

## THE CRUSTAL STRUCTURE AND EVOLUTION OF THE CONTINENTAL MARGIN OFF SENEGAL AND THE GAMBIA, FROM TOTAL-INTENSITY MAGNETIC ANOMALIES<sup>1</sup>

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### ABSTRACT

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Magnetic anomalies over the Cape Verde Basin and the continental margin off Senegal and The Gambia help define the boundary between oceanic crust and attenuated continental crust. Development of the Atlantic continental margin in the region through continental fragmentation, rifting, attenuation and subsidence began presumably in Early Mesozoic, or possibly in Palaeozoic time. Sea-floor spreading and formation of oceanic crust started in the Middle Jurassic. Later, during the Middle Tertiary, after initial uplift, the oceanic and transitional lithosphere off West Africa cracked into a set of fissures through which deep seated magmas intruded abundantly into overlying Mesozoic and Tertiary sediments and in places threw up substantial volcanic mounts. It is suggested that the origin of the Cape Verde Rise and Cape Verde Islands is also due to this process, which is probably related to African and Eurasian plate collision.

### INTRODUCTION

In early 1976 a multidisciplinary survey was carried out over the Cape Verde Basin and the continental margin off Senegal and The Gambia, W. Africa, aboard the CSS Baffin. The survey was executed under the terms agreed upon by the Governments of Canada, Senegal and The Gambia and was funded by Canada through the Canadian International Development Agency. The prime objectives of the cruise were to establish the configuration of the sea-bed and of the earth's gravity and magnetic fields. Additional observations provided information on physical and chemical properties of the watermass and established some characteristics of the biomass of the near-surface waters. In selected areas seismic reflection measurements in the low (150-2000 Hz) and high (1300-4800 Hz) frequency ranges were made to help define the structure of the bottom sediments. The bathymetric and geophysical data were collected predominantly on E-W tracks, spaced at intervals of roughly 18 km (10 nautical miles) in waterdepths greater than 2000 m. The spacing was 9

km or less in more shallow waters nearer shore. Ship's positions were continuously monitored by an integrated Loran C – satellite navigation system that assured positions to be accurate within 200 m over the entire survey area.

In this paper an analysis is made of the magnetic information. It focuses on pattern and trend identification, indicative of the deep structure of this part of the W. African margin. As such the paper expands and elaborates on the interpretation given in an earlier classified report (MEAGHER ET AL., 1977).

Prior to the Baffin survey, HAYES & RABINOWITZ (1976) presented a comprehensive compilation and interpretation of the magnetic field over the NW African margin, between 10° and 35° N. From W to E they identified a zone covered by Mesozoic (M) or Keathley sea-floor spreading anomalies M 1 to M 21', a transition zone with attenuated anomalies M 22 to M 25, and a marginal quiet magnetic zone. They concluded that the seaward boundary of the marginal quiet zone is not a sharp isochron but is time transgressive by a few million years and that it does not appear offset by even major transform faults. The quiet zone itself, they suggested, is underlain by two types of crust; oceanic, adjacent to the M-sequence, generated during the Graham normal epoch, and a landward portion representing either foundered continental crust or demagnetized ocean crust.

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## DATA COLLECTION AND PROCESSING

During the CSS Baffin survey total magnetic intensities were recorded towing the magnetometer sensor (fish) about 160 m astern. Apparently that distance was insufficient to keep the fish out of the ship's magnetic field and a heading difference was observed. All total-field values obtained on W-E tracks

were reduced by 15 nT to correct for that difference. The total field values were then corrected for diurnal variations, using data from the station magnetometer of the ORSTOM geophysical observatory at M'bour, about 60 km SE of Dakar. Total field intensities were finally reduced to IGRF 1975-6 level, which produced anomalies that appeared too high for the region by about 250 nT.

