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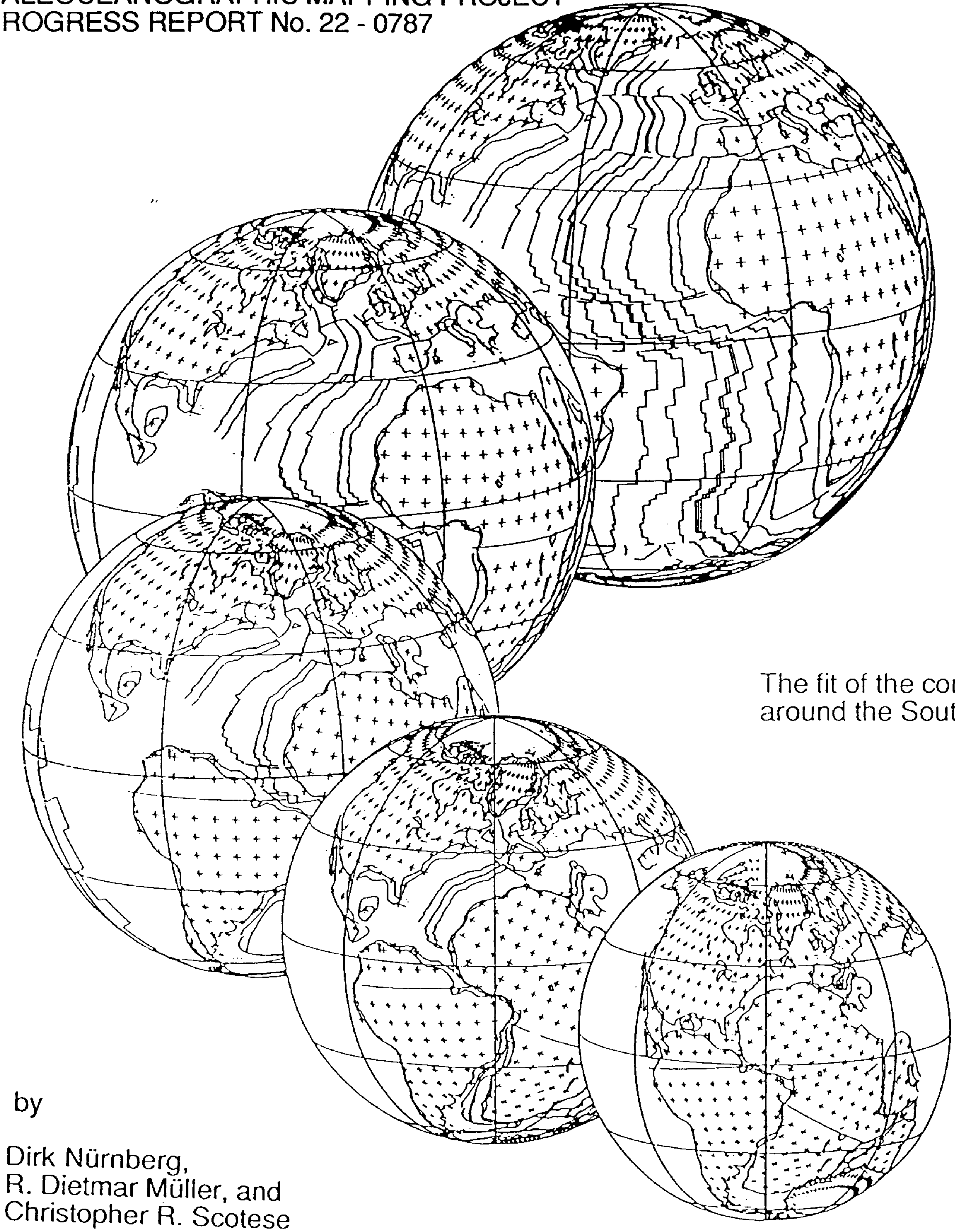

The fit of the continents
around the South Atlantic

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Abstract

All reconstructions proposed for the continents around the South Atlantic that require rigid plates result in substantial misfits either in the southern South Atlantic or in the equatorial Atlantic. Different solutions have been proposed to improve the fit of Africa and South America. We describe and discuss three different proposals: a model that assumes rigid African and South American plates, a model that requires an intraplate deformation zone within Africa, and a model that requires intraplate deformation within South America. Two recent plate tectonic models for opening of the South Atlantic are compared (Klitgord & Schouten 1986 and Pindell et al. in press) by calculating spreading rates and directions.

Though the models that imply non-rigidity of the African and South American plates are an improvement, problems of misfit remain. In this paper we present two new reconstructions that result in an improved fit of Africa and South America. Additional constraints used in this study were derived from Seasat altimetry data. Seasat altimetry data were used to determine the directions of equatorial fracture zones which can be traced from the African to the South American margin. These fracture zones serve as tie-points for the predrift fit. Both models we propose require intraplate deformation within South America and Africa along a complex rift and strike-slip zone. Movements along these faults took place before or simultaneously with the breakup of the continents. These models eliminate gaps between the Guinea and Demarara Plateau and between the Falkland Plateau and South Africa, while avoiding large overlaps of continental margins or coastlines. Onshore geological and geophysical data, although being sparse for some regions, are consistent with the reconstructions we propose.

Introduction

Since 1965 several different predrift reconstructions of the South Atlantic have been published. Assuming rigid continental plates, the reconstructions of Bullard et al. (1965) and Rabinowitz & LaBrecque (1979) result in a misfit, either between the Guinea Plateau (Africa) and the Demarara Plateau (South America) or between South Africa and the Falkland Plateau.

Some authors (Dietz 1973, Smith & Briden 1977, Sibuet & Mascle 1978) proposed that oceanic microplates filled the gap between the Demarara Rise and the Guinea Plateau, whereas Vink (1982) attributed the observed gap in predrift reconstructions of the South Atlantic to differential stretching of conjugate margins during rift propagation. Unternehr et al. (in press), Pindell & Dewey (1982), Fairhead (in press) and Sibuet et al. (1978) question the assumption of rigid continental plates and propose that the larger plates consist of several subplates separated by deformation zones (second order plate boundaries). Unternehr et al.(in press) discuss the deformation of South America along an intraplate boundary that reaches from the Rio Grande Rise to the Andean Cochabamba - Santa Cruz bend. Conversely, Pindell & Dewey (1982), Pindell et al. (in press) and Fairhead (in press) assume a second order plate boundary in Africa along the Benue Trough.

In this paper we compare and evaluate three different published models for predrift reconstructions of the South Atlantic: The first model assumes rigid continental plates (Bullard et al. 1965, Rabinowitz & LaBrecque 1979), the second model requires intraplate deformation within South America (Unternehr et al. in press), and the third model proposes an intracontinental deformation zone within Africa (Pindell & Dewey 1982, Pindell et al. in press, Fairhead in press). After reviewing the published models we present two alternative models (Model A and B) based on a new synthesis of geologic, tectonic and satellite altimetry data. Both models imply rifting and strike slip movement in the Benue Trough and Niger Rift (Africa). In addition Model A follows Unternehr et al.'s (in press) approach and requires a strike slip zone through southern South America, while Model B implies strike slip along the Amazon basin.

