Seismicity, seismotectonics and crustal velocity structure of the Messina Strait

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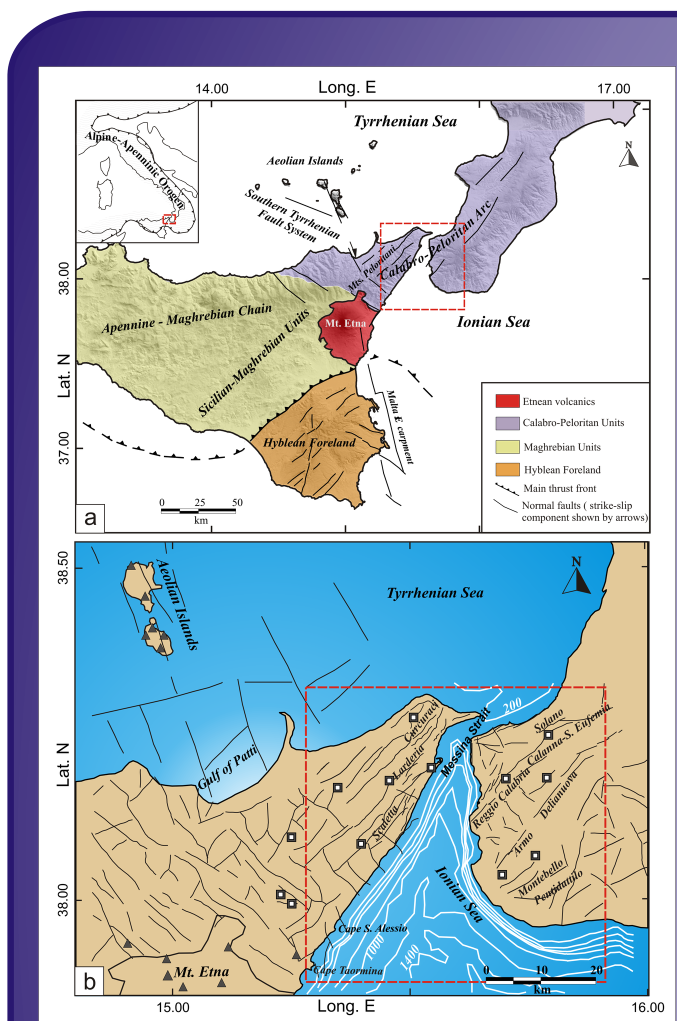

Fig. 1 - Simplified tectonic map (a) and structural sketch map (b) of Sicily and southern Calabria (from Ghisetti, 1992; Lentini et al., 2000; Monaco and Tortorici, 2000). Red boxes represent the area studied in this paper. Permanent seismic network is also reported.

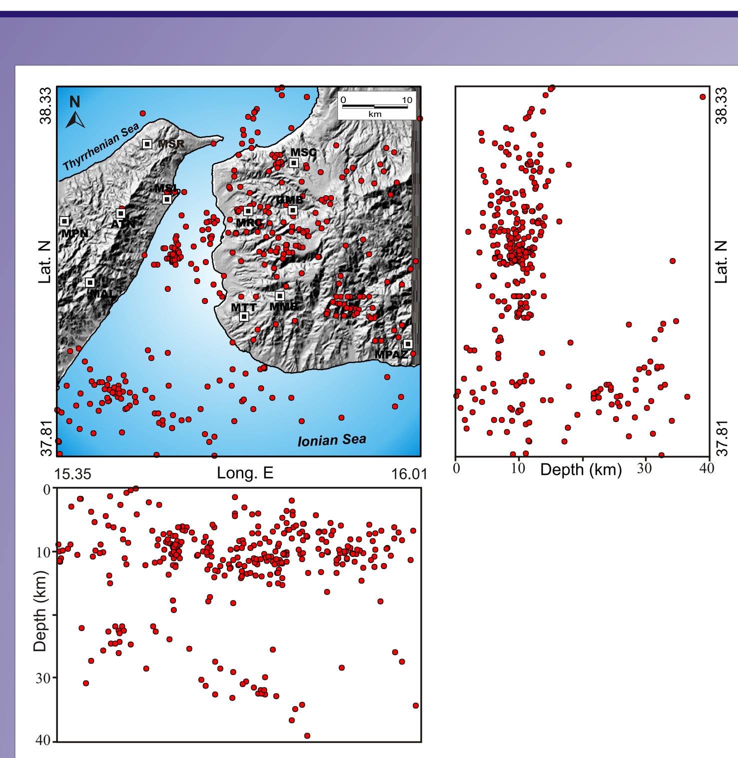

Fig. 2 - Map view, N-S and E-W cross sections of the studied area with earthquakes located from 1999 to 2007. Black/white boxes indicate seismic stations.

