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Palaeomagnetism and the Early Magmatic History of Fuerteventura (Canary Islands)

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Abstract. Thermal and alternating field demagnetization combined with studies of the convergence points of remagnetization circles have been carried out on a variety of rocks from Fuerteventura. The older (post-Albian) rocks, including the basement plutonics, the sheeted dike complex and the earliest subaerial lava sequence (lava Series I), have a multicomponent remanence while the younger lava Series II of Miocene/Pliocene age has dominantly a one-component magnetization. Comparison of the results with recent palaeomagnetic data from Gran Canaria/Tenerife and with results from continental Africa and Europe suggest a late Cretaceous origin of the basal intrusive rocks while the subaerial volcanism (lava Series I) most likely initiated at around the Cretaceous/Tertiary boundary. This implies that there is a nearly 50-m.y.-long period of volcanic quiescence and erosion between lava Series I and lava Series II. The apparent contradiction between these conclusions and the few K/Ar dates available is discussed.

Key words: Palaeomagnetism – Age of early Fuerteventura magmatism.

1. Introduction

The oldest exposed rocks in Fuerteventura are found in the western part of the island, the so-called Betancuria massif (Fuster et al., 1968; Rothe, 1968) (Fig. 1). This basement complex, which Gastesi (1973) believes to be a piece of uplifted oceanic crust, has a core of layered basic and ultra-basic plutonics which in part occurs in faulted contact with Lower-Middle Cretaceous terrigenous and calcareous clastic, deep-water sediments of basically turbiditic origin (Robertson and Stillman, 1979). Upwards, the sedimentary sequence, after a hiatus, passes into submarine volcanics and volcaniclastic sediments. This rock association is in turn cut by a very dense dyke system followed by plutonic intrusions with a second generation of dykes, a carbonatite sequence and finally by a syenitic and trachytic ring dyke system. After an unconformity (Stillman

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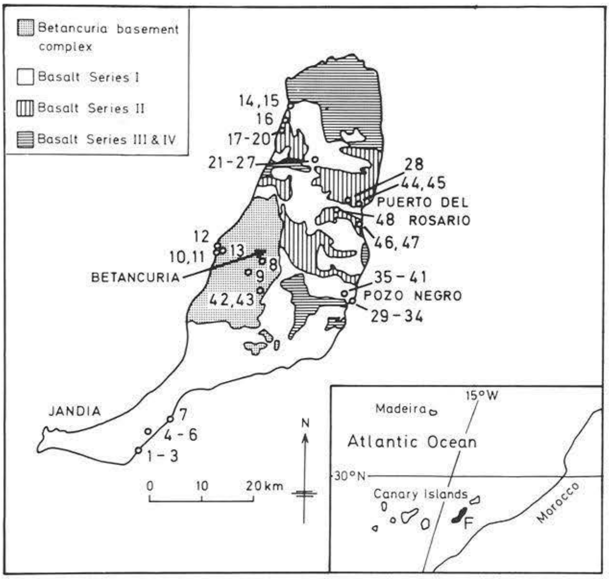

Fig. 1. Simplified geological sketch map of Fuerteventura showing distribution of palaeomagnetic sampling sites.

et al., 1975), four series of subaerial basaltic lavas (Series I–IV; Fuster et al., 1968) were laid down.

A fairly strong secondary alteration has affected all rocks older than lava Series I. Fuster et al. (1968) and Stillman et al. (1975) ascribe these mineral changes to a regional metamorphism equivalent to the greenschist facies. In the Betancuria massif the tectonic situation is complex but at least the Cretaceous sedimentary succession and in part the overlying submarine volcanics have been involved in a relatively strong deformation. The timing of this phase of margin unrest, pre-dating the subaerial lava sequences (Series I–IV), has been a matter of speculation, not least because the existing radiomatric age determinations from the older Fuerteventura volcanics in part are inconsistent and difficult to interpret (cf. Chap. 5). Against these uncertainties an age of Middle Miocene – Pliocene for basalt Series II appears fairly well established (Fuster et al., 1968; Rothe, 1966).

Palaeomagnetic results may provide alternative information on the age problem, but unfortunately the data published so far (Watkins et al., 1966; Watkins, 1973) are not sufficiently detailed to be of much help in this context: only a modest laboratory treatment was performed and discordant directions as well as a marked decrease in the precision parameter (k) towards the base of the subaerial lava succession (Series I) were left unexplained.

In the present study the encountered palaeomagnetic problems are ascribed to unresolved multicomponent magnetizations. After having considered these problems and hopefully estimated the directions of single remanence components the results are compared with recent palaeomagnetic data from Gran Canaria/Tenerife (Storetvedt et al., 1978), and conclusions regarding the early tectono-magmatic evolution of Fuerteventura are drawn.

Table 1. Rock collection details

Site	Sample nos.	Rock type/ series	Locality
1–3	14	Series I	Beach at Cases del Butihondo
4–6	15	Series I	Between Montana Blanca and the sea, ca. 100 m above sea level
7	5	Series I	Beach south of Montana Bay
8	5	Trachyte	Vega de Rio Palmas
9a–e	15	Dyke swarm	Morro Fenduca
10	4	Sediment	Puerto de la Pena
11	4	Dyke	Puerto de la Pena
12	5	Series II	Puerto de la Pena
13a–e	14	Dyke swarm	Puerto de la Pena
14	5	Series I	Toston Cotillo
15	4	Dyke	Toston Cotillo
16–20	19	Series II	Playa del Aguila
21–27	27	Series I	La Matilla
28	4	Series II	4 km west of Puerto del Rosario
29–34	26	Series I	Pozo Negro
35–41	35	Series I	2 km west of Pozo Negro
42–43	8	Trachyte	Tuineje
44–45	10	Series II	Just west of Puerto del Rosario
46–47	10	Series II	Between Puerto del Rosario and the airport
48	5	Series II	Between Casillas del Angel and Puerto del Rosario

