SOCIETAS SCIENTIARUM FENNICA
COMMENTATIONES PHYSICO-MATHEMATICAE XXIII 4

ON THE GEOLOGY OF LANZAROTE

GRACIOSA AND THE ISLETAS

(Canarian Archipelago)

With a geologic map in the scale 1 : 200 000

BY

HANS HAUSEN

Collaborators in the laboratory research:
A. HEIKKINEN, T. MIKKOLA, K. J. NEUVONEN,
P. OJANPERÄ, C. A. WESSMAN and H. B. WIIK

Studies patronized by the Society El Museo Canario
Las Palmas de Gran Canaria

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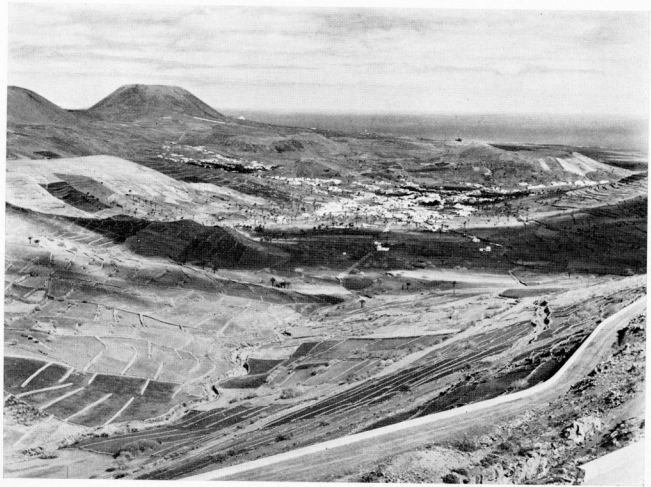

View of the northern part of Lanzarote with the Sub Recent volcano Montaña La Corona in the background (left). Picture forwarded by El Museo Canario, Las Palmas.

»Lanzarote, the Moon Land, the mysterious, unbelievable, burying its secrets deep within the fastness of its dark soul, too dark for penetration by the narrow intelligence of men . . .«

MADGE MACBETH: Three Elysian Islands.

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Collection of samples of rocks from Lanzarote and from Las Isletas

made by the author in the years 1953—1954 has been registred and incorporated in the Canarian rock-collection guarded in the Geological Department of *El Museo Canario*, Las Palmas de Gran Canaria. To the same Museum has been delivered also a geologic map of the area in the scale 1: 50.000, compiled by the author.

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View of the northern part of Lanzarote with the Sub-Recent volcano Montaña La Corona in the left background. Pict. forwarded by El Museo Canario, Las Palmas.

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		locality	Analyst
Anal. n:o 1	Olivine basalt	Alegranza	Pentti Ojanperä
» » 2	Olivine basalt	Roque del Este	Aulis Heikkinen
» » 3	Olivine basalt	Peñas del Chache	Aulis Heikkinen
» » 4	Olivine gabbro	Risco de Famara	J. M. Fuster
» » 5	Gabbro	Risco del Charco	J. M. Fuster
» » 6	Gabbro	Risco del Charco	J. M. Fuster
» » 7	Gabbro	Risco del Charco	J. M. Fuster
» » 8	Trachyandesite	N de Papagayo Los Ajaches.	Aulis Heikkinen

Anal. n:o 9	Olivine basalt	W from La Corona	Aulis Heikkinen
» » 10	Plagioclase basalt	Central part of the island	A. Lassieur
» » 11	Glassy olivine basalt	Volcán Clérigo Duarte	Aulis Heikkinen
» » 12	Picritic basalt	Montaña Nueva del Fuego	A. Lassieur
» » 13	Olivinite bomb	Lanzarote	H. B. Wiik

Preface

In the course of my studies on the geology and volcanology of the Canary Islands, Spain, that began in the year 1947 and ended in the year 1957 as far as the field work is concerned, I have got opportunity to visit all the islands in this archipelago. Most work has been devoted to Tenerife, Fuerteventura, Lanzarote and Gran Canaria, and reports of the results have in parts been published (Tenerife 1956, Fuerteventura 1958). This time I have to present a report on the island of Lanzarote with its small associated Isletas: Graciosa, Montaña Clara, Roque del Este and Alegranza.

Lanzarote is a strange little world of fresh volcanoes displaying all the terrible manifestations of the endogenic forces and the materials carried to the earth's surface. In the tourist literature Lanzarote has been called La isla de los Volcanos, and with much reason. That expression does not mean of course, that the other islands in the archipelago should be devoid of such a sinister adornment; only their volcanic forms are mostly old and in part overgrown with vegetation. Here in Lanzarote one is confronted with the youthful forms, cones of slags and ashes and wide lava and ash fields covering the main part of the island. The landscape has, one may say »a Dantean aspect» as is to be read in the tourist brochures. The geologist will find excellent opportunities to study close at hand the volcanic manifestations in all their grandeur.

The author paid a visit to Lanzarote the first time in the year 1950 spending there only one week, riding a car into different directions Rock material was collected to a certain number and many interesting observations were made. But that all was only a mere orientation. I was therefore enchanted to get occasion to see the island a second time in the years 1953—1954, spending no less than 2 months in the island and in the Isletas, thanks to an invitation from the side of El Museo Canario, Las Palmas de Gran Canaria. From this cultural center interested in the

nature, antropology, enthnography, history and folk lore of its Canarian country the author was entrusted to make reconnaissance work in the eastern islands — i.e. the Province of Las Palmas.

The time provided for the field work — one year — proved soon too short, and another year was added for the three mentioned islands. The material collected had to be treated in Finland and reports to be written. A first one was before published (1958). This is the second in order. Next there is foreseen a similar report on the geology of Gran Canaria, the material from there being under treatment in the company of collaborators since some years ago.

In this place I have only to repeat what I have said in a preface to my memoir on the geology of Fuerteventura: the results are to be considered as only contributions based on a material brought together during a single man's work in the field. Much details have to be left for future surveys, better equipped than in my case.

The collection of rocks from Lanzarote (as well as from the two neghbouring islands) was transferred to the Geological department of El Museo Canario and registered there. Duplicates were taken to Finland for laboratory examination. — My working plan included moreover the construction of a geologic map of the areas in question based on available topographic sheets in an appropriate scale. Here the geologic map of Lanzarote and Isletas is appended, reduced to the scale 1: 200 000.

Acknowledgements. — The author has the agreeable duty to express his sincere thanks to the Society of El Museo Canario, Las Palmas, for its invitation to this insular study and for its confidence demonstrated. Likewise I am grateful for the liberal offering to publish my memoirs in a foreign language (English) in my native country only with the obligation to provide a Spanish version of the text for the disposal of El Museo Canario.

During my stay in Lanzarote I was kindly received by the authorities of the island who helped me in many ways. Among residents there I have also to mention some outstanding citizens interested in my task and giving me a welcome assitance: Don Eugenio Rijo Rocha, Arrecife, a lawyer and land owner, very interested in the natural history of his island, Don Marinao López Socas, Alcalde of the town of Haría in the northern part of the island, also a land owner and thoroughly oriented in the affairs of his island, Don Jaime Lleo Mira, Alcalde of the town of Yaiza, in the southern part of Lanzarote. who offered me his hospitable home and who accompanied me on some trips. The

last named gentleman died already in the year 1952, but his family received me on my second journey with the same kindness facilitating my excursions.

In Finland I have been able to acquire some coworkers in the laboratory treatment of the Canarian material. As far as Lanzarote is concerned I have to mention with gratitude the contributions made by Mr A. HEIKKINEN M. A. (chemical analyses), Mrs. T. MIKKOLA M. A. (optic det. on the U:stage), Mr K. J. NEUVONEN Ph. D. (det. by using the X:ray diffraction method). Mr P. OJANPERÄ M. A. (chem. anal.) and Mr C. A. WESSMAN M. A. (calculations).

These acknowledgements may not be finished without a special address of gratitude to Señor Jefe de Servicios in the Canarian Museum, Don JUAN PÉREZ NAVARRO, who in the most useful manner has been ready to help both with the redaction of my reports and to procure the necessary topographic base maps, not to mention all the good advices I obtained from him during my long lasting field mission in the Canaries.

Brändö, Suburb of Helsingfors—Helsinki

December 1958

Introduction. Physiographic features

The easternmost islands in the Canarian Archipelago, Spain, now to be described, are, excluding Fuerteventura (about which a memoir already has been published) Lanzarote, Graciosa, Montaña Clara, Roque del Oeste, Roque del Este and Alegranza. Of these the main island Lanzarote comprises ab. 796 sq. km:s, whereas all the other are of insignificant size: Graciosa 27 sq. km:s, Montaña Clara 1 sq. km, Roque del Oeste (or Roque del Infierno) 0.06 sq. km, Roque del Este 0.07 sq. km and Alegranza 12 sq. km:s. These small neighbours have been called Las Isletas (except Graciosa) and they lie all upon a submarine platform that apparently marks the former extension of a land area of which these Isletas are the last visible remnants. Organically they consequently belong to Lanzarote and should be described in connection with that island.

The part of the Canarian Archipelago in question extends between the geographic coordinates 29°25′ and 28°50′ N Lat. and 13°25′ and 13°52′ W Long. of Greenw. The islands comprise altogether an area of 836 sq. km:s. The real land block is, however, considerably larger if we add to the *terra firma* also the shelf that extends to the north from Lanzarote, and that may be the result of a rather young marine abrasion. This shelf can be followed NE:ward to Banco de la Concepción and also farther on.

On the other hand, there existed in the nearer past a land connection also with the southern neighbour Fuerteventura, now separated from Lanzarote by the shallow Bocaína Strait.

Lanzarote and its satellites are relatively low islands compared with the lofty western islands of the Archipelago. Only Fuerteventura shares the aspect of reduced heights. The highest summit in Lanzarote is to be found in Peñas del Chache, Acantilado de Famara, N part of the island, with 671 m. Next in order there are two volcanoes of probably Sub Recent age, Montaña la Corona (610 m) in the north and Montaña de la Atalaya (608 m) in the south of the island. There are however

several volcanic cones that attain heights approaching 600 m. — In the Isletas the heights are still more insignificant, in some cases surpassing 250 m.

Lanzarote, the mainland, has a max. length from Punta Fariones in the north to Punta de Pechiguera in the southwest of ab. 60 km:s the max. breath measuring ab. 21 km:s. The island has a rough elliptical form with the main axis extending SW—NE and with two peninsular protoberances: in the north the Guatifay massif, in the south Los Ajaches with the plain of El Rubicón. The topography is typically volcanic: there does not exist any main watershed with determined opposite declivities. The only parts where a »normal» erosion topography has been left behind is in the mentioned peninsulas in the north and in the south, features to which we will return in the following. The general physiographic stamp of Lanzarote is consequently in the main volcanic and differs very clearly from that of Fuerteventura, the 'Canarian Oldland' with its mature erosion forms.

In short Lanzarote is an excellent field of study of volcanic phenomena, it is easily accessible and provided with motor roads. It matches in these respects Iceland and the Hawaiian Islands, only that in Lanzarote the volcanic activity in the present time has come to a standstill.

Graciosa, separated from Lanzarote by the narrow strait El Rio, off the steep northwestern coast of the latter island is a rather flat desolate, sand-swept island dotted with a number of dark volcanic cones. It measures only 9 km:s from north-east to south-west. As will be set forth in a later chapter this island can be considered a tectonically sunken part of the mainland.

Montaña Clara is a volcanic edifice apparently connected with those of Graciosa, but separated from them by a narrow waterway. It is half destroyed by the surf of the surrounding ocean, and the vertical western side exposes a beautiful geologic cross-profile of a volcano. The eiland is accessible only in the southern end. As an isolated part of this badly damaged volcano is to be considered the inaccessible Roque del Infierno or Roque del Oeste.

Roque del Este was not visited by the author but (on an earlier occasion) by his Canarian colleague T. Bravo, who brought from there samples of rocks. It is likewise the remnant of a volcano, seemigly of tuffaceous composition. Great basaltic dikes cross the pyroclastic material.

A l e g r a n z a, the farthest situated of the islands in question is dominated by a »giant» caldera lying at the western coast. There are however also other volcanoes, situated at the eastern coast. The rest of the island is of a rather smooth topography. Along the west coast there is a tremendous abrasion cliff that has cut away a considerable part of the western flank of the caldera wall.

In general the islands are all rather desolate and sparsely populated, wind swept and devoid of ground water. Nevertheless Lanzarote has a population of about 30 000 souls, of which number more than 1/3 lives in Arrecife. There are in the island vast expanses of uninhabitated land also outside the Recent lava fields. But the agriculture is in a state of growth and improvements, and the economic life in the island is in progress far more than is the case with Fuerteventura. The soils of Lanzarote are not bad, it is the lack of ground water that forms a serious problem. There is always the dry farming to be applied, and the fields are covered with basalt lapilli to prevent evaporation and to catch the nocturnal dew. The ashes from the XVIII:th century provide a good ground for grape cultivation. Of the islands surrounding Lanzarote in the north only Graciosa has a population (two settlements). Alegranza has a cattle farm.

Means of communication are at present rather satisfactory. A regular steamer traffic unites Arrecife with Fuerteventura and Las Palmas and also with Ifni, the enclave on the African coast. The aviation company IBERIA has extended its Canarian service to Lanzarote, where a new airport has been constructed (Guasimeta).

The capital Arrecife is busy with its fishing industry. The port provides a base for a large fishing fleet that operates on the African coastal shelf. Also a cannery has in recent years been created. The saline industry is concentrated to two points: to the outskirts of Arrecife and to Charco de Janubio on the west coast. — Of other enterprises there is not much to mention. Basalt lapilli is exploited on a grand scale for the covering of the dry-farming fields. The pits are situated in the immediate vicinity of some large volcanoes. The material (»*picon*») is hauled to the fields with trucks, and from year to year these black covers extend over more and more surfaces of the ground.

In the latest years there has unexpectedly appeared a kind of »mining fever» among the inhabitants, and this is still lingering on judging from what is to be read in the Canarian newspapers. A company has been formed of Canarian shareholders with the fin to exploit »the mineral

richness» of the island of Lanzarote. It has been told to the people that in the volcanic ground there is to be found such precious metals as gold, silver and platinum. Considering the fact that the island is composed of mostly young volcanics of rather uniform basalt rocks such an optimistic expectation seems rather curious to the geologist.

A similar »claim activity» has been set in train also in the island of Gran Canaria. Here the prospects are at least theoretically somewhat more hopeful as far as the author can judge after a two year's campaign in the island.

Previous geologic work in the area

The first geologic informations concerning the island of Lanzarote are to be found in the classic memoir by LEOPOLD VON BUCH (1825) »Physikalische Beschreibung der Canarischen Inseln», in which a special chapter is devoted to this island, accompanied by a topographic sketch map illustrating the repartition of the numerous volcanoes there. The visit to Lanzarote by VON BUCH was made in the year 1815, consequently prior to the latest outbursts in the island, of the year 1824. But only ab. 80 years before the journey VON BUCH's there had ended a six year's long period of volcanic eruptions of devastating magnitude, leaving behind a greater number of new volcanoes and huge masses of glassy lavas and ash fields, covering a great deal of the central part of the island. Consequently VON BUCH's experiences were concentrated to these grim events and their terrific results. VON BUCH counted no less than 30 new cones arranged in a line across the island having a WSW—ENE trend. The extent of the lavas from all these volcanoes was estimated to ab. 165 sq. km:s. The mentioned linear arrangement of the orifices from that six-year's period provided the young science of Volcanology with a (now classical) example of l i n e a r v o l c a n i s m, later on proved to exist in many parts of the world, as for inst. in Iceland.

After the visit by VON BUCH in Lanzarote a long time passed by before any investigator with geologic education found his way to this remote island. We have to mention at first the outstanding German naturalist GEORG HARTUNG who in the fifthies of the preceding century made a thoroughly going investigation of the rock ground of both Fuerteventura and Lanzarote (1857). We will have occasion to return many times to the results in his work, here only a brief summary of the contents will be given as far as Lanzarote is concerned.

After some introductory chapters about the physiography of the two islands (F and L) the author starts with a large description of the geologic conditions. He treats the different formations of the rock ground according to their relative age, and he begins with the oldest one, the so called »Syenite and Trapp formation», confined to Fuerteventura. The next formation in age is the older Basaltformation that has a great expansion in Fuerteventura but in Lanzarote is restricted to the northernmost and the southeasternmost parts of the island. In my memoir on Fuerteventura (1958) I have called it »the basaltic table — land series». Further there follows in the text by HARTUNG the younger Basalt formation, a category of relatively older (in my mind Quaternary) cones with their eruption products. They occupy the whole middle sector of Lanzarote. Moreover they have been found in Graciosa, Montaña Clara and Alegranza.

The youngest basalt formation in the sense of HARTUNG is the group of cones and corresponding lava streams and ashes produced during the six year's long activity-period in the first half of the XVIII:th century. To these volcanoes may be added also the few ones grown up in the year 1824, the lavas of which showed all their freshness at the arrival of HARTUNG 30 years later.

A valuable complement to the descriptive chapters by HARTUNG are his longitudinal and cross-sections of the two islands with explanatory notes and finally of course the geologic map in colours accompanying the work, the first one ever made of this part of the archipelago.

In times to follow there are but few contributions to the geology of Lanzarote or of its satellites. In the year 1867 there appeared in »Petermanns Mitteilungen» (Gotha) a well written characteristic of the Canaries by KARL VON FRITSCH, in which publication Lanzarote is included. The geology is in this connection dealt with briefly. It is to remember that the same author (together with W. REISS) has produced a very comprehensive geologic description of another of the Canaries, Tenerife (1868).

In the year 1884 S. CALDERÓN Y ARANA, resident in Las Palmas, published a description of the sedimentary deposits in the Canaries especially the sandstone and the drifting sand deposits. This paper includes also the island of Lanzarote.

The Austrian naturalist OSKAR SIMONY undertook in the beginning of the last decade of the 19:th century a journey to the Canaries and devoted a special attention to Lanzarote and to its satellites (1892 a

and b). He has given interesting characteristics of all the wonders in the nature seen by him, and the text is accompanied by excellent photographic pictures.

The German geographer KARL SAPPER published in the year 1906 a special study on the two most extreme members of the archipelago — Palma and Lanzarote. The text is accompanied by two maps of the respective islands. The map of Lanzarote in the scale 1: 150 000 indicates all the more important volcanoes and also the extension of the lava fields. showing clearly the overwhelming importance of these young lavas in the physiognomy of the island. Two parallel rows of younger volcanoes are to be seen in the middle sector of the island having a WSW—ENE trend with many corrections of the old map by L. VON BUCH (1825). There is in the Lanzarote map also a small map inserted, referring to the main volcanic focus of the island — Montaña del Fuego, a detailed study made by SAPPER.

Some years later on, 1908 the Genevan physicist, ALBERT BRUN published the results of his investigations of the gases emitted from Pico de Teide in Tenerife and from Timanfaya in Lanzarote. We will later on not return to his observations.

A short time thereafter there appeared important results of investigations in Lanzarote carried out by E. HERNÁNDEZ PACHECO (1910) about the volcanic manifestations in the island and its satellites. The work deals with the following chapters:

I. »Fisiografía y aspecto general»
II. »Formación basaltica de la erupción homogénea»
III. »Serie antigua de la formación volcánica explosiva»
IV. »Erupción de la Corona y malpaís de la Cueva de los Verdes»
V. »Erupción de 1730 a 1736»
VI. »La erupción de 1824»
VII. »Formaciónes sub-aéreas, no-volcánicas»

The work is finished with »Conclusiones».

We will limit ourselves here to the enumeration of the headings since we will get opportunity in the sequel to quote the results of HERNÁNDEZ PACHECO many times. It is here only to observe that this eminent explorer did not treat the volcanic products from a petrographic side, although the characteristics of the volcanic manifestations are otherwise very comprehensive. The contributions to follow in this memoir will to some extent complete the results of H. PACHECO.

The work by HERNÁNDEZ PACHECO is accompained by a geologic map in colours published in the scale 1:150 000. In this map the following lithologic complexes have been indicated: »rocas volcanicas ácidas», »basaltos» (i.e. the old complex), »lavas viejas muy alteradas», »lavas modernas poco alteradas», »lavas de 1730 a 1736», »lavas de 1824», »tobas de proyección», »lapilli», »arenas calcáreas voladoras» (drifting sands) and finally »formación sub-aérea con pseudo-fósiles» (alluvium).

After the publication of this remarkable geologic prestation there are no more contributions about Lanzarote to mention; only some local investigations of technical nature have been made from time to time, referring partly to the agricultural possibilities, partly to the recovery of ground water (Risco de Famara). Moreover the internal heat of the young volcanoes has been taken into consideration as a future source of energy; the matter has been set forth in the official publication »Plan de Riegos e Industrialización de las Islas de Lanzarote y Fuerteventura» by MANUEL CHAMORRO Y CUERVAS-MONS (1952). We may not enter any more into the contents of this book that comprises no less than 254 pages, since it does not provide us with any new data about the rock formations of Lanzarote.

As we have found from the short review above the state of our geologic knowledge of Lanzarote and its satellites has since 1910 remained unaltered up to the present time, if we make exception for some new chemical analyses published by J. M. FUSTER, E. IBARROLA and M. P. LOBATO in the series of the Petrographic Institute »Lucas Mallada», C. S. I. C. Madrid (1952). These analyses refer to some samples of rocks collected in Lanzarote from places geologically not nearer determined[1]. These analyses are the only that in the present time have been published about rocks from Lanzarote.

In the more recent years my Canarian colleague T. BRAVO has undertaken several excursions in Lanzarote and he has also visited the Isletas and Graciosa. From many places he has brought to Las Palmas samples of lava rocks, and these have been freely put to the author's disposal. In the descriptive chapters several of the samples will be described, for inst. from Roque del Este that was never visited by myself, owing to

[1] In a bibliographic list accompanying this paper there is mentioned a coming publication entitled: J. M. FUSTER, Algunas rocas de profundidad de la Isla de Lanzarote (Canarias).

the great landing difficulties. BRAVO has not published any notices about his observations, he has instead given me valuable informations and also offered some photographic vistas, taken by himself.

Geology and Petrography of the Islands

1. ALEGRANZA

This small island (12 sq. km:s) in the northeastern extremity of the archipelago lies 17 km off the northernmost point of Lanzarote, Punta Fariones. The longitudinal axis of the island measures ab. 4 km. The elevations in the island have already been mentioned. The coasts are somewhat sinuous. Sheltered landings are sparsely present — one at the lighthouse on the eastern cape, another on the south shore.

Alegranza forms a kind of plateau of about 50—80 m elevation sloping northward to a low sandy coast. Over this surface there rise some volcanoes, one at the western coast, the gran Caldera, and two cones at the eastern coast. The former includes a nearly ideal caldera (see the map fig. 1). The diameter measured from rim to rim is 1 km, the altitude of the highest point of the circumvallation is 289 m, at the same time the culminating point of the whole island. The bottom of the caldera is dry. The western flank has as was mentioned been cut off by the surf, forming a vertical cliff. No lava streams have been sent from this volcano, at least from its caldera.

In the east there are two other volcanoes. One is Morro de las Atalayas (199 m) the other Morro Rapadura, somewhat lower. The former has in its southern flank to some degree been destroyed by the marine action. Lavas have been sent from the Atalayas-volcano in northwesterly direction forming here a hilly and rocky landscape. The ground in the center of the island lying between the two volcanic mountains — the western Caldera and the eastern cones — is relatively plain and sandy; it is underlain by pyroclastic deposits forming southward a plateau surface tilted in that direction and ending at the south coast in a nearly overhanging precipice of stratified, dark-coloured tuffs underlain at the sea level by basalt lavas.

The landscape is open and desolate with a scanty shrub vegetation. At the low northern coast there is drifting, calcareous sand, called Los Jablillos.

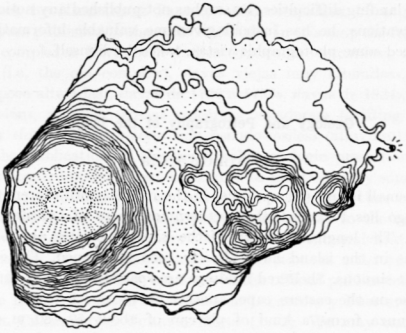

Fig. 1. Topographic map of the Island Alegranza (12 sq. km) in the scale 1:50.000 with contour lines of every 10 m. Reproduced from the topographic map of Lanzarote and the Isletas in the scale 1:25.000.

Alegranza does not offer much of geologic interest except in the great caldera at the west coast, one of the finest examples of that kind among the Canarian volcanoes. The author did not dispose time enough to climb the rim of this caldera, I only passed by on its eastern side. My colleague T. Bravo, however, visited the caldera some time ago and gave me some informations about its nature. It seems to consist in the main of relatively loose pyroclastic material, since the west flank as was told has been severely damaged by the surf, forming one of the most spectacular precipices in the region. A somewhat similar example of marine attack can be seen in the island of Montaña Clara, as we will find from the following chapter. In M. C. the achievements of abrasion has reached a more advanced stage: half of the volcano has disappeared.

As may be found from a bathymetric chart Alegranza lies close to the western limit of a shallow submarine platform. It is apparent that the island once did have had a much wider circumference than now and that the marine destructive forces may have been in operation a long time, especially at the windward (the *barlovento*-) side, as one can

see from the topographic map. But also along the south — and the southeast shores much of the land has been cut away; the character of abrasion cliffs in these sectors is evident. In former times (in the Quaternary period?) the island must have been a large land area covered with pyroclastic strata and subjacent lava banks and it did reach westward to the submarine edge limiting the shallow sea in that direction.

If we now turn our attention to the volcanoes crowning Alegranza we have at first the Great Caldera in the west (Montaña de la Caldera). Some dimensions have already been given. It can be added that the flat bottom of the Caldera lies only 51 m above the tide water level. At the rare occasions when it is raining in Alegranza, the bottom is filled with water, but it soon disappears. SIMONY (1892) says the depth of this temporary lake may attain 3 m. The flanks of the cone are (except the western cliff) rather well preserved as far as I could see when passing by at the eastern foot on the way to the north side of the island. Lava streams emitted from the volcano were not found with certainty. There is, however, a low rocky cape at the northeastern foot of the long slope that may be an end of some lava flow from there. A sample of this lava was guarded.

From here I walked north and northeast to the long northern slope that ends at the coast with Los Jablillos. There are asperous blocky lava ridges on the way, evidently ramifications of streams emitted from the Las Atalayas volcano in the southeast. Samples of the basalt lavas were taken from some points. The rocks are not chemically weathered, only disintegrated into blocks forming a kind of rugged ridges and jumbles. A scanty shrub vegetation covers the ground. The lavas must be of pre-Recent, i.e. Quaternary age.

The eastern volcanoes (Las Atalayas and Morro Rapadura) were not visited by the author, only the lava tongues emitted from Las Atalayas. This volcano has its »caldera» wide open.

Petrographic data

The author's samples from the island are few in number. Complementary samples have been obtained from a collection made by T. BRAVO who visited the island some time ago. He kindly put them to the author's disposal. The following numbers have been examined in slides 1, 2, 3, 4, 4a and 5.

One sample taken from a lava ridge belonging to Las Atalayas-volcano

shows micr. the comp. of a rather ordinary olivine basalt with euhedral phenocrysts of olivine and smaller ones of augite lying in a paste of plagioclase, augite and iron are. Optics of the chief minerals are:

Olivine 2 Vγ=80° (clear) (corr. to forsterite with 0% Fa mol.)
Augite 2 Vγ=60° (kernel) c$\wedge\gamma$=47° zoned
2 Vγ=62° (shell) c$\wedge\gamma$=53°

The plagioclase laths are albite-lamelled and seem to corr. to labradorite-bytownite.

The rock looks rather well conserved.

Another sample is from the vicinity of the Lighthouse on the eastern promontory of the island (Bravo). Micr. it shows olivine and augite as larger grains of the first generation lying in a dark paste (between crossed nicols, glassy?). There are rounded vesicles in the paste (empty). Optics of the main components:

Olivine 2 Vα=84° (25% Fa)
Augite 2 Vγ=50°—60° c$\wedge\gamma$=40°

Of this latter rock a chemical analysis has been made, the weight percentages being accompanied by the usual calculated parameters:

Anal. n:o 1.

Sample n:o 2 (coll. T. Bravo). Olivine basalt (picritic). Lava from the Las Atalayas volcano. Alegranza.

