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GREEK TECTONICS AND SEISMICITY

KOSTAS C. MAKROPOULOS [1] and PAUL W. BURTON [2]

[1] *Seismological Laboratory, Athens University, Panepistimiopoli, Athens (Greece)*
[2] *Natural Environment Research Council, Institute of Geological Sciences, Murchison House, West Mains Road, Edinburgh EH9 3LA (Scotland)*

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ABSTRACT

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The validity of existing tectonic models for the area of Greece is examined in the light of the new recalculated parameters for earthquakes of the region (Makropoulos and Burton, 1981). Relocated hypocentral positions are extracted from the catalogue to form radial and vertical distance–depth cross-sections centred on a reference point near the mid-point of the Aegean Volcanic arc, and these are used to form a three dimensional topography of the base of earthquake occurrence below 60 km. Isodepth maps are extracted from this topography as both three and two dimensional map presentations. These maps reveal several significant features of deep-seated tectonic processes in the region. Isodepths exceeding 150 km are seen in the northwest Aegean, and these are more closely linked to the Sporadhes and Gulf of Thermaicos, rather than the North Aegean trough. The 150 km isodepths are also seen in the northeast Aegean straddling the Dardanelles; in the northeastern part of the Peloponnesus, Gulf of Saronikos and eastern Gulf of Corinth in the southern Peloponnesus towards Crete; and extending from north of Kos to south of Rodos. The largest extent of deepest activity is seen south of Rodos and this continues towards southwest of Turkey. The subduction zone of the Hellenic arc is clear, but smooth Benioff zones are not the norm, and these data show that structural complexity is more readily observed. It is concluded that none of the proposed tectonic models completely explain the observed activity over the whole area, and rather than propose yet another model places where further work is still particularly necessary are identified.

INTRODUCTION

The spatial distribution of earthquakes in a region shows its present active tectonics, and the size of earthquake magnitudes is a measure of the degree of that activity. Hence, maps with the spatial distribution of the epicentres can help to reveal the tectonic features of the region with as much precision as the accuracy of the earthquake parameters used.

Greece and the adjacent areas (that is the Greek mainland, the Aegean Sea and

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western Turkey) have the highest seismic activity in the whole of the Mediterranean and European area (Karnik, 1969; Galanopoulos, 1971; Papazachos, 1977). The high seismic activity shows that this area is tectonically very active. This, coupled with the fact that it is a part of the Alpine–Himalayan zone, which is the only continental region where large scale shortening is now taking place (McKenzie, 1978), makes it a region of great interest for geologists and geophysicists.

During the last 10 years considerable advances have been made towards reaching a better understanding of the tectonic processes of this region. However, the proposed models fail to explain all of the extensive and varied geological and geophysical observations, which, coupled with the high seismicity of the area, make the task of overall reconciliation and mutual compatibility of data and hypotheses particularly difficult.

In this study, using the parameters of the new earthquake catalogue described briefly later in this paper (Makropoulos, 1978; Makropoulos and Burton, 1981), two and three dimensional isodepth maps are produced in an attempt to reconsider the existing models and to distinguish places where further work needs to be done, rather than to present yet another model.

GEOMORPHOLOGICAL FEATURES OF THE AREA

Figure 1 illustrates the main geomorphological features of Greece and the adjacent areas. These features are, from south to north (Allen and Morelli, 1971; Agarwal et al., 1976):

(1) The Mediterranean ridge which extends from the Ionian Sea to Cyprus. It is not a mid-ocean ridge and Finetti (1976) investigating its tectonic features in detail suggests the name "east Mediterranean chain".

(2) The Hellenic trench (or trough) which consists of a series of depressions to a depth of 5000 m and parallels the Hellenic arc.

(3) The Hellenic arc which is formed by the outer sedimentary arc, a link between the southern Dinarides and the Turkish Taurides, and the inner volcanic arc which approximately parallels the sedimentary arc. Between these two arcs is the Cretan trough with water depth to about 2000 m. The outer sedimentary arc consists of Palaeozoic to Tertiary rocks folded and faulted in several phases of the Alpine orogeny, while the inner volcanic arc consists of recent andesitic volcanism at Santorini, Nisyros, Milos and Kos (Maratos, 1972).

(4) The northern Aegean Sea: the Aegean Sea immediately north of the volcanic arc is a rather stable block of folded Palaeozoic and granitoid masses. The extreme north includes the northern Aegean trough with water depth to about 1500 m, the northeast extension of which is probably the small depression of the Marmara Sea (Papazachos and Comninakis, 1976), the western part of which includes the Sporadhes basin (Brooks and Ferentinos, 1980).

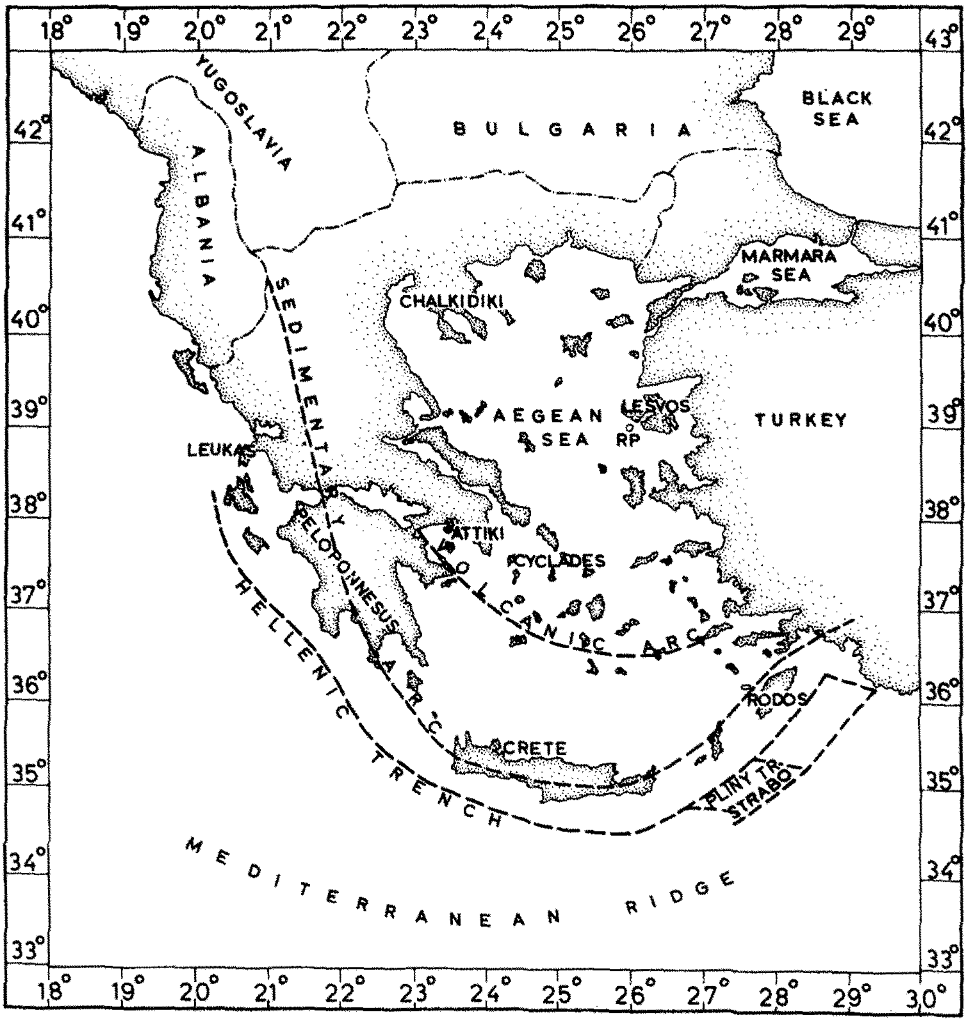


Fig. 1. Sketch map to illustrate the main geomorphological features of Greece and the adjacent areas.

GEOPHYSICAL DATA

Greece was surveyed gravimetrically and magnetically in the years 1971–1973 (Makris, 1975). Along the Greek mainland the Bouguer anomalies have negative values with a gravity minimum of −140 mGal situated at the Pindos Mountains. The Aegean Sea is characterized by positive Bouguer anomalies with a maximum of +175 mGal at the central trough of the Cretan Sea (Makris, 1975), while in the central and northern Aegean it is about +50 mGal. A belt of negative free-air anomalies down to −200 mGal follows the Hellenic trench, while the Bouguer anomalies are positive up to +180 mGal (Morelli et al., 1975).

Positive magnetic anomalies have been determined in several parts of the Aegean Sea. The strongest of these anomalies have been observed along the volcanic arc, in the northern Aegean trough and in the Cretan trough (Vogt and Higgs, 1969; Makris, 1973). The magnetic field is undisturbed in the Mediterranean Sea south of Crete (Vogt and Higgs, 1969).

Heat flow is relatively high in the Aegean Sea floor in the volcanic arc of the southern Aegean, being around 2.1 HFU, and Jongsma (1974) has interpreted this as due to underthrusting of oceanic crust.

Seismic refraction studies and experiments (Papazachos, 1969; Makris, 1973, 1976a) have indicated that the crust thins from about 50 km below the Peloponnesus and the Pindos Mountains towards the Aegean (25–30 km), and that the central part of the Cretan Sea crust is only 20 km thick (Makris, 1976b; see Fig. 2).

