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Crustal structure of the Lunignana-Garfagnana area (Tuscany, Italy): seismicity, fault-plane solutions, and seismic tomography

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Abstract - The accurate analysis of seismicity and its focal mechanisms and the tomographic inversion of a reliable set of local earthquakes allowed us to make an investigation on the crustal structure of the Lunigiana-Garfagnana area. In 1999 the installation of a seismic network of digital enlarged band stations, to monitor the seismicity of this interesting area, made it possible to investigate the seismotectonic features and, upon integration with other data, the 3-D velocity model of this region. The results confirmed and improved what had already been stated in previous works and added new details to the knowledge of this intriguing area. In fact, the distribution of seismicity with depth points out the existence of two seismogenic layers, a shallow one, down to a 35 km depth and a deeper one that begins at the depth of 50 km; in addition, the plane view reveals the presence of a narrow band, running approximately NW-SE, where the seismic activity is less consistent; this feature could be related to the passage from the inner (Tyrrhenian part of the chain) to the outer side of the Apennines. The analysis of a selection of focal solutions suggests that a more complicated situation than just two stress domains (distensive in the inner domain and compressive in the outer one) must exist in this area of the northern Apennines. Evidence of deep compressive mechanisms and the wide spreading of distensive fault-plane solutions suggest that the presence of different stress regimes at different depths is highly likely. Finally, the 3-D velocity model derived from a preliminary tomographic inversion shows the presence of a 20-25 km-thick crust underneath the northern Tyrrhenian Sea and Tuscany which thickens to more than 40 km under the Apenninic chain. Unfortunately, the resolution of tomographic images is very variable and leaves a few question marks on the relationships between deep and shallow structures.

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1. Introduction

The arc of the northern Apennines has evolved in several stages, which were sometimes complexly interrelated and sometimes independent of each other (Laubscher, 1988). Compressional belts produced in these stages have either been of the "push-arc" type (indentation into a deformable mass) or of the "pull-arc" type (backward migration of hinge of a subduction zone), leading to small extensional basins known as back-arc basins, and "pores", with an arcuate mountain range on the subduction side. In the northern Apennines, the formation of a pull-arc in the Oligocene-Early Miocene, associated with spreading in the Balearic Sea, was followed by the push-arc formation, particularly in the middle Miocene, and by a renewed pull-arc formation from the latest Late Miocene to the present. During all these developments, the Moho was modified by such processes as lithospheric stretching, astenospheric intrusions, subhorizontal shearing and isostatic uplift. The present Moho configuration is consequently a collage of Moho patches formed at different intervals.

It was the rotation of the Corso-Sardinia block that provided the dominating mechanism responsible for the formation of the arc of the northern Apennines and the Ligurian Alps. The rotation was accompanied by the rapid sinking of the subduction zone between the European and Adriatic plates: this last vertical movement is in fact needed to provide manoeuvring space for the rotation of Corsica and Sardinia. The slab retreat and the opening of the Tyrrhenian basin have driven the eastward migration of the "extension-compression" system, deforming the Meso-Cenozoic sedimentary unit which forms the Apenninic thrust and fold belt (Reutter, 1981; Malinverno and Ryan, 1986; Philip, 1987; Royden et al., 1987; Laubscher, 1988).

As a consequence of this complex history, three main geodynamic provinces can be distinguished in the northern Apennines (Bigi et al., 1990):

1. a back-arc basin, which includes the Tyrrhenian Sea and the peri-Tyrrhenian region of the Italian peninsula (dominated by extension since the upper Miocene);
2. a belt-foredeep region along the Adriatic margin characterised by crustal shortening and westward passive subduction of the Adriatic plate (Reutter, 1981; Royden et al., 1987; Amato et al., 1993);
3. a foreland region formed by the great sedimentary basin of the Po Plain and the Adriatic Sea, situated over the continental lithosphere.

In this paper, we focus our attention on the crustal structure of the Garfagnana-Lunigiana, positioned in the north-eastern part of the northern Apennines (Fig. 1). The numerous medium magnitude seismic events that shook the area in the past had suggested that a thorough seismic monitoring of the area was needed and have led to the installation of a permanent seismic network. The network started operating in 1999 and became fully operative at the beginning of 2000. We profit from the rich database, compiled over the last few years, to conduct a comprehensive study based on several analyses of selected, high-quality subsets of phase pickings. We first start by displaying the distribution of the best-located events, dedicating special care to the deeper ones and their relationships to any probable subduction plates. We then try to better understand the seismotectonic regime of the area analysing the parameters of the focal mechanisms computed for the main events that occurred in the Lunigiana-Garfagnana

