

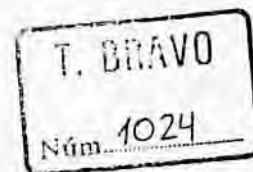
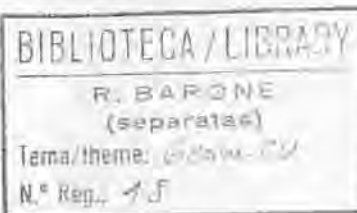
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## REFERENCES

- CALOI, P., A. LOSURDO and G. PONTE, 1948, *Agitazioni microsismiche originate da atti-vità vulcanica*. Ann. Geofisica, 1, p. 5-9.
- LAWRENCE, W. St. and A. QAMAR, 1979a, *Trans-ient Water Flow in Subglacial Channels*. J. Glaciology, 23, p. 432-433.
- LAWRENCE, W. St. and A. QAMAR, 1979b, *Hydraulic Transients: a Seismic Source in Volcanoes and Glaciers*. Science, 203, p. 654-656.
- MORSE, P.M., and K.U. INGARD, 1968, *Theore-tical Acoustics*. McGraw-Hill Book Co., 927 pp.
- RIUSCETTI, M., R. SCHICK and D. SEIDL, 1977, *Spectral Parameters of Volcanic Tremors at Etna*. J. Volc. Geoth. Res., 2, p. 289-298.
- SARTORIUS VON WALTERSHAUSEN, W., 1880, *Der Atna*, 1, 2, W. Engelman, Leipzig.
- SASSA, K., 1935, *Micro-seismometric Study on Eruptions of the Volcano Aso*. Mem. Coll. Sc. Kyoto Imp. Univ., Series A, 18, p. 255-294.
- SCHICK, R., and M. RIUSCETTI, 1973, *An Analysis of Volcanic Tremors at South Italian Volcanoes*. Z. Geophysik, 39, p. 247-262.
- SCHNEIDER, G., 1980, *Seismological Study of the Urach Geothermal Anomaly*. Geol. Jb., (in press).
- STREETER, V.L. and E.B. WYLIE, 1967, *Hydraulic Transients*. McGraw-Hill Book Co., 470 pp.

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## Vulcanicity of Historic Times in the Middle Atlantic Islands

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## ABSTRACT

Of the five Middle Atlantic archipelagos, three, Azores, Canaries and Cape Verde, have been volcanically active probably from the mid-14th century onwards. Though Fogo is the only island in the Cape Verde group to show such activity, of all these islands it has erupted most frequently. Historic submarine vulcanism is associated only with the Azores. As per the imperfect data available, it is possible that the sixty five eruptions here recorded, have resulted in the production of some 24 km<sup>3</sup> of lavas and ejecta. The matter of correlating vulcanism in these islands with Sunspot activity and/or Earth minima tides is open to ques-tion. Average peridocity values for vulcanism are 8.1 years, for Sunspot activity, 11.1 years (1700-1965), and 18.6 years for Earth minima tides (1400-1978). Such extra-terrestrial agen-cies are to be considered more as trigger actions rather than basic causes of vulcanicity.

## INTRODUCTION

The volcanic islands of the Middle Atlantic appear to be not older than Jurassic (Upper?), with almost all dating from Late Palaeogene-Neogene. Vulcanism in many islands continued down to Quaternary, even Sub-Recent time, but only in three of five archipelagos, Azores, Canaries and Cape Verde, has vulcanism occurred within historic times. Through there is a relatively large documentation of such, many reports are not couched in scientific terminology, significant data are lacking, often accounts are vague. Hence, although we have testimonies dating back to the beginning of the 16th century, essentially only events of about the last hundred years give more satisfactory and accurate information.

Here we shall review briefly historic vulcanism in the above three archipelagos.

## AZORES

All the island were discovered between 1427 and 1452, settlement beginning in Sta. Maria in 1439. More islands in this archipelago have been historically active than in the others, this archipelago being, also more active seismically within the same period. Historic eruptions have been described by FOUQUE (1867, 1868, 1873), CANTO (1879, 1880, 1881, 1882, 1883, 1884, 1887), CHAVES (1915), FRIEDLÄNDER (1929), AGOSTINHO (1932, 1936, 1937, 1960), MACHADO (1955, 1965a), ZBY-SZEWSKI (1963) and catalogued by WESTON (1964) and MACHADO (1967a).

## S. Miguel

This, the largest island, was discovered sometime between 1427 and 1432, settle-ment beginning in 1439. There is some doubt as to the first historic eruption, the dates of 1439 (WESTON, op. cit.), 1440, (MACHADO, op. cit.), and 1444 (AGOSTINHO, op. cit.) all being given, but 1444 is thought more accurate by several authors. Weston catalogued an eruption off the NW coast in 1460 but others do not mention this. The first well-docu-mented event is that of 1563-64, described in detail by FRUCTUOSO (1591), as well as by MACHADO (1955), AGOSTINHO (1960), ZBYSEWSKI & FERREIRA (1961) and WALKER & CROASDALE (1970). It was during this eruption that the present Lagoa do Fogo was formed as a result of



FIG 1 - Middle Atlantic Islands.

further collapse of the Agus de Pau caldera. Notably different from other archipelagos is the added occurrence of submarine volcanicity in the Azores area, seven such events taking place off the shores of S. Miguel, that of 1682 involving so much pumice eruptions that for a long time afterwards, vessels had difficulty ploughing through the dense floating accumulations.

#### Terceira

Four submarine eruptions have occurred within some 30 km of the island, but only one, that of 1761, was terrestrial, (FOUQUE, 1867, CANTO, 1882; AGOSTINHO, 1960). From four mushroom domes well down the eastern flanks of Sta. Barbara caldera, explosions and lava extrusions continued for about a week.

#### S. Jorge

The submarine eruption of 1757 - off the S coast but exact locality not known - coincided with the most violent earthquake ever to strike the Azores, centred in the eastern part of the island, and causing several hundred deaths (AGOSTINHO, 1937). According to KREJCI-GRAF (1956), 18 islets resulted from this eruption, all soon destroyed by wave attacks. The 1808 eruption was notable for the development of nuées ardentes resulting in many deaths, and lava inundations causing great building damage. Seismic activity in February, 1964, is suspected of having triggered submarine volcanic action off the S coast, sulphurous smells were noted in coastal regions, but no actual volcanic phenomena were seen above sea level, «probably because the bottom was too deep under that area». (MACHADO & FORJAZ, 1964, 1965).