PRINCIPLE SEISMOTECTONIC AND TECTONIC MODELS

McKenzie (1970, 1972) was the first to delineate a small, rapidly moving plate, which contains the Aegean, part of Greece, Crete and part of western Turkey (see

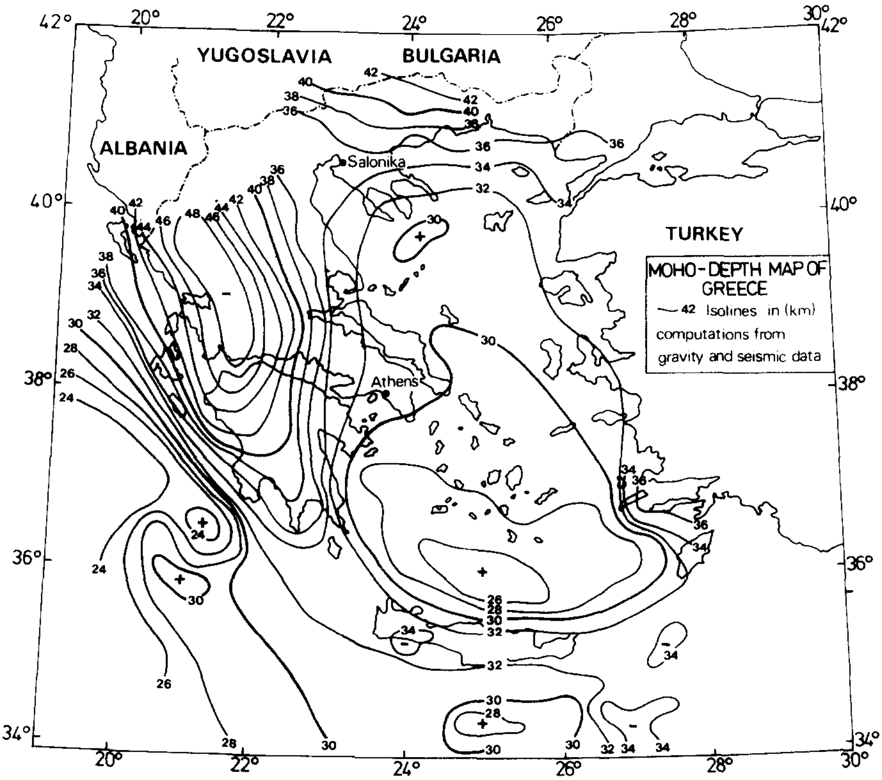
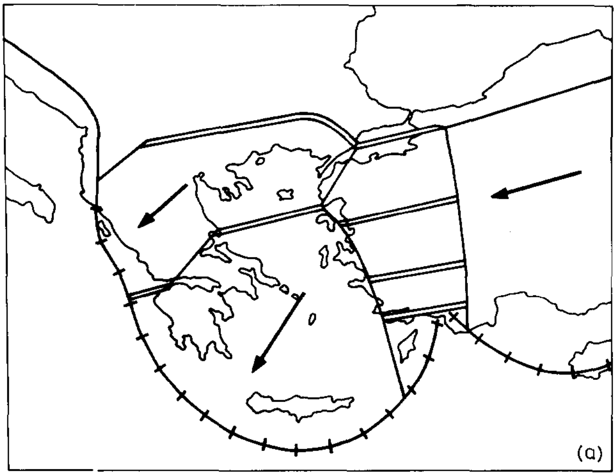


Fig. 2. Crustal thickness and the Moho discontinuity from gravity and seismic data (after Makris, 1973).



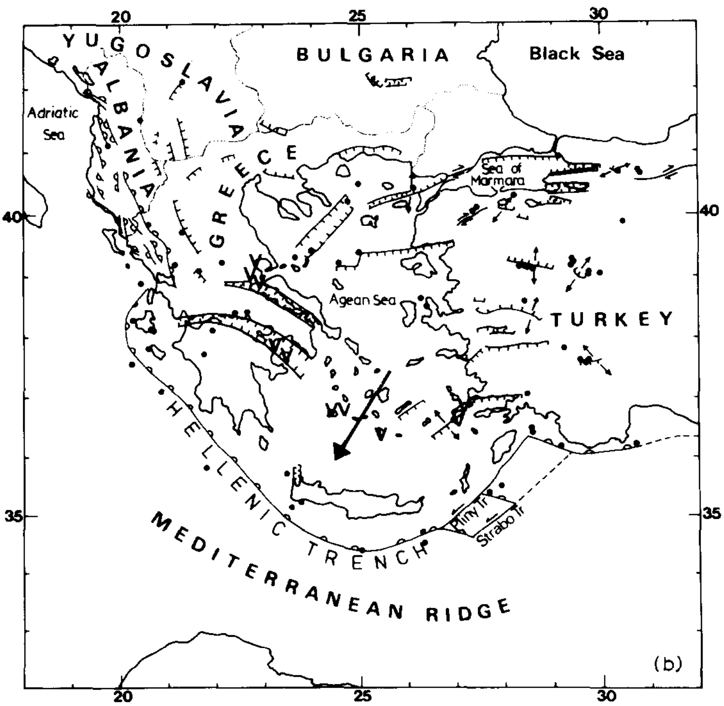


Fig. 3. McKenzie's models for the Aegean. a. The "Aegean plate" and other plate boundaries in the Aegean area from seismicity and fault plane solutions, after McKenzie (1972). b. Improved summary of deformation of the Aegean area, after McKenzie (1978). Long curved lines = normal faults; lines with open semicircles = thrust faults; arrows = direction of motion from fault plane solutions; long heavy arrow = direction of relative motion between the Aegean and Africa; heavy V = recent volcanism.

Fig. 3). He called it the "Aegean plate". The southwestern boundaries were well defined, and earthquake fault plane solutions show that the motion between the Aegean and African plates is in a north–south direction. The northern boundary was defined by extensional and transform faults, and he concluded that it was a continuation of the North Anatolian fault (but see below). The boundary with the other plate, the "Turkish plate", was poorly defined.

After McKenzie's work, contemporary plate tectonics in the area, and its problems, were discussed by Lort (1971), Papazachos and Comninakis (1971, 1976, 1978), Galanopoulos (1972, 1973, 1974, 1975), Comninakis and Papazachos (1972, 1976), Alvarez (1973), Dewey et al. (1973), Papazachos (1973, 1974, 1976a, 1976b, 1977), Makris (1973, 1975, 1976a, 1976b, 1978), Gregersen (1977) and others. The common point of almost all these studies is that the African plate underthrusts Greece and the adjacent areas along the Hellenic arc. The mean dipping angle is about 35° (Papazachos and Comninakis, 1971; Galanopoulos, 1973; Agarwal et al., 1976; Gregersen, 1977). However, McKenzie's model has been criticized by a number of authors (Papazachos, 1973, 1976a, 1976b, 1977; Crampin and Ücer, 1975; Mercier et al., 1976) for its simplicity and its definition of its northern and western boundaries.

From the definition of the boundaries of a plate (McKenzie and Parker, 1967), it is difficult to talk about truly stable aseismic microplates in this region. All the maps of spatial distribution of epicentres show that several small aseismic blocks exist. Hence, most geologists and geophysicists now prefer the name "Aegean area" rather than "plate" because of its real complexity.

As Fig. 3(a) shows, the northern boundary of McKenzie's plate consists of transform faults, but Mercier et al. (1976), after extensive investigation in central Greece, found no evidence of a transform fault. The continuation of that northern boundary towards the North Anatolian fault has also been debated (Papazachos, 1976a, 1977; Crampin and Ücer, 1975).

Papazachos (1976a), using focal mechanisms and the spatial distribution of earthquakes in the northern Aegean, has concluded that there is an amphitheatrical Benioff-zone, which, although less well defined compared with the similar one in the south Aegean, is dipping towards a thrust region which includes the northernmost part of the Aegean and part of the Marmara area.

A different model for the Aegean area has been suggested by Makris (1976b, 1978). According to his model, the deformation of the region is the surface expression of a hot mantle plume which extends to the base of the lithosphere and has been mobilized through compressional processes that forced the lithosphere to sink into the asthenosphere.

This model explains that the crustal thickening along the Hellenic arc is due to the crustal down-buckling which causes thickening at the compressional front. This collision is responsible for the high seismicity along the arc. The Hellenic trench is the result of the upwards movement of the Aegean crust which is forced to override part of the Ionian East Mediterranean crust and lithosphere towards Africa. This movement causes a subduction zone to develop at the collision front. According to this model the deep seismicity is caused by crust and upper mantle fragments dislocated from their original positions and subducted into the soft, low Q asthenosphere. Båth (1983) has also suggested a soft low-velocity layer with lower stress in the upper mantle compared to the crust as an explanation of his observation that the Gutenberg-Richter b value increases with focal depth on average throughout the area.

McKenzie (1978) has proposed another model for the Aegean Sea and surrounding regions. This model is a modification of his previous one. It is based on new fault plane solutions of earthquakes from USGS and NOAA, Landsat photographs, and seismic refraction records. The main differences of this model are summarized in Fig. 3(b), taken from the above paper (McKenzie's fig. 18). The main points of this model are:

(1) Rapid extension is taking place in the northern and eastern parts of the Aegean Sea region.

(2) The thin crust of the Aegean has been produced by stretching the orogenic belt by a factor of two since the Miocene which can account for the high heat flow.

(3) In northwestern Greece and Albania, where both thrust and normal faults are present, the term "blob" of cold mantle detaching from the lower half of the lithosphere is introduced. These blobs are produced by thermal instability when lithosphere is thickened by thrusting.

(4) The direction of relative motion between the southern Aegean region and Africa is 211°E.

(5) No evidence was found to support the suggestion made in the previous model (1972) that the Anatolian trough is connected to the Gulf of Corinth. Extensional tectonics with vertical movements is also accepted by Le Pichon and Angelier (1981) using geological rather than seismic data, and with the advantage that their modelling quantifies necessary extensions which are compatible with the geological data; the largest of which are associated with the high seismicity in the Hellenic Arc near Crete and Rodos.

McKenzie (1978) also comments that "the theory of plate tectonics is of little value in regions such as northern Greece and Turkey where the deformation is spread over a zone". Dewey and Sengör (1979) also point out that plate tectonics is not useful in the Aegean area where normal faulting is not confined to a narrow zone. These two comments, and the wide criticism which McKenzie directed against almost all the proposed models for the region, may reflect the real complexity of the Aegean area.

SPATIAL DISTRIBUTION OF THE HYPOCENTRES

An essential prerequisite to the careful consideration of alternative seismotectonic models and tectonic hypotheses is an earthquake catalogue which is homogeneous and consistent in its approach to the area under study, and the ensuing data in such a catalogue must be allowed to provide a vital constraint on the range of preferred tectonic hypotheses leading to a compatible seismotectonic model.

The earthquake catalogue

A new homogeneous earthquake catalogue has been prepared for Greece and the Aegean (Makropoulos, 1978; Makropoulos and Burton, 1981, Paper 1) with the intention of using a long period of instrumentally recorded data as a basis for detailed seismotectonic studies. The catalogue presently spans the instrumental period 1901–1978 and includes several hundred systematically relocated earthquakes, relocated using master event and restrained JED techniques (Douglas, 1967; Lilwall, 1969). In principal, therefore, the first arrival phase data documented by the International Seismological Summary is the primary data source, and the JED technique is supplemented by using exceptionally well recorded or macroseismically controlled events as the master events. Relocation vectors were typically found to be of order 17 km for the latter part of the catalogue, but are typically an average 165 km in the earlier years. Paper 1 provides full details of catalogue preparation, and includes the catalogue list itself. Paper 1 draws attention to the epicentral distribution resolved, but makes no attempt to exploit the seismotectonic control available from full use of the hypocentral data which may be analyzed in three dimensions.

Epicentral distributions obtained from this catalogue in general reveal a clearer definition of seismic lineations than has been apparent in those maps previously published (Galanopoulos et al., 1971; Comminakis and Papazachos, 1972). Figure 4 shows the principal seismic zones apparent from scrutiny of this catalogue. These are seen to be delineated as follows:

Zone 1: Parallel to the Hellenic Arc, extending from within Albania in the north to the west coast of Turkey in the east.

