SEISMIC REFLECTION PROFILING AND BASEMENT TOPOGRAPHY IN THE SOMALI BASIN:
POSSIBLE FRACTURE ZONES BETWEEN MADAGASCAR AND AFRICA

Elizabeth T. Bunce
Department of Geology and Geophysics, Woods Hole Oceanographic Institution
Woods Hole, Massachusetts 02543

Peter Molnar
Department of Earth and Planetary Sciences, Massachusetts Institute of Technology,
Cambridge, Massachusetts 02139

Abstract. Continuous seismic profiling in the western Somali Basin reveals basement topography aligned approximately north to south. We interpret three buried ridges, approximately 50 km apart, approximately parallel to the Davie Ridge in the Mozambique Channel, as fracture zones along which Madagascar moved away from Africa. These data therefore support the northern paleopositions of Madagascar suggested by du Toit [1937] and Smith and Hallam [1970]. The ridges seem to provide an eastern barrier to sedimentation. The basement topography forming these fracture zones has a different origin from that of Chain Ridge.

Introduction and Background

We present 2920 km (1520 nm) of continuous seismic profiles in the Somali Basin obtained by the R/V Atlantis II in April and May 1976 on the tracks shown in Figure 1. We then interpret the basement topography in terms of approximately north-south trending fracture zones.

One of the original motivations of this study was to examine the basement topography for evidence that would constrain the relative movements of Madagascar and Africa. The three most commonly cited positions for Madagascar are against Somalia [e.g., du Toit, 1937; Smith and Hallam, 1970], against Mozambique [e.g., Flores, 1970], or its present position [e.g., Tarling, 1971]. (See Heirtzler and Burroughs [1971] or Emberton and McElhinny [1975] for a review of this controversy.) Heirtzler and Burroughs [1971] showed that the north trending Davie Ridge between Africa and Madagascar is a continuous feature and suggested that it is an old fracture zone along which Madagascar moved south from Somalia. If this interpretation were correct, then parallel structures might exist north of Madagascar.

On an east-west profile, Schlich et al. [1972] found that the basement depth and sediment horizons abruptly changed near a prominent topographic feature at about 3°30'S, 47°15'E. They suggested that this feature might in fact be the southern extension of Chain Ridge (Figure 1). This same feature is clear also on the profile made by the GLOMAR Challenger on leg 25 of the Deep Sea Drilling Project [Schlich, 1974b] slightly to the north. Moreover, Fisher et al. [1968] had correlated a prominent magnetic anomaly on four east-west profiles across the Somali Basin. This correlation implied an approximately north-south linear source of the anomalies. Burroughs [1975] noted that one of these magnetic signatures is associated with basement topography similar to that found by Schlich et al. [1972]. He further suggested that Chain Ridge extends nearly to the north end of Madagascar, although no recognizable magnetic pattern can be associated with the Chain Ridge north of 2°N. With these hypotheses in mind, we set out to examine the continuity of this apparent basement ridge of Schlich et al. [1972] and Burroughs [1975] and to establish its relationship to Chain Ridge.

We find that the general grain of the basement topography in the Somali Basin is north to south and parallel to the Davie Ridge, although the question of continuity of any single ridge with Chain Ridge is moot. These data support the inference that Madagascar once lay next to Somalia. In retrospect this result is not so surprising, since recent paleomagnetic studies seem to have established this already [Emerton and McElhinny, 1975; McElhinny and Emerton, 1976; McElhinny et al., 1976]. Nevertheless, the interpretation of the basement topography in terms of fracture zones allows us to be more precise in reconstructing the relative positions of Africa and Madagascar than paleomagnetic data alone allow or than was suggested by Smith and Hallam [1970].

Seismic Reflection Profiles

Profiles and line drawings are shown in Figures 2a and 2b for segments of the ship track in Figure 1. We interpret the basement topography as indicating three nearly north-south trending ridges, apparently aligned on an echelon and approximately 50 km apart (Figure 3). This interpretation is based in part on the bathymetric chart of this region of Fisher et al. [1968]. Although the region is an abyssal plain, Fisher's chart shows several isolated peaks, usually defined by only one crossing and never more than two. These 'peaks' are plotted in Figure 3 and are clearly part of the linear topographic highs seen on the continuous seismic profiles (Figures 2a and 2b).