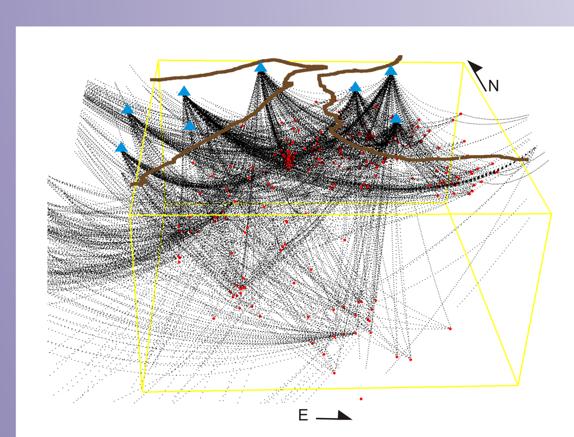

Fig. 3 - 3D sketch of P-wave ray paths traced in the minimum 1D model (Langer et al., 2007). Earthquakes and seismic stations are indicated by red circles and blue triangles respectively.

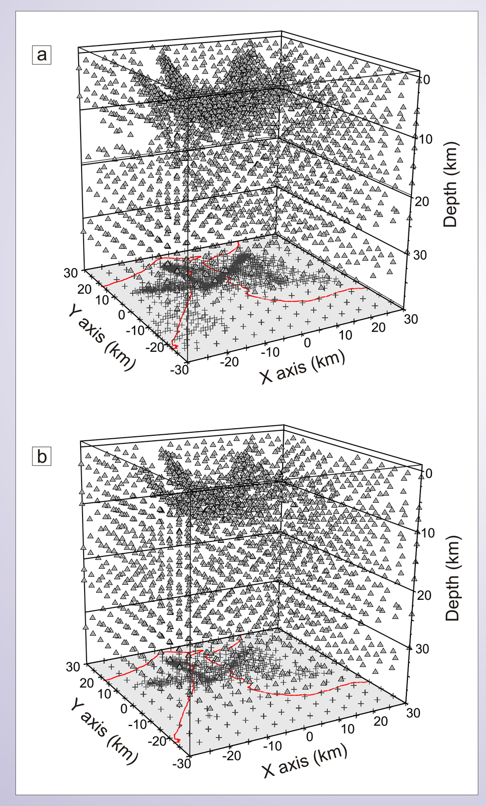

Fig. 4 - Irregular mesh nodes (triangles) for P- (a) and S-waves (b) at the final iteration. On the bottom, the projection of the mesh (crosses) and the map of the area (red contour line) are shown.

A) Introduction

It's now 100 years ago that a disastrous earthquake on December 28, 1908, one of the largest events ever recorded in the central Mediterranean, destroyed Messina, Reggio Calabria and the adjacent areas. In addition to the damage due to the impact of the seismic waves, a great deal of losses was due to a Tsunami which developed as a consequence of the earthquake. In the last decades plenty of material has been collected in the Messina Strait, both concerning seismic data as well as the tectonic structure. From topography and the bathymetry we infer marked escarpments which separates the sicilian and calabrian mainlands (Fig. 1). From geological investigations at the surface, however, we have no proof whether the important topographical elements around the Messina Strait form main fault systems, perhaps cutting the whole crust and reaching the upper mantle.
In the present study we present a synoptic view on seismotectonics, seismicity and 3D velocity structure. The analyses are based on seismic data collected in the time span from 1999 to 2007 (Fig. 2). Fault plane solutions and seismicity patterns help to identify regimes of tectonic motion. Besides this, 3D seismic imaging permits to identify the presence of lateral velocity contrasts along major fault systems.

Tectonic settings

The investigated area belongs to the Calabro-Peloritan Arc which is a part of the Apennine-Maghrebian orogenic belt, along the Africa-Europe plate boundary (see Fig. 1). The Messina Strait appears to be the most important of the structural discontinuities cutting the southern part of the Arc, being a narrow fan-shaped basin that links the Ionian sea to the Tyrrhenian sea. It is bounded by high angle normal faults with prevailing N-S to NE-SW orientation, detected on land and offshore, active during Pliocene and Pleistocene times (Ghisetti, 1992). The complementary NW striking elements are particularly evident in the Eolian Islands and NE Sicily, contributing to a rather complex structural picture.