Database

In order to model the intraplate deformation proposed within Africa and South America, we digitized the intracontinental plate boundaries as proposed by Unternehr et al. (in press), Pindell & Dewey (1982), Pindel et al. (in press), Fairhead (in press), Grabert (1983) and Szatmari (1983). Additional geographic and geologic information was compiled:

1. Bathymetric lines were taken from the GEBCO oceanographic survey sheets.
2. Coastlines were derived from the World Data Base (CIA).
3. Intracontinental or marginal basins, outcrops of volcanics or alkaline intrusives and tectonic lineaments such as faults, oceanic basement highs and the oceanic / continental crust boundary were based on the compilation of Emery & Utchupi (1984).
4. The contours of the West and Central African Rift System were derived from Fairhead (in press).
5. Seasat altimetry data for the South Atlantic are based on the recent tectonic fabric map of Gahagan et al. (in prep.).

Constraints used to reconstruct Africa and South America

Oceanic/continental crust boundary

One of the main constraints for refitting Africa and South America is the location of the oceanic / continental crust boundary. No attempt has been made to palinspastically restore the continental margins, however, we have attempted to take into account extension along the margins by allowing a certain degree of overlap between the two corresponding oceanic / continental crust boundaries.

Onshore geologic data

Onshore geological data constraining the fit of the continents around the South Atlantic are rare. The Precambrian Pernambuco lineament in Brazil and the Cameroon volcanic line in Africa are assumed to have a common origin (Emery & Utchupi 1984). Both features appear to have been reactivated during the initial phase of opening in the South Atlantic.

Seasat lineations

Seasat data provide a high resolution picture of the tectonic fabric of the South Atlantic (Fig.1). As viewed to the north, the blue lines delineate positive gravity gradients, and the red lines negative gravity gradients. Broad gravity gradients, mostly identified near the continental margins, are represented by hatched blue and red areas. The processing technique of the Seasat data is discussed by Gahagan et al. (in press).

Those Seasat lineations that represent tectonic flowlines, provide additional constraints for the fit of continental margins. We outline five prominent flowlines in the equatorial Atlantic and northernmost South Atlantic that can be traced from the African to the South American margin. The fracture zone flowlines that have been identified include:

1. St. Paul Fracture Zone. The western extension of the St. Paul Fracture Zone runs into the mouth of the Amazon river (A'), cutting two broad zones of geoid anomalies near the continental shelf. The eastern extension (A) intersects the African continent directly beneath Cape Palmas (Ivory Coast Basin), where it offsets broad zones of geoid anomalies and is in line with the general strike of the coastline eastwards of Cape Palmas (Fig. 1).

2. Romanche Fracture Zone. The western end of the Romanche Fracture Zone (B') is located along the southeastern boundary of the Amazon delta (Berreirinhas Basin), whereas on the west coast of Africa there is clear evidence that the fracture zone roughly bounds the northwestern edge of the Dahomey Basin (B). Both ends of the fracture zone display the same strike direction and, in addition, a broad zone of geoid anomalies off the Ivory Coast is offset by the fracture zone (Fig.1).

3. Chain Fracture Zone. The eastern extension of the Chain Fracture Zone runs into the Benue Trough of Nigeria (C), whereas the western extension intersects the Brazilian margin about 2° south of the Romanche fracture zone (C') in the Potiguar Basin (Fig. 1).

4. Ascension Fracture Zone. The western end of the Ascension Fracture Zone is interpreted to intersect the South American continent about 1° southward of the Pernambuco lineament in Brazil (D'), where it divides two broad zones of geoid anomalies to the north. This contradicts the suggestion that the Pernambuco lineament forms the continuation of the Ascension Fracture Zone (Emery & Utchupi 1984). The eastern extension of the

Ascension Fracture Zone crosses the African continental margin about 2° south of the Cameroon volcanic line (D) (Fig.1).

Broad zones of geoid anomalies

Broad zones of geoid anomalies, outlined as hatched red and blue areas in Fig.1, are common on the continental shelf and slope. Their correspondence with tectonic lineaments indicate that these geoid anomalies reflect basement blockfaulting, associated with the onshore expression of fracture zones or marginal basins parallel to the coast, that were formed during the initial stage of South Atlantic opening.

Rezende et al. (1977) describe several structural features perpendicular to the eastern Brazilian and Argentinian continental margin (normal faults with and without lateral offsets, normal fault zones with offsets, magnetic lineaments) on the basis of magnetic, gravimetric, seismic and bathymetric data. The authors suggested that these features formed as a result of transform motions that intersected the continent (Fig.1). Some of these lineaments are located between two adjacent broad zones of geoid anomalies (Fig.1, #1-9), and might reflect blockfaulted structures in the basement that were produced during the early opening phase of the South Atlantic. Urien et al. (1973) describe basins and faults trending ESE-WNW or ENE-WSW on the mid-Argentinian shelf; this agrees with the strike of geoid anomalies in this region (Fig.1).

Faulting and tilting of the basement, accompanied by extensive salt diapirism, is widespread in marginal basins along the west coast of Africa, especially adjacent to Angola. Emery et al. (1975) and Emery & Utchupi (1984) describe Aptian salt diapirism bounded by horst- and graben structures in the Gabon Basin (GB) and the Congo-Cabinda Basin (CCB) (Fig.1). The prominent geoid anomalies in these areas reflect these crustal structures. Seismic data identify steeply dipping fault blocks in the Cabinda area (Sibuet et al. 1984). In the Cuanza Basin (CB) NW-SE oriented faulting and tilting of the basement accompanied by salt diapirism (Emery et al. 1975) agrees with NW-SE oriented shelf geoid anomalies in this area (Fig.1). A broad NW-SE oriented shelf geoid anomaly situated near 11°S coincides with the Angolan Salt Basin Kink, which is controlled by basement structures (Cande & Rabinowitz 1978).

Seismic investigations south of the Oranje River (SW-Africa) reveal grabens and halfgrabens parallel or subparallel to the coast that vary in width from 2 to 35 km and that were formed during the early rifting episode (Sibuet et al. 1984). The long and broad shelf geoid anomalies parallel to the African coast in this region correspond to these basement structures. Fracture zone intersections off Ivory Coast (Fig.1: B, C), according to our interpretations, match offsets in broad zones of geoid anomalies in this area very well.