Perhaps more important, the depth of water changes at the inferred ridges; ocean floor is shallower on the west side. This is particularly clear at the westernmost and central ridges (profiles 21-23 and 24-27 in Figures 2b and 2a respectively). If the sea floor relief were due solely to isolated seamounts, the difference in

Copyright 1977 by the American Geophysical Union.

Paper number 780736.
depth would probably be less marked. Ridges, however, would act as a barrier to sedimentation from the west and therefore cause such changes in ocean depth.

We think that the seismic stratigraphy also supports the inference of nearly north-south ridges. Lapping up onto the westernmost ridge (ridge #D) is a very clear reflector (profiles 21-23 in Figure 2b). This reflector is not apparent on the east side. If the topographic features onto which it laps were isolated seamounts and not continuous, the reflector would probably be seen on both sides. There would be no natural barriers. The origin of this sedimentary horizon is beyond the scope of this paper, but its westward dip is probably depositional and not due to later tectonic activity, again because of its absence to the east.

For each of these ridges the shallowest basement lies at a different latitude. The westernmost ridge cannot be traced north beyond about 1°N, and the easternmost ridge is not obvious near 2°N (profile 27) or south of it (Figure 2a). It is conceivable that there are additional ridges southwest of the surveyed region.

As these three ridges are nearly parallel to the Davie Ridge, following Heirtzler and Burroughs [1971], we consider them to be fracture zones and refer to them as the Dhow, the very large crude carrier (VLCC), and the auxiliary rescue and
Fig. 2a. Profiles 24–29 of Figure 1. Inferred ridges are designated by arrows and letters A (ARS), V (VLCC), and D (Dhow). Line drawings are tracings of the records; ticks along base line are 15-min intervals on records and 1-hour intervals on tracings; distance covered along the ground varies with track speed and direction for equal time increments; an average scale is one interval approximately equal to 50 km (30 nm.).
Fig. 2b. Profiles 18-23 of Figure 1, otherwise the same as Figure 2a.
salvage (ARS) fracture zones after three important types of ships that have sailed these waters. Dhows are Arab merchant ships that sailed and continue to sail south along the coast of Africa during the winter monsoon and back north during the summer monsoon. See Villiers [1940] for more details. VLCC's are the enormous (>10^8 tons) ships that travel at high speeds (>55 km/hr) through the Somali Basin carrying oil from the Middle East around the Cape of Good Hope and generating much noise on the seismic records. See Mostert [1975]. ARS is a Navy ship designation, of which an example is the R/V Chain.

Although magnetic anomalies were measured continuously along all tracks, the region was notably quiet. Chain Ridge is known for producing no magnetic signature [Bunce et al., 1967], and the buried ridges could not be associated with any characteristic anomaly. Thus the anomalies mapped by Fisher et al. [1968] do not appear to continue northward. The south-southwest track between segments 29 and 31 also was quiet and did not indicate a western extension of anomalies 24-28 north of the Seychelles, mapped by Fisher et al. [1968] and McKenzie and Sclater [1971].

Relative Motions of Madagascar and Africa

The tectonic setting of this region at the time of formation of these fracture zones was
probably similar to that in the Gulf of California now. Madagascar moved south, away from the Somali coast of Africa, along a system of short spreading centers and long transform faults. The spacing between the proposed fracture zones is similar to that in the Gulf of California [Rusnak et al., 1964]. Fracture zone topography is usually a maximum near the spreading center and decreases from it with the age of the ocean floor [Menard and Atwater, 1969]. Thus in a system of closely spaced fracture zones that successively offset the spreading center in the same direction, the areas of greatest relief on adjacent fracture zones will also be offset from one another. We think that the apparent en echelon arrangement of the ARS, VLCC, and Dhow ridges resulted from such a configuration of fracture zones and spreading centers at the time that spreading ceased.

