Geo-Marine Letters (1986) 5:203–209

Geo-Marine Letters
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The Tectonic Style of the Northern Red Sea

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Abstract

Multichannel seismic reflection profiles recorded in the northern Red Sea show structures that we interpret to be a result of the intrusion of uppermost Miocene salt. We believe that the evaporites are underlaid by attenuated continental crust and the flow of salt is due to renewed faulting of basement in the Pliocene when sea floor spreading began between latitudes 21°N and 15°30′N.

Introduction

In this report we present results from an investigation of the northern Red Sea from the Sinai Peninsula to about latitude 26°N. Multichannel seismic reflection profiles recorded in the area were obtained with a six-channel (each channel containing 150 elements) approximately 750 m long streamer, and a sound source consisting of a 300, 120, 80, and 40 cubic inch air guns operating at 1,850 psi and fired every 30 seconds. Signals from all channels were digitally recorded, deconvolved, and stacked. In addition to the seismic profiles, bathymetric data were obtained using 3.5 and 12 kHz transducers, and the total magnetic field was measured with a proton precession magnetometer and computed as total magnetic anomaly by subtraction of the International Geomagnetic Reference Field 1965 [1].

Bathymetry

The morphologic elements dominating the northern Red Sea area are the Red Sea proper and the Gulfs of Suez and Aqaba (Elat) separated by the Sinai Peninsula (Fig. 1). The northwest trending Gulf of Suez is the shallowest of the topographic provinces with coral reefs along its edges, and a channel in its middle which is slightly deeper than 80 m. Depths along the southeast edge of the Gulf of Suez are about 100 m. The gulf is bordered on the southeast side by an 800 m high slope that is entrenched by a northwest trending submarine canyon. The northeast-trending Gulf of Aqaba has no coastal plain (or where present is very narrow), practically no continental shelves, and steep side slopes [2]. In the center of the Gulf of Aqaba is a series of elongated *en echelon* deeps. These include, from north to south, Elat, Aragonese, Arnona (off the chart in Fig. 1), Dakar, and Tiran deeps. These northeast trending depressions extend beyond the Gulf of Aqaba, with Hume and Ras Muhammad (named in this article for Ras Muhammad in the Sinai) cutting across the topographic trend in the Gulf of Suez and the Red Sea.

Extending southeastward from this trend of depressions is the Red Sea rift. Topographically the rift can be divided into narrow shelves which are less than 50 m deep, marginal slopes with reliefs of about 600 m, and the main trough below 600 m depth. In contrast to the central and southern segments of the Red Sea, no axial trough can be distinguished in the northern Red Sea. In the northern region the central part of the main trough consists of northwest trending highs and lows truncated at the north by the Gulf of Aqaba trend. Our 3.5 kHz profiles recorded across this rough terrain show long segments where little acoustic penetration was obtained, with short segments where penetration exceeded 30 m. Where penetration occurs there is commonly some suggestion of faulting that affects the sea floor. We could not identify any morphologic feature that we could unequivocably interpret as a spreading axis in any of the profiles (Fig. 1).

