carboxyl terminal residue of the protein is occupied by either alanine or valine.

Several other points of interest deserve comment. First, the amino terminal portion of the molecule, which has been partly sequenced, indicates that dogfish trypsinogen probably contains an activation peptide with the sequence H-Ala–Pro–Asx–Asx–Asx–Asx–Lys. The position of the sixth and seventh residues has not been confirmed nor has the nature of the side chain groups of the four aspartic acid/asparagine residues. By analogy with other trypsinogens[9], these are likely to be aspartic acid. It is of interest to note that tryptic digestion of S-(β-aminoethyl)-trypsinogen did not cleave the lysyl–isoleucine bond associated with activation of the native zymogen, an observation in accord with that of Pèchere *et al.*[18] with bovine S-sulphotrypsinogen.

Second, the tyrosyl residue at position 137 of the bovine protein has apparently been deleted in the dogfish protein because four different peptides from both the tryptic and peptic digestions have been assigned to this region. Because dogfish trypsinogen has an additional residue at the N-terminus, the two proteins are of similar if not identical length.

Although the cystinyl peptides have not yet been fully characterized, it is likely that the positions of the disulphide bonds in the dogfish protein are identical to those in the bovine protein. In fact, the ten residues of half-cystine already located occur at identical positions in both proteins. Only two residues of half-cystine, at positions 203 and 216, have not been isolated, but because these two residues are bonded in the bovine protein to the half-cystinyl residues at positions 179 and 115, respectively, and are present in identical positions in the dogfish protein, it may be supposed that the missing half-cystinyl residues occupy identical, or very nearly identical, positions in the dogfish protein. The probable identity of the disulphide bridges as well as the high degree of homology already documented suggest that the three-dimensional structures of these two proteins will be very similar.

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Plate Tectonics of the Mediterranean Region

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The seismicity and fault plane solutions in the Mediterranean area show that two small rapidly moving plates exist in the Eastern Mediterranean, and such plates may be a common feature of contracting ocean basins. The results show that the concepts of plate tectonics apply to instantaneous motions across continental plate boundaries.

THE hypothesis of sea floor spreading[1–5] has been extended recently to include all motions observed at the Earth's surface. The additional hypothesis required is that all aseismic areas of the surface move as rigid plates without internal deformation. The new theory is often called "plate tectonics", to distinguish it from earlier and less precise versions of the theory of continental drift. Plate tectonics was first suggested by Wilson[6] and by Bullard *et al.*[7], but has been applied only recently to the tectonics of ridges and trenches[8–11]. It is clear from this recent work that the assumption of plate rigidity is justified, and that plate tectonics provides an excellent description of present motions. In its original form the theory had, however, several limitations. Perhaps the most important was that the evolution of plates was not considered at all; the theory was essentially an instantaneous theory only. This limitation has now been partly overcome[12]. Another major shortcoming was that the simple concepts of plate tectonics could not be applied to continental boundaries. The reason for this difficulty is the complicated nature of most plate boundaries wherever they cross continents. In such regions no sharp seismic boundary exists, and the focal mechanisms of earthquakes do not reflect the motion of the major plates on each side in any simple way (Fig. 1). This behaviour is in striking contrast to the properties of plate boundaries in oceanic areas[11], where the majority of earthquake mechanisms are directly related to the plate movements and the width of the seismic zones is often less than the present errors in epicentre locations. This difference between the tectonics of oceans and continents is not caused by the use of different methods on land and at sea, for the same worldwide distribution of seismic stations is used for all seismic studies.

The relation between sea floor spreading and continental geology has always been of interest, but no progress can be made until the nature of continental plate boundaries has been understood. For several reasons the Mediterranean region seemed to be a suitable area for this purpose. The entire region is seismically active, and many of the surrounding countries maintain good seismic stations. Also the outlines of the land and the marine geology of the area are known. Perhaps the most important reason was the general belief among land geologists that a large ocean, Tethys, once existed between Eurasia and Africa during the Cretaceous and early Tertiary time. The present Mediterranean is believed to be the remnant of this ocean. There was therefore some hope that the present tectonics of the area would demonstrate what happens when a trench attempts to consume a continent.