Review of Published Models

Rigid plate model

Bullard et al. (1965) propose a predrift reconstruction of the South Atlantic, in which the 500 fathom isobaths of Africa and South America (1 fathom = 1.83m) were fitted by assuming both continents behaved as rigid plates. Rabinowitz & LaBrecque (1979) used the oceanic / continental crust boundary interpreted from isostatic gravity anomalies and the associated magnetic edge effect anomalies to derive an improved reconstruction of the predrift situation between Africa and South America. Their model also implies rigid plate behavior and minimum stretching of continental crust during the early opening of the southern South Atlantic. For the early opening phase, Rabinowitz & LaBrecque (1979) determined two rotation poles. The resulting reconstruction satisfies geophysical data as well as the geological setting north of the Rio Grande - Walvis Ridge area, and aligns the seaward edges of the salt boundaries off Brazil and West Africa very well. However, in the reconstruction of Rabinowitz & LaBrecque (1979) there are large overlaps of the continental margins in the equatorial Atlantic. Furthermore the Rabinowitz & LaBrecque (1979) fit results in a misfit between the Guinea Plateau and the Demarara Plateau, and requires major shortening (100 km) between Ivory Coast (Africa) and the northernmost Brazilian margin during the earliest phase of opening (131.5 Ma to 110 Ma). No geologic evidence has been found to support this phase of compression (Unternehr et al. in press).

Two plates in Africa

According to Jones (1987), neither the fracture zone pattern nor seismic stratigraphy of the deepwater sediments permits a gap between the African and Brazilian margins as seen in Bullard et al.'s (1965) fit of the continents around the South Atlantic. Thus to eliminate the gap between the northern Brazilian (Demarara plateau) and Guinean margin (Guinea plateau) and to avoid an early shortening phase between the Ivory Coast (Africa) and the northernmost Brazilian margin, Pindell & Dewey (1982), Pindell et al. (in press) and Fairhead (in press) tried to improve the South Atlantic fit by assuming post-Jurassic intracontinental deformation zones. Deformation is thought to have occurred in Africa via the Benue Trough of Nigeria (Pindell & Dewey 1982), which is considered to be a failed arm of a triple junction that was situated on the site of the present Niger Delta (Burk et al. 1971, Burk & Dewey 1974).

According to Fairhead (in prep.), the Benue Trough is a sinistral wrench fault zone consisting of a series of *en echelon* basins (Fig. 2), that shows a thick succession of marine Cretaceous (Aptian) to younger (Maastrichtian?) sediments. Deformation of these sediments occurred during a Santonian folding event shortly before Chron 34. Further to the Northeast, geophysical studies and hydrocarbon exploration activities revealed the Gongola Rift and the Niger Rift (Fig. 2). These structures are thought to be inland extensions of the Benue Trough that are blanketed by a thick cover of Cenozoic sediments (Fairhead in press).

The tectonic model derived by Fairhead (in press) mainly consists of wrench faults diverging from the Gulf of Guinea into Africa, that are transformed into major extensional basins perpendicular to the direction of shearing. Thus, the Benue Trough acted as a major sinsitral wrench fault and gave rise to a NNW-trending extensional basin in the Lake Chad region (eastern Niger). The implied ca. 60 km of extension for the eastern Niger Rift reflects the approximate magnitude of the sinistral shear movement within the Benue Trough.

Assuming a plate boundary zone between NW and SE Africa, Pindell & Dewey (1982) imply that the northwestern part of Africa and South America behaved as one plate until the equatorial Atlantic opened after Chron M0 (118.7 Ma). They apply the rotation pole of Rabinowitz & LaBrecque (1979) for the M0 closure of the equatorial Atlantic (Lat. 55.1°, Lon. -35.7°, angle 50.9°). This reconstruction results in a very tight fit that overlaps the Guinea and Demarara Plateau and matches our proposed fracture zone flow lines fairly well. In order to close the southern South Atlantic, Pindell & Dewey (1982) rotate the southwestern subplate of Africa 8 degrees clockwise about a stagepole situated at Lat 19°, Lon 2° (Fig. 3).

This rotation results in a considerable overlap of South American and African coastlines south of the Benue Trough. The model also requires a sinistral motion along the Benue Trough accompanied by a small amount of extension in the western part of the Benue Trough. Although the required deformation is supported by recent geological and geophysical data (Fairhead in press), the predicted compressional deformation in North Africa and in the eastern part of the Benue Trough is not supported by any geological evidence. Furthermore, this predrift fit implies a mismatch between the Pernambuco lineament (South America) and the Cameroon volcanic line (Africa), which are assumed to have represented a continuous feature before breakup (Emery & Utchupi 1984). Though the model of Pindell & Dewey (1982), Pindell et al. (in press) and Fairhead (in press) leaves open questions and is not in accordance with all geologic data, the implication of an intracontinental deformation zone in the Benue Trough improves the overall predrift fit around the South Atlantic.

Two plates in South America

In order to solve the predrift misfit problem of the South Atlantic, Unternehr et al. (in press) consider a second order plate boundary within South America. According to Sibuet et al. (1984), the Parana Basin of South America, the Torres Syncline, parts of the eastern Walvis Ridge and the Kaokoveld region of Namibia form a volcanic feature that was originally continuous (Fig.4). It was created in a continental domain between 148 and 110 Ma with maximum volcanic activity between 130 and 120 Ma (Berriasian - Valanginian) (Sibuet et al. 1984). This volcanic structure may represent a failed rift on the South American plate (100 km of N-S extension) that was active during the late Jurassic and early Cretaceous (Sibuet et al. 1984).

Unternehr et al. (in press) propose an intraplate deformation zone (second order plate boundary) within South America, which is in line with this proposed failed rift and extends through the South American Parana and Chacos Basins to the Andean Cochabamba - Santa Cruz Bend (Fig.5). Direct geological evidence for this strike slip movement is obscured by widespread basalt flows which cover the area. Unternehr et al. (in press) outline the following arguments for the proposed intraplate boundary:

1. The proposed second order plate boundary lies in line with the marginal limbs of the Rio Grande Rise and Walvis Ridge.
2. The deformation is considered to have occurred during the initial phase of opening of the southern domain of the South Atlantic (south of the Walvis Ridge - Rio Grande Rise line), which is in good temporal agreement with the Parana volcanic episode about 120 Ma (Barremian) (Campos et al. 1974). Thus, the motion between the northern and the southern South American subplates would be synchronous with or shortly pre-date the early opening of the entire South Atlantic. The movement is assumed to have finished before the Albian (Unternehr et al. in press).

3. The dextral displacement of 150 km between the two South American subplates is in good accordance with the general southwesterly motion of southern Gondwana (Australia, India, Antarctica) with respect to northern Gondwana (Africa and northern South America) (Unternehr et al. in press).

The movement of the southern South American subplate with respect to the northern one eliminates the gap between the southern South African margin (Agulhas Fracture Zone) and the northern South American margin (Falkland Fracture Zone) seen in reconstructions of Bullard et al. (1965), Rabinowitz & LaBrecque (1979), Pindell & Dewey (1982).