B) Data

We analyzed seismicity located in the area of the Messina Strait by using the data recorded by a local network deployed by the Istituto Nazionale di Geofisica e Vulcanologia in eastern Sicily and southern Calabria (Figs. 1 and 2) since the 1990's. Our data set consists of more than 300 events occurring in the years from 1999 to 2007 and having a magnitude range from 1.0 to 3.8 (Fig. 2).

Tomography Method

The data set was exploited in a local earthquake tomography, carrying out a simultaneous inversion of both the three-dimensional velocity structure and the distribution of seismic foci. We applied the "tomoADD" algorithm (Zhang and Thurber, 2005), which use a combination of absolute and differential arrival times and a self-adaptative mesh of nodes, based on the ray density. This method is able to produce more accurate event locations and velocity structure near the source region than standard tomography.
We started the inversion from a regular horizontal grid, with 5x5 km node spacing covering an area of 60x60 km, based on the P and S ray paths (Fig. 3). Unlike the most common tomography methods which use regular three-dimensional grid approaches, the adaptive mesh method, based on tetrahedral and Voronoi diagrams, is able to automatically adapt the inversion mesh to match with the data distribution, such that the ray sampling densities on inversion mesh nodes are more uniform than the regular grid case (Fig. 4).

C) Revisited Seismicity

Applying the new 3D velocity model to well locatable events we obtain a seismicity pattern with a much higher degree of clustering than before (Fig. 5). In particular, we recognize epicenters nicely aligned along the Reggio Calabria-Calanna-S. Eufemia fault and the Armo-Delianuova fault systems in SW Calabria. We noticed a limiting depth of ca. 20 km for foci in the area of the Messina Strait. Depth of up to 40 km are found for the events south of the calabrian coast.
Well defined clusters of multiplet events (S1 and S2) (Fig 5) are found in the Messina Strait. High precision relative location, with the master-event technique, permits to learn more about the clusters geometry. For S2 we infer a cluster forming a N 30° E striking planar element, whereas S1 forms a more stocky body in N-S direction (Figs 6a and 6b).

3D Imaging

From the pattern of high- and low-velocity anomalies visible in the layers at different depths as well as in the crossections (Figs 7 and 8) we identify a NE-SW striking strip with negative velocity anomalies. On the calabrian mainland this strip coincides essentially with the zone delimited by the Reggio Calabria - Calanna - S Eufemia (northern border) and Armo - Delianuova faults (southern border, see Fig. 8, crossections A-A'', B-B'', C-C'' and also F-F''). The continuation of this trend in the Ionian Sea is well identifiable in the southernmost profiles. Clear positive P-wave velocity anomalies are found in the northern part of the Messina Strait and along the eastern coast of Sicily. The positive anomaly in the Peloritani Mountains is separated from the one of the Strait by a narrow but evident strip of relatively low velocities. The picture of the deeper layers (12, 15 and 18 km) are characterized by a ridge of positive anomalies starting in the area of Cape Taormina, then bending in ENE direction. The ridge crosses the Ionian Sea and is also found in Calabria.
For the sake of clarity, in figure 9 we show the topography of the 6.5 km/s V_P isosurface which summarize the main features of the obtained velocity structure. In the figure, we also plot the epicenters of the earthquakes located above the isosurface.