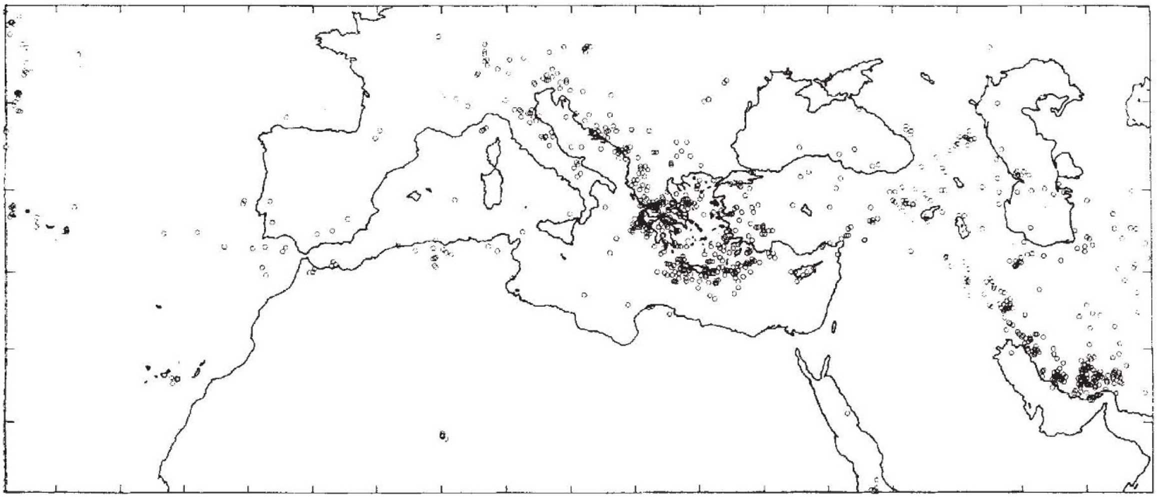

Fig. 1. Epicentres of all earthquakes with foci shallower than 70 km located by the Coast and Geodetic Survey between 1962 and 1967. The scattered activity in Eastern Turkey and Persia shows that the northward movement of Arabia is not taken up on a single fault. Six years' observations are not sufficient to show the North Anatolian Fault, though the Aegean plate is well defined. The plate boundary across North Africa is much less active than those further east, and continues into the Atlantic as the Azores–Gibraltar Ridge.

