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Magnetic Discordance in Gran Canaria/Tenerife and Its Possible Relevance to the Formation of the NW. African Continental Margin

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Abstract. The palaeomagnetic stratigraphy of Gran Canaria and Tenerife suggests that these islands have been built up during two major volcanic 'pulses', i.e. in Mesozoic (probably late Cretaceous) and Upper Tertiary/Quaternary times. The palaeomagnetic implications are compared with other evidences from the NW. African shelf and margin such as geological data from drill holes in coastal basins, Deep Sea Drilling Project results and information from various marine geophysical surveys. The combined evidence favours a continental origin of a crustal belt (including the Canary Islands) extending seaward into water depths of at least 4500 m.

Key words: Palaeomagnetism – Marine geology/geophysics – Formation of Canary Islands and adjacent oceanic tracts.

1. Introduction

The origin of the Canarian Archipelago has been a matter of much speculation and a continental as well as an oceanic sub-stratum for the islands have been proposed. The oldest stage of development of the islands appears to have produced a basal complex of mostly mafic and ultramafic plutonics, but submarine volcanics and various types of sediments occur also. This basement complex, which appears to underlie the entire island group, is exposed in La Palma, Gomera and Fuerteventura (Cendrero, 1971; Fúster et al., 1968a–d; Hausen, 1956, 1958, 1959, 1962; Ibarrola, 1970) and it is likely to be represented as inclusions in the younger basalts of Lanzarote (Fúster et al., 1970). According to Fúster et al. (1970) the chemical composition of the basement plutonics differs from that of the overlying volcanic rocks and there is an erosional discordance between the two series. The thick section of marine sedimentary rocks in the basal complex of Fuerteventura is strongly folded and fossil evidence points towards a Mesozoic origin of these strata (Rothe, 1968; Rothe and Schmincke, 1968). On the other hand, the major column of subaerial volcanics of the islands have generally been assigned to the middle or late Tertiary on

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the basis of palaeontologic and radiometric dating (Fúster et al., 1968a–d; Abdel-Monem et al., 1971). There seems to be no doubt that a marked peak of volcanic activity swept the islands in Miocene-Pliocene time but one may be sceptical as to whether the outpouring of all the older volcanics actually represents this time interval. Thus, the oldest series, at least in some areas, are extremely weathered (having turned into red soil in places) compared to the overlying, rather fresh rocks for which a Miocene-Pliocene age seems well established. In Gran Canaria, for example, an erosional discordance is found between the two groups of subaerial lavas as well as between the various petrographically different units of the older series (Fúster et al., 1968d). Consequently, one of the fundamental problems of the volcanologic evolution of the Canary Islands is the question of whether there are major time gaps between and within the older subaerial lava sequences of the islands.

For marine geophysical studies, the Canarian archipelago, together with the Cape Verde Islands and Madeira, hold a key position in the Atlantic, as they are situated either within or close to the border zone of the 'quiet' magnetic anomaly field. At present, the favoured explanation of the 'quiet' zone seems to be in terms of sea-floor spreading during a constant geomagnetic polarity epoch sometime in the Mesozoic. Another, but less accepted, way of explaining quiet magnetic zones is through the mechanism of continental crust conversion into a transitional/oceanic structure by the processes of subsidence and sub-crustal erosion (Van Bemmelen, 1966). Unfortunately, standard crustal structure studies seem to be of little help in chosing between the two alternatives (sea floor spreading versus continental oceanization); probably only very young subsidence structures can in some cases be distinguished from a true oceanic crust by the presence of low upper mantle seismic velocities and the absence or suppression of seismic wave propagation along the Moho. In support of an oceanization process, Rona and Nalwalk (1970) and Dietz and Sproll (1970) have given evidence for a sialic substratum under the Canary Islands based on postulated predrift reconstructions of N. America and NW. Africa. Palaeomagnetism of regions like the Cape Verde and Canary Islands may provide important information relevant to these problems. It cannot, unfortunately, be said that there are complete palaeomagnetic analysis of these islands. At present, there exist some palaeomagnetic results by Carracedo and Talavera (1971) of the Anaga peninsula of Tenerife and numerous reconnaissance data by Watkins (1973) and Watkins et al. (1966, 1968) of the Canary Islands/Madeira and the Cape Verde Islands respectively.

In an attempt to provide further information on the abovementioned aspects a detailed experimental study of the palaeomagnetic record of the Canary Islands is at present being undertaken by this department. The present synthesis is based upon the analysis of palaeomagnetic data obtained from Gran Canaria and Tenerife and by consideration of available marine geological and geophysical structures of the adjacent oceanic tracts.

2. Palaeomagnetic Discordance in Gran Canaria and Tenerife

The present palaeomagnetic study of Gran Canaria and Tenerife is based on a total of 305 oriented hand samples from altogether 63 sites (lavas or intrusives).