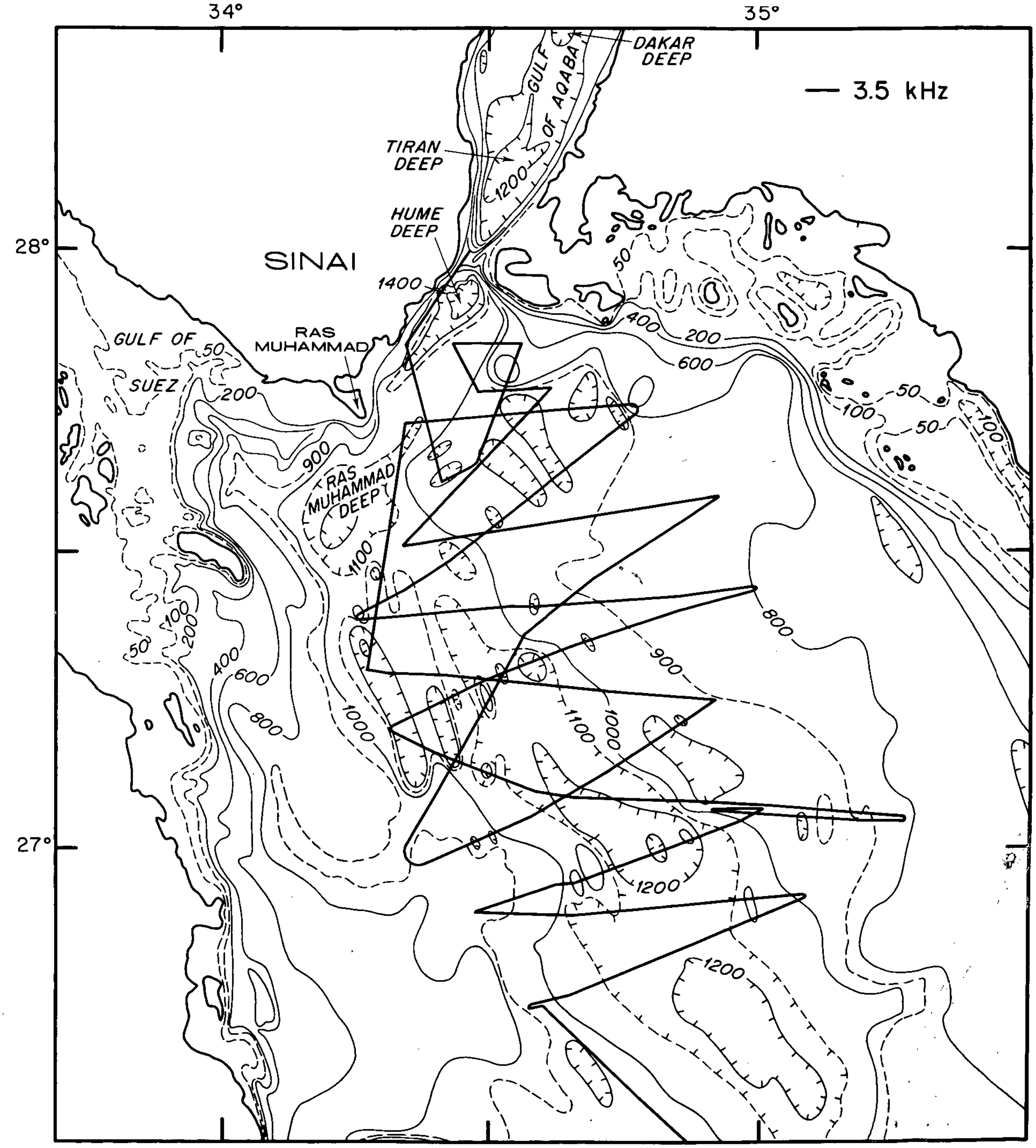

Figure 1. Bathymetric chart of the northern Red Sea region. Compiled from data obtained during the present investigation supplemented by information from Laughton, Hall, and Hall and Ben-Avraham [3–5], and U.S. Naval Oceanographic Office charts 2,491, 62,020, and 62,220 and British Admiralty chart 8. Heavy lines represent ship tracks traversed during present investigation. Contours are in meters corrected for sound velocity.

Structure

Earlier investigators described the structural elements of the northern Red Sea as elongated northwest trending horsts of crystalline basement and grabens filled by Tertiary sediments [8]. Knott and coworkers [8] stated that the deeper parts of the main trough consisted of a zone of rugged floor and intense subbottom deformation flanked by marginal zones of more gentle topography and milder deformation. Phillips and Ross [9] described the area as being dominated by thick sequences of gently folded strata. Within the folded