#### Pico

There is much doubt about vulcanism in 1500 and thus we consider that of 1562 as the first of historic times (MACHADO, 1962a), and actually the first to be observed by Europeans in the Azores since settlement began, (FOUQUE, 1867b,c; CANTO 1879; ZBYSZEWSKI, 1964. Though the main volcanic peak of the island, Ponta Pico (2351m) last erupted in 1719-20, fumarolic activity on the mountain slopes have been observed many times since. WESTON (1964) has mentioned submarine vulcanism off the NW coast in 1963. This locality in the Canal do Faial may possibly be related to fractures extending from Faial to Pico on the northern rim of a submarine caldera. (MACHADO, 1957; MITCHELL-THOME, 1980).

#### Faial

Volcanically, this has been the most quiescent in historic times, but shows the latest terrestrial vulcanism, that of 1957-

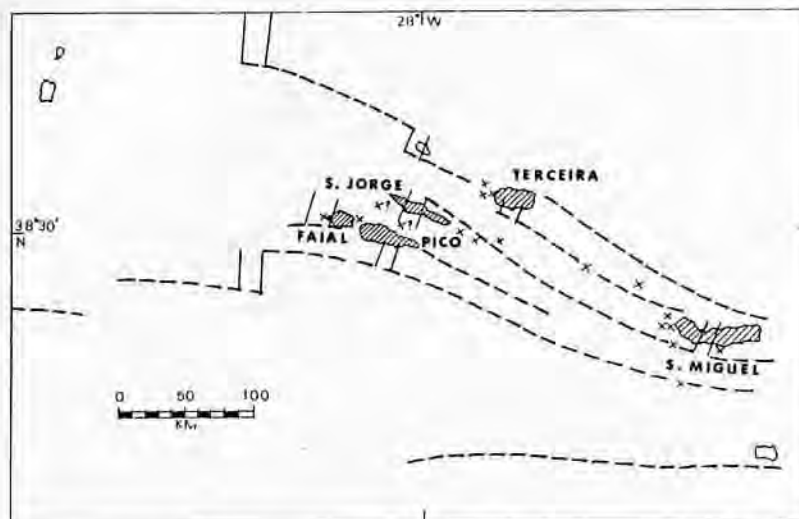


FIG 2 - Azores Archipelago fractures patterns (dashed lines), 'rift' zones (solid lines) and locations of submarine eruptions (X).

58. This last eruption has been well described by MACHADO (1958a, 1959a, 1960a, 1965a), MACHADO *et al.*, (1962), TAZIEFF (1958), RIBEIRO & BRITO (1958), BRANCO *et al.*, (1959), ZBYSZEWSKI & FERREIRA (1959), ZBYSZEWSKI (1960, 1962), FORJAZ (1963, 1965-66), MACHADO & FORJAZ (1968). Submarine activity began ca. 1 km offshore of the westernmost point of the island, repeated explosive materials and lava outpourings eventually linking up with the mainland, and so adding 2.4 km<sup>2</sup> of land to Faial, initially. Marine attack on the loose, friable pyroclastics has been drastic, detailed maps of Machado & Forjaz showing successive retreat of shorelines and topographic changes up to 1967. Between November, 1958 and March, 1967, the created volcanic promontory was being wave-eroded at rates varying from 2.6 to 23.3 cm daily along the N coast, from 9.4 to 84.5 cms daily along the W coast, and from 1 to 57.8 cm daily along the S coast. Though explosive and lava expulsion activity ended in October,

1958, solfataric actions continued long afterwards, with temperatures more than 550°C still being recorded in September, 1962, 400°C in December, 1963. Powerful and awe-inspiring though this Capelinhos eruptions was, with a great many earth tremors before and during eruptions, it is surprising that no human lives were lost. It was the opinion of Tazieff that Capelinhos was not a new volcanic outburst, after the fashion of Paricutin, but rather re-activation of a pre-existing volcanic feature. Machado (MACHADO & FORJAZ, 1968) considered that during the thirteen months of vulcanism, there were two distinct, superimposed eruptions, the first beginning September, 1957, the second in May, 1958. The eruption produced lavas all of vesicular basanitoid type, on occasion trending more towards andesitic, and thus lavas were of similar type to those of the 1672-73 Faial eruption. (ASSUNÇÃO, in ZBYSZEWSKI *et al.*, 1959).

Terrestrial vulcanicity in the Azores (12 occurrences) as also submarine (16 occur-

rences) is confined within a 70 km broad NW-SE oriented zone of fracturing. Historic vulcanism is chiefly restricted to topographic lows traversing the middle sections of the islands which appear to mark the presence of 'rifts', as per the patterns of magnetic anomalies. (MACHADO *et al.*, 1972). These authors believed that the Mid-Atlantic Ridge was here displaced by transcurrent faults striking through all islands from Faial to S. Miguel. The East Atlantic Fracture Zone and the Mid-Atlantic Ridge thus intersect in the Azores region. The more widespread vulcanism and greater seismicity of this archipelago suggest causal relations to these two tectonic units, but in specific terms, such are difficult to establish.

#### CANARIES

This is the only Middle Atlantic archipelago which had an aboriginal population, probably being first settled sometime between 2500-2000 B.C. Early Mediterranean peoples knew these islands ('Hesperis', 'Insulae Fortunatae', 'Kaledad-al Yezair al Jaldad'), but it was only in the 14th. century that the archipelago was 're-discovered'. Official conquest began in 1402 and was completed by 1496. Historic eruptions are limited to three of the ten islands.

#### Lanzarote

Historic vulcanism has been reported by PERDOMO (1824), VON BUCH (1825), WEBB & BERTHOLET (1839), HARTUNG (1857), CLAVIJO (1859), VON FRITSCH (1867), SIMONY (1892), SAPPER (1906), HERNANDEZ-PACHECO (1910, 1960), FERNANDEZ (1919, 1925), BRAVO (1954, 1964), HAUSEN (1959), MACHADO (1965c), TINKLER (1966), IBARROLA & LOPEZ (1967), SAN MIGUEL DE LA CAMARA & BRAVO (1967), FUSTER *et al.*, (1968). The earliest reported eruption began in September, 1730, and continued with a great number of sporadic outbursts until April, 1736. As per HERNANDEZ-PACHECO

(1960): «this was... one of the most intense ever registered in the history of vulcanism as regards the quantity of materials ejected and the long period from 1730 to 1736, greater than that of almost any known». From twenty five eruptive centres, lavas spewed forth over an area of 200 km<sup>2</sup> - almost one quarter of the island. The priest Curbelo, then living in Yaiza, at the edge of the volcanic region, witnessed this long episode and compiled a detailed manuscript which was long unknown until found by von Buch, the text of which he copied in his work of 1825. Even today this NW part of the island is a chaotic, blocky-lava region devoid of all human life and all but bare of vegetation. Still remarkable are the high ground temperatures here at negligible depths - 360°C has been recorded 60 cms below the surface! These local thermal anomalies are related to hot fluids issuing from volcano-tectonic fractures, where thermal gradients of 0.2°C/m have been measured, some 6x that of the average gradient (ARANA *et al.*, 1973). The 1824 eruption occurred in the same general region, with three distinct emission centres. Compared to the earlier vulcanism, this was a very minor occurrence as regards duration, volume and areal extent of lavas. Generally the lavas of both eruptions are normal basalts, at times limburgitic type, some being highly vesicular and porphyritic, and some 1824 flows show superb pahoehoe structure. All lavas tend to be glassy, with dunite (?) -harzburgite (?) xenoliths.