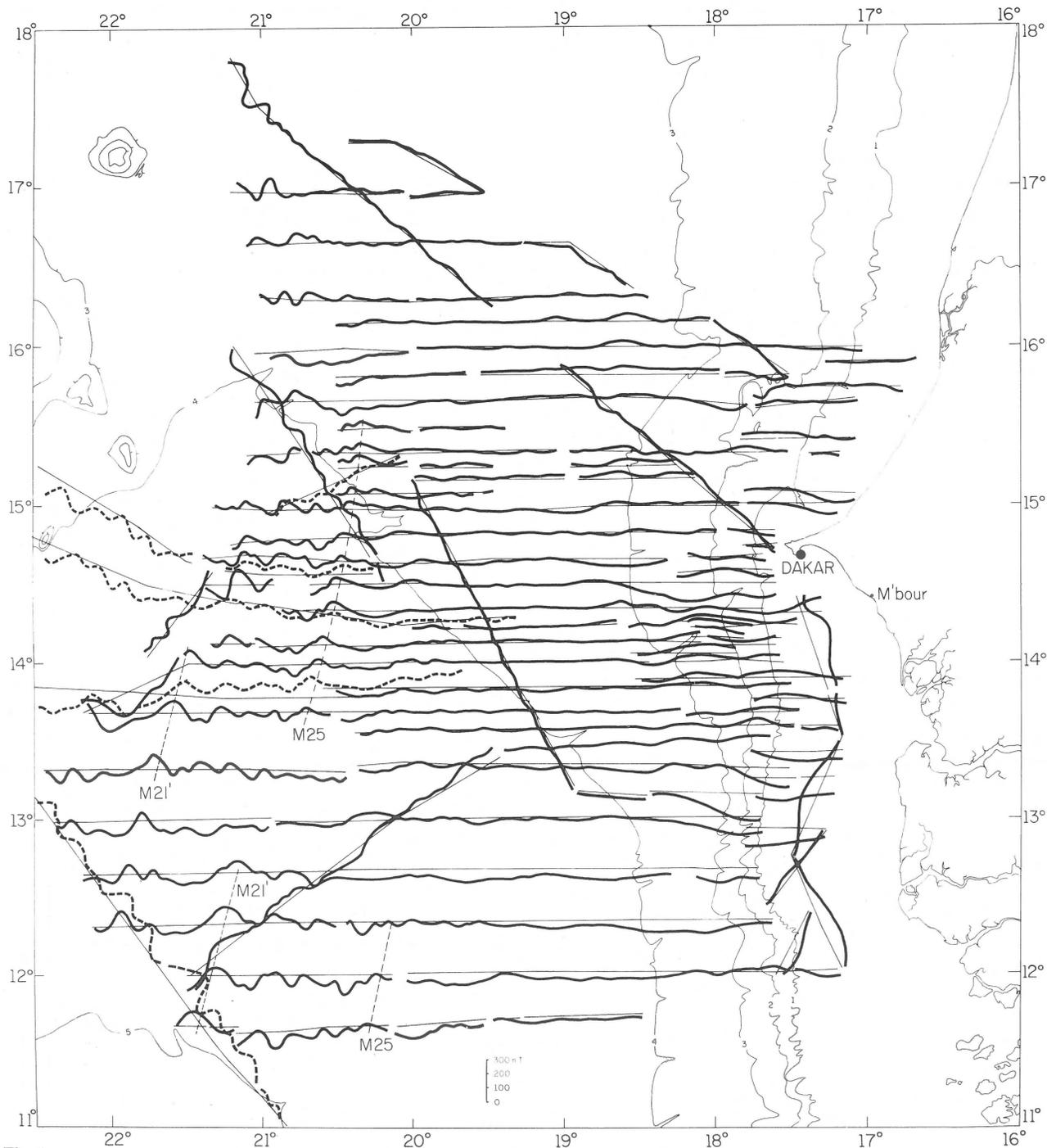


Fig. 1  
Magnetic anomaly profiles across the Cape Verde Basin and the continental margin of W. Africa, reduced to IGRF + 250 nT. Results obtained during the CSS Baffin cruise 76-001 are marked in heavy full lines; those from Hayes & Rabinowitz (1976) are shown as heavy dashed lines. Depth contours are in kilometres. Identification of anomalies M 21' and M 25 follows Hayes & Rabinowitz.

The results are presented as anomaly along track profiles in figure 1 (reduced to IGRF + 250 nT). Five magnetic anomaly profiles taken from HAYES & RABINOWITZ (1976) were added after proper scale adjustments to improve the data coverage in the western part of the Baffin survey area.

Figure 2 shows the contour chart of the total magnetic intensity anomalies at 50 nT intervals. Contouring of the

magnetic field was done originally at a scale of 1 : 5,000,000 directly on the profile chart, using a template with 50 nT divisions. In this way the congruence that is apparent between profiles could be easily maintained.

South of 12° N the map is extended over the continental slope of Guinea Bissau to include contoured information taken from MCMASTER ET AL. (1970). South and west of Dakar