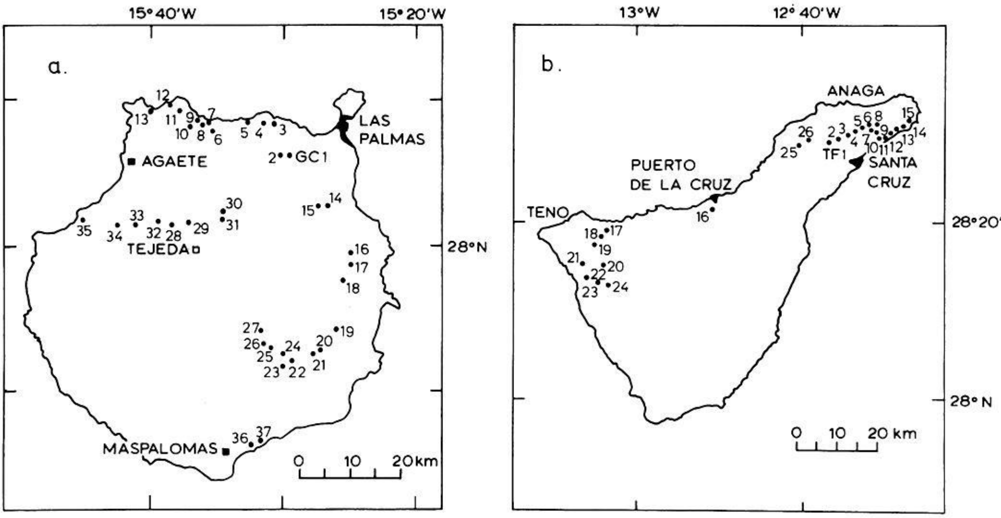

Fig. 1a and b. Distribution of collecting sites on Gran Canaria (**a**) and Tenerife (**b**)

In Gran Canaria the collected sites are concentrated in the northeastern half of the island and span all the major rock units. In stratigraphic order (from 'bottom') these are: Basalt Series 1, Trachyte, Phonolite, Pre-Roque Nublo, Roque Nublo, Ordanchitica Series, Basalt Series 2, and Basalt Series 3 and 4 (Fúster et al., 1968d). In Tenerife the lavas of Series 1 in the Anaga peninsula as well as dikes cutting through this lava sequence were collected in addition to Basalt Series 3 and 4 from various parts of the island. At the collecting sites post-emplacement tectonics seem too small to be of importance for the present study. For orientation both magnetic and sun compasses were used. Figure 1 shows the distribution of sampling sites. It is not known to which extent these sampling localities may duplicate those of earlier studies.

All collected material has been subjected to detailed thermal and/or alternating field (AF) demagnetization. A test of the entire stability spectrum has been aimed at, i.e. the progressive demagnetization was in general continued until the remanence either became too weak for reliable measurements (this occurred in particular on thermal demagnetization above 500° C) or came into a stage where the remanence parameters initiated an erratic behaviour. All phonolite specimens exploded when heated above 500° C. A large proportion of the rocks had a fairly high resistance to alternating field demagnetization, having a rather high percentage of their remanence intensity left after treatment in the highest available field (1500 Oe).

In general, the Pre-Roque Nublo and younger rocks are easy to deal with in the laboratory, giving mostly stable and consistent within-site directions of magnetization. The palaeomagnetic axis of the Quaternary volcanics (Series 3 and 4) corresponds extremely well with the late Tertiary axis as defined by data from Pre-Roque Nublo, Roque Nublo, Ordanchitica and Basalt Series 2 (cf. Fig. 2a and b and Table 1). Also, as shown in Figure 5, the overall palaeomagnetic pole is in close agreement with middle-late Tertiary poles for Africa.