		Mol. prop.		Norm:		
SiO_2	43.80%	7264	or	8.5		
TiO_2	3.12 »	389	ab	10.1	33.5	
Al_2O_3	12.47 »	1220	an	14.9		
Cr_2O_3	0.05 »	3	ne	9.6		
Fe_2O_3	4.23 »	265	Σ Sal		43.1	
FeO	8.45 »	1176				
MnO	0.21 »	30				
NiO	0.01 »	1	di	26.5		
MgO	11.09 »	2750	ol	15.9		
CaO	10.67 »	1902	mt	6.2		
Na_2O	3.29 »	531	cm	0.1		
K_2O	1.43 »	152	il	5.9		

P_2O_5	0.73%	51	ap	1.7	
CO_2	0.00 »		Σ Fem:		56.3
H_2O+	0.29 »	161	H_2O		0.4
H_2O-	0.09 »			Sum:	99.8
	Sum: 99.93%				

Analyst: PENTTI OJANPERÄ

Niggli values:
si = 87½, ti = 4.7, p = 0.6, h + = 1.9, al = 14½, fm = 54½, c = 23, alk = 8, k = 0.22, mg = 0.61, qz = −44½, al − fm′ = −40, al − alk = +6½.

C. I. P. W. Classif. — III. 6. 3. 4.
Limburgose
Magma type: kaulaitic/hornblenditic
Mol. prop. of normative feldspars %
Ab:An:Or = 22:61:17
MgO:FeO = 83:17

The lava described above may be regarded as typical of the Alegranza Quaternary volcanoes. We will find from the chapters in the following that very similar lavas are repeated all over the region including the most recent ones (from the year 1824).

Still another sample refers to a lava rock exposed at the north-eastern foot of the great caldera, and it seems that this lava belongs to that volcano, issued from the flank. Micr. it shows clear olivine phenocrysts in a paste of feldspar laths, augite and ore. Texture is basaltic. $2V\gamma$ of the olivine = 86°. Besides the augite found in the shape of prisms chiefly in the groundmass there are stray colourless grains of enstatite (?) with $2V\alpha = 84°$. The plagioclase laths are very small and difficult to determine. There must be some sec. isotropic substance in the paste (analcime).

There are still two other samples of lavas available collected by T. BRAVO. One is from the rock at the water's edge just to the east from the usual landing place (above which the finca house is situated), the other a short distance farther to the east. These lavas seem to lie under the mighty cover of stratified tuffs, which form the shore — Playa de Trabuco.

The one sample is an olivine basalt with micr. well developed crystals of olivine of dim. ab. 1 mm. They represent the first generation of components and lie in an intergranular mass of plagioclase, pyroxene and iron ore grains. The texture of the groundmass is doleritic. The olivine

is clear, but an alteration to bowlingite has started from the margins, a sign that this lava is not very young. The olivines correspond to ab. 35% of the rock mass. Opt.: $2V \sim 90°$. Composition of the plagioclase is difficult to determine, but it may be an An_{50}, judging from the ind. of refr. The pyroxene is monoclinic, colourless or with a faint purple tinge. It may be a diopsidic augite. The iron ore is abundant, magnetite but certainly with some Ti.

The other sample was taken from a lava bed close to the sea level. This lava underlies a mighty mass of stratified tuff-agglomerates and represents no doubt a somewhat older effusion. Micr. one will find only olivine phenocrysts, the augite being restricted to the groundmass. Some stray prisms of pyroxene could however be detected. The olivine has $2V\gamma = 84°$. The mineral is somewhat corroded with embayments. Augite has the ext. on (010) $c \wedge \gamma = 45°$. The plagioclase is confined to the groundmass, where it is mingled with the pyroxene and the ore grains. Pores in the rock are filled with a colourless isotropic substance that seems to be analcime; but there are also radiating bundles of a birefr. zeolite. The rock may be considered a picritic basalt.

All the lavas from the island of Alegranza are as we have found of a rather uniform composition — they are olivine basalts of the more basic kind with olivine (forsterite) and augite as belonging to the first generation. In the fine grained matrix the relative amount of plagioclase is restricted. The volcanoes in this wing of the bowed row of the Canary Islands belong no doubt to the category of the Late-Tertiary to Quaternary volcanoes that are met with in Lanzarote and Graciosa. That the Alegranza volcanoes really are of such advanced age is seen already from the fact that along the coasts the marine abrasion has achieved considerable results.

2. ROQUE DEL ESTE

This little and lonely island (*isleta*) lies 11 km to the north-northeast from the nearest point of Lanzarote (Orzola) and has an area of only 0.07 sq. km. Its highest summit attains 84 metres above the sea and is called El Campanario, situated in the northeastern part of the island. Roque del Este consists according to O. Simony (1892) and T. Bravo (verbal comm.) chiefly of a brownish-yellowish tuffaceous rock dissected by steeply dipping dikes of basalt. The latter have a NNE trend. The greatest of the dikes supports the highest point of the island. These

dikes have a dull colour contrasting against the more bright coloured tuff masses. The ancient crater that belonged to this very abraded volcano lay open to the northwest. Now only the crescent shaped opposite sector has been conserved.

The author did not try to visit the island, since the bad weather did impede any landing. The heavy surf embraces the whole island when the ocean is agitated. Some years before my colleague T. Bravo succeded to land there and he collected a series of samples of the rocks. These consist in part of basalts from the dikes, in part of the tuffs and of limestone-ejecta from the hidden underground of the volcano. The limestone proved to be wholly marmorized.

The ancient volcano of which Roque del Este is a vanishing remnant must have been of considerable dimensions and stood on a platform that now is inundated by the ocean. A subjacent layer seems to have been a foraminiferan (?) limestone judging from the ejecta of marmorized lime found in the tuffs. The great result of the marine destruction is of course due to the soft tuffaceous material.

The author has been informed by Bravo that there are two dikes, the one of considerable breadth, the other narrow. They run in the direction NNE—SSW. The eastern dike stands close to the sea border. The western dike measures ab. 300 metres in length, being the longer one. Along with the western dike one will find a small »satellite» dike.

The samples brought to the Canarian Museum in Las Palmas were used for this memoir. They consist in the main of basalts from the great dike (6, 8, 11, 11 a, 11 b, 14), and slides have been prepared of them. They are olivine basalts of the more picritic kind. Micr. one sample shows olivine phenocrysts of euhedral forms lying in a paste of very fine grain charged with iron ore powder. The minerals in this intergranular mass are plagioclase, augite and magnetite. The olivine phenocrysts have $2V\alpha = 86°$ (corr. to 20% of the Fa mol.). The mineral is always fresh, not even marginal alterations are perceptible. On the other hand the grains are somewhat magmatically corroded, showing deep embayments. The grains of augite, belonging to the second generation are partly isometric, partly elongated (acc. to c). The optic angle of some of the bigger grains $2V\gamma = 56°$, and the ext. on (010) $c \wedge \gamma = 49°$. The plagioclase laths have the comp. An_{50}.

A chemical analysis of this sample, taken from the northeastern termination of the dike, Cerro Campanario, has been carried out, the data being communicated here together with the calculated parameters:

Anal. n:o 2.

Sample n:o 8. Olivine basalt from the great dike in the northeastern part of the island, Cerro Campanario. (Coll. T. Bravo) Roque del Este.

		Mol prop.	Norm:		
SiO_2	46.22%	7665	or	5.0	
TiO_2	2.76 »	345	ab	21.2	49.3
Al_2O_3	13.99 »	1369	an	23.1	
Cr_2O_3	0.07 »	5	ne	1.2	
Fe_2O_3	2.83 »	177	Σ Sal:		50.5
FeO	8.90 »	1239			
MnO	0.19 »	27			
NiO	0.03 »	4	di	18.9	
MgO	10.55 »	2617	ol	19.4	
CaO	10.18 »	1815	mt	4.1	
Na_2O	2.78 »	448	cm	0.1	
K_2O	0.85 »	90	il	5.2	
P_2O_5	0.60 »	42	ap	1.4	
CO_2	0.00 »		Σ Fem:		49.1
H_2O+	0.24 »	133	H_2O		0.3
H_2O-	0.04 »			Sum:	99.9
	Sum: 100.23%				

Analyst: Aulis Heikkinen

Niggli values:
si = 96, ti = 4.4, p = 0.5, h+ = 1.6, al = 17, fm = 53, c = 23, alk = 7, k = 0.17, mg = 0.62, qz = −30, al − fm′ = −36, al − alk = +10.

C. I. P. W. Classif. — III. 5. 3. 4.
Camptonose
Magma type: hornblenditic
Mol prop. of normative feldspars %
Ab:An:Or = 30:63:7
MgO:FeO = 78:22

Besides there are also other slides of the basalt rocks composing the great dike. They show naturally about the same features: olivine in the first generation often with nearly ideal crystallogr. forms, lying in a paste of fine grain with plag., augite and magnetite. The types are fresh looking. Only in some cases the vesicles in the paste have been filled with sec. minerals (a zeolite with radial aggregate polarization).

The rocks of the great dike of Roque del Este are compared with the

types from Alegranza (above described) rather similar — olivine basalts with the olivine alone belonging to the first generation of minerals in the crystallization process. The composition of the rocks approaches to picrites, with the plagioclase in more restricted quantity. It seems to be without doubt that the great dike in Roque del Este belongs to the category of Quaternary volcanic manifestations like those of Alegranza. It cannot be of a Recent age since the marine abrasion has worked too far for such a short time. And the relatively fresh condition of the rock types speak against any connection with the old table-land basalts exposed in the north cape of Lanzarote (11 km distant).

Hence this small *isleta* Roque del Este stands as a rather curious witness to a far reaching marine attack. It has met with the common fate of insular volcanic edifices exposed to the ocean waves; a fate that awaits every such accumulative mass after the cessation of constructive volcanic activity. In the special case of Roque del Este the rate of destruction has been comparatively rapid owing to the presence of the soft tuff cone. Judging from the bathymetric contour line of 100 m that surrounds the *isleta*, the original cone seems to have been of considerable dimensions.

3. MONTAÑA CLARA

This interesting little island of an area of only 1 sq. km has a maximum elevation of 256 m. Its name owes its origin to the light coloured cliffs facing the ocean in the west side. It lies close to the island of Graciosa (northern cape) separated by a shallow strait, and it is apparent that the two eilands formerly have formed one single land area, now dissected by marine ingression (eustatic rise of the sea level) accompanied by abrasion.

The author called at this island on the way from Graciosa to Alegranza. There is at the southern end of the *isleta* a small harbourlike embayment in the basaltic lava rockground — a remnant of some ancient lava flows.

The *isleta* was already described topographically by O. Simony (1892) and this author gives also some excellent photographic pictures of the same. In fig. 2 a reproduction of one of them is given (in a simplified manner).

The author of this memoir climbed the southern slope up to the central plateau-like summit. The way up is very steep, and the outmost care is necessary to prevent accident. In the summit region there is however

a rather level ground to walk on and to admire the far reaching panoramas.

Montaña Clara is a huge volcanic edifice (256 m) or in the reality a twin volcano composed as it seems chiefly of pyroclastic material, stratified conformably with the original slopes of the mountain. But one will also find cross-cutting dikes of basaltic aspect. In the nearly vertical western cliff of the *isleta* one will observe — when passing in boat at some distance from the water's edge that there is a lava fill in a half conserved crater. Also the feeding channel is exposed leading upward from the base. — In the north side of the *isleta* we will find another crater here better conserved, and it should form an excellent harbour, if the waves of the northern trade wind did not penetrate with all their vigour through the gate open in that direction.

In the southernmost part of the *isleta* there is the remnant of a third cone, of smaller dimensions, as may be found from the sketch made after the photograph O. SIMONY's.

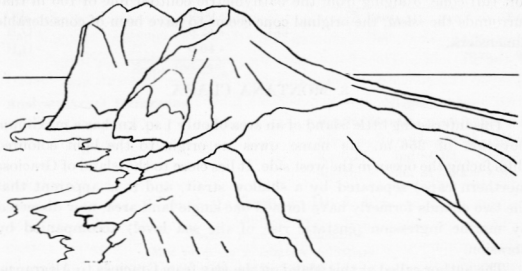

Fig. 2. Montaña Clara from the southern end of the island. A copy after a photograph taken by O. SIMONY (1892). In the foreground a smaller cone. The main part of the island consists of a twin volcano, half destroyed by the surf.

Montaña Clara is on they way to complete destruction by the attack of the ocean, and much of it has already disappeared. It offers another good example of such a destructive process, far more impressive than that of Roque del Este.

The author has a few samples from Monataña Clara, later on completed with some committed to his disposal by T. BRAVO, who also had

made call on the *isleta* (n:ris 17, 17 a, 17 b, 20, all referring to eruptive rocks).

One sample taken of the lava at the landing place in the low southern part of the *isleta* is a fine grained basalt. Micr. it contains rel. small phenocrysts of olivine, marginally altered to bowlingite. Other constituents are a clear plagioclase, augite and magnetite. It is a rather ordinary olivine basalt. The olivine has opt. char. negative, $2V \sim 90°$. The lava shows vertical columnar jointings. It is the vanishing remnant of an (once vast) lava sheet that has expanded over the surrounding ground, probably emitted from a vent in the small southern cone.

In the upper region of the *isleta* there are *dikes* of basalt cutting across the tuff and agglomerate masses that build the main part of the island. They carry in places xenoliths of alien rocks. From the collection belonging to the Canarian Museum (Bravo) I got a sample of such a xenolith. It proved to be a basic granular rock consisting micr. of three components: olivine, augite and iron ore. Olivine is the main mineral appearing in rel. large allotriomorphic individuals; between them augite and ore form a kind of mesostasis (see the microphoto fig. 1, 2, plate II). On the U: stage the olivine shows $2V\alpha = 80°-85°$ (corr. to 25—35% of the Fa mol.). The augite has $2V\gamma = 60°-70°$. Ext. on (010) $c \wedge \gamma = 40°-45°$. Plagioclase did not appear in the slide. The rock may be classified as a peridotite. It is conceivable that it belongs to a group of basic and ultrabasic ophiolitic rocks that we will meet in the so-called Trapp formation forming the basement of the southernmost neighbour island Fuerteventura (Hausen 1958).

In the collection of T. Bravo there are also samples of olivine bombs (?) from the same *isleta*, but the author does not dispose of such ones. — The dikes enclosing the fragments of deep seated rocks seem to be rather ordinary olivine basalts. The only sample to the author's use is a somewhat glassy olivine basalt with small olivine phenocrysts lying in a paste carrying small augite prisms and plagioclase microlites. Besides there is plenty of iron ore powder. The type shows similarity with the basalts described from Roque del Este and from Alegranza. The olivine of the dike rock from Montaña Clara is crystallogr. well developed. $2V\alpha = 80°$ (corr. to 35% of the Fa mol.).

A short distance to the northeast from Montaña Clara there lies the small abrasion remnant Roque del Oeste, or Roque del Infierno. I have no sample from this *isleta*, and O. Simony (1892) who landed there, does not mention anything of geologic interest. It

seems that this *isleta* once belonged to the volcanic apparatus of Montaña Clara but has since then been separated from it (by abrasion).

In the southern part of Montaña Clara there is a relatively flat ground called Llano de Aljibe, and this ground is in parts covered with a sandstone of calcareous composition, carrying fossils of *Helix* and *Stenogyra*. It is a terrestric deposit of a kind that we will meet with rather abundantly in the island of Graciosa and especially in Lanzarote.

Montaña Clara is as was mentioned the remnant of a larger land area that comprised also Graciosa. The connection was broken probably at the fin of the Quaternary era as a consequence of the eustatic rise of the ocean level. To the same transgression belongs also the destruction of the western part of the same *isleta* and probably also the isolation of Roque del Infierno from Montaña Clara. The softness of the material composing the *isletas* favoured this relatively great speed of land conquest.

All the mentioned *isletas* scattered over a vast expanse to the north of Lanzarote lie inside a shelf that in the west drops to considerable depths. We have to suppose the former existence of a land area in th the northern prolongation of Lanzarote at a time when this island was united also with the southern neighbour Fuerteventura, i.e. over the present Strait of La Bocaina. All these eastern members of the Canarian archipelago lack that kind of independence we will find concerning the western Canaries (including Gran Canaria). The latter are really well isolated insular masses surrounded by great depths.

4. GRACIOSA

The island of Graciosa lies close to the northwestern coast of Lanzarote, separated from it by the rather shallow strait of El Río. Graciosa has an area of only 27 sq. km and an elongated shape with the longitudinal axis running NE—SW. The basement of the island is of insignificant heights, but it is crowned with a number of volcanic cones, the loftiest of them attaining 266 m, called Montaña de Pedro Barba. The coasts are low and sandy, the only precipice is to be found at the southern shore, a cut across the foot of the volcano Montaña Amarilla. One small sector of the eastern coast has also some rocky capes, the ends of old lava streams. The southeastern coast is sandy and low and here the one of the two settlements of the island, Caleta del Sebo is situated.

Geologically Graciosa does not offer much of interest. As far as the

basement is concerned this is nearly completely hidden beneath the materials of the superimposed volcanoes numbering 7, but also by sedimentary deposits — a calcareous sandstone and masses of drifting sands. The author is of the opinion that the (invisible) basement of Graciosa consists of the old basaltic table-land series that composes the near lying Acantilado de Guatifay — Famara of Lanzarote. The western continuation of this table-land was however thrown down by great displacements at a time antedating the accumulation of the volcanoes in Graciosa. No direct proofs are however to be found to support this idea.

The volcanic activity that created the row of cones following the axis of the island seems to belong to the same period as the volcanoes of the isletas above described — they are Quaternary in age. The name of the cones are (from north to south): Montaña Bermeja, Morro de las Corujas, Morros de Pedro Barba, Agujas Chicas y Grandes, Montaña del Mojón and Montaña Amarilla (at the southern end of the island). The cones are slaggy, and they have all a dull colour contrasting against the bright yellow sand fields in the surroundings.

The author made several excursions, one to the south shore (Mont. Amarilla), another to the north (Mont. Bermeja) and the whole northern shore, then I followed the east shore in its whole length. Moreover I climbed the volcanic massif of Pedro Barba and visited one sector of the western coast. Samples of the lava rocks were collected in places (30, 35, 37, 41) and likewise a number of limestones samples.

Here some geologic details will follow concerning both the volcanoes and the sedimentary cover.

If we start in the north, we will find here a long beach consisting at the water's edge of flat lying basalt surfaces, a platform that slopes gently seawards. It is a stretch extending from Playa Lambra in the west to Punta Pedro Barba in the east. Inland the basalt surface is overlain by sheets of limestone, to some extent used for burning purposes. It seems that this limestone formerly did have a wider extension seawards, but has been abraded to the high tide level during the general rise of the sea in the latest geologic period. It is not known how far inland the limestone can be followed, since the whole smooth surface in this northern part of the island is covered with sand as alluvial flats. The presence of the yellowish drifting calcareous sand (the so called *jable*) indicates the presence of a calcareous sandstone under the sand cover, a sediment of the same kind as that met with in Montaña Clara.

To the south from the northwesternmost cape, Punta Gorda there rises the volcano Montaña Bermeja (157 m) a scoriaceous cone that has sent lavas down to the northern coast and also to the west. In the lava fields that do not make impression of freshness, there are several *hornitos*, mostly as it seems collapsed into blocky humps. I took a sample of a lava to the west from the volcano, at the sea border. Micr. it is a blistery basalt with small phenocrysts of olivine showing the margins of the crystals altered to bowlingite. Opt. char. of the olivine is positive. The intergranular mass consists of plagioclase microlites, augite and magnetite. It seems to be a rather ordinary olivine basalt, not very fresh looking.

The lavas that have reached the sea have to some extent been abraded by the surf, — hence they cannot be of very late date.

To the south from the northern — sand covered — plain there rises the great group of the central volcanoes of the island the names of which have been mentioned above. The cones seem to consist of slags, and lavas have been sent to the north and to the east. A large «caldera» (the northernmost) is open to the north and was visited. A sample of such a lava from this northernmost of the cones is micr. of fine grain with phenocrysts of olivine (clear) and partly euhedral. Opt. char. is positive. The paste consists of plag., augite and ore, the latter abundantly. The rock is of more picritic composition.

Between the southernmost of the central cones Morros de Pedro Barba with Agujas Grandes and the next one to the south, Montaña del Mojón there is a broad gate, the bottom of which is covered with dune sands. It opens the way to the west coast from the eastern settlement. After passing through this gate one enters a rather wide coastal plain underlain by lavas, which appear at the sea border. The plain is called Llano de la Mareta. It is in the surface covered with a calcareous sandstone and drifting sand. At the sea border there are also loose boulders of a firm limestone (a rather pure lime), the stratum of which does not appear.

Montaña del Mojón (188 m) is an impressive cone, the sides of which are somewhat furrowed by erosion. The base of the cone lies relatively high above the sea, but there is no exposure of the basement as far as I could see. In the stretches down to the east coast sandstone layers do appear but these are certainly of later date than the cone.

No samples of lavas from this volcano have been collected. It seems that a stream has been emitted into southerly direction.

The southernmost of the Graciosa volcanoes is Montaña Amarilla (172 m) the name of which refers to a yellow-coloured precipice of sandstone in its southern foot, visible from long distances. Most of the southern part of the island is sandy with small dunes, but nerarer to Mont. Amarilla the ground exposes black lavas sent down to the north from the volcano. This has a wide »caldera» open to the north. I did not enter into the same, but proceeded over the western flanks to the south side. Some samples of the lavas were taken. One type in the north slope is micr. a typical olivine basalt with clear olivine phenorcrysts ($2V\sim90°$) lying in a paste of plagioclase, augite and ore. The augite is finely granulated and fills with the ore the interstices between the feldspar laths. The texture is basaltic.

Another lava sample was taken from the south side of the volcano resting on tuffs. It is micr. of the same type showing clear olivine phenocrysts in a paste of plagioclase (plenty), clinopyroxene and ore. Optics of the pyroxene: $2V\gamma=84°-88°$, $c\wedge\gamma=58°$ (aegirite-augite). Texture is basaltic. The rock is more feldsparrich than the ordinary ones that do approach the picrites in comp.

Of interest is the geologic profile that is exposed in the steep southern shore cliff of the island at the foot of the mountain. The bluff is composed of a brownish-yellowish mass, more like a sandstone, well stratified. The strata have a slight distal inclination, they seem to belong to the volcano; that must however be only an error. Seen from the sea the whole sediment is of imposing thickness and the stratification looks nearly horizontal. In the lower strata (close to the water's edge) there are plenty of nests of *Antophora* enclosed. The whole complex must belong to a terrestric calcareous sandstone formation that extends over wide stretches in Lanzarote. When following the shore to the east and passing the high profile one arrives suddenly to a tectonic limit, a vertical fault that separates the yellow sandstone from a grayish-white one, exposed in the shore bluffs farther to the east.

The yellow sandstone (calcareous sediment) is overlain by the basalt lavas appearing as black banks in higher levels above the substratum, and that leads to the conclusion that the cone and its lavas must be of later date than the sediment. — The former extension of the yellow strata was formerly certainly much greater, the sea has afterwards (in Post-glacial time?) conquered the major part of this soft material.

Looking at the geologic map of the whole region one will find the row of volcanoes lining Graciosa from NNE- to SSW to continue (after

a break of some km) in the mainland of Lanzarote in the Sóo volcanic file. Perhaps they all are arranged along a single volcano-tectonic fissure.

Along the southeast shore of Graciosa there are some interesting exposures of rocks that may briefly be described. — The edge of the shore is not high — only some m. One will find here at the top a light-yellowish, calcareous sandstone that seems to underlie considerable areas farther inland (or up to the foot of the volcanoes). This sediment rests on a limestone that is not in horizontal position but is *inclined* to the north and contains in some of its strata plenty of rounded pebbles consisting of various calcareous sandstones. One gets the impression that these dislocated strata belong to a sedimentary cover that once capped the old basement of the island, and that the disturbed position of the strata has something to do with the great tectonic movements producing the fault scarp of Guatifay—Famara along with the coast of Lanzarote.

Graciosa seems to be t h e f o r e l a n d to the horst mountains in the east, a low lying step fault platform, upon which the volcanoes in later time have been accumulated.

5. LANZAROTE

This main island of our region has already been briefly characterized. As was said it is *par préference* a volcanic island, and that means the island is in its main part crowded with young volcanoes, their lavas and pyroclastics, a real »nature reservation» of achievements of the endogenic forces, a fact that does not exclude examples of vigorous exogenic accumulative and destructive work as well.

The main geologic interest offered by Lanzarote is hence connected with the overwhelming multitude of fresh volcanic superficial manifestations. A book on Lanzarote will consequently be in the main a narration about volcanic phenomena, in this case limited to b a s a l t i c v o l c a n o e s. Lanzarote is a basaltic island, and this character is valid regarding all its formations. There exists as far as the author knows only one insignificant exception regarding the nature of volcanic material — an occurrence in Los Ajaches of a trachyandesite rock.

If we compare Lanzarote with its neighbour Fuerteventura (Hausen 1958) one geologic difference can immediately be recognized: the former island is devoid of an old basement, to which the so called »Syenite and Trapp formation» Fuerteventuras belongs. W e w i l l f i n d

in Lanzarote only the covering formations, beginning with a basaltic table-land series, whereas the old basement remains hidden in the depths. Such a supposition may be justified by the fact that the spilite series of Fuerteventura has a constant NNE trend straight toward the northern neighbour. —

We will in the following try to characterize the rock formations of Lanzarote starting with the relatively oldest one — the flat lying basalt formation, of which two separate parts — one in the north and another in the south — have been conserved. Then we will pass to the description of the group of volcanoes, whose age seems to start with the fin of the Tertiary and fill the time span of the Quaternary period. At last there are the young volcanoes giving the island its special stamp — belonging to the great eruptive spectacles 1730—1736 and ultimately those of the short activity-period in the year 1824.

a. THE BASALTIC BASEMENT FORMATION

As may be found from the geologic map appended to this memoir there appears an old basaltic formation in two widely separated parts of the island: on the one hand we have in the extreme north the peninsula-like Guatifay-Famara complex, a highland plateau, on the other, in the fartest south the mountain system of Los Ajaches with its western foreland, the plain of El Rubicón. Between these two end regions of the island there lies a large middle sector of completely different nature: it is an area filled with younger volcanic cones and their eruption-materials: lavas, lapillis and ashes. This general repartition has found its expression already in the map by KARL SAPPER (1906) and especially in the coloured geologic map by E. HERNÁNDEZ PACHECO (1910).

In the following we will somewhat more closely examine the geologic conditions both in the north and in the south, where the old formation dominates, looking both at the surface conditions and at the rocks that compose these remnants of a basement formation.

Guatifay — Famara Complex

This northern part of the island consists in the main of an elevated plateau of ab. 500—600 m heights with a culminating summit, Peñas del Chache 671 m, at the same time the highest point of Lanzarote. It is a very interesting and exciting part of the insular nature: to the west

there stretches a gigantic precipice ab. 20 km from Punta Fariones in the north to the vicinity of Teguise in the south with a southward decreasing height. The main part of this *acantilado* is limited by the sea, the narrow strait El Río that separates the island of Graciosa from the mainland. To the east the mountain plateau slopes less abruptly to the sea; here we meet with a system of old *V*:shaped valleys, all sloping to the coast. Some of these valleys have their head region cut off by the escarpment at El Río, as we will see later on more in detail (page 106); we have here apparently a part of an old drainage system that antedates the present day limitation of the island.

Some rather imposing volcanic cones have been superimposed on this mountain block, the loftiest of them being La Corona that has sent huge masses of lavas down the eastern declivities, filling in parts the old valleys. We will later on (page 67) describe these young volcanic manifestations.

The author has got familiar with most parts of this mountain block — only the western *acantilado* has not been examined sufficiently owing to the steepness of the precipices. The number of samples of rocks met with in the sequence of strata — lavas and tuffs — in these large geologic profiles does not cover the entire succession of flows and ash deposits that has built the mountain block. As far as I can see there is however a rather apparent monotony in the composition of the lavas (picritic olivine basalts), so that the lack of a complete collection does not mean so much.

If we begin in the extreme north, in Punta Fariones, the impressive cape of Meseta de Guatifay, where the surf of the ocean has cut off from the knife sharp lands end some stacks of rocks now rising above the foaming water, we have here a good geologic profile just to the east from the cape. In this profile we meet unexpectedly with a series of limestone layers intercalated into a mighty pile of basalt lava beds, the total thickness of which may be ab. 400 m; The limestone contains at least in its upper parts shells of *Helix* in well preserved condition. There is a sharp limit between the uppermost limestone bank and the overlying basalt lava bed. It is apparent that the limestone in this upper part has been altered into a semi-crystalline state thanks to the caloric effect of the superimposed lava.