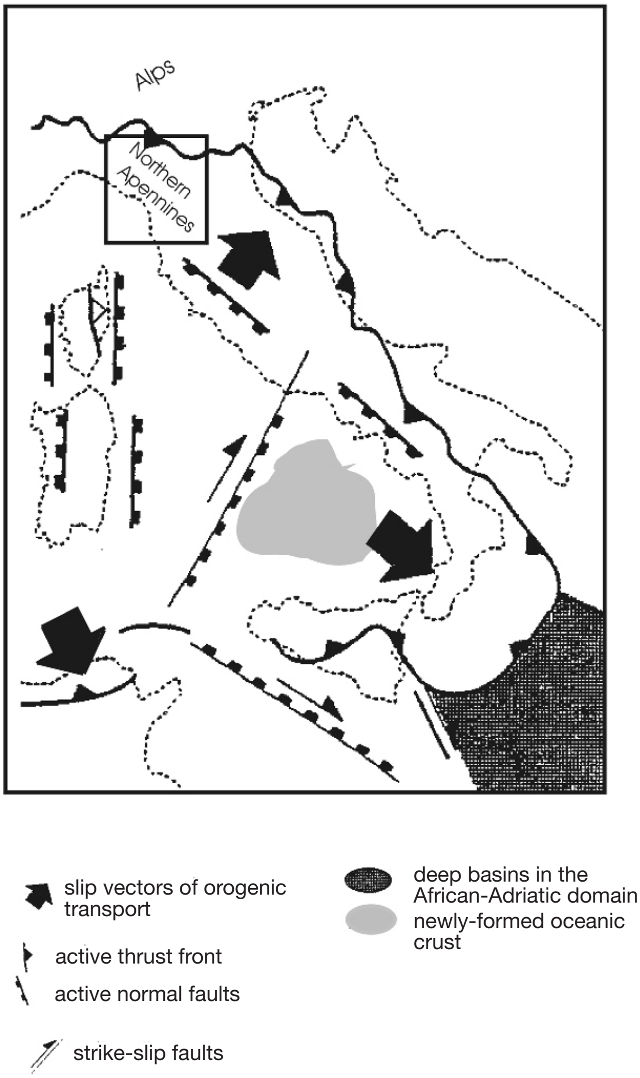

Fig. 1 - Structural sketch of the Apennines. The square indicates the region under study.

area. Finally, we apply a non-linear iterative inversion to a database, integrated with additional data provided by other seismic networks, to reconstruct the crustal structure of the Garfagnana area.

2. Recent seismicity of the Garfagnana-Lunigiana area as recorded by the RSLG

The historical seismicity of medium energy (1481, macroseismic magnitude $M_m = 5.8$; 1902, $M_m = 4.8$; 1920, $M_m = 6.4$) and, more recently, the 5.0 magnitude event of October 10, 1995, were a great impulse to the installation of a permanent network in the Lunigiana-Garfagnana area. The network designed to monitor seismic activity in this region (hereinafter RSLG, Regional Seismic network of Lunigiana-Garfagnana), reached its final configuration at the end of 2000 but, by 1999, the number of stations installed was already sufficient to accurately locate events inside the Lunigiana-Garfagnana area (Solarino et al., 2002). The network has been designed as an eastern branch of the Regional Seismic network of North-western Italy (RSNI in the following) and currently consists of eight seismic stations, supplied with digital acquisition systems with more than a 120 dB dynamic range coupled with enlarged band, three-component sensors with flat response between 5 seconds and 40 Hz.

In about two years, more than 700 seismic events were recorded and located. The location routine consists in applying the Hypoellipse code (Lahr, 1979) to phase pickings obtained by manual reading, adopting different 1-D propagation models and standard weighting parameters for the different groups of RSLG and RSNI stations. Although the quality of seismic locations for the events occurring inside the network depends on the number of instruments that trigger the event, Solarino et al. (2002) proposed that, in such a dense network, the recordings from 4 to 5 stations are sufficient to ensure a constrained location, while additional information diminishes the errors associated to the locations but does not substantially move the location.

Of course the seismicity occurring outside the network is biased by a smaller level of accuracy and reliability, the locations being affected by relevant position errors and small-gap values. In order to improve the azimuthal coverage of the permanent network, to increase the quality of locations of the events occurring close to the RSLG network and to lower the magnitude threshold for these events, four temporary stations were installed along the Apenninic chain, to the east of the RSLG network.

In Fig. 2, top panel, the eight stations of the RSLG network (black triangles) and the four temporary stations (black squares) are reported together with the selection of the seismicity (horizontal error ERH ≤ 5 km, vertical error ERZ ≤ 5 km) recorded since 1999, for a total of 408 events. In the same figure, in the bottom panels, the distributions of magnitude and of depth for the events located inside the framed area (270 events) are shown. The borders of this frame, designed on the basis of the distribution of enlarged (permanent + temporary) RSLG network, include events located with the smaller gap values. The seismicity is diffuse and of relatively low energy, and sometimes proved to be organised in sequences (in Fig. 2: Bardi-Borgotaro area, close to station BADL, 15 events in one day; Fivizzano area, between BACM and SARM, 9 events in two days; Barga area, eastern of SARM, 60 earthquakes in two days). It is worth noting the presence of a thin band, running NW-SE (dashes in Fig. 2), where the seismicity is less frequent. This feature, confirmed by the distribution of historical events, could be ascribed to artefacts in the event locations due to the odd geometry of the network but could be also explained by the passage from the inner to the outer (Ghisetti and Vezzani, 2001) side of the Apennines. The existence of this narrow band has been underlined by other studies, even though it has not been specifically linked to low seismicity (Mariucci et al., 1999).

The magnitude of the selected events (Fig. 2a), spans from 1 to 4 duration magnitude Md; the upper value strongly depends on the short recording period as many historical events suggest that the area is potentially source of higher energy events.