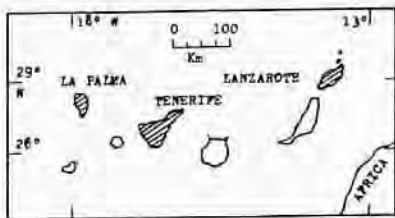


FIG. 3 - Canaries Archipelago.

#### Tenerife

Perhaps as early as 1393 or 1399 (Tenerife was the last to be subdued a hundred years later) vulcanism occurred, but exactly when or where is not known. (VON FRITSCH & REISS, 1868). Aboriginal tales refer to eruptions in the lower Orotava valley in 1430, (WEBB & BERTHOLET, 1839). CA' DA MOSTA (1948), who made extensive voyages amongst these Middle Atlantic Islands and also along West African shores in the middle of the 15th century, mentioned vulcanicity (probably fumarolic) at Pico teide (3718 m) in 1444. During his first outward-bound voyage to the New World in 1492, Columbus noted in his log-book immense fires on the island (BALLESTEROS, 1945). All such reported events are lacking in detail, their authenticity may be questioned, though that vulcanism occurred in the 14th. and 15th. centuries is indeed plausible. The first documented event dates from the years 1704-06. Those of 1704-05 have three emission centres aligned NE-SW along the Pedro Gil ridge crest, whereas that of 1706 took place far down the NW slopes of Pico Teide, the spilled lavas reaching the NW coast. In 1798 eruptions occurred from several vents on the W flank of Pico Viejo (3047 m), within the Las Canadas caldera (MACHADO, 1964). The last eruption of 1909 at Montana Chinero has been well studied (FERNANDEZ, 1910, 1911, 1912, 1919, 1925; COLLET & MONTEGNIER, 1910; PERRET, 1914; HAUSEN, 1955; SAN MIGUEL DE LA CAMARA & BRAVO, 1967). There has been dispute as to whether Chinero was a non-parasitic episode but rather a renewal of activity of the central Viejo-Teide edifice (PERRET, *op. cit.*), or a typical parasitic cinder cone with no immediate relation to Viejo-Teide (HAUSEN, *op. cit.*). The historic lavas of Tenerife are of basaltic type, commonly showing phenocrysts of augite, olivine and plagioclase, all more or less feldspathoidal, as well as trachy-basalts rich in alkalis. This petrography contrasts with the next older Recent eruptions of Viejo-Teide, whose lavas are distinctly felsic and highly viscous, involving vitrophyres of trachytic and phono-

litic obsidians (MITCHELL-THOMÉ, *in press*).

#### La Palma

Apart from some authors shown for Lanzarote, historic eruptivity in this island has been described by ORTIZ (1951), BENITEZ (1951), SAN MIGUEL DE LA CAMARA *et al.*, (1952), SANTIAGO (1960), MARTEL (1960), MACHADO (1963), CHAIGNEAU & FUSTER (1972) and several authors who contributed to the volume concerning the 1971 eruptions (Symposium, 1974). Historic vulcanicity has occurred principally along the spine and western flanks of Cumbre Vieja, in the southern half of the island. The earliest vulcanism dates from 1585, with only one longer pause between the six eruptions in the four month period. The various eruptions are characterized by glassy basalts (1585), normal basalts (1646), ordanichites, tephrites and tephritoids (1677-78), basanitoids (1712), alkali basalts (1949) and highly alkaline basalts and rhyolitic pumice (1971).

#### CAPE VERDE

##### Fogo

Only in this island has there been historic vulcanicity, but Fogo (= fire) has erupted more frequently than any other Middle Atlantic island. Presumably the

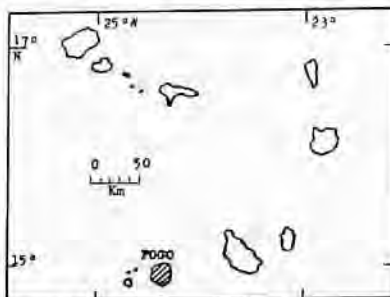


FIG. 4 - Cape Verde Archipelago.



TABLE 1 - Volume of lavas (and ejecta for S. Miguel and Faial) produced during some historic eruptions in some islands.

Island	Eruption	V o l u m e	A u t h o r i t y
S. Miguel	1583-84	Ca. 133 mill. m <sup>3</sup> .	Walker & Grandale, 1971
La Palma	1559	20 - 30 mill. m <sup>3</sup> .	Wachado, 1961
La Palma	1648	20 - 30 mill. m <sup>3</sup> .	Wachado, 1961
Faial	1672-73	"Several hundreds of Mill. m <sup>3</sup> ."	Wachado, 1969
La Palma	1577	20 - 30 mill. m <sup>3</sup> .	Wachado, 1961
Tenerife	1704-05	77 mill. m <sup>3</sup> .	Wachado, 1964
	1704-06	70 mill. m <sup>3</sup> .	Fernandez, 1925
La Palma	1712	20 - 30 mill. m <sup>3</sup> .	Wachado, 1961
Lanzarote	1730-36	At least 700 mill. m <sup>3</sup> .	Hernandez-Pacheco, 1910
Tenerife	1796	17 mill. m <sup>3</sup> .	Wachado, 1964
Tenerife	1809	15 mill. m <sup>3</sup> .	Fernandez, 1911
		11 mill. m <sup>3</sup> .	Wachado, 1964
		55 mill. m <sup>3</sup> .	Ortiz, 1921
La Palma	1849	20 - 30 mill. m <sup>3</sup> .	Wachado, 1961
		10 mill. m <sup>3</sup> .	Wachado, 1965a
Fogo	1951	11 mill. m <sup>3</sup> .	Assuncao, 1954
Faial	1957-58	85 mill. m <sup>3</sup> .	Wachado, 1965a
		More than 150 mill. m <sup>3</sup> . †	Wachado & Purjes, 1968
La Palma	1971	Ca. 12 mill. m <sup>3</sup> .	Wachado, pers. commun.