When following the mountain slope to the SE one will find that the limestone formation thins out in that direction. The slopes are here rather steep, and one short valley follows another ending in the low

and relatively plain foreland to the east — the plain of Orzola. This plain — an old abrasion platform (?) — has more recently been overridden by a blocky lava stream that has been sent from a volcano more to the south in the vicinity of Los Lajares, called Quemadita de Orzola.

The meseta-like upper surface of this mountain block (Guatifay) is surprisingly even and is covered with a layer of *tosca blanca*. The northern termination is known as La Batería, from where an excellent panorama view can be obtained, when the weather is good.

Of the lavas composing the Guatifay mountain corner I have in my collection some samples (43, 44, 62). These lavas are all very like one another: they show phenocrysts of olivine, euhedral, surrounded by a dark rim of bowlingite. The paste consists of plagioclase, augite and iron ore. The augite is sometimes glomerophyric. The content of plagioclase is varying.

One sample of a lava bank lying ab. 100 m above the sea level and resting on the limestone formation (described page 108) shows micr. phenocrysts of olivine with a dark brown fringe of bowlingite and also larger grains of augite, the latter with a zonal structure with wandering extinction. $2Va$ of the olivine $=80°-85°$. The opt. axis of the augite is comp. small. Opt. char +. The paste is composed of plagioclase laths, of augite grains and magnetite in a basaltic texture. The rock looks quite fresh. — Another sample taken from a lava bed immediately above the limestone formation is micr. of similar aspect: euhedral phenocrysts of olivine with the dark rim around the grains lying in a dull coloured paste rich in augite and iron ore dust. The feldspar is subordinate in quantity. The olivine grains are magmatically corroded. The rock may be classified as a picrite basalt.

When following the steep cliffs at Punta Fariones somewhat to the south (opposite the Orzola village), one will find a promontory consisting of a somewhat coarser grained basalt type. The exposure of the rock is not of a horizontal bed in the lava series but as a small intrusion or a dike. Micr. one will find euhedral grains of olivine and also of augite (abundantly), often clustered into groups. The augite is zonal with a wandering extinction. The olivine is clear, but has a narrow fringe of opacite. There is in the paste sparsely of feldspar substance. Optics of the leading minerals are:

Olivine:	$2\ V\alpha = 83°$	(25% of the Fa mol.)
Augite:	$2\ V\gamma = 54°$,	$c \wedge \gamma = 53°$ (core)
	$2\ V\gamma = 44°$,	$c \wedge \gamma = 58°$ (shell)

The rock may be called a picrite of the more typical kind.

The author followed the highland border farther southwest to the head of Valle de Máguez, NW from Haría. Here some hard banks of fine grained basalts are met with resting on tuffs of redbrown colour. One sample of basalt proved to be rather heavy — apparently rich in magnetite. Micr. the rock shows clear phenocrysts of olivine, euhedral as the dominating mineral of the first generation. The crystals are surrounded by a dark fringe. Augite appears rather sparingly and with a glomerophyric arrangement. The paste consists chiefly of augite and magnetite, the latter very abundantly. Specific gravity of the rock =3,001. It is a picrite (ankaramite) with the feldspar component very restricted.

Not far from here, in the head region of Valle de Máguez (left side) there is a mighty exposure of lavas and brown tuffs of the old series well to be studied along a path that ascends from the valley bottom to the high *meseta*: southernmost part of Guatifay. From this slope there are no more samples than of a great dike cutting the concordant series (11, 71) Micr. they show euhedral but corroded phenocrysts of olivine surrounded by a brownish-yellowish fringe and lying in a paste of augite, plagioclase and iron ore. Texture is basaltic. $2Va$ of the olivine $=80°$. The rock is decidedly picritic in composition. The ratio plag.: augite is about 1:1. Magnetite appears with appr. 10%.

Starting from Haría as a base of operations one has good opportunities to study the old basalt formation in the surroundings. To the west from the town one can follow Valle de Haría uphill to its head (Rincón del Valle) that has the form of a *degollada* in the great Acantilado de Famara. The pass is limited to the north by Matos Verdes and La Mesa, two erosion summits, and to the south by the imposing table mountain Ganada (ab. 585 m), which latter was climbed by the author. The steepness of the north and east-sides of this table mountain is due to a hard and fine-grained lava bank forming the entire horizontal upper surface. It rests on brown tuffs apparently of great thickness. These soft layers have caused the *cuesta* with its protruding hard edge. Masses of angular boulders cover the slopes on all sides, loosened from the top lava bank.

The *meseta* Mont. Ganada has been covered with stratified brown and yellowish tuffs to a thickness of several metres. Later erosion has dissected much of the mantle.

Somewhat to the southeast from this *meseta* there is a high *cuesta* that is climbed in many turns by the highroad from Haría to Teguise.

Following the road uphill one has opportunity to study the rock succession here. We cannot describe the lava beds in detail but refer to the list page 43. The upper part of this great profile encloses a rather mighty agglomerate bank.

Following the same highroad further on in southerly direction the author arrived to the high plateau of Famara and headed for the highest point of the same, Peñas del Chache (671 m), the culminating point of the whole island.

Peñas del Chache is particularly the last remnant of a top lava sheet that from the surroundings has been worn away. The rock composing the summit is a fine-grained basalt with columnar jointings. Micr. the rock shows abundantly of phenocrysts of augite and olivine, the latter surrounded by a brown fringe. There are also small olivines completely altered. The paste has the usual composition. Optic data (U:stage) are:

Augite: 2 $V\gamma = 62°$, $c \wedge \gamma = 48°$
Olivine: 2 $V\gamma = 86° - 88°$ (0—10% Fa)

The extension of this summit rock is as was pointed out rather limited, and it is clear that the columnar partings have facilitated the disintegration of the formerly certainly very extensive top sheet.

Of this uppermost lava rock a chemical analysis was carried out with the following results:

Anal. n:o 3.

Sample n:o 92. Olivine basalt. Peñas del Chache (671 m altitude) Risco de Famara. Lanzarote

		Mol. prop.		Norm:		
SiO_2	41.85%	6940	or	2.4		
TiO_2	3.21 »	401	ab	10.3	31.5	
Al_2O_3	12.24 »	1198	an	18.8		
Cr_2O_3	0.09 »	6	ne	8.0		
Fe_2O_3	5.20 »	326	Σ Sal:		39.5	
FeO	7.07 »	984				
MnO	0.20 »	28				
NiO	0.05 »	7	di	26.8		
MgO	12.95 »	3212	ol	16.5		
CaO	11.75 »	2095	mt	7.6		
Na_2O	2.97 »	479	cm	0.1		
K_2O	0.41 »	43	il	6.1		
P_2O_5	0.82 »	58	ap	2.0		

S_2	0.01%	2	pr	(0.02)	
CO_2	0.00 »		Σ Fem:		59.1
H_2O+	0.72 »	400	H_2O		1.0
H_2O-	0.27 »			Sum:	99.6
	Sum: 99.81%				

Analyst: AULIS HEIKKINEN

Niggli values:
si = 79½, ti = 4.6, p = 0.7, s_2 = 0.02, h + = 4.6, al = 14, fm = 56, c = 24, alk = 6, k = 0.08, mg = 0.66, qz = −44½, al − fm′ = −42, al − alk = +8.

C. I. P. W. Classif. — III. 6. 3. 5.
Magma type: hornblenditic
Mol. prop. of normative feldspars %
Ab:An:Or = 21:74:5
MgO:FeO = 92:8

Valle de Temisa, the head of which lies to the south from Haría (see the topogr. map, fig. 12) slopes straight *E* to the *sotavento* coast. It is followed in its entire length by a road, branching off from the main road Teguise-Haría in a *degollada* on the watershed between this valley and Valle de Haría. The author followed Valle de Temisa and took a series of samples (see the list page 43). The old rock ground is rather well displayed in the steep sides and in the head region, where the rock sides plunge down rather suddenly. One can see a concordant succession of at least 10 basalt sheets in the precipices. In the middle of the altitude of these slopes there is a 5 m thick layer of brown soft tuff, at the lower limit of which a spring appears (Fuente de Chafaris). A tunnel has been opened in this tuff bank to recover more of the groundwater, but without any notable success. Sample from the lava sheet immediately above the tuff is micr. a quite ordinary pieritic olivine basalt with euhedral phenocrysts of olivine with a dark margin, lying in a paste filled with feldspar microlites, augite grains and iron ore dust. Some of the olivines are completely altered to a brown, isotropic substance. Farther down the right side of the valley along the road there appears another thick bank of brown tuff, interstratified between basalt sheets. There are both dense and amygdaloidal lavas (vesicles filled with radial bundles of zeolite). Some optic data about the minerals in the lavas are condensed in the list page 43.

The smooth highland plain that we could call M e s e t a d e F a-

m a r a, and whose culminating point is Peñas del Chache, is the remaining part of a very extensive table-land. The circumference of this has in the course of time been successively reduced, owing in part to great fault movements (and subsequent marine abrasion and weathering) in the west, and partly to the backward erosion of the many radiating valleys in the eastern half (see the topogr. map fig. 12). The same fate has suffered also the northern Meseta de Guatifay although the progress of the destructive agencies seems to have gone much farther here.

One of the east bound valleys has already been described — Valle de Temísa. Of the other valleys the author has followed the largest of them, Barranco de Teneguime, in its upper part canyon-like, lower down broadening into Vega de Guatiza. This valley has a SSE trend. It is the most vigorously eroded valley in the whole island.

There are many lava banks and tuff layers exposed in the sides of this *barranco*. The author could however not devote much time to their study. Only a few samples were collected. Barranco de Teneguime was followed first on the left side, where a mighty slope exposes a concordant series of rather thin lava banks, then on the right side along a rock terrace that broadens downward. The lava banks are here of great thickness. Then the terrace drops suddenly to the level ground of Vega de Guatiza that is covered with clasmatic products from the near lying large volcanoes (Mont. Guenia, M. Guatiza, M. Tinamala).

There are in the southern part of the highland other valleys sloping straight south. They are open and of mature aspect. The road from Haría descends one of them in great swings to Teguise, where the Famara massif is already considerably lower (and crowned with a volcanic cone Mont. Guanapay).

There are still to mention some rock types of the old table-land series, this time from the lower part of Acantilado de Famara, opposite Bahía de Penedo. I refer to the exposures in connection with the recently opened tunnel works for the recovery of ground water in the lower part of Acantilado de Famara (below Peñas del Chache).

The author has a small collection of samples from the tunnels there. The lavas belonging to the basal part of the table-land series, are as it seems mostly amygdaloidal basalts (n:ris 94, 95, 96, 97, 98 and 99).

One type shows phenocrysts of olivine marginally altered, but with the core also changed into aggregates of sec. minerals (calcite, chlorite) Diagnosis is therefore not possible. There are also euhedral phenocrysts of a grayish-lilaic augite showing zonal structure with a dark margin

and a paler coloured core ($2V\gamma = 70°$ diopside). The paste is very fine grained containing plagioclase, augite and ore. There are vesicles filled with zeolite subst.

There is in the same collection also a basalt without olivine showing euhedral phenocrysts of augite (of larger dimensions) lying in a paste composed of augite, plagioclase and ore (abundantly). Vesicles in the rock are filled with aragonite in radial bundles of elongated indiv., arranged in zones. Also isotropic zeolite occurs. There are also other amygdaloidal types with zeolite fills in the vesicles. Olivine represents the first generation.

From a lava bank of ab. 30 m thickness a sample was taken (lower part of the series, vicinity of the water tunnels); it shows micr. clear olivine phenocrysts, partly corroded with deep embayments. $2V$-large. There are also phenocrysts of augite, euhedral; in the paste we find more abundantly of the same in the shape of elongated prisms. $2V$ is large. There is very sparsely plagioclase (microlites) but instead powder of iron ore. Vesicles are filled with zeolite in radial bundles ($n<1.54$). The rock can be classified as an amygdaloidal picritic lava.

This basal part of the lava series of the old formation contains as it seems chiefly amygdaloidal types of basalts, in parts olivine bearing in parts without olivine.

Dikes are present cutting across the sequence of strata; no samples of them have been guarded as far as this western profile is concerned. They play their important rôle in the way of natural storage of the percolating ground water in this mountain block, as may be found from a report of technical nature written by T. Bravo for the Insular Government.

Finally we may try to arrange the samples examined in a list comprising 12 rocks (i.e. lava sheets) in which these samples follow one another from the highest situated sheet (Peñas del Chache) down to the lowermost one, encountered in the water gallery at Bahía de Penedo. At the same time the reader will be referred to the schematic cross profile E—W of the Famara massif with the numbers of samples placed appr. according to their relative altitude (fig. 3).

N:o	Rock name	leading minerals: olivine	augite	paste	Locality
92	picritic basalt	2 $V\gamma - 86°$ $-88°$	2 $V\gamma = 62°$, $c \wedge \gamma = 48°$,	plag. sparsely, iron-rich	Peñas del Chache (top sheet 671 m)
91	picritic basalt	2 $V\alpha - 88°$	in the paste	plag. sparsely, ore, zeolite	Upper part of the profile S fr. Haria
90	picritic basalt	2 $V\alpha - 88°$	zoned $c \wedge \gamma = 45°$	plag. sparsely, irou-rich, zeolite	Upper part of the profile S fr. Haría
89	picritic basalt	2 $V\alpha - 88°$	no phenocrysts	augite, ore plag. sparsely	Upper part of the profile S fr. Haría, below tuffs
88	picritic basalt	2 $V \sim 90°$	zoned	augite, ore, zeolite	Profile S fr. Haria
87	picritic basalt	altered	$\wedge \gamma = 54$ (max.zoned)	augite, plag., calcite	Lower part of the profile S fr. Haría
81	picritic basalt	2 $V\alpha - 85°$ corroded	only in the paste	augite, ore, plag. sparse	Valle de Temisa, upper part
82	picritic basalt	2 $V\alpha - 87°$ $-88°$	only in the paste	plag., augite, ore	Galeria Chafaris, Valle de Temisa
84	olivine basalt	2 $V\gamma - 85°$	only in the paste	augite, ore, zeolite	Valle de Temisa, upper part
85	picritic basalt	2 $V\gamma - 85°$	only in the paste	augite, ore, plag.,	Valle de Temisa, middle part
86	picritic basalt	2 V-large	sparsely, zoned	augite, ore, zeolite	Valle de Temisa, middle part
99	amygdaloid. basalt	altered	2 $V\gamma = 70°$, zoned	plag., augite, ore, zeolite	Galería de Famara, (Acantilado) 100 m ab. sea

This list does not represent a complete succession of lava beds; they follow however one another in relative age from base to top the whole comprising ab. 600 m in vertical direction. Layers of tuffs and agglomerates are excluded. We observe the rather small variations — there are chiefly lavas of picritic composition. Only one chemical analysis refers to the series (anal. n:o 3, corr. to sample n:o 92), as we will find representing a hornblenditic magma type. Most of the lavas are very probably of the same magma type or of an associate of it.

In the compilartory work by J. M. Fuster, E. Ibarrola and M. P. Lobato (1952) there are no less than 4 chemical analyses of rocks referring to Lanzarote, one of a sample from Risco de Famara (base), the

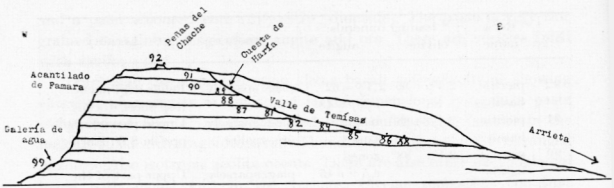

Fig. 3. Schematic cross profile W—E of the Famara massif with its concordant series of basalt lavas, tuffs and agglomerates. Numbered points corr. to the samples in the list page 43.

other from Risco del Charco. I suppose that the three latter ones also belong to the mountain block. These data have been reserved for a coming publication by J. M. FUSTER to which the reader is referred. I myself did not come upon such occurrences of deep seated granular rocks in the island. Maybe they are simply ejecta.

The Niggli-values of these 4 chemical analyses are reproduced here:

	Anal. n:o 4	Anal. n:o 5	Anal. n:o 6	Anal. n:o 7
si	117	101½	93	87½
ti	4.6	0.2	0.2	0.2
p	0.9	0.1	0.1	—
h+	22.0	0.1	0.3	1.1
al	26½	23½	32	28½
fm	34½	39½	36½	42½
c	23½	33	27	25½
alk	15½	4	4½	3½
k	0.41	0.25	0.17	0.23
mg	0.39	0.81	0.81	0.77
qz	−45	−14½	−25	−26½
al−fm.=	−8	−16	−4½	−14
al−alk=	+11	+19½	+27½	+25
		Ratios of normative feldspars %		
	Ab:An:Or 19:50:31	Ab:An:Or 13:83:4	Ab:An:Or 10:88:2	Ab:An:Or 8:89:3
		Magma types (Niggli)		
	normal sommaitic or normal theralitic gabbroid.	pyroxene gabbroid. or berondritic	ossipitic	achnahaitic
	Risco de Famara	Risco del Charco	Risco del Charco	Risco del Charco

The series quoted above shows as we will find a greater variation of types (a greater differentiation) than what is the case with most of the basaltic lavas of different ages. The first of the types quoted (of Risco de Famara) is the most salic of all the types known from the magmatic region of Lanzarote (except the porphyrite from Los Ajaches).

The southern mountains Los Ajaches

In the southeastern corner of the island there rises as we already have mentioned a quite well limited mountain massif called Los Ajaches. The length of the same from Punta del Papagayo (the south cape —) to the vicinity of Yaiza is ab. 6 km. Highest elevations are in Montaña de Atalaya 608 m, in Hacha Grande 561 m. The former summit is however, only a relatively young volcanic cone superimposed on the old rock ground.

Los Ajaches represent a counterpart to the Guatifay-Famara massif in the north, although it is much smaller in circumference. It is as the northern massif apparently a horst block standing above its downfaulted surroundings. — As we have found the northern massif has at least in its northern part the aspect of a *meseta* or a *tablero* according to local language, whereas the southern mountains have been much dissected by erosion. This valley erosion has progressed to such a stage that the cross-profile of the valleys is rather open, and the bottoms are filled with gravels. All the valleys are directed to the *sotavento* coast, as is the case also in the northern massif. The head of every one of the valleys coincides well with the western mountain rim, the main divide. The erosion pattern is consequently typically monosymmetric. To the west there is a fault scarp, facing the plain of Rubicón.

When following the individual valleys down to the *sotavento* coast one will observe that they do not widen to the coast as may be expected; instead they cross a rock terrace in a narrow gorge. This terrace has an elevation of ab. 15 m above the sea and may represent an old shore line (see page 107).

The author has made some excursions into this mountain system from the north, from Las Breñas and from Playa Blanca in the south. A number of samples has been collected (5, 6, 7, 8, 9, 10, 13, 14, 15, 157, 158). One of these, the most interesting of all (8) was obtained from the collection guarded in El Museo Canario, Las Palmas.

The series of basaltic lavas, tuffs, agglomerates and cross-cutting

dikes that compose Los Ajaches, do show a great similarity in their lithology with the northern massif. The same slight tilting of the sheets toward the *sotavento* coast is also to be found in the southern massif.

A great geologic profile is exposed in the steep slopes of the mountains towards the plains of Rubicón, especially in the upper parts of the escarpment that is free from the piedmont gravels. One will see here a great number of concordant lava sheets, apparently all basaltic, at least in the upper parts. Lower down (or to the limit of the gravel accumulations) there are huge masses of brown tuffs, which the author has followed for some while. Many dikes intersect the sheets, generally standing in a steep position.

The summits of Pico del Aceitunal (481 m), of Pico Redondo (550 m), Hacha Grande (561 m) and Hacha Chica (262 m) are the most prominent elevations standing on the very crest line. Sheets of lavas can be seen in these summits lying in a nearly horizontal position. The lava series can be followed northward to Lomo del Cura in the vicinity of Yaiza; the last named is a promontory due to erosion and not a volcano as indicated in the map by H. PACHECO.

A good profile is to be studied in the steep *cuesta* just to the west from Femés, opposite Las Breñas, where a path ascends to Femés. There are in the slope mighty brown tuffs covered with many hard banks of black basalt lavas, all crossed by dikes of basalt.

The village Femés lies in a broad saddle formed *degollada*, underlain by the basalts. — Going south from the village one ascends a long slope towards Pico del Aceitunal, the former completely travertine-covered. After reaching the watershed toward Barranco de Higueras one can see the steep slope of Pico del Aceitunal, where the brown tuffs and in the upper regions lavas are displayed. Many dikes cross the series, as it seems consisting of basalts or lamprophyres. The *barranco* was followed downward for some distance on its right side, then the author took a southern direction to Barranco de la Casita that descends from Pico Redondo. There are only basalt lavas to be seen in gently inclined position.

Another excursion was made to the southern part of the mountains, along the small Barranco de Juan Perdomo down to its mouth at the *sotavento* coast. Also in this region there are only the basaltic lavas to be seen, all gently inclined to the east. Besides there are cross cutting dikes. Also the boulders in the bottom gravels of the *barrancos* are all of basalts.

At the western base of Hacha Chica there is an exposure of a pale coloured trachytic rock acc. to a sample given to the author in El Museo Canario, Las Palmas (see below page 48).

Petrography of the rock samples

A lava bed in the upper part of the profile to the west from Femés (below the church) is an olivine basalt containing rather large phenocrysts of olivine, either euhedral or showing deep embayments due to magmatic corrosion. Some of the grains of the mineral are clustered. $2V\alpha$ of the olivine $=80°-90°$ (det. on the U:stage). Other components are augite and plagioclase and iron ore (magnetite) the proportions being appr. 40:30:20:10. The lava can be considered a picrite.

The dike rocks cutting across the lavas and tuffs are also olivine basalts. One dike in the Femés slope shows micr. well developed euhedral olivine phenocrysts, somewhat altered, representing the first generation. The paste is composed of plagioclase, augite and magnetite with the typical basaltic texture. The plagioclase matches the augite in quantity. The rock may be a rather ordinary olivine basalt, somewhat alkaline judging from the presence of analcime patches in the interstices between the feldspar laths.

One sample of a dike cutting through the brown tuffs in the eastern precipice of Pico del Aceitunal shows micr. olivine grains (altered) and also somewhat larger grains of augite in a paste of plagioclase, augite and iron ore. The augite has (U:stage det.) $2V\gamma=54°$. Ext. angle on (010) $c\wedge\gamma=44°$. The feldspar laths are turbid and cannot be nearer identified. Ore is abundantly present. The rock is a picrite.

Other samples refer to the southern part of the mountains. A type from Barranco Juan Perdomo shows micr. a picritic composition with phenocrysts of completely altered olivine, euhedral, and besides also phenocrysts of augite. That mineral appears however also abundantly in the groundmass, mostly as elongated prisms. Ext. angle on (010) $c\wedge\gamma=45°$. Iron ore grains are plenty present (appr. 10%). The texture is more granular than basaltic. Vesicles are mostly filled with a colourless isotropic substance (analcime?). Feldspar is very subordinately present, and the rock can be classified as an (altered) picrite lava.

Of a loose boulder in the bottom of Barr. Juan Perdomo one sample shows micr. a very similar composition with altered olivine phenocrysts

in a paste of plagioclase, augite and ore. There are also patches of an isotropic zeolite subst. Vesicles are filled with anisotropic zeolite with radial texture, but in the centre replaced by an isotropic subst. (analcime?)

There was found also a type somewhat richer in feldspar laths: plagioclase mingled with augite and ore, whereas completely altered olivine forms smaller phenocrysts. There is also an isotropic zeolite filling the interstices between the feldspar laths. The rock is an olivine basalt (altered) of the more ordinary kind.

We will find in the southern part of Los Ajaches many dikes cutting through the lava series, types with only olivine as the component of the first generation, whereas other have also augite belonging to the same group. The paste contains plagioclase, augite and ore in the usual proportions, sometimes, however, with the first named component more abundantly. — Still another dike rock shows except phenocrysts of olivine and augite also clear phenocrysts of a plagioclase, this mineral being richly present also in the paste. The larger grains are twinned acc. to the albite law, but the lamellae are few and broad. Acc. to meas. of the max. angle of ext. in the zone $\perp$ (010) the comp. may be that of a bytownite (Opt. char. —). The rock is an olivine basalt of the calc-alkaline series.

With the samples above characterized we may finish with our short descriptions of the basic series of Los Ajaches.

An occurrence of trachyandesite at the foot of Hacha Chica

E. Hernández Pacheco (l. c.) mentions the occurrence of »a salic intrusive rock» (petrographically not nearer characterized) in Los Ajaches, and according to his map the place lies near to the western foot of Hacha Chica. To find this place was the goal of the present author when he visited the region (1950). He failed, however, to locate the occurrence. By chance he was provided with a sample of the same rock from the collections of *El Museo Canario* in Las Palmas. This sample was labeled with »*Pereira Galbiati*» (as the collector) »Papagayos Lanzarote», no doubt from the same occurrence that was mentioned by H. Pacheco. This sample was used for a chemical analysis (n:o 8). During a visit to *El Museo de Historia Natural* in Madrid this year I got from Dr J. M. Fuster a slide of apparently the same rock that has been used in the following determinations of components together with a slide made from

the sample mentioned. The latter slide is labeled: »Base de Hacha Chica».

My co-worker Mr C. A. Wessman (Academy of Åbo) undertook an examination on the U:stage of the two slides of this rock. His attention was directed chiefly to the feldspar phenocrysts lying in a feldspar-rich paste with trachytoidal texture. — These phenocrysts are not very well crystallographically developed and comparatively small (mostly as fragments with dim. ab. 1 mm × 1 mm max.). These feldspars are twinned according to the Albite—Ala—B (Esterél) law, the two sets of lamellae (1 and 2) showing somewhat different values of $2V$, the values in the resp. sets varying also zoanlly and with the methods employed. The following figures may be presented here:

Feldspar phenocrysts in the slide made of the sample from *El Museo Canario* (Las Palmas):

$2\ V\alpha = 71° - 84°$ $\quad$ %An 29—30/35

Feldspar phenocrysts in the slide borrowed from the collections in *Museo de Historia Natural* (Madrid):

$2\ V\alpha = 79° - 80°$ $\quad$ %An 34

Mean figures are:

$2\ V\alpha = 78.5$ $\quad$ %An 32

The paste consists as was mentioned, chiefly of minute feldspar laths arranged acc. to a flow texture. They are clear and show ind. of refr. >1.54. Ext. in cuts $\perp$ to (010) of the laths is nearly parallel with the trace of this face, hence we may have a plagioclase of the oligoclase comp. — Of mafic minerals there are in the two slides scarcely any traces, except small laminated individuals of a brown-green mica with a feeble pleochroism. But on the other hand we will find stray grains of pseudomorphs with contours suggesting a hornblende. They consist of ferric oxide with the center occupied by chlorite. Quartz is not to be seen. Of accessory comp. there must be some apatite judging from the anal. data.

In the following a chemical analysis of this rock is given with the necessary calculated parameters:

Anal. n:o 8

Sample n:o 8. Trachyandesite[1] from Los Ajaches, foot of Hacha Chica. (Coll. El Museo Canario, Las Palmas). L a n z a r o t e.

		Mol prop.		Norm:		
SiO_2	59.03 %	9789	or	23.1		
TiO_2	0.68 »	85	ab	55.5	85.5	
Al_2O_3	18.20 »	1781	an	6.9		
Fe_2O_3	0.54 »	34	ne	0.2		
FeO	5.25 »	731	th	0.3		
MnO	0.14 »	20	C	0.5		
MgO	0.88 »	218		Σ Sal:		86.5
CaO	2.60 »	463				
Na_2O	6.77 »	1092	ol	8.0		
K_2O	3.91 »	415	mt	0.8		
P_2O_5	0.41 »	29	il	1.3		
SO_3	0.19 »	24	ap	1.0		
CO_2	0.52 »	118		Σ Fem:		11.1
H_2O+	0.77 »	427		Cal.		1.2
H_2O-	0.16 »			H_2O		0.9
	Sum: 100.05 %				Sum:	99.7

Analyst: Aulis Heikkinen

Niggli values:
si = 205, ti = 1.9, p = 0.6, so_3 = 0.4, co_2 = 2.5, h + = 9.0, al = 37½, fm = 21½, c = 9½, alk = 31½, k = 0.28, mg = 0.21, qz = −21, al − fm′ = +16, al − alk = +6.

