ON THE ORIGIN OF THE RED SEA

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(Received 31st August, 1959)

SUMMARY

In spite of a number of similar features, the Red Sea differs from the African rifts in that it is accompanied by positive isostatic anomalies. Girdler has interpreted this anomaly by supposing the surge of a basic mass along the axis of the Red Sea. He thinks the negative anomalies of the African rifts to be due to a different mechanism.

Author shows that the entire rift system, the Red Sea included, may be derived from crustal tension, involving also the upper 6—700 kilometres of the mantle, which are supposed to be rigid and mechanically coupled to the crust. The crust and this part of the mantle are that part of the Earth which may be termed with right "tectonosphere". The young phase of rift formation involves a thinning of the tectonosphere layer, by fracturing near the surface, and by plastic deformation in the mantle. The thickness of the crust being small as related to that of the tectonosphere, the sialic crust will sink, thus bringing about a negative gravity anomaly.

At the same time, the plastic deformation leads to the accumulation of heat energy, resulting in the formation of a magma chamber. In the mature stage of rift formation the basic magma thus formed may surge along deep fractures in the neighbourhood of the surface, giving rise to the positive isostatic and magnetic anomalies interpreted so well by Girdler. This nature phase is encountered in the Red Sea, while the Gulf of Suez and the Gulf of Aqaba are still in the young phase.

The inspection of Fig. 1. shows the Red Sea and the African rifts to belong to one and the same contiguous rift system. The morphological similarity becomes even more marked when the proportion of smallest width to greatest depht is considered. However, gravity measurements in the Red Sea have unearthed a difference which seems to be significant, namely that there is a zone of positive isostatic anomalies along the Red Sea axis, while the rest of the African rifts are characterized by negative isostatic anomalies of 50 to 100 milligals (Fig. 2). The Gulfs of Suez and of Aqaba, which are rifts themselves, exhibit negative isostatic anomalies, in spite of being continuations of the Red Sea (Fig. 3). Airborne magnetometry in the Red Sea area has demonstrated a characteristic magnetic anomaly along the Red Sea axis.

Recently, R. W. Girdler (1) has attempted an explanation of the gravity and magnetic anomalies of the Red Sea. In a paper entitled "The relationship of the Red Sea to the East African rift system", he has shown that both gravity and magnetic anomalies can be interpreted by supposing the existence of a basic mass along the axis of the Red Sea, which has risen into the neighbourhood of, or even up to, the surface. For this reason, he deducts the origin of the Red Sea from tensile stresses in the crust, with magma masses from below the crust surging along the rift line. On the other hand, for the African rifts he considers two possibilities of different nature.