2. Palaeomagnetic Collection

The present palaeomagnetic study is based on a total of 234 samples from 56 sites, comprising trachyte (3 sites), dykes (12 sites), sediment (1 site) lava Series I (28 sites) and lava Series II (12 sites). Only one site has been sampled from each rock body (lava, dyke etc.). About half of the sites were collected by portable drill, the remaining material being collected by standard hand sampling. On the average four samples (drill cores or hand samples) were collected from each site. Sun compass readings are available for about 25% of the sites. The mean declination estimated from the difference between magnetic and sun compass readings is 11.9 W which is in fairly good agreement with the inferred present regional declination for Fuerteventura (ca. 10° W). Total variation in declination estimates is between 6.6 W and 22.3 W, but the majority of the results are close to the mean value. For further collection details refer to Table 1 and Fig. 1.

3. Palaeomagnetic Results

In the laboratory an average of six specimens from each site has been subjected to progressive demagnetization in alternating field (AF) or temperature, ranging upwards to 1,500 Oe and 580° C respectively. Palaeomagnetic properties of individual specimens after each demagnetization step were determined by using

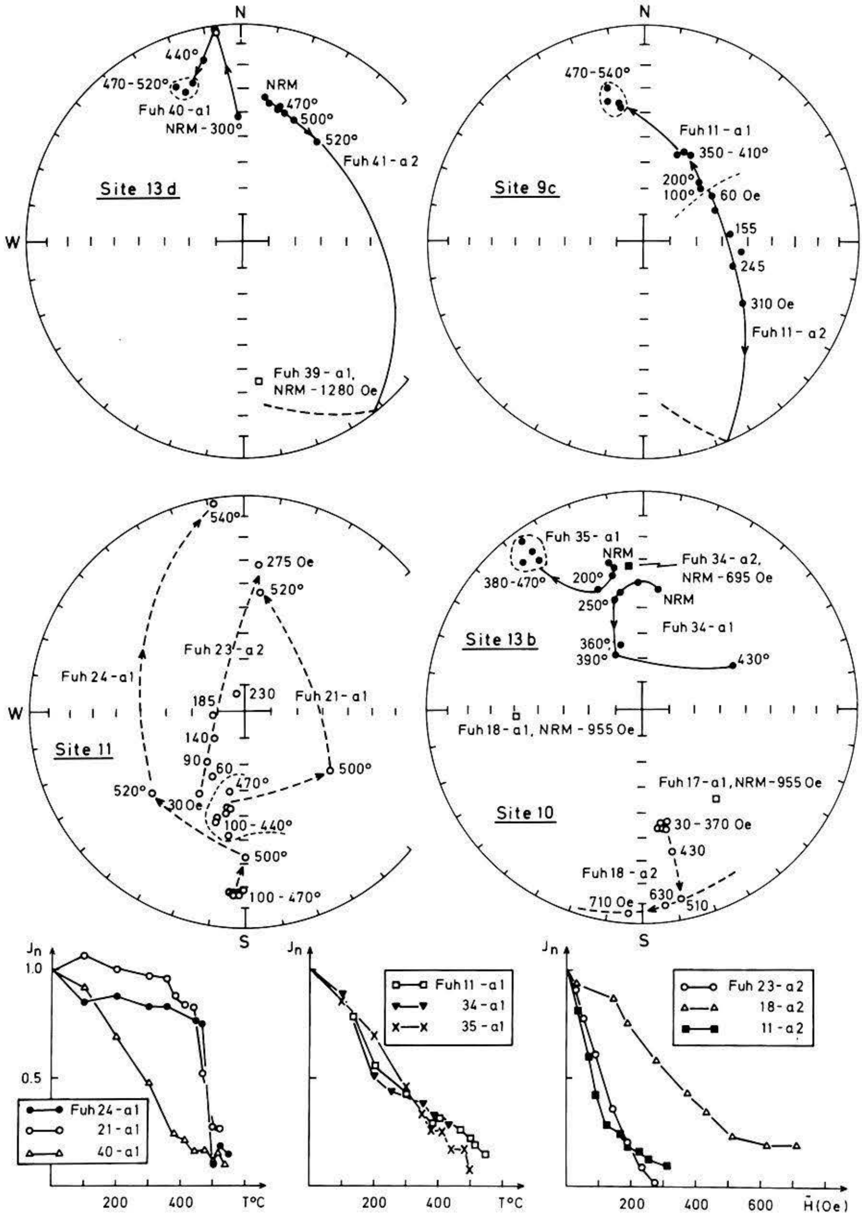

Fig. 2. Demagnetization results of dike rocks from the Betancuria complex. Fuh 40-al denotes specimen al cut from sample Fuh 40 etc. Projection is equal area and open (*closed*) symbols represent the direction of upward (downward) pointing magnetization vectors. Square symbols are mean magnetization directions of closely spaced results obtained within demagnetization ranges (field of temperature) as indicated on the diagrams. Note that neighbouring specimens (from same drill core or site) may show opposite polarity of their bulk remanences (cf. site 13 d) or may be heading towards opposite directions as demagnetization progresses (cf. sites 9c and 13d). Also, the initial (and sometimes fairly stable) remanence directions have often a smeared distribution that lines up with the directional movements that take place at a more advanced stage of demagnetization (cf. site 11). In specimen Fuh 18-a2 (site 10) the predominating remanence appears to be the C (or possibly A) magnetization (cf. Fig. 5) but at fields ≧510 Oe the directional pattern tends to define a practically horizontal great circle path probably associated with an interplay between the normal and reverse B components. Note also the discordant (but stable) direction of magnetization of the adjacent specimen Fuh 18-al

