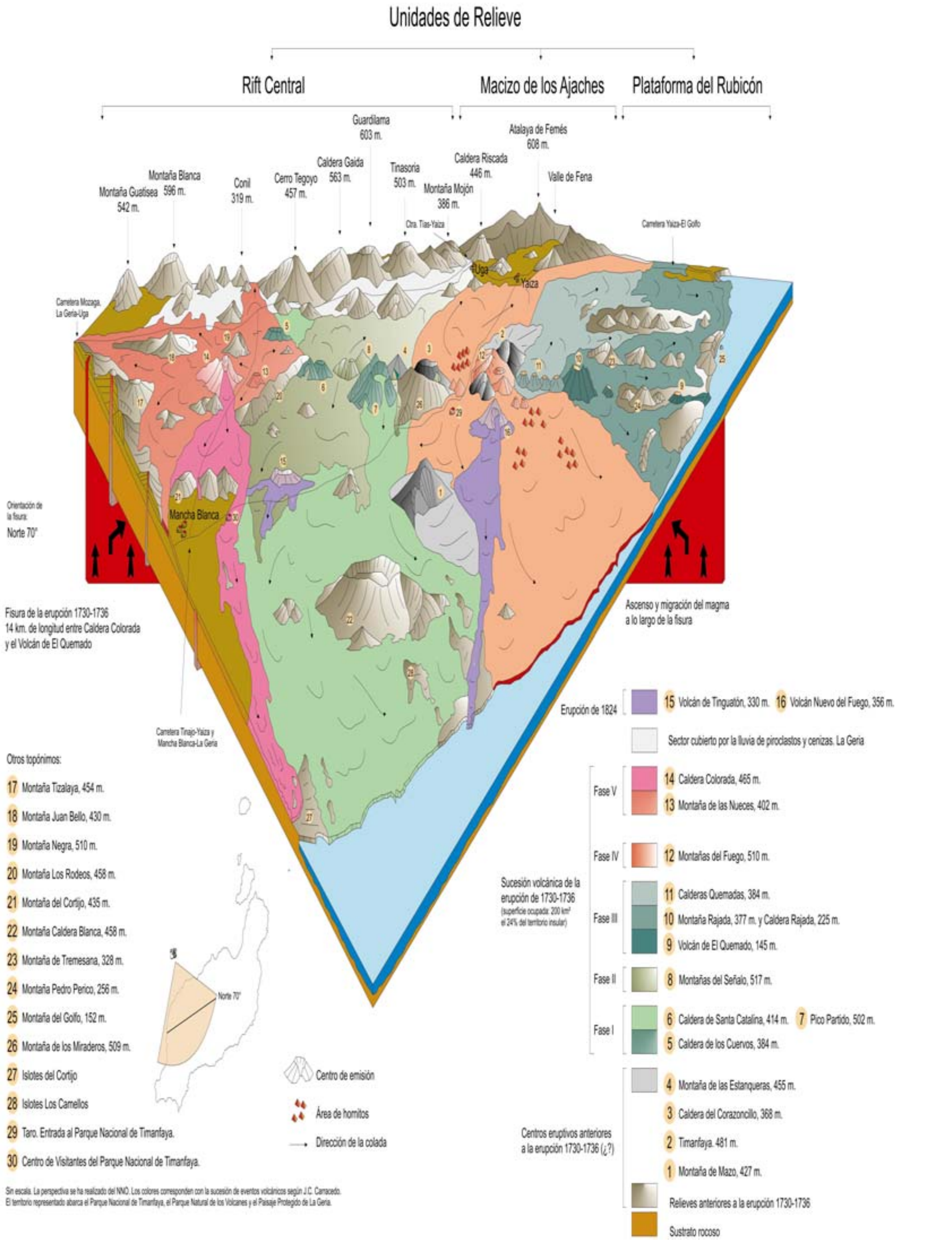

Fig. 9. Block diagram of Timanfaya showing the materials from the different eruptive stages. A. Hansen and C. Moreno, 1999.

But the La Geria relief was not created by the volcano alone. This created the veil of pyroclasts, which it let fall over the land, but this was followed by "man", who embroidered it. La Geria is a beautiful and unique example of how a farming system can adapt to the environment, and improve it without loosing any of its idiosyncrasies. The labour of man, working for generations to create hollows and walls of all shapes has sculpted an extraordinarily striking landscape. And volcano and man have also worked together to extend the coarse *"picon"* cinder flats artificially all over the island geography, in an efficient intervention to conserve the soils, improve farming and create the typical Lanzarote landscape.

The youngest volcanic units

The volcanic landscape units of Lanzarote created in the last few hundred or thousands of years comprise the main attraction of Lanzarote. The lava fields and pyroclasts that carpet the evolved island cover an area of 250 km^2 if we consider the areas of Timanfaya and the areas covered by La Corona volcano and its group. If we add the Atalaya de Femes malpais to this figure, which covers 27 km^2 of the Rubicon platform, we reach the conclusion that 33.7% of the surface area of Lanzarote is covered by these materials, that is, over one third of the area of the Island, which makes a major contribution to rejuvenating the relief of the Lanzarote landscapes.