C. I. P. W. Classif. — I. 5. 2. 4.
Laurvikose
Magma type: pulaskitic
Mol. prop. of normative feldspars %
Ab:An:Or = 62:14:24
MgO:FeO = 26:74

Sp.gr. = 2.239.

[1] The name trachyandesite (standing close to latite) was introduced by H. Rosenbusch to be kept apart as a group intermediate between alk. trachyte + phonolite on the one hand and trachydolerite on the other, but of course with transition types on both sides. The plutonic equivalent may be monzonite. Our rock may belong to the »Field n:o 9» in the double triangle Niggli—Tröger classifying the volcanic rocks. It would correspond to A. Rittmann's »light trachyandesite» with melanocrates (M) < 20. (See A. Rittmann, Nomenclature of Volcanic Rocks. Bulletin Volcanologique. Napoli 1952).

This pulaskitic magma fraction belongs no doubt to the late differentiates of the basalt lava series that builds the pile exposed in the mountains of Los Ajaches. There are in Fuerteventura very similar intrusive rocks of the same salic kind in the table-land series, as has been demonstrated in a previous publication by the author (1958). Regarding Lanzarote one will be somewhat surprised not to find such salic differentiates more commonly exposed by erosion. This scarceness reminds one of the conditions in the diametrally distant Isla de Hierro, where the existence of some solitary occurrence of a trachyte long ago has been indirectly proved and ultimately demonstrated by T. Bravo (verbal communications and show of a sample — taken from Roques de Salmor at El Golfo on the N coast).

The phenomenon with salic plugs and smaller intrusions is a rather common feature in the archipelago, where the old basaltic table-land lava series is met with (Hausen 1958).

In short: Los Ajaches is a mountain complex with a very concordant pile of olivine basalt lavas, tuffs and agglomerates to a min. thickness of ab. 600 m, slightly tilted to the east from a crest line that seems to coincide with the location of a great fault line that has cut off the series from its western continuation. The last named seems to be represented in the basement of the low foreland in that direction: the plain of Rubicón (see the following page!). An easterly continuation on the other hand has been cut off by marine abrasion; the same has occurred with the east trending old valley system furrowing the mountain block to a nearly mature stage.

The plain of Rubicón

Enclosed by the fault scarp of Los Ajaches in the east, by the great *malpaises* of Montaña del Fuego in the north and on the remaining sides by the sea there extends the level ground of Rubicón so called after its southern rim, the coast stretch at La Bocaína. This corner of the island has more the shape of a peninsula protruding in southwesterly direction, where it ends with Punta Pechiguera, on which a lighthouse stands. The whole area comprises ab. 20 sq. km. Near to its southwestern termination it is provided with a volcano cone of smaller size — Montaña Roja (194 m).

This plain lies approximately 50 m above the sea and rises slowly with the approach to the foot of Los Ajaches. The plain is underlain as has been proved by E. Hernández Pacheco (1910) by the old table-

land series, i.e. the same formation that composes the mountains in the east. The ancient beds of lavas and tuffs are exposed along the south and the west coast, forming abrasion cliffs. The series is dissected by a multitude of dikes that in parts have offered more resistance to the attack of the ocean. Near to Punta del Papagayo the colours of the formation are varying due to different weathering, hence the name Papagayo.

In the plain itself the old basalts are seldom exposed to the daylight; they are covered with gravel, sand or *tosca blanca*, to some extent also with blocky lavas emitted from the great Quaternary (?) volcano Montaña de Atalaya (608 m) that stands on the mountain edge above the small settlement Las Breñas. Other lavas have flowed from the small volcano Mont. Roja. All these effusions are as we will find, relatively young. Nearer to the foot of Los Ajaches there appears according to E. Hernández Pacheco (l. c.) also a marine limestone containing molluscs, a sediment-occurrence that did escape my observation.

H. Pacheco explains the presence of the wide and smooth western foreland to the mountains as the result of long lasting marine abrasion and the abrupt western side of the elevated part should be interpreted as and old sea cliff. The molluscs occurring at the foot of the slope should be an evidence of this transgression. The supposed abrasion must hence have terminated and changed into a regression before the volcano Montaña Roja had grown up on the same plain.

We will in the following return to these speculations.

No samples of rocks were collected from the rims of the plain of Rubicón (the sea cliffs in the west and in the south).

Part of the basement exposed in the vicinity of Tias

(Middle sector of the island)

During his traverses of Lanzarote G. Hartung (1857) did observe some exposures of the old table-land series in a region lying to the south from the Quaternary volcano Montaña Blanca in the south slope of the island, and he fixed this occurrence in his geologic map. The exposure here has never been covered by younger volcanic products — it represents a kind of »window» in the extensive mantle of the young volcanics. E. Hernández Pacheco (1910) has also found the occurrence (»Afloramiento basáltico de Montaña Blanca») and he mentions also a second site, close to Arrecife, found in a deep boring. — The former one has been fixed

in the map by H. PACHECO. He mentions also that sr S. PEREYRO has been able to prove that the old basalts do reach to the village Tías (direction WSW). Here we will find according to him, an old »sea cliff» of the table-land series.

Guided by these interesting notices the author devoted some time to excursions around Montaña Blanca and from here to Tías and its surroundings.

After leaving Arrecife in the direction of Montaña Blanca (the summit of which reaches 596 m above the sea) one sees how the old volcanoes (M. Blanca, M. Tersa, M. Bermeja) are standing on the upper rim of a highland that slopes to the *sotavento* coast. It is evident that these cones have been built upon an edge, and this latter may consist of some kind of an old basement.

Under such circumstances one would expect to find in the slopes toward the coast some erosion furrows or *barrancos* in the old rock ground. My excursions in the area did not prove the existence of such exposures except in the end of a small *barranco* just to the north from Aeropuerto de Guasimeta. Here a basement is overlain by a yellowish sandstone (Quaternary calcareous sediment) and this in its turn by a basalt lava sheet (emanated probably from Mont. Blanca).

I followed also the road from the village Güime to Tías on which route the small area of old basalts indicated in the map by H. PACHECO has to be traversed. There was on the route no such rock to be seen, only hard, dark-coloured agglomerates and lapillis, a superficial cover connected with the eruptions from Montaña Blanca. More to the west there are slopes leading down from the same volcano, but the ground here is extensively covered with loose pyroclastic products cut into furrows by erosion.

In the village Tías the conditions are however more illustrative. The settlement lies on the edge of an escarpment and is embraced on both sides by younger lava streams of blocky nature. These have emanated from the volcano Montaña Bermeja rising as a mighty cone straight to the north and situated on the edge of the inland plateau.

The author approached the village ascending from the sea shore. The path runs up the slope of a broad plain limited on both sides by the ridges formed by the mentioned lava arms. The path follows a dry water course, where the bedrock is exposed, forming smaller tresholds. The rock is an amygdaloidal lava of more ancient aspect. It is generally

covered with stratified tuffs of brownish colour. These tuffs are older than the lava streams in the sides, which immediately overlie the tuffs.

At the village Tías there has been conserved a bit of an old erosion landscape: the settlement is situated upon the broad treshold formed in the ancient lava formation (amygdaloidal, lime impregnated basalts) that has a very marked escarpment facing the *sotavento* coast. In this escarpment several *barrancos* have been eroded. That this bit of an old slope has been left free from later lava inundations (embracing it on both sides) depends on the fact that the treshold has the shape of a broad promontory. The houses of the village occupy the whole space between the two young lava arms and the village has to some degree also expanded over the bordering young lavas.

The author has only one sample of a lava from the old ground taken from a point below the escarpment (from a dry water course). Micr. this type is an olivine basalt of the more picritic kind with clear phenocrysts of olivine in a fine-grained paste with abundantly of augite in minute prisms, much iron ore dust and sparsely plagioclase microlites. The preponderance in the rock of the mafic minerals and the magnetite powder makes it considerably heavier than the young lavas of the Quaternary volcanoes in the vicinity. The relatively fresh aspect of this old lava seems to contradict its age in relation to the flows embracing it. The fields relations however are clear, and moreover the old lavas are intensely lime-impregnated, and — as was mentioned — furrowed by *barrancos*.

With this small visible part of the old basement the descriptions of the formation — the table-land series — is ended. We have now to turn our attention to the later volcanic products of the island.

b. THE LATE-TERTIARY AND THE QUATERNARY VOLCANOES AND THEIR PRODUCTS

There seems to exist a considerable hiatus between the formation of the basaltic table-land series and the great group of volcanoes now to be described. The basaltic table-land once forming a vast plateau surface far more extent that the circumference of the present Lanzarote — had been dissected by faultings in many ways, and horst mountains had come into existence. Such elevated portions are the northern and the southern ends of the present island, whereas the large middle sector represents a downthrow or a tectonic graben. This horst relief was of

course subjected to denudation, and many valleys were excavated. This period of exogene alterations of the surface seems to coincide with a pause separating the fault movements from the new volcanic cycle, now to be treated.

The new outbursts covered a major part of the island, and most of the orifices were located in the depressed middle sector. The material brought to the surface was to a large part of pyroclastic nature, in accordance with the fact that the eruptions did have the shape of violent explosions. Most of the cones are composed of slags, scoriae and lapilli, and the form of the cones has often attained a considerable height with slopes of the sliding-angle (33°). Typical of these cones is their wide caldera-like crater open in the northern sector. This circumstance is due to the trade wind that prevailed here also in these rather remote times.

As may be found from the geologic map of the island most of the cones are arranged along some master fissure lines running WSW—ENE, although there seem to be also other trends. E. Hernández Pacheco (l. c.) has stressed this linear arrangement also in his geologic map. It seems therefore that this chiefly Quaternary volcanic phase has been provoked by new faultings along the mentioned lines.

The author has visited most of these volcanoes and their surroundings and studied their erupted material. We may in the following pages shortly characterize these volcanoes and the composition of their lavas. It is not necessary to enter into details regarding the morphology of the cones, since this side of the matter has been largely dealt with by Hernández Pacheco (l. c.).

As is the case in the southern neighbour island Fuerteventura it is comparatively easy to recognize in the field the Quaternary volcanoes owing to the fact that they are coated with lime incrustations, and their flanks are generally furrowed by erosion. The lavas and the ash fields surrounding them are likewise lime incrusted or overgrown with a (scanty) bush vegetation — a *matorral*. In later time it has happened that a number of these cones has been coated by black ashes settled down during the great explosions in the XVIII:th century. This »false clothing» suggests a younger age of such cones than really is the case. In the time to follow the black ashes have in some cones been partly washed away by rains or swept clean by the wind.

If we start in the north with our study of these volcanoes we should indeed begin with the island of Alegranza, since here great cones of

Quaternary age are present. But we have already dealt with these volcanoes (page 19). The same can be said about the volcanoes of the isletas Roque del Este (nearly completely gnawed away by marine abrasion), Montaña Clara and of Graciosa (pages 27 and 34).

If we now go over to Lanzarote and look at the row of cones following the *barlovento* coast to the west from Bahía de Penedo, we will find a NNE—SSW trend that suggests a southern continuation of the file of cones crowning Graciosa. The group in Lanzarote is called Montañetas de Sóo, and these have wide caldera-like craters. The material consists of slags and scoriae, often red oxydized. In the E flank of the great cone Caldera Trasera there are in the upper regions also blocky basalt lavas, from which huge boulders have dropped down the slope to the foot. Sample was taken of this lava.

The cones are surrounded by fields of drifting sand (*jable*), the same that covers the wide plain to the east.

Going into the direction SW from the village Sóo one arrives after passing a desolate plain of blocky lavas and sand to the crescent shaped Caldera del Cuchillo with its crater wide open to the north. This relatively low volcano consists entirely of stratified brown tuffs and agglomerates enclosing a multitude of ejecta of basalts, olivinite and a marble-like limestone containing shells of molluscs. The strata are inclined comformably with the slopes. It is a typical explosion caldera of smaller dimensions from whose orifice stones of the underground have been hurled up. This basement consists as it seems (at least in part) of limestone of Tertiary age (?).

If we proceed farther south from Caldera del Cuchillo we arrive after crossing a sandy desert to a large group of older volcanoes arranged in an approximately E—W row between Tiagua and the *barlovento* coast. They seem all to have their wide craters open to the north and to consist in the main of clasmatics. The mostly smooth ground between these cones seems to consist also of loose ejecta forming a rather thick cover, decomposed and to a certain extent cultivated. Here lie the villages Tao, Tiagua, Vegueta, Tinajo and the finca Mancha Blanca. This relatively fertile region is limited to the south by another row of old cones of which Montaña Tamia (480 m) is the highest one. This volcano is provided with a large crater open to the NE and stands at the eastern end of the row, if we do not take into account the low lava-shield Lomo de San Andrés just to the east. On the extreme western end of the row we will find the largest caldera in the island, Caldera Blanca, climbed

from its northern side by the author. The Caldera is open to the north-west. This great cone is however separated from its eastern neighbours by a wide lava stream of later age (from the XVIII:th century) that has found its way down to the coast through this gap.

The mentioned lava stream is only an arm of a great flood of lavas from the same century covering most of the land surface to the south from the row of volcanoes. These lava fields are a part of the great »lava triangle» filling a great deal of the mid-western part of the island that will be treated in a succeding chapter.

There are some old cones rising above the vast lava deluge such as Montaña Ortiz, Mont. Negra, Mont. de Testeina and Mont. de Miraderos, all covered by ashes from the time of eruptions in the XVIII:th century. The last named large volcano was climbed by the author, and from the top a most impressive volcanic panorama was obtained (see the fig. 1 plate III). — M. Miraderos is entirely covered with a thick layer of black ash, lapilli and bombs. These old cones lie in the same ENE-WSW line that was used by the young orifices from the mentioned century. The western end of the row lies at the coast, and here we will find some interesting volcanoes, such as Mont. Juan Perdomo with a huge caldera nearly closed, and at the sea border the El Golfo volcano, half destroyed by the surf. The latter locality is much visited by tourists, and a carriage road connects it with Yaiza. I made also a visit to El Golfo.

The El Golfo volcano has two craters, the one in the north and the other in the west facing the open ocean. In the latter place one can see the cross profile of a volcanic apparatus: the half of the crater is conserved and the walls of it consist of stratified brown tuffs, covered with firm black lava sheets. At the base of this cross-profile there stands a neck of lava, the ancient volcanic throat-fill, smoothed by the swirling water at high tide. There is a gravel bar off the shore forming a small lagoon some 100 yards wide, and the water inside is yellowish (due to sea weed). To the north of the crater there is a vertical sea cliff consisting of red slags.

All the old cones of this region are coated with black ash, lapilli and bombs from the great eruptions in the XVIII:th century.

Farther south from the mentioned row one will find still other volcanoes of the old group, such as Pico Redondo, Caldera de la Vieja Gabriela, Caldera de Chozas etc. all completely or partly surrounded by lavas from the XVIII:th century (see the map). They are separated from the southern mountains (Los Ajaches) by a wide stream of lavas

emitted from Montaña del Fuego and described in the following. This lava stream is crossed by the highroad Yaiza—El Golfo. Passing along this road one will find in the midst of the lava jumble some *islotes* of the old ground, lime incrusted.

If we now leave this *barlovento* part of the island with its many cones of certainly Quaternary age mingled with the volcanoes of the later centuries, and go over to the *sotavento* coast region, we will find here a stately row of old cones following the coast line at a certain distance (varying between ab. 4 and 6 km:s). This southeastern row has a total length of no less than 40 km:s from the volcanoes of Guatiza in the extreme northeast to Montaña de Atalaya in the southwest. The author has visited nearly all these volcanoes and climbed many of them or entered into their craters. Samples of the lavas have also been collected although not to a greater amount.

The fact that the volcanic row in question stands at some distance from the *sotavento* coast can as it seems be explained in such a way that streams of lavas, sent from many of these orifices have successively built a broad coast slope (except in one sector, in the region of Tías as has been pointed out before, page 52). In fact wandering along the coast one will find many places where lavas of basaltic nature have been exposed either by marine abrasion or by *barranco* erosion. Especially to the north from the capital Arrecife the coast line has the typical rugged features of a lava shore with many small capes and engulfments. This rocky coast can be followed to Punta de Mala, where the row of volcanoes in fact finds its N termination. In the opposite direction to the west from Arrecife the coast line is mostly smooth and sandy, except in one small sector, and that may depend of the appearance of the old basaltic table-land formation here.

The city of Arrecife (*arrecife* — reef) is built upon the terminus of long lava streams that probably originated in the volcano La Mina 7 km distant.

Starting in the northern end of the row of cones we have here the impressive group of the Guatiza volcanoes, the largest of them in the south with a caldera open in northerly direction. The cones stand rather close one to another and are surrounded by mighty sediments of pyroclastic material, stratified. Here numerous explosions have taken place, whereas lavas have found their way to the coast; streams of black jumble. Somewhat to the south from this group there rises the great cone Tinamala 323 m ab. one kilometer distant from the sea. It has likewise

a large crater and its flanks are furrowed by erosion. About one km inland from this cone there rises another, Montaña de Guenia (359 m) also with furrowed flanks. I entered its one crater (open to the north) and got a sample of its lavas, always basalts. The pyroclastic material from all these wents has of course settled down in the region and filled all basins, so that a plain — Vega de Guatiza has been formed, a good farming ground. Also to the south from Mont. Guenia there has been deposited much pyroclastic material, now largely exploited for the dry farming.

More to the south there follows the group of the Saga volcanoes, rather low hills, sending streams of lavas to the sea in NE. Sample was taken of the basalt lava. — A short distance from here to the southwest there rises the conspicuous cone Montaña Tahiche (321 m) with huge masses of blocky lavas sent into the direction NE and E down to the coast. The village Tahiche lies at the western foot of the cone that has been somewhat eroded. The coast opposite this volcano, »Costa del Tiburón», is very rugged and rocky, cut into the lavas of basalts that have reached the sea.

Further in the southwesterly direction there is a break in the row of the volcanoes that has been used as backdoor of escape of lava from the outbursts in the XVIII:th century. A narrow tongue has found its way down to the coast to the vicinity of the small Puerto Naos lying to the north from Arrecife. This tongue is still clearly visible as a black, low ridge contrasting against the pale-yellowish *tosca*-covered ground in the surroundings (see the fig. 6).

Before continuing our way in the southwestern direction we have to look at some more solitary cones located in the southern declivities of the Famara highland that ends in the vicinity of Tahiche. Of these inland cones the most remarkable is Montaña de Guanapay (452 m) standing on a basement of the old table-land series of basalts. The cone was climbed by the author. It consists of slags and blocky lavas, but the lower slopes are covered with clasmatics. In the top there is a large and deep crater, completely enclosed by its walls. On the western rim there stands a ruin of a castle, from where one gets a magnificent panorama over this part of the island and of the adjoined sea. It was in old times an important lookout (*Atalaya*) for the sentries that kept an eye on the sea, when buccaneers roamed in these latitudes, trying to assault the inhabitants of the island. The old capital of Lanzarote, Teguise lies at the foot of this volcano.

I looked for lava streams that may have been sent from this cone or from its vicinity, but nothing was found,[1] only the pyroclastic material covering a surface of considerable extension. Remarkable is the solitary situation of the cone rising over the relatively smooth highland plain.

Turning again to the coastal row of cones, these follow one after another in a glorious parade all the way to the Atalaya volcano in the vicinity of Yaiza. There are Mont. de Maneje, M. de Zonzamas, M. de Mina (443 m) and M. Guatisea (521 m), the three last named visited by the author. They have all large caldera-like craters open to the north. In the vicinity of the last named volcano just to the north of it there are the twin calderas of San Bartolomé, also visited by me. From them samples of lavas were collected.

Quite close to the south from M. Guatisea there rises the most impressive cone of the row in question, Montaña Blanca (596 m) with flanks furrowed by erosion and a veil of travertine (hence the name). There is left a gate between the two stately cones, and a river has formerly eroded a *barranco* in the pass leading down to the coast slope. — M. Blanca has sent lavas to the coast exposed in a *barranco* not far from Aeropuerto de Guasimeta. A sample of lava was taken from here.

Montaña Blanca stands as has been mentioned on the edge of the old basalt series of the table-land (page 53), hence the considerable height of the cone. Its eruptions consisted in the ejection of pyroclastics and emission of lavas (»Strombolian» activity). The former are accumulated chiefly at the southern flank of the volcano.

Montaña Blanca is a regular cone with a top crater quite closed. The cone has a small »satellite» of red slags at the southeastern foot.

From Montaña Blanca onwards into the direction WSW there is a line of volcanoes right down to the vicinity of the village Uga, ending with the cone Montaña Miguel Ruiz. The cones stand rather closely one to another so that the whole aspect is like a »cordillera», provided with several saddle-like passes or *degolladas*. The number of cones in this sector amounts 10. The barrier that has been formed in this way against the *sotavento* coastal slope has prevented the great lava inundations of the XVIII:th century from an advance toward the sea, except in one place: at the eastern flank of the cone Montaña Asomada,

[1] Nothing with certainty at least. In the escarpment to the SW from the villa there has been exposed a lava that seems to be younger than the basement series.

where a narrow lava arm has reached down to the sea border (indicated already in the map by E. HERNÁNDEZ PACHECO). Most of the volcanoes in the row are coated with black ashes belonging to the young eruptions in the interior, here and there washed away by the rains in the course of the nearly 230 years that have elapsed since the eruptions.

Many of the Quaternary cones offer interesting details concerning their morphology, described already by H. PACHECO. The author climbed several of the cones, such as Montaña de Guardilama that has a very deep crater not visible from an outside standpoint.

Lavas have been emitted from several of the cones, of which Mont. Bermeja (above Tías) has been especially productive. It has sent streams down to the coast that have dropped like cascades over the ancient treshold of the basement formation, in this sector embracing as has been told the area in which the village Tías has later on been built.

Inside the row here characterized there lie some volcanoes among which Mont. Diama and Mont. Chupaderos are the most important. The latter has a wide caldera facing the lava fields in the northwest. They are all coated with the black ashes of the XVIII:th century, and the same is of course the case with the intervening low ground in the surroundings of the village Gería, the renowned wine yards-district of the island. Also fig tree plantations have been raised here.

There is a wide gap in the row of cones just before reaching the town Uga, and here the highroad from Arrecife finds a passage to the settlement. Montaña Miguel Ruiz (318 m) that stands on the left side of the gate, is a stately cone with a crater open to the northeast. It is a cone that has not been veiled by the young black ashes.

The lavas of the great inundations from the XVIII:th century did not find an outlet through the pass of Uga, although the end of a tongue stopped immediately at the outskirts of the menaced town.

Passing the town of Yaiza we have to observe the imposing cone Montaña Atalaya standing on the northwestern corner of Los Ajaches. It rises to 608 m, one of the higher points of the island. One may ask if this volcano really belongs to the old row of cones or if it eventually is to be placed in the group of the sub-Recent volcanoes of which Montaña de la Corona in the north is a good representative (of pre-historic age). The author is inclined to think that Mont. Atalaya is of the old group. It fits well into the lineation of these cones and should mark its extremity end in WSW. The cone is somewhat eroded in its flanks, and the lavas emitted over the low foreland at Las Breñas are already weathered.

The cone has grown upon the basis of the old table-land series that constitutes the mountains here (Los Ajaches).

There remains a cone still to be mentioned, Montaña Roja, lying isolatedly in the southwestern corner of the island and rising to only 194 m height. The author has seen it only from some distance, but it does not make impression of a fresh cone (the name suggests a certain oxydation of the material). If this cone is to be added to the old row it will mark the ultimate end of it. In the reality it fits well into the lineation.

S u m m i n g u p what has been told about the Late-Tertiary and Quaternary volcanoes of Lanzarote we can state that these are in the main composed of loose eruptive material: of slags and scoriae, products of violent explosive activities. That is indicated also by the common presence of wide explosion-craters in the cones and in the amphitheatre-like shape of them: The accumulation of the loose material has been influenced by the trade wind that seems to have hold sway over the island since the times in question.

Nearly all the cones have been coated with lime incrustations (*tosca blanca*) indicating a more advanced age revealed also by the achievements of the flank erosion. Lavas have been produced in great quantities, now however mostly hidden beneath covers of drifting sands (see page 112) and — in the interior of the island — by the vast lava inundations and ashes of the XVIII:th century.

P e t r o g r a p h y o f t h e l a v a s

There are in the author's collection of lava rocks not very numerous samples referring to the volcanoes above described[1]. Chemical analyses of the lavas are still lacking, but this gap in our knowledge is filled with some analyses of (more or less) contemporaneous lavas from Alegranza and Roque del Este (pages 22 and 26).

Samples have been taken numbering 13, rather occasionally. Most of the slides show however a surprising monotony in mineral composition of the lavas. We will here give some details concerning them, starting with the more northerly situated volcanoes and proceed southward (southwestward).

In the crater of Montaña Guenia in the vicinity of Guatiza there

[1] Samples n:ris 106, 107, 109, 112, 121, 122, 124, 126, 127, 129, 149, 150 and 151.

is an olivine basalt showing micr. clear olivine phenocrysts of euhedral habit. The crystals are surrounded by a dark brownish fringe, bowlingite. Twins can be observed acc. to (011). $2V$ of the olivine $\sim 90°$. The paste consists of a fine grained aggregate of slender augite, of plagioclase microlites (partly altered) and iron ore powder, the latter abundantly. The paste shows the usual basaltic texture. The rock may be called an olivine basalt of more picritic composition.

To the south from Mont. Guenia, at the highroad from Guatiza to Teguise one will find at the border of a canyon lava sheets, sloping gently to the east. A sample from here is a typical olivine basalt with clear phenocrysts of olivine surrounded by a narrow rim of brownish subst. $2V\alpha$ of the olivine $= 85°$. The intergranular mass consists of plagioclase laths abundantly (comp. acc. to meas. in the S.Z. An_{69}), augite grains and iron ore. This lava is less picritic in comp. than most of the other samples belonging to the same group of volcanoes. It seems that the point of departure of the lava beds here may be sought for in the immediate vicinity of Mont. Guenia.

A sample in my collection refers to the end of a lava tongue emitted from one of the Saga volcanoes somewhat farther south in the immediate vicinity of the coast. Micr. the rock contains clear phenocrysts of olivine ($2V \sim 90°$) lying in a dark paste consisting of augite in small elongated prisms, iron ore abundantly and feldspar scarcely visible. Between crossed nicols the paste is rather dark. The composition of the lava indicates a picrite quite different from the feldspar-richer type just mentioned, from the vicinity of Mont. Guenia.

Of the lavas from Mont. Tahiche samples have not been guarded. On the other hand I have some from Caldera Honda and Caldera Chica de San Bartolomé (farther SW). The former sample refers to the southern rim of the great crater. The lava here is slaggy and blistery. Micr. one finds clear phenocrysts of olivine ($2V \sim 90°$). The plagioclase in the paste seems to be a labradorite judging from the max. ext. angle in the zone $\perp$ (010). The pyroxene is finely granulated. There are numerous rounded vesicles, all empty. The rock is to be considered a typical picrite basalt.

The sample from Caldera Chica de San Bartolomé is similar in comp., the olivine appearing likewise as clear phenocrysts ($2\ V\alpha = 85°$). In the paste the relative amount of plagioclase seems to be somewhat greater than in the preceding sample.

A rock at Puerto Naos (a sea cliff just to the south from the end of the long lava tongue of the XVIII:th century) on the *sotavento* coast is

micr. also an olivine basalt with the olivine of the first generation and with plagioclase rather abundantly in the paste. The comp. of this feldspar is acc. to the max. angle of ext. in the zone $\perp$ (010)=An_{55}. Besides there is about the same quantity of augite in the paste, sometimes also as larger grains of grayish-lilaic colour. The ore mineral is mostly flaky (ilmenite). Texture is basaltic. This lava looks somewhat younger than those described before; it is also decidedly more feldsparrich. It belongs to some streams that can be traced back to the volcanoes in the west. A microphoto of the rock is seen in the fig. 1, plate IV.

Further to the west we approach the lava streams that have emanated from the volcanoes beginning with Montaña Blanca and ending with Montaña Tinasoria.

A sample from a basalt lava bed resting on tuffs in the wall of a small *barranco* to the north from Aeropuerto de Guasimeta is likewise an olivine basalt with clear phenocrysts of olivine ($2V \sim 90°$) without any marginal alterations, lying in a fine-grained paste wery crowded with iron ore powder, with plagioclase microlites and augite grains. The lava looks rather fresh, has however been considerably eroded. It may be traced back either to Mont. Guatisea or to Mont. Blanca.

