A COMPARATIVE STUDY ON THE DEFORMATION OF THE MEDITERRANEAN SUBDUCTION ZONES: THE HELLENIC ARC, THE CALABRIAN ARC AND VRANCEA

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A B S T R A C T

The distribution of stresses derived from fault plane solutions and the geometry of deformation, based on previous work, combined with seismicity data, showed that: In the Hellenic arc the subducting lithosphere is in a state of down dip extension performed at a rate of 8mm/yr. However, considerable horizontal shortening, at a rate of 21 mm/yr, occurs parallel to the trend of the arc. In the Calabrian arc, on the contrary, the descending slab is undergoing down dip compression at a rate of about 2 mm/yr. In the Vrancea area, in Rumania, the westward subduction of the Carpathian trench has terminated, leaving continental lithosphere at present at the arc. The slab is descending, due to negative buoyancy, and is in a state of nearly vertical down dip tension, at a rate of about 2 cm/yr.

ΜΕΛΕΤΗ ΠΑΡΑΜΟΡΦΩΣΗΣ ΣΕ ΤΡΕΙΣ ΠΕΡΙΟΧΕΣ ΚΑΤΑΔΥΣΗΣ ΤΗΣ ΜΕΣΟΓΕΙΟΥ: ΤΟ ΕΛΛΗΝΙΚΟ ΤΟΞΟ, ΤΟ ΤΟΞΟ ΤΗΣ ΚΑΛΑΒΡΙΑΣ (ΙΤΑΛΙΑ) ΚΑΙ ΤΟ ΤΟΞΟ ΤΗΣ ΒΡΑΝΤΣΙΑΣ (ΡΟΥΜΑΝΙΑ)

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Π Ε Ρ Ι Λ Η Ψ Η

Η κατανομή των τάσεων και της παραμόρφωσης καθώς και σεισμολογικές παρατηρήσεις σε τρείς περιοχές κατάδυσης της Μεσογείου έδειξαν ότι: στο Ελληνικό τόξο η καταδυόμενη πλάκα υφίσταται εφελκυσμό κατά μήκος της διεύθυνσης της βύθισης, με ταχύτητα παραμόρφωσης 8 mm/yr. Ομως, υπάρχει και μία συνιστώσα οριζόντιας συμπίεσης με ταχύτητα 21 mm/yr. Στο τόξο της Καλαβρίας (Ιταλία), η βυθιζόμενη πλάκα υφίσταται συμπίεση κατά τη διεύθυνση κατάδυσης με ταχύτητα 2 mm/yr. Στην περιοχή της Βράντσιας (Ρουμανία), η προς τα δυτικά βύθιση της τάφρου των Καρπαθίων έχει τερματισθεί και σήμερα υπάρχει ηπειρωτική λιθόσφαιρα στο τόξο. Η πλάκα βυθίζεται κυρίως λόγω του βάρους της, και βρίσκεται σε κατάσταση εφελκυσμού κατά τη διεύθυνση κατάδυσης με ταχύτητα 2 cm/yr.

INTRODUCTION

Seismology may provide very adequate information about the internal deformations of descending lithospheric slabs. This can be done by mapping earthquake moment release and source mechanisms, which measure the rate of strain occurring within slabs on the time scale over which the events were recorded.

In a sequence of papers, using this approach, the seismic deformation at the subduction zones of the Mediterranean area has been studied (Kiratzi and Papazachos, 1992; Kiratzi, 1993a, b). In the present study, a comparative study of the distribution of stress and of the pattern of deformation in the Hellenic arc, in the Calabrian arc (Italy) and in Vrancea (Rumania) is attempted.

The methodology followed in order to constrain the seismic strain rate release and the seismic velocities has been published in Papazachos and Kiratzi (1992) and will not be repeated here.

The data used in the present study are seismicity parameters and fault plane solutions listed in Kiratzi and Papazachos (1992) and Kiratzi (1993a, b).

GEOMETRY OF THE SUBDUCTION ZONES

The Hellenic arc

The African plate is subducting under the Aegean lithosphere along the Hellenic arc in an amphitheatre-like shape which is outlined by earthquake hypocenters (Papazachos and Comninakis, 1969;1971, McKenzie, 1978; LePichon and Angelier, 1979). Thus, intensive seismic activity in the Aegean area and especially in the southern part is observed. Earthquake activity reaches depths up to 183 Km (Comninakis and Papazachos, 1980; Hatzfeld and Martin, 1992) and the magnitudes can be as high as 7.8 (Papazachos, 1990). Even though the activity is significant there are not many large intermediate depth earthquakes that occurred during the last six decades.