Regarding the depth (Fig. 2b), two seismogenic zones seem to exist: a shallow one, which deepens down to 25-35 km and that shows the largest number of events and a deeper one, which starts at the depth of 50 km, characterised by a small number of recorded events. Between 35

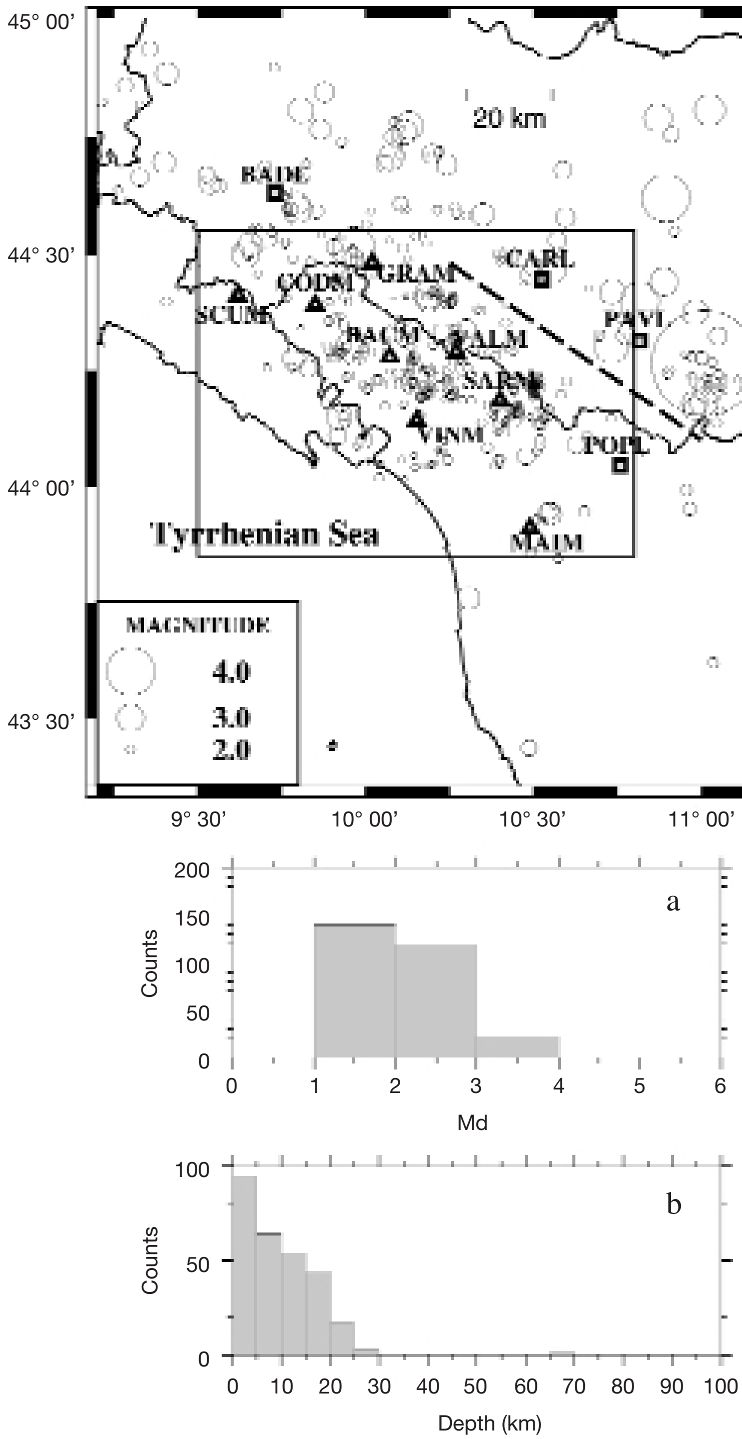

Fig. 2 - Top panel: the triangles indicate the seismic stations of the RSLG; the squares, the stations of the temporary network; the circles, the seismic events recorded between January 1999 and October 2001 (selected considering ERH ≤ 5 km and ERZ ≤ 5 km). The dashes indicate the area where the seismicity is less consistent or almost absent.
Bottom panels: distributions of magnitude (a) and depth (b) of the events located inside the framed area of the top panel (see text for details).

and 50 km, a zone where the seismicity is absent seems to exist. At present, its feature is still under investigation and must be confirmed by a longer monitoring time.

In the second part of this paper, we make use of an additional data set, taken from a published catalogue (Catalogo Strumentale dei Terremoti Italiani dal 1981 al 1996; ING-GNDT Gruppo di Lavoro Catalogo Strumentale, 2001), to improve the distribution of both seismic events and stations for a preliminary tomographic study of the Garfagnana-Lunigiana sector. The data extracted from the catalogue have been relocated using the same models as those used for the RSLG data and a selection of earthquakes to enrich the original data set has been made according to the following guidelines:

- time selection: only recent events (1990-1996) have been used;
- space selection: evenly distributed events on the whole area to be investigated by tomographic inversions have been selected;
- quality selection: relocated events have been selected applying as same criteria as for the selection of the RSLG data (at least 10 P + S readings, ERH and ERZ ≤ 5.0 km).