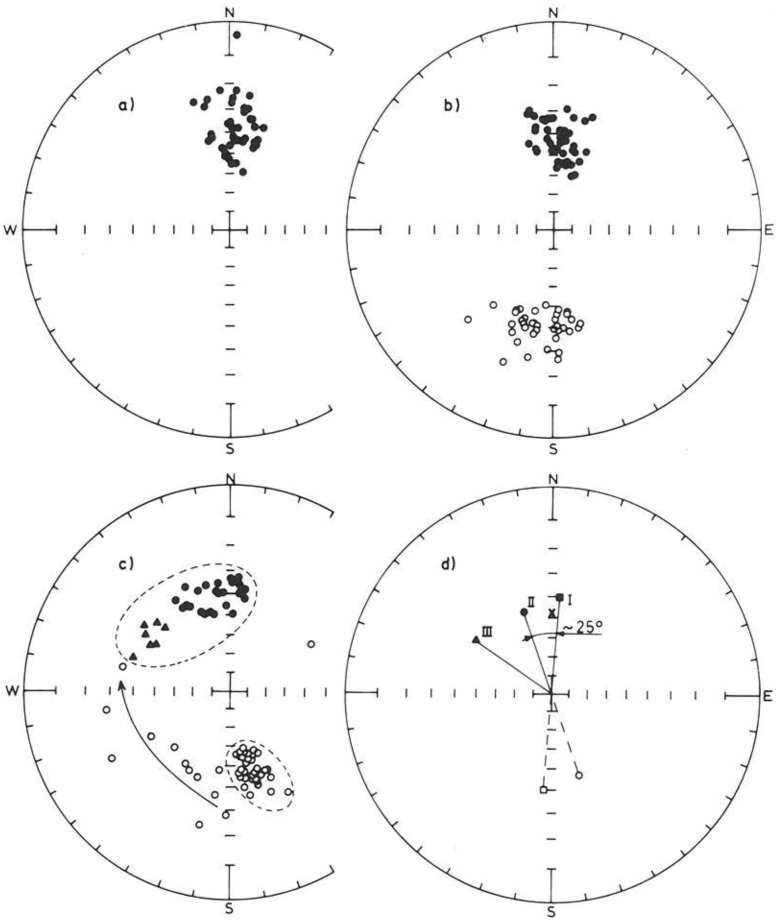

Fig. 2a–d. Palaeomagnetic directions from Gran Canaria and Tenerife; (**a**) Basalt Series 3 and 4 (Quaternary) (**b**) Upper Tertiary formations and (**c**) Basalt Series 1, Trachyte and Phonolite (triangles). Axis 1 (**d**) gives the estimated time-average palaeomagnetic direction for the Upper Tertiary-Quaternary and axis II represents the overall directions of the older formations (Series 1, Trachyte and Phonolite). Axis III is the mean directions for the Phonolite rocks taken separately. The cross is the present axial geocentric dipole field relative to the Canary Islands. Full symbols are downward inclinations and open symbols upward inclination

The corresponding field direction from Gran Canaria/Tenerife, is however, significantly different (at the 95% level of confidence) from that of an axial geocentric dipole model (cf. Fig. 2d and Table 1); the somewhat shallower inclination of the observed field lines up with recent ideas (Wilson, 1971; Wilson and McElhinny, 1974) of the dipole source being axial but slightly displaced north of the equatorial plane.

Rocks older than Pre-Roque Nublo in Gran Canaria (i.e. Basalt Series 1, Trachyte and Phonolite) and the Series 1 rocks from the Anaga peninsula of Tenerife show a more complex magnetization than the younger sequences. The

Table 1. Mean palaeomagnetic data from Gran Canaria and Tenerife

Formation		N	R	K	α_{95}	$\bar{D}$	$\bar{I}$	Pole location	Remarks
Quaternary basalts; series 3 and 4	a	43	41.9	39.4	3.5	003.7	+38.2	317.9E 82.2S	a: unit weight on specimen
	b	11	10.9	102.4	4.5	004.1	+34.7	316.2E 81.8S	b: unit weight on site
Late Tertiary formations; Pre-Roque Nublo(−), Roque Nublo(−), Bas. Series 2 (±) and Ordanchitica Series (+)	a	85	83.1	43.9	2.3	186.0	−41.6	293.2E 82.9S	
	b	13	12.8	65.6	5.2	184.1	−41.0	306.8E 83.8S	
Quaternary and late Tertiary formations combined	a	128	125	41.7	2	185.2	−40.4	302.1E 82.8S	
	b	24	23.7	79.2	3.4	184.1	−39.5	311.9E 82.9S	
Older lavas: Bas. Series (±) Trachyte (±) and Phonolite (+)	a	70	68.1	35.6	2.9	162.8	−45.1	071.2E 74.7S	
	b	12	11.6	30.7	8.0	159.9	−44.5	071.2E 72.0S	

N=number of unit vectors (specimens or sites); R=length of resultant; K=precision parameter; α_{95}=radius of circle of confidence at 5% significance level; $\bar{D}$, $\bar{I}$=declination and inclination of mean vector

increased complexity is in part shown by more irregular within-site (and within-sample) distribution of magnetization and in part by the occurrence of an increased number of systematic directional trends on demagnetization for which stable end-points could not be achieved. The dikes gave considerably more scattered results than all the other formations studied—because of the greater uncertainties in the palaeomagnetic parameters of these rocks they have been excluded from the present analysis.

All stable specimen directions (AF or thermal treatment) from Series 1, Trachyte and Phonolite are shown in Figure 2c. Basalt Series 1 rocks from Tenerife are reversely magnetized while Series 1 lavas and Phonolites of Gran Canaria are normally magnetized. The Trachyte lavas show both polarities. The remanence parameters of many of these older rocks were followed to temperatures well above 600° C (see Fig. 3) suggesting haematite as a relatively important magnetic carrier. This evidence is in line with the generally much more altered state of the older strata compared with the younger series. It is not surprising therefore that evidence of multicomponent magnetization (of high magnetic stability) within individual specimens is relatively important in the older strata while such features are practically absent in the more recent ones (Pre-Roque Nublo and younger).