Figure (1) shows the intermediate depth earthquakes that occurred in the southern Aegean area (from Kiratzi and Papazachos, 1992) and the three seismogenic source volumes identified by Papazachos (1990).

The Benioff zone has a shallow dip (14°) for depths in the range 40-100 Km. Then, as we go further away from the trench, its dip steepens to reach a mean value of 35° (Papazachos et al., 1991). The thickness of the seismogenic volume is estimated to be 30 Km from the distribution of the best depth contsrained events (Kiratzi and Papazachos, 1992).

The Calabrian arc

In the Calabrian arc, the intermediate depth seismicity, shown in figure (2), appears to be characteristic of a subduction zone although it is not known if subduction is presently occurring there. There is evidence, however, that support the idea of a terminated subduction process. Earthquake hypocentres reach a depth of about 500 Km which suggests that subduction took place over a long period of time. The slab is descending NW at a high angle (70°) above 250 Km which changes to a more gentle dip (45°) at greater depths. The thickness of the seismogenic layer is 50 Km (Anderson and Jackson, 1987).

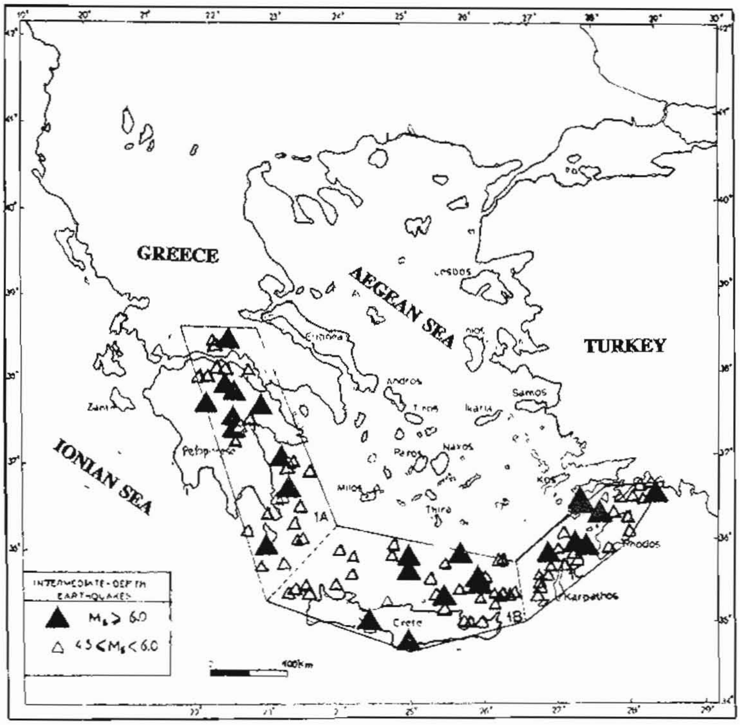

Fig.1. Distribution of the intermediate depth seismicity along the southern Aegean, for the period 1900-1990 (Kiratzi and Papazachos, 1992).

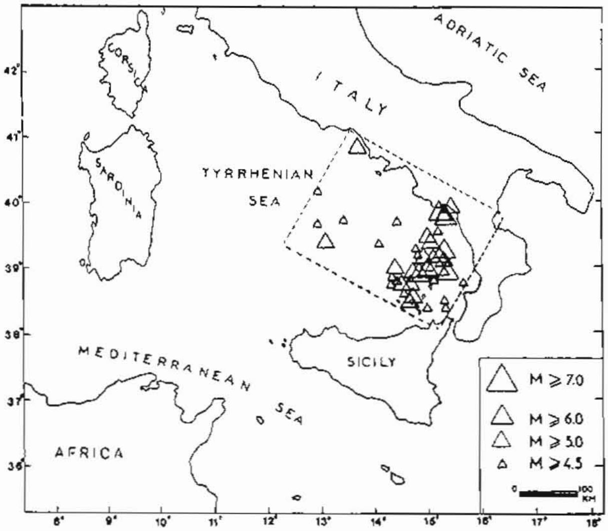

Fig.2. Distribution of the intermediate depth seismicity along the Calabrian arc, Italy, for the period 1900 -1990 (Kiratzi, 1993a).

The Vrancea region, Rumania

The Vrancea-Carpathian region of the SE Carpathian Arc Bend, is an area where intense seismic activity is observed with earthquakes that extend to depths up to 200 Km and have magnitudes as great as 7.5.