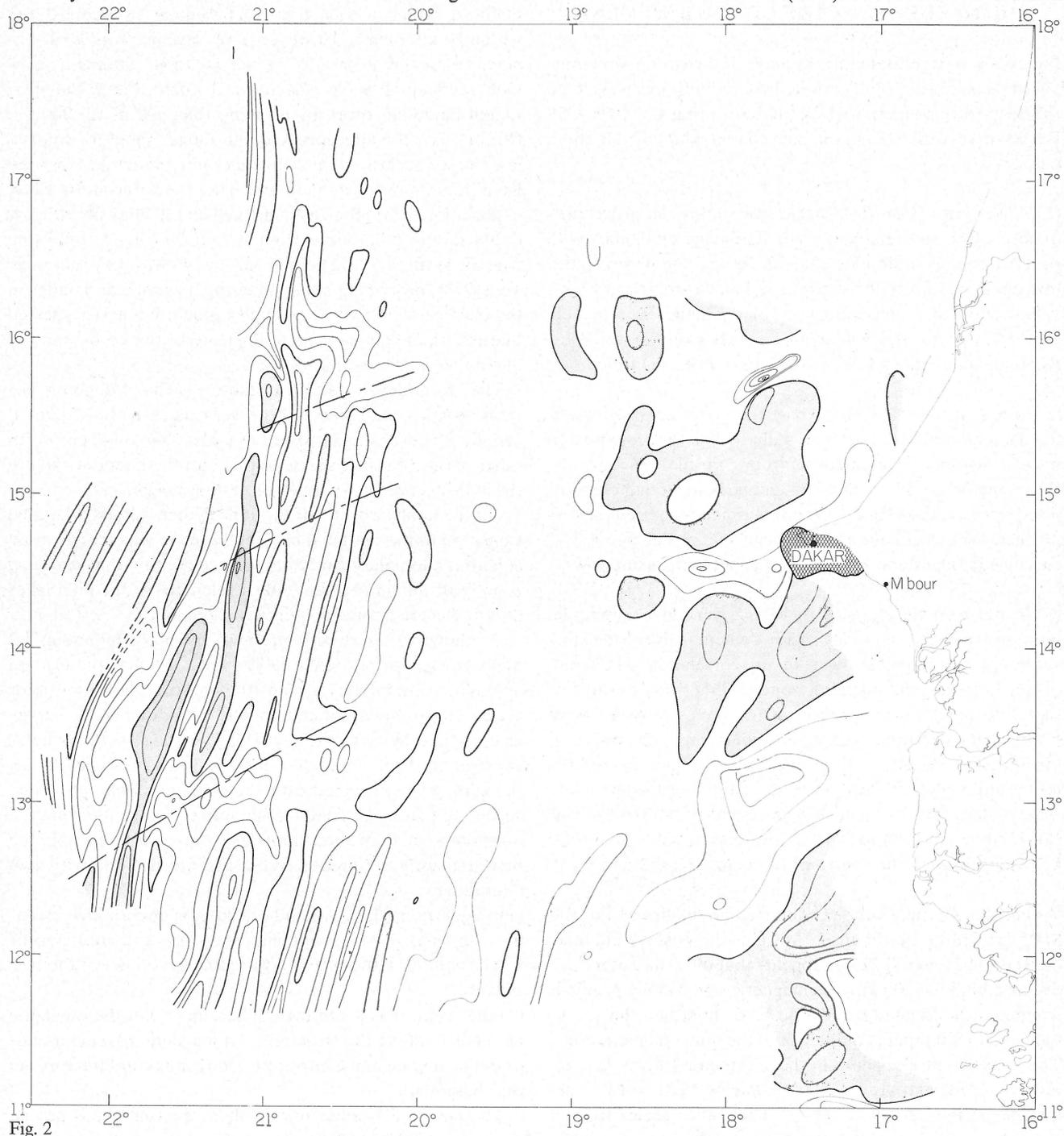


Fig. 2

Magnetic anomaly map across the Cape Verde Basin and the continental margin of W. Africa. Contour interval 50 nT. Field values above IGRF + 250 nT are shaded. Cross hatching marks the region off Dakar with high-frequency anomalies. Note the dash-dotted WSW to ENE trending discontinuities in the anomaly pattern.

peninsula an area is identified from Baffin and BRGM information (FROIDEFOND ET AL., 1973; HORN ET AL., 1974) with high-frequency fluctuations of the magnetic field. They are an expression of the extent of the Dakar volcanic province over the adjacent shelf.

### THE NATURE AND AGE OF THE BASEMENT

Figure 3 is a structural interpretation of the continental margin of Senegal and The Gambia, based almost exclusively on the seaborne magnetic data gathered during the 1976 CSS Baffin survey. Like Gaul, the area can be subdivided in three parts.

(1) A western region that is characterized by an orderly sequence of linear, relatively high frequency anomalies with peak to trough amplitudes of about 200 nT and wavelengths, measured along profile, of about 19 km. Correlation of individual anomalies and sequences of anomalies is relatively easy between profiles. Following HAYES & RABINOWITZ (1976) Keathley anomalies M 19 to M 25 have been identified.

(2) Marginal to the African coast there is a zone with subdued anomalies. It is, however, still possible to recognise and trace individual anomalies from profile to profile. Wavelengths are 35 km or more and peak to trough amplitudes do not exceed 100 nT. Where anomalies continue across profiles, such correlations have been marked in figure 3 as curvilinear ridges and troughs of magnetic highs and lows.

(3) In between these zones there is a very low amplitude, large wavelength anomaly zone, where, given the line spacing, it is impossible to make any correlation. The width of this Jurassic quiet magnetic zone (JQMZ) thus defined, is therefore much narrower than in the HAYES & RABINOWITZ (1976) interpretation, where the quiet magnetic zone also incorporates the zone with subdued anomalies nearer the shore (although they show a few discontinuous magnetic lineaments adjacent to Spanish Sahara and Mauretania). The JQMZ shows as a blank NNW-SSE trending zone, about 120 km wide, through the centre of the maps (Figs. 2 and 3).

Within the Keathleys the pronounced anomalies M 21' and M 25 are marked in figure 1 (M 21' is the positive anomaly between M 21 and M 22). It appears that over that interval, a distance of about 100 km, the magnetic signal along profile is damped or attenuated from W to E to about half the amplitude and that it tapers gradually into the quiet magnetic zone. This is apparent elsewhere in the E Atlantic (HAYES & RABINOWITZ, 1976) and also in the NE Pacific M 21 to M 25 sequence (LARSON & HILDE, 1975). There thus seems to be a transition zone between non-attenuated Keathleys and the JQMZ that is independent of the region. Off Africa this zone is about 150 to 200 km wide. The transition is probably attri-

butable to a gradual change in magnetic field intensity, to a gradual deepening of the magnetic source layer (basement), or to both.

Such a wide transition zone was not obvious to HAYES & RABINOWITZ (1976) and they preferred an almost instantaneous change in magnetization at anomaly M 22 (from  $J = 0.007$  to  $J = 0.0035$  emu/cm<sup>3</sup>) or, what they considered less likely, a rather sudden drop of basement by about 3 km within 20 km or less. However, E-W seismic profiles off Senegal (UCHUPI & EMERY, 1974) indicate, if we assume an average sediment P-wave velocity of 3 km/s, that within that region basement drops by no more than 600 m per 200 km (Fig. 4). For the appropriate depth range, about 6.7 km below the sea surface, that is obviously not enough to taper the Keathleys as much as they are. Therefore, the most likely explanation is that the earth's magnetic field intensity roughly doubled during that time, from M 25 to M 21', i.e., following LARSON & HILDE (1975), from 153 to 146 Ma B.P. CANDE ET AL. (1978), describing and comparing magnetic anomalies in the NW Pacific, arrived at a similar conclusion and suggested that the dipole magnetic field intensity increased by a factor of four from 160 to 140 Ma B.P.