Model A and B

In the following section we summarize what we believe to be the most important constraints for the predrift reconstruction of the South Atlantic. Rigid plate models for Africa and South America inevitably result in fit reconstructions with either a large gap between the continental margins of the Guinea and Demarara Plateau or a gap in the southern South Atlantic. If the assumption of rigid plates is used then a considerable overlap of African and South American coastlines is required in order to achieve a reasonable fit. Neither the described gap nor large overlaps of coastlines can be justified on geologic or tectonic grounds. Different lines of evidence suggest that intraplate movements within Africa and South America have occurred during the Early Cretaceous. Geologic data strongly support rifting and sinistral strike-slip movement in the Benue Trough as well as rifting in the Niger Rift (Fairhead in press). Rifting and dextral strike slip movement is inferred to have been active within southern South America (Sibuet et al. 1984, Unternehr et al. in press), although geologic evidence for strike slip motion in this area is not conclusive. According to Grabert (1983) rifting and sinistral shear movement might have occurred in the Jurassic and early Cretaceous along the Amazon rift in northern South America, although no clear evidence for strike-slip offset is presented. By considering all available constraints for the predrift reconstruction, we develop two different models, both of which give satisfactory predrift fits but which imply different intraplate movements.

For model A we started with Pindell et al.'s (in press) pole for the M0 closure of the Equatorial Atlantic. This reconstruction results in a reasonable fit of the continental margins in the equatorial Atlantic and gives a good fit for the Guinea and Demarara plateau (Fig. 6). Northwest Africa is assumed to be rigidly attached to South America before Chron M0. We then apply a rotation (Table 3) that restores South Africa relative to Northwest Africa closing the Benue Trough. Here we followed a different approach by assuming only a small amount of rifting and strike slip (about 50 km) in the Benue Trough and the same amount of rifting in the Niger rift, being in accordance with Fairhead (in press). A minor folding phase north of the Niger rift is implied in this model, too. Tectonic movements in North Africa are assumed to have occurred between Chron M10 and M0, covering the early opening phase of the South Atlantic, when the equatorial Atlantic was still closed. After closing the Benue Trough a gap still remains in the southern South Atlantic. We close this gap by rotating southern South America about a pole that implies 150 to 200 km of sinistral strike-slip movement and around 100 to 150 km of rifting along the intracontinental plate boundary as proposed by Unternehr et al. (in press). This amount of rifting is in good agreement with 100 km of north-south extension in the Torres Syncline - Parana-Basin as suggested by Sibuet et al. (1984). Following Unternehr et al. (in press) we assume intraplate movements along this line to have ceased after Chron M0.

In our alternative model B (Fig.7) we start with the assumption that intracontinental movement between northern and southern South America is unlikely. Hence we close the South Atlantic using a pole (Table 3) that results in a reasonable fit for the continental margins south of the Benue Trough, but leaves a substantial gap between the Guinea and Demarara plateaus. The Brazilian Pernambuco lineament and the African Cameroon volcanic line as well as the marginal transforms of the Ascension Fracture Zone are well aligned in this reconstruction and there is no gap between the Falkland Plateau and South Africa. The large overlap of the oceanic / continental crust boundary in the area of the Brazilian and Angolian salt basins is probably the result of extension and errors in mapping the oceanic / continental crust boundary in this region. Emery & Uchupi (1984) define the oceanic / continental crust boundary as the seaward edge of the salt basins, which may in fact extend onto oceanic crust.

In order to close the equatorial Atlantic north of the Benue Trough, we again assume an intraplate boundary in the Benue Trough. The reconstruction pole for Northwest Africa results in a tectonic history for the Benue Trough, the character and timing of which is the same as that assumed in model A. However the implied amounts of tectonic motions are different. Here rifting in the Benue Trough is assumed to have reached 50 to 100 km, associated with left-lateral strike-slip movement of about 150 km, which gave rise to the same amount of extension in the Niger rift.

However, a remaining gap between the Guinea and Demarara Plateau cannot be closed by means of the described rotations. The gap in this model can only be eliminated by assuming shear movements along the Amazon rift as proposed by Grabert (1983). The Amazon region is characterized by an east - west striking trough covered by Paleozoic sediments (Grabert 1983) that was reactivated in early Mesozoic time by the separation of North America from Gondwana (Szatmari 1983). Jurassic basalts intruded into the Paleozoic strata support this suggestion (Grabert 1983). According to Grabert (1983) the Guyana Shield is shifted westward relative to the Brazilian Shield in the Amazon graben system.

To improve the position of the Guinea and Demarara Plateaus in our reconstruction shown in Fig.7 we rotated the northernmost South American subplate with respect to South America 300 km along a dextral shear zone in the Amazon basin. This tectonic movement is assumed to have extended from early Jurassic to early Cretaceous time (Grabert 1983), before seafloor spreading in the equatorial Atlantic was initiated. In our reconstruction we arbitrarily assume an age of 180 Ma for the beginning of shear movement.

Plate reconstructions for Chron M4 (126.5 Ma) are shown in addition to the fit reconstructions since on these maps the match of broad zones of geoid anomalies on the continental shelves can be evaluated. Fig.10 shows model A for Chron M4 (126.5 Ma), where geoid anomalies from both margins match considerably well. Model B, which is only slightly different in the South Atlantic, shows good match as well for the M4 reconstruction (Fig.11). Model A, however, shows a slightly better overall match of geoid anomalies in the southern South Atlantic.

Spreading rates and directions for the South Atlantic

Two recent plate tectonic models for the opening history of the South Atlantic since Chron M0 (Pindell et al. in press, Klitgord & Schouten 1986) are compared by calculating the resulting spreading rates and directions (Fig.8, 9) (Heubeck & Royer 1987). Ages used for all reconstructions were standardized according to the DNAG timescale (Palmer 1983). Spreading rates and directions were calculated at two points along the mid Atlantic ridge:

	Latitude	Longitude
point 1:	0.45 N	25.11 W
point 2:	39.94 S	16.70 E

Spreading rates and directions for the South Atlantic were calculated for Klitgord & Schouten's (1986) (Table 1) and Pindell's et al. (in press) (Table 2) plate tectonic models. The plate tectonic model proposed by Klitgord & Schouten (1986) (Fig.8) is characterized by rapid changes in the rate and direction of seafloor spreading.

In contrast Fig.9 shows the spreading direction and rate for the model of Pindell et al. (in press). Both lines, for the northern as well as for the southern point on the spreading axis, are nearly parallel and show a well-balanced, gradual trend from southwesterly (between Chron M0 and 34) to more westerly directions without rapid changes in spreading directions.

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Fig.1: Present-day map of the continents around the South Atlantic showing: 1. Seasat lineations (blue and red lines); 2. broad zones of geoid anomalies (blue and red hatched areas); 3. oceanic / continental crust boundary from Emery & Utchupi (1984); 4. transform directions of fracture zones (A,A' St. Paul Fracture Zone; B,B' Romanche Fracture Zone; C,C' Chain Fracture Zone; D,D' Ascension Fracture Zone); 5. transverse structures 1-9 (Rezende et al. 1977); 6. basins (GB Gabon Basin; CCB Congo Cabinda Basin; CU Cuanza Basin); 7. proposed intracontinental plate boundaries within South America (Unternehr et al. in press; Grabert 1983; Szatmari 1983) and Africa (Fairhead in press; Pindell & Dewey 1982; Pindell et al. in press); 8. tectonic lineaments (Emery & Utchupi 1984; Fairhead in press); 9. plate identification numbers 201 (mid South America); 202 (southern South America); 203 (northern South America); 701 (southeast Africa); 714 (northwest Africa).