The quaternary units of construction: The islets

The Islets of La Graciosa, Alegranza, Motaña Clara, Roque del Este and Roque del Oeste, grouped together as the Chinijo Archipelago, have risen from a shallow marine platform (100 - 200 m) that stretches over 10 km north of Lanzarote to the La Concepcion submarine Bank.

La Graciosa is separated from Lanzarote by the El Rio strait, a kilometre of shallow water. Its shape is elongated, running N.E.-S.W. The islet of Montaña Clara is situated 1700 m north of La Graciosa. The depth of the waters in the Rio de Montaña Clara straits between the two does not exceed 20 m. 600 m to the N.E. of Montaña Clara is Roque del Oeste, or Roque el Infierno. Alegranza, the northernmost island of the Canary Island Archipelago, is somewhat further away, 7.5 km north of Roque del Oeste. With Punta Mosegos as its northern tip (29º 24' 35''N), Roque del Este, the only one to emerge from a depth of over 100 m, is the easternmost landfall of the Canary Island Archipelago (13º 19' 59''W), 11 km. from Lanzarote, 13 km from La Graciosa and 20 km from Alegranza. Table 4 shows the area and height of each of these islets.

The Islets rest on a marine abrasion platform created during the Pliocene and Quaternary Periods by the action of the waves wearing down the Famara-Guatifay ridge edifice that was constructed during Lanzarote's first volcanic cycle (Series I, Mio-Pliocene). The volcanic activity of the upper Quaternary period, equivalent to Series III and IV in Lanzarote, was responsible for the emergence of a large number of volcanoes that have built the islets with their materials. Most of this volcanic process has occurred between 45000 years ago and up until recent times, and, as is to be expected in eruptions occurring on shallow sea beds or coastal environments, water has played an important role in the eruptive mechanisms, the transport of materials and the morphological character of the resulting structures. There is a major presence of hydro-magmatic volcanism in the Chinijo Archipelago. The so-called Chinijo Archipelago has also attracted the attention of a large number of scientists, including the specialised works of Fúster, J.M., Ibarrola, E. and Lopez Ruiz, J. (1966) and Nuez, J., Quesada, M.L. and Alonso, J.J. (1997).

La Graciosa

La Graciosa is a low platform created by lavas and pyroclasts from different eruptive moments. The island runs N.E.-S.W. (45º N) for some nine kilometres. It is triangular in shape with the vertex pointing S.W. There is a chain of 3 volcanic cones that run in the same direction, dividing the island and providing most of its bulk. A fourth cone, Montaña Bermeja, the youngest of the four, is situated to the N.E. The following succession of events explains the evolution of the islet according to Julio de La Nuez and other researchers (1997).

Photo 7. La Graciosa from El Rio Look Out.

- There was an existing eroded platform made up of materials from the Lanzarote Series III, at the base over 43,000 years ago.
- A dune system on which the now destroyed volcanoes of Morros Negros would be established between 43,000 and 39,000 years ago, and a new sea level and new dunes, with nests of Hymenopters and Gasteropods, over these.
- The volcanoes of the present central chain: Montaña Amarilla, Montaña del Mojon, Agujas Grandes, Agujas Chicas, Morros de Pedro Barbay and El Vachichuelo emerged between 39,000 and 11,130 years ago, through major hydro-magmatic mechanisms combined with strombolian mechanisms.
- Between 11,130 and 5,100 years ago, a new dune system, once again with Hymenopters and Gasteropods, and a new sea level corresponding to the Erbanese.
- Between 5,100 years ago and the present day, Montaña Bermeja erupted. Its materials are very fresh and their morphologies remain in a good state of conservation. Its lavas wrested land from the sea at the northern tip of the islet and its pyroclasts created a large field.

Montaña Clara

The islet of Montaña Clara is a mere 1.3 Km^2 so, with the exception of Roque del Este and Roque del Oeste, it is the smallest of the islets of the Chinijo Archipelago. Although it is small in area, it rises to a height of 256 m at the upper edge of the crater of the La Caldera volcano, which gives an idea of the steep slopes that are characteristic of the islet. The islet measures 1.9 km from north to south, with an irregular and varying width. The northern half is formed of the La Caldera volcano, which is in an advanced state of decline and much smaller than the original area, which stretched further north, towards Roque del Oeste. The crater, covered with water, is a small, sheltered cove. The southern half of the island is lower lying, in the area of the Llano del Aljibe volcanoes. Despite its small size, this islet is a complex edifice that was forged in different volcanic stages:

Photo 8. Islet of Montaña Clara.