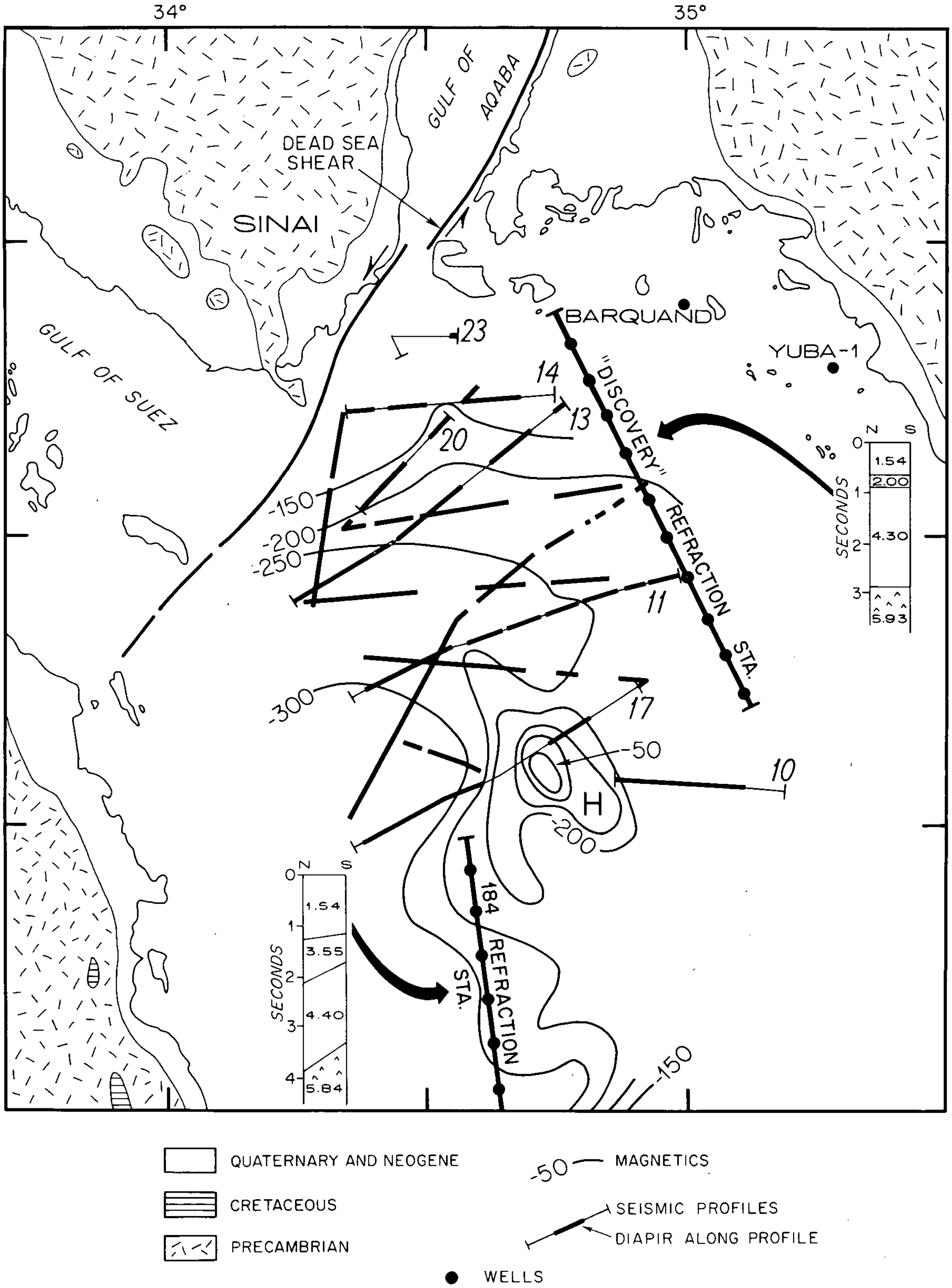

Figure 2. Tectonic map of the northern Red Sea compiled from geophysical measurements recorded during the present cruises and refraction data from Drake and Girdler [14], and Girdler [15]. Also shown are the locations of the multichannel profiles in Figures 3–6 and the wells drilled along the Saudi Arabian coast [6,7]

unit they identified a prominent horizon, Reflector S, which they believe represented a hiatus of late Miocene-early Pliocene age. They ascribe the deformation of the sediments below S and immediately above the reflector as a result of sea floor spreading that was initiated in early Pliocene. Drilling by the Deep Sea Drilling Project later showed that Horizon S marks the top of upper Miocene evaporites [10]. Deformation of the strata below S was suggested by Ross and Schlee [11] to be the result of the flow of the evaporites, a flow that may have been triggered by sediment loading or renewed faulting during the initiation of sea floor spreading 5 to 4 my ago. In a more recent study, Mart and Hall [12] noted that the northern Red Sea is marked by a series of rifts and elongated diapirs that trend northwest at the south and north toward the north. Due to this change in structural trend they postulated that tectonic extension in the area changed from northwest to north during the Pliocene.

Our multichannel seismic reflection profiles also show that the structural grain in the northern Red Sea is dominated by a series of highs and lows. However, these features may not be quite as long as proposed by Mart and Hall [12], but may be a chain of lobate structures separated by narrow troughs trending approximately east-west and northwest-southeast. Although the structures have not been sampled, lack of magnetic signature, the presence of collapse structures along some of their crests, and the occurrence of uppermost Miocene evaporites in the subsurface in the Red Sea [6,7,10] indicate that these features probably are diapiric salt structures.