Zone 2: Levkas Island in the west, through central Greece to Volos in the east. Zone 2 divides near Volos extending into Zone 2A: northeastwards from Volos extending into the Chalkidiki Peninsula, and, Zone 2B: eastwards from Volos through the Sporadhes Islands, north of Lesvos Island, and into Turkey.

Zone 3: The Gulf of Saronikos and Gulf of Corinth.

Three dimensional analysis will now be invoked to exploit the hypocentral data and allow fuller examination of the earthquake distribution.

Isodepth maps from radial vertical cross-sections

Two and three dimensional isodepth maps are produced here in an attempt to examine the validity of the existing models, and to distinguish places where further work must be done, rather than to present another model.

These maps result from continuous radial vertical cross-sections obtained using

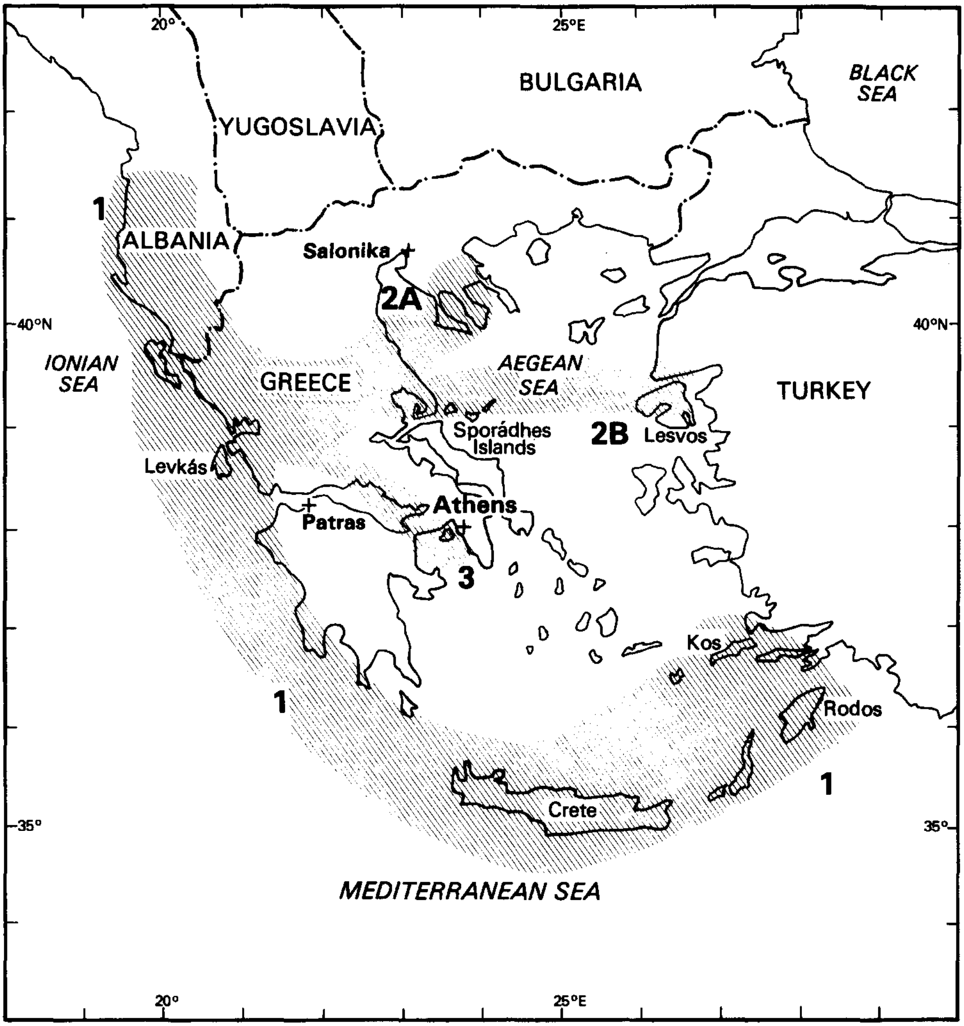


Fig. 4. Diagram of approximate extent of principal seismic zones in Greece inferred from the spatial distribution of epicentres in the earthquake catalogue (Makropoulos and Burton, 1981).

the following procedure:

(1) The approximate centre of the volcanic arc is chosen as a reference point. Its coordinates are 38.9°N, 26.0°E.

(2) Radial vertical planes are drawn with a common axis to the one passing through the reference point, and differing by an azimuth of 10° (36 vertical planes).

(3) In each plane the epicentral distance from the centre versus focal depth is plotted for all earthquakes within $\pm 10°$ azimuth from that plane. Thus, 36 radial vertical cross-sections are produced, each of which overlaps the one adjacent by an azimuth of 10°.

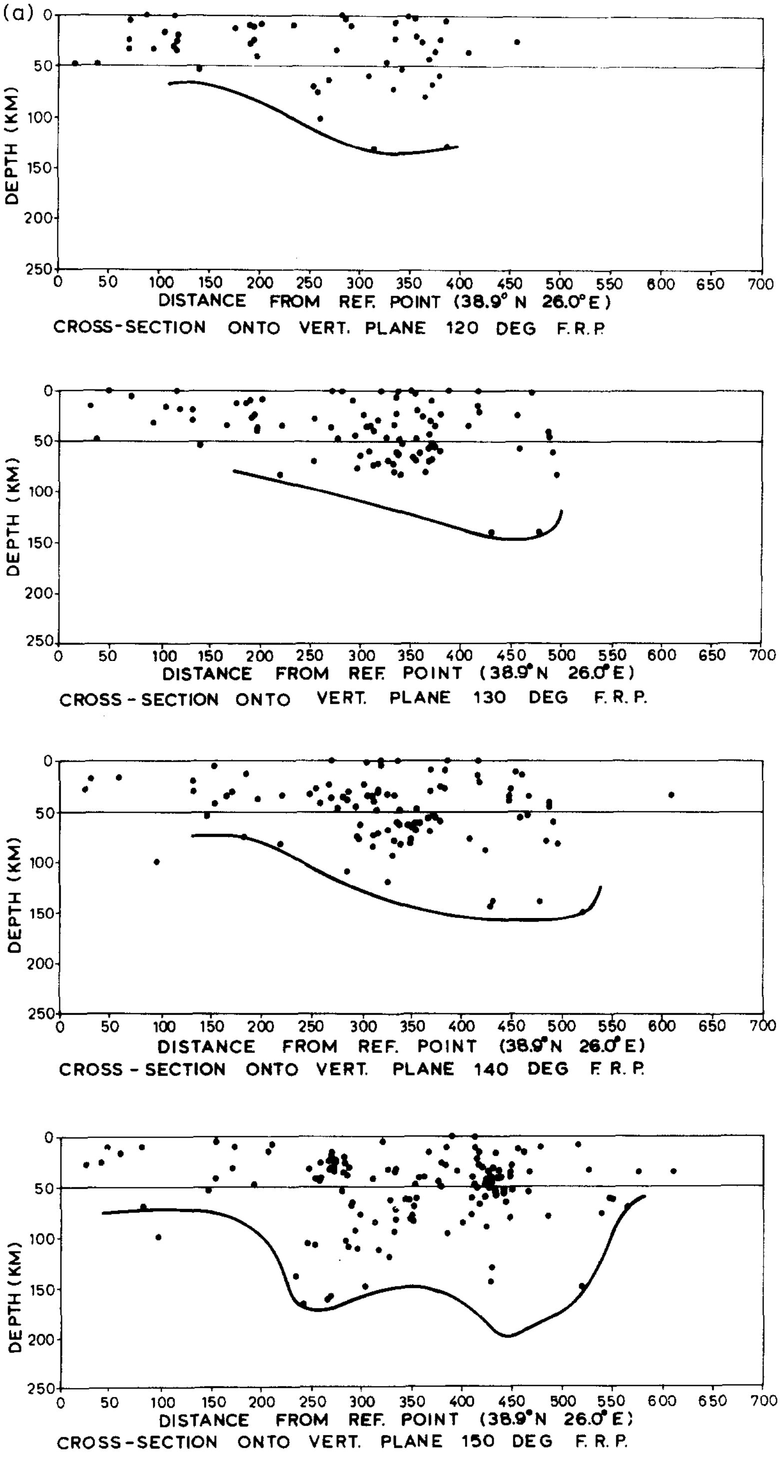


Fig. 5a. For legend see p. 289.

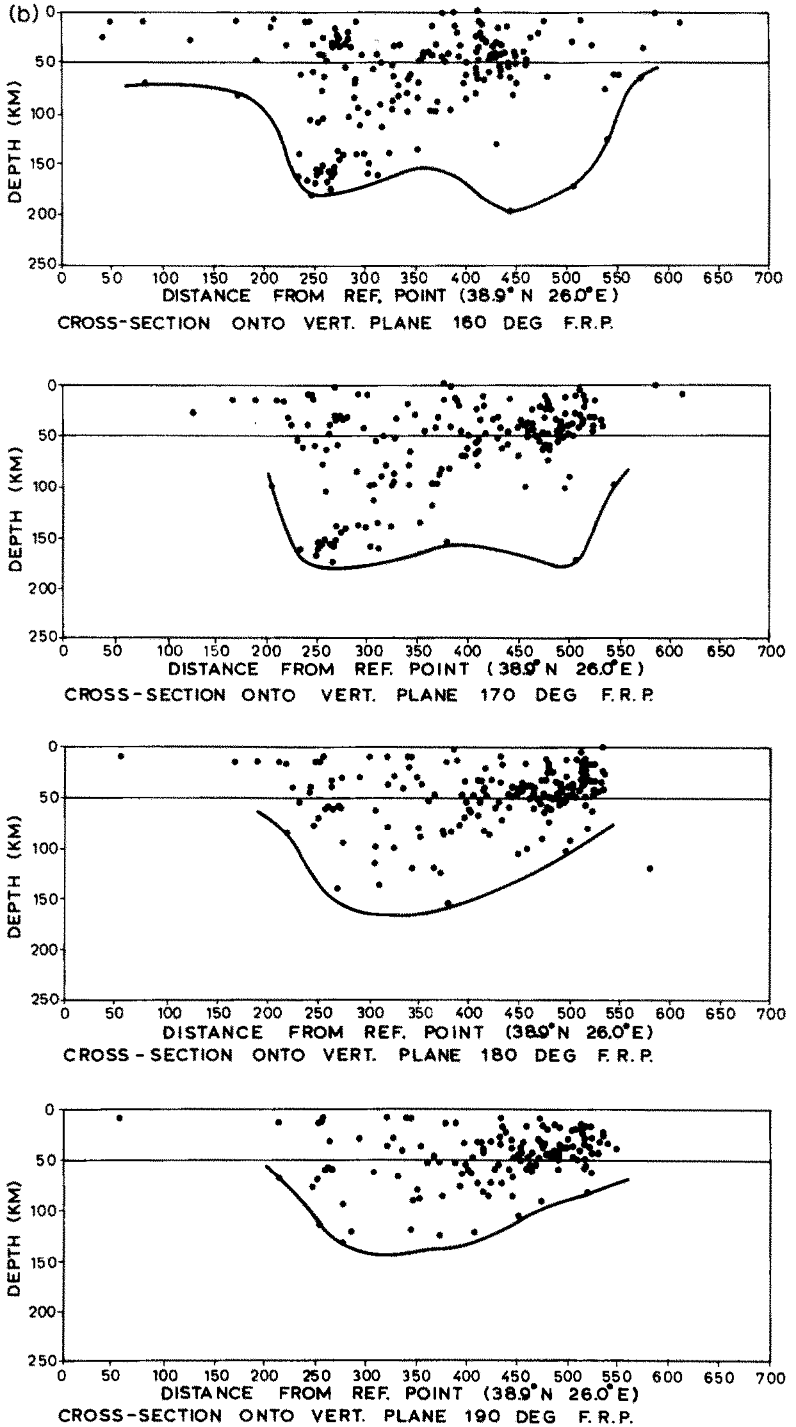


Fig. 5b. For legend see p. 289.