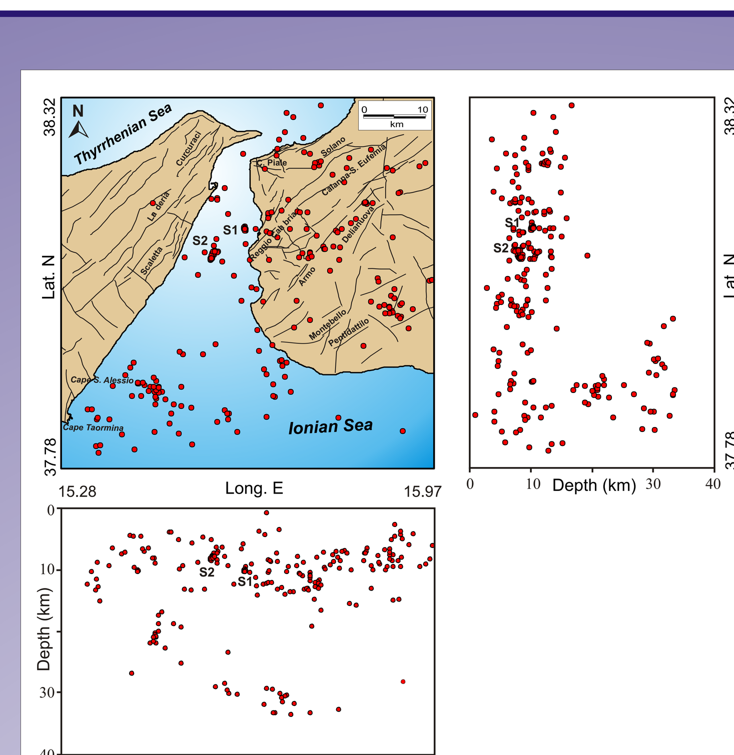

Fig. 5 - Final event locations in map and vertical sections. In the map, the main fault system are also shown.

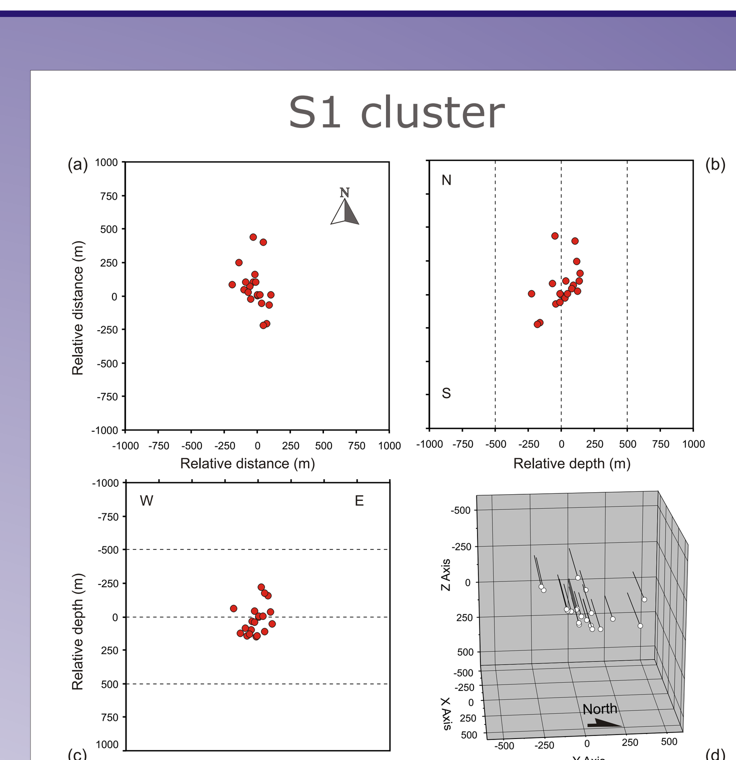

Fig. 6a - Relative locations of S1 cluster using the master-event-technique; map view (a), vertical cross-sections (b, c) and 3 D sketch (d).