The linear spread of apparently stable directions in the SW-quadrant of Figure 2c is confined to the Series 1 lavas of Tenerife. This pattern appears to be best interpreted in terms of partial remagnetization: a variable normal

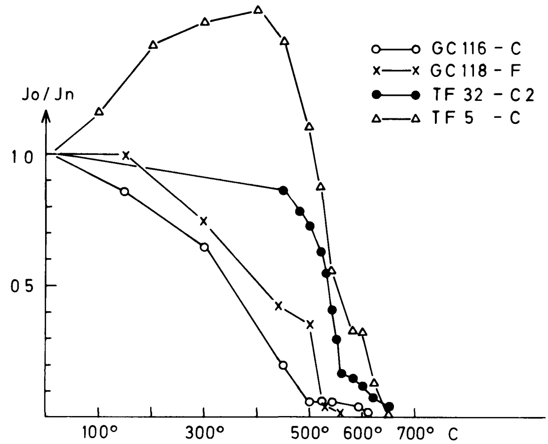

Fig. 3. Examples of thermal decay patterns from the older basalt sequences. *TF* Tenerife specimens; *GC* Gran Canaria specimens

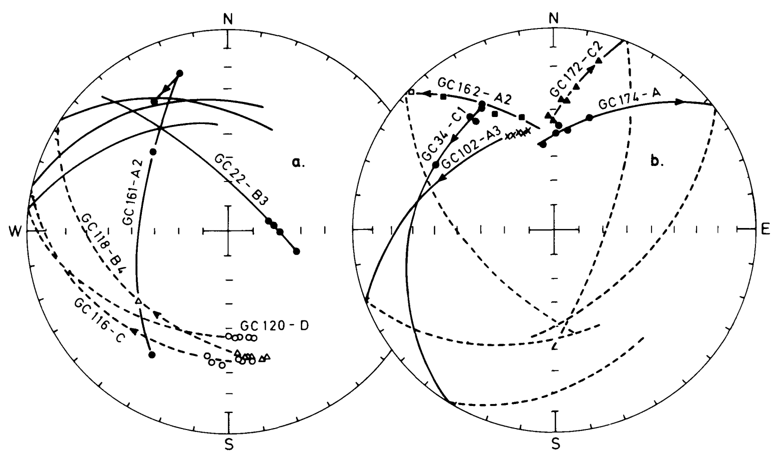

Fig. 4a and b. Examples of directional variation vs. demagnetization along with the extended great circle (remagnetization) paths and their convergence points. Full (open) symbols are downward (upward) inclinations

component of high magnetic stability (probably of chemical origin) having been added to a supposed original reversed magnetization of south-southeasterly declination causing deviating directions of the resultants. This explanation is further supported by the fact that the linear directional spread agrees with great circle paths of the older Series as defined for individual specimens through stepwise demagnetization. Figure 4 gives a number of examples where the resultant remanence directions move along well defined great circles (Halls, 1976) suggesting an interplay between two components of magnetization. Specimens of this type do not qualify to be included in the groups of stable end point data though magnetic stability alone does not prove that one actually is dealing with a single-component remanence. The extended remagnetization circles define intersection points that are either in agreement with the majority of stable end points for the older lavas (cf. Fig. 4a) or are in line with stable directions for the younger rocks (axis I, cf. Fig. 2d). This component variability merely implies that remagnetization of the older rock sequences continued into axis I time. The important consequence of this prolonged magnetization history is that the original axis will have a tendency of being deflected towards the younger axis. However, as illustrated in Figure 4a, the same deflection effect can certainly be accomplished through remagnetization in the opposite field polarity, axis remaining constant. The encircled reversed group of Figure 2c is considered to represent an actual palaeomagnetic direction to a reasonable approximation but based on the experimental evidence it appears very likely that this reversed group had a slightly more easterly declination originally than that shown at present.

The series 1 lavas as well as the Phonolites of Gran Canaria are of normal polarity, but the combined directional data exhibit a certain smeared distribution which needs further consideration. Firstly, some of the Series 1 sites concerned tend to have become at least partially remagnetized in the normal direction of the late Tertiary/Quaternary field (axis I of Fig. 2d). This suggestion appears properly demonstrated in the collection of 3 sites from the southeastern part of Gran Canaria. One of these sites, which was located close to a thick Series 2 lava gave directions of magnetization in excellent agreement with the inferred late Tertiary axis. The remaining two sites, which probably have not been in immediate proximity to late Tertiary igneous activity, show more westerly declinations (330°–340°) and are in nearly perfect alignment with the axis based on the reversed group (cf. Fig. 2c). Another reason for the smeared normal distribution is that the Phonolites tend to have a characteristic magnetization with more westerly declination. Two of the three sites collected were closely grouped having declinations between about 290° and 315° (cf. triangles of Fig. 2c), while the third site, having north-northwesterly NRM directions, tends to have a composite magnetization. Demagnetization of the latter site suggests that the relatively stable NRM directions are deflected away from the position of the other two sites by a superposition of a middle-late Tertiary normal component. It is possible, therefore, that the Phonolite Series represent a palaeomagnetic axis which is different from that of the investigated Trachytes and Series 1 lavas, but they could also represent a polyphase remanence caused by partial remagnetization. Owing to the limited number of Phonolite data presently at hand the 'safest' way of estimating mean palaeomagnetic directions for the older series would be to combine all the normal directions of Figure 2c with those of the encircled reversed group. By doing so, the strong westerly directions of the Phonolites would at least in part compensate the demonstrable remagnetization effect of some of the Series 1 samples of Gran Canaria into the more recent field axis.