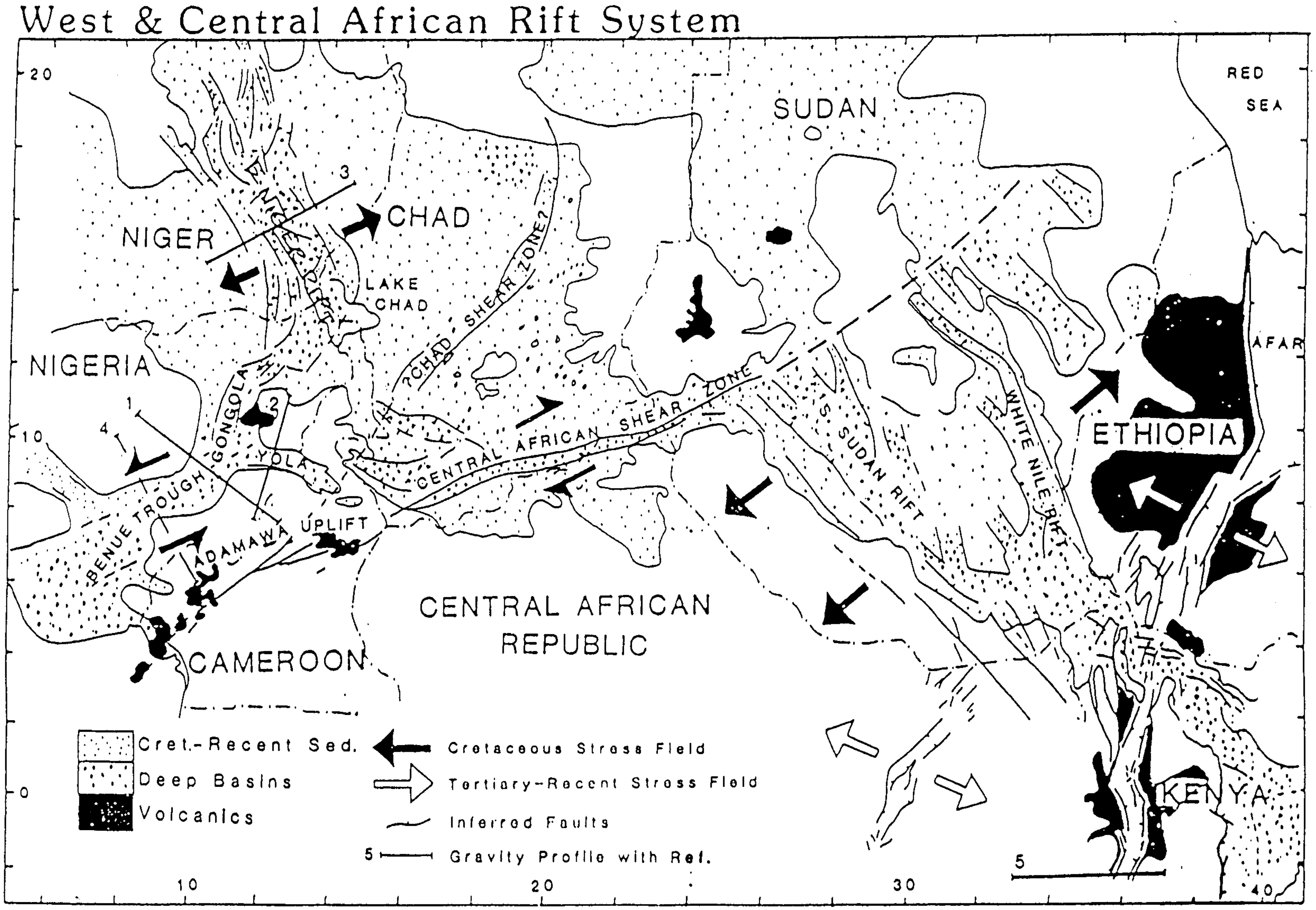

Fig.2: Tectonic model of the West- and Central African Rift System (from Fairhead in prep.).

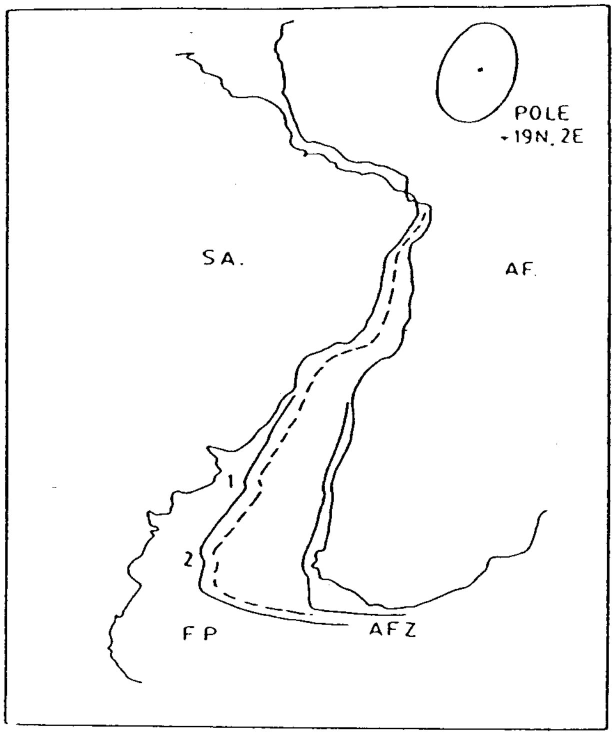

Fig.3: Difference between pre-Cretaceous and present shapes of Africa. Solid lines are present shapes of the continents and continental shelves, dashed line is proposed pre-deformational position of southern Africa with respect to South America. FP = Falkland Plateau; AFZ = Agulhas Fracture Zone: 1 and 2 are other fracture zones proposed by Rabinowitz & LaBrecque (1979). Pole position is that which defines early motion of southern Africa with respect to North-Africa - South-America (from Pindell & Dewey 1982).