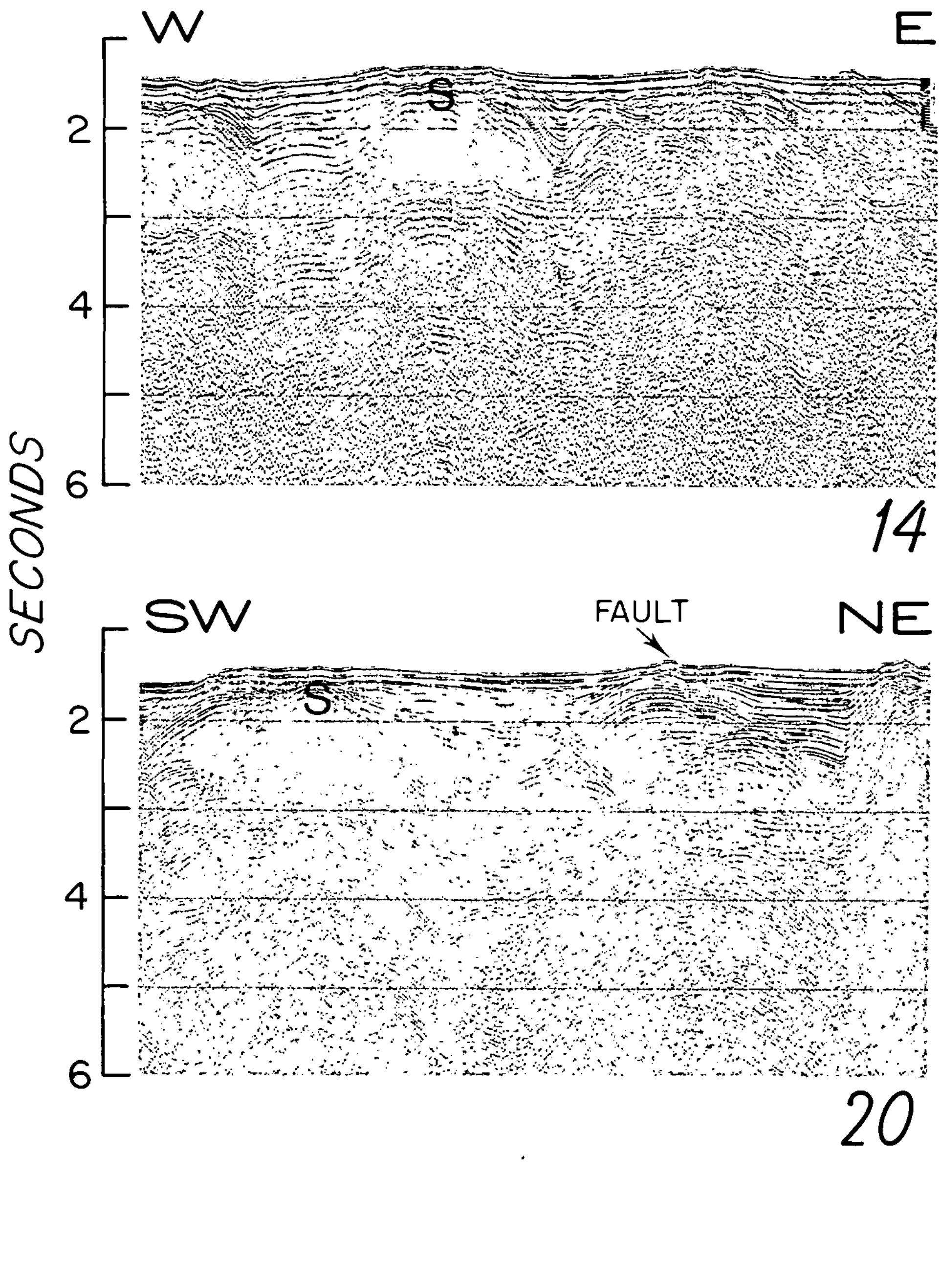

Figure 3. Seismic reflection profiles 14 and 20 of the central northern Red Sea area. See Figure 2 for profile locations. The tectonic style along these profiles is due to salt diapirism. Reflector S is the top of the Miocene evaporites.