The timing of the relative motions of Madagascar and Africa is poorly constrained, since magnetic anomalies between them have not been identified. Drilling in the Somali Basin indicates that ocean floor existed in the middle Cretaceous [Schlich et al., 1974]. Madagascar must have separated from Africa before this time. Thus the opening here predates the creation of ocean floor to the east [McKenzie and Sclater, 1971; Schlich, 1974a] and to the south [Bergh and Norton, 1976]. Paleomagnetic data imply that Madagascar and Africa were contiguous from the Carboniferous to Middle Jurassic [Embleton and McElhinny, 1975; McElhinny and Embleton, 1976; McElhinny et al., 1976]. Using the strikes of the Davie Ridge and the Dhow, VLCC, and ARS fracture zones, we calculated a pole at 7°S, 109°E. The latitude of the pole is well constrained to within a few degrees, but the longitude is very uncertain. This pole differs from that of Smith and Hallam [1970] for the total motion of Madagascar and Africa. If one uses our pole for entire opening, the calculated initial positions of Madagascar and Africa leave a large gap between the coast of Kenya and the west coast of Madagascar, as in fact, the Smith-Hallam fit does also. Thus our pole should not be used to reconstruct the two continental fragments to their initial relative positions. It follows, however, that if the pole at 7°S, 109°E does describe the final relative motion of Madagascar and Africa, then two stages of opening are required. In fact, the Davie Ridge does seem to trend slightly more northwesterly at its north and south ends [See Figure 1 of Schlich et al., 1974]. As the Smith-Hallam fit also leaves a narrow seaway between Madagascar and East Africa, we arbitrarily fit the two together without such a seaway. Figure 4 shows the reconstructed positions for two possible stages, and the caption gives the parameters used.

In summary, the data presented above imply two (not very different) stages of relative motion between Madagascar and Africa, and they place a constraint on the direction of relative motion in the final stage. The amount of relative motion during this stage and the initial positions shown in Figure 4 were arbitrarily chosen. Note also that the difference between these positions and those of Smith and Hallam [1970] are negligibly different for many studies, such as paleomagnetic comparisons.

The Continuity of Chain Ridge

Whether or not Chain Ridge is continuous through the Somali Basin depends to a large extent on one's point of view. The basement topography associated with what are called the Dhow, VLCC, and ARS fracture zones is much less dramatic than that of Chain Ridge proper. Yet, with imagination the apparent en echelon arrangement of these fracture zones allows one to continue Chain Ridge to the south. For hydrographic purposes or deepwater circulation, such a continuation might be meaningful.

The origin of Chain Ridge, however, appears to be different from that of the topography to its west and southwest. By the interpretation given
above, the southwest end of Chain Ridge deepens and abuts against the ARS fracture zone, which continues north beyond the southern end of Chain Ridge. Clearly, Chain Ridge is not parallel to the Dhow, VLCC, or ARS fracture zones.

A simple interpretation of this region is that Madagascar, with India attached to it, moved south from Somalia in the Mesozoic (probably Early or middle Cretaceous) to form an ocean basin. The western Somali Basin, including the region west of Chain Ridge, is a remnant of this ocean basin. Spreading presumably stopped by the middle Cretaceous. In the Late Cretaceous, India moved away from Madagascar and took with it the portion of this older basin that once lay to the east of the Dhow, VLCC, and ARS fracture zones. Chain Ridge formed next to (or was) a transform fault along which the India plate moved with respect to the Madagascar–Africa plate. The sharp contrast in basement depth across it [Bunce et al., 1966, 1967] is the result of the younger Maastrichtian age of the ocean floor to the east [Bunce and Fisher, 1974] and the presumably Early or middle Cretaceous age to the west.

Acknowledgments. We thank David Casiles and the crew and other members of the scientific party of the R/V Atlantis II for their assistance. We are especially grateful to E. Young for his patience with the Ph.D.'s on board and his willingness to help save graduate students. D. A. Johnson and G. P. Lohmann critically reviewed the manuscript. This work was supported primarily by the Oceanography Section, National Science Foundation, through grant 21522. Peter Molnar acknowledges support from grant 81903. Contribution 3950 of the Woods Hole Oceanographic Institution.

References


Villiers, A., Sons of Sinbad, 414 pp., Charles Scribner's, New York, 1940.

(Received April 4, 1977; revised June 6, 1977; accepted July 8, 1977.)