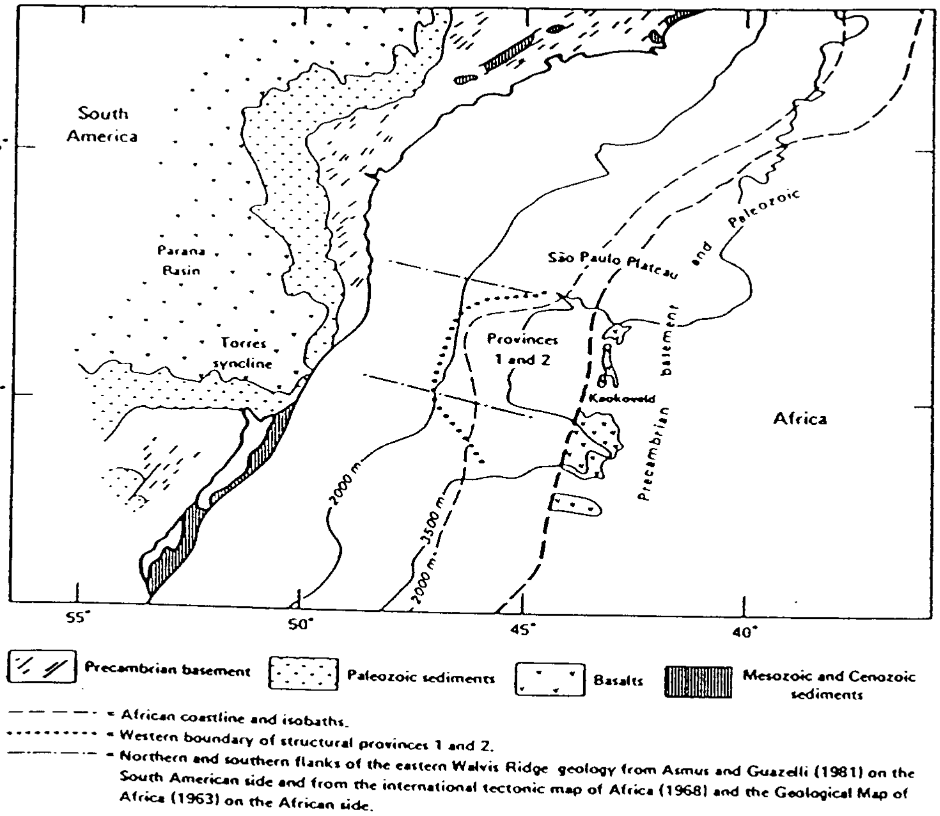

Fig.4: Initial reconstruction of the continents using the Bullard et al. (1965) fit in the area of the Parana Basin, Torres syncline, structural provinces 1 and 2 of the eastern Walvis Ridge, and Kaokoveld region (from Sibuet et al. 1984).

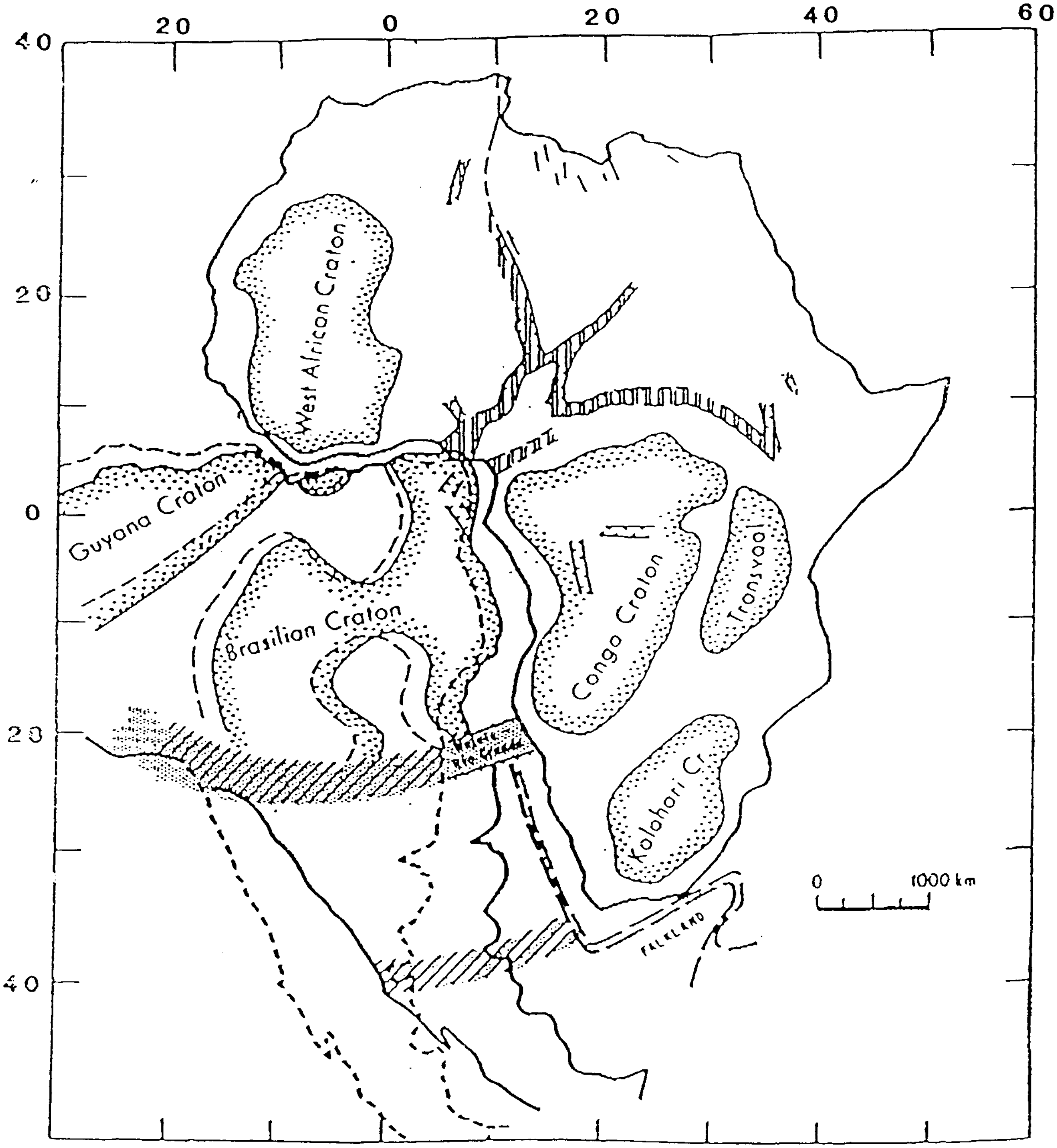

Fig.5: Initial fit from Curie (1983) showing Africa in its present position and shape. The hatched line delineates the position of South America after relative motion between the northern and southern subplates has taken place along the proposed Parana - Cochabamba second order boundary (shaded area), whereas, the solid line outlines the pre-deformational position of the southern subplate of South America. The second shaded area north of the Falklands shows another possible second order plate boundary, which is not discussed here (from Unternehr et al. in prep.).