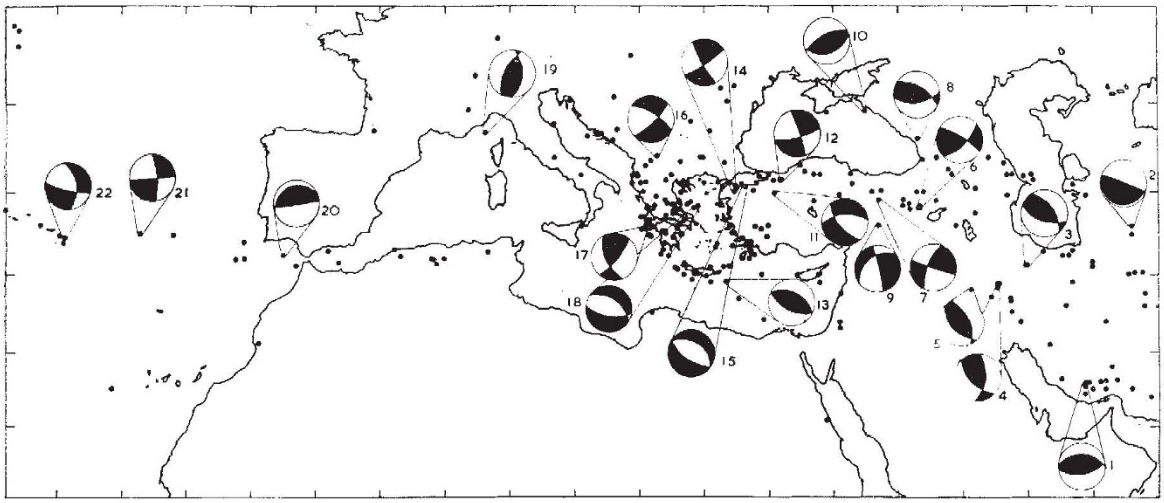

Fig. 2. Epicentres of earthquakes since 1925 whose magnitude was greater than about 6 are shown as solid dots. The focal mechanisms of some of these shocks are represented by balloons which show the lower hemisphere in stereographic projection with the compressional quadrants black. The North Anatolian Fault and the Azores–Gibraltar ridge and its eastward extension are more obvious than in Fig. 1, but otherwise the seismic activity resembles that of the shorter period.

This process is believed to produce wide belts of fold mountains.

Fig. 1 shows the region selected, which extends far beyond the boundaries of the Mediterranean Sea. The epicentres of earthquakes are plotted, taken from the United States Coast and Geodetic Survey between 1961 and 1967. It is clear from the seismicity (Figs. 1 and 2) that many small plates occur in the Mediterranean, but in two places, the Caucasus and the Azores–Gibraltar ridge, intervening plates are absent. These two special cases greatly simplify the problem of understanding the tectonics elsewhere. The seismicity of continental areas shows that such simple boundaries often exist[13], and it is essential to choose a region sufficiently large to include them. If, for instance, this study had been restricted to the Mediterranean itself it is doubtful if any progress would have been made.

There are now several methods of determining the position of plate boundaries and the magnitude and direction of the relative slip vectors between adjacent plates. Only epicentres and focal mechanisms of earthquakes are used in this study; thus the shape and direction of motion of the plates can be obtained, but not the rate of slip[5,8]. Figs. 1 and 2 show the position of the plate boundaries in this region. The seismicity associated with the Azores–Gibraltar ridge marks the junction between the African and the European plates, but east of Sicily the boundary is no longer sharp and the focal mechanisms do not reflect the motion between Europe and Africa. The focal mechanisms in Fig. 2 are in stereographic projection. They are projections of the lower hemisphere onto a horizontal plane, with the compressional quadrants shown as black regions. Thus right handed strike slip faulting gives a solution like 21 if the faulting is on an east–west fault, normal faulting gives a solution like 15, and overthrusts solutions like 13. Solutions like 11 and 17 are combinations of normal and strike slip faulting, and of thrust and strike slip faulting respectively. All solutions except 2, 4, 11, 17 and 21 were obtained by reading the vertical long period seismograms obtained from the World Wide Network of Standardized Stations. No such solutions could be obtained for the five earthquakes just mentioned because they took place before the network was installed. They were obtained by plotting all available readings in an equal area projection, then fitting nodal planes. About 100 solutions have now been obtained in this area, and will be published individually elsewhere. The plate boundaries and motions described account for most of these mechanisms, except those obtained for earthquakes on the Greek mainland. Here the deformation is rather complicated, and may be related to the motion of plates too small to be resolved by the seismicity. The solutions in Fig. 2 are some of the best obtained, and are chosen for this reason alone.