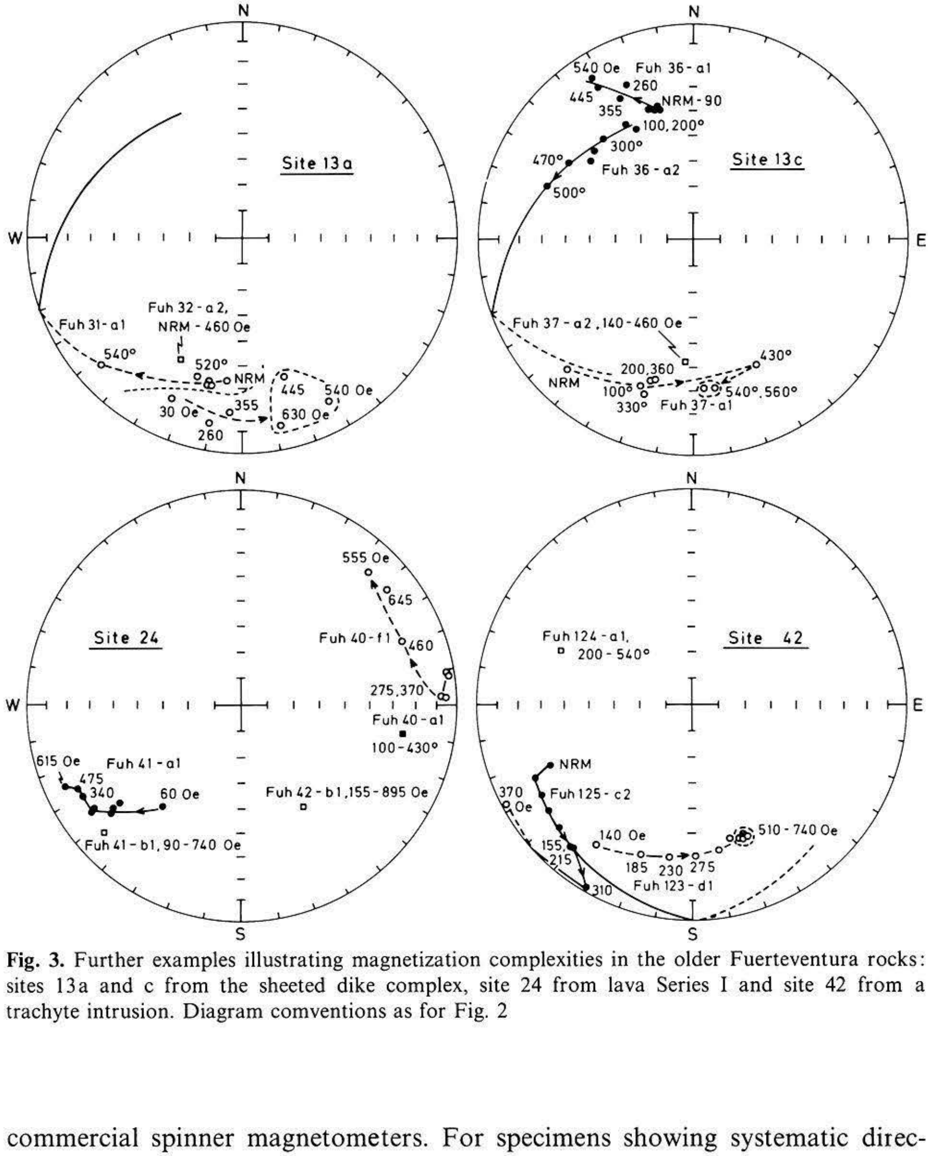

Fig. 3. Further examples illustrating magnetization complexities in the older Fuerteventura rocks: sites 13a and c from the sheeted dike complex, site 24 from lava Series I and site 42 from a trachyte intrusion. Diagram comventions as for Fig. 2

commercial spinner magnetometers. For specimens showing systematic directional trends (AF or thermal) the adopted acceptance criteria for 'stable end points' is that such terminal directions must be experimentally confirmed by at least three successive demagnetization steps (for each specimen). However, at some stages of demagnetization a great number of specimens came into an erratic stage (anomalously varying results both in direction and intensity) before stable end points could be defined. Specimens of the latter category and which, over a certain range of demagnetization, were shown to move along great circle paths (see below) have been employed in an analysis to estimate palaeomagnetic components through estimation of best intersection points of remagnetization circles (Halls, 1976; 1978).