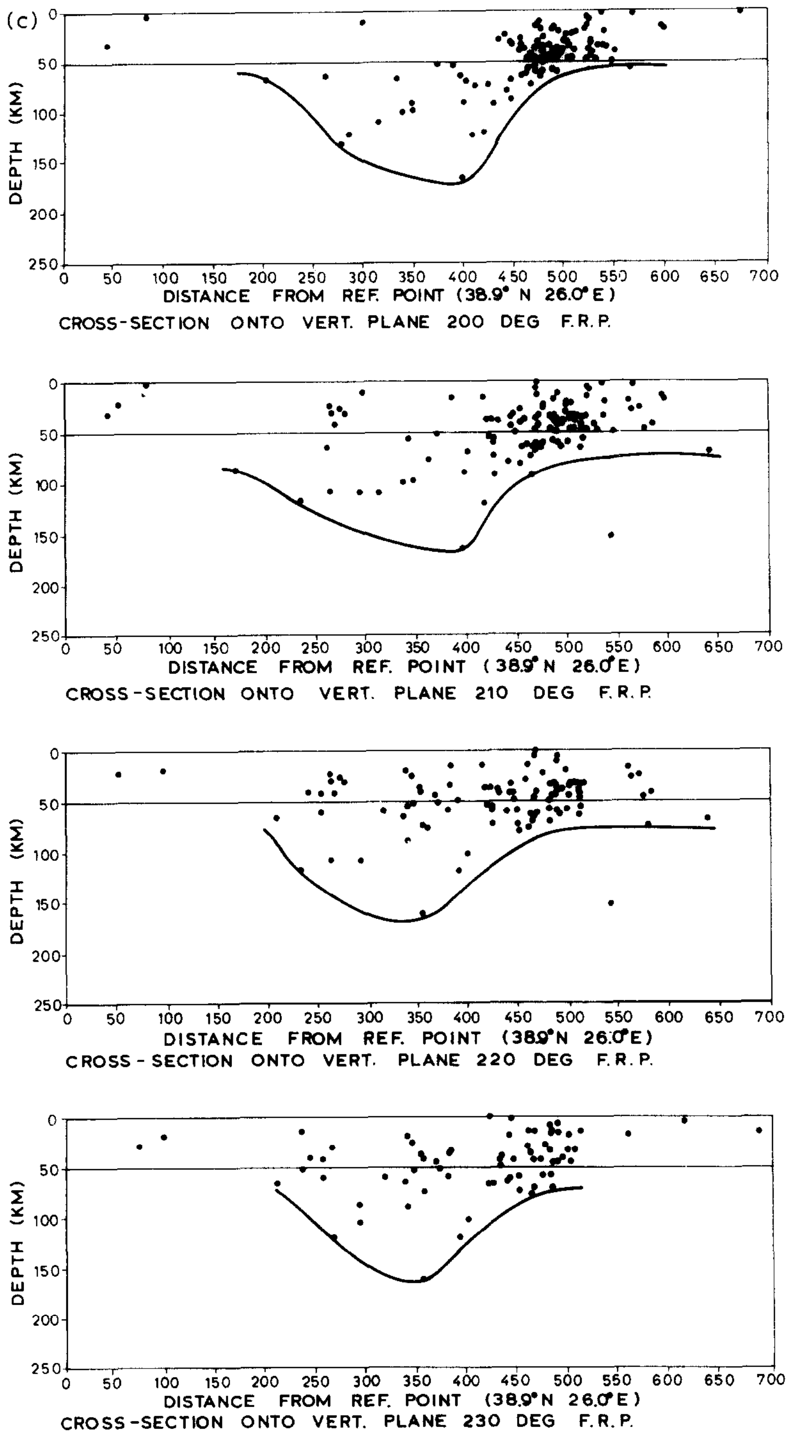


Fig. 5c. For legend see p. 289.

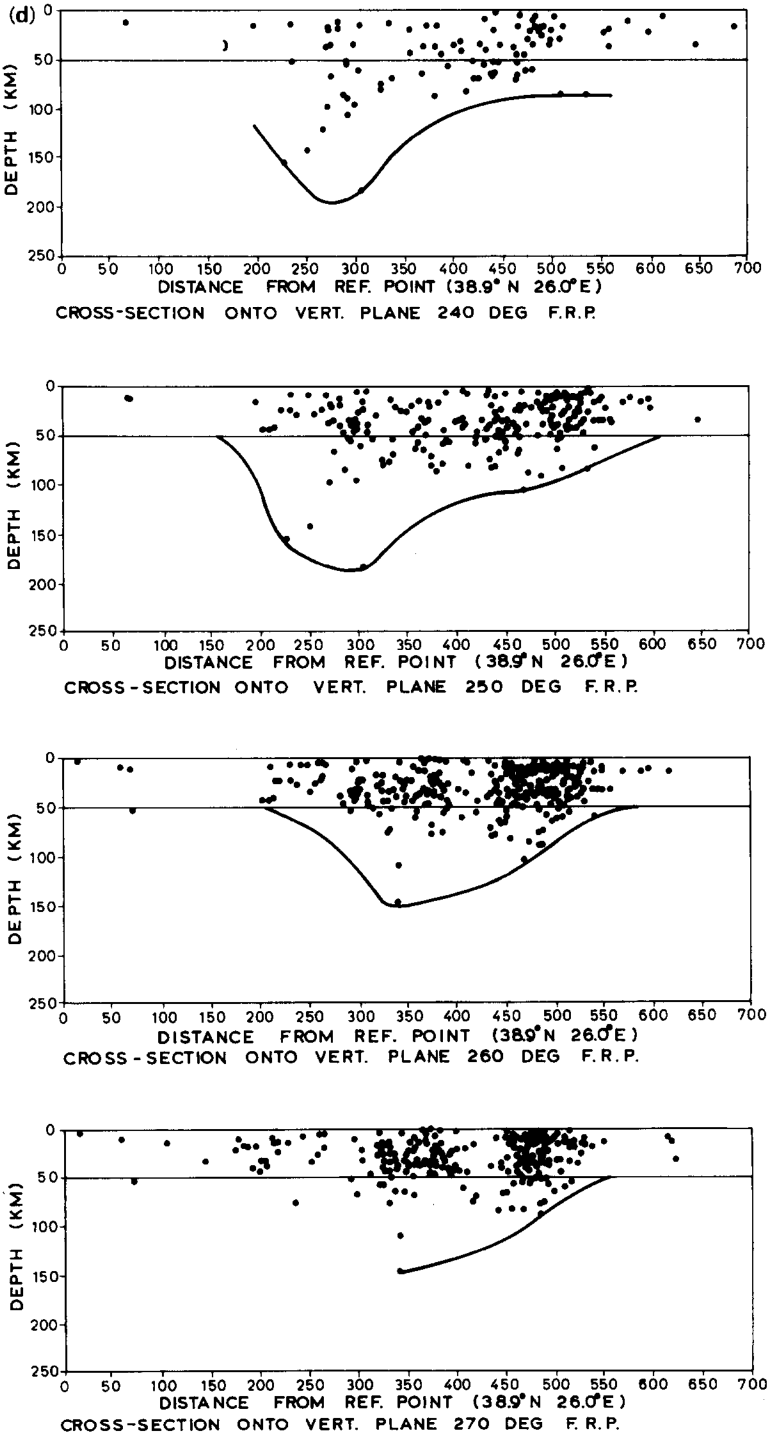
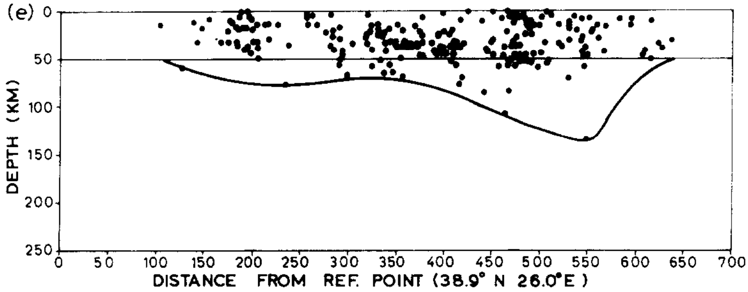
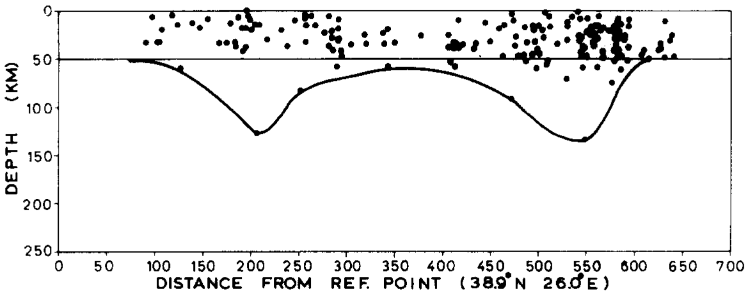


Fig. 5d. For legend see p. 289.

(e)



CROSS-SECTION ONTO VERT. PLANE 280 DEG F. R. P.