If we follow the highroad to Tías from Aeropuerto Guasimeta we arrive at first to the dry river bed of Barranco de la Puente fringed by a lava stream that has descended from the volcano Montaña Bermeja. The lava rests on tuffs. Micr. it is rather coarse grained (doleritic) with ophitic texture. The olivine phenocrysts are often elongated acc. to c. They are surrounded by a dark brown fringe of bowlingite (?). $2V \sim 90°$. The paste contains abundantly of plagioclase laths. They have appr. the comp. An_{60} (judging from the max. angle of ext. in the S.Z.). The rock may be classified as a rather ordinary olivine basalt, somewhat blistery with the pores empty.

In the immediate E vicinity of the village Tías there is another lava stream that like the former one can be traced to a vent connected with the volcano Montaña Bermeja. The lava is blocky in the surface and looks as if it were somewhat younger than the Quaternary lava streams which have built the declivities toward the *sotavento* coast. Micr. the rock is an olivine basalt with clear phenocrysts of olivine lying in a paste that consists of laths of plagioclase, augite and iron ore grains.

From Tías to the west there follows the row of great Quaternary volcanoes closely united one with another giving the aspect of a real

mountain chain (Mont. Asomada. Mont.[1] Gaida, Mont.[1] Guardilama, Mont.[1] Tinasoria). Then there follows the broad gate before approaching the town Uga.

The cones in this row are individualized by saddle-formed passes or *degolladas*. They are all heavily coated with the black ashes from the great eruptions in the XVIII:th century. The ash is very loose, and to climb the slopes is an uncomfortable undertaking. The author crossed the *degollada* between Mont. Gaida and Mont. Guardilama and climbed the northern rim of the deep caldera-like crater of the latter cone.

In the *degollada* that separates M. Gaida from the last named cone I took some samples of lava rocks, boulders dropped from the summit of the former one. Of these samples one is an olivine basalt with xenoliths of green olivinite. The rock is afanitic in the hand piece. Micr. the basalt is rather ordinary, olivine bearing with fresh olivine crystals as the first generation. One will find clear laths of plagioclase with the comp. An_{60-70} with well developed lamellae acc. to the albite law. In some of the larger plagioclase grains there occurs inclusions of augite.

After passing the above mentioned *degollada* one looks over a great deal of the interior parts of the island with its many volcanoes in the distance. The slopes of the row of volcanoes that now was crossed is also wrapped in the black ash veil right down to the smooth ground in the region of Gería (the wine district). In some of the steeper slopes the ash cover has been washed away by the rains. Down in the low ground the ash lies to a considerable thickness.

Climbing the northern rim of Caldera de Guardilama (highest point 603 m) I took some samples of the slaggy lava here that seems to compose the upper part of the mountain. There is a certain bed structure in the inner very steep sides of the crater wall. The rock is very tough and dense, and with a blow of the hammer it splits into knife-sharp wedges — apparently a glassy lava. It is mentioned already by E. Hernández Pacheco (l. c.) as a somewhat different type amongst the other basic lavas of the region. — Micr. (slides 149, 151) it is very fine grained without any distinct porphyritic texture. There are however smaller olivine grains scattered in a paste consisting to a great deal of fine feldspar needles (ind. of refr. >1.54). The olivine grains have a dark-brown rim or they are completely altered. $2V\alpha$ is large. The paste contains also opaque grains that seem to be some altered mafic component, and

[1] Also »Caldera de» . . .

besides there are plenty of divergently arranged flaky ore grains (ilmenite). but also smaller isometric grains, a powder disseminated in a glassy mesostasis of dark brown colour (isotropic). Pores in the rock are empty. — It is possible that this fine intersertal texture is a mere superficial phenomenon and that the rock in the interior may be holocrystalline. — This lava type may be classified as a basaltic vitrophyre, perhaps grading into andesite. Only a chemical analysis would reveal the true nature of the rock.

The data communicated above are all what here can be stated about the lavas belonging to the older group of volcanoes. To these characteristics are to be added (as we already have pointed out) also the descriptions of the Alegranza, Roque del Este, Montaña Clara and the Graciosa volcanoes, outliers that may belong to the same age group.

These Late-Tertiary (?) and Quaternary lavas are all olivine basalts, mostly approaching picrites.[1] This pronounced basic character is also manifested in the composition of the leading mineral — the olivine that has a composition with 10—20% of the Fa mol. These olivine grains that always belong to the first generation are sometimes marginally altered, but not so much as is the case in the old table-land basalts. The plagioclase mostly restricted to the paste in the shape of microlites is here subordinate in the most cases (except n:o 402, lava from Puerto Naos), and the augite dominates, having the form of prisms, mingled with magnetite grains and sometimes with a colourless isotropic substance (that may be analcime?). — Typical of these volcanic products are also the huge masses of pyroclastics, ashes, lapilli, slags and bombs piled in mighty covers around the cones. In the many gravel pits opened in them one will find a kind of stratification. The upper layers are always lime incrusted. — Among the ejecta there are often found types of deep seated, granular rocks such as olivinite, peridotite and anorthosite.

c. SUB-RECENT VOLCANIC MANIFESTATIONS

The very long period of volcanic activity that created the certainly one hundred cones strewn over the middle sector of the island lasted probably to the beginning of the (geologically) Recent period, prehistoric time. Since then the activity seems to have returned again to the island for some time, building a number of imposing volcanoes. This activity faded completely into silence before the arrival of the

[1] Or ankaramites *sensu* LACROIX.

first Europeans belonging to the expedition of JEAN DE BETHENCOURT. At least there are no verbal traditions left behind and kept in the mind from ancient colonists, which did come into contact with the aborigenes.

Owing to the freshness of the cones in question and of their vast lava fields that distinguishes them from *tosca*-coated Quaternary cones in the middle sector of the island they can be considered as representing a distinct phase of volcanism. This is a forerunner to the great volcanic catastrophes occurring in the first half of the 18:th century.

If we at first look at the northern part of Lanzarote, we observe here the impressive cone La Corona (610 m), described already by G. HARTUNG and HERNÁNDEZ PACHECO.[1] The cone with its truncated summit stands on a basement of the old basalt formation, hence the real altitude of this volcano is much lesser. From the crater huge masses of lavas have found their way into the surroundings, chiefly eastward, flooding a large sector of the declivities down to the coast. Another part of the lavas ran to the west in a relatively narrow stream and plunged down the precipice here to the border of Estrecho del Río, in the manner illustrated already by HARTUNG in his sketch (reproduced in fig. 4).

Lapilli, slag and ash materials were ejected also in considerable quantities, chiefly over the southern sector of the nearer surroundings and here a large gravel pit has been opened, from where truck loads are hauled into the fields around Máguez and Haría.

I have climbed the volcano from its northeastern side to the crater rim on this side, which is considerably lower than the other parts of the wall. Over this treshold lavas have poured down. It is apparent that at the time of the flows the crater was filled with lava up to the level of the treshold, but now there is a deep crater left behind: the fill was drained into the interior after the lava emission. As a consequence of this inward emptying of the volcanic throat a great deal of the inner sides of the crater walls have collapsed and the circumference has been greatly enlarged. The summit of the cone has got a much more truncated aspect than before. The depth of the crater down to the débris-filled bottom is according to measurements performed by O. SIMONY (1892) 170 m. The inner walls of the crater display a singular aspect of roughness with many overhanging rocky precipices reflecting the inner structure of the scoriaceous cone.

The lava floods found as was mentioned their way chiefly to the east,

[1] See the frontispiece panorama picture.

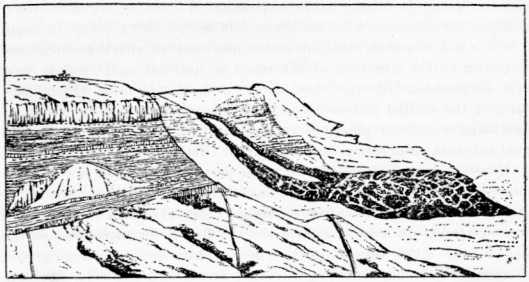

Fig. 4. Copy of a sketch published by G. HARTUNG (1857) in his book on Lanzarote and Fuerteventura illustrating the geologic conditions in Acantilado de Guatifay. A lava cascade (the southern one) of Sub Recent age can be seen issued from the volcano Los Helechos.

where they overran the valley-furrowed slopes of the old basement and reached the sea in many flows. The valleys were filled completely so that their existence can only be guessed. The great lava caves in the lower part of the lava field or *malpais* have been formed in the drowned valleys. The extension of this *malpais* is seen from the geologic map, and also from the special topographic map fig. 12. Northward the *malpais* coalesced with another lava stream issued from a northern smaller neighbour, Quemadita de Orzola.

Off the northern foot of the cone, where the ground is comparatively even, there were accumulated chaotic masses of blocky lavas. From here a part of the molten material has flowed to the west along a shallow valley-like depression and reached the rim of Acantilado de Guatifay, then it has plunged down in a tremendous cascade of more than 300 m altitude to the flat sandy beach at Estrecho del Río. If there lived at that time any pre-historic inhabitants in Graciosa, it must have been a frightening spectacle for them to see the glowing mass rushing down.

The lavas of Mont. La Corona are always slaggy and scoriaceous and generally full of empty cavities and air bubbles. Some samples have been collected by the author (63, 64, 65 (anal.), 66, 69, 70).

A sample from Vega Chica del Vallecito, i.e. from the western lava

arm, not far from the rim of the *acantilado*, where the lava flow made a sudden turn, is black and fine grained. Micr. it shows a basaltic texture of the paste, in which there are euhedral olivine phenocrysts, clear and without any border alterations. There are also prisms of augite. The clear plagioclase laths in the paste are relatively abundantly present. Opt. axial angle of the olivine phenocrysts is ~90°. The plagioclase seems to be of the comp. An_{60} judging from the max. ext. angle in the S.Z. The rock is to be classified as an ordinary olivine basalt. Probably there are in the paste some patches of analcime (altered nepheline?), since it is rather dark between +nic.

Another sample of the Coronalava taken at Los Lajares, a wine yard farm owned by the family LÓPEZ SOCAS, is of much the same micr. aspect. Meas. of the opt. angle on the U:stage of the olivine phenocrysts gave $2Va=80°$. There are no phenocrysts of augite, only glomerophyric lumps of smaller individuals. In the paste colourless isotropic patches are probably analcime. Texture is basaltic.

One sample taken from the very border of Acantilado de Guatifay, where the lava tongue plunged down the precipice, is somewhat more coarse grained than the previous types, and contains likewise olivine of the first generation. $2Va$ of the latter=84° (corr. to 20% of the Fa mol.). The laths of plagioclase are clear and seem to be of the comp. An_{50} (judging from the max. ext. angle in the S. Z.).

Of this rock a chemical analysis was performed the results of which are communicated below together with the usual parameters calculated:

Anal. n:o 9.

Sample n:o 65. Olivine basalt. Valle Dorado. lava from Montaña la Corona, (Coll. HAUSEN). Lanzarote.

		Mol. prop.			Norm:		
SiO_2	46.30%	7678	or		7.2		
TiO_2	2.78 »	347	ab		18.4	45.4	
Al_2O_3	13.70 »	1340	an		19.8		
Cr_2O_3	0.02 »	1	ne		4.2		
Fe_2O_3	2.70 »	169		Σ Sal:			49.6
FeO	8.46 »	1177					
MnO	0.18 »	25					
NiO	0.01 »	1	di		21.0		
MgO	10.65 »	2641	ol		18.3		
CaO	10.20 »	1818	mt		3.9		

Na_2O	3.09%	498	cm	(0.02)	
K_2O	1.22 »	129	il	5.3	
P_2O_5	0.70 »	49	ap	1.7	
CO_2	0.00 »		Σ Fem:	50.2	
H_2O+	0.20 »	111	H_2O	0.3	
H_2O-	0.10 »		Sum:	100.1	
Sum:	100.31%				

Analyst: AULIS HEIKKINEN

Niggli values:
si=96, ti=4.4, p=0.6, h+=1.4, al=16½, fm=52½, c=23, alk=8, k=0.21, mg=0.63, qz=−36, al−fm′=36, al−alk=+8½.

C. I. P. W. Classif. — III. 5. 3. 4.
Camptonose
Magma type: hornblenditic/essexitic gabbroid
Mol. prop. of normative feldspars %
Ab:An:Or=29:60:11
MgO:FeO=79:21

This one chemical analysis shows that the magmatic character has since the remote period, when the table-land series was expanded over the earth's surface remained almost the same. — The lavas are alk.-poor and they show more or less decidedly affinities to the alk-calcic-assemblage of rocks. The reader is referred to the petrochemical chapter at the end of this memoir and to the diagrams presented there (fig. 7 and 8).

A short distance from Mont. La Corona to the NNE there are two cones perhaps mere »satellites» to the main volcano: Torrecilla de los Apares and Quemadita de Orzola. The latter has sent a copious mass of blocky lavas down to the coastal plain of Orzola (in the northern end of Lanzarote) and covered the same except a small marginal zone at the foot of the steep mountain slope in the west. The lavas do form an asperous *malpais* reaching the sea and is united to the south (as was mentioned) with the vast lavas field of Mont. La Corona. Typical of the Orzola *malpais* are the enormous lava blocks lying in the lavas and carried down from the volcano (»lava ships» as they could be called). Such loose gigantic rootless blocks of lavas will be found also in other parts of the island. I have seen similar »erratics» likewise in Gran Canaria (Valle del Guiniguada).

No sample of the Orzola lava has been kept in the collection.

Not far in southwesterly direction from La Corona there is a group

of volcanoes known as Los Helechos, to which may be added a huge explosion caldera, Montaña Quemada, the southernmost one in the group. They stand all approximately in a line with La Corona and the space between the last named and the great cone of Los Helechos is filled up with some small lava hills that have been secondary centres of lava emission. Lavas were not sent from Montaña Quemada — the explosion caldera, but from two orifices just to the east from the caldera. They were the largest and filled a great deal of the highland plain called Los Llanos, over which a »witness hill» (M. Los Llanos) consisting of the old basalt series stands.

The author traversed all these volcanoes proceeding from the south. Very impressive is the caldera of Montaña La Quemada, closed on all sides. Its northern summit, culminating part of the wall, is called Montaña del Gallo, and here a triangulation mark (vertex) of INSTITUTO GEOGRÁFICO DE ESPAÑA has been fixed.

Los Helechos are two volcanic cones that have coalesced one into another; the northern larger one has a wide crater open in the same direction. From here large lava streams have been issued. One arm turned west down to the flat-bottomed Valle de Guinate, from where a part of the lava spilled down the *acantilado* to the coast of El Río, exactly in the same manner as the lava from the volcano La Corona farther north (Fig. 4).

The very curious *portillo* through which the Helechos-lava has passed seems to have been opened thanks to the straight cutting fault movements that created the *acantilado*.

Another lava stream of larger dimensions was directed to the east (east-southeast) running down to the coast, covering the declivities. The *malpaís* here comes into a close contact with the floods from Mont. la Corona, and one gets the impression that the former are the older ones.

Of the blocky lavas emitted from all these centres but a few samples have been guarded (68, 72, 73). A lava in the western wall of M. La Quemada shows micr. a very fine basaltic texture with small elongated (prismatic) olivine phenocrysts. The paste is rich in magnetite powder, and between +nic. it looks quite dark (zeolite?). $2V\alpha$ of the olivine — $=80°$. Another similar type picked up from the lava field near to the coast shows the same micr. characteristics. A third sample, taken from the road fork to Jameo de Agua (i.e. from the northern rim of the Helechos-lava stream) is micr. a glassy lava with euhedral olivine

phenocrysts. $2V\alpha = 80°$. The paste has a fluidal texture, and microlites of feldspar are scarcely discernible.

Of other Sub-Recent volcanoes we can mention Atalaya de Haría rising in the immediate vicinity of the town Haría, likewise in the northern part of Lanzarote.[1] It was climbed by the author, who in its culminating part found it to enclose a shallow caldera-like depression. On the whole the volcano does not look very fresh, and it seems to belong to a time antedating the eruptions in the vicinity (Los Helechos).

There are in my collection a few samples taken from the summit region of Atalaya de Haría. One type from the W part of the mountain is micr. rather ordinary in composition with clear phenocrysts of olivine ($2V\gamma = 88°$ corr. to a comp. with 5% of the Fa mol.) lying in a paste with plagioclase, augite and ore and with a typical basaltic texture. Pyroxene appears also in somewhat larger grains, glomerophyric. Another sample from the summit of the mountain is similar in composition. The olivine shows $2V\alpha = 85°$ (corr. to a comp. with 25% Fa). The paste is very fine grained. In both cases a marginal alteration of the olivine has taken place, hence the lavas are not perfectly fresh. The whole mountain leaves the impression of a somewhat more ancient volcano, older than those in the vicinity. No lavas from here could be detected, and one will perhaps be in doubt if this volcano really belongs to the Sub-Recent group.

In the vast volcanic field of the middle sector of the island there seems to be no representatives of the Sub-Recent (pre-historic) volcanoes.

In short: the Sub-Recent volcanic activity in Lanzarote has been concentrated to the northern part of the island, a rather curious fact if we consider that the main stage of endogenic events during the preceding long volcanic period — comprising perhaps millions of years — was confined to the middle sector of the island. In fact the most recent volcanism r e t u r n e d to the old stage after the cessation of the eruptive events in the north. The cause of this change is of course obscure. Perhaps it was the strait of El Río, a tectonically unstable zone that may have affected the Guatifay-Famara block at some time.

[1] This volcano is well discernible in the frontispiece panorama picture (to the right in the background).

d. VOLCANIC OUTBURSTS IN HISTORIC TIME

We have now to look at the volcanic formations in Lanzarote dating from times that followed after the arrival of the first European conquerors of the island (in the XV:th century). As far as is known there are but two periods of activity to be mentioned — the one comprising six years of the first half on the XVIII:th century, the other a part of the year 1824. In the Isletas there did not occur any outbursts in these later centuries. The first period lasted from 1730 to 1736 with some interruptions, and the other but some months. It is not necessary to describe these remarkable events in detail or the ravages they did cause, since all that has been dealt with by various writers beginning with L. von Buch (1825) (he did visit the island b e f o r e the outbursts in 1824) followed by G. Hartung (1857), K. von Fritsch (1867), O. Simony (1892), Karl Sapper (1906), E. Hernández Pacheco (1910), and L. Fernández Navarro (1919, 1925). We may therefore limit ourselves to the descriptions of some important centers of activity and to the lithologic side of the matter.

The great volcanic eruptions in the time 1730—36; their lavas and ash deposits

A glance at the appended geologic map reveals that the eruptions in question affected nearly 1/4 of the whole island and that this area is confined chiefly to the middle sector. The area has roughly the shape of a triangle with the apex in the east. Remarkable is that the broad coastal zone in the east (*sotavento*) nearly completely escaped the lava inundations thanks to the presence of a barrier of old volcanoes following at some distance the coast. On the other hand there was a broad front of advance of lavas toward the *barlovento* coast.

The magnitude of outbursts and the quantity of erupted material (lavas as well as ashes) surpassed all the events of that kind in the Canaries in Sub-Recent and Recent times. No less remarkable is the great number of orifices that were opened in this six year's period. They may be explained as depending on the great volcano-tectonic fissures running across the island in the ENE—WSW direction. These outbursts repeat the similar processes of the Quaternary period of activity in the same sector of the island, and one must only wonder that so long an interlude lies between the two acts of volcanic catastrophes.

The sequence of outbursts lasted as has been pointed out already, no less than six years, or from 1:th of November 1730 to 16:th of April 1736. The spectacles of the eruptions themselves and the ravages caused by them have found their describer in a contemporary reverend of the town of Yaiza, ANDRÉS LORENZO CURBELO. From his town that lies close to the southern rim of the great lava floods thence moving past the settlement to the west coast, he could follow the terrible events devastating nearly the entire middle sector of the island. His manuscript — meanwhile hidden in oblivion for a long time, was found by the German geologist LEOPOLD VON BUCH in a house in Santa Cruz de Tenerife at the beginning of the XIX:th century. The text is copied by him in his great work on the Canary Islands (1825), to which book the reader is referred in case of a major interest in the matter.

The accumulations of materials erupted from the many orifices during the six year's period have conquered no less than 1/4 of the entire surface of the island or approximately 200 sq. km. This area is in fact covered with a rough *malpaís* of blocky lavas, a wilderness still hostile to all human efforts to bring it under useful control, except what in later years has been done in the form of some thin roads (Mancha Blanca — Yaiza). Looking at the geologic map we will find that the area of devastation has a roughly triangular shape with the base at the *barlovento* coast, measuring here a length of ab. 20 km:s. The top of this triangle is to be found in the vicinity of the village Mosága in the backbone line of the island, ab 10 km:s from Arrecife. To the north and to the south this *malpaís*, the grandest in the Canaries, is confined by some old rows of volcanoes described in a previous chapter. These rows have hindered the lava from further inundations, except at two points: at Mosaga, in the apex of the »triangle» and at the eastern foot of the Quaternary volcano Montaña Asomada, where a very narrow pass was used by the lava to escape. The one of the outflows was directed to the east, the other to the south. The former one was the more important. It soon branched off into two arms, one running to the north into the plain of Penedo (between Teguise and Sóo), another turned east and in a winding course it advanced across the row of old volcanoes to the *sotavento* coast and ended at a point to the north from Puerto Naos (some km:s to the north from Arrecife). The latter lava arm is very impressive: a black, blocky stream crossing the whitish *tosca* covered coastal plain. The lava was followed by the author for several km:s A sketch of the same represents the fig. 5, made from the summit of

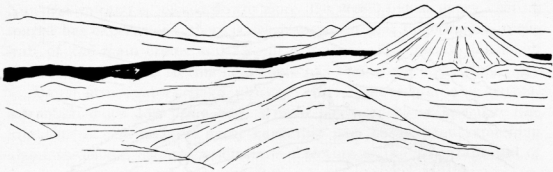

Fig. 5. A panorama view of the lava tongue (black) that found its way to the east and ended at Puerto Naos during the great eruptions in the year 1731. After a field sketch made by the author 1954 from the summit of Montaña Zonzamas to the northeast.

the volcano Montaña Zonzamas toward the northeast. See also G. HARTUNG's sketch, fig. 6.

The southward directed narrow lava tongue that passed by the cone Montaña Asomada and menaced the village Máguez, was also studied by the author.

It is no simple task to try to trace the lavas back to their points of issue, since most of the streams have coalesced into a single *malpais*. It seems however that a major part of these lava inundations did come from the center Montaña del Fuego, the old Timanfaya volcano that had suddenly awakened to a new and stormy life. Other important points of lava emissions were in the east in the region of Caldera Colorada.

The old surface of the island inundated by these lavas was a fertile agricultural area with a number of villages, now completely disappeared. Only scattered cupolas of the undulating old ground have here and there remained above the rugged *malpaises* and are now called by the inhabitants »islotes« (not to be confounded with the expression »isletas«, applied to the small islands to the north of Lanzarote).

The main mass of the lavas in question turned however west and advanced to the *barlovento* coast (as may be found from the geologic map). The front of the glowing, moving masses stopped at the sea border, where a lava coast of a singular shape was created. It was a gigantic stream or (more exactly) a great number of streams different also in time, but finally forming a nearly coherent field of lavas, interrupted by the old cones and the many *islotes*.

But there were erupted also immense quantities of ashes, lapillis and bombs. They were strewn over most of the area affected, but most

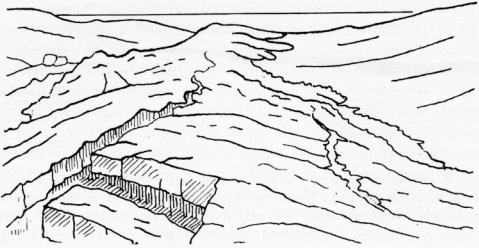

Fig. 6. Lower end of the basalt lava tongue that in the year 1731 found its way to the east coast of Lanzarote (Puerto Naos) from the Mosaga lava field during the great eruptions in the center of the island. After a sketch by G. HARTUNG (1857) published in his book on the geology of Lanzarote and Fuerteventura. Looking east.

abundantly at the southern rim of the triangle, inside the row of the Quaternary volcanoes there. The ashes appear over wide stretches as a continuous cover that comprises also many of the old cones such as Mont. Gaida, Mont. Guardilama, Mont. Tinasoria, Mont. Negra etc.

The author has undertaken several excursions into the area in question, the main route being the newly constructed highroad between Mancha Blanca in the north and Yaiza in the south. Besides I have followed a road from Yaiza northwestward to El Golfo and surroundings, and on the other hand the road from Yaiza over Uga to Tao, not to speak of smaller side excursions. Montaña del Fuego was visited two times, and many of the cones were climbed, several of the craters inspected.

We cannot enter here into descriptive details. Such ones are to be found chiefly in the work by E. HERNÁNDEZ PACHECO (1910). The author will, however, give a more particular picture of the most important center of eruptions — Montaña del Fuego and also make some remarks about other of the youngest volcanoes based on his personal impressions.

M o n t a ñ a d e l F u e g o. — This volcano with the significative name (»Mountain of Fire») is as we have mentioned in the reality an old volcano named Timanfaya, silent since time immemorial, but burst into activity in the year 1730. Then the volcano got its present name.

Now the volcano is »closed down» since 220 years; but as every visiting tourist has experienced, there is a subterranean heat lingering on in the wall of the main crater and also in a western side volcano (although about the real cause to this heat there has been some dispute).

Many investigators have already visited the remarkable natural attraction since 150 years ago. We do not need to recapitulate the literature in this respect; every naturalist who has written something about the island has given somehow a picture of the mountain and of the events once connected with it.

KARL SAPPER (1906) who made a croquis of the area (in the scale 1:50.000) has counted here no less than 25 volcanic orifices, of old age as well as from the Recent eruptions. The principal elevation, 510 m above the sea and 250 m above the surrounding lava fields, lies in the southern rim of the main crater that is elongated into the direction NW—SE. From the summit there extends a marked ridge (the SW crater wall) called Lomo de Azufre to the vicinity of Islote de Hilario.

Lavas have been emitted partly from the main crater, partly from side vents. A mighty lava cascade was formed over the NE treshold of the main crater down to the low ground in the north. Other still mightier flows turned east, south and then west to fill the whole space between Mont. del Fuego and the northern rim of Los Ajaches at Yaiza. On a broad front these lavas moved down to the *barlovento* coast stretching to the north from Charco de Janubio.

This gigantic lava field, (or more exactly lava stream) of max. 10 km breadth is now traversed by the highroad from Yaiza to Mancha Blanca, and there are consequently good opportunities to study the details of the flows. The same can be said about the traverse from Yaiza to El Golfo. The lavas are mostly blocky with many walls of jumbles of glassy boulders surrounding rather smooth surfaces with flow ripples in graceful curves. There are no possibilities to estimate the thickness of the lavas: certainly it must be rather varying regarding the fact that they have covered a hilly landscape. Following the flood of lavas from their point of issue at the crater opening down to the coast one will find the gradient changing: there are several »cataracts» on the way, where the lavas have plunged over obstacles or tresholds. Already in the uppermost course of the flows, where they are directed due south, the fall is ab. 50 m on a distance of 1 km.

At the southeastern foot of Montaña del Fuego there is a secondary vent from the last activity period, appearing as a group of hornitos

surrounding a collapsed caldera. A stream of lava has found its way to the southwest (see the photo fig. 1 plate IV). More to the west in the southern declivities of the chief volcano there are several other craters, which have sent blocky lavas down the slopes. In general the sides in this direction are much covered with ashes and lapilli.

Some distance to the northwest from the main focus there rises a hill called Islote de Hilario, being an old volcano. In the saddle pass between the Islote and the main complex of Mont. del Fuego there is an emanation of hot air from the ground, especially at places where a hole has been dug. This curious phenomenon is nearly an obligatory goal for the foreigners visiting the island. The temperature in the holes varies between 200° and 420°C. Such abnormal geothermic conditions are to be found also in other parts of the Mont. del Fuego complex as is more particularly explained in the report by M. CHAMORRO Y CUERVAS-MONS (1952). The general conception is that the heat may be the survival of »postmagmatic» nature of the lavas once erupted in this region, but there is no unanimity in this respect among the scientists.[1] In fact Montaña del Fuego — Islote de Hilario are the only places in the island where the subterranean heat has been observed, although many other centres of eruption appeared at the same time in the first half of the XVIII:th century.