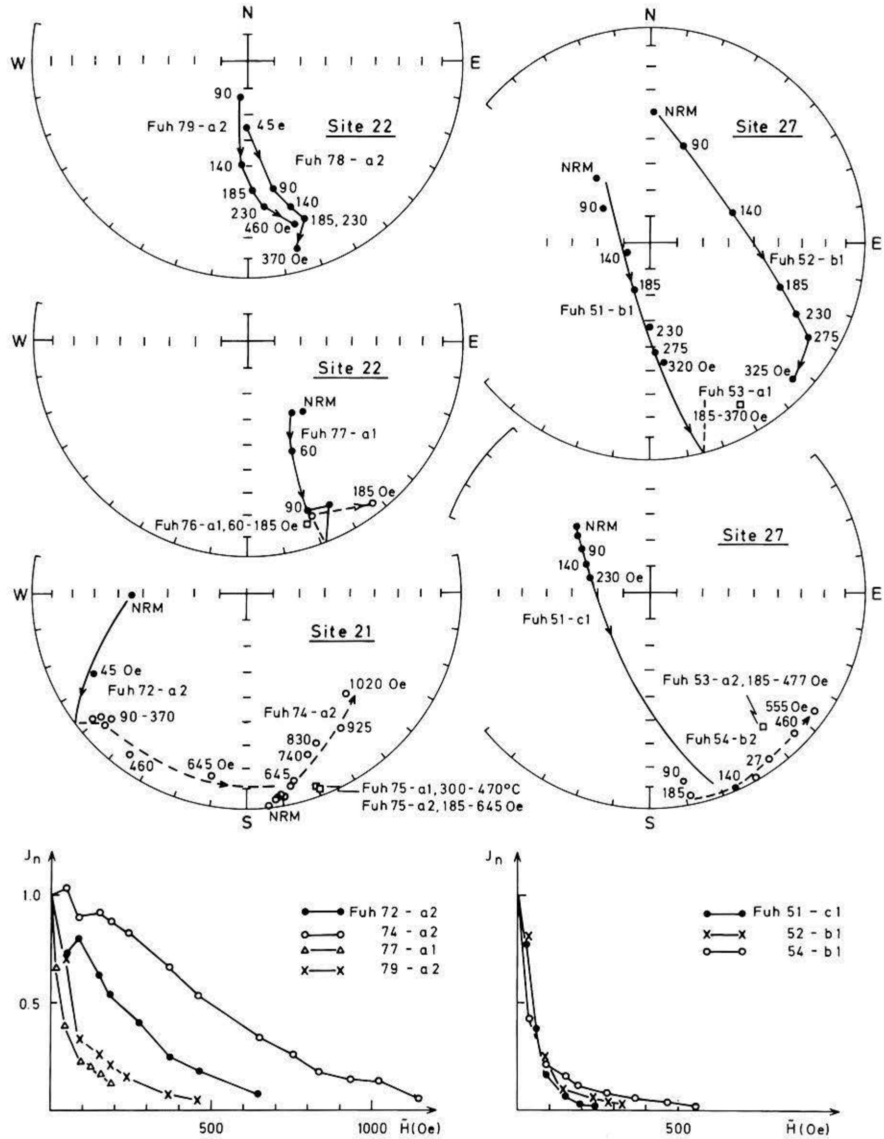

Fig. 4. Demagnetization results from lava Series I sites in which the B magnetization appears to be an important palaeomagnetic component. Diagram conventions as for Fig. 2

Lava series I (the oldest sequence of subaerial volcanics) and the Betancuria rocks have primarily a multivectorial NRM. Directional changes versus increasing demagnetization characterize these rocks but very often the remanence decays into the 'noise level' before a terminal direction is reached. An important observation is the occurrence of superimposed normal and reverse magnetizations, demonstrated by the directional behaviour versus demagnetization of individual specimens or by 'anti parallel' directions of stable bulk magnetization in neighbouring specimens (cf. Figs. 2–4). For many sites the total palaeomagnetic

Table 2. Palaeomagnetic results ('stable end point' data) from Fuerteventura. The *D* and *I* values represent averaged figures over the ranges quoted. See text for other details

Site		Lava series I (palaeomagnetic groups A and B)					
		Specimen	*D*	*I*	κ	α_{95}	Range (th. or AF)
1	Fuh	1–a3	161	−14			230–650 Oe
		3–b2	182	−29			190–370 Oe
		3–a3	189	−28			250–520° C
		5–b1	172	−28			30–220 Oe
2		6–b2	170	−29			NRM–920 Oe
		7–a2	160	−30			45–830 Oe
		8–b3	160	−40			830–920 Oe
		9–a	179	−27			NRM–920 Oe
Site mean			168	−32	69	11°	
3		12–a2	174	−25			NRM–620 Oe
		12–b2	170	−24			100–475° C
		13–b2	185	−33			NRM–830 Oe
		14–b3	160	−27			70–920 Oe
Site mean			172	−28	67	11°	
4		15–b3	159	− 2			140–920 Oe
		16–b2	169	− 9			90–830 Oe
		17–b2	150	−11			280–510 Oe
		17–a2	156	−17			450–520° C
		18–a3	166	− 3			140–9200e
		19–a	155	−17			320–1200 Oe
		19–b	156	−37			375–470° C
5		20–a1	155	+ 2			NRM–550 Oe
		20–b2	153	+ 2			NRM–550° C
		21–a2	161	+ 2			NRM–830 Oe
		21–a1	161	+ 1			NRM–525° C
		21–b1	168	−10			540–580° C
		22–b2	169	+ 4			NRM–650 Oe
		22–a2	167	+ 4			NRM–560° C
		22–b1	165	+ 6			NRM–510° C
		23–a2	150	+ 3			NRM–740 Oe
		23–b1	153	+ 6			NRM–525° C
		23–b2	153	+ 3			NRM–540° C
		24–b1	171	+ 4			NRM–510° C
		24–b2	169	+ 3			NRM–550 Oe
Site mean			161	+ 2	91	4°	
32		72–a2	318	+24			NRM–740 Oe
		72–b2	329	+24			NRM–400° C
		74–a	352	+29			NRM–465° C
		75–a	339	+40			NRM–540° C
		76–c	343	+42			NRM–740 Oe
Site mean			336	+32	32	14°	
33		77–b2	344	+27			NRM–920 Oe
		77–a3	339	+28			NRM–570° C
		78–a	353	+19			NRM–920 Oe
		79–a2	334	+22			NRM–920 Oe
		79–b2	334	+20			NRM–540° C
Site mean			341	+23	92	8°	