Only three plate boundaries of any importance enter the area, and therefore only three major plates are involved in the tectonics. These plates are the African, Eurasian and Arabian plates, and the boundaries between them are the Azores–Gibraltar ridge and its extension across North Africa, the Red Sea and the Alpide zone in Iran (Fig. 4). The line of earthquakes extending from Sicily to the Azores across North Africa out into the Atlantic following the Azores–Gibraltar ridge marks the boundary between the African and Eurasian plates. Several large earthquakes have occurred on this boundary, of which the most famous was the Lisbon earthquake of 1755. Two more recent earthquakes, in 1942 and 1969, were of magnitude 8 or more. The pole of relative motion between these plates has been calculated to be at 9° N, 46° W by Le Pichon (misprinted in his original paper). This pole requires the motion between Africa and Eurasia to be strike slip at the Azores, changing to overthrust south of Spain and in North Africa. Such motion agrees excellently with the fault plane solutions in Fig. 2, and with some other less good solutions in North Africa. Both the pole position and the fault plane solutions show that the motion between these plates is strike slip with a small amount of extension near the Azores. Because the pole of rotation is close to the area, the direction of motion changes rapidly going eastward along the Azores–Gibraltar ridge. The fault plane solutions show this change in more detail (Fig. 2), with the strike slip faulting changing to overthrusting in the Straits of Gibraltar and across North Africa. This remarkable variation is rare, and studies of this boundary are therefore of considerable interest. Also few examples of plate boundaries are known with slow consumption rates, and the features associated with such structures have not been studied in any detail. It is surprising that few intermediate depth earthquakes are associated with this boundary. Those beneath the Tyrrhenian Sea are unlikely to be directly related to the motion of Africa towards Europe because they are confined to a local area, and also because they are within a slab which dips west[14], or at right angles to the direction of motion of Africa.

The seismicity east of Sicily does not show whether the plate boundary between Africa and Europe extends across the south end of the Adriatic to join the Cretan Arc, or whether the motion is taken up by the activity in Italy and Yugoslavia. A dramatic change occurs in the eastern Mediterranean. The seismic activity of Albania, southern Yugoslavia, Greece and Turkey is very much greater than that of the western Mediterranean. Large earthquakes of magnitude greater than 7 are common, and are often associated with slip on major faults. Also the fault plane solutions become complicated (Fig. 2). This change is not the result of an active plate boundary joining that between Africa and Europe, nor is it the effect of the opening of the Red Sea[15]. The cause of this local increase in activity is the existence of two small rapidly moving plates, one containing the Aegean, part of Greece, Crete and part of western Turkey, the other containing most of Turkey and Cyprus. These plates will be called the Aegean and Turkish plates respectively. The motion between the Aegean and the Eurasian plate is shown by fault plane solutions such as 11, 14, 15 and 18. These solutions vary between strike slip and normal faulting. They therefore permit the fault plane to be distinguished from the auxiliary plane, and hence determine the slip vectors. These solutions show that the Aegean plate is moving towards the south-west relative to the European plate, producing extension and strike slip on the boundary between them. This boundary crosses from the Sea of Marmara across the northern Aegean, and probably reaches Greece between the island of Evvoia and the mainland. A deep trough exists in this part of the Aegean which reaches to a depth of 1,500 m and is associated with large magnetic anomalies[16]. The fault plane solutions suggest that this trough has been produced by extension of the crust, associated with large basic intrusions. Therefore from the point of view of plate tectonics this feature is a ridge. It is, however, very different from most oceanic ridges because the relative motion between the two sides is partly right-handed strike slip and partly extension, and also because the total extension is comparable to that of the East African Rift, rather than the major oceanic ridges. The present seismicity in the northern Aegean does not follow this trough, though the faulting is of the type which could produce it.

The southern boundary of the Aegean plate is moving south-west relative to the African plate, and is overthrusting the Mediterranean Sea floor. The direction of motion is given by solutions 13 and 17 (Figs. 2 and 4) and also by the existence of intermediate earthquakes beneath Greece and the southern part of the Aegean (Fig. 3). This plate boundary has several other features which show