In Table 1 mean directions of magnetization, statistical parameters (Fisher, 1953) and pole locations have been calculated both with unit weight on specimen (a) and with unit weight on site (b).

It may be argued that the observed magnetic discordance here concerned is merely the result of the older lavas representing a shortlieved excursion of the geomagnetic field. However, the observed erosional discordances as well as the more advanced state of mineral alteration in these strata (compared to the younger ones) are not in favour of such an idea. In fact, the probable involvement of a chemical remanence in these rocks suggest that the total time span covered by axis II (Fig. 2d) may be considerably longer than the actual duration of extrusive activity (and may even exceed that of axis I). Also, the lava sequences of Fuerteventura, for which the detailed palaeomagnetic structures will be dealt with in a following paper, define the same general palaeomagnetic discordance as found in Gran Canaria/Tenerife. It is therefore contended that unlike Pre-Roque Nublo and younger rocks the older volcanics (at least Series 1 and the Trachytes) did not acquire their original magnetization in the late Tertiary geomagnetic field.

Before considering the geophysical and geological implications of the data it is of some importance to compare our results with those of Watkins (1973). It may be pointed out here that the procedure of the two studies are different: the present analysis includes both extensive thermal as well as alternating field demagnetization (involving a large number of demagnetization steps), whereas Watkins used a more restrictive procedure of alternating field treatment (100, 200 and 300 Oe). It is clear from a comparison that, as far as the Pliocene and younger volcanics are concerned, the overall data agree very well. This agreement is thought to be due to the fact that these rocks basically appear to possess a simple remanence structure (a small soft secondary component added to a primary component of high stability) so that the final results are not critically dependent upon the extent of the experimental analysis. There are, however, discrepancies between the two studies as regards the older lava series. This is due to the fact that here we are dealing with a more complex magnetization which requires more extensive laboratory analysis. In this regard it is contended that the present results must supersede those of Watkins (it may be remarked that Watkins' data do in fact also demonstrate the higher magnetic complexity of the older lava series: his Table 2(b) shows drastic reductions in the precision parameters, K, along with corresponding increases in the respective circles of confidence, α_{95}, for these rocks compared to the younger ones). Also, in a study of the Anaga peninsula of Tenerife, Carracedo and Talavera (1971) obtained directional data in close agreement with those of the present study.

As expected, the late Tertiary—Quaternary pole for the Canary Islands presented here is in good agreement with corresponding poles for continental Africa (see Fig. 5). The most interesting observation, however, is that the relative pole location for the older Gran Canaria/Tenerife strata corresponds very well with those for the Mesozoic of Africa. Based on magnetization axis II (Fig. 2d) the inferred pole is situated at a slightly higher palaeolatitude than the African Mesozoic poles, but an anticlockwise adjustment of axis II by only 5° (this is justified by the experimental evidence which suggests that a partial remagnetization has imposed a slight clockwise rotation of the original time-average magnetic vector) is sufficient to bring the pole into the major Mesozoic polar group. Recent evidence suggests that in the earliest Cretaceous the African palaeomagnetic pole underwent an excursion to a lower palaeolatitude (Bardon et al., 1973; Gidskehaug et al., 1975: poles 6 and 11 of Fig. 5) but returned to the previous position before Middle Cretaceous times (Gidskehaug et al., 1975). Further information in support of this polar behaviour is provided by

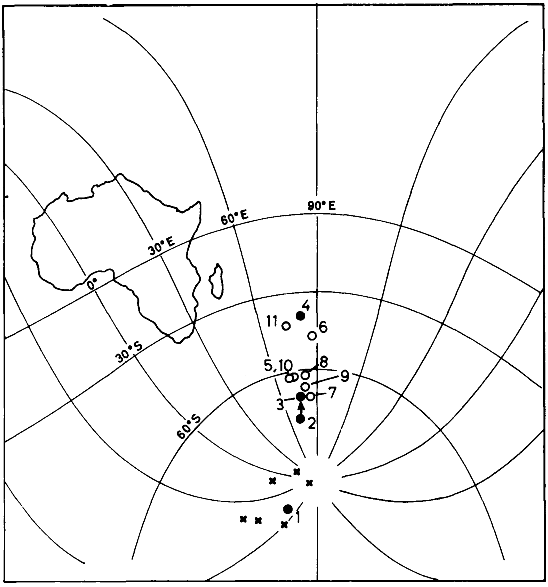

Fig. 5. Estimated pole locations for Gran Canaria/Tenerife basalts (poles 1–4) in comparison with relevant polar estimates from Africa. Pole 1 is the Upper Tertiary/Quaternary pole, poles 2 and 3 represents the older series (axis II of Fig. 1) before and after a 5° anticlockwise adjustment of the mean declination (cf. text) respectively, and 4 is the Phonolite pole. Crosses are African Tertiary poles. The other poles are as follows: 5, Hoachanas 161–173 (Gidskehaug et al., 1975); 6, Kaoko 110–128 (Gidskehaug et al., 1975); 7, Mlanje (Gough and Opdyke, 1963; Briden, 1967) (suggested to be post-Kaoko by Gidskehaug et al., 1975); 9, mean Mesozoic SE. African (Hailwood and Mitchell, 1971); 10, mean Mesozoic NW. African (Hailwood and Mitchell, 1971); Lower Cretaceous, Atlas Mountains (Bardon et al., 1973)