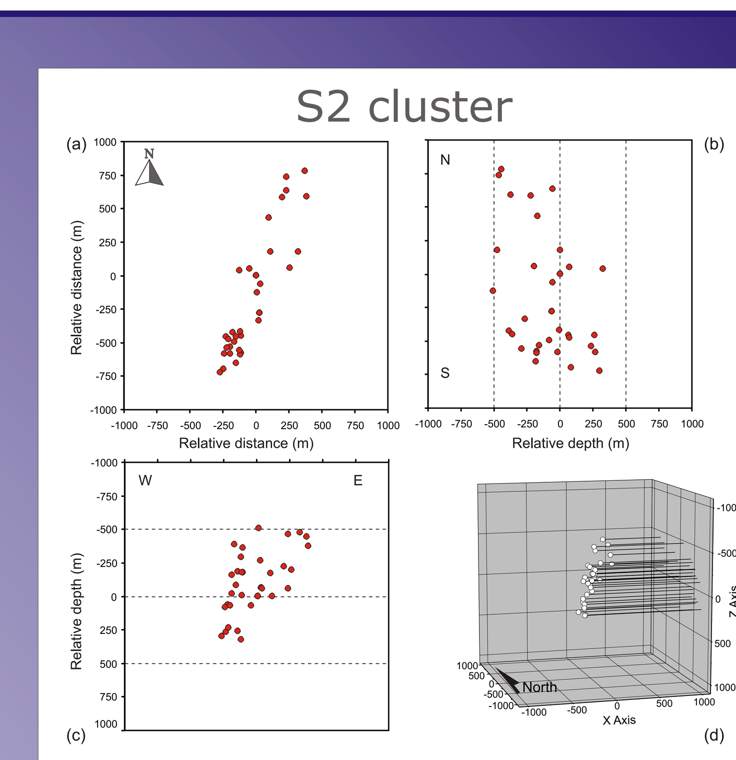

Fig. 6b - Relative locations of S2 cluster using the master-event-technique; map view (a), vertical cross-sections (b, c) and 3 D sketch (d).

D) Fault plane solutions

On the base of the event locations and of the fault plane solutions we have distinguished the focal mechanism in four groups: (i) the Messina Strait, (ii) the Aspromonte complex, (iii) the Ionian Sea adjacent to the southernmost coast of Calabria, (iv) the offshore region of Cape Taormina and Cape S. Alessio (see Fig. 10).
In the Messina Strait area, focal mechanism confirm the characteristics encountered by Schick for the 1908 Messina earthquake, with normal faulting along NNE striking elements. This type is typical also for the Peloritani mountains, adjacent to the Messina Strait. Towards south, in the Taormina area, horizontal strike slip movement with NE-striking P-axes become important. In the context of the stress field they could be understood as transform faults in the context of an extension perpendicular to a NE axis. The earthquakes falling in the Ionian Sea, south to the calabrian coast, are affected by the change of the global stress field. In fact, accordingly in their fault plane solutions, P-axes striking in NW direction prevail.
Earthquakes located in the Calabrian mainland belong to a regime with an extension perpendicular to NE striking P-axis. On the whole, the picture here resembles to the one obtained for the Peloritani mountains and the Messina Strait.

Conclusion

In conclusion, the various seismological evidences - 3D velocity structure, seismicity patterns, fault plane solutions - confirm that important tectonic elements visible at the surface reach a considerable depth, at least down to the levels illuminated by earthquake activity. The graben-like structure well identifiable in the calabrian inland, continues underneath the Messina Strait. The northeastern coastline of Sicily from Taormina to Messina is accompanied by considerable velocity contrasts well identifiable down to a depth of 12 to 15 km. The Messina Strait as well as the adjacent Perloritani Mountains are characterized by extension perpendicular to the NNE striking elements. Both hypocenter locations as well as focal mechanisms give hints that in the southern part of the area some features change. In particular, focal depth of the events increase and the principal direction of major horizontal stress turns from NNE to NW.

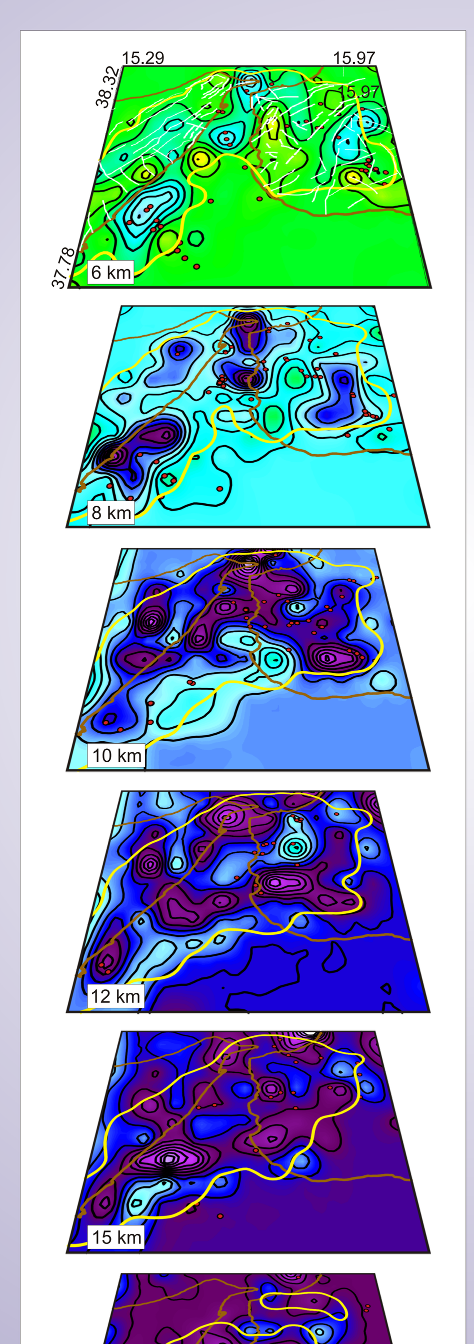

Fig. 7 - P-wave velocity model for six representative layers resulting from the 3D inversion. Contour lines are at interval of 0.2 km/s. On the 6 km layer the main structural features are reported with white lines. Red circles represent the relocated earthquakes within half the grid size of the slice. The zones with DWS>100 are circumscribed by yellow contour lines.