The resulting high-quality data set (214 earthquakes) is representative of the best locatable events for the period 1990-1996, covers a larger area and a longer period and can be used as a comparison with respect to the findings of our analysis of seismicity (Fig. 3). Regarding the plane view, the band of low seismicity (Fig. 3, top) is not as evident as with the locations by the RSLG network, being characterised by few, low magnitude events. The existence of an aseismic band, as revealed by our recordings (dashes in Figs. 2 and 3), could have been biased by the geometry of the network and/or by the low magnitude character of the seismicity.

The plot (Fig. 3b) of the locations and the distribution of depth for events comprised in the framed area confirms that the seismicity seems to be organised into two layers, one of about a 30 km depth, the second starting from a 55 km depth.

One feature, common to the two data sets, is the low seismic activity in the right-lower corner of the framed area (close to MAIM), that appears not biased by the distribution of seismic stations since many are surrounding the area. All these findings need, of course, a more accurate and prolonged analysis before any definitive interpretation can be made.

3. Seismotectonic regime

In this section, we try to have a better view of the stress regimes that dominate the region under study by analysing the characteristics of the focal mechanisms computed for the most interesting events that occurred in the area.

The criteria that led the choice of the earthquakes for consideration in this section are the minimum number of available polarities (15) and the magnitude of the events (local magnitude $M_L > 2.7$). In most cases, an optimal azimuthal coverage has been reached by adding waveforms recorded by stations belonging to other networks (OGS - Istituto Nazionale di Oceanografia e di Geofisica Sperimentale, Trieste; ETH - Institute of Geophysics, Zürich; and INGV - Istituto Nazionale di Geofisica e Vulcanologia, Roma).

Unfortunately, in the two years odd of full operation of the RSLG network, the low

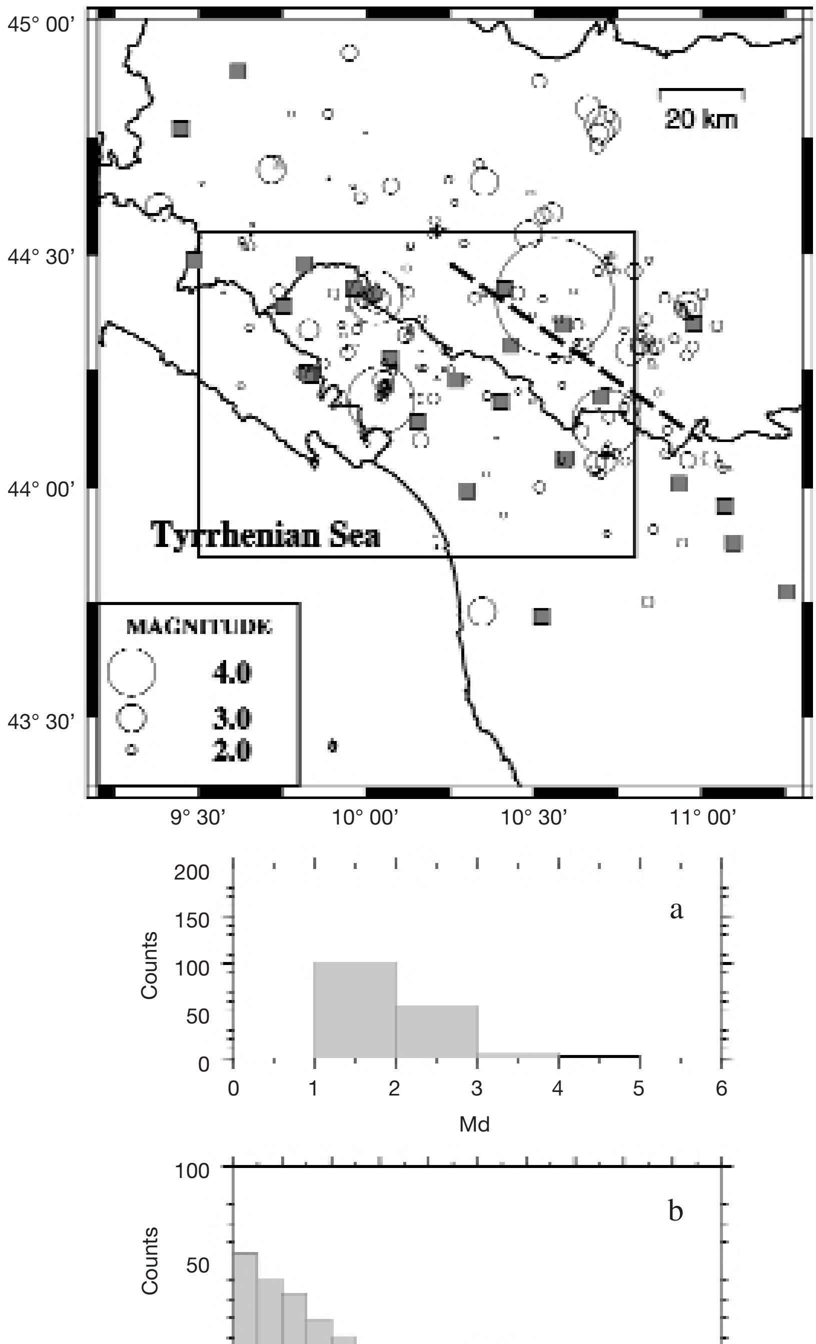

Fig. 3 - Top panel: the squares, over the location of the seismic stations whose data have been used for the compilation of the CSTI (ING-GNDT Gruppo di Lavoro Catalogo Strumentale, 2001) catalogue; the circles, on the seismic events extracted from the catalogue for the period 1990-1996, relocated and selected (ERH ≤ 5 km and ERZ ≤ 5 km). The dashes indicate the area where the seismicity is less consistent.
Bottom panels: distributions of magnitude (a) and depth (b) of the events located inside the framed area of top panel (see text for details).