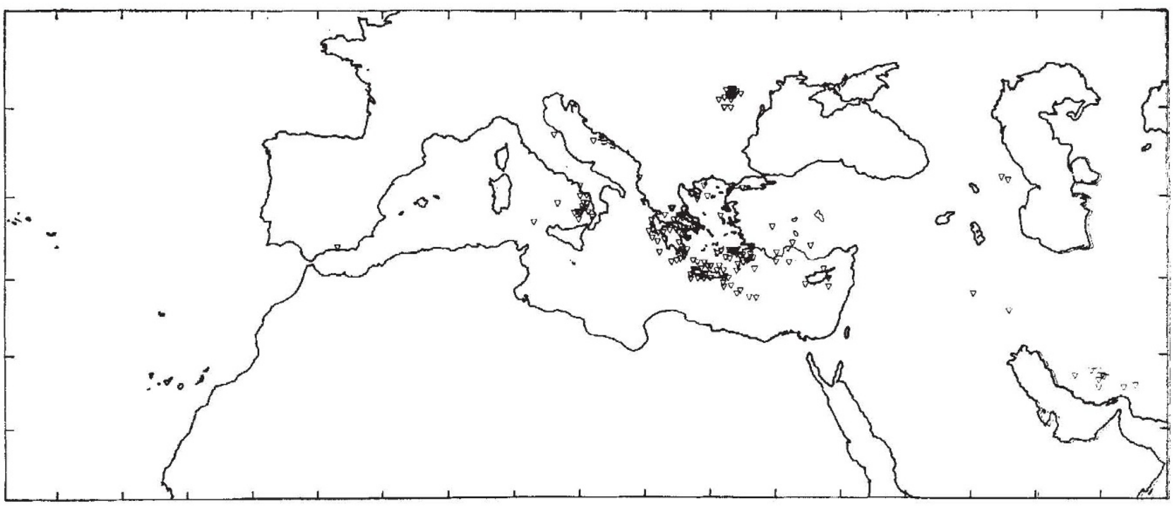

Fig. 3. Epicentres of all earthquakes with foci below 70 km depth which occurred since 1925. The active regions are localized and, if the concepts of plate tectonics are correct, mark the sites of consumption of lithosphere active during the last 10 m.y. (refs. 11 and 24).

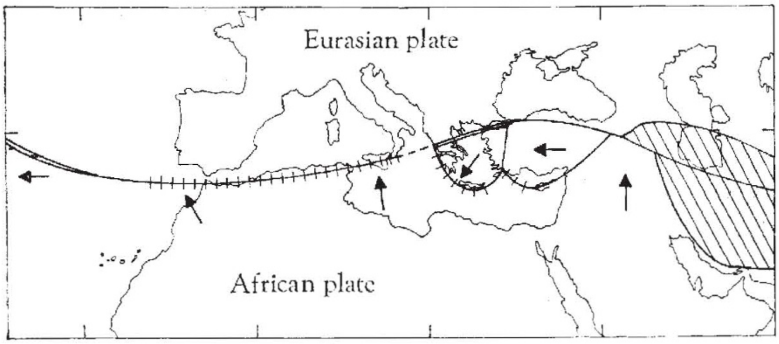

Fig. 4. Approximate positions of plate boundaries at present active, with arrows marking the directions of motion relative to the Eurasian plate. Boundaries creating lithosphere are shown with a double line, boundaries consuming plates with short lines at right-angles to them. The cross-hatched region in Eastern Turkey and Iran is seismically active throughout. Fault plane solutions here are all overthrusts (Fig. 2), and show that the crust is being thickened all over this region. Most major shocks within the cross-hatched area occur on major active faults mapped by Wellman[26] from aerial photographs and shown as solid lines.

that it is indeed a trench. Active and dormant andesite volcanoes occur in Greece and in several of the Aegean islands, of which Santorini is the most famous. Several surveys have detected a large negative free-air gravity anomaly[17,18] and deep depression in the sea floor extending from Zakinthos to Rhodes[19]. Also Ryan[20] has demonstrated the existence of thrust features in the seismic reflexion records of sediment deformation. All these observations show that the sea floor south of the Cretan arc is being overridden from the north-east and sinks beneath the Aegean Sea.