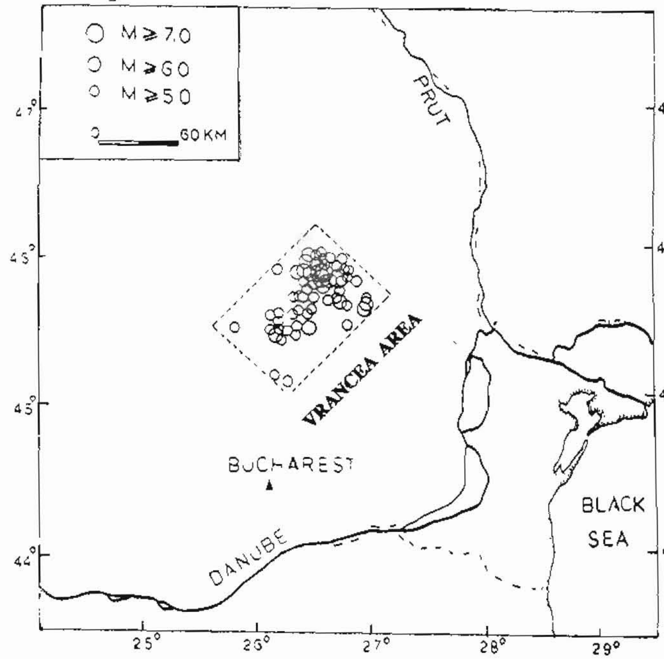

Fig.3. Distribution of the intermediate depth seismicity in Vrancea, Rumania, for the period 1900-1991. (Kiratzi, 1993b).

Figure (3) shows the distribution of the intermediate depth earthquakes in the Vrancea region. One characteristic of these intermediate depth events is that spatially occur in a very limited area. The slab is dipping to the NW at a high angle 75° and the thickness of the seismogenic layer is 30 Km (Trifu, 1990).

ORIENTATION OF THE PRINCIPAL STRESS AXES

Figure (4) shows the fault plane solutions of the intermediate depth earthquakes for each area of study. A lower hemisphere equal area projection is used where the black quadrants denote compression while the white ones denote dilatation.

Figure (5) shows a lower hemisphere equal area projection of the T-axes (open circles) and of the P axes (filled circles) of these focal mechanisms. For the Hellenic arc the projection of the slip vectors is also shown on the plots (black triangles). The approximate dip and strike of the subducting slab, for each area, is also shown on the plots.

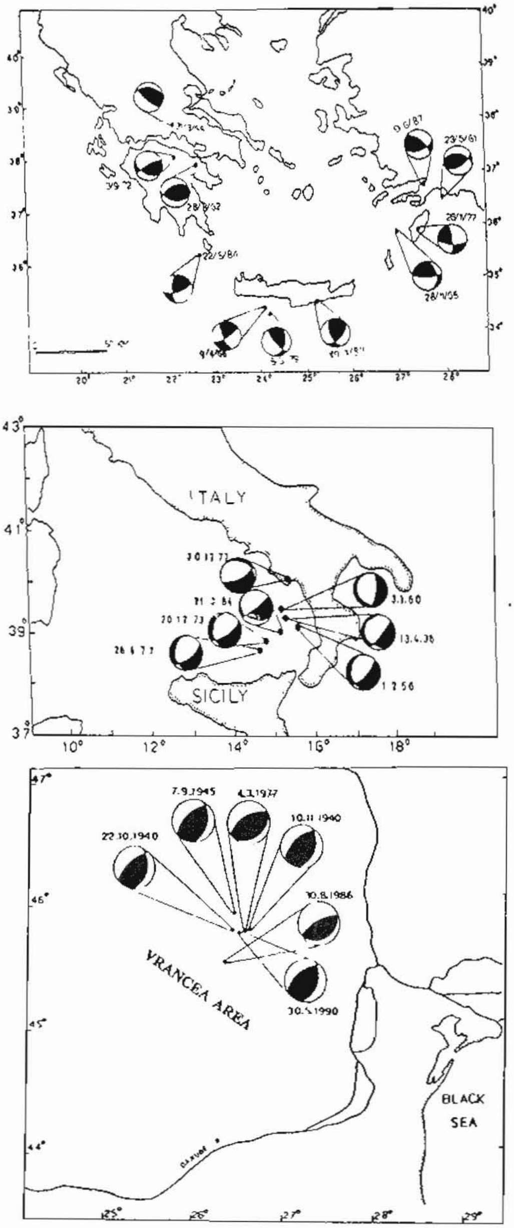

Fig.4. Reliable fault plane solutions of intermediate depth earthquakes (a) in the Hellenic arc, (b) in the Calabrian arc and (c) in Vrancea area of the SE Carpathian arc.