- The oldest materials are cones and lava flows, well covered by later materials and which only appear as outcrops on the cliffs on the south and west of the islet. These must have formed the original islet on which the material expelled by later eruptions settled.
- This was followed by the great hydro-magmatic eruption of La Caldera that constructed a tuff cone 1.5 km in diameter. Shortly afterwards, or even during the same eruption, the El Bermejo volcano was created, now in an advanced state of decline, although its materials are still to be found on La Caldera.
- The final manifestations of Montaña Clara are situated at the southern tip of the islet, in El Llano del Aljibe. This is a volcano made up of the alignment of three cinder cones that carpeted the entire south of the islet. It was a Strombolian eruption, with lava flows being expelled before and during the emission of pyroclasts.
- Between the El Llano de Aljibe and El Bermejo volcano eruptions, several levels of dune sediments were deposited, dated between 30,000 and 10,100 years ago, while a layer of sand has later covered all this material.

Alegranza

The Islet of Alegranza is oblong in shape, with its longest axis running N.E.-S.W. for 4.3 km and a shorter, 3 km axis running N.W.-S.E. This shape is the result of a combination of two volcanic fissures running in the afore-mentioned directions, which translate, from a morphological point of view, into the presence of two inter-twining alignments of different ages.

The coasts of the islet are more elevated in the southern and western sectors as the volcanic cones have been eroded into cliffs by the sea. The northern coast is, in general, lower-lying and forged over the lavas from the group of volcanoes that cover the centre of the island: Montaña Lobos, La Atalaya, Morros de la Vega and other lesser ones that are assembled, juxtaposed and declining in height to the N.W. They are laid out along a fissure running 150º N. The lava outlets are highly characteristic, forming dome-shaped swellings several metres high, like those on La Graciosa. The surface of the lava flows is “aa” type lava, softened by later pyroclasts. On the eastern tip of Alegranza is El Lomo de la Rapadura volcano, whose lavas stretch as far as Punta Delgada. This is a hydro-magmatic volcano that evolved into a strombolian volcano in its last stages, expelling lava flows that reached the coast in the area of Faro de Alegranza. Another small cone of lapilli and bombs emerged inside the crater at the end of the eruption.

Photo 9. Islet of Alegranza.

The western sector of the island is built from the great pyroclast edifice of La Caldera. This grand circular cone has a crater diameter of 1.2 km and an exterior diameter of 2 km, very similar in dimensions to the Caldera Blanca volcano, in the territorial unit of the centre of Lanzarote. Its hydro-magmatic materials have moulded the entire apparatus as a wet wave type tuff cone, attaining a visible thickness of 270 metres high. In a second stage, La Caldera expelled large volumes of pyroclasts in dry waves that crashed into the volcanoes of central chain, covering them and most of the islet. The accumulations of accretion lapilli are spectacular. This islet evolved as follows:

- Eruption of the Montaña de Lobos hydro-magmatic volcano and strombolian volcanoes of La Atalaya and its group around 40,000 years ago.
- Construction of the hydro-magmatic edifice of Morro de La Rapadura and the enormous yellow tuff cone of La Caldera some 29,000 years ago.
- A floor with nests of Hymenopters that has been dubiously dated as 11,000 years old, has been located over the material expelled by the volcanoes. An elevated beach, one metre above the current sea level, small areas of volcanic cinder in the north of the islet and the current level of the beach, complete the succession of morphological events and the inventory of forms and materials to be found on Alegranza.

Roque del Oeste or Roque del Infierno

This is the smallest of the islets and rock fingers of the Chinijo Archipelago. It is 600 m from the northern tip of Motaña Clara, separated from this by waters no deeper than 20 m. It is a lava monolith built by two lava flows piling up on top of each other. There are doubts as to whether this is an eruptive centre that has declined or, on the contrary, its origin could be related to La Caldera volcano on Montaña Clara.

Roque del Este

This is a saddle shaped islet, i.e. with two elevated points (Risco Falso, 63 m. and Campanario, 84m.) separated by a pass. It is formed from the remains of a hydro-magmatic cone. Access is difficult, especially from the west, which they call “Risco Falso”, or “False Crag” because the structure is so weak and crumbling.

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ROAD-LOG

Day 12:
Meeting in Conference Hall.
Airplane trip to the Island of Lanzarote.
Meeting in the lobby of the Hotel Miramar
Trip through the Timanfaya National Park and its Interpretation Centre.

Day 13:
Trip through the old volcanic massif of.
Visit to the El Rio Look Out.
Bus trip through the La Corona Volcano malpaises.
Lunch in Orzola.
Visit to La Casa de Los Volcanes.
Walk along the La Cueva de Los Verdes volcanic tube.

Day 14:
Bus trip around the Los Volcanes y La Geria Nature Park.
Visit to El Grifo wineries.
Walk around the Pico Partido volcano.
Lunch in Haría.
Visit to the El Golfo freato-magmatic volcano.
Trip through Los Ajaches old volcanic massif.

Day 15:
Visit to the Cesar Manrique Museum.
Lunch: Restaurante El Campesino. End of field trip.

Note: All distances by road are short in Lanzarote, so the bus trips are short too.