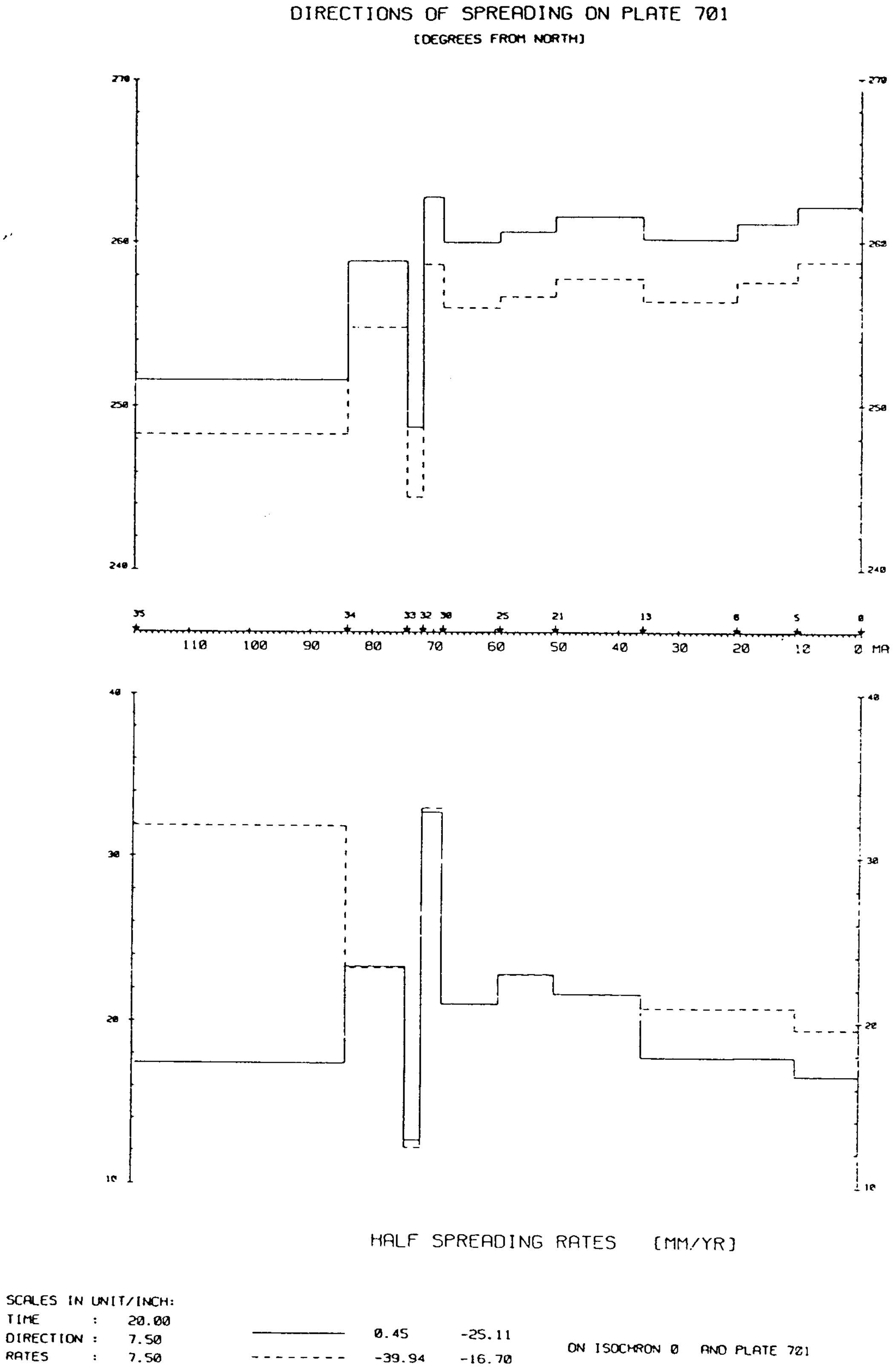

Fig. 8: Histograms showing the spreading rates and directions according to the plate tectonic model for the South Atlantic of Klitgord & Schouten (1986).

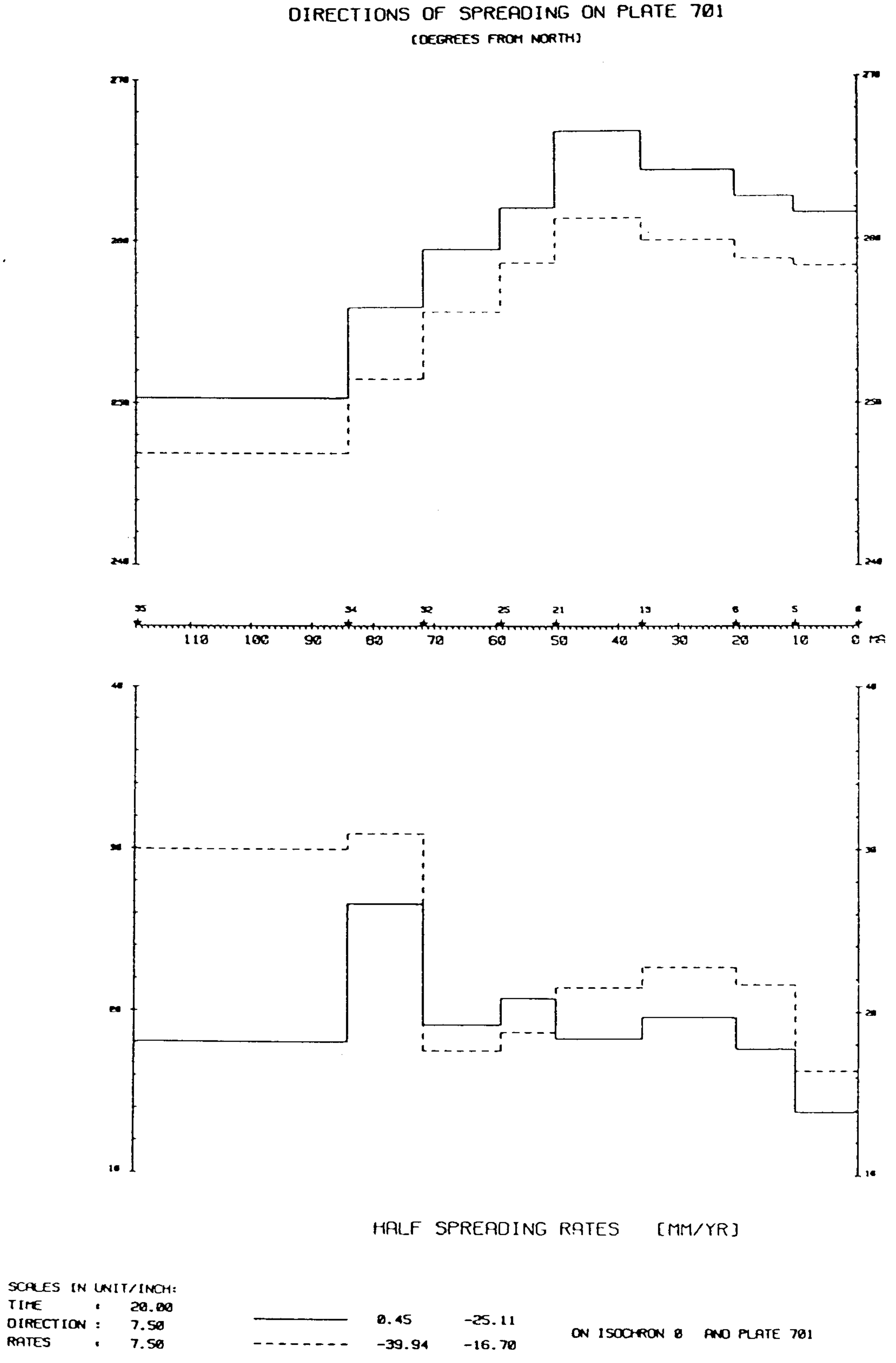

Fig. 9: Histograms showing the spreading rates and directions according to the plate tectonic model for the South Atlantic of Pindell et al. (in prep.).