The Keathley-JQMZ transition in the foregoing interpretation would thus still be very much a time zone; it cannot, however, be narrowed to a time-line or isochron. In other words: it is impossible to pinpoint the boundary where the JQMZ ends or where the Keathleys begin.

On the landward side of the JQMZ there also is a gradual transition to the marginal magnetic zone in which once more coherent anomalies can be recognized. Within that marginal zone itself the amplitudes and wavelengths of the anomalies do not change appreciably in any direction.

As shown in figure 3 the trend of the marginal anomalies offshore conforms remarkably well to the pattern of anomalies observed over land (the onshore magnetic trends are an interpretation of an unpublished aeromagnetic survey as presented by TEMPLETON, 1971). This suggests that whatever produced the anomalies onshore is also responsible for the anomalies generated over the continental margin. Now, accepting that and excluding the unlikely possibility that the magnetic source for these anomalies is to be found within the predominantly calcareous sediments, we are left with two alternatives:

- (1) the entire region, on- and offshore, is underlain by oceanic crust and the magnetic anomalies are an expression of either polarity differences and/or structural relief of the basement;
- (2) the region has a continental basement and the magnetic anomalies reflect the structure of a magnetic basement and/or delineate magmatic intrusions along faults and fractures in that basement.

The choice for either one of these alternatives is not an easy one and the available deep information does not permit an unambiguous solution. At the one extreme we find DASH ET AL. (1976) who stated that the magnetic quiet zone, land-