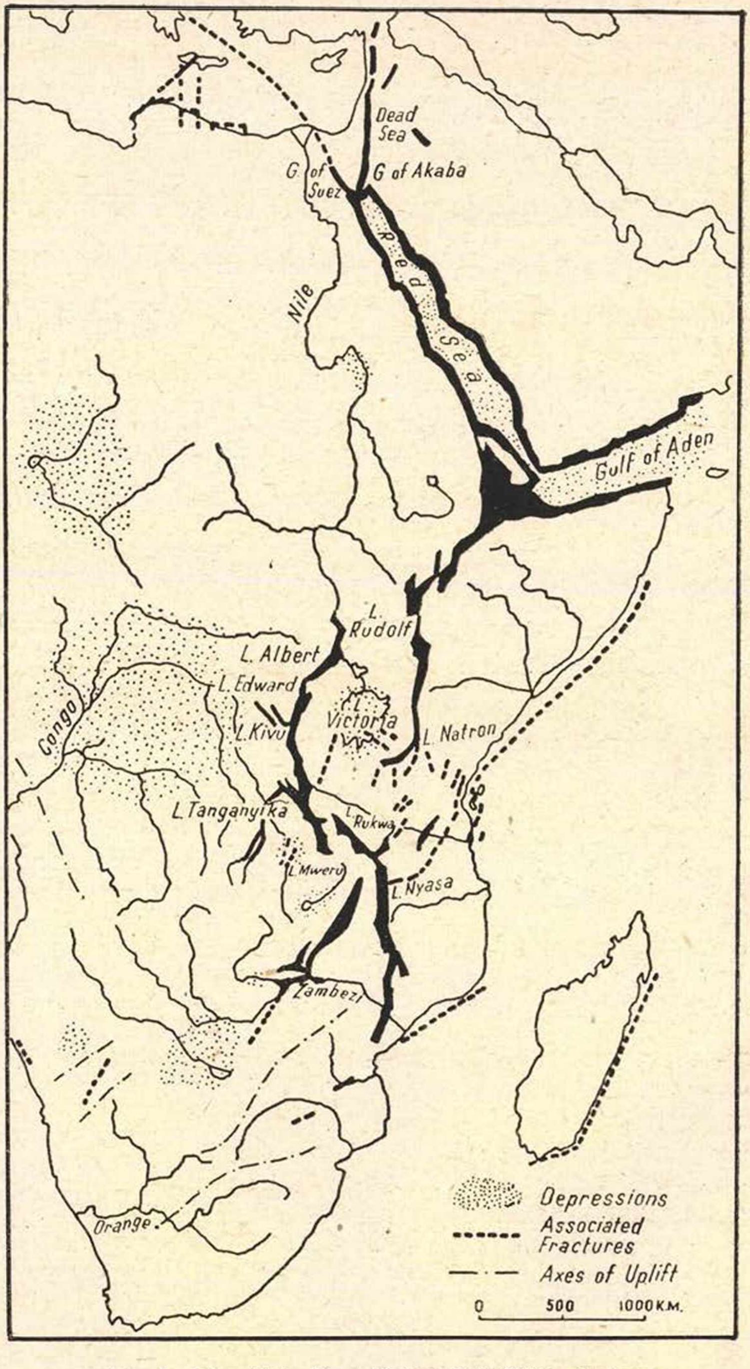

Fig. 1. Map of the East-African Rift Valley System

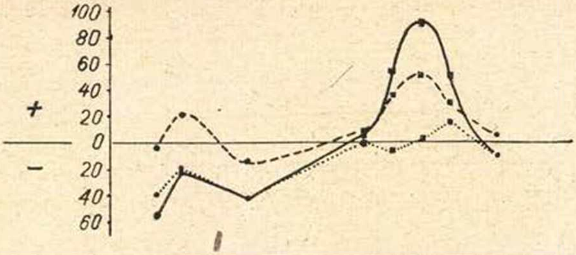

Fig. 2. Gravity anomalies across the Red Sea, after Girdler

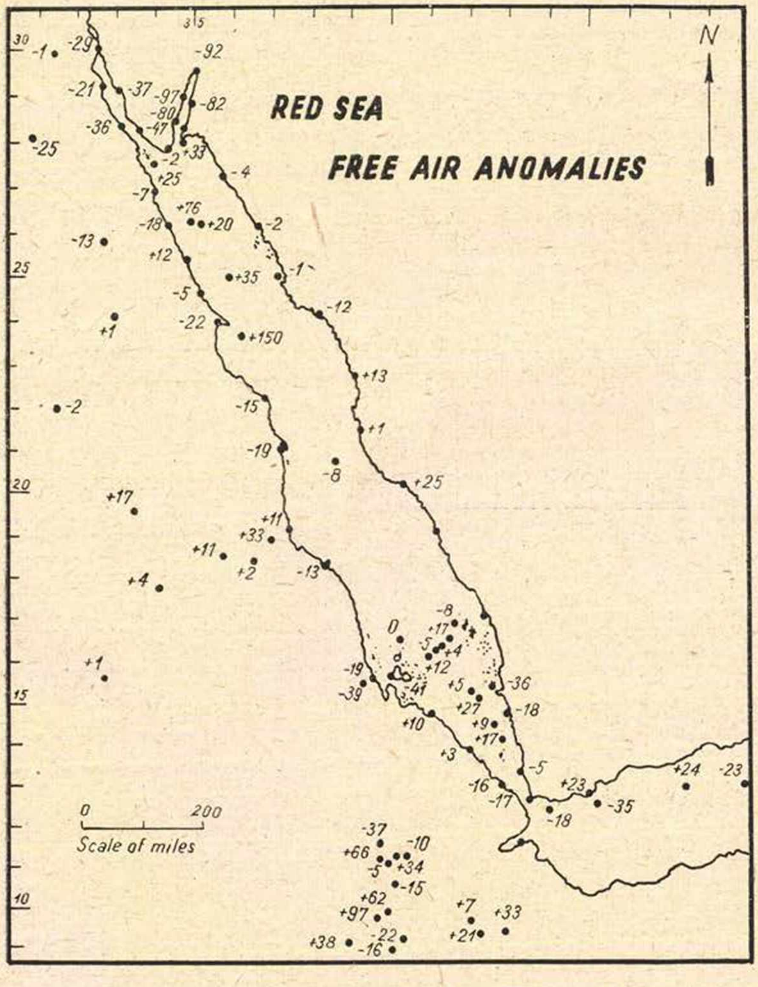

Fig. 3 Free air anomalies in the Red Sea area, after Girdler

Either the tensile stress was smaller, resulting merely in the sinking of the central blocks along the marginal rift faults, or the rifts were formed by compressive stresses along these same faults, as postulated by Bullard (2). He pays, however, due attention to the circumstance that both geologically and geophysically the Gulfs of Suez and of Aqaba are perfect counterparts of the African rifts.