contemporaneous poles from South America. When the two continents are re-assembled in the manner proposed by Bullard et al. (1965) it is seen that the Serra Geral pole of Lower Cretaceous age exhibits a nearly identical excursion from the Mesozoic group as do the Kaoko pole (pole 6 of Fig. 5) of SW. Africa which is of similar age. As seen from Figure 5 the Phonolite pole of Gran Canaria (pole 4) is situated close to the Kaoko pole and the Lower Cretaceous pole for Morocco. This agreement may, however, be purely coincidental as pole 4 is only based on two sites and may therefore be biased either by geomagnetic secular variation or, perhaps more likely in this case, by partial remagnetization. In the following the Phonolites will therefore not be considered as representing a palaeomagnetic marker horizon.

For assessing an upward age limit of axis II it is very unfortunate that there are practically no palaeomagnetic data available for the Lower Tertiary of Africa. However, the Ethiopian traps which have K/Ar ages ranging between 69 m.y. and 30 m.y. give an estimated pole in good agreement with the Upper Tertiary poles for Africa suggesting that also the Lower Tertiary geomagnetic field was significantly different from that of the Mesozoic. It is therefore concluded that based on palaeomagnetism the minimum age of the oldest volcanic series in Gran Canaria/Tenerife is Upper Cretaceous.

3. Geology of NW. African Continental Margin

On the coasts of Morocco and Spanish Sahara data from petroleum exploration wells suggest that the sedimentary strata of the Essaouira and Aaiun basins are distributed in a 'down-to-basin' flexuring and normal fault pattern paralleling the coast and related to seaward subsidence (Martinis and Visintin, 1966; Querol, 1966; Seibold and Hinz, 1974). This fault system (having a NE-NNE trend) may be an important tectonic feature even several hundred kilometres from the NW. African shelf edge. For example, Dash and Bosshard (1969) and Bosshard and McFarlane (1970), through gravity and seismic refraction work, have suggested a major fault west of Gran Canaria as well as one passing through the islands of Tenerife, Gomera and Hierro. Similar faults have also been traced by Rona (1970) in seismic reflection profiles west and northwest of Cap Blanc.

In both the Essaouria and Aaiun basins late Triassic continental sediments (redbeds and evaporites) are interbedded with great amounts of basaltic lavas (Dillon and Sougy, 1974; Martinis and Visintin, 1966; Querol, 1966). The great importance of Triassic/Jurassic volcanism in W. Africa is further manifested by extensive outpouring of basic lavas in Algeria, Mauritania, Senegal, Guinea, Sierra Leone and Ivory Coast (Dillon and Sougy, 1974).

The coastal basin geology suggests that on the slope and shelf the Lower Mesozoic through Lower Caenozoic sediments are thickening seaward (Dillon and Sougy, 1974; Rona, 1970). Though the younger strata have terminations at the slope (due to erosion) the pre-Upper Cretaceous sediments appear to continue further seaward at least across the upper continental rise (Rona, 1970; Seibold and Hinz, 1974). The latter strata may however be vertically offset when crossing the general NE-NNE trending fault pattern. Except for a general transgression in Jurassic times the Lower Mesozoic to Tertiary depositional environment (at least beneath the coastal plain) was continental/shallow water marine, implying a more or less continuous crustal subsidence since late Triassic (Dillon and Sougy, 1974; Rona, 1970). Based on evidence for deep sea diapirism, Rona (1970) has suggested that the late Triassic salt layer may extend at least 1000 km west of Cap Blanc. Similarly, Schneider (1969) has reported deep sea diapiric features in the vicinity of the Cape Verde Islands though Pitman and Talwani (1972) have suggested that these may be of volcanic origin. However, more important information in favour of a salt layer extending seaward far from the continental shelf comes from DSDP holes 139 and 140 (cf. Fig. 6). Site 139 is situated at the middle continental rise at a water depth of around 3000 m and site 140 at the lower continental rise at depths of about 4500 m (Hayes et al., 1971). At site 139 the drill did not penetrate below Miocene strata but a site 140 the Upper Cretaceous sequence was reached though sonobuoy data suggest that beneath the cored Upper Cretaceous there is at least 1 km of sediments above the suggested basement. Furthermore, in the two DSDP sites a pronounced increase in salinity with depth takes place, suggesting the existence of a pre-Upper Cretaceous evaporite horizon at a greater depth.