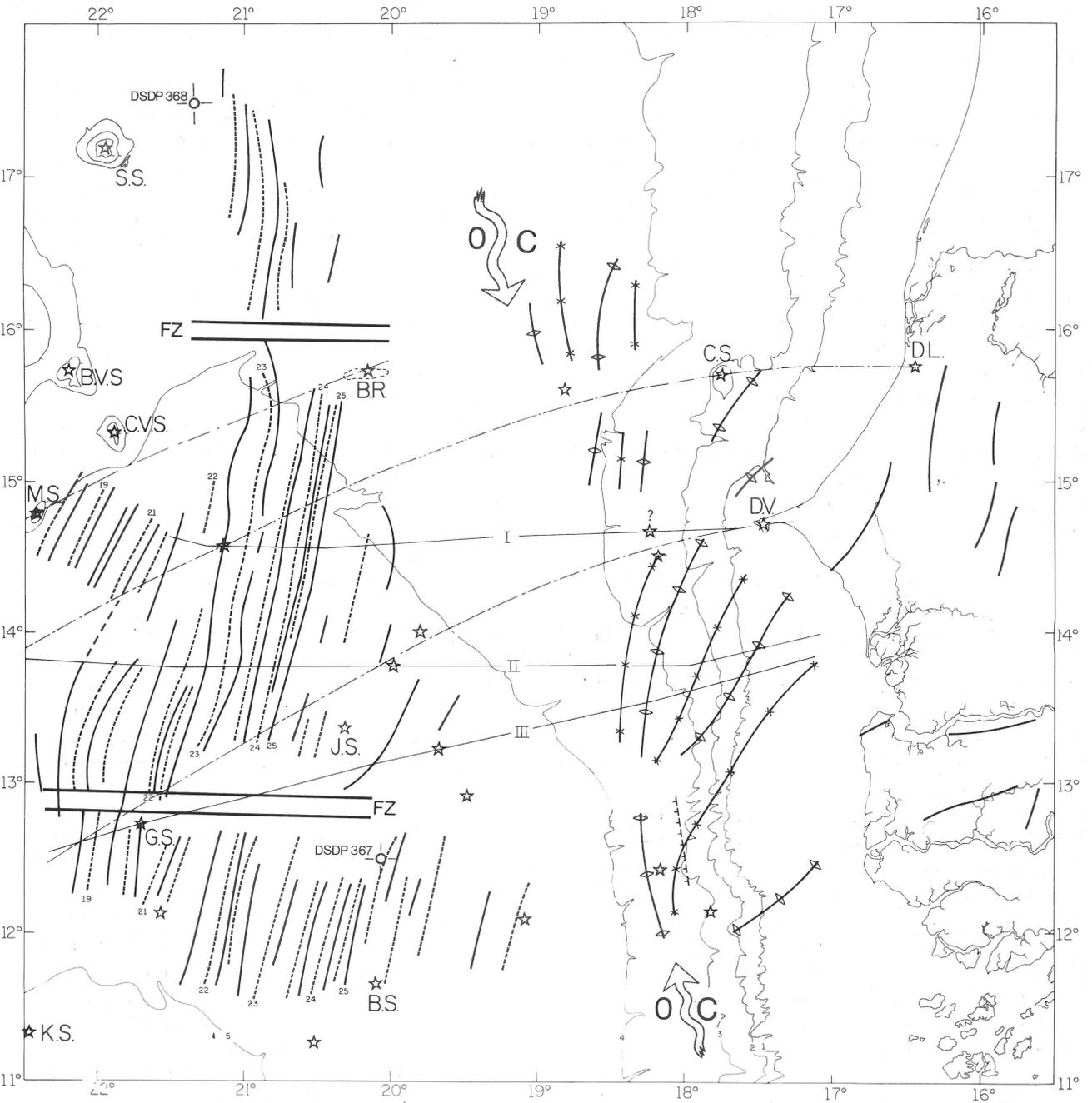


Fig. 3

Magnetic and tectonic fabric of the Cape Verde Basin and the continental margin of Senegal and The Gambia, W. Africa. Eastern Keathley or Mesozoic magnetic anomalies (highs in full, lows in dashed lines) are labelled 19 to 25, following the identifications of Hayes & Rabinowitz (1976). Axes of magnetic highs and lows across the continental rise and slope (full lines) are marked with  $\sphericalangle$  and  $\times$  respectively. Aeromagnetic trends on shore as shown by Templeton (1971). I, II, and III are the positions of profiles shown in figure 4. The dashed line and bars mark the edge of the Mesozoic carbonate platform (Lehner & De Ruiter, 1977). The Keathley anomalies are obliquely cut by two fracture zones or transform faults (double heavy lines). Dash-dotted curvilinear lines are extensions of similar ones shown in figure 2. They are suggested volcano-tectonic lineaments of presumably Oligo-Miocene age. Starred positions mark centres of known Miocene volcanic activity on land and seamounts and/or basement highs observed in seismic profiles (Fig. 4), the bathymetry (Ruffman et al., 1977), and as shown on a map of the basement (Goldflam et al., 1980). B.R. = Bafoulabé Rise (3.5 km depth contour shown); B.S. = Bissau Seamount; B.V.S. = Boa Vista Seamount; C.S. = Cayar Seamount; C.V.S. = Cape Verde Seamount; D.L. = Dôme de Leona; D.V. = Dakar volcanic centre; G.S. = Gambia Seamount; J.S. = Joal Seamount; K.S. = Katri Seamount; M.S. = Maio Seamount; S.S. = Senghor Seamount. Open wavy arrows show the inferred ocean-attenuated continent boundary (this paper). Depth contours in kilometres.

ward of the Cape Verde Islands, almost follows the transitional crustal zone. On the other hand RABINOWITZ (1974) placed the ocean-continent boundary well within the Senegal Basin and concluded that the basin fill prograded westward over oceanic basement over a distance of at least 200 km.

Refraction results across the continental margin off Mauretania, immediately north of the Baffin survey area, show that the marginal magnetic zone is underlain by basement that exhibits P-wave velocities of 7.1 km/s (WEIGEL & WISSMANN, 1977; GOLDFLAM ET AL., 1980). These velocities are commonly found under tectonized zones such as continental rifts and Atlantic-type continental margins (VAN DER LINDEN, 1977), where they would be indicative of hybrid or transitional type crust. Certainly, 7.1 km/s would also be a good oceanic layer 3B velocity, but then, at least off Mauretania, layer 3A (with velocities in the 6.4 to 6.8 km/s range) would be missing.

A cross-section through the eastern Senegal Basin that is based on exploratory wells and on geophysical data shows a Precambrian crystalline basement that dips west under a wedge of Palaeozoic sedimentary rocks and more than 5 km of Mesozoic and Cenozoic sediments (AYMÉ, 1965). DE SPENGLER ET AL. (1966) extend this section westward across the continental margin and suggest that crystalline and metamorphic basement is stepped down under the Senegal Basin, from surficial outcrop, several hundred kilometres E of Dakar, to a depth of more than 15 km, about 100 km offshore. Such an extrapolation, certainly to that depth and over that distance without any well control into deep basement, may seem rather tendentious. The general attitude of that cross-section with stepped-down, normal-faulted continental basement, however, is known to underly many Atlantic-type continental margins in zones several hundred kilometres wide (VAN DER LINDEN, 1977). If the magnetic anomalies are produced by mafic intrusions into continental basement faults of pre-Atlantic or rift age, i.e. Jurassic or older, as suggested in DE SPENGLER ET AL.'s (1966) diagram, then it is logical to accept the same explanation for the magnetic anomalies of the entire marginal magnetic zone.

Although Miocene and Quaternary magmatic activity is considered largely responsible for the formation of the Dakar volcanics (see also next section), there are reports (TEMPLETON, 1971; FURON, 1968) on deposition of pyroclastics and injections of Late Cretaceous intrusives in the area. Triassic and Early Jurassic dykes have been suggested for the coastal areas of Mauretania (producing magnetic anomalies with amplitudes of about 75 nT!) and Liberia respectively (RONA ET AL., 1970; BEHRENDT & WOTORSON, 1969; DILLON & SOUGY, 1974). Thus, it is quite likely that the Mesozoic rifting and subsidence of the W. African margin, responsible for the formation of the continental margin (and the Senegal Basin), was widely accompanied by intrusion of magmatic material into predominantly coast-parallel fissures and fractures. It is here suggested that such Mesozoic dyke injections are revealed in the magnetics of the marginal zone.

Oil company data (LEHNER & DE RUITER, 1977) indicate that, whatever the deep basement may be, it is carrying a thick, presumably Jurassic to Cenomanian, carbonate platform. That is exactly the equivalent of the juxtaposed reef complexes that constitute the Blake Plateau and carbonate banks of the E. American margin. According to BUFFLER ET AL. (1979), there the strong reflector at depth under the continental margin (i.e. under the carbonate banks) may represent the top of Early Jurassic volcanics, the top of crystalline basement, or the top of high-velocity sedimentary rock. It seems uncalled for at this stage, without evidence to the contrary, to accept an early evolution of the W. African margin that is not closely mirrored in the evolution of the E. American margin.

On the basis of the foregoing arguments I propose that the boundary of the attenuated African continental crust coincides with the boundary between the JQMZ and the marginal magnetic zone. This thus specifies the HAYES & RABINOWITZ (1976) conclusion, mentioned in the last sentence of the introduction.