In the following the present author wishes to give a more uniform and more plausible explanation of the formation of both Red Sea and African rifts, and to refute, at the same time, some generally accepted erroneous ideas on crustal structure.

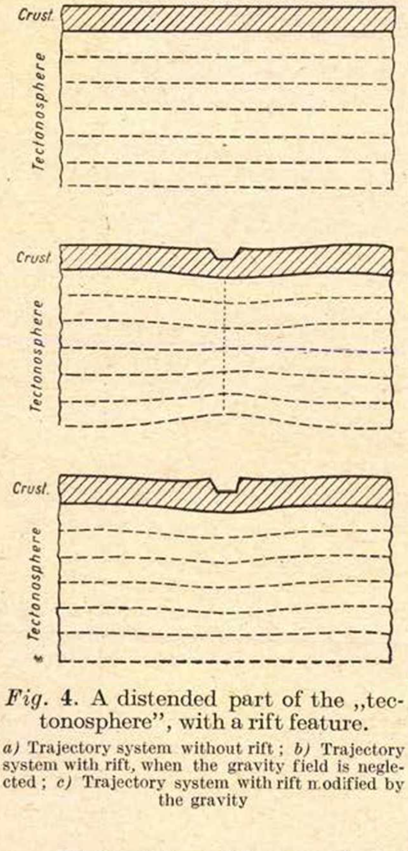

Fig. 4. A distended part of the „tectonosphere", with a rift feature.

a) Trajectory system without rift ; *b)* Trajectory system with rift, when the gravity field is neglected ; *c)* Trajectory system with rift modified by the gravity

First of all, the author would like to point out that there is no contiguous layer of latent magma beneath the crust, i. e. beneath the Mohorovičić interface, which latter is by no means a thermal boundary. Consequently, a pressure decrease in itself will not result in a melting of the magma.

To corroborate this statement, the following evidence is offered: In the areas of the continental shields (Africa, Canada, Russian Platform) the geothermal gradient is about 1 centigrade per one hundred metres (3), corresponding to a temperature of 300 to 350 centigrades in a depth of 35 kilometres. A sharper rise of temperature with depth occurs in areas of younger orogenies only. This indicates at once that the rise in temperature is due to the heat of deformation of rocks, accumulated in the poorly conductive silicates.

A subcrustal temperature of 200 to 500 centigrades was reached at by J. F. Lovering, too (4). This temperature is, however, far below the point of fusion of the silicates constituting crust and mantle.

The origin and hypocentral distribution of deep-focus earthquakes indicates that the temperature in the mantle reaches the temperature of fusion of the involved silicates in a rather great depth, of about 750 kilometres.

Furthermore, an increasing number of scientists seem to accept the proposition (4) that the Mohorovičić interface is not due to any change in chemical composition, but that it represents a pressuredependent phase transition.

All the above said leads to the unavoidable conclusion that from the point of view of crustal mechanics, crust and mantle cannot be regarded as two independent systems, with the crust gliding and swimming upon the mantle, because the crust is, in fact, closely coupled with the upper part of the mantle, of some hundreds of kilometres thickness. Therefore, the phenomena observed on the surface are the results of a play of forces upon an earth shell of such thickness. The term "tectonosphere", if correctly used, should designate this shell.

Let us consider now the problem of origin of the magmatic masses invading the terrestrial crust. It was mentioned above that in areas of more intense deformation a heat reserve is accumulated. Most of the energy of fracturing, friction and especially of plastic deformation are converted in the Earth into heat. The heat conductivity of the silicates constituting crust and mantle being very poor, the heat thus formed is accumulated with small loss. A series of appropriate deformations may raise the temperature to the point of fusion (at one atmosphere), so that in the zones of plastic deformation some nests of latent magma will come to exist. If the pressure drops, as e. g. due to the formation of a fracture, these nests will melt and rise into the upper parts of the mantle and the crust, respectively.