Montaña del Fuego is as we already have found situated on a volcano-tectonic line running WSW—ENE (N 70° E), and this coincides with an old line of similar nature from the Quaternary period. The line in question is hence dotted with cones of Quaternary as well as Recent origin. The author has followed the zone in nearly its whole extent, from Mont. Juan Perdomo on the *barlovento* coast (or from El Golfo volcano) to Mont. Ortiz and Caldera Colorada in the extreme ENE. The arrangement of all these cones is, however, not strictly linear; there are several cones outside the main line. The most important of the volcanoes from the XVIII:th century are to be found in the middle sector of the line, where Mont. del Fuego stands at the one end, Mont. Rajada at the other. Then there are more to ENE stray cones in part of greater magnitude, such as Mont. Pico Partido and Mont. Caldera Colorada. A very impressive row of fresh cones is the so-called »Los Quemaditos» to the west from Montaña del Fuego. A curious aspect is offered by the

[1] CHAMORRO Y CUERVAS-MONS is inclined to count also with the disintegration heat of radioactive minerals (page 126).

deep Caldera de Fuencalientes, SE from Mont. del Fuego. It lies in the midst of the lava flood from the latter volcano like an island, and its bottom is much deeper than the surface of the surrounding lava. The author made his way to this caldera across the glassy *malpaises* starting from the highroad. The inner sides of this typical explosion caldera are very steep, and avalanches have often occurred. The caldera must have been formed at a time before the emission of the del-Fuego-lavas.

Pico Partido was climbed to its medium height. Its crater has been filled with lavas and an overflow has occurred to the northwest along a curious channel-like runway with vertical walls. In the lower surroundings NW of the cone there are numerous bombs of a peridotite with olivine as the leading mineral besides enstatite and some magnetite. The rock of the bombs has a rusty crust, and the fresh fracture is grass green.

Another volcano more to the east is Mont. Caldera Colorada the crater of which was climbed by the author. It is an important center of eruption, and huge masses of blocky lavas have flowed from here covering wide stretches of the surrounding ground. The crater is completely filled up with lavas, and the overflow has occurred in the north sector of the crater wall, where a veritable lava cascade has congealed to stone. The name Colorada owes its origin from the reddish oxydized slaggy material covering the slopes of the cone. Huge masses of ash seem also to have been ejected at some time since the old cone Montaña Negra somewhat to the south has been wrapped in a coating of black ash and lapilli (hence the name), a veritable »mourning attire». A part of the lava floods from here found its way to the west passing the gate between Pico Partido and a southern cone.

Petrographic data about the lavas from the XVIII:th century

The author has 1954 collected a number of samples from different parts of the volcanic area in question (n:ris 136, 139, 142, 144, 148, 152. 154, 155 and 17, coll. 1950). These samples are mostly in a glassy condition taken as they are from the superficial parts of the lava streams. The slides do not offer much interest, and mostly only the ever present leading mineral — the olivine — is well developed. A greater number of chemical analyses would complete the scanty petrographic data obtained from the slides, but of such ones there is only one to our disposal (see below, n:o 10!).

From the vicinity of the stately volcano Caldera Colorada that has

sent copious masses of lavas into the surroundings I have some samples. One shows micr. clear phenocrysts of olivine ($2V\alpha = 85°$) in a paste filled with plagioclase microlites, augite and iron ore. The relative amount of the ore (magnetite) is considerable. Vesicles in the paste are empty. The rock may be called an ordinary olivine basalt. — Another sample is of a lava emitted from the same volcano at the highroad from Mancha Blanca to Yaiza. It is an olivine basalt of rather fresh aspect with clear olivine phenocrysts ($2V\alpha$=nearly 90°). They lie in a paste consisting of plagioclase, augite and ore, the latter not very abundantly present. Vesicles in the rock are empty.

Another sample from a stream of lava that has flowed down to the west between Pico Partido and a cone to the south from it is of a less picritic aspect; there are plenty of plagioclase laths in the paste.

There are also other samples of the lavas from Caldera Colorada. They show but little variations. Olivine is the only mineral of the first generation with opt. char. negative and $2V \sim 90°$. The paste contains in a basaltic texture plag., augite and ore. Pores are empty. The same characteristics are met with in a lava taken from the road between Mancha Blanca and Máguez, and Teguise-Uga, 16 km from the latter place, or from the vicinity of the old ash-coated cone Montaña Negra.

If we go farther south we have the lavas issued from Montaña del Fuego. A sample was taken from the roadside on the way from the volcano to Yaiza. It is an usual olivine basalt but with fluidal texture of the paste. Also here the olivine phenocrysts lie in a paste of the other comp. $2V$ of the olivine $\sim 90°$. Another sample from the same broad stream of lavas that fills the space between Montaña del Fuego and the hills at Yaiza was taken at the road that leads from the mentioned village to El Golfo. $2V\alpha$ of the olivine phenocrysts in this rock $= 85°$.

From Lomo de Azufre, the southern rim of the main crater of Montaña del Fuego there is in the collection a sample that shows about the same characteristics; only that the olivine phenocrysts have opt. char. positive and $2V < 90°$. These grains have been magmatically corroded.

These lavas from the XVIII:th century are as we have found all of similar nature as far as the collections allow to conclude. They are olivine basalts with the olivine as the only component of the first generation, and the types approach the picrites; the content of salic minerals does not attain 50%. The plagioclase of the paste is as it seems generally of the intermediary kind (ind. of refr. > 1.54).

The ashes from the eruption period 1730—36 have not been more

exactly examined. They are black and of a rather coarse grain approaching lapillis in size. The thickness of the ash cover is mostly considerable, up to several metres, and the mass is stratified. The ash fields have proved suitable for the plantation of grape and of fig trees, especially in the district of Gería between Tao and Uga.

A special feature of the olivine basaltic lavas are the enclaves of olivinite (grass- green, granular) found in abundance in some parts of the lavas as for inst. between Tinajo and Uga, some km:s to the south from the former place. In this sense they are identical with the lavas from the outbursts 1824 that will be described later on.

There are still to mention some samples referring to l a r g e b o u l d e r s found at the southern side of Caldera Colorada, apparently ejected from the crater of this great volcano (n:ris 140, 143). They may belong to the basement of this cone, but if they represent the table-land series seems doubtful. Micr. these types are more feldspar-rich than those described above. The grains of the first generation are olivine and augite, the latter appears in parts in glomerophyric aggregates. Texture is basaltic. The olivine, (not altered) has opt. char. positive. The plagioclase has a comp. corr. to bytownite (acc. to meas. of the max. angle of ext. in the S.Z.). Hence the blocks are not very identical in composition with the Recent lavas but seem to be older, perhaps Sub-Recent in age (?).

Chemical analyses of samples collected by the author from the lavas of the XVIII:th century have not been carried out. There exists one of an earlier date, found in a paper by L. Fernández Navarro (1919) on the volcanic eruptions of historic time in the Canaries, and this analysis refers to a lava from a not nearer indicated locality. The data will here be quoted as filling a gap in the series of analyses of rocks of decreasing age. The rock in question is a »feldspar basalt».

Anal. n:o 10.

Basalt lava from the eruption period 1730—36. Locality not indicated. Data quoted from *L.* Fernández Navarro (1919). L a n z a r o t e.

		Mol. prop.	Norm:		
SiO_2	49.30%	8176	or	9.3	
TiO_2	3.79 »	473	ab	21.9	50.5
Al_2O_3	13.08 »	1280	an	19.3	
Fe_2O_3	0.96 »	60	Σ Sal:		50.5

FeO	10.44%	1453
MnO	0.00 »	
MgO	9.57 »	2373
CaO	9.40 »	1676
Na_2O	2.59 »	418
K_2O	1.58 »	168
P_2O_5	tr	
F_2	0.00 »	
H_2O	0.00 »	
Sum:	100.71%	

di	22.1
hy	3.3
ol	15.8
mt	1.4
il	7.2
Σ Fem:	49.8
Sum:	100.3

Analyst: A. LASSIEUR

Niggli values:
si = 109, ti = 6.3, al = 17, fm = 52½, c = 22½, alk = 8, k = 0.29, mg = 0.60, qz = −23, al − fm′ = −35½, al − alk = +9.

C. I. P. W. Classif. — III. 5. 3. 4.
Camptonose
Magma type: essexitic gabbroid.hornblenditic
Mol. prop. of normative feldspars %
Ab:An:Or = 33:54:13
MgO:FeO = 72:28

The ultimate volcanic outbursts — in the year 1824. Their 3 vents and their products

Not more than 9 years after LEOPOLD VON BUCH's visit to Lanzarote (1815) when he studied the fresh vestiges of the great catastrophes that had raged in Lanzarote in the time 1730—36, there was a somewhat unexpected volcanic activity in the same region, although on a much smaller scale. The manifestations of the subterranean forces were confined to three localities rather distant one from another, but attached approximately to one and the same volcano — tectonic fissure (?). These outbursts have been described by K. VON FRITSCH, KARL SAPPER and by E. HERNÁNDEZ PACHECO so that there is no necessity to enter into details. The author will deal only with the main facts and with personal impressions obtained during a visit in two of the eruptive centers (Clérigo Duarte and Tinguatón). Samples were taken and one of them was submitted to chemical analysis (n:o 11).

The three points of eruption lie as was mentioned in a line. This has an ENE—WSW trend. The easternmost volcano is Montaña Clérigo Duarte situated in the vicinity of the village Tao. It started its activity 31:th of July 1824, and a cinder cone grew up in a place where no sign of eruptions existed before. A blocky lava was emitted and lapillis were

ejected. The height of the cone grew to only 30 m above the surroundings.

The volcano is situated on a fissure in the old lava ground.

If we follow the above mentioned volcano-tectonic line (direction WSW) we will meet with the second new volcano, Tinguatón. This volcano is now easily accessible. One has only to follow the highroad from Mancha Blanca for some km into direction Yaiza and then take a side walk across a field of blocky lava to the left. Then one enters the »caldera» of Tinguatón in a narrow gate, a *portillo* that has the aspect of a small erosion channel, formed by running water (see the foto fig. 4 plate II). Inside the caldera-like crater of this young volcano one soon is aware of some deep eruption throats or empty natural shafts in the bottom of the caldera. The lavas all around consist of black, glassy basalt with many inclusions of green olivinite (or peridotite?). The caldera is well formed but not very deep in relation to the broad base of the cone.

Tinguatón appeared as a new volcano 16:th of October 1824 and was in the reality the latest of the three outbursts.

Its activity did not consist solely in the production of lavas, scoriae and lapilli, the last named settled over a vast surface to the south from the cone. From the mentioned holes in the bottom of the caldera great quantities of hot water were ejected and ran through the *portillo* in the north side into the fields. The erosion channel along which the water passed is completely unaltered since the 1 ¼ century that has elapsed since the remarkable phenomenon took place. — One may ask what kind of water was that? According to the author it seems likely that the water did come from the basal part of the island, where an infiltration of ocean water had taken place, perhaps mingled with a certain quantity of meteoric water percolating from the surface (basal ground water body). The fact that the island in our days is practically rainless does not exclude the possibility that atmospheric precipitation in earlier times may have accumulated water in the deep levels of the island.

The third volcano of the last century — Volcán Nuevo del Fuego- erupted 29:th of September, hence somewhat before Tinguatón. There has according to Hernández Pacheco (l. c.) been some discussion about the exact site of the new volcano that appeared in the vicinity of Montaña del Fuego. The author undertook an excursion to the region of the mentioned great volcano to try to locate the new orifice, but that proved rather difficult. Hernández Pacheco has in his geologic map (1910) placed this new volcano somewhat to the NNW from the main elevation of

Montaña del Fuego. From that point he has drawn a lava tongue of at least 6 km length in WNW direction straight to the *barlovento* coast (»Costa de Betancuria»), extending across the lava fields from the preceding century.

The last named orifice was not visited by H. PACHECO, and no sample of lavas from there have been available to me. On the other hand L. FERNÁNDEZ NAVARRO did dispose material for a chemical analysis of the lava (n:o 12).

These three eruptions confined to one and the same line (as it seems) covered a time span of only ab. 3 months, a rather insignificant episode compared with that of the preceding century. And the damage connected with the new outbursts may accordingly have been of no greater importance.

About the petrography of the young lavas connected with the three volcanoes there is not much to say. They seem all to be glassy including in parts olivine xenoliths.

A sample from a slaggy lava block taken from the summit of the volcano Clérigo Duarte is coke-black and glassy. Micr. one observes abundantly of olivine grains of insignificant sizes lying in an opaque glass basis with many empty pores. Besides there are stray prisms of a pale coloured augite, while plagioclase seems to have remained in the potential state. The opt. axial angle in the olivine was determined with the aid of the U:stage: $2V\alpha = 88°$ (corr. to 14% of the Fa mol.).

Of this lava rock a chemical analysis was carried out giving the following results:

Anal. n:o 11.

		Mol. prop.
SiO_2	44.35%	7355
TiO_2	2.55 »	318
Al_2O_3	12.63 »	1236
Cr_2O_3	0.06 »	4
Fe_2O_3	4.97 »	311
FeO	6.65 »	925
MnO	0.20 »	28
NiO	0.06 »	8
MgO	12.00 »	2976
CaO	11.07 »	1974
Na_2O	3.17 »	511

Sample n:o 113. Glassy lava from the new volcano Clérigo Duarte (eruption 1824). Lanzarote.

Norm:

or	7.4		
ab	12.6	36.5	
an	16.5		
ne	7.7		
Σ Sal:			44.2
di	25.3		
ol	15.7		
mt	7.2		
cm	0.1		
il	4.8		

K_2O	1.25%	133
P_2O_5	0.95 »	67
S_2	0.00 »	
CO_2	0.00 »	
H_2O+	0.18 »	100
H_2O-	0.00 »	
	Sum: 100.09%	

ap	2.3
Σ Fem:	55.4
H_2O	0.2
Sum:	99.8

Analyst: AULIS HEIKKINEN

Niggli values:
si = 87½, ti = 3.8, p = 0.8, h + − 1.2, al = 15, fm = 54, c = 23½, alk − 7½, k = 0.20, mg = 0.65, qz = −42½, al − fm, = −39, al − alk = +7½.

C. I. P. W. Classif. — III. 6. 3. 4.
Limburgose
Magma type: hornblenditic/kaulaitic
Mol. prop. of normative feldspars %
Ab:An:Or = 25:61:14
MgO:FeO = 90:10

Of the two remaining volcanoes from the same year of activity — 1824 — Tinguatón and Montaña Nueva del Fuego I have a sample of the former one taken from the bottom of the small caldera-like crater open in the northern side. The lava is black and glassy like that of Clérigo Duarte, but it carries rather abundantly of fragments of a green olivinite rock. — Micr. one observes clear crystals of olivine, somewhat magmatically corroded. Besides there are small prisms of augite and in the glassy paste minute laths of plagioclase. The lava is a picrite basalt. The olivine shows $2V\alpha = 88°$ (corr. to 14% of the Fa mol.).

No chemical analysis of this rock has been carried out.

From the third volcano of that year — Montaña Nueva del Fuego, lying close to Islote de Hilario, to the northwest from the main focus of Montaña del Fuego, I have no sample at hand. L. FERNÁNDEZ NAVARRO has (1919) published a chemical analysis of the lava in question which we may reproduce here together with calculated parameters:

Anal. n:o 12.

Sample taken by L. FERNANDEZ NAVARRO (1919) of the lava issued from Montaña Nueva del Fuego (eurption 1824). Lanzarote.

		Mol. prop.	Norm:		
SiO_2	42.40%	7031	or	7.9	
TiO_2	3.37 »	421	ab	0.8	20.5
Al_2O_3	11.15 »	1091	an	11.8	
Fe_2O_3	4.88 »	306	ne	14.5	
FeO	9.00 »	1253	Σ Sal:		35,0

MnO	—		
MgO	13.10%	3249	
CaO	11.10 »	1979	
Na_2O	3.26 »	526	
K_2O	1.34 »	142	
P_2O_5	tr.		
H_2O	0.35 »		
Sum:	99.95%		

di	34.4	
ol	16.6	
mt	7.1	
il	6.4	
Σ Fem:		64.5
H_2O		0.4
Sum:		99.9

Analyst: A. LASSIEUR

Niggli values:
si = 79½, ti = 4.7, al = 12½,
fm = 57½, c = 22½, alk = 7½,
k = 0.21, mg = 0.63, qz = −50½,
al − fm' = −45, al − alk = +5.

C. I. P. W. Classif. — IV. 2. 2. 2. 2.
Magma type: hornblenditic/kaulaitic
Mol. prop. of normative feldspars %
Ab:An:Or = 3:73:24
MgO:FeO = 86:14

As was the case with the lavas from the earlier periods of activity in Lanzarote these young lavas are likewise of the picrite basaltic kind, and they show the hornblenditic magma type as well. At least in the case of the volcano Tinguatón (the middle orifice) the olivine inclusions reappear, a phenomenon very typical of the lavas of the XVIII:th century.

Only two volcanic eruptions have taken place in the archipelago since 1824, viz. in Tenerife (Chinyero 1909) and in La Palma (1949).

Of all the islands in the archipelago three can consequently be considered »active». In Fuerteventura, Gran Canaria and in Hierro there are some cones and lavas of a fresh aspect (glassy, scoriaceous), but the eruptions must in these cases be considered finished long before the arrival of the first Europeans. New outbursts can be expected in the three first named islands attached to marked tectonic lines there. Or is in Lanzarote the subterranean heat on the way to cool down considering the small scale manifestations in the year 1824?

We will in a later chapter compare the magmachemical behaviour of all the young lavas from Lanzarote, also with those from Fuerteventura.

e. PETROGRAPHIC SUMMARY OF THE LAVAS FROM THE DIFFERENT PERIODS.

Rock types and their minerals

The lava rocks from the area investigated do not show much external variations: mostly they are fine grained, black to grayish black, sometimes also blistery, and the pores are in the older lavas filled with zeolites or calcite or aragonite (amygdaloidal basalts). Most of these basalt lavas are nearly always olivine bearing, this mineral being of the first generation in the mineral assemblage; sometimes there is augite too in well developed crystals. The olivine is mostly visible to the unaided eye as greenish dots (or in the case of alterations as brownish dots). The younger lavas are mostly glassy and porous. Here also the olivine is generally visible in hand specimen.

Salic (trachytic) derivatives are practically absent from the area.

Dike rocks are commonly met with in the ancient complex of the table-land crossing the lava series. They are also fine grained, afanitic basalts, olivine bearing.

Ejectamenta have been found in a large number lying around in the ground. They consist of various granular deep seated rocks such as olivinite, peridotite, gabbroidal types and anorthosite etc.

Besides the lava rocks we will find in the old series of the north and south of the island of Lanzarote and also in the isletas plenty of tuffaceous rocks, mostly of brownish colour, also agglomerates. Their coherence is generally not very strong. The thickness of these rock banks may sometimes be considerable (Femés).

The old basalts of which there is a great number in the author's collection are nearly throughout olivine basalts of a composition that tends to the picrites. They are seldom fresh looking under the micr. and in the first place olivine has been submitted to alterations, at least in the marginal parts of the grains. These secondary products are as it seems mostly bowlingite[1], more or less iron stained. Magmatic corrosion of the olivine has generally occurred, and deep embayments

[1] Of the alteration products of olivine from the Canaries I have seldom seen serpentine — antigorite. Mostly it is a reddish-yellowish to brownish and-pleochroic product forming the rim of the phenocrysts. It is either iddingsite or bowlingite. The latter is reported from the Canarian basalts by E. JÉRÉMINE, the former seems to be very common in the olivine basalts of the Juan Fernández Islands acc. to P. QUENSEL. Since the two products have very similar optics it is difficult to decide the nature, especially when the product is iron stained.

are to be seen. According to determinations on the U:stage the olivine is decidedly forsteritic in the most cases (Fa max. 20%). When the grains have escaped corrosion the crystallographic forms (110), (010) and (021) being the commonest faces.

— The mineral belongs exclusively to the first generation, whereas in the paste only augite, plagioclase and magnetite are to be found, in part also an isotropic, colourless substance that may be analcime. The relative quantity of plagioclase is somewhat changing. Its composition is intermediary (labradorite) in cases when measurements have taken place. Generally the mineral appears in the form of microlites that make diagnosis difficult. It seems that the picritic basalts (with the ankaramites) are the dominating ones. The pyroxene, mostly a Ti-augite appears seldom as phenocrysts, but chiefly in the paste mingled with the plagioclase and the ore mineral; sometimes the augite appears as glomerophyric aggregates. The ore mineral is magnetite certainly with a Ti-content. Mean figures of quantitative relations between the chief minerals in these picritic types are as follows (vol.):

Plagioclase (with zeolite)	30%
Augite	49 »
olivine	20 »
ore	10 »

Accessories are included in the ore.

This is of course not the composition of the typical picrite that is more rich in the mafic components esp. olivine. But it may illustrate the average relat. Besides there are of course many transition types to the ordinary olivine basalts in which the salic and the mafic constituents equal one another.[1]

We have moreover types in which the dominance of olivine in the first generation is assumed by augite (Ti: augite), but that may depend not on a changing composition of the rock, but on the physical environment during the crystallization.

P l a g i o c l a s e-r i c h e r t y p e s are as far as I know not common. One such type was found in a lava at Puerto Naos in a shore cliff, lying close to the end of the lava tongue from the year 1731. Plagioclase (comp. An_{60-70}) is plenty in the groundmass, not in the first generation, where olivine and augite have their place. The share of the plagioclase in the min. composition is ab. 35%, matching the rel. quantity of augite.

[1] Olivine basalt (weight %): plag. — 51, aug. — 31, ol. — 12, ore + ap. — 6. (W. E. Tröger 1935).

The rock types of the many intersecting dikes in the old tableland complex are always as it seems olivine basalts with phenocrysts of olivine and augite, both euhedral. The plagioclase and the augite are composing the paste together with magnetite. Vesicles in the rocks are filled with zeolite or calcite. The comp. of the rocks in question tends to be picritic.

The Quaternary, the Sub-Recent and the Recent basaltic lavas do show but small variations both in the mineral composition and in the texture. They seem to be generally of the picritic kind with the obligatory olivine phenocrysts in a rather fine grained or glassy matrix. It seems that the rocks produced during the whole time span from the beginning of the Quaternary epoch (or the fin of the Tertiary epoch?) down to the Recent time do not have undergone any notable changes, although it may be admitted that more chemical analyses especially of the glassy rocks are still needed. In the following we will tabulate some optic data referring to the olivines (phenocrysts) of the lavas in question:

List of optical angle of olivine phenocrysts in the young lavas (Quaternary-Recent)

Mont. La Corona	$2V\alpha = 80°$	Lava	Sample n:o		63
—»—	$2V\alpha = 84°$	»	»	»	65
Malpaís de los Helechos	$2V\alpha = 80°$	N border of the stream	»	»	68
Volcán de Los Helechos	$2V \sim 90°$	The cone	»	»	72
Caldera Quemada (Máguez)	$2V\alpha = 80°$	W border	»	»	73
Atalaya de Haría	$2V\gamma = 88°$	Summit	»	»	74
—»—	$2V\alpha = 85°$	»	»	»	75
N from the Saga volcano	$2V \sim 90°$	End of lava tongue	»	»	109
Caldera de Sóo	$2V\gamma = 85°$	E slope	»	»	112
Volcán Clérigo Duarte	$2V\alpha = 88°$	Lava tongue	»	»	113
Caldera Chica de San Bartolomé	$2V\alpha = 85°$	N slope of the cone	»	»	121
Caldera Honda de San Bartolomé	$2V \sim 90°$	Southern rim of the caldera	»	»	122
E from Tías	$2V \sim 90°$	E border of lava tongue	»	»	127
Tías	$2V$-large	Lava from M. Bermeja	»	»	129
Volcán Nuevo de Tinguatón	$2V\alpha = 88°$	Crater bottom	»	»	137
Mont. del Fuego, stream	$2V\alpha$-large	Road Yaiza-Uga	»	»	152
Lava stream betw. Yaiza — El Golfo	$2V\alpha = 85°$	Blocky lava on the road.	»	»	154

Rocks of salic composition are as has been pointed out nearly absent from the island of Lanzarote and never found in the Isletas. E. HERNÁNDEZ PACHECO (l.c.) mentions the sole occurrence in Los Ajaches N from Punta del Papagayo, a sample of which was submitted to a chemical analysis. It is a distinctly porphyritic alk. trachyandesite, with 1 mm large phenocrysts of plagioclase of the comp. An_{29-35}. It is practically a feldspar rock. According to the anal. n:o 8 it is decidedly Na-alkaline in composition with a great preponderance of the albite mol., whereas the anorthite mol. is very restricted. The scarceness of mafic constituents in the rock is remarkable.

Since the occurrence in question has not been found in the field by the author, it is not possible to state anything with certainty about its relation to the surrounding rocks; it seems however most likely that it represents an ultimate differentiate of the basaltic magmas belonging to the table-land series that composes the mountain block of Los Ajaches. Probably it is some dike crossing the series of lavas and tuffs, as is the case in many parts of Fuerteventura, where the old table-land series is exposed (see HAUSEN 1958).

As we have found from the summary in the preceding pages the area investigated shows a remarkable monotony in the composition of the lavas of all ages, the only exception being the trachyandesite occurrence in Los Ajaches. One gets the impression that as far as these lavas are concerned any differentiation on a larger scale has not taken place. This fact stands in a remarkable contrast to the conditions met with in the western Canaries and to a certain degree also in Fuerteventura. We will return to the question and to some comparations in a later chapter.

But there are in Lanzarote some indications that speak in favour of a more differentiated deep-lying basement in the island. I refer to the many enclaves in the lavas and to the bombs lying around many of the volcanoes. We may devote some attention to these fragments in the following pages.

Enclaves and volcanic bombs of different age

In the descriptive chapters we have shortly characterized some samples of rocks of basic to ultrabasic composition that have been found either as xenoliths in lavas and dike rocks or in the shape of volcanic

bombs lying loose on the ground in the vicinity of some of the volcanoes. In this place it should be convenient to enumerate the types in question. They are few it is true but they offer some interest being the only proofs of rock formations in the hidden underground of the islands in our area.

1. The inclusions encountered by T. BRAVO in a basalt dike in Montaña Clara consist as we have found (page 29) of olivine as the chief mineral with augite and magnetite. The olivine is somewhat more Fe-rich than generally is the case in the olivine basalts (Fa 25—35%). The rock has no feldspar, it is a peridotite.

2. From the side of Acantilado de Famara J. M. FUSTER CASAS (1952) has obtained some samples of granular deep seated rocks and these have been subjected to chemical analysis (data, see page 44). A coming publication about the matter is to be expected. It seems to be boulders enclosed in agglomerates (?) of the table-land series. The types are gabbroidal rocks according to the chemical data, not very congruent with those of the basalt types of the island.

3. From the vicinity of the Guatiza volcanoes on the *sotavento* coast E. HERNÁNDEZ PACHECO (1910) mentions some ejecta such as »hypersthenite», but I could not find such ones during a search on the spot. Instead I got from the hand of T. BRAVO some other samples collected from bombs at Guatiza, of which one proved to be an anorthosite, with a plagioclase of the comp. An_{70-80} according to a determination kindly made by Dr K. J. NEUVONEN on my request, with the use of the *X*-ray diffraction method. Besides there is in the sample also some diallage.

4. Other bombs and inclusions in the lavas are olivinites and allied rocks. The former are generally rusty in the surface and of high spec. gravity. Fresh fractures show an emerald-green colour. In the surroundings of the new volcano Pico Partido (page 79) there are as has been mentioned plenty of olivinite bombs, one of them of considerable size. A sample from here contains olivine, rhomb. pyroxene and iron ore. Optic data reveal an olivine of the usual kind ($2V\alpha = 84° - 86°$) and an enstatite with 15% of the ferrosilite mol. The rock is an enstatite peridotite.

During a visit in *El Museo de Historia Natural* in Madrid in the spring 1958 the author got from Doctor J. M. FUSTER, head of the Mineralogical Department, a sample of an olivinite bomb picked up in Lanzarote. It was brought to Finland and submitted to a chemical

analysis in the Geological Survey. There was also made a slide of the same rock.

Micr. one finds chiefly olivine (see the microphoto fig. 1, plate I) in anhedral grains. The mineral is unaltered. Besides there are — in reduced quantity — grains of a clinopyroxene, nearly colourless in the slide. Also some iron ore is to be seen. There are empty pores between the mineral grains (white patches in the microphoto).

The olivine shows $2V \sim 90°$. The pyroxene has a rather well developed prismatic cleavage. The ext. angle on (010) $c \wedge \gamma = 41°$. The axial plane stands $\perp$ (010), and the opt. angle $2V$ is small. Opt. char. is positive. It may be pigeonite.