Table 2 (continued)

Site		Lava series I (palaeomagnetic groups A and B)					
		Specimen	*D*	*I*	κ	α_{95}	Range (th. or AF)
34	Fuh	82–a	354	+36			45–920 Oe
		84–b	317	+20			45–920 Oe
		85–b2	342	+22			500–540° C
		86–b	338	+19			45–415 Oe
Site mean			337	+25	26	18°	
36		92–a2	342	+20			45–450 Oe
		93–b	345	+33			NRM–510 Oe
		94–c2	354	+19			830–1480 Oe
		95–a	345	+31			NRM–560° C
Site mean			347	+26	87	10°	
37		97–a3	340	+15			480–550° C
		97–b2	336	+29			45–460 Oe
		99–a3	326	+29			90–1480 Oe
		99–b2	316	+34			400–555° C
		99–b3	311	+30			140–1525 Oe
		100–b2	338	+26			480–540° C
		100–b3	327	+25			45–920 Oe
		101–b3	335	+27			90–1480 Oe
Site mean			329	+27	55	7°	
38		102–a3	343	+29			NRM–460 Oe
		102–b2	340	+12			495–550° C
		104–b2	339	+28			NRM–1480 Oe
		105–a2	351	+18			100–400° C
		106–b2	343	+37			NRM–500° C
Site mean			343	+25	57	10°	
39		107–a3	344	+26			45–450 Oe
		107–b3	346	+28			200–540° C
		108–a3	340	+30			NRM–1480 Oe
		109–a	336	+21			400–540° C
		110–a2	325	+35			400–560° C
		110–b	352	+34			45–1480 Oe
		111–a2	341	+26			NRM–475° C
		111–b	341	+34			NRM–550° C
Site mean			341	+30	87	6°	
40		112–a3	344	+41			NRM–460 Oe
		112–b3	341	+33			NRM–450° C
		113–b2	337	+25			NRM–1480 Oe
		114–b	336	+26			90–920 Oe
		115–a3	340	+34			NRM–520° C
		116–b2	327	+15			180–920 Oe
Site mean			337	+29	61	9°	
41		117–a2	335	+34			NRM–1380 Oe
		117–b2	335	+32			NRM–500° C
		118–a3	335	+34			NRM–475° C
		118–b2	333	+36			NRM–740 Oe
		119–a2	339	+34			NRM–555° C
		121–a2	332	+20			NRM–320 Oe
Site mean			335	+32	171	5°	

Site		Lava series II (palaeomagnetic group C)					
		Specimen	*D*	*I*	κ	α_{95}	Range (th. or AF)
12		26–a2	183	−29			355–585 Oe
		27–a1	189	−31			NRM–460 Oe
		27–a2	184	−38			355–490 Oe
		28–a2	182	−22			30–370 Oe
		29–a2	196	−16			30–370 Oe
Site mean			187	−27	66	9,5°	
16		53–a2	184	−25			350–860 Oe
		54–a1	179	−24			NRM–390 Oe
		55–a2	182	−22			NRM–860 Oe
		56–a1	168	−22			NRM–470° C
Site mean			178	−23	145	7,5°	
17		57–a1	171	−48			NRM–560° C
		58–a1	187	−37			30–830 Oe
		58–a2	189	−40			30–755 Oe
		59–a1	187	−28			NRM–520° C
		59–a2	183	−30			NRM–755 Oe
		60–a1	187	−22			NRM–560° C
		61–a2	193	−26			NRM–560° C
Site mean			186	−33	59	8°	
18		62–a1	181	−28			NRM–830 Oe
		62–a2	184	−32			470–550° C
		63–a1	197	−25			NRM–390° C
		64–a1	190	−27			NRM–830 Oe
		64–a2	191	−28			NRM–755 Oe
		65–a1	187	−32			NRM–700 Oe
		65–a2	192	−35			90–660 Oe
Site mean			189	−30	193	4,5°	
19		67–a1	183	−29			NRM–830 Oe
		67–a2	189	−29			NRM–755 Oe
		68–a1	190	−29			NRM–540° C
		68–a2	189	−23			NRM–830 Oe
Site mean			188	−28	387	4,5°	
20	Fuh	70–a1	178	−25			90–740 Oe
		70–a2	175	−26			60–370 Oe
		71–a1	180	−30			NRM–740 Oe
		71–a2	176	−26			100–470° C
Site mean			177	−27	747	3°	
44		131–a2	203	−37			45–925 Oe
		132–b	191	−34			NRM–520° C
		133–a2	190	−18			NRM–500° C
		134–a	204	−21			NRM–475° C
		134–b2	203	−21			NRM–1480 Oe
Site mean			198	−26	57	10°	
45		136–a	188	−39			NRM–925 Oe
		138–a2	186	−28			45–740 Oe
		139–a2	171	−38			450–540° C
		139–b2	191	−34			45–740 Oe
Site mean			184	−35	86	10°	

Table 2 (continued)