## TECTONISM AND VOLCANISM

In the survey area two transform faults or fracture zones (FZ) are identified that cut east-west through the Keathley anomalies in latitudes 12°50' N and 16°00' N respectively (Fig. 3). The southern one offsets M 21' by 75 km and M 25 by 90 km in a left lateral sense. Because there is insufficient information to identify anomalies north of 16° N, no offset along the northern FZ could be determined. The pattern suggests that the offset is also left lateral. The FZs as shown in figure 3, which are a best fit to the Baffin data, deviate by 10° from the orthogonal to the magnetic anomalies.

Both FZs are also shown by HAYES & RABINOWITZ (1976). There is not enough information within the region to corroborate the existence of yet another FZ which HAYES & RABINOWITZ (1976) identify in about 17° N. LEHNER & DE RUITER (1977, in their figure 4) show a very broad FZ at about 14° N which they label the Cape Verde Fracture Zone. The present results, however, do not support this; the nearest FZ identified magnetically is the one at 12°50' N. The identification of anomalies south of 13° N, as labelled in figures 1 and 3, differs from that given by JONES & MGBATOBU (1977). M 25 in the present interpretation corresponds with M 21' in their profile 1 and they therefore arrive at a left-lateral displacement along the 12°50' N FZ of no less than 160 km.

There is no evidence that the two FZs extend landward much beyond 20° W, unless the one at 16°00' N passes (but not exactly on trend) through Cayar Seamount and the Dôme de Leona, a volcano near St. Louis. The latter extension, however, does not offset the pattern of marginal anomalies between 18° W and 19° W.

There are three more discontinuities marked in figures 2 and 3 that dissect the region in an ENE direction. These were

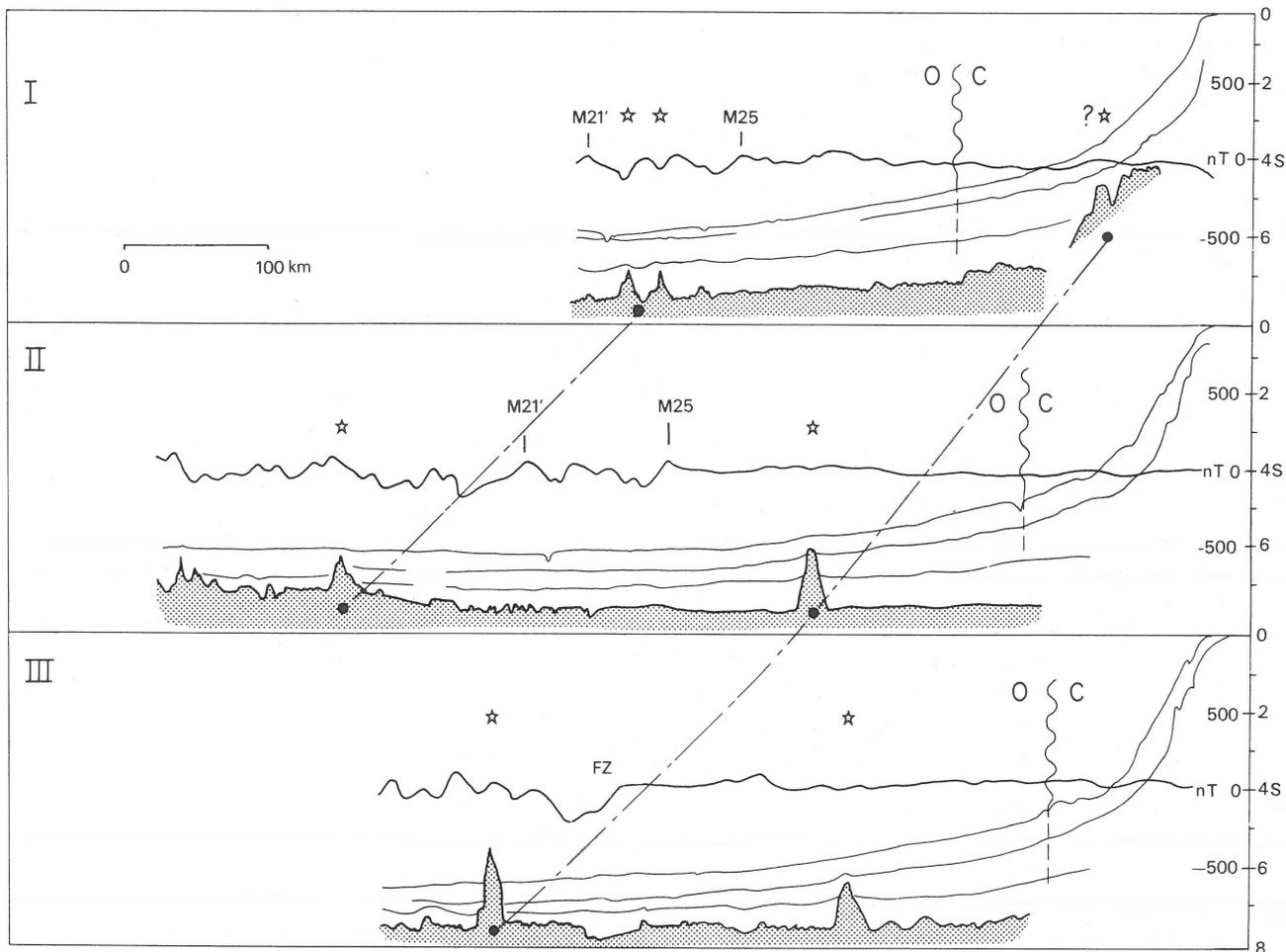


Fig 4 Tracings from seismic profiles and magnetic anomalies across the Cape Verde Basin and the W. African margin, redrawn from Uchupi & Emery (1974). Ocean-attenuated continent boundary as defined in figure 3. Dash-dotted lines through the profiles represent Mid-Tertiary volcano-tectonic lineaments or fissures discussed in the text. The positions of the profiles are shown in figure 3.