From a seismic survey around the western Canary Islands Dash and Bosshard (1969) suggested a four-layered crustal structure comprising unconsolidated sedi-

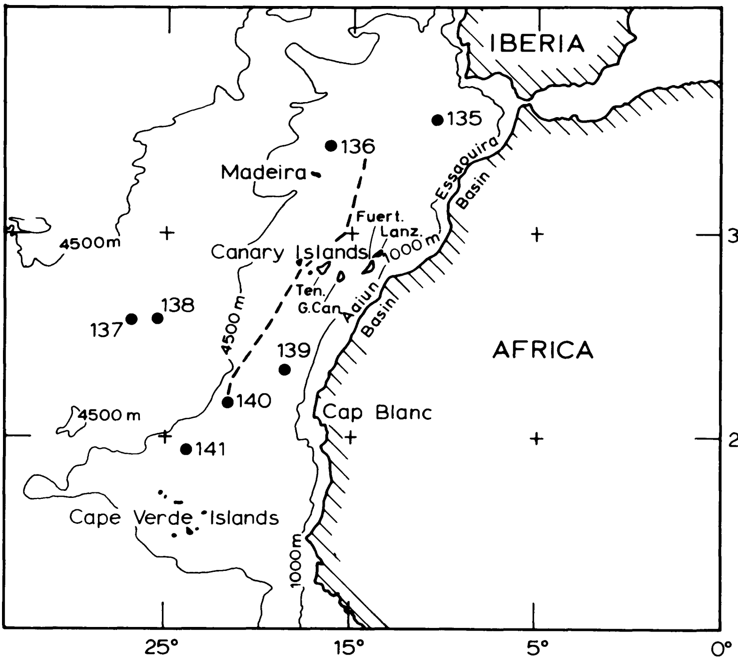

Fig. 6. Sketch map of coastal NW. Africa and adjacent oceanic areas. Numbers refer to drill sites explored by DSDP. Dashed line represents part of the westward boundary of the quiet magnetic zone

ments (a top layer of tuff and clastic material), consolidated sediments, basalt and oceanic layer, respectively. Special attention should be paid to the second layer, which in the seismic profiles has a thickness ranging between 2.2 km and 3.7 km, and for which Dash and Bosshard (1969) found no satisfactory explanation. If the geological interpretation of this layer in terms of consolidated sediments (1969) is the corrected one, a considerable time span must have elapsed between the first volcanic period (forming the basalts of layer 3) and the more recent volcanism forming the top layer of unconsolidated tuffs and other clastics. This upper crustal layering agrees very well with the palaeomagnetic structure from Gran Canaria and Tenerife (cf. Table 2) and represents further support in favour of a major gap between the to major subaerial volcanic sequences. However, based on the inferred episodic nature of the older volcanism of Gran Canaria the suggested consolidated sediments of layer 2 are likely to contain some tuff horizons at least in its lower stratigraphic levels. Further evidence of extreme importance for the present problem is that the crustal layer 2 (consolidated sediments) of Dash and Bosshard is thickening westward. This is in complete agreement with the sedimentary thickness distribution below the shelf and slope of West Africa. This combined evidence not only supports the Dash and Bosshard interpretation of their layer 2 but it also suggest a continental origin of the oceanic crust in the western Canaries region. If one had been dealing with a true oceanic crust formed by sea-floor spreading one

Table 2. Suggested correlation of upper crustal oceanic layering in the western Canaries region (Dash and Bosshard, 1969) with subaerial volcanic features of Gran Canaria/Tenerife

	Oceanic structure	Subaerial activity
layer 1:	Unconsolidated tuffs and clastics (V=3.00–3.35 km/s)	Miocene – recent volcanism
layer 2:	Probably consolidated sediments (V=3.90–4.75 km/s)	Long period (probable time span: Mesozoic – Miocene) of basically weathering and erosion
layer 3:	Basalts (V=5.63–6.00 km/s)	Formation of Series 1 plateau basalts in the Mesozoic, probably in the Upper Cretaceous
layer 4:	Lower crustal layer	

would have thought that on the whole the greater accumulations of sediments would be concentrated closer to the continental slope and with decreasing thicknesses seaward. A pronounced sediment distribution in the opposite sense even at large distances from the continent is in line with the well-established and marked down-to-basin faulting off NW. Africa as well as off eastern N. America, forming an extensive graben structure as the first stage in the separation process between the two continental blocks. The evidence from DSDP drilling of a salt layer beneath deep water (holes 139 and 140) may strengthen this idea, particularly if the salt is of Triassic/Jurassic age (i.e. correlatable with the adjacent continental deposits) but salt can certainly also form on an oceanic crust in a system of intermittent spreading.

4. Conclusions on Formation of the Canary Islands and the Adjacent Oceanic Terrain

According to the available palaeomagnetic results Gran Canaria and Tenerife were principally build up during two distinctly different periods of volcanicity of which the older one at least dates back to the Upper Cretaceous, but it may well have covered a broad time span within the Mesozoic. After culmination of the first magmatic period there appears to have been volcanic quiescence until late Tertiary times when another major period of outbursts swept the islands. While the first period of activity most likely reflects early phases of rifting between Africa and North America the second major period of volcanicity in the Canaries was probably related to the Miocene deformation of the Atlas Mountains (Bosshard and McFarlane, 1970).