The diapiric structures extend to the Dead Sea shear where they abruptly end (Fig. 2). However, Mart and Rabinowitz [13] have reported what they believe to be diapiric structures from the southern Gulf of Aqaba. But the seismic reflection profile recorded by us near the southeastern edge of the shear only shows a fairly well-stratified section above an undulating reflector beneath which the strata are deformed. A high at the eastern end of the profile may represent a salt diapir. The set of profiles in Figures 3 and 4 (profiles 14, 20, 13, and 11) show that deformation in the northern Red Sea ranges from block-like highs at the western end of profiles 14 and 13 to dome-like structures on most of the profiles. Profile 13 is rather unique in that it displays a collapse structure which may be the result of solution above one of the highs, and a structure with a relief of 0.5 seconds at the eastern end of the profile. Intervening between the larger diapirs are smaller folds that also may be due to the plastic mobility of the evaporites. Sediment thickness of the Plio-Quaternary sediments between the diapiric structures reach values of 1.5 seconds along some of the profiles (13, 20, 14). Thicknesses along the crests of the highs are much less, being in the order of tenths of seconds. At the crest of most highs the sea floor displays some relief which may be fault controlled or due to bottom current activity. Along profile 20 a high at the northeast end of the profile is breached by a fault that has reached the sea floor. Faulting along some segments of profiles 13 and 14 also appear to extend to the sea floor.

The structural style along the southernmost profiles (17 and 10, Fig. 5) is very distinct from the profiles to the north. Along profiles 17 and 10 the post-evaporite sequence is relatively thin, about 0.2 seconds along most of the length of these profiles. The diapirism also is more massive, consisting not of distinct relatively narrow, lobate, individual structures, but of broad tabular forms. Lack of sediment cover also indicates that sediment loading was not the cause of the mobility of the salt in this region. We believe that the flow of the salt resulted from renewed faulting in continental basement when sea floor spreading began in the Red Sea between latitudes 21°N to 15°30′N during the Pliocene.