Tab.1: Finite rotation poles for the South Atlantic plate tectonic model of Klitgord & Schouten (1986). From left to right: chron; age in million years; latitude, longitude of rotation pole; angle of rotation. For plate 701 (Africa) stage poles are calculated for the time-interval between two adjacant anomaly lineations. From left to right: Chron 1; Chron 2; ages 1 and 2; latitude, longitude of rotation pole, angle of rotation; distance of point, where spreading rates and directions are calculated, from rotation pole; spreading rate; spreading direction.

```
MOB. plate: 201, REF. plate: 701

Data points where directions & rates of spreading are calculated :

  2    0.45 -25.11 -39.94 -16.70

          These points are on ISOCHRON#    0   and PLATE ID# 701

Finite rotations :

    0    0.00    0.00    0.00    0.00
    5   10.60   57.40  -37.50    3.78
    6   20.50   57.40  -37.50    7.55
   13   35.90   57.40  -37.50   13.40
   21   50.30   61.16  -37.73   19.31
   25   59.20   62.59  -37.83   23.19
   30   68.40   63.56  -37.90   26.89
   32   71.70   64.00  -37.40   28.96
   33   74.30   64.12  -37.90   29.57
   34   84.00   64.84  -38.01   33.90
   35  118.70   51.78  -34.74   52.51
   38  126.50   49.33  -33.67   54.30
   44  130.20   47.53  -32.94   54.74

Stage poles for plate 701

 A1   A2     T1     DT          Lat    Lon    Angle      Dist   V   Dir    Dist   V   Dir

  0    5    0.00  10.60        57.4   -37.5   -3.78       58. -34. 262.    99. -39. 259.

  5    6   10.60   9.90        57.4   -37.5   -3.77       58. -36. 261.    99. -42. 258.

  6   13   20.50  15.40        57.4   -37.5   -5.85       58. -36. 260.    99. -42. 256.

 13   21   35.90  14.40        69.3   -42.5   -6.00       70. -43. 262.   111. -43. 258.

 21   25   50.30   8.90        69.4   -42.5   -3.92       70. -46. 261.   111. -46. 257.

 25   30   59.20   9.20        69.3   -42.4   -3.72       70. -42. 260.   111. -42. 256.

 30   32   68.40   3.30        70.1   -33.4   -2.08       69. -66. 263.   110. -66. 259.

 32   33   71.70   2.60        64.2   -64.7   -0.62       72. -25. 249.   113. -25. 244.

 33   34   74.30   9.70        69.3   -42.9   -4.35       70. -47. 259.   111. -47. 255.

 34   35   84.00  34.70        32.6   -21.3  -20.88       32. -35. 252.    73. -64. 248.
```

Tab.2: Finite rotation poles for the South Atlantic plate tectonic model of Pindell et al. (in prep.). From left to right: chron; age in million years; latitude, longitude of rotation pole; angle of rotation. For plate 701 (Africa) stage poles are calculated for the time-interval between two adjacent anomaly lineations. From left to right: Chron 1; Chron 2; ages 1 and 2; latitude, longitude of rotation pole, angle of rotation; distance of point, where spreading rates and directions are calculated, from rotation pole; spreading rate; spreading direction.

```
MOD. plate: 201, REF. plate: 701

Data points where directions & rates of spreading are calculated :

  2   0.45 -25.11 -39.94 -16.70

         These points are on ISOCHRON#    0   and PLATE ID# 701

Finite rotations :

     0    0.00    0.00    0.00    0.00
     5   10.60   56.43 -37.81    3.16
     6   20.50   55.38 -35.79    7.04
    13   35.90   57.09 -33.78   13.43
    21   50.30   57.45 -31.13   19.05
    25   59.20   60.53 -31.64   22.28
    32   71.70   63.10 -32.95   26.58
    34   84.00   61.94 -34.22   33.49
    35  118.70   52.08 -34.03   51.39

Stage poles for plate 701

 A1   A2     T1     DT        Lat    Lon   Angle      Dist    V   Dir    Dist    V   Dir

  0    5    0.00  10.60      56.4  -37.8   -3.16       57.  -28.  262.    98.  -33.  258.

  5    6   10.60   9.90      54.6  -34.1   -3.88       55.  -36.  263.    96.  -43.  259.

  6   13   20.50  15.40      59.1  -31.8   -6.40       59.  -39.  264.   100.  -46.  260.

 13   21   35.90  14.40      58.6  -24.9   -5.64       58.  -37.  267.    98.  -43.  261.

 21   25   50.30   8.90      76.4  -52.6   -3.41       78.  -42.  262.   118.  -37.  259.

 25   32   59.20  12.50      73.8  -55.2   -4.44       76.  -38.  259.   117.  -35.  256.

 32   34   71.70  12.30      57.1  -35.7   -6.94       58.  -53.  256.    99.  -62.  251.

 34   35   84.00  34.70      36.2  -24.7  -19.21       36.  -36.  250.    77.  -60.  247.
```

Tab.3: Finite reconstruction poles of model A and model B for the following African and South American subplates: SE-Africa (701); NW-Africa (714); northern South America (203); mid South America (201); southern South America (202).

```
MODEL A

ID#  AGE    LAT.     LON.   ANGLE ID#
201 118.7  52.08   -34.03  51.39 701   ! SAM-AFR M0
201 131.5  50.57   -32.02  53.00 701   ! SAM-AFR M10-N

202 118.7   0.00     0.00   0.00 201   ! SWSAM-NESAM M0
202 131.5  18.22   -50.41   3.21 201   ! SWSAM-NESAM M10-N

714 118.7  52.08   -34.03 -51.39 201   ! NWAFR-SAM M0
714 131.5  52.08   -34.03 -51.39 201   ! NWAFR-SAM M10-N


MODEL B

ID#  AGE    LAT.     LON.   ANGLE ID#
714 118.7  47.82   -31.45 -52.68 201   ! NWAFR-SAM M0
714 180.0  47.82   -31.45 -52.68 201   ! NWAFR-SAM

201 118.7  47.82   -31.45  52.68 701   ! SAM-AFR M0
201 131.5  45.71   -29.20  55.78 701   ! SAM_AFR M10-N
201 180.0  45.71   -29.20  55.78 701   ! SAM_AFR

202 118.7   0.00     0.00   0.00 201   ! SWSAM-NESAM M0
202 180.0   0.00     0.00   0.00 201   ! SWSAM-NESAM

203 118.7   0.00     0.00   0.00 201   ! NWSAM-NESAM M0
203 180.0  50.00   -81.00   3.90 201   ! NWSAM-NESAM
```