magnitudes of occurred events made the computation of only 7 focal mechanisms possible. Since any analyses on such a small number of events would be meaningless, we added numerous fault-plane solutions extracted from the database of focal mechanisms compiled in previous studies (Eva and Solarino, 1998) upon checking for quality, thus reaching a good spatial coverage for the area. The reliability of these focal solutions is enriched by the use of recordings from temporary stations installed in several field experiments. All focal mechanisms have been computed applying the first onset methodology through the FPFIT program (Reasenberg and Oppenheimer, 1985) to events for which at least 15 polarities and a good azimuthal spread were available. Fig. 4 displays the distribution of the focal solutions.

Previous studies (Frepoli and Amato, 1997; Mariucci et al., 1999) conducted on instrumental data, pointed out that the tectonic regime of the Apennines can be distinguished into two sectors. The internal one is guided by extensional stress (it coincides with the Tyrrhenian part of the chain, since in the classical terminology external is the direction of the vergence of thrusting) while in the external one, reverse and strike-slip focal solutions prevail. Both groups of authors take into account shallow earthquakes (only a few events are deeper than 20 km). According to these authors, the two domains are clearly distinct, and possibly a narrow sector between them,

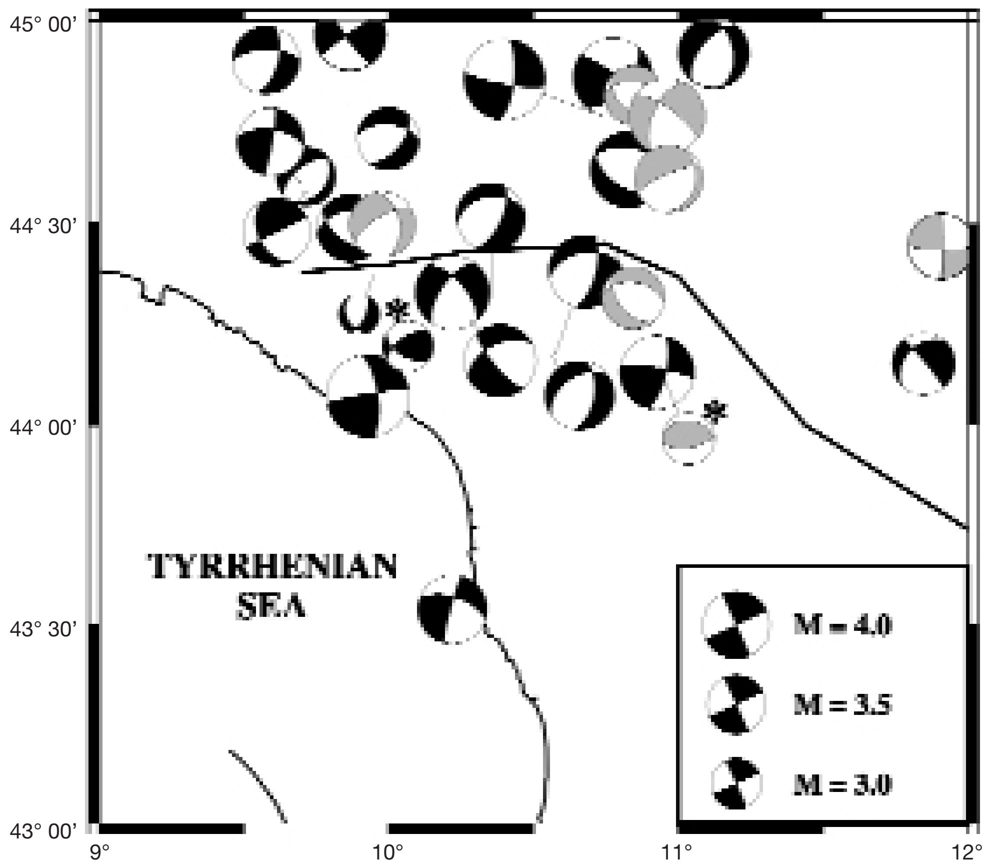

Fig. 4 - Distribution of the relevant focal mechanisms for the period 1985-1996 (black beach balls) and for the period 2000-2001 (grey beach balls). The thick line separates the compressive (north-eastern side) from the distensive (south-western side) domain according to Frepoli and Amato (1997). The focal solutions marked by a star indicate the two compressive-deep earthquakes.

which can be considered a transition zone, is present. For convenience, the probable geometry of the two domains as proposed by Frepoli and Amato (1997) is plotted in Fig. 4.