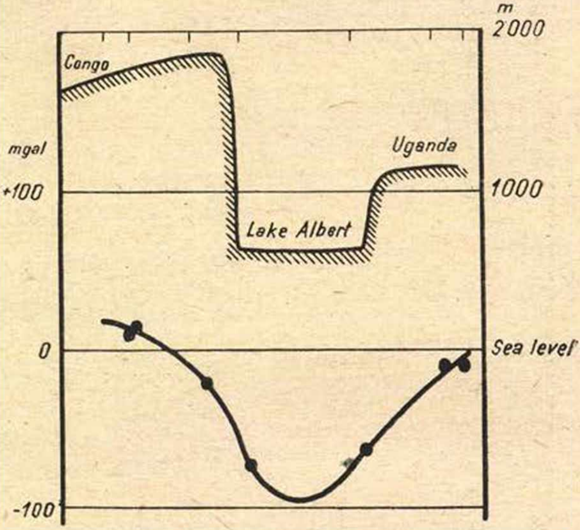

Fig. 5. Gravity anomalies over the Lake Albert Rift Valley

This concept gives a quite simple and uniform explanation for the origin of the African rifts and the Red Sea. Namely, due to tensile stresses caused by the expansion of the Earth, a zone of tension is formed in the crust of the Earth. In the first place, the uppermost rigid part of the crust is disrupted and superficial faulting occurs. As part of the profile is no more able to bear tensile stresses, the tension will increase in the cross section below the ruptured zone, and the system of trajectories shown in Fig. 4. is developed (a). Because of the presence of the gravity field, this trajectory zone is asymmetrical (b). The tectonosphere will undergo a plastic deformation, in the first place in the zone of smaller cross section, i. e. below the ruptured zone of the surface. Thus, a magma nest is gradually formed.

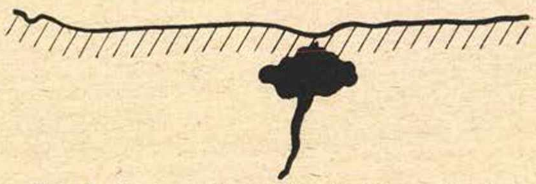

Fig. 6. Cross section of the Red Sea with the intruded magmatic mass

Thus, in the first stage a rift is formed, manifesting itself mainly in superficial morphology. The thinning — disregarding the morphologically conspicuous rift zone — is distributed in the entire tectonosphere, and only a small part of it involves the crust. Because of the asymmetry of the trajectories, the Mohorovičić interface will sink rather than rise. The size of the vertical movements is minute as related to the thickness of the tectonosphere.

When considering the distribution of the gravity anomalies we find, under the assumption of an isostatic compensation after Airy and Heiskanen, e. g. in the case of Lake Albert (depth of bottom 300 metres below the sea), a gravity deficit corresponding to a horizontal column 1,35 kilometres thick, 40 kilometres wide, situated in a depth of 35 kilometres and characterized by a density contrast of 0,6 cgs. This body gives rise to a negative isostatic anomaly of roughly 60 milligal, while the actual anomaly is 95 milligal. The difference may be due to the sediments accumulated on the bottom of Lake Albert, which assumption is corroborated, according to Girdler, by a rather sharp decrease of the anomalies in the area of the lake.