Site	Lava series II (palaeomagnetic group C)					
	Specimen	*D*	*I*	κ	α_{95}	Range (th. or AF)
46	140–a3	165	−39			45–740 Oe
	141–a3	169	−47			45–740 Oe
	142–a	167	−33			NRM–540° C
	143–c2	184	−29			90–510 Oe
	144–b2	175	−42			NRM–500° C
Site mean		172	−38	73	9°	
47	145–b	184	−40			NRM–740 Oe
	146–a2	186	−39			NRM–740 Oe
	147–a2	192	−36			NRM–525° C
	148–b2	179	−33			NRM–520° C
	149–a2	180	−48			NRM–520° C
	149–b2	178	−53			NRM–1480 Oe
Site mean		183	−41	90	7°	

information consists of a number of directional paths (without stable end points) in addition to one or more stable (apparently one-component) directions. There may however, be large disagreements between such stable specimen directions, indicating that at least in part they may represent unresolved multicomponent remanences. This assumption is strenghtened by the unsuccessful attempt of estimating the direction(s) of erased single-component vectors for specimens following great circle paths on demagnetization: there appears to be no range of demagnetization for which vector subtracted directions cluster, indicating that the stability spectra are closely overlapping. Therefore, in order to eliminate as many as possible of unresolved multicomponent (but stable) directions of magnetization from the distribution of true palaeomagnetic observations a strict acceptance criteria has been adopted: only sites which have a minimum of four relatively well-grouped specimens (i.e., 60 − 100% of analysed specimens per site) have been considered for estimation of palaeomagnetic parameters. In none of these sites does the total directional spread of stable directions exceed 35° of arc. In addition to the accepted directions of magnetization these sites may exhibit a number of specimens that perform systematic directional variation without achieving stable end points, but they have no stable directions in divergent positions. Of the older Fuerteventura rocks only lava Series I sites have given acceptable palaeomagnetic results (i.e., stable end points corresponding to criteria outlined above). Lava series II have a simple remanence: the results from a total of 10 out of 12 sampled flows comply with the acceptance criteria. The bulk magnetization of the two remaining Series II lavas (site nos. 28 and 48) are also in accord with the Series II results but directional trends on demagnetization are relatively frequent and the number of stable specimens are fewer than here required.

The individual specimen results from all acceptable sites are listed in Table 2 and the total directional variation is shown in Fig. 5. Many of these specimens

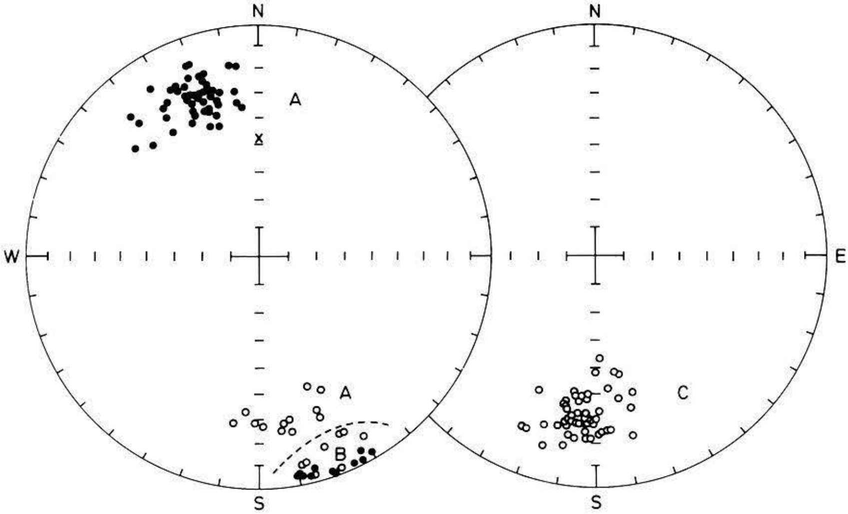

Fig. 5. Palaeomagnetic directions (specimens) from Fuerteventura. Groups *A* and *B* represent lava Series I and Group C Series II. The *cross* is the present axial dipole field direction relative to the Canary Islands. Further diagram conventions as for Fig. 2

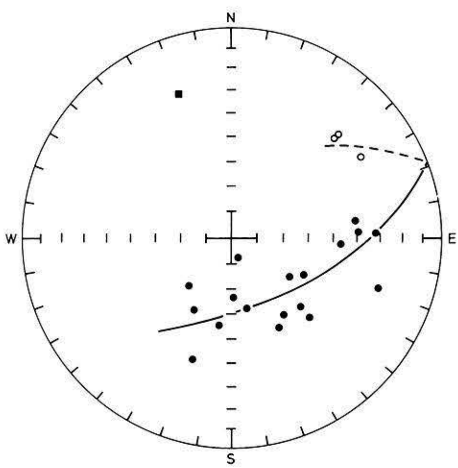

Fig. 6. Specimen remagnetization circle data (21 specimens). See text for details on data base. *Closed (open) circles* are downward (upward) pointing normals to specimen remagnetization circles. *The closed square* is the downward pointing normal to the great circle (drawn on diagram) fitted by least squares to the specimen normals

exhibit directional stability over the entire or major range of demagnetization, involving a minimum of 90% of the NRM moment. The Series II data (magnetization C) are exclusively reversed while Series I shows both polarities. From the reversed Series I data there is evidence that this lava sequence actually contains two palaeomagnetic axes: a major two polarity magnetization with an inclination of about 30°, referred to as magnetization A, and a subordinate reversed component that is practically horizontal (magnetization B). Following the acceptance criteria for stable end point results here adopted, only one site