Looking at the distribution of the focal mechanisms used in this study, the recognition of these distinct domains is not as simple. Taking into account all shallow events, normal and strike-slip solutions are spread over the whole area, and the direction of P and T axes does not show as a trend as expected in a situation like the one proposed for the area. The complexity of the area has already been pointed out by several authors that showed the existence of both compressive fault plane solutions for deep events (10-20 km; Selvaggi et al., 2001) and normal faulting mechanisms for shallow earthquakes (3-6 km of depth; Zollo et al., 1995) in the Reggio Emilia region, north-east of the area under study.

The interesting finding of the present work is the two compressive focal solutions, situated where the distensive regime is supposed to exist, at a 72 km and a 60 km depth. These two mechanisms are marked by a star in Fig. 4. Fig. 5 shows the plot of the Schmidt lower-hemisphere projection for these fault-plane solutions.

The presence of deep-compressive focal solutions has already been proposed by Selvaggi and Amato (1992), who found compressive focal solutions in the sector south-east of the area under study and related these subcrustal earthquakes to the active subduction of the Adriatic lithoshpere beneath the Apenninic chain.

It is premature at the moment to define a compressive deep regime in the sector under study, but the idea has not to be rejected. In fact, the number of deep events recorded by the network is very low (see previous sections); the difficulties in constraining focal mechanisms for deep events further reduce their number and make these two fault-plane solutions representative of a whole family. Only a greater number of deep, compressive focal solutions and a detailed geometry of the subducting slab could solve the ambiguity of the presence of compressive mechanisms in a distensive area. In any case, our findings confirm that the tectonic regime in this area is complex. The dependence of tectonic domains on depth has already been pointed out in the western Alps (Eva et al., 1997), and could be proper of recent orogenic chains.

4. Seismic tomography

With the aim of investigating the crustal and possibly subcrustal structure of the Garfagnana-Lunigiana area, a non-linear tomography has been carried out. The data set used in the inversion procedure comprehends recent seismicity, recorded since 1999 by the RSLG network (Fig. 2), and instrumental readings extracted from the CSTI catalogue (ING-GNDT Gruppo di Lavoro Catalogo Strumentale, 2001; Fig. 3), relocated and selected according to the criteria described in the previous paragraph (ERH, ERZ $\leq$ 5 km).

The whole data set is made up of 622 seismic events and shows a good azimuthal coverage of the investigated area. Nevertheless, the lack of deep seismicity (only a few tens of events are located at a depth greater than 25 km) represents a constraint on the accuracy and the reliability of the final 3-D velocity model, especially for deeper layers. The coverage of the considered stations is biased by their distribution concentrated in a narrow strip that permits an accurate