Based on marine geophysical and geological evidence it can be inferred that considerable crustal subsidence took place in the area during the second half of the Mesozoic. The subaerial basalts of Gran Canaria/Tenerife of suggested Upper Mesozoic age are likely to have taken part in this subsidence.

In regions which were not subjected to substantial upwarping and erosion prior to the Miocene (unlikely the Cape Verde and Canary Islands) one would expect to find a major succesion of sediments intercallated between the two major volcanic 'horizons'. This is exactly what can be inferred from studies of the upper crustal layering northwest of Tenerife. Thus, there appears to be a very good correspondence between the marine geophysical evidence and the palaeomagnetic data as far as a major time gap in volcanic activity is concerned. The time span of volcanic quiesence within the region of Gran Canaria/Tenerife may at least have been of the order of 50 m.y. A late Cretaceous age for the older volcanic strata does not contradict palaeontologic evidence from Fuerteventura where the earlier plutonics seem to intrude Albian to Upper Cretaceous sediments (Rothe, 1968).

As regards the older basalts sequences the present results apparently diverge from available K/Ar age determinations (Abdel-Monem et al., 1971, 1972; Watkins, 1973). The present authors, naturally enough, rely on their palaeomagnetic data and are inclined to explain the discrepancy in terms of incomplete retention of the radiogenic argon in the older lavas, possibly caused both by the fairly extensive mineral alteration in these rocks as well as by the extensive magmatic activity in late Tertiary times. The authors attach considerably weight to the evidence for remagnetization (probably of chemical/thermochemical origin) within the older sequences and suggest that this evidence throws doubt on the reliability of the K/Ar ages for these rocks. Also, the K/Ar data themselves may pose severe problems of interpretation. For example, in Tenerife Abdel-Monem et al. (1972) have deduced radiometric ages from the old basalts in four different areas of the Island (Anaga, Teno, Ladera de Guimar and Tiagaia) obtaining ages ranging from 15.7 m.y. to 0.67 m.y. which are conflicting with geological observations by Hausen (1956) and Fúster et al. (1968) that the sequences concerned are time equivalent units. More alarming, however, is the occurrence of internal inconsistencies of stratigraphically controlled sections. In fact, these results indicate that argon loss may be an important problem. In the present situation one finds it hard to believe that any of the estimated dates from the older lavas represent true rock ages. We therefore fully agree with Abdel-Monem et al. (1972) that 'the final resolution of these stratigraphic and radiometric age inconsistencies require further study'.

The marked crustal subsidence of the continental shelf and rise of NW. Africa along with corresponding sedimentary thicknesses increasing seaward (at distances several hundred kilometers from the seaboard) and the evidence for a salt layer beneath water depths of around 4500 m (probably the Triassic/Jurassic evaporite horizon as found beneath the coastal plain) indicate that portions of the deep oceanic crust of NW. Africa may be of continental origin. For the area under consideration this conclusion applies at least to the region of the quiet magnetic anomaly field – the existence of some more marked magnetic lineations here and there inside the quiet zone (with a NE-NNE trend) would be a natural consequence of magmatic infill along the prevailing fault pattern of the region during the stages of foundering. This idea is supported by recent seismic evidence (Wissman et al., 1977) which shows that off Morocco and

Mauritania a true oceanic crust can only be found west of the quiet magnetic zone.

By invoking a sea-floor spreading origin for the quiet magnetic zone there are obvious problems in fitting Central America in pre-drift reconstructions. Also, one has to envisage an asymetric (Mesozoic) spreading between N. America and Africa in the initial stages of continental separation. On the other hand, if the quiet zones (or perhaps even wider belts) represent original continental crust having turned into oceanic-like structures in situ (as suggested by the present authors) such anomalies may virtually disappear. This suggestion is opposed neither by the DSDP leg 11 results (Hollister et al., 1972) from sites 100 and 105 (off eastern N. America) nor from the recent DSDP drilling in the Cape Verde Basin (Lancelot et al., 1975). In both areas a basaltic 'basement' was uncovered below apparently unbaked Middle-Upper Jurassic sediments. However, so far, no proper evidence in favour of a sea-floor spreading origin of these basalts has been given: it is at least equally plausible that they were formed during a process of rifting and subsidence of a continental to sub-continental basement. Recalling the existence of erosional discordances within the older lava sequence of Gran Canaria there are in fact reasons to suggest that rifting and lava extrusion may have taken place intermittently (within a subsiding continental belt between Africa and N. America) over a time span covering at least a greater part of the Mesozoic. Therefore, when sea-floor spreading between Africa and North America started, an ocean basin, formed by foundering of a zone of continental basement, seems to have been in existence at these latitudes in the Atlantic.

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Note Added in Proof

Some recent K/Ar dates of younger Gran Canaria lavas by Lietz and Schmincke (Palaeogeography, Palaeochin. Palaeoeclology, 18, 1975) have no implications for the ideas presented in the present paper.