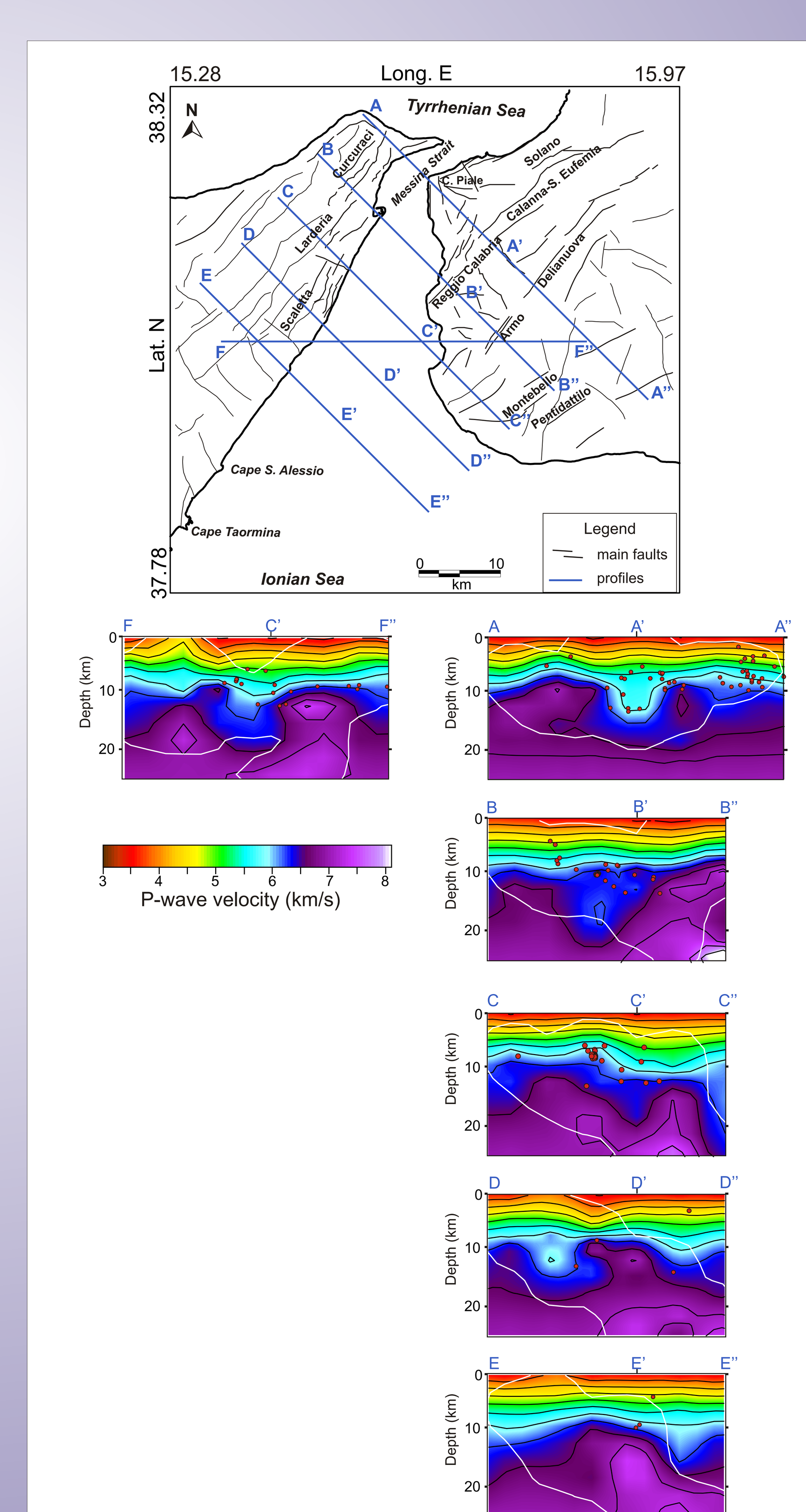

Fig. 8 - Vertical sections through the P-wave velocity model. The traces of sections are reported in the sketch map (A-A'', ... F-F''). Contour lines are at an interval of 0.4 km/s. White curves contour the zones with DWS>100. Relocated earthquakes, within ± 4 km from the sections, are plotted as red circles.