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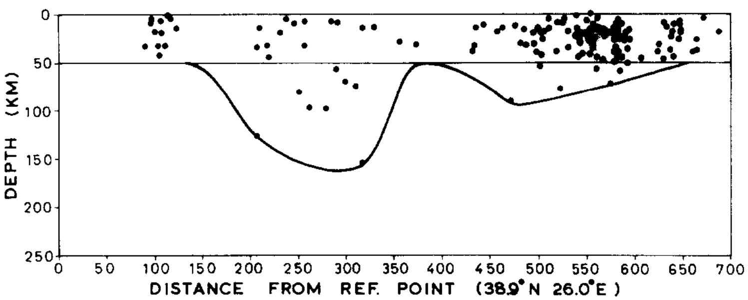

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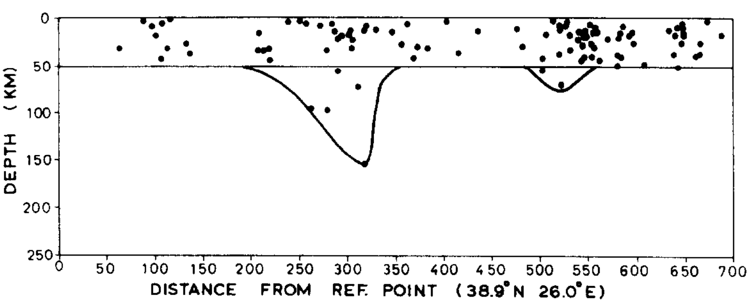


CROSS-SECTION ONTO VERT. PLANE 310 DEG F. R. P.

(4) For each of these 36 cross-sections a smooth curve is fitted by eye enveloping the lower part (deeper earthquakes) of the projected events below 60 km. When the enveloping lines are drawn by eye such factors as differences in hypocentral densities between radial cross-sections have to be evaluated and taken into account as well as the variation in depth estimates.

Earthquakes which have a focal depth less than 60 km are excluded.

Figure 5 illustrates the cross-sections obtained by this procedure. Coordinates of points along these smoothed curves or envelopes to the cross-sections may then be taken, and these coordinates (distance from the reference point in kilometres and depth in kilometres) constitute a new three dimensional data set which may subsequently be contoured by any chosen means. This three dimensional matrix of latitude, longitude and depth points is a topographical surface corresponding to the base of earthquake occurrence. Two different approaches are now adopted to present this topography in visual form.

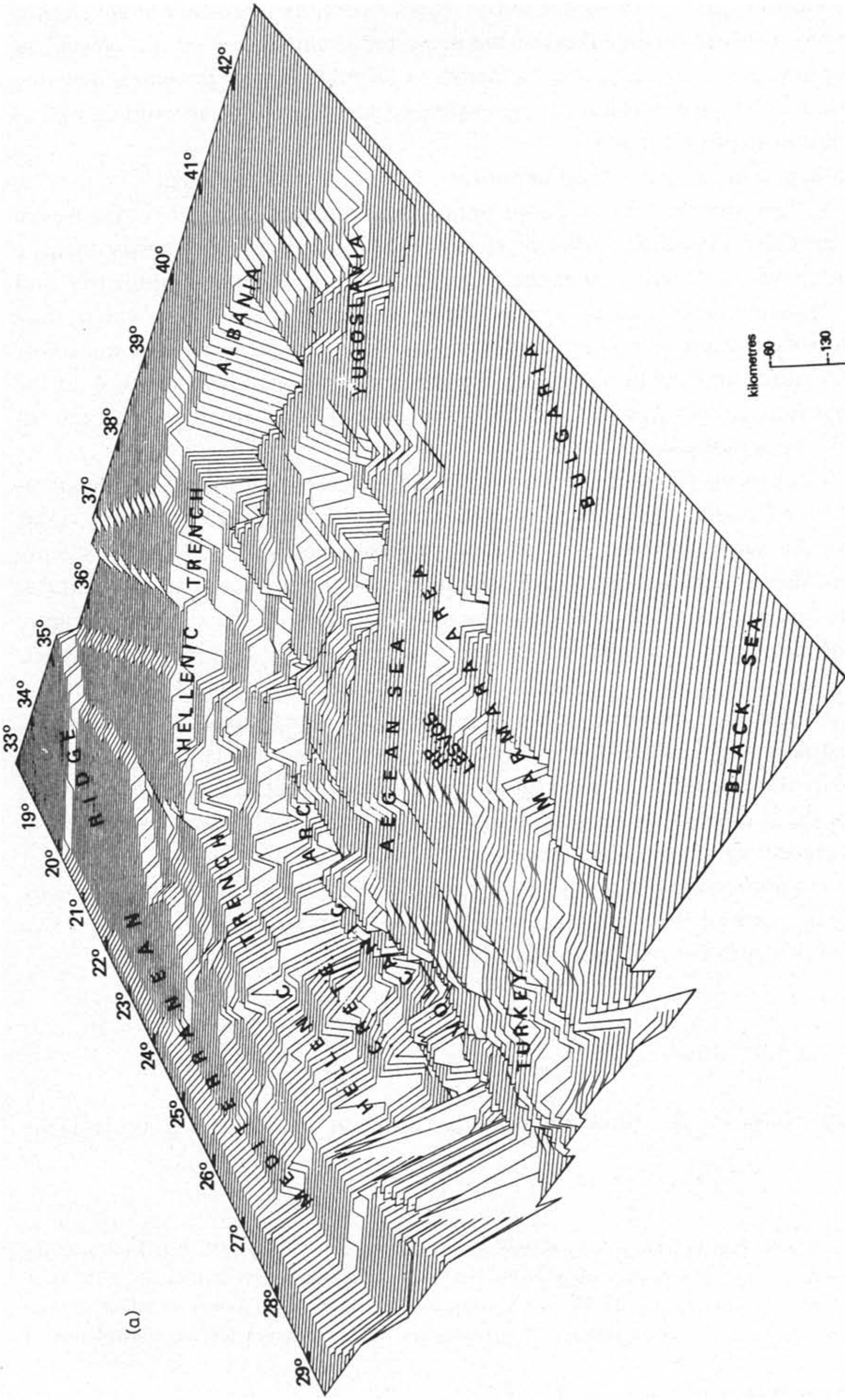
The first approach produces pseudo three dimensional "views" of the topography; the "view" point may be any arbitrarily selected azimuth. Each view is taken from above the earth's surface. As with any view the depths of trenches or steeply down-going slopes may be obscured by the foreground, and therefore each natural view of the topography presented is accompanied by a view of the same topography reflected at the earth's surface: each trench bottom which had previously been obscured then appears as a conspicuous ridge. Four topographical views of the earthquake occurrence appear in Fig. 6 as pseudo three dimensional isodepth maps. Specific features are labelled in Fig. 6(a) only, where the view is taken from the Black Sea in the northeast of the region, looking southwest. The other views are taken from the southwest, northwest, and southeast respectively; each view giving a different perspective to the topography.

The second approach produces a more normal representation of the isodepths by contouring the base of the earthquake occurrence topography and presenting a two dimensional isodepth contour map (Fig. 7).

RESULTS AND DISCUSSION

The four views of the three dimensional isodepth maps in Fig. 6, and the

Fig. 5. a. Four vertical radial planes passing through the reference point RP (38.9°N, 26.0°E) near to the centre of the volcanic arc. Hypocentres are projected onto each plane from azimuths between ±10° from the plane. Heavy lines enveloping the base of earthquake occurrence are those from which a three dimensional topographic surface of latitudes, longitudes and depths emerges for the construction of isodepth maps.
b, c, d, e. For explanation see caption Fig. 5a.



MEDITERRANEAN RIDGE
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(a)

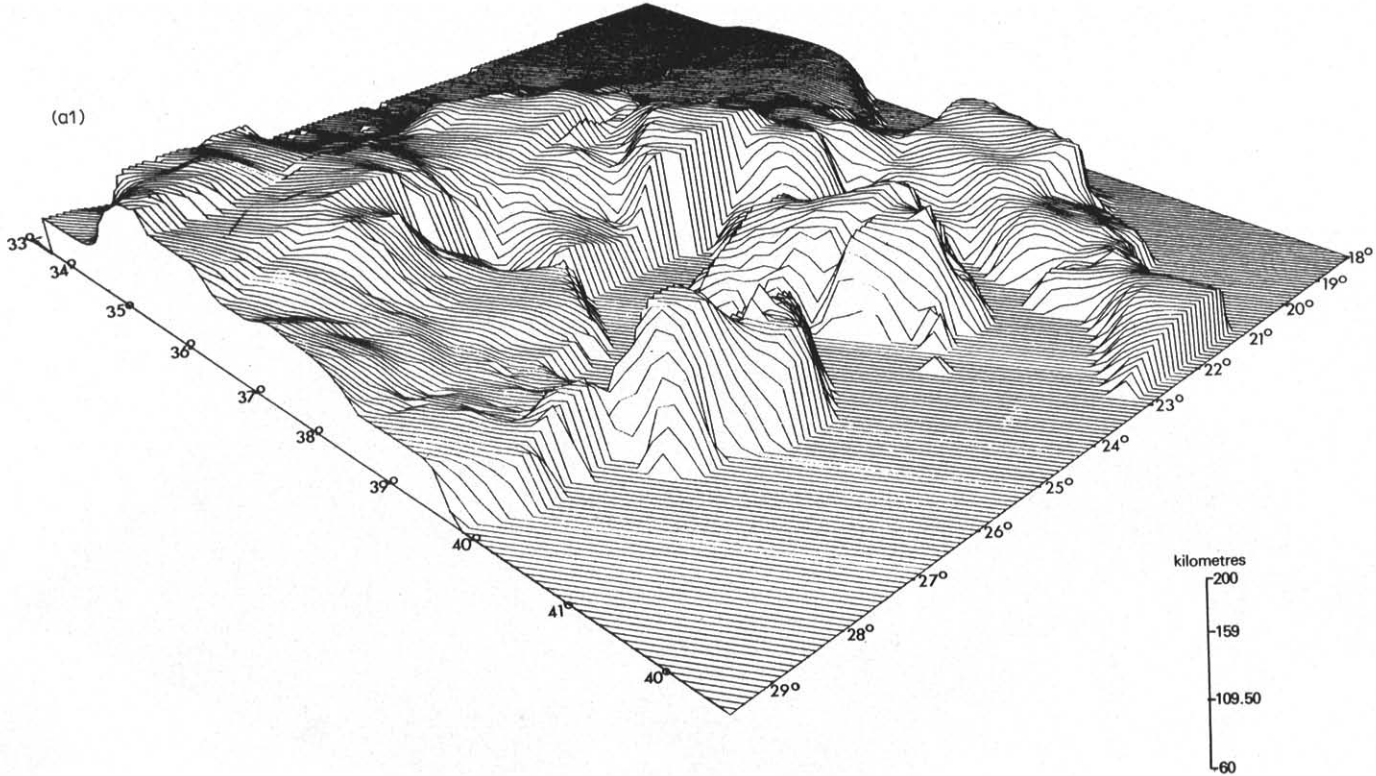
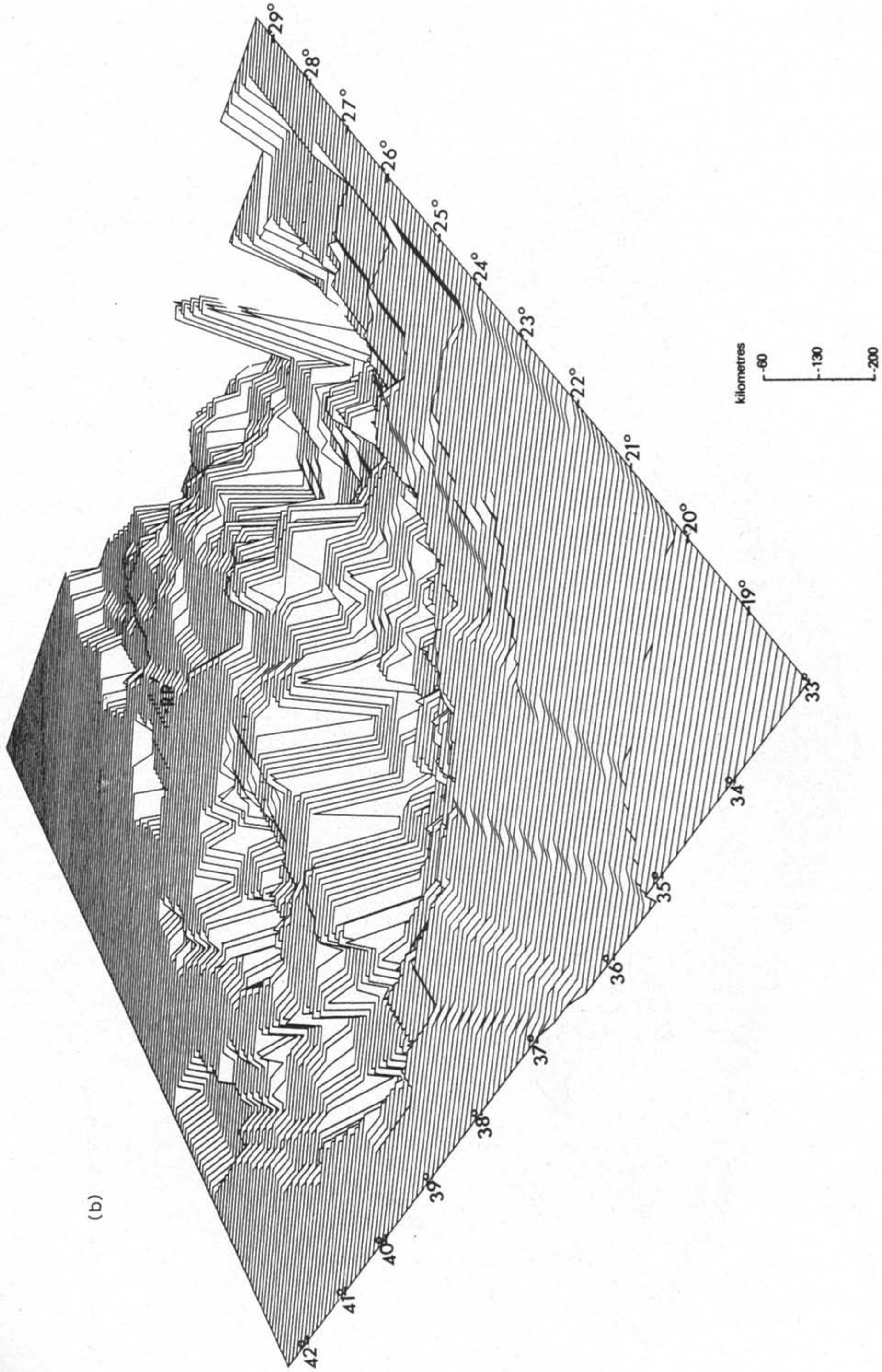