noticed first of all as subtle but persistent discontinuities in the Keathley sequence (Fig. 2) although there is no offset. Along these trends the character of the anomalies changes and in the contoured version the anomalies appear interrupted or squeezed. The landward extensions of two of these lines, following parallel gentle curves, pass through a number of starred positions as shown in figure 3. Three of these stars are known volcanic centres, Dakar, Cayar Seamount and the Dôme de Leona; a fourth marks the position of a relatively pronounced negative anomaly about 80 km west of Dakar (Fig. 2). This latter anomaly and the one associated with Cayar Seamount form broad negative interruptions in the overall positive marginal anomaly pattern, as does the broad anomaly centred on about  $13^{\circ}$  N –  $17^{\circ}$  40' W (cf. Figs. 2 and 3).

Maybe this is just fortuitous. However, when the curves thus defined are checked against the bathymetry (RUFFMAN ET AL., 1977) and against three seismic profiles (Fig. 4, after UCHUPI & EMERY, 1974) the intersections of the curves and the profiles coincide rather closely in every instance with conspic-

uous seamounts or basement highs which are also marked with stars in figure 3. To check the coincidence I furthermore marked a best estimated position of a 2 s high-basement peak on a Vema profile (LANCLOT & SEIBOLD, 1978), various seamounts mapped by RUFFMAN ET AL. (1977) and what are shown in GOLDFLAM ET AL. (1980) as volcanic intrusives or seamounts (of post-Senonian or predominantly Miocene age).

From the scatter of stars that now mark figure 3 it is clear that many more curves can be drawn, with characteristics as defined, that parallel the three shown in figure 3, but also in other directions. It is important to note, however, that although other structural and morphological trends are apparent, SW-NE alignments are conspicuous through the Cape Verde Islands and nearby seamounts (DASH ET AL., 1976).

It is here suggested that the SW-NE alignments of the discontinuities in the Keathley sequence, the seamounts, rises and basement highs, and the volcanic centres of the continental margin reveal a trend in regional structure.

As mentioned there is no horizontal offset of the Keathley

anomalies along the discontinuities, at least none are large enough to be resolvable from the present data, and there are no sharp and systematic differences in basement depths on either side of them that might indicate normal or reversed faulting. What is left therefore is that the curves are cracks or fissures, along which no horizontal or vertical movement took place, but which acted as conduits for the intrusives that formed seamounts, basement highs and islands.

On reflection records (UCHUPI & EMERY, 1974) the seamounts and basement highs show clearly as intrusives or piercement structures and they are thus definitely younger than the oceanic basement. The age of the basement for the region is estimated to range from 141 Ma at anomaly M 19 to about 168 Ma near the ocean-attenuated continent boundary as defined in this paper. The age of the intrusives is probably Miocene to Recent, because that is the age of the youngest sequence of Dakar volcanics; the age of the fissures themselves may be somewhat older.

Tertiary to Recent volcanism is rather common throughout the entire central E Atlantic Ocean. The Late Cretaceous to Late Tertiary was an interval of increased volcanic activity along the NW African and SW European margins. It incorporates the volcanism that formed the Madeira Islands and probably also the Horseshoe Seamounts and Madeira-Tore Rise, W. of Portugal (VAN DER LINDEN, 1979). Cape Verde and Canary Islands volcanism peaked during the Miocene and continued until the Present (DILLON & SOUGY, 1974). Miocene volcanism, 11 to 16 Ma ago, is known from the Atlantic-Plato-Cruiser-Meteor complex (WENDT ET AL., 1976), which strikes obliquely to the regional direction of sea-floor spreading. The Azores volcanism began in the Pliocene (MACHADO ET AL., 1972). Diabase sills were drilled at DSDP site 368 on the Cape Verde Rise (site marked on Fig. 3) and gave a radiometric age of 19 Ma (Early Miocene: LANCELOT ET AL., 1978). Heavily serpentinized basalt, diapiric in appearance on seismic records and of low magnetic intensity (therefore originally considered to be salt: RONA, 1969, 1970), has been drilled at DSDP site 141, about 200 km north of the Cape Verde Islands (PIMM & HAYES, 1972) and may also belong to these Tertiary E. Atlantic volcanics.

DILLON & SOUGY (1974) suggested that the collision of the African and Eurasian plates precipitated Miocene volcanism along the African coast. Collision of these plates, responsible for the Alpine orogeny in the collision zone, also must have set up stresses elsewhere in the plates, cracking and fissuring them in response. Depending on the respective positions relative to the place of plate collision, different tectonic trends developed at different sites for different times within the entire E Atlantic region. It is suggested that for the margin off Senegal and The Gambia the curvilinear discontinuities shown in figure 3 define a trend in the regional stress pattern, a local adjustment to Tertiary changes in the motion of the African Plate. This trend also happens to be the strike of the Cape Verde Rise.

For the W. African margin the scenario of events then was

probably as follows: during the Early(?) Tertiary the crust and lithosphere cracked and fissured in response to the collision of Africa and Eurasia. The fissures enabled mafic intrusives to reach into upper crustal levels, to intrude into Late Cretaceous and Tertiary turbidites on the Cape Verde Rise (LANCELOT ET AL., 1978) and to produce the basement peaks and seamounts described in this paper.