† Includes 80% "material protrusivo".

archipelago was discovered sometime between 1445 and 1460, and Fogo first appeared on a map in 1460. The earliest report on present-day vulcanism was compiled between 1506 and 1510 by the German V. FERNANDES (1510), though RIBEIRO (1960) doubted if he actually witnessed the event. Although various troops were stationed on the island in the previous half-century, this 1500 eruption is the first known, vulcanism occurring in the central vent, now known as Pico Novo or Pico (2829 m). Many navigators, explorers, travellers, merchant-pirates in the earlier years reported Fogo eruptions, no less Government resident officials and ecclesiastics referred to such events. Many of these accounts were collected together and briefly mentioned by SAINTE CLAIRE-DEVILLE (1848), 21 eruptions by seventeen observers. Log-book entries, diaries, manuscripts, left by witnesses, with the exception of those of the Brazilian naturalist Feijo regarding the 1785 event, all lack scientific precision, are often fancifully described, so that it is only at the beginning of the 19th century that documentation is more specific and accurate. Events of the

19th century have been reported by CASTILHO (1836), BRITO CAPELLO (1847, 1857), VASCONCELOS (1847), BARREIROS (1852), and summary accounts of all eruptions in RIBEIRO (1960). There is considerable doubt about vulcanism in 1909. FRIEDLÄNDER (1913) accepted witness accounts of great clouds (cinder explosions) and sudden rise in atmospheric temperatures as indicative of eruptions, but Ribeiro thought the observed phenomena were purely of atmospheric and not volcanic origin. The last eruption of 1951 has been described by ASSUNÇÃO (1954), PASTOR (1954), ASSUNÇÃO (1955), RIBEIRO (1960), MACHADO (1962b, 1965a,b) and ASSUNÇÃO *et al.*, (1967). Naturally this last episode has left the most vivid and concrete impressions, with the production of fresh, blocky lava flows within the great caldera, from the caldera rim down to the eastern coast, two pronounced new scoria cones within the caldera. A feature of note regarding these Fogo eruptions, is that the principal cone, Pico, was active in all eruptions till 1785 (perhaps 1799), but thereafter has been quiescent, later vulcanism taking place within the caldera

TABLE 2 - Years of eruptivity, duration and periodicity of historic vulcanism. (Note: Only those eruptions of reasonable authenticity are listed. Durations of eruptivity do not necessarily imply that activity was continuous during days enumerated.)

Arch.	Island	Year	Began	Ended	Duration in Days	Interval in Years
A	S.	1444	?	?	?	119
		1563	June 28	Jly. 10?	13?	.5
		1564	Feb. 10	Feb. 12	2	46
		1630	Sept. 3	Sept. 10	7	8
		1638	Jly. 3	?	?	?
		1652	Oct. 19	Oct. 26	8	14
		1682?	Sept. 5	?	?	129
		1811?	Feb. 1	Jly. 14	164	50
		1861?	Apr. 4	?	?	19
		1880?	?	?	?	27
E	Faijal	1907	Apr. 1	?	?	4
		1911	?	?	?	?
		1720?	Dec. 8	?	?	41
		1761	Apr. 14	Apr. 21	10	39
		1800?	?	?	?	67
		1867?	Apr. 18	June 18	62	35
		1902?	May 27	?	?	?
		1580	May 1	Aug. 10?	122?	177
		1757?	Jly. 9	Jly. 10	2	51
		1808	May 1	June 10	41	89
S	Fico	1007?	?	?	?	57
		1064?	Feb. 18	?	?	?
		1562	Sept. 21	Nov. 20?	61?	156
		1718	Feb. 2	Mid-Dec?	317?	2
		1720	Jly. 10	End 1720?	175?	243
		1963?	Nov. 6	?	?	?
		1672-73	Apr. 24/72	Feb. 28/73	311	284
		1957-58?	Sept. 27/57	Oct. 24/58	393	?
		1730-36	Sept. 1/30	Apr. 16/36	?	88
		1824	Jly. 31	Oct. 25	87	?
A	Tenerife	1704-05	Dec. 31/04	Feb. 25/05	58	1.2
		1706	May 5	May 19	15	92
		1798	June 8	June 18?	9?	111
		1909	Nov. 18	Nov. 28	11	?
		1585	Apr. 15	Aug. 10	118	61
		1546	Oct. 2	Dec. 21	81	31
		1577-78	Nov. 17/77	Jan. 21/78	56	34
		1712	Oct. 9	Dec. 3	55	237
		1949	June 24	Jly. 30	37	22
		1971	Oct. 26	Nov. 18	24	?
G	F	1500	?	?	?	64
		1564	?	?	?	32
		1596	Sept. 11	?	?	8
		1604	Mar. 10	Mar. 22	11	60
		1664	?	?	?	11
		1675	?	?	?	5
		1680	?	?	?	3
		1683	Autumn	?	?	6
		1689	June	?	?	4
		1691	Dec. 17	?	?	2
E	o	1695	Oct. 5	Oct. 5	2	2
		1697	Mar. 2	Mar. 5	4	2
		1699	Feb.	?	?	?
		1712	Feb?	?	?	11
		1713	Nov?	?	?	1
		1721-25?	?	?	?	8
		1761	?	?	?	16?
		1769/74?	?	?	?	8?
		1785	Jan. 24	Feb. 25	31	15?
		1798	June 2	June 28	27	14
D	o	1816	?	?	?	17
		1847	Apr. 9	May 27	24?	31
		1852	Feb. 19	Mar. 10?	41?	5
		1857	June 27	Dec. 15	172	6
		1951	June 12	Aug. 21	71	94

‡ Submarine Eruptions

floor, well down the slopes of Pico, or then on the breached eastern caldera slopes. Lavas of historic times show fewer alkalis and alumina and more magnesia than those erupted before the collapse of the caldera - probably in Sub-Recent times. Lavas are chiefly basanites, olivine-basalts, limburgites, ankaramites and augites.

#### VOLUME OF VOLCANIC PRODUCTS

Estimates of the volumes of lavas and ejecta are scarce indeed. For submarine activity, volumes are quite unknown, and in many instances terrestrial lava flows continued below sea level. With such relatively small oceanic islands, experiencing rather strong and persistent winds ejecta have been scattered far over islands and even farther out into the seas - Fogo ashes have been swept as far as 145 km eastward to Maio (CASTILHO, 1836). Atlantic cores have detected Miocene volcanic glass originating probably from Gran Canaria and the Cape Verde Islands at distances of ca. 150 km and 300 km eastward. (ROTHE & KOCH, 1977).

HUANG *et al.*, (1979) mentioned megascopically recognizable ash layers in deep-sea cores up to about 1000 km eastward of the Azores. A minimum of  $3 \times 10^{10}$  metric tons in the 4 mm to 11  $\mu$ m fraction were deposited in seas to E during the last 125,000 years at distances further than 200 km from source in a fall-out area of some  $0.6 \times 10^6$  km<sup>2</sup>. It follows then that volumes of volcanic products of historic eruptions are very imperfectly known, but some indication of such is given in Table 1. For thirteen out of sixty five eruptions we have lava volume estimates at least of the order of 1.3 km<sup>3</sup>. As per descriptions of eruptions, extents and average flow thicknesses, taking into account the remaining fifty two eruptions, there may be a grand total of at least 9 km<sup>3</sup> for lava flows. From all descriptions, the volume of ejecta must have been great, perhaps of the order of 15 km<sup>3</sup>. These historic eruptions therefore may have produced some 24 km<sup>3</sup> volcanic material.