Except the more even grained mass of the rock there are also parts where the two silicate minerals are granulated and mingled. They are cemented by a brown, isotropic substance that may be glass. Moreover the iron ore grains have been concentrated in these granulated parts appearing in skeletal forms (see the microphoto fig. 2, plate I). But there are also narrow veins of the ore in the coarse grained non-granulated mass filling the space between the silicate minerals. Also the cracks in the olivines have been invaded by the ore mineral.

Of this bomb there was made as mentioned a chemical analysis after the outer shell of weathered rock had been removed. Here the data are published:

Anal. n:o 13.

Olivinite (dunite) bomb, sample obtained from *Museo de Historia Natural* in Madrid. Locality of the bomb not nearer known, but it is from Lanzarote.

		Mol. prop.		Norm:		
SiO_2	42.06%	6975	ab	2.4	3.9	
TiO_2	0.13 »	16	an	1.5		
Al_2O_3	1.00 »	98	Σ Sal:		3.9	
Fe_2O_3	0.81 »	51				
FeO	8.78 »	1222				
MnO	0.17 »	24	di	1.7		
MgO	46.19 »	11456	hy	3.5		
CaO	0.82 »	146	ol	89.2		
Na_2O	0.28 »	45	mt	1.2		
K_2O	0.00 »		il	0.2		

P_2O_5	0.08%	6	ap	0.2	
H_2O+	0.00 »		Σ Fem:		96.0
H_2O-	0.02 »		H_2O		(0.02)
CO_2	0.00 »		Sum:		99.9
Sum:	100.34%				

Analyst: H. B. Wiik

Niggli values:
si = 53½, ti = 0.2, p = 0.1, al = 1, fm = 97½, c = 1, alk = ½, k = 0.00, mg = 0.90, qz = −48½, al−fm' = = −96½, al−alk = +½.

C. I. P. W. Classif. — V. 1. 5. 1. 1.
Dunose
Magma type: peridotitic
Mol. prop. of normative feldspars %
Ab:An:Or = 46:54:0
MgO:FeO = 91:9

This rock is according to all our data a typical olivinite or dunite consisting in the main of olivine of forsteritic composition with some insignificant amount of clinopyroxene corresponding to a pigeonite. Ore (Ti:magnetite) seems to be the third mineral component. Notable is the lacking content of +:water; it was a dry magma that crystallized in the depth.

It should be interesting to have a more complete collection of bombs and enclosures (xenoliths) from Lanzarote and also chemical data of all the types to get an idea about the lines of differentiation that have been followed in the interior of the island. Since such a search of ejecta etc. demands plenty of time I did not have occasion to fulfill this side of the surveys.

f. GEOCHEMICAL DATA

The chemical analyses of rocks from our area made for this memoir are only 7 in number. To these are to be added 6 borrowed from the literature; 4 (J. M. Fuster, E. Ibarrola y M. P. Lobato 1952) referring to some deep seated rock types collected in Lanzarote but from sites not nearer indicated; nor have the geologic relations about the occurrences been communicated. They may perhaps represent in part samples of volcanic ejecta from the underground. Two analyses referring to lavas from the Recent time are quoted from a publication by L. Fernández Navarro (1919), the one of which of a sample, whose locality is not nearer indicated.

Among the analyses made for the present *exposé* the bulk i.e. 5 are of basalt lavas (»sub-basalts»). Only one refers to a salic rock an alk. trachyandesite that according to E. Hernández Pacheco occurs in the southernmost part of the mountains Los Ajaches, to the north from

THE NIGGLI VALUES

TABULATED ACCORDING TO THE DECREASING AGE OF THE FORMATIONS INVOLVED

N:o of anal.	si	ti	al	fm	c	alk	al—alk	k	mg	Magma type
					The table-land basalt series (oldest)					
3	79½	4.6	14	56	24	6	+ 8	.08	.66	hornblenditic
7	87½	0.2	28½	42½	25½	3½	+25	.23	.77	achnahaitic
6	93	0.2	32	36½	27	4½	+27½	.17	.81	ossipitic
5	101½	0.2	23½	39½	33	4	+19½	.25	.81	pyroxene gabbroidal
4	117	4.6	26½	34½	23½	15½	+11	.41	.39	normal sommaitic or normal sommaitic 'gabbroidal
8	205	1.9	37½	21½	9½	31½	+ 6	.28	.21	pulaskitic
					Late-Tertiary — Quaternary volcanoes					
1	87½	4.7	14½	54½	23	8	+ 6½	.22	.61	kaulaitic or hornblenditic
2	96	4.4	17	53	23	7	+10	.17	.62	hornblenditic
					Sub-Recent volcanoes (La Corona)					
9	96	4.4	16½	52½	23	8	+ 8½	.21	.63	kaulaitic or hornblenditic
					Volcanoes of the XVIII:th century					
10	109	6.3	17	52½	22½	8	+ 9	.29	.60	hornblenditic or essexitic gabbroidal?
					Youngest volcanoes of the LX:th century					
12	79½	4.7	12½	57½	22½	7½	+ 5	.21	.63	kaulaitic or hornblenditic
11	87½	3.8	15	54	23½	7½	+ 7½	.20	.65	kaulaitic or hornblenditic
					Volcanic bomb (olivinite), age unknown					
13	53½	0.2	1	97½	1	½	+ ½	.00	.90	peridotitic

Punta del Papagayo (8). As was mentioned earlier in this text the author failed to locate the remarkable occurrence, but has from *El Museo Canario* obtained a sample of which the chemical analysis was carried out.

At first we have to study the list of NIGGLI parameters *si, ti, al, fm, c, alk, k, mg* and *al—alk* with the names of *magma types* created by NIGGLI. The data are arranged according the decreasing age.

Of the mighty table-land basalt complex there is to our disposal only o n e chemical analysis (anal. n:o 3). The remaining 4 belong to rock types outside the lavas. I have put them in this group because they have been found inside the northern massif. They represent deep-seated, granular types. If they are intrusive masses or if they are loose ejecta (in tuffs?) a coming publication by J. M. FUSTER will bring nearer explanation. We see that of these types two are more gabbroidal to sommaitic gabbroidal. Anal. n:o 8 belongs to the pulaskitic magma type an ultimate magmatic differentiation product of the hornblenditic magmas of the lava series. It stands as the only representative of the true Na-alkaline magmas in Lanzarote.

All the following age groups of lavas are rather uniform in composition; the magmas are mostly hornblenditic/kaulaitic (to essexitic gabbroidal).

There is not a single example of an isofalic relation. *al—alk* is always positive, also in the case of anal. n:o 8.

D i a g r a m s

The following statistical diagrams have been constructed by using parameters calculated from the chemical data of the analyses published in the descriptive chapters.

1. The NIGGLI variation diagram *si*: *al, fm, c,* alk of the rocks from Lanzarote and the Isletas.
2. The *k* : *mg* variation diagram(NIGGLI) of the rocks from Lanzarote and Isletas.
3. The *si* : *alk* variation diagram (acc. to BURRI & NIGGLI 1945) of the Lanzarote-Isletas basalt rocks.
4. A ternary variation diagram of the % mol. prop. of the normative feldspars *Ab* : *An* : *Or*.
5. A comparative (joint) *k* : *mg* variation diagram (NIGGLI) of rocks from Lanzarote-Isletas and Fuerteventura (only basalts of the groups B I, B II, B III and B IV, HAUSEN 1958).

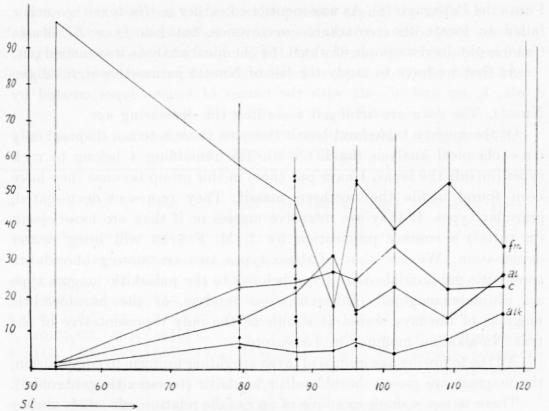

Fig. 7. The NIGGLI — variation diagram *si* : *al*, *fm*, *c*, *alk* of the rocks from Lanzarote and the Isletas.

If we at first look at the NIGGLI variation diagram (n:o 1) *si* : *al*, *fm*, *c*, *alk* it is to be observed that only the left half of the whole range of *si* values has been constructed. The right half contains only a single analysis, the pulaskitic magma type (*si*=205). Next highest value of *si* = 117. The lines of variations do not run very regularly, there is a couple of errant magma types, a pyroxene gabbroidal and an ossipitic type (anal. n:ris 5 and 6). These two do not belong to the assemblage of volcanic lavas, they represent perhaps ejecta (J. M. FUSTER). The same can be said about the extremely ultrabasic magma type (peridotitic) at the extreme left of the diagram, practically a forsterite rock (*si* — 53½). Notable is the low value of *alk* that does rise only at the right end (15½). But that type may also be an ejectum (?).

The variation diagram (n:o 2) *k* : *mg* of NIGGLI referring to all the Lanzarote and Isletas rocks is of some interest showing a gathering of the dots at the upper left hand corner of the diagram except some errant

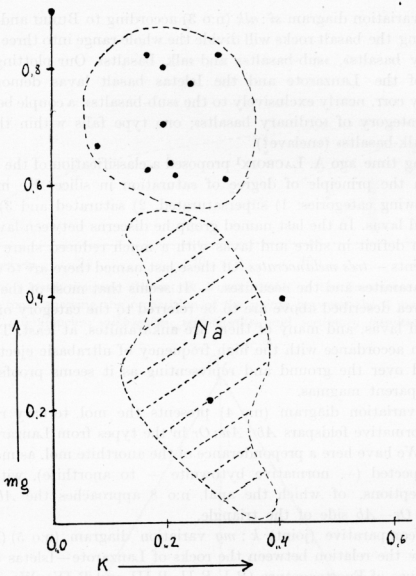

Fig. 8. The *k*:*mg* NIGGLI variation diagram of the Lanzarote — Isletas rocks. Nearly all the dots fall into the upper left corner above the parameter *mg* 0.60 and to the left of the parameter *k* 0.30. The hatched area with the sign *Na* indicates the field of dots belonging to the *Na*-alkaline series according to P. NIGGLI (1920).

types. Most of the dots fall outside the field of frequency of rocks belonging to the Na-alkaline series (acc. to P. NIGGLI 1920; hatched area with »Na»)[1]. Only the pulaskitic magma type from Los Ajaches (anal. n:o 8) shares the field of the Na-rocks. The diagram hence stresses the calc.-alkaline melanocratic trend of most of the rocks of our area.

[1] P. NIGGLI, Lehrbuch der Mineralogie. Berlin 1920. Page 491.

The variation diagram *si* : *alk* (n:o 3) according to BURRI and NIGGLI comprising the basalt rocks will divide the whole range into three groups: »ordinary basalts», »sub-basalts» and »alk. basalts». Our plotting of the points of the Lanzarote and the Isletas basalt lavas demonstrates that they corr. nearly exclusively to the »sub-basalts», a couple belonging to the category of »ordinary basalts»; one type falls within the limit of the »alk-basalts» (enclave?).

A long time ago A. LACROIX[1] proposed a classification of the basaltic lavas on the principle of degree of saturation in silice. He mentions the following categories: 1) supersaturated, 2) saturated and 3) undersaturated lavas. In the last named group he discerns between lavas with a certain deficit in silice and lavas with a much reduced share of salic components — *trés melanocrates*. Of these last named there are to mention the ankaramites and the oceanites. — It seems that most of the basalts of our area described above are to be referred to the category of undersaturated lavas, and many of them are ankaramites, at least. This fact stands in accordance with the high frequency of ultrabasic ejectamenta scattered over the ground and representing as it seems proofs of the abyssal parent magmas.

The variation diagram (n:o 4) presents the mol. ternary relations of the normative feldspars *Ab* : *An* : *Or* in the types from Lanzarote and Isletas. We have here a preponderance of the anorthite mol. as may have been expected (— normative bytownite — to anorthite), with some few exceptions, of which the anal. n:o 8 approaches the *Ab*-corner and the *Or*—*Ab* side of the triangle.

The comparative (joint) *k* : *mg* variation diagram (n:o 5) (NIGGLI) will show the relation between the rocks of Lanzarote—Isletas and the basalt lavas of Fuerteventura (B I, B II, B III and B IV). We will find only a slight difference: the Fuerteventuran lavas are in parts more alkaline.

Lanzarote and the Isletas may according to all our data available at the present time be considered as a sub-province of alkalipoor, olivine, rich basalts, grading into picrites, the magma types being hornblenditic to kaulaitic or essexitic gabbroidal. Remarkable is that there were no notable changes in the composition of the lavas from time to time or

[1] ALFRED LACROIX, La constitution lithologique de l'Archipel des Comores. Congrès géol. International. Comptes Rendus de la XIII:e session en Belgique 1922. Liège 1925.

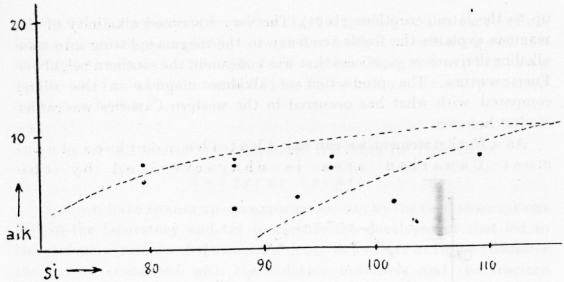

Fig. 9. An *si:alk* diagram (Burri & Niggli 1945) of the Lanzarote — Isletas basaltic rocks showing the repartition of the points between the 3 magmachem. tendencies: »*alkbasalts*», »*sub-basalts*» and »*ordinary basalts*».

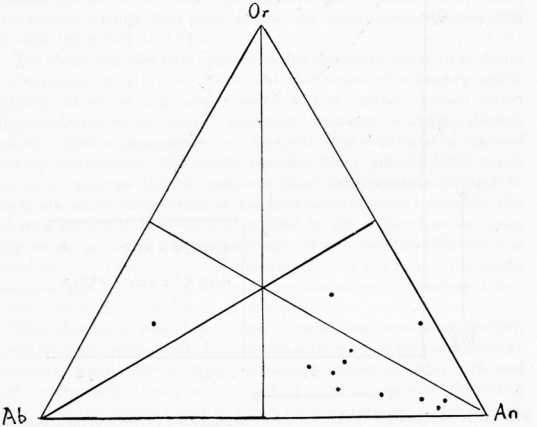

Fig. 10. Triangular % relations of the normative Ab:An:Or feldspars of the Lanzarote — Isletas rocks.

up to the latest eruptions (1824). The very restricted alkalinity of the magmas explains the feeble tendency to the magma-splitting into salic alkaline derivatives, a process that was gone on in the southern neighbour Fuerteventura. The production of alkaline magmas in this island compared with what has occurred in the western Canaries was rather modest however.

Aa a final statement we can say that the north-eastern-most Canarian area is characterized by the

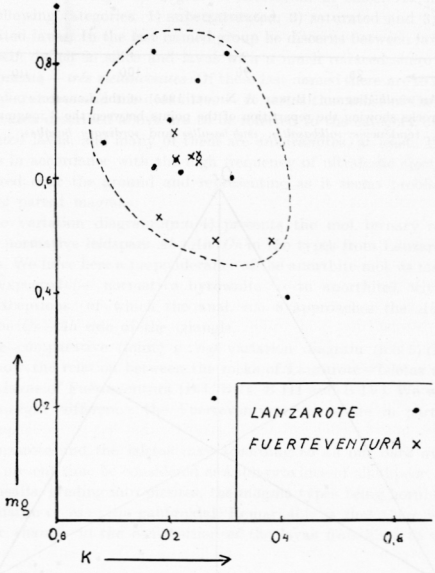

Fig. 11. A comparative (joint) variation diagram *k:mg* (NIGGLI) of the Lanzarote —Isletas and Fuerteventura rocks, of the last named island comprising only the basalts (B I, B II, B III, B IV).

preponderance of alkalipoor, Mg-olivine-rich basalts apparently with slight changes in composition through the ages. Magma splitting into salic alkaline derivatives has been practically absent.

g. OUTLINES OF THE GEOLOGIC HISTORY OF THE AREA

Endogene events

Now we have to sum up our experiences won by the field observations and in the laboratory and try to picture the development that led to the geologic structure of the area. In doing so we have at first to consider the events connected with the volcanic outbursts and the fracture displacements, later on we will look at the exogene processes.

Considering our volcanic area as a whole we have to remember that it is only a part of the eastern Canarian area; the island of Fuerteventura belongs to the same region. In fact these eastern Canaries have once formed a single land mass, maybe also sometimes connected with the near lying part of Africa.

The oldest complex that appears in this eastern region is to be found in Fuerteventura (HAUSEN 1958) and it consists of a mighty spilite complex turned on edge and intruded with a number of deep seated intrusive bodies of pyroxenitic, gabbroidal, essexitic, nepheline syenitic and alk. syenitic composition, not to speak of a multitude of dikes of varying composition. This spilite complex has a general NNE trend, and it is apparent that it continues from Fuerteventura straight to Lanzarote under the bottom of La Bocaína strait. In Lanzarote this old rock ground is however not exposed in the surface; we can only suppose its presence. The geologic age of this basement complex is uncertain, but it seems that the diastrofism that has turned the spilite series on edge may belong to the Hercynian orogeny, manifested also in the near lying coastal area of Africa.

This basement was then during a large time span base-levelled, a peneplain was worked out. This smooth surface was in the early Tertiary time covered with sheets of olivine basalts repeatedly. Also tuffs and agglomerates participated in the building up of the so-called table-land series. Over the eastern Canarian region there was created a vast basaltic table-land that maybe reached also to the west over the present western Canaries.

Remnants of this basaltic table-land — composed of olivine basalts of mostly picritic composition are still to be seen in Fuerteventura in the so-called eastern Cordillera (HAUSEN 1958), in Lanzarote only in the northernmost and the southernmost parts, where they appear in the shape of eroded horst mountains.

The lavas found in Lanzarote belonging to this table-land series are more uniform in composition than is the case in Fuerteventura. In the latter island the lavas are in parts also plagioclase-rich types[1]. Moreover there are rather plenty of salic derivatives — alk. trachytes and phonolites, partly as smaller laccoliths, partly as plugs or dikes. In Lanzarote such salic fractions of the basalt magma are nearly absent as far as is known — there is only one small occurrence of a trachyandesite to be registered.

In the Isletas and in Graciosa there are no visible parts of the table-land basalt series. The sudden break of the series in the north cape of Lanzarote, Punta Fariones, suggests the vision of a former land mass far to the north, but this continuation has apparently been cut off by tectonic displacements.

The ancient basaltic table-land had in the course of time been very dissected by fractures and displacements, so that much of it had been depressed to lower levels and gone out of sight owing to later covering by volcanic and sedimentary deposits. The geologic map of Lanzarote is in this sense a very good illustration: there have been left behind only scattered visible remnants of the former table-land.

One of the most imposing lines of displacements is the fault scarp along the northwestern coast of Lanzarote—Acantilado de Guatifay and Famara, several hundred of metres high. Graciosa that forms a kind of foreland may represent a part of the sunken western wing. Nothing is seen, it is true, of the table-land formation in this island, but the Quaternary volcanoes there must have a basement upon which they have been accumulated, and that basement cannot be anything but the named formation.

Long before the fracture movements ceased, erosion took over its destructive work, and an elaborate system of *barrancos* came into existence in the standing horst mountains. This erosion period was as it seems of rather long duration, it corresponded partly to a pause in the endogene events.

Then there followed new cycles of volcanism. At first we have to

[1] Sakalavites *sensu* LACROIX (silica- supersaturated).

mention the Late-Tertiary (?) and the Quaternary volcanoes piled up to a great number all over the area investigated. In Fuerteventura volcanoes of this category were relatively sparse, but in Lanzarote they grew up in abundance, often to considerable dimensions. The lavas show a rather monotonous composition. Much pyroclastic material was also deposited over the surface of the islands. In Lanzarote there is a striking linear arrangement of the cones, as may be seen from the geologic map. Most of the cones was gathered in the middle sector of Lanzarote, an expanse between the northern and the southern horst mountains. This middle area may be considered a sector of subsidence (tectonical graben).

All the lavas and other materials produced during this period of activity are of olivine basaltic composition. The cones themselves are no lava volcanoes, but composed of slags and scoriae, lapillis and ashes. There were many phases of violent explosions. Owing to this production of loose material large craters were formed, often caldera-like, and most of them have their northern sector open. That depends on the fact that the trade winds dominated already in these times.

Later on — in Sub-Recent time a new volcanic cycle started, this time confined to Lanzarote, and especially to its northernmost part. Neither Graciosa nor the Isletas were affected. The most remarkable of the Sub-Recent volcanoes is Montaña La Corona standing on the upland of the northern horst block. It was a very productive volcano sending huge masses of lavas down the eastern declivities of the horst mountains here and filling with them some old *barrancos*. Also to the west there was an outflow, here in the shape of a narrow stream that spilled down the Acantilado de Guatifay to the beach at El Río. The lavas are of the olivine basaltic kind approaching picrites in composition.

The eruptions of La Corona and the other volcanoes in the vicinity took place at a time before the arrival of the first European invaders in the Canaries, and L. Fernández Navarro is of the opinion that the eruptions occurred about 1000 years before Chr. In every case the lavas are all of a fresh aspect, justifying the signature Sub-Recent.

There seems to have been a long break in the volcanic activity in later times or up till the XVIII:th century, when in the year 1730 the famous six year's period of violent outbursts started. This Recent volcanism was confined to the same middle sector that had been the stage in Quaternary time of the endogene manifestations. This time the lava and ash production was copious and no less than 1/4 of the island

was affected or devastated. The lavas seem to be of the usual olivine basaltic kind. — The most important of the eruptive centres was Montaña del Fuego, in the reality an old volcano named Timanfaya. Subterranean heat is still lingering on in this mountain.

The volcanoes that now appeared were in the same way controlled by large fissures or volcano — tectonic lines as was the case with the Quaternary volcanoes. Also the general trend of the rows remained about the same.

No signs of this young volcanism are to be found in Graciosa or in the Isletas.

The production of volcanic material in the named six year's period was so copious that it exceeds all the effusions in quantity of the other Canaries, including Fuerteventura, if we do not count with the old effusions that created the basaltic table-land series. Remarkably enough these large outbursts in Lanzarote appeared rather unexpectedly or without any preceding notable subterranean unrest. The outbreaks were a revival of the old Quaternary lines of eruption (lines of weakness) and that occurred after a time span of certainly hundred thousand of years (?).

This remarkable activity faded out rather suddenly, but a minor revival took place nearly one hundred years later on — or in the year 1824, when within the same old stage of events there were eruptions successively at three points. The outbreaks were of relatively small amplitude characterized in part by the production of hot water (Tinguatón). Also these lavas are of the olivine basaltic kind.

In Fuerteventura no outbursts were seen in the six year's period of the XVIII:th century, not even in the following century. The relatively fresh volcanoes crowded in the northern part of that island may belong to the Sub-Recent period and hence they are perhaps contemporaneous with the cones in the northernmost part of Lanzarote. Also the young volcanoes of Fuerteventura are olivine basaltic (basanitoid) in composition.

As far as the petrochemical trend of our sub-province is concerned it is apparent that there is but a slight alkalinity in the basalts to be seen and this fact explains also the very insignificant amount of salic alkaline derivatives, practically to be neglected.

The xenoliths in the lavas and dikes met with in the area and the bombs ejected from the Lanzarote volcanoes of different age reveal the existence in the depth of an assemblage of granular rocks of olivinite

— peridotite — anorthosite composition. If these types belong to the old basement cannot be stated; it seems more likely that they are the abyssal, differentiated parental magmas of the superficial products.

Exogene processes

In spite of the fact that Lanzarote and its satellites are of a pronounced volcanic nature we will find in the area also plenty of purely exogene achievements that have alternated with the constructive and the destructive endogenic changes. The geologic records of the former category of forces consist partly in the erosion and abrasion forms, partly in the sedimentary layers of the islands. We may at first look at the

erosion relief

of the islands, including the coastal morphology. — In a region of decidedly volcanic nature the basic question to be dealt with is to what extent the two antagonistic geologic forces have battled one against the other and what has been the end result of this struggle.

Looking at the islands in particular one will find that the outcome has been rather different in the different parts of the area.

In the Isletas and in Graciosa there have not been left behind any notable signs of running surface water. These eilands are too small and the climate is too dry for such an activity. Instead the marine abrasion has been vigorous and has in the course of the Quaternary and Sub-Recent times achieved considerable results. The maximum of efficiency has been of course on the windward side (preferably in northwest). Roque del Este stands as an impressive witness of the abrading power of the waves.

With the main island Lanzarote the things happened in a more complicated way. Here the marine abrasion has in the windward coasts developed the same force as in the small islands and good examples are to be found: steep sea cliffs, such as Punta Fariones and the *acantilado* along El Río (originally a fault scarp). Moreover we have in the island raised beaches showing signs of former (Quaternary) abrasion. But Lanzarote has also typical erosion landscapes: the horst mountains in the north and in the south. The formation of this erosion relief is not very young — it antedates the great displacements along Acantilado de Famara and at the plain of Rubicón in the south.

We may here look somewhat nearer at the two erosion landscapes.

The Guatifay — Famara highland.

This *meseta* is only an eastern remnant of a formerly wide table-land cut off by the Famara fault. The original drainage pattern can therefore only in part be reconstructed (see the topogr. map fig. 12). In the eastern and southeastern (and southern) slopes there are several *barrancos* and valleys, some of which have previously been mentioned in connection with the description of the rock ground. These valleys radiate from a central *meseta* of nearly 700 m elevation as is shown by the map. In the extreme north they have the shape of *barrancos* with a narrow cross profile and a steep gradient. Further south they are generally open valleys with a bottom gravel fill. Only Barr. de Teneguime is in its upper course very deeply eroded and canyon-like. Downstream it broadens suddenly and ends in the plain of Vega de Guatiza.

In spite of the dissection of the ancient table-land in question there has been left behind a bit of the old watershed of the erosion relief. La Corona and Los Helechos, the most important volcanic cones in the region of Guatifay-Famára stand on such a watershed, and the lavas issued from these orifices have used the ancient flow directions — to the east and to the west. Many of the valleys, such as Valle de Máguez and Valle de Haría have however »lost their heads», a most curious sight for one who follows the upstream course. Suddenly he stands at the border of a precipice of several hundred m altitude with the sea shore straight down. It has been formed an oneside *degollada*.

The old valley systems would be well visibles if there did not exist the lava floods that have not only filled some of the valleys completely but also covered the sec. watersheds down to the coast (in the east).

If we now look at the conditions in the southern massif

Los Ajaches,

the old erosion relief is better conserved there, and no valley heads have been cut off by faultings. But the main watershed is one-sided: the western declivities have entirely disappeared thanks to faultings, and the plain of Rubicón indicates the amount of displacement. The foreland consists as we already have found, of the old table-land basalt series, the same that is met with in Los Ajaches.

The valley erosion in these mountains has reached a rather mature stage, and the cross-profile of the valleys is openly V:formed. Lower down the valleys broaden still more, but shortly before their mouth

at the coast they have to cross a rock terrace in a canyon. This is apparently a later adjustment due to the rise of the land in a time after the longitudinal profile of the valley was worked out. This terrace may correspond to a stage of the ocean level in the Quaternary time (Monastirian?).

In the region of Tías at the south coast (to the west from Arrecife) there is as we have seen, a small area where the old basement is exposed and some old *barrancos* have been left behind, not covered by lavas from the Quaternary volcanoes close to the north.

We have found from the foregoing data that Lanzarote lacks a main watershed, most of the relief is controlled by faults and by volcanic accumulations. The northern and the southern massif are subordinate parts of the island, contrasting against the dominating volcanic forms in the nature of Lanzarote.

Sedimentary deposits

Lanzarote and the Isletas are as we have seen chiefly of volcanic nature. Most of the relief owes its origin to the endogenic forces both of accumulative and of destructive kind. That is especially true with the whole middle part of Lanzarote, a real »nature reservation» of volcanic phenomena. There are nevertheless in various parts of the area investigated several kinds of sediments, partly diagenetized to rocks, partly loose accumulations.

If we look at Lanzarote, this island has as we have found at least two separate areas of erosion relief. Valley making ought to have its correspondence in deposition of detracted material. Such material has however in the areas referred to, been left behind only in smaller quantities.