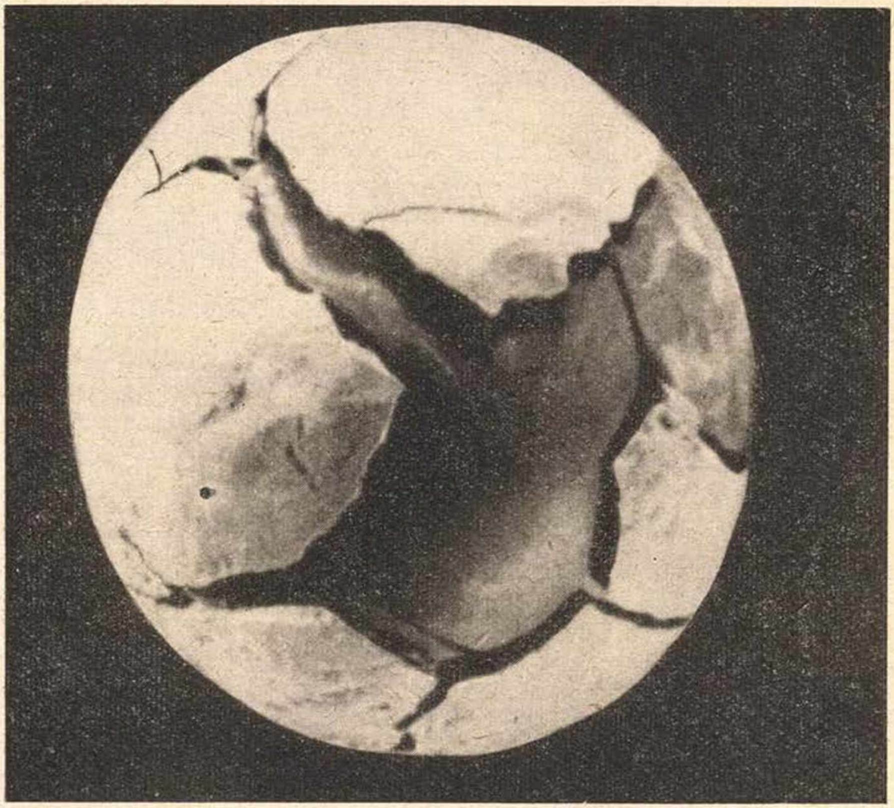

Fig. 7. The experiment of Kádár, showing Red Sea-like features

If the deformation due to tension reaches such a degree as to grant the formation of a magma nest and a deep fracture connecting the same with the surface along the axis of the rift, as seen in the case of the Red Sea, the surging melt will fill the empty space due to rifting and there is developed that complex of phenomena which was so lucidly treated by Girdler. The tension in the Gulf of Suez and Akaba region has reached the first stage only. That is why the anomalies are negative there.

The fact that morphological patterns resembling the Red Sea can come to exist in a crust subjected to tensile stresses was beautifully illustrated by experiments of L. Kádár, which consisted in the cracking of a plaster of Paris shell smeared on a balloon by inflating the same (5).

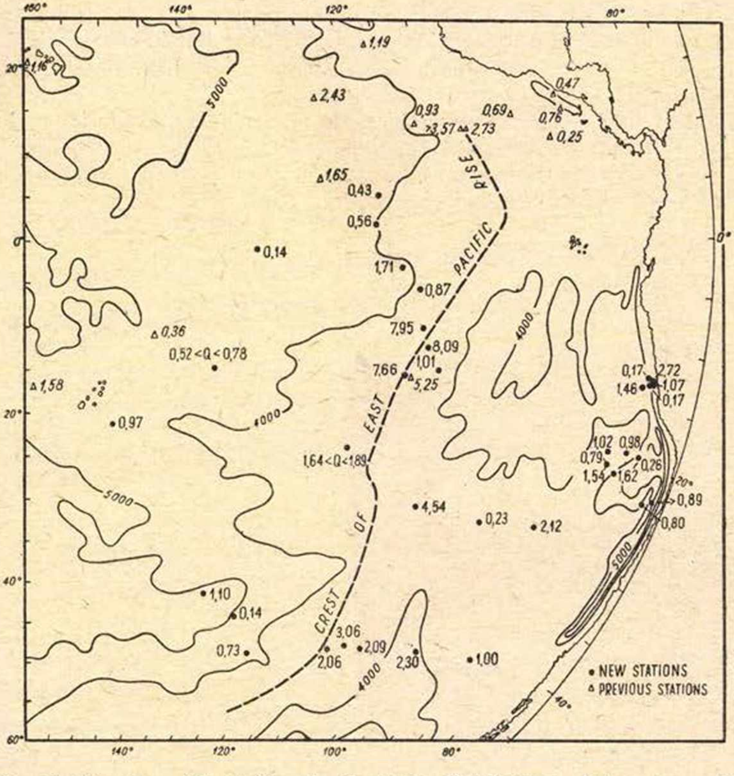

Fig. 8. The distribution of heat flow in the area of Albatros plateau according to the data of Herzen

The continuation of the rift system can be seen in the zones of tension of the Mid-Atlantic Ridge. Along these zones there is a belt of elevated temperature which can result eventually in the formation of a magma nest, as is amply proved by heat flow measurements in the environment of the mid-oceanic ridges, with a peak of heat flow values along the ridge axis and with decreasing values on both sides. The strained condition of the rift systems is shown by intense seismicity along the African rifts as well as along the mid-oceanic ridges.

It is unnecessary to derive the heat flow anomaly of the mid-oceanic ridges from an ill-proved magma current hypothesis (6), as the above interpretation gives a natural and even quantitatively correct explanation of the heat flow phenomena in question.

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