#### DURATION OF VOLCANICITY

Data are lacking or then vague as regards duration of many eruptions. For the volcanic periods 1721-25 in Fogo and 1730-36 in Lanzarote, we certainly cannot assume continuous activity, but how long actual vulcanism was in progress is unknown. For most of the submarine activity, we likewise have no information. Of the sixty five eruptions listed in Table 2, we have reasonably accurate duration data for twenty six episodes and more questionable information regarding eight more. Totalling such data would give 2616 days of eruptions. Such is an absolute minimum, and taking into account missing information for thirty one events, it is quite feasible that total duration should be more of the order of some 4600 days minimum. During the period 1444-1971, 527 years, this would average about nine days vulcanism annually, but considering the unknowns and imprecisions, this can only be a rough estimate.

#### PERIODICITY OF VOLCANISM

In Fogo there appear to have been repeated eruptions since 1500 till the middle of the 18th century, ceasing abruptly in the 1760s, since when there have been only short flank eruptions, lasting less than two months. Since first colonized, three longer quiescent periods occurred, and equally notable are eight eruptions in the twenty four years 1875-99. For most of the islands mentioned here, similar active and inactive periods can be noted, as seen from Table 2. For the three archipelagos, average intervals between vulcanism increases from S to N. In several publications, *e.g.* MACHADO (1958b, 1960b, 1965c, 1967b, 1968), as also DIAS (1962), have commented upon volcanic periodicities in these islands. Both appeal to the influence of Sunspot cycles and Earth tides. Regarding the Azores, especially the Sunspot-eruptivity correlations, these depend so greatly upon the range in time variation we are prepared to accept. For example, if we take 4 years as the maximum time differ-

TABLE 3 - Chronologic sequence of historic vulcanism in the Middle Atlantic Islands.

Date	S. Miguel	Ten- terife	S. Jor- ge	Pico	Fogo	Lan- zarote	Tener- ife	L. Palma	Fogo
1444	x								x
1500				x					
1562									
1563	x								
1564	x								x
1580			x						
1585								x	
1595									x
1604									x
1630	x								
1638	x								
1646								x	
1652	x								
1664									x
1672-73					x				
1675									x
1677-78								x	x
1680									x
1682	x								x
1683									x
1689									x
1693									x
1695									x
1697									x
1699									x
1704-05							x		
1706							x		
1712								x	x
1713									x
1716				x					
1720									
1721-25		x		x					x
1730-36			x			x			
1757									x
1761		x							x
1762, 74, 77									x
1771									x
1798							x		
1799									x
1800		x							
1808			x						
1811	x								x
1816									x
1824									x
1847									x
1852									x
1857									x
1861	x								
1867		x							
1868	x								
1892	x	x							
1907									
1909									
1911	x								
1949								x	
1951									x
1957-58					x				
1963					x				
1964			x						
1971								x	

ence permissible, then eleven eruptions can be correlated with eight Sunspot maxima activities in the three archipelagos. Whilst the average interval between Sunspot maxima is 11.1 years, that between eruptions is 8.1 years. The lunar period of 18.6 years, where sharp minima of the Earth tide component occur, shows only six volcanic time-intervals reasonably close to this figure in Fogo. There is a difference in minima periods N and S of lat. 35° 16', from which Machado indicates a somewhat different Earth tide behaviour

between Cape Verde-Canaries (S of this latitude), and the Azores to the N thereof. Time correlations of vulcanism in the three archipelagos can be seen, for example: 1798 Tenerife, 1799 Fogo; 1808 S. Jorge, 1811 S. Miguel; 1857 Fogo, 1861 S. Miguel; 1949 La Palma, 1951 Fogo, etc. (Table 3). Though one can, here and there, detect some Sunspot-Earth tide correlations with eruptivity, such are probably only trigger-forces, and other cause(s) as yet unknown have been operative. The question of periodicities, like all

statistical presentations, must be viewed with caution. Seldom are the criteria for reality rigorously applied, as set forth, e.g. by SCHUSTER (1897) and WALKER (1925). In the majority of empirical periodicities associated with natural phenomena, a satisfactory explanation of the relations is not forthcoming.

#### CONCLUSION

Of the sixty five eruptions referred to here, there is adequate, detailed scientific data for only five. For natural phenomena of historic times, there are always difficulties in attempting to make direct comparisons down through the centuries, due to increased lack of concrete data as we go backward in time. For these Atlantic historic eruptions, that of Lanzarote in 1730-36 was the major event. From 1444 to 1971, forty nine subaerial and sixteen submarine reasonably well substantiated events have occurred, an average of one eruption per 8.1 years. Such vulcanism took place within a terrestrial area of ca. 4100 km<sup>2</sup> (area of islands in question) and ca. 200 km<sup>2</sup> oceanic area. In Hawaii, the best studied of all archipelagos as regards vulcanism, the islands not only become progressively younger from NW to SE along the chain, but there is also a progressive migration of volcanic activity in the same direction, vulcanism ending some four-five million years ago at the NW end, but being still in progress at the SE end. In the Middle Atlantic Islands, on palaeomagnetic, isotopic, stratigraphic and geomorphologic grounds, western islands seem to be younger than eastern ones, though as yet we are not certain whether there is progressive aging eastwards. Lanzarote and S. Miguel, eastern islands, and La Palma and Fogo, western islands, as also the central islands of Tenerife, Terceira, S. Jorge, Pico and Faial, have all been volcanically active in historic times. Hence in these Atlantic islands there is not the same consistent pattern of island aging and migration of vulcanism within the last five million odd years as it is