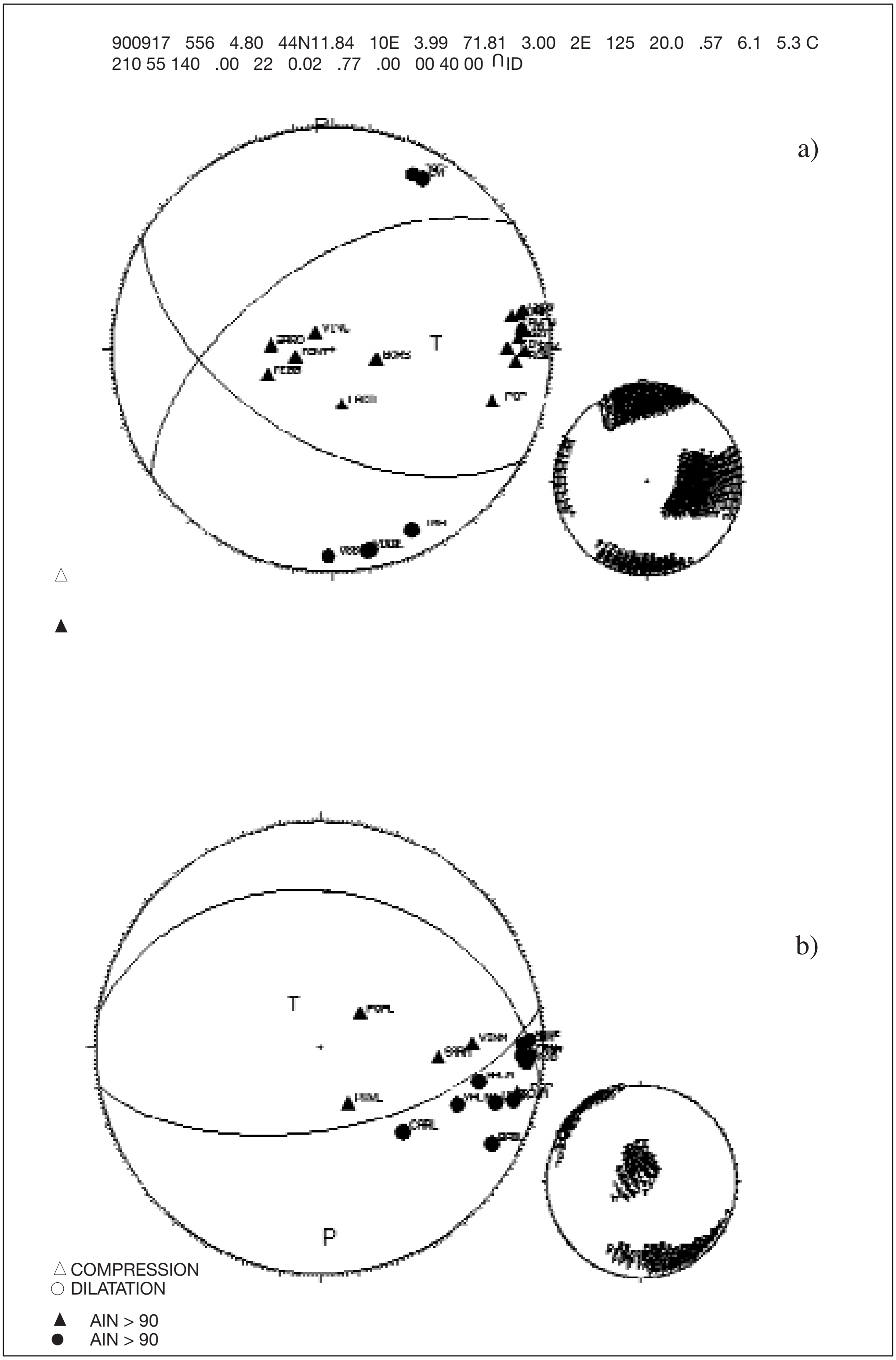

Fig. 5 - Schmidt lower-hemisphere projection of the fault-plane solutions of the event at a 71.81 (a) and a 59.17 (b) km depth (black beach balls marked by a star in Fig. 3).

sampling in the central part of the investigated area only.

A non-linear iterative inversion algorithm has been adopted to solve the tomographic problem with the Simulps14 code based on the scheme proposed by Thurber (1983). To overcome the computational burden of a mathematical problem that might interest more than a thousand nodes by which the model is parameterised and a similar number of seismic events, the approach subdivides the two problems (determination of hypocenters and of 3-D velocity distribution) via a parameter separation and then separately solves the two groups of unknowns. Both are then linearized and iteratively solved considering an initial guess of model parameters (Menke, 1984). After the preliminary location step, the inversion of the velocity nodes (Vp and Vp/Vs) is carried out on the basis of the resulting locations. In this phase, the inverse problem (solving for 3-D velocity) is treated as strictly undetermined and therefore solved by a damped least square approach. The mathematical problem is formulated adding a damping value, which must be carefully chosen to render the problem meaningful. Once the 3-D velocity model has been computed, it is used for the relocation of the hypocenters. This part of the problem is solved adopting the Singular Value Decomposition method. In this case, the quality of the solution depends on the correct choice of a cut-off value (hereinafter eigtol) that basically sets the number of singular values to be taken into account by shifting the "zero" values to the eigtol variable. The routine is repeated again until a stopping condition is reached.

In this procedure, the choice of the damping and eigtol values plays a fundamental role for the quality of the results. The method proposed by Eberhart-Phillips (1986) to plot curves of data variance vs. solution variance as a function of the damping values, appears over-simplified since the eigtol values, ruling the location step, must be taken into account too. This is why we propose three-variable trade-off curves (Figs. 6b and 6c). Values allowing a high (possibly the highest) reduction in the data variance along with a moderate increase in the solution variance, represent the best choice for the parameters which lead the joint inversion. From the curves it turns out that the best starting values for this data set are 60, 60, 0.026 (Vp, Vp/Vs, and eigtol respectively).

To avoid any biasing of the final 3-D model, particular care has been adopted in choosing the starting 1-D velocity model, selecting the best performing from a series of published velocity distributions (Fig. 6a). In particular, the models included in the CSTI catalogue (ING-GNDT Gruppo di Lavoro Catalogo Strumentale, 2001), in the paper by Cattaneo et al. (1986), and those published in the paper by Tomaselli et al. (1992) have been used for this comparison.

In Figs. 7 and 8, the preliminary results of the inversion are shown by plotting six horizontal layers in slowness perturbation (percentage with respect to the average velocity of each layer) and by means of three vertical cross sections in absolute P velocity.

The validation of the results is always very important and it assumes a special significance in cases where only a little a priori information about the crustal structure of the investigated area is available. In this work, the reliability of the results has been evaluated by analysing the resolution and sampling matrices. In fact, the number of hits per sample alone is not able to discriminate between well or poor resolved areas, being dependent from any preferential direction of hitting rays and must be accompanied by a more quantitative analysis. Though the