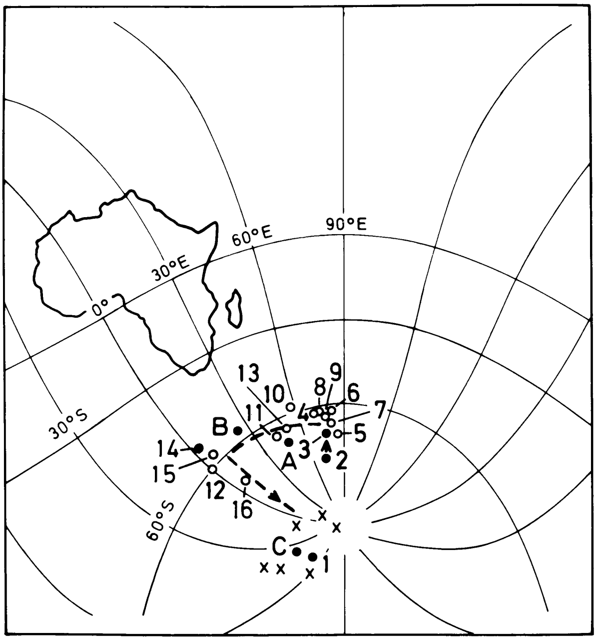

Fig. 7. Estimated pole positions for Fuerteventura basalts, poles A – C, in comparison with other relevant poles. Closed symbols are data from the Canary Islands. Poles A and B represent lava Series I and pole C lava Series II. Pole 1 is the Upper Tertiary/Quaternary pole for Gran Canaria/ Tenerife and poles 2 and 3 represent the older volcanic rocks in these islands, before and after a 5° anticlockwise adjustment of the mean declination respectively (Storetvedt et al., 1978). Pole 14 is from lava Series I of N.Lanzarote (Johansen, 1976). *Crosses* are African Tertiary poles. Other poles are as follows: 4: Hoachanas (Gidskehaug et al., 1975); 5: Mlanje (Gough and Opdyke, 1963; Briden 1967); 6: Lupata, 106 m.y. (Gough and Opdyke, 1963; Gough et al., 1964); 7: mean Mesozoic SE. Africa (Hailwood and Mitchell, 1971); 8: mean Mesozoic NW. Africa (Hailwood and Mitchell, 1971); 9: Shava ijolite (Gough and Brock, 1964); 10: Kimberlite pipes, 83–89 m.y. (McFadden and Jones, 1977); 11: Wadi Natash volcanics, 81–90 m.y. (El Shazly and Krs, 1973); 12: mean Lower Tertiary of Europe (Storetvedt, 1978); 13: volcanics SE. Sicily, 70–80 m.y. (Schult, 1973); 15 and 16: L.-(M) Tertiary volcanics Egypt (Gouda Hussain et al., 1979)

(no. 5) shows an unambiguous B magnetization. In the other sites this component either interferes with the A magnetization, causing for example an inclination spread of the resultant remanence (see for example site 4, and probably also site 1, Table 2) or it may form part of a highly variable and complex magnetization. Examples of within-site magnetization and detailed demagnetization behaviour for sites that are not included in the final palaeomagnetic results are given in Figs. 2 – 4. A number of specimens have ranges of demagnetization in which the resultant vectors move along practically horizontal great circle paths, suggesting that two antiparallel *B* axis components are present. In Fig. 5 the distinction between magnetizations A and B is fairly tentative but considering also all the directional information from sites not included in Table 2 (see for example Fig. 4) there appears to be little doubt that Series I contains two axes of magnetization. Additional evidence in support of the B magnetization comes from the nearby Island of Lanzarote (cf. Fig. 7) and where the A component has not been found (Johansen, 1976; Skårnes, 1977).

Table 3. Mean palaeomagnetic data from Fuerteventura

Formation		N	R	K	α_{95}	$\bar{D}$	$\bar{I}$	Pole	
Group C; lava series II	a	51	50.1	53.5	2:8	184.8,	−31.4	324.5E,	77.9S
	b	10	9.9	89.1	5.2	184.3,	−31.0	326.2E,	77.8S
Group B; lava series I	a	20	19.7	59.6	4.3	160.6,	−02.1	023.6E,	57.0S
Group A; lava series I	a	62	60.7	46.6	2.7	340.5,	+28.4	043.9E,	67.6S
	b	12	11.9	98.7	4.4	342.2,	+28.2	040.8E,	68.8S
	c	21	–	–	–	340.5,	+28.2	043.9E,	67.6S

N: Number of unit vectors (a: specimens, b: sites, c: specimens in great circle analysis)
R: Length of resultant vector
K: Precision parameter
α_{95}: Radius of circle of confidence at 95% significance level
$\bar{D}, \bar{I}$: Declination and inclination of mean vector

In an attempt to retrieve palaeomagnetic information from specimens that do not achieve stable end points on demagnetization the great circle technique (Halls, 1976; 1978) was used for all specimen trends that had a quality factor $Q < 1 \cdot 10^{-5}$ (Halls, 1978). Fifty specimens satisfied this requirement. The average number of demagnetization steps for each great circle segment is 6. Figure 6 shows the distribution of poles for specimen great circles used for independent estimation of the direction of normal A magnetization. Of the 21 specimens concerned 12 are Series I rocks, 8 are from dykes and 1 from a trachyte intrusion. Eleven of the specimens have northward trending great circle paths for which the individual great circle segments, traced out by the successive total vectors, are mostly several tens of degrees away from the convergence area, while the remaining 10 specimens move into and basically within the area of stable normal A magnetization. As seen from Table 3 the best normal intersection point of this group of specimens is in perfect agreement with the mean A axis magnetization based on stable end points. The excellent agreement of the two methods and the fact that they are based on totally different specimen populations strengthen the palaeomagnetic reliability of the A magnetization.