Then there are other kinds of deposits such as limestones and sandstones of calcareous composition, drifting calcareous sand, chemical precipitates of calcium carbonate (travertine), basin alluvium. Moreover we have to mention the soils, the climatic reaction products of the superpficial layers of sediments.

A general classification of the sedimentary deposits of Lanzarote and the Isletas may appear as follows:

1. Limestones of marine or lacustrine origin
2. Terrestric calcareous sandstones
3. Travertine incrustations

4. Terrestric sands and gravels. Drifting sands
5. Littoral sands and gravels.

I have in this list put the groups according to decreasing geologic age.

1. Limestones of marine and lacustrine origin

During an excursion from Orzola to the vicinity of Punta Fariones (north cape of Lanzarote), where the basaltic table-land series is exposed in profiles of several hundred metres altitude I found in the lower part of the precipice facing Orzola limestone and lime-agglomerate layers underlying a mighty series of the old basalt lava banks. The uppermost layers of the sediment consist of pure, fine grained, nearly marmorized cream-coloured limestone, and the hanging basalt lava sheet shows a knife sharp limit against the substratum. Lower down the limestone is getting more and more impure, intermingled with fragments of lavas. At the sea border itself there appears again a basalt-lava bank. The whole series of this unexpected sediment attains appr. 30 m.

To my surprise I found in the uppermost of the limestone layers (the purest ones exploited on a small scale) shells of *Helix* embedded. These shells are very well conserved, and with some care they can be collected in a great number. During a second exursion to the same locality I was in company with the Alcalde of Haría Don Mariano López Socas, an amateur malacologist, and this gentleman collected a great number of shells of *Helix*. The collection was said to be sent to a specialist in Madrid to be proved if the age of the stratum on the basis of these finds could be estimated. Up to the present time the author has not get any informations about the matter.

The occurrence of the snail *Helix* in these sediments is naturally of paramount interest, since it indicates that during the effusion of the lavas belonging to the table-land series (the oldest formation in Lanzarote) there existed a *terra firma* in the region in question where lime carbonate (in a pond or lagoon?) was sedimented probably as a chemical precipitate. The limestone belongs consequently to a fairly remote period — perhaps early Tertiary.

The occurrence at Punta Fariones is the first find of fossiliferous sediments in the old Canarian basalt formation.

In this connection we may briefly recall into memory some data mentioned about the sediments of Graciosa (page 34). It is a limestone

occurrence at the southeastern shore of the island exposed in the beach and well to be studied at low tide. There are several layers of limestone and also conglomerate layers with well rounded pebbles of some dark coloured limestone varieties. The series is d i s l o c a t e d with a northern inclination. Hence these sediments cannot be of very late date, their position seems to be correlated with the great displacements that created the Guatifay escarpment.

During an examination of the tuffitic semi-caldera Caldera del Cuchillo in the vicinity of Sóo I found as has been mentioned among the numerous bombs in the tuff material also limestone with remnants of shells. The origin of this sediment must be sought for in the underground that underlies the low region of Sóo (with its volcanic cones).

Since the position of Caldera del Cuchillo above the sea level is rather insignificant (base 50 m), it is to be assumed that the limestone with its basement has been thrown down during the displacements that have affected the whole lowland of Sóo and the plains of Penedo.

Another find of limestone ejecta has been mentioned from the *isleta* Roque del Este, and here the bombs show a marmorized condition. No doubt these fragments have also been forced to the surface by explosions from the deep interior and embedded in the brown tuffs that built the major part of this *isleta*.

2. *Terrestric calcareous sandstone*

This kind of sediment is not very well exposed in the surface because it is mostly covered with younger alluvial material. In the paper by E. Hernández Pacheco it is not mentioned at all. I have found occurrences of such a sediment in several places, as will be nearer described in the following.

The sandstone is in the reality an oolite limestone but of rather brittle consistency so that the grains are easily disintegrated. Its texture is clastic and a stratification can be seen although it is not very distinct. Apparent is the fact that coarse grained as well as fine silt layers are absent. The rock seems to be rather equigranular, hence the slight stratification. In some places there are however layers consisting of a »conglomerate» i.e. accumulated masses of the fossilized nests of the genus *Antophora*. The rock makes the impression of an eolic sediment, but on the other hand there seems to have been also running water at work during the sedimentation. In every case the sediment is terrestric,

a fact that can be proved by the presence of fossil shells of *Gastropoaa* such as *Helix* and *Stenogyra*.

Owing to the softness of the rock it is easily destroyed by exogene agencies. The sediment is therefore conserved only in such places where it has been sheltered in a relatively deep position or where it has been covered by some hard layers lime-cemented.

If we begin in the northern part of Lanzarote we will find here some remnants at the foot of Cuesta de Famara, to the west from Villa de Teguise, at the eastern rim of the plains of Penedo. All the piedmont cones and-slopes here consist in their interior part of the sandstone in question. It would be entirely concealed by hard superficial layers of gravels and *tosca* if there did not have been eroded a number of *barrancos* leading from the *cuesta* down to the lowland. These *barrancos* are very narrow and several metres deep, and the sides are walls, showing the sediment in good vertical profiles. The sands that cover the plains have been extracted by way of these narrow *barrancos*. It is conceivable that in the underground of the same plain there lies the same sediment. Now it may lie below the sea level, but earlier, in the Quaternary glacial periods it was on *terra firma* (due to regressions).

Maximum thickness of the sandstone in the ravines may be appr. 10 m.

Another occurrence of the same yellowish calcareous sediment is on the other side of the island, in the region of Guatiza. During an excursion around the broad volcanic cone Montaña Tinamala (323 m) that lies only 1 km distant from the sea border, I found on a level of about 50 m above the sea, an extensive layer of the same calcareous sediment having oolithic microtexture (see fig. 1, plate VII!).

Still another occurrence was met with a short distance to the north from Aeropuerto de Guasimeta, where a *barranco* has disclosed the sediment that seems to measure a thickness of ab. 10 m max.

More of such remnants of a sedimentary cover were not found by the author. It is conceivable that there is still plenty of it in other parts of the island, they may be hidden beneath superficial layers of gravels and also drifting sands, which last named are derived from the oolitic sandstone. It is moreover not impossible that similar sediments have been overridden by the lavas or covered by the ashes from the latest great outbursts in the island.

3. Superficial terrestric travertine incrustations

Lanzarote is like its southern neighbour Fuerteventura extensively covered with the so called *tosca blanca* or *canto blanco*, a dense fine-grained, concretionary limestone that can be of great purity in its more superficial parts. This limestone covers all the parts of Lanzarote not affected by the young volcanic outbursts (from the »historic time»), but there are variations in the thickness of the incrustations.

This formation may be considered a chemical precipitate concentrated from the lime bicarbonate solutions that have risen from the underground due to evaporation in the surface. The great quantities of lime required for the precipitates have been furnished by the lime content of the common minerals in the rocks of the island — the basalts. Most important of these minerals are the plagioclases and the pyroxenes, to a small degree the apatite. The process including the migration of the bicarbonate solutions to the surface and the precipitation layer after layer requires a special type of climate, characterized by alternating wet and dry seasons. A certain amount of rain is necessary for the ground water accumulation, and insolation indispensable for the capillary ascending movement and for the evaporation. Such conditions are no more existing, they must have governed the island in Quaternary time with more marked seasonal changes.

The *tosca blanca* of Lanzarote is not of the same economic importance as is the case in Fuerteventura, where there exists a lime industry.

4. Terrestric sands and gravels. Drifting dune sands

There exists a great contrast between Lanzarote and Fuerteventura regarding the accumulation of fluvial sands and gravels as well as so-called piedmont gravels, not to speak of the creeping debris of the mountain slopes. This difference lies in the fact that Fuerteventura is mainly an old erosion surface, over which river transport in earlier times has gone on, whereas Lanzarote has only small areas of erosion relief and areas of accumulation.

Looking around in the island we will however find here and there some more insignificant valley fills of gravel and sand, and covered plains. That is the case with the plain of Rubicón in the south, in the bottom of the broader valleys in Los Ajaches (Valle de Femés) in the region of Aeropuerto de Guasimeta (W from Arrecife), in Vega de Guatiza and

along the *sotavento* coast from the last named place to Arrieta including the lower course of the valleys that here have their ends.

The sands and gravels deposited in the places and stretches enumerated have been laid down by intermittent rivers as it seems in earlier times, when the climate was less arid. — The most extensive alluvial plain that lies to the south from Golfo de Penedo seems to be in the main a tectonic downthrow that has been filled with limestone? and Quaternary calcareous sandstone, in the surface hidden beneath moving sands.

In the Isletas there are very sparsely alluvial deposits carried to their place by running water, such as in the northern part of Graciosa and in the center of Alegranza.

Drifting sands are generally of more common occurrence. The most important train of such fine calcareous migratory sand masses runs N—S across Lanzarote from Bahia de Penedo to the coast of Guasimeta (*sotavento*). This broad zone is narrowed where it crosses the chain of Quaternary volcanoes (region Zonzamas) but this obstacle does not prevent the general migration under the impact of the trade wind. This wind holds sway nearly the whole year. The sand masses have been loosened from the above described calcareous sandstone that lies in the lowland of Penedo and also in patches more to the south. The sand transport stops at the *sotavento* coast where a broad *playa* or beach of fine sand has been formed stretching for miles to the west from the capital Arrecife.

The ultimate source of the calcareous material seems to have been marine shells and foraminiferan ooze (of Quaternary time).

Ground water aspects of Lanzarote. — The recovery of ground water both for domestic demands and for irrigation cultures is a very serious problem in Lanzarote as has been mentioned already in the introduction. There has in the course of time been made much prospecting work to get the ground water, but nearly always without success. Most of the island is extremely devoid of infiltrated and stored atmospheric water; no rains, except occasional showers have been registered since past centuries. And these showers do not appear every year, it can pass several years without any precipitation.

The island is however in some way a receptor of the atmospheric humidity although mostly not in the shape of rain. The trade wind clouds bring some moisture especially during the night, when they strike the cooled ground. The earth and the stones are thus catching some moisture in the from of drops that percolate into the ground. The

rough lapilli (*arena*) that is brought to the fields to cover the cultures do not only prevent the evaporation in the course of the day, they help to concentrate the moisture of the low flying clouds in the night. In such a way the field cultures have been made possible, and most of the cultivated areas are therefore covered with the black *arena*.

The occasional showers and the night moisture condensation help to fill the domestic tanks or *los aljibes* with water that stored in this way will provide the household with drinkwater all the year round.

In later times the Insular Government has made great efforts to provide the capital Arrecife with water that generally has been brought by sea transport. A water gallery (a tunnel-) system has been opened in Acantilado de Famara ab. 100 metres above the plain of Penedo. Here deep seated ground water has really been found and more is to be expected when the tunnels are prolonged into the mountain massif. The water here accumulated has percolated from the upper regions (the mountain summits) which are stricken by the drifting clouds of the trade wind. — A pipe line (25 km) has already been established from here to Arrecife. The author is not fully informed if the question of recovery has been satisfactorily settled already.

Soils of Lanzarote. — The superficial decomposition products of the alluvial deposits in the lowlands and in the slopes of the ancient rock ground are the result of climatic influence. The process has hitherto not been more closely investigated but according to experiences won in the other Canaries by W. L. Kubiena (1956) the arable soil seems to correspond to the so-called »meridionale Kalkbraunerde» (meridional brown calcareous earth).

5. Littoral sands and gravels

There is not much to say about these kinds of accumulations. Marine beaches have been formed where sand masses have been disponible as is the case along the *sotavento* coast, as was just mentioned. Another strip of sand coast is in the extreme south, W from Punta Papagayo (Playa Blanca). Graciosa is also bordered by sand beaches; gravel strings appear where rock cliffs have been attacked (N coast).

Rather mighty gravel accumulations along the shore line are to be found at he *sotavento* coast of Los Ajaches, where an old marine rock terrace has been abraded and where the *barrancos* that here have their end, have delivered plenty of gravels from their beds.

An imposing barrier lies off the lagoon of Janubio on the *barlovento* coast where Salinas de Janubio are situated. Another barrier lies in El Golfo at the foot of the old volcano of the same name.

Remarks about the accompanying geologic map

The geologic map in colours accompanying this memoir has been constructed on the basis of the topographic map of Lanzarote in the scale 1:100 000 kindly put to the author's disposal by *El Museo Canario*. This map does not show much more geologic particulars than what will be found in the old coloured map by E. HERNÁNDEZ PACHECO (1910). The contours are however corrected in the present map according to the measurements carried out in later times.

With the necessary reduction for the publication the scale has been changed to 1:200 000.

Contour lines illustrating the relief conditions of the island have in parts been left aside owing to the outmost difficulty to follow them in the original base map.

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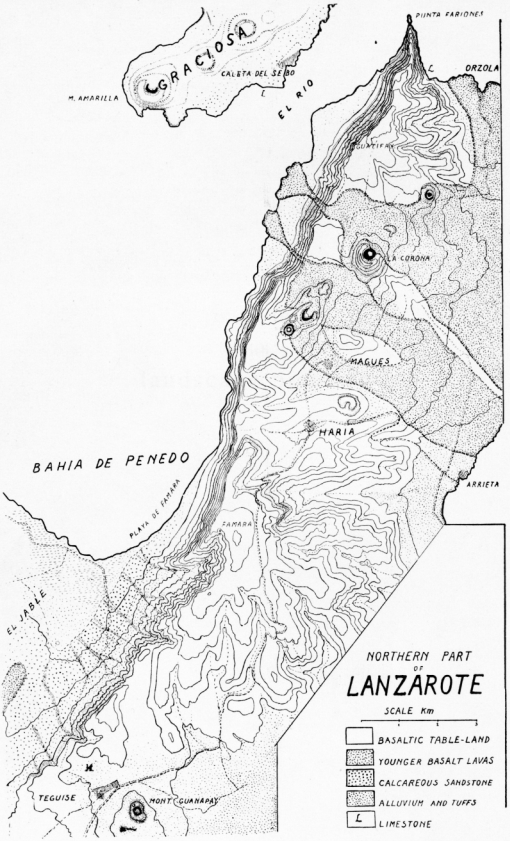

Fig. 12.

IV PLATES

with

landscape pictures

Fig. 1. Acantilado de Famara facing El Rio, northern part of Lanzarote showing the horizontal series of basalt-lavas and tuffs abruptly cut off by a great fault following the western side of the mountain block. Looking NW.
Photo by H. H—n 1950.

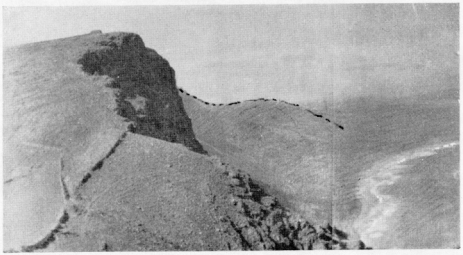

Fig. 2. Acantilado de Famara, looking south, with Playa de Penedo to the right. The slopes to the left indicate a former continuation up to a watershed.
Photo by H. H—n 1950.

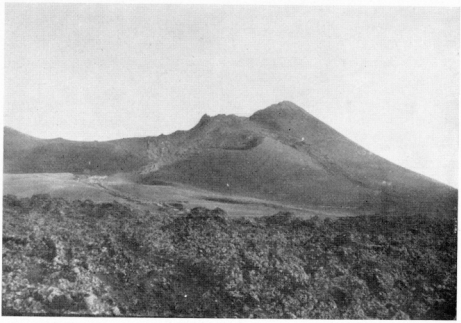

Fig. 1. Pico Partido from the north-western side, a volcano from the XVIII:th century.

Photo by T. Bravo 1954.

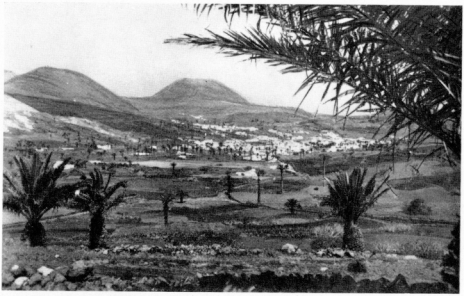

Fig. 2. Looking north from *la cuesta* over Villa de Haría to Montaña La Corona (in the background.)

Photo from a post card.

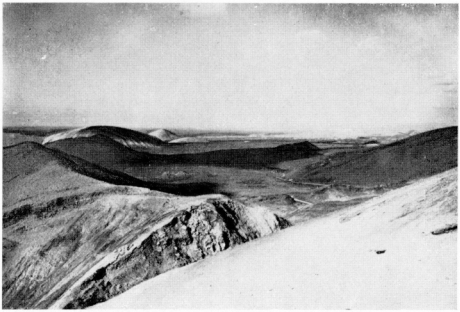

Fig. 1. A distant view of the young volcanic landscape to the N from the rim of the crater of Montaña del Fuego.

From a post card.

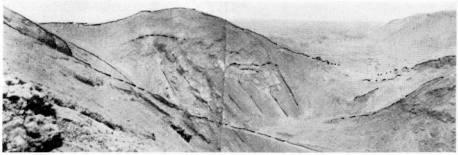

Fig. 2. Main crater of Montaña del Fuego seen from the southern rim, Lomo de Azufre.

Photo by H. H—n 1950.

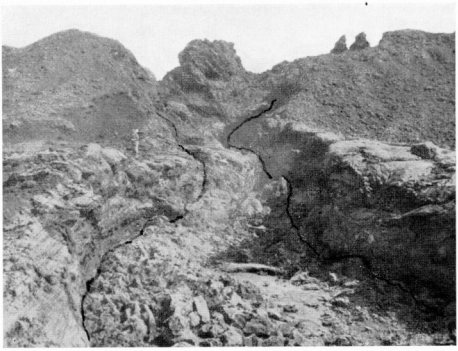

Fig. 1. A small lava stream issued from a secondary vent at the foot of Montaña del Fuego. A hornito in the background. Looking east.
Photo by H. H—n 1954.

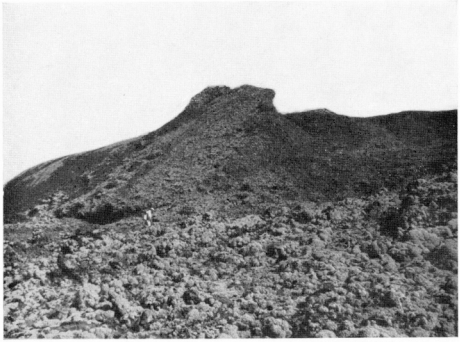

Fig. 2. The new volcano Tinguatón from the XIX:th century seen from the west. Blocky lava in the foreground. The author stands in a small gully, along which hot water escaped during the eruptions.
Photo by T. Bravo 1954.

VII PLATES

with

microphotos

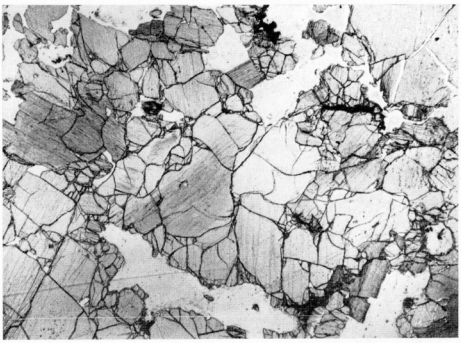

Fig. 1. Volcanic ejectamentum composed of allotriom. olivine grains (forsterite) with some ore and empty pores. Sample obtained from the Lanzarote-collection in Museo de Historia Natural, Madrid.

Nic. // Magn. 8×.

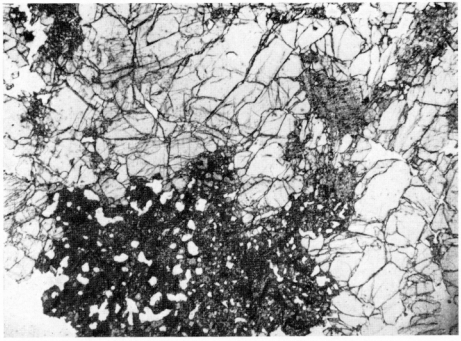

Fig. 2. Another part of the same bomb showing granulated olivine and pyroxene (pigeonite) with some skeletal ore and glass substance.

Nic.+ Magn. 8×.

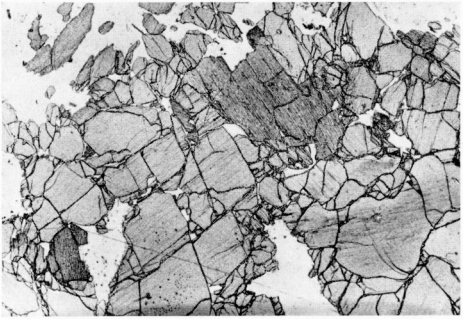

Fig. 1. Peridotite enclosure in a dike rock showing allotriom. grains of olivine and augite (upper part, right) and empty pores. Ore is present but not seen in the pict. Montaña Clara.

Nic. //. Magn. 8×.

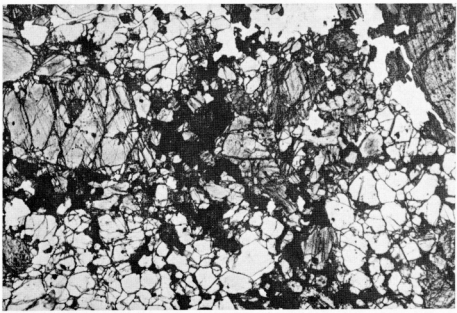

Fig. 2. Another part of the same rock showing granulation of olivine, augite and ore.

Nic. //. Magn. 8×.

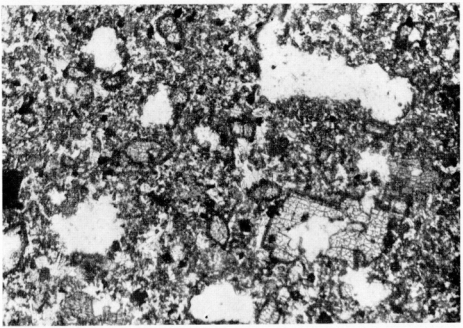

Fig. 1. Brown rimmed olivine phenocrysts in a fine grained paste consisting of plagioclase, augite and ore. Pores in the rock are empty. Lava bed in the basalt series exposed in Acantilado de Fariones (N cape), Lanzarote.
Nic. //. Magn. 24×.

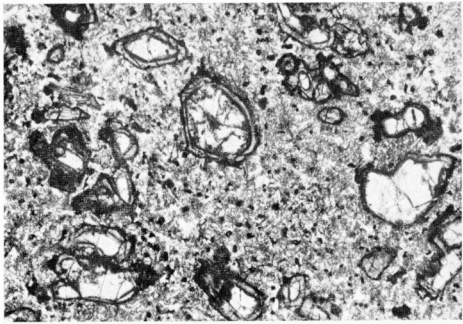

Fig. 2. Olivine basalt of picritic comp. with euhedral olivine phenocrysts rimmed with bowlingite and lying in a paste consisting of plag., augite and ore. Valle de Temisa, N part of Lanzarote.
Nic. //. Magn. 24×.

Fig. 1. Olivine basalt (plagioclase-rich) with sparsely phenocrysts of olivine and augite in a paste consisting of plag., augite and ore. Quaternary lava at Puerto Naos, to the north from Arrecife, Lanzarote.

Nic. +, Magn. 8 ×.

Fig. 2. Trachyandesite with stray phenocrysts of a Na-rich plagioclase in a fine grained paste of alk. feldspar microlites with trachytoidal texture. Mafic minerals as pseudomorphs. Los Ajaches, N fr. P. Papagayo, Lanzarote.

Nic. +, Magn. 8 ×.

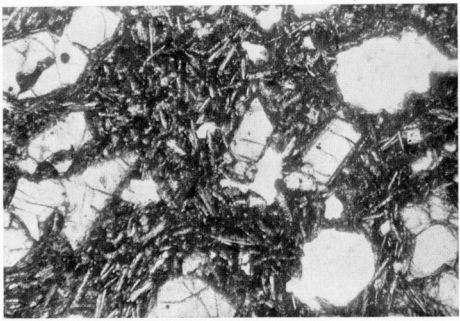

Fig. 1. Olivine basalt, vesicular, with phenocrysts of olivine in a groundmass of augite, plag. and ore (abundantly). Great dike cutting the tuffs in Roque del Este.

Nic. //. Magn. 16×.

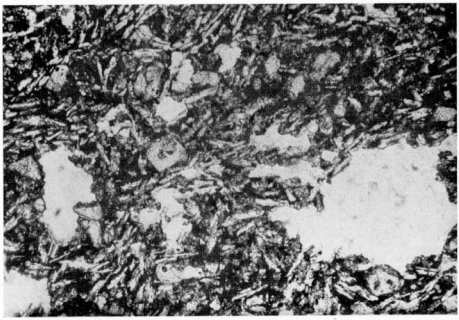

Fig. 2. Another part of the same rock.

Nic. //. Magn. 16×.

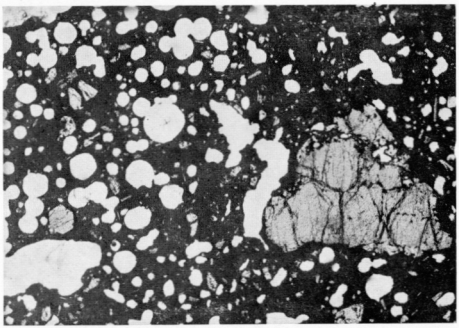

Fig. 1. Olivine basalt, glassy, porous, Phenocrysts of olivine (right) in a dark coloured glassy matrix containing scattered augite, olivine and plag. microlites. Lava from Volcán de Tinguatón (eruption 1824). Lanzarote.
Nic. //. Magn. 16×.

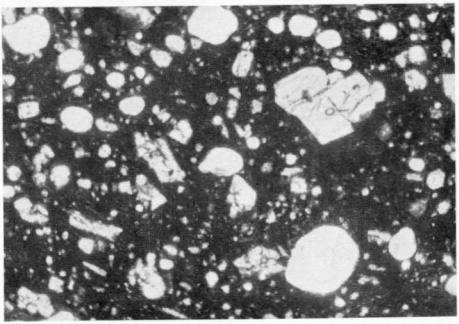

Fig. 2. Porous, glassy olivine basalt lava from the slaggy cone Volcán Clérigo Duarte (eruption 1824). Olivine phenocrysts. Lanzarote.
Nic. //. Magn. 16×.

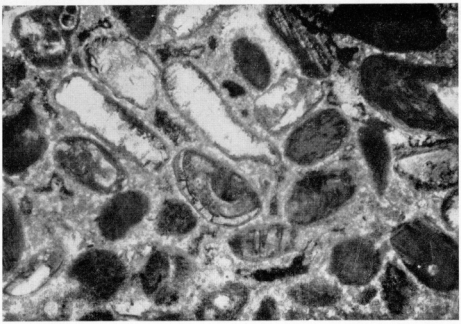

Fig. 1. Oolithic limestone (of Quaternary age) at the southeastern foot of the Quaternary volcano Montaña Tinamala, region of Guatiza. Lanzarote.
Nic. +. Magn. 32×.

GEOLOGIC MAP of LANZAROTE

GRACIOSA and adjacent ISLETAS

(CANARIAN ARCHIPELAGO)

Compiled by Hans Hausen 1958

Horst mountains consisting of the basaltic table-land series (the basement complex)

The Quaternary basaltic volcanoes and their lavas (partly hidden beneath gravels and later lavas)

The Sub-Recent volcanoes and their lavas (northern part of the island)

The great basaltic lava inundations from the first half of the XVIII:th century

Black circle: eruptive vent of the year 1824

Calcareous (oolitic) sandstone / Alluvium

ALEGRANZA

MONTAÑA CLARA

ROQUE DEL ESTE

GRACIOSA

M. AMARILLA

PUNTA FARIONES

ORZOLA

EL RÍO

GUATIFAY

MAGUEZ

HARIA

BAHIA DE PENEDO

BARLOVENTO

FAMARA

ARRIETA

EL JABLE

SOO

TINAJO

TIAGUA

TEGUISE

GUATIZA

TINGUATON

SAGA

S. BARTOLOME

MONT. DEL FUEGO

EL GOLFO

P. NAOS

ARRECIFE

SALINA DE JANUBIO

TIAS

FEMES

COSTA DE RUBICÓN

BAHIA DE JUAN DE AVILA

SOTAVENTO

LOS AJACHES

PUNTA PECHIGUERA

PLAYA BLANCA

P PAPAGAYO

LA BOCAINA

SCALE 1:200000

(approx.)

29°

29°

29°

29°

28°

28°

10°10′ 10°05′ 10°00′ 9°55′ 9°50′ 9°40′ W of Madrid

Mk 1000: —