Because of the high acoustic impedence of the

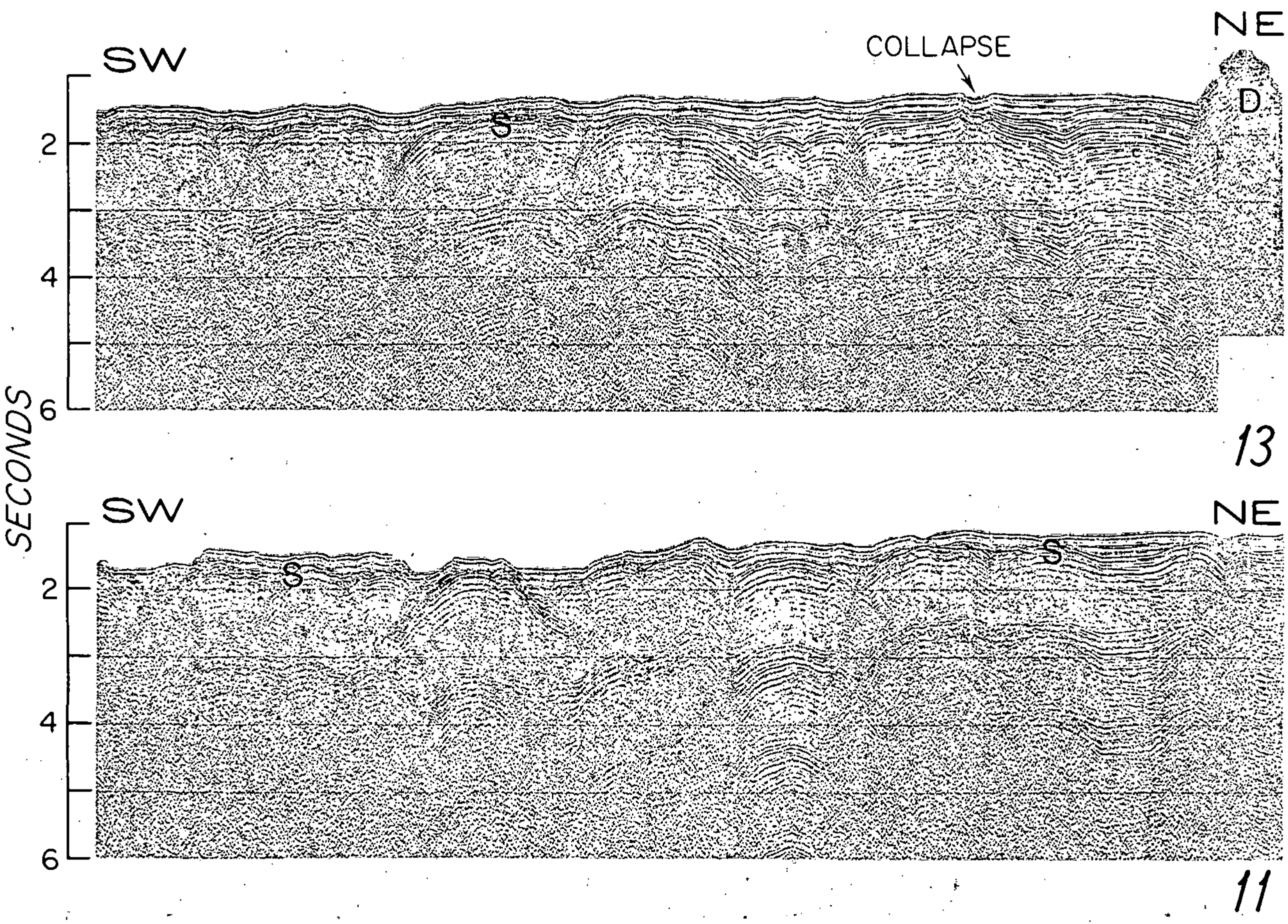

Figure 4. Seismic reflection profiles 13 and 11 in the central northern Red Sea. See Figure 2 for profile locations. Note collapse structure and diapir (D) along profile 13. Reflector S is the top of the Miocene evaporites.