While the northward trending remagnetization circles have a reasonably well defined intersection point this is not the case for those moving towards the reversed component(s). For this group (29 specimens) the distribution of poles for individual specimen trends are too complex to allow estimation of palaeomagnetic directions. Since the majority of these specimens have resultant magnetizations that are reversed, it seems likely that an interplay between the three reversed components (A, B, C) causes the complexity in the distribution of poles to specimen remagnetization circles.

Account of investigated specimens:

(a) 332 specimens have been studied, (b) 134 have given palaeomagnetic results according to acceptance criteria (Table 2), (c) of the remaining 198 specimens ca. 50% gave stable end points, in frequent agreement with inferred magnetization components (A, B, or C), but the associated site magnetizations still remained multicomponent (and scattered) after demagnetization. Finally, ca. 100 specimens did not define stable end points – 50 of these formed great circle segments on progressive demagnetization and were used in the remagnetization circle analysis, and the rest had a more complex behaviour.

4. Palaeomagnetic Interpretations

Summary of palaeomagnetic results including mean directions of magnetization, statistical parameters and pole locations are given in Table 3.

As seen from Fig. 7 the Fuerteventura C pole (lava Series II) plot in close agreement with a late Tertiary-Quaternary pole recently obtained from the Canary Islands (Storetvedt et al., 1978) and corresponds well with data of similar age for continental Africa. Like the pole for the older Gran Canaria/Tenerife volcanic strata (Storetvedt et al., 1978) the Fuerteventura A pole, corresponding to the principal palaeomagnetic direction in baselt Series I, agrees fairly well with those for the Mesozoic of Africa. Pole B has a rather limited data base but the scatter of individual specimen directions is similar to those for groups A and C. In view of the ample evidence for partial remagnetization in basalt Series I (as well as in the older rocks) it is likely that the magnetization at least in part is of CRM or TCRM origin (note that from Table 2 and Figs. 2–4 some sites are likely to contain both the A and the B magnetization). Considering all the available evidence it appears reasonable to conclude that the B pole reflects an average palaeomagnetic field axis rather than being an 'artifact' of incomplete averaging-out of geomagnetic secular variation.

Figure 7 shows the estimated Fuerteventura pole positions in comparison with other relevant data. The eastern pole cluster (poles 5–9) defines the representative pole lacation relative to Africa for the major part of Mesozoic time, the youngest representative being that for the Lupata volcanics that date back to ca. 106 m.y. Poles 10, 11, and 13, situated west of the previous group, represent volcanic rocks from Africa and SE. Sicily in the approximate age range 70–90 m.y. A further westward extension of the polar pattern encounters the Lower Tertiary pole position for Europe at around 0° E, 60° S (pole 12) which is in very good agreement with recent Lower-(Middle) Tertiary palaeomagnetic results from Egypt, poles 15 and 16 (Gouda Hussain et al., 1979). It has been concluded that the European Tertiary polar shift towards the present pole location occurred at around Middle Oligocene (Storetvedt, 1973) and from the available data there is good evidence to infer a similar axis shift relative to Africa at the same time. Therefore, it appears that Europe and Africa define 'identical' polar patterns for the last 90 m.y. or so. It is interesting to note that based on palaeoclimatological evidence Köppen and Wegner (1924) suggest a Mesozoic-Lower Tertiary-Upper Tertiary polar track relative to Africa that is closely similar to the one outlined here (cf. their Fig. 22). The Fuerteventura A and B poles fit well into this framework. With reference to Fig. 7 and the geological evidence summarized above (Chap. 1) it is appropriate to conclude that the basal complex originated in the Upper Cretaceous (post-Albian) while basalt Series I was laid down at around the Cretaceous-Tertiary boundary.

5. Conclusion and Discussion

From geological evidence (Robertson and Stillman, 1979) passive margin conditions in the area of Fuerteventura ended in Albian time and was followed by uplift and tectonism. According to the palaeomagnetic results outlined above it appears reasonable to assume that emplacement of the basal igneous core of Fuerteventura (the Betancuria complex) accompanied these tectonic processes, forming sometime in the Upper Cretaceous. The plutonic activity was succeeded by an erosional unconformity after which the Series I plateau basalts were laid down probably at around the Cretaceous/Tertiary boundary.

After Series I had been formed there followed a period of ca. 50 m.y. of magmatic quiescence and erosion. In Middle Miocene-Pliocene the eroded surface was overstepped by a second major sequence of plateau basalt (Series II). We believe that the long period of erosion and weathering (in a tropical – subtropical environment) along with the penetrative thermochemical effects accompanying the younger lava series led to partial remagnetization, manifested by the present multicomponent magnetization, of the older formations.

These conclusions are at variance with the radiometric age determinations (conventional whole rock K/Ar results) available from the older igneous rocks of Fuerteventura (Rona and Nalwalk, 1970; Abdel-Monem et al., 1971; Grunau et al., 1975; Stillman et al., 1975). However, the radiometric data pose interpretational problems. For example, Grunau et al. (1975) have noted that, following a normal differentiation trend for the plutonics, the oldest age of these rocks (38 m.y.) in fact comes from one of the supposed youngest intrusive members (an alkali syenite). The same authors also report on extremely poor reproducibility of the Argon analyses from different splits of two plutonic samples (diorite and syenite). For the sheeted dyke complex the total apparent age ranges from 12.1 m.y. to 46 m.y. At least the oldest of these ages is in contradiction to the 35 m.y. age estimate that has been obtained from the submarine volcanics (at the base of the igneous series). Some of these problems are certainly related to the general metamorphism of the basement complex. However, we believe in particular that the extensive magmatism that swept the island in Miocene/Pliocene time lead to a partial degassing of the older igneous rocks (including basalt Series I), giving rise to a complex and geologically too young K/Ar age distribution.

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