It is seen that in the Hellenic arc the T axes are less variable, compared to the P axes, and follow the dip direction of the subduction. However, the mean dip angle of the T axes is 57°, when the dip of the Benioff zone is only 14°. The black triangles in the plots show the projection of the slip vectors of the earthquakes along the Hellenic arc. As it is seen, the dip of the T axes is much steeper than the dip of the subducting slab however, the slip occurs along the slab.

In Vrancea the situation is the same, with the T axes aligned along the dip direction of the slab. Both the dip angle of the T axes (mean value 75°) and of the slab are the same. At the Calabrian arc, on the contrary, it is the P axes that follow the descending slab and are lying within it, as they have the same dip angle.

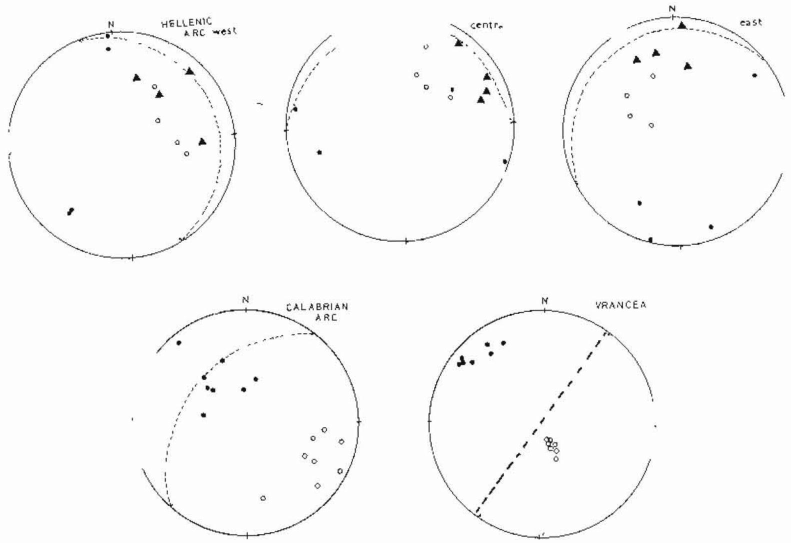

Fig.5. Equal area lower hemisphere projection of the P axes (black circles) and of the T axes (open circles) of the fault plane solutions shown in fig.4. The black triangles in the plots for the Hellenic arc are the projection of the slip vectors of the earthquakes. The dashed lines indicate the approximate projection the approximate dip and strike of the subducting slab in each case.

SEISMIC VELOCITY RATES

Figure (6) is a sketch map which shows the maximum seismic velocities observed at these subduction zones as they were calculated in Papazachos and Kiratzi (1992), Kiratzi (1993a, b).

In the Hellenic arc, even though the T axes dip steeper than the slab, the maximum slip though is observed along the dip direction of the slab. The down dip extension, of 8 mm/yr in average, can be explained by pull forces acting at the slab. The horizontal compression though, that follows the trend of the Hellenic arc, is rather difficult to explain. Taymaz et al., (1990) believe that this compression is possibly due to the fact that eastern Meditterranean is in a state of compression from processes that are unrelated to the subduction.

In the Calabrian arc the descending slab is in a state of down dip compression with a maximum velocity of about 2 mm/yr. The pattern of deformation indicates that this deformation is taking place off of the plane of the descending slab (Kiratzi, 1993a). This would probably cause the breaking up of the slab or the generation of topography in its surface as pointed out by Anderson and Jackson (1987).