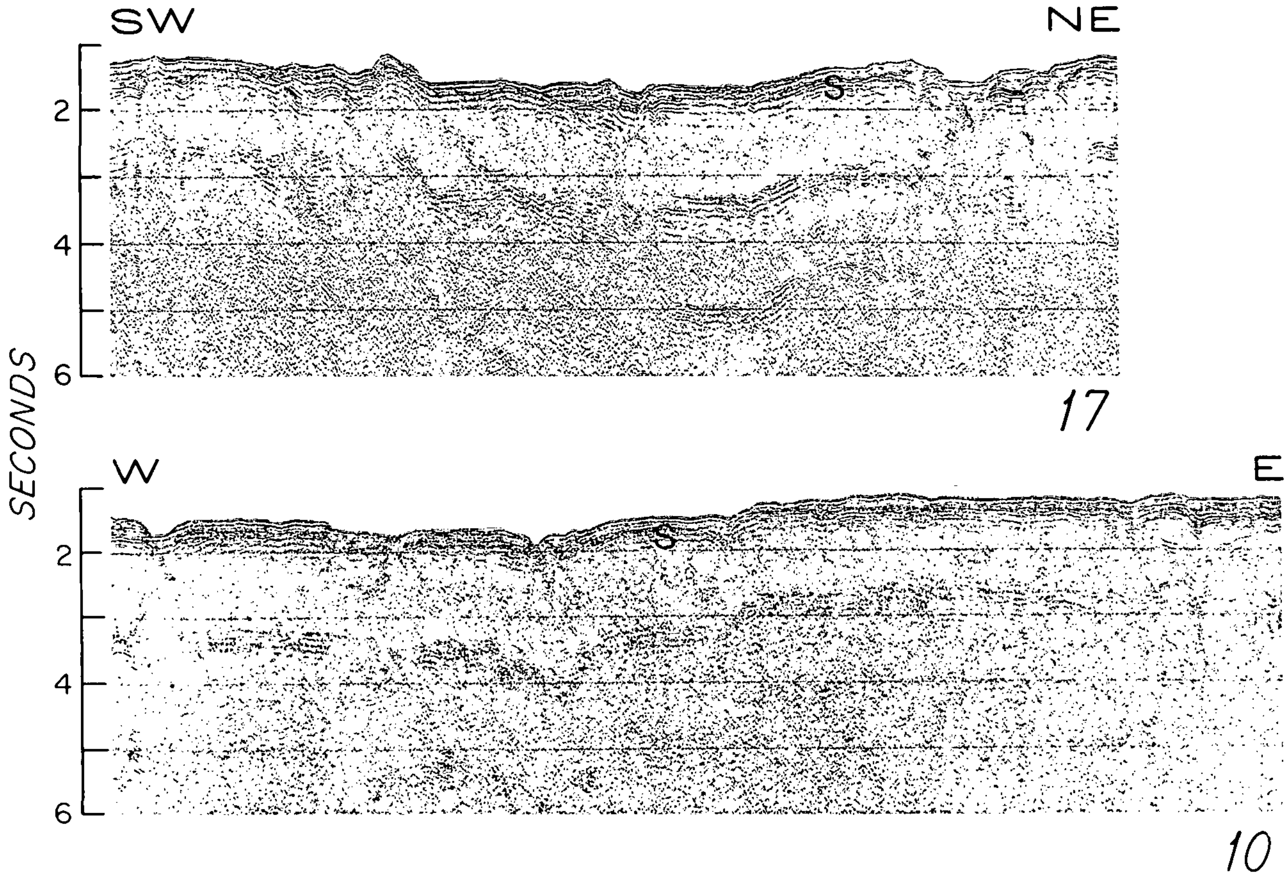

Figure 5. Seismic reflection profiles 17 and 10 along the southern end of the northern Red Sea. Diapirism along these profiles is much more massive than along the profiles in Figure 4. Reflector S is the top of Miocene evaporites. See Figure 2 for profile locations.

evaporites, none of the seismic reflection profiles recorded in the northern Red Sea display any evidence of basement. However, we believe that the Miocene evaporites are underlain by continental basement. Our reason for making such an assumption is that none of the seismic profiles display any evidence of a spreading axis as do the profiles recorded further south (see 9 and 11). Further the magnetic anomalies that characterize the region (Fig. 2) do not resemble sea floor spreading anomalies associated with oceanic crust. Their low amplitude also suggests that the diapirs themselves are not the source of the magnetic anomalies. These magnetic structures may be best explained by faulting of continental basement or individual intrusions associated with the rifting processes that formed the Red Sea. Finally the crustal structure of the northern Red Sea (Fig. 2) more closely resembles continental rather than oceanic crust with the layers with velocities of 3.55 to 4.0 km/sec representing sedimentary rocks, evaporites, and pyroclastics of probably Miocene age, and the layer with an assumed velocity of 2.00 km/sec post-Miocene unconsolidated sediments [14,15].

Conclusions

Seismic reflection profiles recorded in the northern Red Sea show that the structures in this part of the rift trough consist of oblong low relief features. These gently folded structures appear to be the result of the intrusion of Miocene evaporites. Absence of a spreading axis (mid-ocean ridge) and sea floor spreading magnetic anomalies suggest that these evaporites were deposited on an attenuated continental crust. Such an observation tends to support Cochran's [16] contention that oceanic crust in the Red Sea is of limited extent. He believes that north of latutude 25°N and south of latitude 15°30′N the Red Sea is underlain by attenuated continental crust, that from latitudes 21°N to 15°30′N oceanic crust of Pliocene and younger age is restricted to a narrow belt in the area of the spreading axis, and that from latitudes 25°N to 21°N, where continental extension is presently changing to sea floor spreading, oceanic crust is restricted to the Atlantis II, Chain, Discovery, and Shagara deeps. Mobility of the salt in the northern Red Sea may be due to renewed faulting in basement in the Pliocene as sea floor spreading began between latutudes 21°N to 15°30′N.

This conclusion differs from the one proposed by Girdler and Underwood [17]. They believe that oceanic lithosphere consisting mainly of coarse gabbroic intrusives is present in the northern Red Sea and that the lack of sea floor spreading anomalies is due to a combination of large thickness of salt, slow spreading rate, high heat flow, and slow cooling of the intrusive rocks.

Acknowledgments

We thank the officers and crew of the R/V *Atlantis II*, Keith von der Heydt, T. F. O'Brien, and D. R. Shaughnessy III who operated the multichannel system during the cruise, and D. H. Gever who processed data onshore. Drafting was done by Mrs. Ruth Davies of the Graphic Arts Department of the Woods Hole Oceanographic Institution, and typing by Ms. Prudence Stratton. We also thank D. G. Aubrey and K. O. Emery for their suggestions during the preparation of this report, and Y. Mart at the Israel Oceanographic and Limnological Research Ltd. for providing us with preprints of his articles on the northern Red Sea and the Gulf of Aqaba. Funding was received from the National Science Foundation, Grant 76-10417 and the Department of Commerce, NOAA, National Sea Grant College Program under Grant No. NA84AA-D-00033 (M/0-1). Woods Hole Oceanographic Institution Contribution No. 5861.

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Manuscript received 22 August 1985; revision received 16 October 1985.