#### REFERENCES

- AGOSTINHO, J., 1932, *Vulcanismo dos Açores. Vista Geral*. rev. A Terra, 4, p. 32-36.  
 —, 1936, *The Volcanoes of the Azores Islands*. Bull. Volcanol., 8, p. 123-138.  
 —, 1937, *Tectonica, Sismicidade e Vulcanismo das ilhas dos Açores*. Bol. Soc. A. Chaves, 1., p. 85-98.  
 —, 1960, *Actividade vulcanica nos Açores*. Bol. Soc. A. Chaves, 5, p. 362-478.  
 ARANA, V., ORTIZ, R., and YUGUERO, J., 1973, *Thermal Anomalies in Lanzarote (Canary Islands)*. Geothermics, 2, 2, p. 73-75.  
 ASSUNÇÃO, C. F. T., 1954, *Expedição Científica a Ilha do Fogo. Estudos Petrográficos*. Mém. Sér. Pétrog., Junta Invest. Ultramar, 156 pp.  
 —, 1955, *A Permanencia da Composição das Lavas na Actividade Eruptiva da Ilha do Fogo*. Garcia de Orta, 3, p. 199-204.  
 —, MACHADO F., and SILVA, L. C., 1967, *Petrologia e Vulcanismo da Ilha do Fogo (Cabo Verde)*. Garcia de Orta, 15, 1, p. 99-110.  
 BALLESTEROS Y BERETTE, A., 1945, *Cristobal Colon y el descubrimiento de America*. 2 vols.  
 BARREIROS, F. J., 1852, *Visita no vulcao da Ilha do Fogo em Março 1852*. Bol. Off. Prov. de Cabo Verde, 85.  
 BENITEZ, S., 1951, *La erupcion de «Las Manchas» en la Isla de La Palma y el vulcanismo canario*. Rev. El Museo Canario, 37-40, p. 51-72.  
 BRANCO, A. C., ZBYSZEWSKI, G., ALMEIDA, F. M. and FERREIRA, O. V., 1959, *Le volcanisme de l'île de Faial*. Rapp. de la prem. miss. géol. Mem. Serv. Geol. Portugal, 4, p. 9-27.  
 BRAVO, T., 1954, *Geografia General de las Islas Canarias*. 1., 410 pp., Goya Edic.  
 —, 1964a, *Geografia general de las Islas Canarias*, 2, 552 pp., Goya Edic.  
 —, 1964b, *El Volcan y el malpais de La Corona. La «Cueva de los Verdes» y los «Jameos»*. Publ. Cabild. Insul. Lanzarote, 31 pp.  
 BRITO CAPELLO, F. A., 1847, *Erupção do Vulcano de Ilha do Fogo*. Bol. Off. Prov. de Cabo Verde, 183.  
 —, 1857, *Relatorio sobre o vulcao da Ilha do Fogo*. Bol. Off. Prov. de Cabo Verde, 205.  
 BUCH L. von, 1825, *Physikalische Beschreibung der Canarischen Inseln*. Berlin. 201 pp.  
 CA' da MOSTA, L. A., 1948, *Viagens de Luis de Ca' da Mosta e de Pedro de Sintra*. Edit. by D. Peres. Lisbon, Acad. Port. Hist.  
 CANTO, E. P., 1879, *Anno de 1562 Erupção na*
- CANTO, E. P., 1880a, *Anno de 1580. Erupção na Ilha de S. Jorge*. Arch. Açores, 2, p. 188-193.  
 —, 1880b, *Anno de 1630 Erupção na valle das Furnas, Ilha de S. Miguel*. Arch. Açores, 2, p. 527-547.  
 —, 1881, *Anno de 1672. Erupção na Ilha do Fayal*. Arch. Açores, 3, p. 344-351, p. 426-434.  
 —, 1882a, *Anno de 1760-1761. Terremote e erupções na Ilha Terceira*. Arch. Açores, 4, p. 362-365.  
 —, 1882b, *Anno de 1718. Erupção na Ilha do Pico*. Arch. Açores, 4, p. 497-506.  
 —, 1883a, *Anno de 1720. Erupção na Ilha do Pico*. Arch. Açores, 5, p. 343-345.  
 —, 1883b, *Anno de 1867. Erupção submarina junto da Ilha Terceira*. Arch. Açores, 5, p. 499-503.  
 —, 1884, *Anno de 1808. Erupção na Ilha de S. Jorge*. Arch. Açores, 6, p. 437-447.  
 —, 1887, *Anno de 1672. Erupção no Capello, Ilha do Fayal*. Arch. Açores, 9, p. 425-432.  
 CASTILHO, J. F., 1836, *Memoria sobre a Provincia da Ilhas de Cabo Verde*. Jor. Soc. Amigos Letras.  
 CHAIGNEAU, M. and FUSTER, J. M., 1972, *L'éruption du Teneguia (La Palma) et la composition des laves et gaz sumeroliens*. C. R. Acad. Sci., 274, p. 2948-2951.  
 CHAVES, F. A., 1915, *Erupções submarinas nos Açores*. Lisbon, Tip. Modesta.  
 CLAVIJO, J.V., 1859, *Noticias de la Historia general de las Islas Canarias*. 2, 3, Sta. Cruz de Tenerife, Imp. Ielena D.J.N. Romero.  
 COLLET, W. and MONTEGNIER, F., 1910, *Sur la récente eruption de Chinyero à Ténérife*. Arch. Sci. Phys. Nat., 29.  
 DIAS, A. A. M., 1962, *The Volcano of Capelinhos (Azores), the Solar Activity and the Earth-Tide*. Bull. Volcanol., 24, p. 211-221.  
 FEIJO, J. S., 1786, *Memoria sobre a nova irrupção do Pico da Ilha do Fogo*. Arq. Hist. Ultramarino, Cabo Verde.  
 —, 1857, *Memoria sobre a ultima erupção volcanica do Pico da Ilha do Fogo*. Mem. Acad. Real das Cien. de Lisboa, Cl. Cien., Math. Fis. e Nat., 2, 1.  
 FERNANDES, V., 1510, *Coadice, com Crônicas, Relações e Cartas em Portugal 1506-1508*. Vd. also: O Manuscrito «Valentim Fernandes», Edit. by Acad. Port. Hist., 1940.  
 FERNANDEZ, L., 1910, *Sobre la erupción volcanica de Chinyero (Tenerife)*. Bol. R. Soc. Esp. Hist. Nat., 10, p. 104-122.  
 —, 1911, *Erupción volcanica del Chinyero (Tenerife) en noviembre de 1909*. Ann. Junta