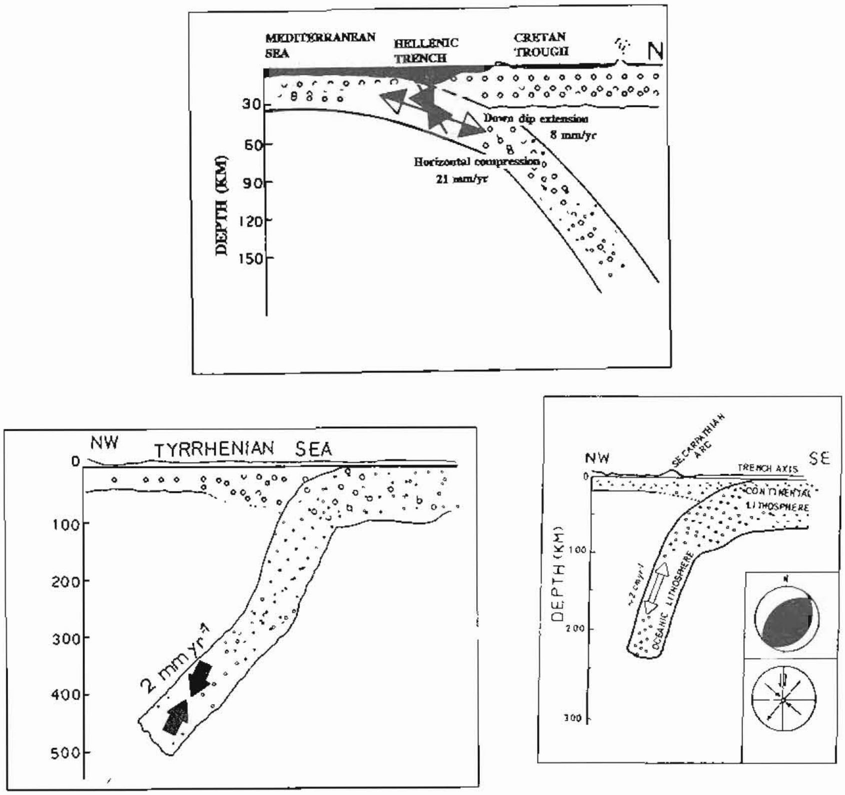

Fig.6. Sketch map that illustrates the deformation pattern in each of the subduction zones examined in this paper.

Finally, in the Vrancea area, the pattern of deformation is rather simple. The slab is descending due to its own weight which causes a down dip extension of 2 cm/yr and at the same time nearly horizontal shortening of 1 cm/yr. At a late stage, due to this geometry of deformation, the slab will be eventually detached.

CONCLUSIONS

Three subduction zones of the Mediterranean area are examined in order to compare the distribution of stress and the geometry of deformation.

The subducting slab at the the Hellenic arc is in a state of down dip tension. The T axes have a mean dip of 57°, when the dip of the Benioff zone, at the depth range of 40-100 Km, is about 14°. The direction of the dip is from the outer part of the Hellenic arc (eastern Mediterranean) to the inner part (Aegean Sea). The maximum deformation is expressed as down dip extension at a rate of 8 mm/yr and as horizontal compression, following the strike of the slab, at a rate of 21 mm/yr. This is the deformation due to the seismicity of the depth range 40-100 Km, where the Benioff zone has a shallow dip. The fault plane solutions of these events declare reverse faulting on steeply dipping nodal planes. As we go closer to the trench, towards eastern Mediterranean, the fault plane solutions declare low angle thrust faulting (Papazachos et al., 1991). These thrust faults contribute to the deformation along the Hellenic arc, which is expressed as compression at a rate of 6 mm/yr that has a direction 214° (Papazachos et al., 1992). This is in accordance with the direction of Africa relative to Eurasia. Plate motions predict that the convergence rate between these two plates is 1 cm/yr under Crete. If we consider the deformation attributed to the thrust faulting near the trench and to the reverse faulting at the shallow part of the Benioff zone, then there is no strong evidence for aseismic deformation processes involved at the Hellenic arc, an observation supported by various researchers (Main and Burton, 1989).

The subducting slab at the Calabrian arc is in a state of down dip compression. The P axes have a mean dip angle of 45°, exactly the same as the dip angle of the descending slab. However, the maximum seismic compressional velocity is observed off the plane of the slab, at a rate of 1.7 mm/yr.

In the SE Carpathian arc, in Vrancea area, the descending slab is in a state of down dip extension. The T axes have a mean dip of 74° like the dip of the slab. The maximum deformation is expressed as extension at a rate of 2 cm/yr in the direction of the subduction. This zone of subduction is the oldest of the ones studied and the slab is descending due to its own weight nearly in a vertical direction.

This variation in the distribution of stress, either down dip compression or down dip tension, is controlled mainly by the degree of resistance experienced by the plate during its descent. In the case of the Hellenic arc and the Vrancea, for instance, the slab pull forces are dominating. In the Calabria arc, however, the plate approaches depths of 500 Km, where the mesosphere prevents further descent and supports the lower margin of the plate so that the majority of the seismic zone experiences compression. Another explanation is that the compressional events at depth in the subducting plate may originate from the unbending of the slab. The angle at which a specific plate is descending plays a key role also to the distribution of stress. The very steep angle of the Benioff zone at Vrancea make the slab to descend due to negative buoyancy and the tension to prevail to any compressional effects.

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