Fig. 6a, a1. For legend see p. 297.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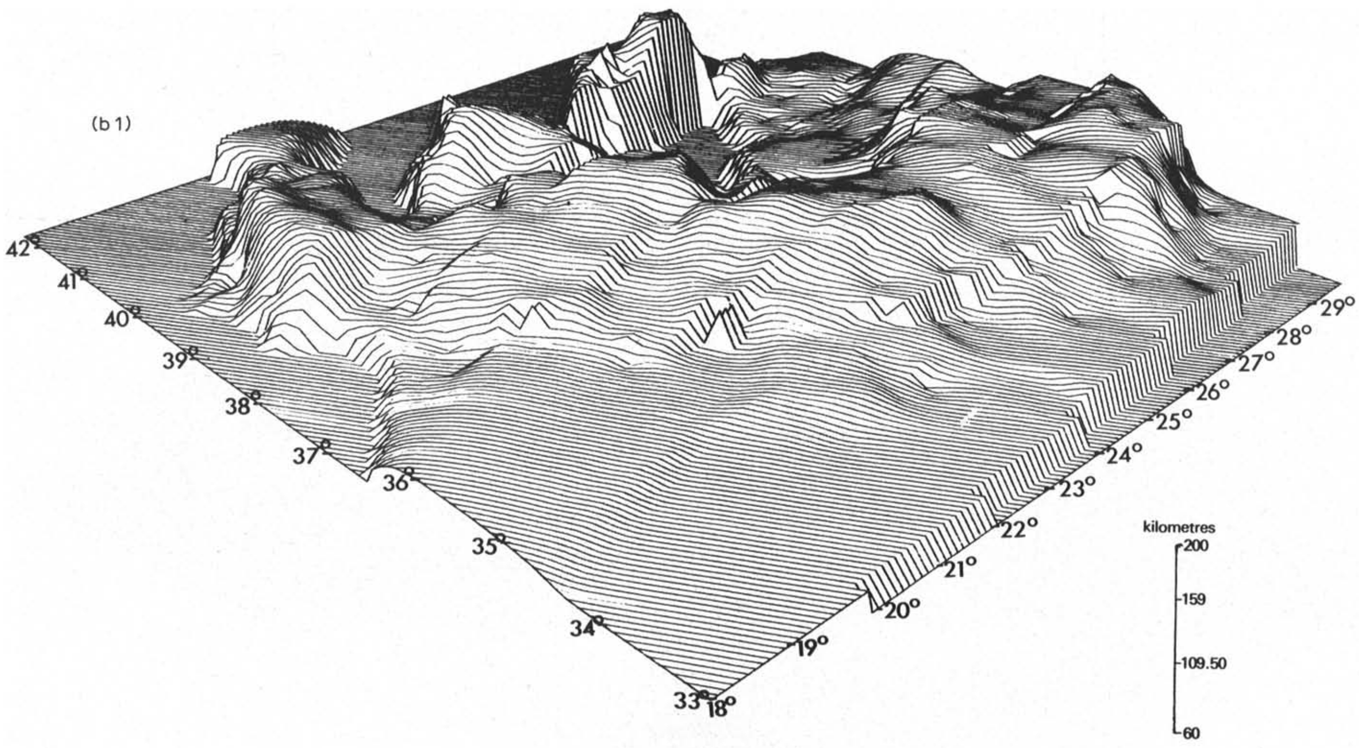
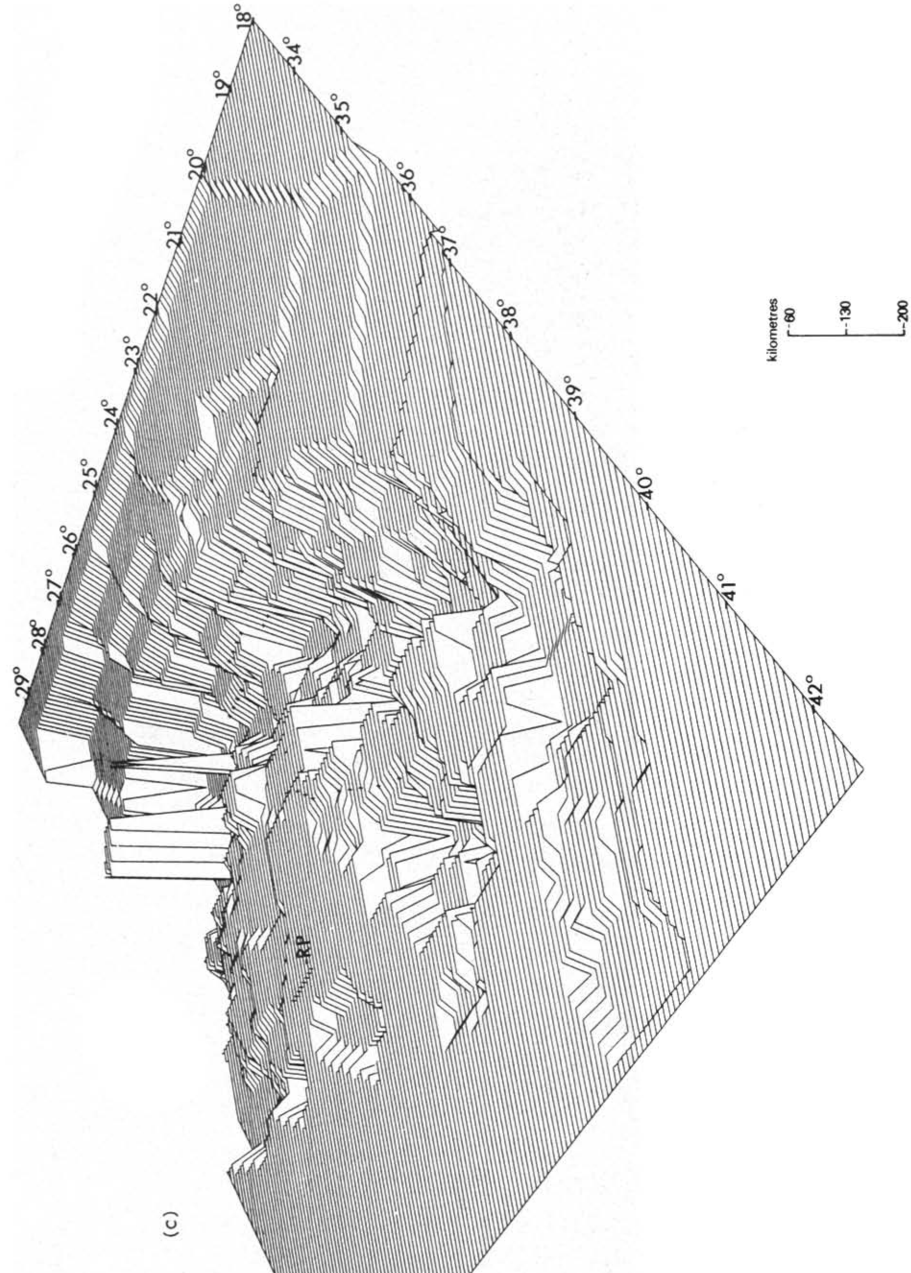