There seems to have been a direct relationship between volcanism and regional uplift. SEIBOLD & HINZ (1974) identified a distinct Oligocene to Early Miocene discontinuity under the continental slope of W. Africa, that cuts deeply into pre-Miocene and even pre-Cenomanian sediments (their discontinuity D 2). DILLON & SOUGY (1974) showed a general seaward migration of the W. African shore line (regression) from the Eocene to about the end of the Oligocene. This indicates for the region a 'Cloos sequence' of 'Hebung-Spaltung-Vulkanismus', uplift-fissuring-volcanism (CLOOS, 1939). Results from DSDP site 368 on the Cape Verde Rise (LANCELOT ET AL., 1978) indicate that the rise was uplifted by a 1000 m, most likely after emplacement of the diabase sills that were cored and thus the story may be more complex. Sedimentation rates, however, were conspicuously low from middle Eocene to middle Miocene. There is of course the undeniable fact that the Cape Verde Rise is a rise. Perhaps a much larger volume of magma was injected through the fissures in the Cape Verde Rise than through the fissures in the Cape Verde Basin on its southern flank. Maybe the heat contained in the injected material itself can be held responsible for the much greater and longer lasting period of uplift of the Cape Verde Rise.

It should be noted that most seamounts and basement peaks in the region have no associated prominent magnetic anomalies (Fig. 4); none are obvious against the background of the Keathley anomalies, nothing is visible within the JQMZ. This contrasts, however, with the magnetic signal over the Cayar Seamount, the Dôme de Leona, and especially with the high-frequency anomalies over the Dakar region. The reason for this discrepancy may be that comparatively small masses of magnetic material intruded into the sea and into water-logged sediment would be subject to strong hydrothermal alteration. This could oxidize magnetite into haematite or change the magnetic domain structure. Such effects would be proportionally small for larger masses of intrusives and ultimately would become negligible when extrusion occurred subaerially (R. D. SCHULING, pers. comm., 1980).

## SUMMARY AND CONCLUSIONS

Magnetic anomalies recovered during the 1976 CSS Baffin survey help define the nature and age of the basement under the continental margin of Senegal and The Gambia. Although there is no sharp boundary there is a difference between the magnetic signature of what has been interpreted as

attenuated continental basement and that of oceanic basement.

Magnetic anomalies with wavelengths of about 35 km and amplitudes less than 100 nT, are considered to reflect magmatic intrusions into attenuated and foundered Precambrian sialic rocks and overlying Palaeozoic sediments. Attenuation and foundering of this basement and the magmatic intrusions all belong to the rifting phase that preceded the opening of the Atlantic Ocean. Basement thus defined underlies the Senegal Basin including the Atlantic continental margin to a distance of roughly 200 km offshore (Fig. 3).

The western part of the region is underlain by oceanic crust that was formed since about 168 Ma ago, assuming a constant sea-floor spreading rate of 1.5 cm/yr over the interval shown in figures 1 to 3. In the magnetic signature over the oceanic region one recognises the oldest anomalies of the Keathley or Mesozoic sequence, which from anomaly M 21 are attenuated, backward in time, to disappear in the Jurassic Quiet Magnetic Zone. The magnetic quiescence of that zone is accepted to reflect the low intensity of the earth's dipole field during that period. Between 12° and 17° N, the Keathleys are dissected by two E-W-trending oblique fracture zones.

Three WSW to ENE curvilinear fissures have been identified (Fig. 2) from rather subtle discontinuities or interruptions in the magnetic anomaly pattern; others are probably present. The extensions of two of these discontinuities pass through known centres of Miocene volcanic activity ashore (Fig. 3). Additional information shows that the curves coincide, or very nearly so, with the positions of basement peaks and seamounts that are presumably volcanic mounts of inferred Miocene age. Fissures and associated volcanics are considered the volcano-tectonic response to changes in regional stress, induced by the collision of the African and Eurasian plates.

In terms of structure and lithology the Cape Verde Rise and Cape Verde Islands are quite likely controlled by the same process. The difference between Cape Verde Rise and Islands on the one hand and the linear volcano-tectonic features of the Cape Verde Basin can be attributed to local differences in the volume of magmatic material injected and extruded. Such differences in volume can perhaps also explain why the Miocene volcanoes of the W. African coast and the Cape Verde Islands are highly magnetic, whereas the basement peaks and seamounts have no clear expression. As stated, the difference may reflect the degree of hydrothermal alteration.

The volcano-tectonic relation that is suggested here for the W. African margin differs from that advocated by SYKES (1978). He favoured major transform faults and their extensions on land to be the locus of post-separation and Recent magmatism and seismic activity, a re-activation of former zones of weakness. For the continental margin of Senegal and The Gambia the Tertiary volcanism, on- and offshore including the Cape Verde Rise and Islands, does not fit the transform fault pattern. It does fit, however, a regional pat-

tern in which an ENE to WSW trend is recognized that as suggested reveals local stress adjustments in response to plate collision elsewhere. Very likely a similar relationship exists for many other Tertiary volcanic seamount and island complexes in the central Eastern Atlantic.

It has been suggested that the geology of the ocean is far simpler than that of the continents. The statement may appear acceptable on the grounds that the geological history of today's oceans covers only a fraction of the time taken to evolve, shape and repeatedly reshape the continents. It is, however, quite possible that as more areas of the ocean floor are surveyed and sampled in ever greater detail the simplistic view of a simple structure will have to be modified or even abandoned. This paper supports that statement on the basis of a not-so-widely-spaced survey. It acknowledges and stresses features that reveal processes that affect the oceanic crust long after its formation through sea-floor spreading. It also shows that the response of (old) oceanic crust to endogenic forces may not be all that different from the tectonic processes known from the land.

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