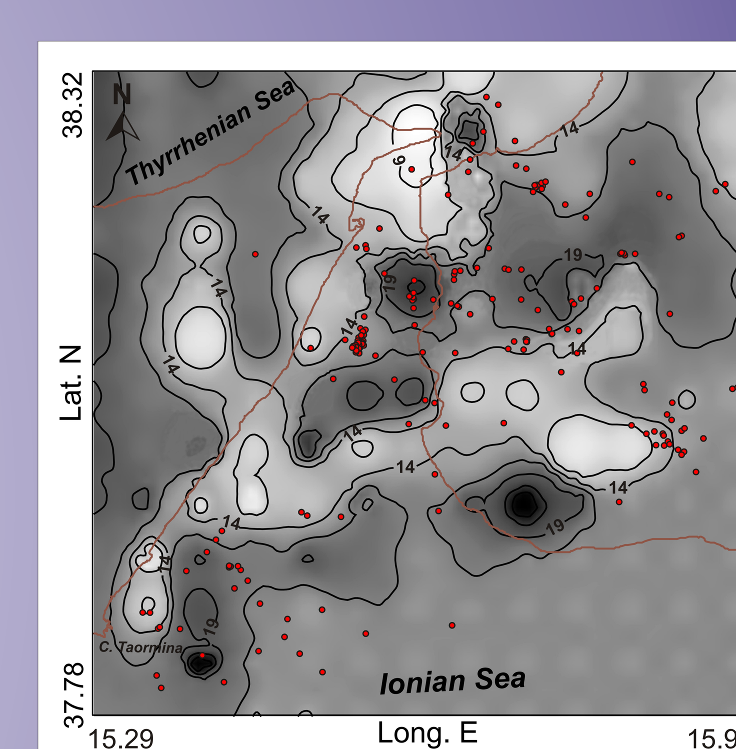

Fig. 9 - Topography of the 6.5 km/s P-wave velocity isosurface. Darker colour indicate a greater depth. Contours are at an interval of 2.5 km and the numbers indicate the corresponding depth. Relocated earthquakes, above the isosurface, are plotted as red circles.

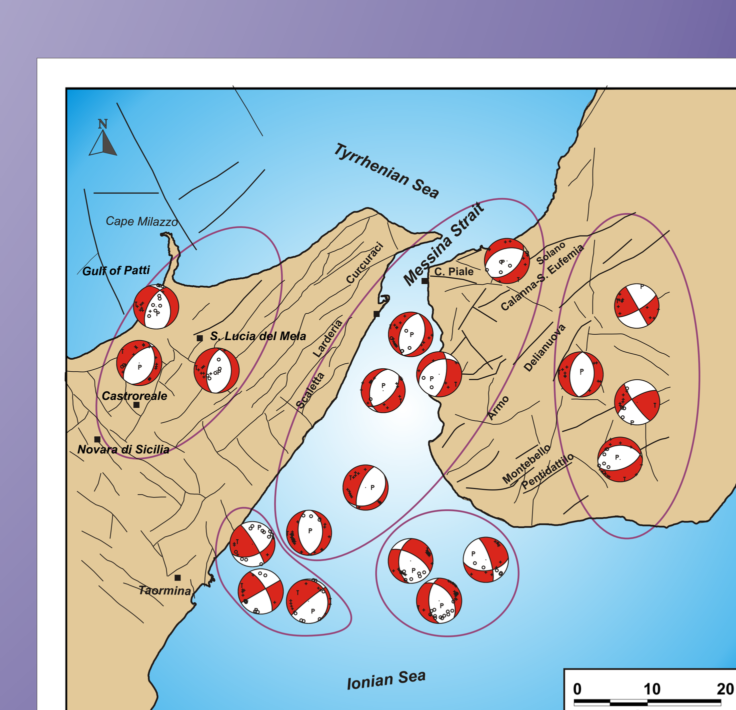

Fig. 10 - Focal Mechanisms of the major events of the northeastern Sicily and southern Calabria.

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