The seismicity of the Turkish plate and the fault plane solutions show that it is moving approximately due west relative to both Europe and Africa. The northern boundary of the plate is the North Anatolian fault, which is an active east–west right-handed strike slip fault whose slip rate has been estimated[21] to be 11 cm yr^{-1}. It is continuous with the northern boundary of the Aegean plate, which takes up the motion towards the west. Many earthquakes have occurred on this fault throughout northern Turkey, and many have produced surface displacements[22,23]. There is therefore no ambiguity between the fault plane and the auxiliary plane. The southern boundary of the Turkish plate is not well defined by the seismicity, and only one poor solution, No. 9, has been obtained on it. It seems to join the southern boundary of the Aegean plate south of south-west Turkey, and to run south of Cyprus into the Gulf of Alexandretta to join the North Anatolian fault east of Erzincan. The motion across this boundary is mostly left-handed strike slip, probably with some overthrusting in the south-west. The surface features and fault plane solutions associated with the North Anatolian fault show a striking change east of Erzincan. West of this point the fault is strike slip and has a surface trace which closely resembles that of the San Andreas. To the east, however, there is no distinct trace, and the fault plane solutions show a large component of thrusting, with the north overriding the south. Solutions in the Caucasus and further south show that the horizontal projection slip vector is north–south, and the fault plane solutions are overthrust. In this region the seismic activity is confined to a narrower belt than it is either to the east or west, though it is still spread over a wider belt than is common in the oceans. Thus in eastern Turkey, the Caucasus and western Iran the fault plane solutions show that Africa and Arabia are moving northwards, and though the motion is taken up on several faults, there are no small plates moving rapidly east or west. Thus the existence of the Anatolian fault and other large strike slip faults is caused by the rapid motion of the Turkish plate westward. The geometry and motions of both the Turkish and Aegean plates are both complicated and surprising. A possible explanation depends on the difference in behaviour between continental and oceanic lithosphere. Continental material is too light to sink through the mantle, and therefore cannot vanish[24]. In parts of the Alpide belt such as Iran and the Caucasus, large thicknesses of continental rocks have accumulated, and considerable work must be done against gravitational forces to further thicken the continental crust. No such work need be done if oceanic lithosphere can be consumed, rather than continental lithosphere thickened. This is indeed the result of the motion of the Aegean and Turkish plates, which avoids further overthrusting in Turkey and instead consumes the Mediterranean Sea floor in front of the Cretan arc. Thus the present motions are such as to minimize the work which need be done to move the African Plate towards the Eurasian. This particular mechanism may also account for the existence of localized sources of intermediate earthquakes, such as those beneath Roumania and the Hindu Kush[13]. The earthquakes in these regions occur in slabs within the mantle which closely resemble those beneath island arcs[25]. These sources are puzzling because both are now overlain by continental crust, yet all other sources of intermediate earthquakes occur within a slab of what was originally oceanic lithosphere. The process at present taking place in the eastern Mediterranean is producing a localized source of intermediate earthquakes by rapid underthrusting beneath the Cretan arc. A similar mechanism could consume remnants of oceanic crust in other regions, such as the southern part of the Caspian Sea. This process is only possible if small plates of continental lithosphere are easily formed to consume oceanic crust in a limited region. It is therefore important to search for geological evidence for the previous existence of such plates in Roumania and the Hindu Kush.

The tectonics from the Caucasus to the eastern limit of the area appears to be considerably simpler than that further west. All fault plane solutions east of 44° E are overthrust, some with small components of strike slip faulting. Many solutions contained only one dilatational reading, always from a close station; and if the focus was taken to be in the mantle it was rarely possible to draw two orthogonal planes separating the compressions from the dilatations. Because several of the earthquakes in question produced surface breaks on faults[26,27], this difficulty is not caused by an explosive type of source mechanism but by refraction of the rays at the Moho or above. If the foci were taken to be in the crust, with a velocity of 6·8 km s^{-1}, all mechanisms could be described by a double couple source with the fault plane at right angles to the auxiliary plane. There is, however, at present little accurate information about the deep crustal velocity structure in this region, and therefore none of these mechanisms is well determined. In particular, most could have a larger component of strike slip than shown in Fig. 2.