Fig. 6b, b1. For legend see p. 297.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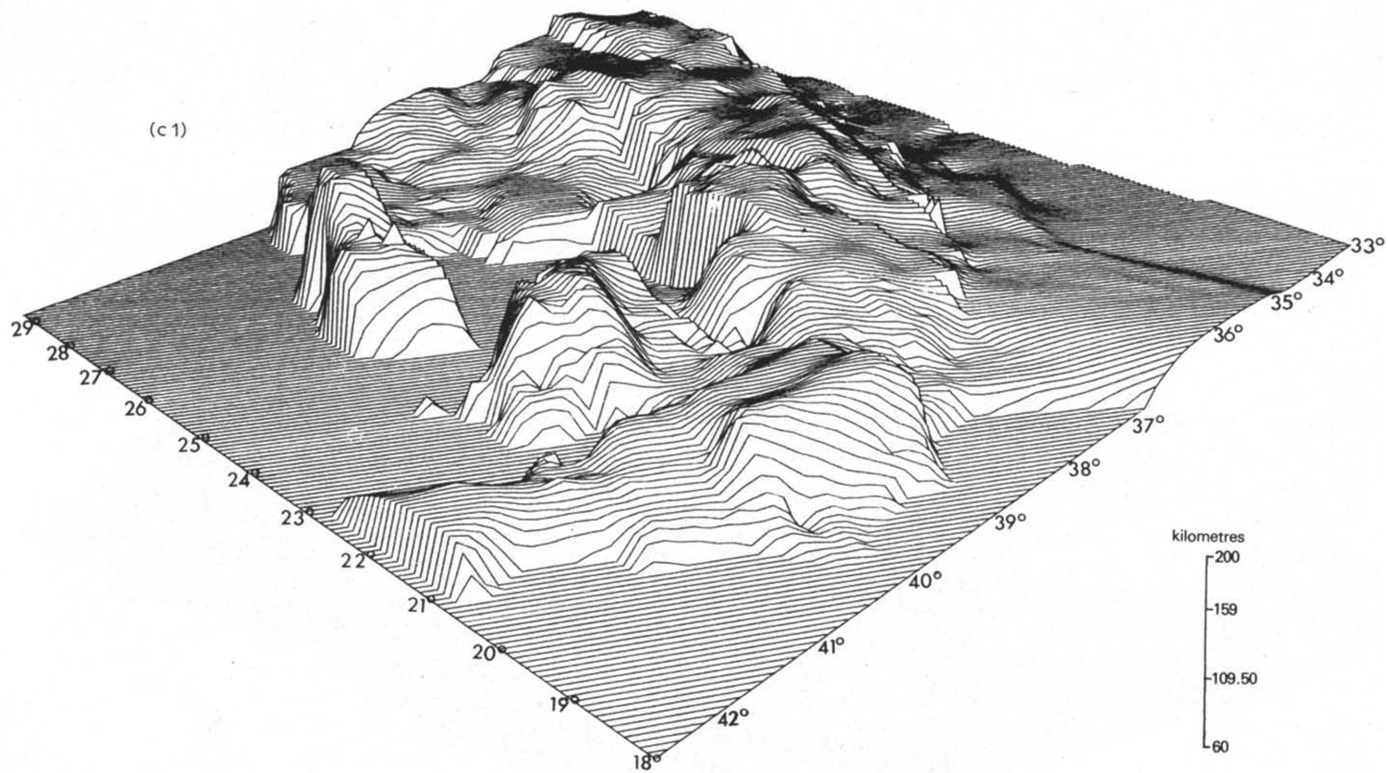
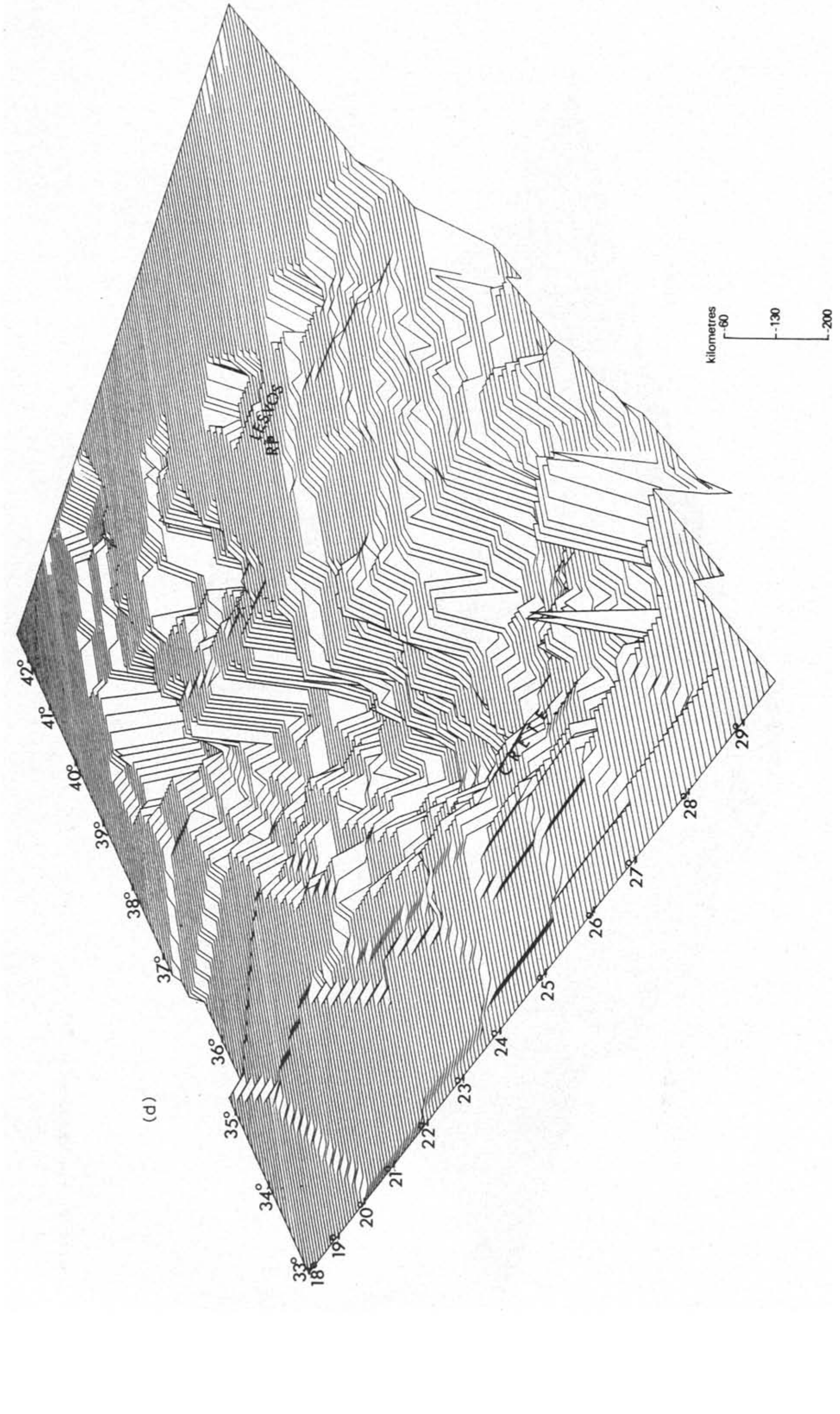


Fig. 6c, c1. For legend see p. 297.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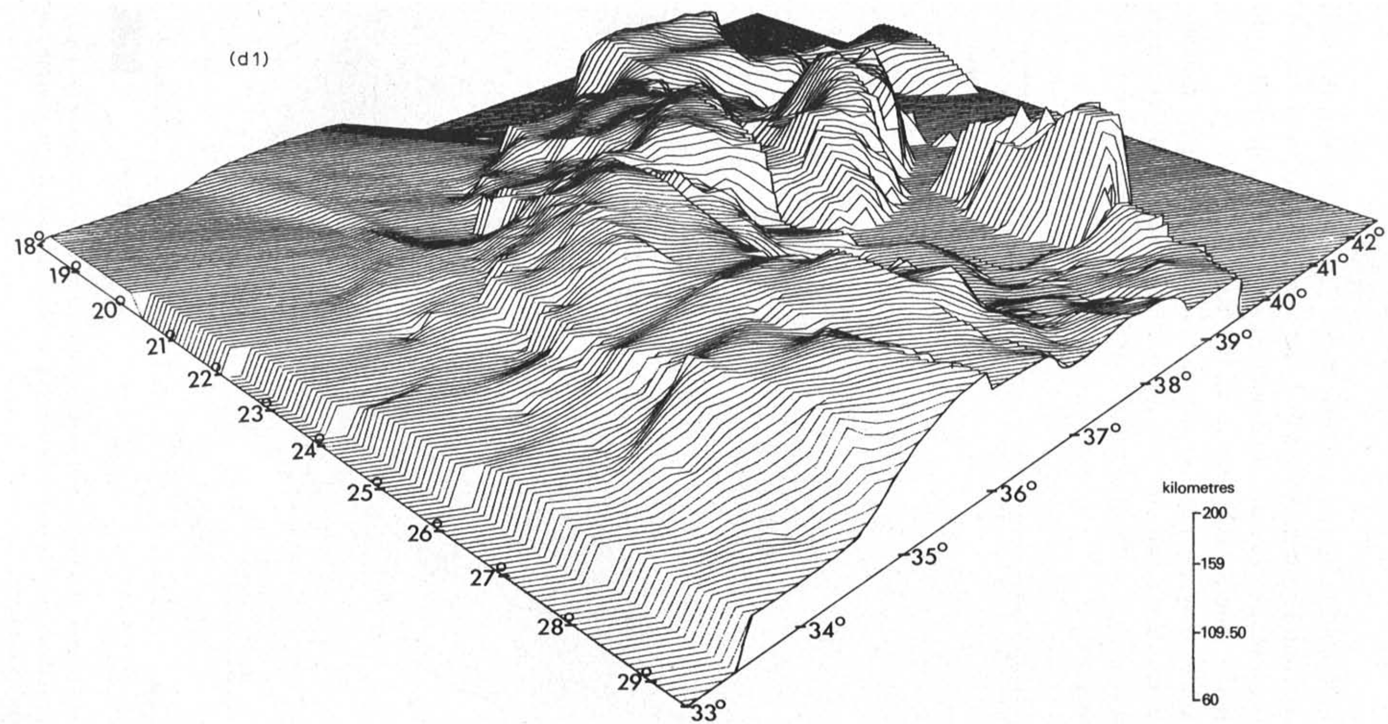

Fig. 6. Three-dimensional isodepth maps for Greek earthquakes produced using the topographic surface obtained from vertical cross-sections shown in Fig. 5. The depth scale in kilometres is indicated in the insert. RP—reference point for all cross-sectional diagrams, approximately at the centre of the volcanic arc. All views are taken from above the surface of the earth. Trench bottoms and other deeps are usually obscured by foreground, and so reflections of the same topography are presented in which obscured troughs appear as ridges. Pseudo three-dimensional isodepth map of Greek earthquakes viewed from (a) the northeast, (b) the southwest, (c) the northwest and (d) the southeast. a1, b1, c1 and d1 as for a, b, c, and d respectively, but reflected at the surface of the earth.

two-dimensional isodepth map of Fig. 7, which result from the above procedures, show the following features:

(a) *Hellenic trench*: All the tectonic models of the region agree that the Hellenic arc is a collision front between Africa and the Aegean area, and that Africa underthrusts the Aegean area causing a subduction zone to develop at the collision front. This subduction zone is easily seen in all the figures.