- , 1912, *Nuevos datos sobre el volcan Chinyero (Tenerife)*. Bol. R. Soc. Esp. Hist. Nat., 12, p. 74-78.  
 —, 1919, *Las erupciones de fecha historica en Canarias*. Mem. R. Soc. Esp. Hist. Nat., 11., p. 37-75.  
 —, 1925, *Datos sobre el vulcanismo canario*. Bull. Volcanol., 2, p. 129-155.  
 FORJAZ, V. H., 1963, *Topografia e temperaturas de vulcao dos capelinhos (Setembre 1962)*. Bol. Mus. Lab. Min. Geol., Fac. Cien. Univ. Lisboa, 9, 2, p. 125-130.  
 —, 1965-66, *Observações realizadas no vulcao dos Capelinhos (Açores) em Agosto e Setembro de 1963*. Bol. Mus. Lab. Min. Geol., Fac. Cien. Univ. Porto, 10, 2, p. 89-94.  
 FOUQUÉ, F., 1867a, *Sur les gaz qui se dégagent en mer, du lieu de l'éruption qui s'est manifestée aux Açores le 1er Juin, 1867*. C.R. Acad. Sci., 65, p. 674-675.  
 —, 1867b, *Sur les phénomènes volcaniques observés à Terceira*. C.R. Acad. Sci., 65, p. 965-971.  
 —, 1867c, *Sur les phénomènes volcaniques observés aux Açores*. C.R. Acad. Sci., 65, p. 1050-1053.  
 —, 1868a, *Eruptions sous-marines des Açores*. Rev. Cours Scient. de la France et de l'Etranger, 11., p. 179-183.  
 —, 1868b, *Communication*. C.R. Acad. Sci., 66, p. 915-917.  
 —, 1873a, *San Jorge et ses éruptions*. Rev. Cours Scient. de la France et de l'Etranger, 11, p. 1198-1201.  
 —, 1873b, *Voyages géologiques aux Açores*. Rev. Deux Mondes, 103, p. 40-65.  
 FRIEDLANDER, I., 1913, *Beiträge zur Kenntnis der Kapverdischen Inseln*. Berlin, D. Reiner, 109 pp.  
 —, 1929, *Die Azoren*. Zeit. Vulkan., 12, p. 77-107.  
 FRITSCH, K. von, 1867, *Reisebilder von den Canarischen Inseln*. Peter. geogr. Mitt., 5, 22, p. 1-44.  
 —, and REISS, W., 1868, *Geologische Beschreibung der Insel Tenerife*. Winterthur, Wurster Verlag. 496 pp.  
 FRUCTUOSO, G., 1591, *Saudades da Terra*. Introd. by D. Peres, 3 vols., 1924-31. Porto. Vd. also: Saudades da Terra, Ponta Delgada, 1926, Tip. Diario dos Açores.  
 FUSTER, J. M., FERNANDEZ, S.S. and SAGREDO, J., 1968, *Geologia y Volcanologia de las Islas Canarias*. Lanzarote. Inst. «Lucas Mallada», Madrid. 177 pp.  
 HARTUNG, G., 1857, *Die geologischen Verhältnisse der Inseln Lanzarote und Fuerteventura*. N. Denk. allg. Schweiz. Ges. Naturwiss., 15, 4, p. 1-168.



- HAUSEN, H., 1955, *Contributions to the Geology of Tenerife*. Soc. Sci. Fenn., Comm. Phys.-Math., 18, 254 pp.
- , 1959, *On the Geology of Lanzarote, Graciosa and the Isletas*. Soc. Sci. Fenn., Comm. Phys.-Math., 24, 116 p.
- HERNANDEZ-PACHECO, E., 1910, *Estudio geológico de Lanzarote y de las Isletas Canarias*. Mem. R. Soc. Esp. Hist. Nat., 6, p. 1-331.
- , 1960, *En relación con las grandes erupciones del siglo XVIII y 1824 en Lanzarote*. Rev. El Museo Canario, 73-74, p. 239-254.
- HIANG, T. C., WATRINS, N. D. and WILSON, L., 1979, *Deep-sea Tephra from the Azores during the Past 300,000 Years: Eruptive Cloud Height and Ash Volume Estimates: Summary*. Bull. Geol. Soc. Amer., 1, 90, p. 131-133.
- IBARROLA, E. and LOPEZ, J. R., 1967, *Estudio petrográfico y químico de las erupciones recientes (Series IV) de Lanzarote*. Estud. Geol., 23, p. 203-213.
- JEREMINE, E., 1933, *Contribution à l'étude de pétrographie des trois Iles l'archipel Canarien: Ténérife, La Palma, Gran Canaria*. Bull. Soc. Minér. France, 56, p. 189-261.
- KHEICHI-GRAF, K., 1956, *Vulkanologische Beobachtungen auf den Azoren*. Frankfurter Geogr., 30, p. 5-30.
- MACHADO, F., 1955, *The Fracture Pattern of Azoren Volcanoes*. Bull. Volcanol., 17, p. 119-125.
- , 1957, *Caldeiras vulcánicas dos Açores*. Atlantida, 1, p. 275-278.
- , 1958a, *Actividade vulcânica de ilha do Faial (1957-58)*. Atlantida, 2, p. 225-236, p. 305-315.
- , 1958b, *Variação secular do vulcanismo açoreano*. Bol. Nuc. Cult. Horta, 1, 3, p. 225-235.
- , 1959a, *Actividade vulcânica de ilha do Faial. Notícia preliminar*. Atlantida, 3, p. 40-45, p. 153-159.
- , 1959b, *A erupção do Faial em 1672*. Mem. Serv. Geol. Portugal, 4, p. 89-99.
- , 1960a, *A erupção dos Capelinhos (Açores) e a energia das regiões vulcánicas*. Electricidade, 4, p. 344-346.
- , 1960b, *Secular Variation of Seismo-Volcanic Phenomena in the Azores*. Bull. Volcanol., 23, p. 101-108.
- , 1962a, *Erupções históricas do sistema vulcânico Faial-Pico-S. Jorge*. Atlantida, 6, p. 84-91.
- , 1962b, *Actividade do Vulcano do Fogo, Cabo Verde*. Atlantida, 6, p. 183-191.
- , 1962c, *Sobre o mecanismo da erupção dos Capelinhos*. Mem. Serv. Geol. Portugal,
- , 1963, *Erupções da ilha de La Palma (Canarias)*. Bol. Mus. Lab. Min. Geol., Univ. Lisboa, 9, 2, p. 143-155.
- , 1964, *Alguns problemas do vulcanismo da ilha de Tenerife*. Bol. Soc. Port. Cien. Nat., 10, p. 26-45.
- , 1965a, *Vulcanismo das Ilhas de Cabo Verde e das outras Ilhas Atlântidas*. Junta Invest. Ultramar, Estud. Ens. e Docum., 117, 83 pp.
- , 1965a, *Mechanism of Fogo Volcano, Cabo Verde*. Garcia de Orta, 13, 1, p. 51-56.
- , 1965c, *Sequências eruptivas das Canarias, Cabo Verde e Açores*. Bol. Soc. Geol. Portugal, 16, p. 11-18.
- , 1967a, *Active Volcanoes of the Azores. Catalogue of the Active Volcanoes of the World, 21, Atlantic Ocean*. (M. NEUMANN VAN PADANG et al.) Inter. Assoc. Volcan., p. 9-52.
- , 1967b, *Activity of the Atlantic Volcanoes 1947-65*. Bull. Volcanol., 30, p. 29-34.
- and ASSUNÇÃO, C. F. T., 1965, *Carta Geológica de Cabo Verde. Notícia explicativa da folha da Ilha do Fogo*. Estudios Petrográficos. Garcia de Orta, 13, 4, p. 597-604.
- and FORJAZ, V. H., 1968, *Actividade Vulcânica do Faial, 1957-67*. Com. Reg. Turismo da Horta, 151 p.
- and FORJAZ, V. N., 1964, *Seismic Swarm in the Azores, Feb. 1964*. (Preliminary Report). Bol. Soc. Geol. Portugal, 15, p. 201-206.
- and —, 1965, *A crise sísmica de S. Jorge de Fev. de 1964*. Bol. Soc. Geol. Portugal, 16, p. 19-36.
- , PARSONS, W. H., RICHARDS, A. F. and MULFORD, J. W., 1962, *Capelinhos Eruption of Faial Volcano, Azores, 1957-58*. Jour. Geophy. Res., 67, p. 3519-3529.
- , QUINTINO, J., and MONTEIRO, J. H., 1972, *Geology of the Azores and the Mid-Atlantic Rift*. Proc. 24th Int. Geol. Congr., Montréal, 3, p. 134-142.
- MARTEL, M., 1960, *El Volcan de San Juan, La Palma, Canarias*.
- MITCHELL-THOME, R. C., 1980, *The Caldeiras of Macaronesia*. Bol. Mus. Mun. do Funchal, 33, 141, p. 5-43.
- , in press, *On the Occurrence of Vitrophyres in Macaronesia*. Paper presented at the Int. Symp. on the Activity of Oceanic Volcanoes, IAVCEI & Azores Univ., Aug. 1980, Ponta Delgada, S. Miguel, Azores.
- ORTIZ, J. R., 1951, *La erupción del Nambrague en la Isla de La Palma*. Bol. Inst. Geol. Min. Esp., 63, p. 1-165.
- PASTOR, F. J. F., 1954, *Relatório Expedição*