All solutions in southern Russia and Iran show that this part of the Alpide belt is taking up the motion of India and Arabia towards Asia by overthrusting over a wide belt from southern Iran to the central Caspian. Most earthquakes are associated with the major active faults described by Wellman. The sense of displacement on surface faults may be used to determine the fault plane and the auxiliary plane, and hence to obtain slip vectors. The resulting vectors show that the motion direction varies little from 35° E over the entire region. This direction is little different from 15° E, the direction to be expected from the Arabia–Eurasia pole at about 25° N, 12° W. Thus the deformation of Iran and southern

Russia appears to be much simpler than that of the Eastern Mediterranean. The result of present activity in this part of the Alpide belt is to thicken the continental crust over a wide region. Though Gutenberg and Richter[28] show a few intermediate earthquakes in southern Iran, the deepest shocks with reliable depths from 1962 to 1967 were at about 100 km. There are not sufficient stations in this area to produce reliable depth estimates if, as seems probable, there are high velocity slabs still present in the mantle. Thus there is little evidence for any destruction of continental lithosphere throughout this region.

This account of the tectonics of the Mediterranean and Western Asia shows that the concepts of plate tectonics provide a useful description of continental tectonics. It also suggests that the boundaries of continental plates often may be complicated by the existence of small rapidly moving plates whose motion is not simply related to the motion of any of the major plates involved. A more complete account containing about 100 fault plane solutions on which this study is based is to be published elsewhere.

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Plate Tectonics of the Red Sea and East Africa

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The relative motion between the plates on each side of the East African Rift Valley can be obtained from the opening of the Red Sea and the Gulf of Aden. The calculated direction of relative motion agrees well with fault plane solutions for earthquakes north of the equator.

THE Red Sea and the East African Rift Valley were the first major features to be recognized as having been produced by extension of the Earth's crust[1,2]. Normal faulting along the sides of the Rift Valley during earthquakes shows that this motion still continues[3]. As the seismic activity of the Indian Ocean ridges is continuous with that of the East African Rift (ref. 4 and unpublished work of Fairhead), the African Rift served as a model for oceanic rifts. It was therefore studied in some detail because the significance of rifting in the oceans was not at first understood.

It is somewhat surprising that this situation is now reversed. Modern theories and oceanographic methods have been so successful that the evolution and tectonics of the ocean floor are now much better studied and understood than similar processes on land. It is therefore now possible to construct an outline of the movements involved in the formation of the Rift Valley from the history of the surrounding ocean basins. Such a reconstruction is attempted here, and the results are in general agreement with studies of the Rift Valley itself. Perhaps the principal result of this and other studies of this region is that, though the Rift is still of great interest, it is not of global importance. The discussion below demonstrates that the extension by which it was produced is everywhere less than 65 km, and probably took place in the last 20 million years. This motion is small compared with 3,000 km in the East Central Pacific during the same period, or even with 500 km in the North Atlantic.

The seismicity of the Red Sea, Gulf of Aden and the East African Rift (Fig. 1*a*) shows that three plates meet at the south end of the Red Sea. These plates we will call the Arabian, Nubian and Somalian Plates, and will only consider the relative motions between these plates in Africa north of the equator, in the Red Sea and Gulf of Aden, and in Egypt, Jordan and Israel. If the motions between the Arabian plate and the Somalian and Nubian plates respectively can be determined, the motion between the Somalian and Nubian plates may be calculated from the postulates of plate tectonics[5,6]. The results of such calculations are shown in Fig. 1*b*, where the heavy double lines mark the three extensional plate boundaries and the arrows show the relative motion between the plate on which the arrow lies and the adjoining plate. A junction between three ridges is possible without compression of any of the plates involved.

The motion between the Arabian and Somalian plate was first determined by Laughton[7] from the strike of transform faults in the Gulf of Aden. He used them to fit the coast of Africa to that of Arabia, and showed that the geological structures on each side then matched remarkably well. The seismicity and fault plane solutions for earthquakes[3,4] in the Gulf and the magnetic lineations agree with the direction of motion proposed by Laughton.