The isodepth of 70–110 km runs almost parallel to the Hellenic trench, with increasing depth towards the two ends. In the northwestern end of the trench this isodepth continues to the north, and runs well into Albania, where it has not previously been mapped.

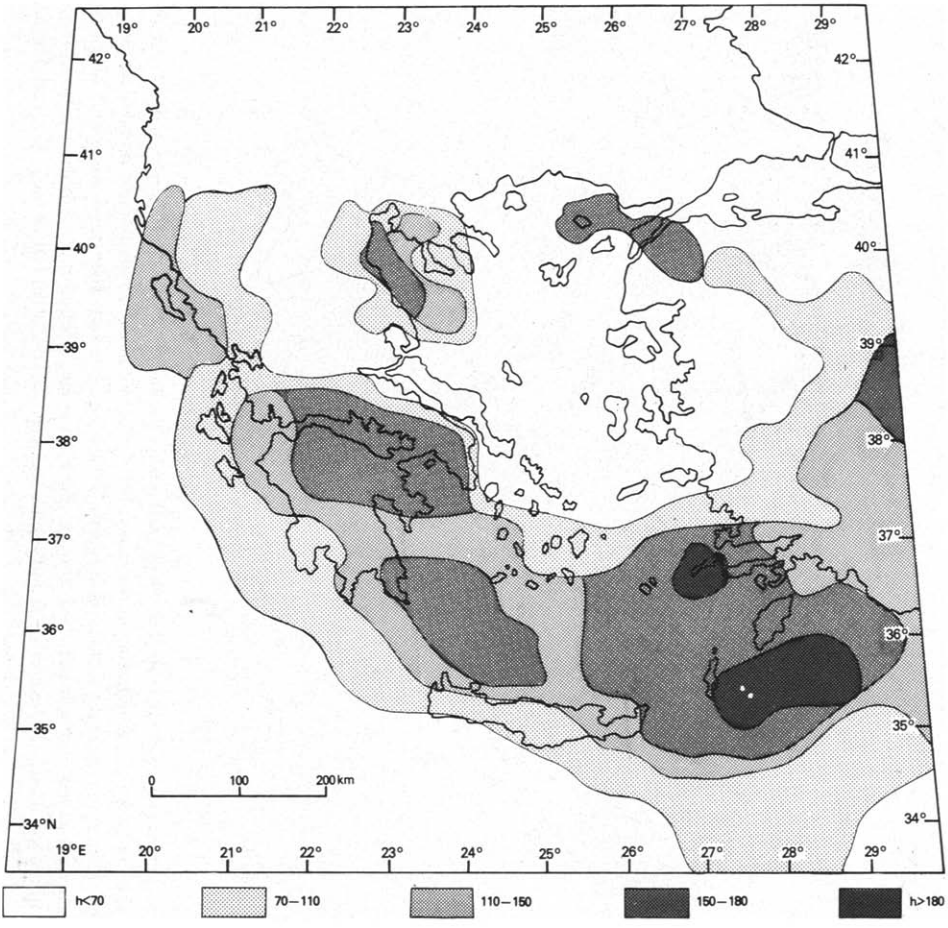

Fig. 7. Two-dimensional contoured isodepth map for Greek earthquakes produced using the topographic surface obtained from vertical cross-sections shown in Fig. 5. Shadings used for focal depth ranges in kilometres are indicated in the insert.

An isodepth of 110–150 km is developed on the convex northwestern end of the Hellenic trench which includes the northwestern part of Greece, Corfu Island and the southwest coast of Albania. From these isodepths alone it is difficult to conclude if there is a "blob" (McKenzie, 1978) or a poorly defined Benioff zone (Papazachos and Comninakis, 1976), or if this thickening is caused by the existence of the rigid Apullian block beneath the sea to the west, which is stronger than the heavily deformed belts of Albania and Greece (McKenzie, 1978). However, the clear continuation of this arcuated zone north of Leukas Island and the existance of thrust faults (see Fig. 3b), may suggest that subduction is taking place. This area is certainly among those where more work is needed in order to understand the present tectonic process.

At the southeastern end of the Hellenic trench (east of Crete) the depth distribution and topographical views show that the subduction zone continues, and meets western Turkey and Cyprus through the Pliny and Strabo trenches, rather than at the coast of western Turkey near Rodos Island. From the isodepth maps it is apparent that south of Rodos the most extensive and deepest seismicity of the whole area is found, and earthquakes with depths within 180–210 km dominate the area.

Although the majority of the intermediate shocks are related to the subduction zone now occurring along the Hellenic arc, from the isodepth topographies and map it can be seen that there is no clear increase in depth with distance from the thrust zone, and the distribution of deeper earthquakes does not follow the volcanic arc. Thus, it is difficult to define a simple Benioff zone in the southern part of the Aegean region.

The less active part of the arc is between the Peloponnesus and western Crete, but if the relative motion between the Aegean area and Africa is in a southwest direction, as the results of McKenzie's fault plane solutions show (big arrow in Fig. 3b), then this part of the arc should be the most active. Furthermore, the dip of the slab of subduction in that direction should be greater beneath southern Greece than beneath the southeastern part of the Aegean. McKenzie (1978) points out that this may indicate a seismic gap or changes in direction during the period of subduction. The seismic gap hypothesis has been taken up by Wyss and Baer (1981), considered by Ambraseys (1981), and appears compatible with the analysis of contemporary seismic risk by Burton et al. (1984). Only further work on determining the history of deformation behind the Hellenic arc may explain the relative movements here.

(b) *The Aegean area:* In the southern part of the Aegean area there are four places with maximum or near-maximum isodepths:

(1) The northeastern part of the Peloponnesus, the Gulf of Saronikos and the eastern part of the Gulf of Corinth. Papazachos (1977) interprets the existence of thrust faulting for three intermediate earthquakes, and their difference from the surrounding shallow earthquakes in this region, as due to a sinking slab from the Ionian Sea to the Aegean. However, McKenzie's fault plane solutions (1978), and

field mapping of Mercier et al. (1976), show that most of the deformation in this area is produced by normal faulting (see also Fig. 3b). Fieldwork following the Corinth earthquakes of 1981 February and March is also consistent with graben-like extensional normal faulting (Jackson et al., 1982).

(2) The southeastern part of the Peloponnesus, extending towards Crete.

(3) South of Rodos Island.

(4) West of Kos Island (south of Rodos and west of Kos are maximum isodepths, and the entire region between and surrounding these two maxima shows isodepths in the range 150–180 km).

The general picture of the south part of the region is an arcuated distribution, but with a complex rather than a simple increase of depths with distance from the trench, the deepest part of the regional activity being south of Rodos which probably continues towards southwestern Turkey.

The main feature in the central part of the Aegean area is that central Greece and the Aegean Sea are characterized by shallow seismic activity. This, coupled with the existence of two aseismic blocks, shows that there is no subcrustal evidence that the Northern Anatolian fault is connected with the seismic zone of central Greece, or the Gulf of Corinth. The attikocycladic block in the Aegean and the block associated with the Ptolemais basin in central Greece are evident in the isodepth maps as plateau, and identify with general lows of seismicity.

In the northern part of the Aegean the features are more complicated than elsewhere. The intermediate depth shocks are fewer than in the southern part. The fact that thrust and normal faulting exist (Ritsema, 1974; Papazachos, 1976a), and the low depth seismicity of the region, lead Papazachos (1976a) to suggest a northerly sinking slab produced by a subduction zone in the northern Aegean. McKenzie (1978) points out that there is no evidence of thrusting on the scale required for such a suggestion, and that these shocks may lie within material subducted at a trench which is no longer active. From the depth distribution alone none of these hypotheses can be rejected.

The area north of Volos and the Sporadhes, towards the Chalkidiki Peninsula in the northwest Aegean, is particularly complex. Although the shallower seismicity and isodepths lie just to the northwest of the Sporadhes basin, the deeper isodepths are even further northwest into the Gulf of Thermaicos. The overall trend might correspond to the Vardar zone, which Brooks and Ferentinos (1980) point out underwent extensive subsidence in the post-Eocene. There is little evidence in the isodepth maps for the North Aegean trough to be accepted as a plate boundary. This region is also one for which more geophysical data are necessary for better understanding of its deep tectonic process. West of here the aseismic block associated with northeast Greece is seen as a plateau in the isodepth maps.

CONCLUSIONS

The earthquake catalogue of Paper 1, and the spatial and depth distribution maps based on it, reveal that Greece, and the adjacent areas of the Aegean, are tectonically more complicated than had previously been recognized. The seismicity of the region is mainly due to the collision between the underthrusting African plate and the Aegean area along the Hellenic arc. Using the parameters of the earthquake catalogue, a better delineation of the seismic activity of the region is achieved, and the spatial and depth distribution of earthquakes show that none of the proposed tectonic models completely explain the observed activity over the whole area.

The existence of small aseismic blocks, of which three are well defined, shows that the lithosphere is very fragmented, and the region can not be modelled by a simple plate. The earthquake depth distribution and the clear continuation of the seismic activity within Albania along the Hellenic arc may suggest that in the northwestern end of the Hellenic trench subduction is taking place. At the southeastern end of this trench the depth distribution shows that the subduction zone continues and meets Turkey much further south than the existing models suggest. It is difficult to define a simple Benioff zone in the north part, or even in the south part of the Aegean Sea, because there is no simple increase in depth with distance from the thrust zone, and the distribution of deeper earthquakes does not follow the volcanic arc. Rather than conclude simple and uniform subduction taking place along a continuous and smooth Benioff zone (Comninakis and Papazachos, 1980), complexity seems to be what is demonstrated by the data. The northwestern Aegean beyond Volos into the Gulf of Thermaicos is particularly complex, but compatible with local crustal extension overlying a low Q upper mantle.

To fully understand the tectonic process further work is still necessary, especially in the following places:

(1) the northwestern part of the Hellenic arc (northwestern Greece, southwestern coast of Albania);

(2) the southeastern end of the arc (eastern Crete, Karpathos and Rodos Islands);

(3) the northwestern Aegean Sea (north of Volos and the Sporadhes Islands and into the Gulf of Thermaicos) and the northeastern Aegean Sea (including northwestern Turkey and the Dardanelles).

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