1953. Publ. Serv. Meteor. Nac. Portugal, RT-134-REL 49.
- PERDOMO, B., 1824, *Noticias del volcan que reavente en la Isla de Lanzarote el año 1824*. Manuscript. El Museo Canario.
- PERRET, F. A., 1914, *The Volcanic Eruption of Tenerife in the Autumn 1909*. Zeit. Vulk., 1, p. 20-31.
- RIBEIRO, O., 1960, *A Ilha do Fogo e as suas Erupções*. Junta Invest. Ultramar, Mém., Sér. Géogr., 1, 2nd edit. 319 pp.
- and BRITO, R. S., 1958, *Primeira notícia da erupção dos Capelinhos*. Naturalia, 7, p. 192-224.
- ROTHER, P. and KOCH, R., 1977, *Miocene Volcanic Glass from DSDP Sites 368, 369 and 370*. Initial reports, Deep Sea Drilling Project, Washington, US Gov't. Print. Off., 41, p. 1061-1064.
- SAN MIGUEL DE LA CAMARA, M., FUSTER, J. M. and MARTEL, M., 1952, *Las erupciones y materiales arrojados por ellas en la Isla de La Palma, Junio-Julio 1949*. Bull. Volcanol., 12 P. 145-163.
- and BRAVO, T., 1967, *Active Volcanoes of the Canary Islands. Catalogue of the Active Volcanoes of the World Including Solfatara Fields, 21, Atlantic Ocean*. Inter. Assoc. Volcan., p. 55-106.
- SAINTE CLAIRE-DEVILLE, C., 1848, *Voyage géologique aux Antilles et aux îles de Ténérife et de Fogo*. Gide et Boudry, 1.
- SANTIAGO, M., 1960, *Los Volcanes de La Palma*. Rev. El Museo Canario, 75-76, p. 281-346.
- SAPPER, K., 1906, *Beiträge zur Kenntnis von Palma und Lanzarote*. Peter. Mitt., 52, p. 143-153.
- SCHUSTER, A., 1897, *Proc. Roy. Soc., A*, 61, p. 455-465.
- SIMONY, O., 1892, *Canarische Inseln, insbesondere Lanzarote und die isletas*. Schr. Ver. Verbreit. Natur. Kennt., 32, p. 325-398.
- SYMPOSIUM, 1974, *Tenequia*. Estud. Geol., Vol. Tenequia.
- TAZIEFF, H., 1958, *L'éruption 1957-58 et la tectonique de Faial (Açores)*. Bull. Soc. belge Géol., 67, p. 13-49.
- TINKLER, K. J., 1966, *Volcanic Chronology of Lanzarote (Canary Islands)*. Nature, 209, 5028, p. 1122-1123.
- VASCENCELOS, J. V., 1847, *Erupção do Vulcão da Ilha do Fogo*. Bol. Off. Prov. de Cabo Verde, 190.
- WALKER, G. P. L. and CROSSDALE, R., 1970, *Two Plinian-type Eruptions in the Azores*. J. Geol. Soc., 127, p. 17-55.
- WALKER, G. T., 1925, *Quart. J. Roy. Met. Soc.*, 51, p. 337-346.
- WEBB, P. B. and BERTHOLET, S., 1839, *Histoire naturelle des Iles Canaries*. 2, Géologie. Bethune Ed.
- WESTON, F.S., 1964, *List of Recorded Volcanic Eruptions in the Azores*. Bol. Mus. Lab. Min. Geol. Univ. Lisboa, 10, p. 3-18.
- ZBYSZEWSKI, G., 1960, *L'éruption du Volcan de Capelinhos (Ile de Faial, Açores)*. Bull. Volcanol., 23, p. 77-100.
- , 1961, *Etude géologique de l'île de S. Miguel (Açores)*. Comun. Serv. Geol. Portugal, 45, p. 5-79.
- , 1962, *A erupção do vulcão do Capelinhos no quadro da estrutura da ilha do Faial (Açores)*. Mem. Acad. Cien., 8, p. 3-17.
- , 1963, *Les phénomènes volcaniques modernes dans l'archipel des Açores*. Comun. Serv. Geol. Portugal, 47, 231 pp.
- , 1964, *Contribuição para o conhecimento da geologia da ilha do Pico*. Mem. Acad. Cien., 9, p. 3-13.
- , 1966-67, *As observações de F. Fouqué sobre o vulcanismo dos Açores*. Bol. Nucl. Cult. Horta, 4, p. 17-95.
- , ALMEIDA, F. M., FERREIRA, O. V. and ASSUNÇÃO, C. F. T., 1959, *Carta Geológica de Portugal na escala de 1:25,000. Notícia explicativa da folha Faial (Açores)*. Serv. Geol. Portugal, 25 pp.
- and FERREIRA, O. V., 1959, *Le vulcanisme de l'île de Faial*. Rapp. de la deuxième miss. géol. Mem. Serv. Geol. Portugal, 4, p. 29-55.
- and —, 1961, *A erupção do Pico do Sapateiro e o Fogo do século XVI da Ribeira Seca, Ilha de S. Miguel (Açores)*. Comun. Serv. Geol. Portugal, 45, p. 565-571.

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