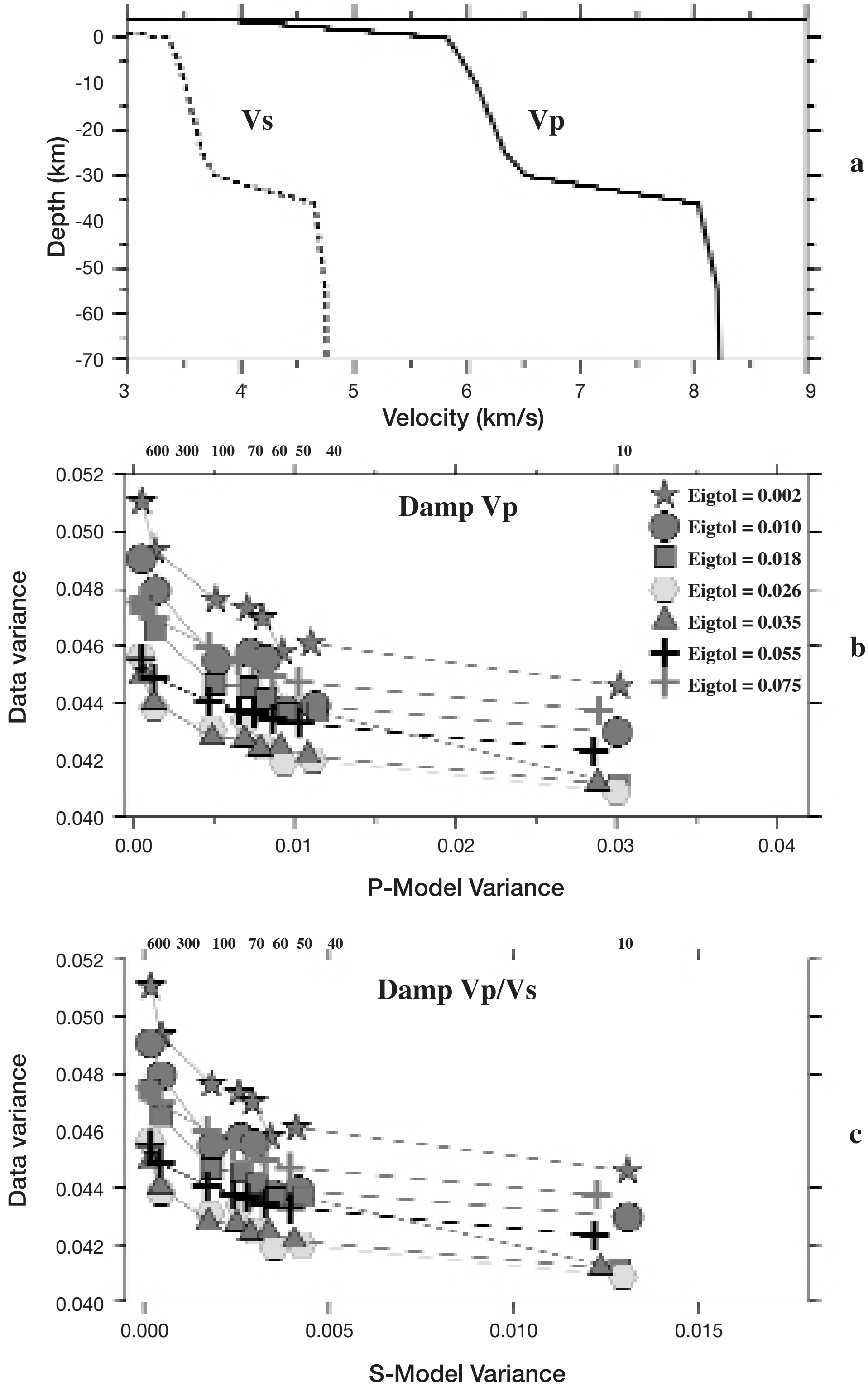

Fig. 6 - a) starting P- and S- waves velocity model; b) and c) trade-off curves for the P and S solution variance vs. the data variance; curves have been obtained varying both the damping parameters (Vp and Vp/Vs damp) in the velocity determination problem, and eigtol values in the locating problem.

resolution diagonal analysis is only an approximation of the full resolution, its usage proved to be good enough to discriminate well resolved areas, thus it is here used as a tool to discriminate between resolved and not-resolved areas (Eva et al., 2001).

In Figs. 7 and 8, the dotted lines enclose the area where the Resolution Diagonal Element (RDE) value is 0.1 and 0.02; 0.1 can be treated as a good minimum value for assessing reliability, at least for this data set, and in the following we will consider all areas characterised by equal or greater values as reliable for interpretation. Since the deeper layers are seldom resolved with such a value, we will take into account also all areas where the RDE is greater than 0.02 as lower limit for interpretation, to distinguish them from areas where there is no resolution at all. The details for these areas will not be discussed, since their reliability must be further confirmed.

Keeping in mind the constraints due to the reliability of results, in looking at Figs. 7 and 8 we can make a few hypotheses about the crustal structure of the Lunigiana-Garfagnana region.

In the first layer (Fig. 7, top left), at 0 km depth, the distribution of velocity anomalies resembles the structural setting of the area (Baldacci et al., 1992). In particular, the Tuscan units are characterised by high velocity perturbations, while the Ligurian units are in general characterised by low-velocity anomalies. Only in the north-western corner of the plot the high-velocity perturbation interests the Ligurian domains: this feature can be due to the smearing of a deeper high-velocity area (as visible at a 3 and 10 km depth) or to the deepening of the Tuscan units: such a situation does not appear in the structural map, being the result of a surface geological survey, if the Ligurian units overlay the Tuscan ones.

In the rest of the plane views, the spot-like appearance of the velocity perturbations does not allow us any accurate interpretation, and the reliability of results becomes very poor when deeper than 25 km. However, the existence of a low-velocity perturbation at depths of 15 and 20 km could be related to the thickening of the crust due to the transition from the oceanic to the continental Moho.

The same feature can be observed in the tomographic cross-sections (Fig. 8). In fact, at a depth of 10 to 20 km, the behaviour of the absolute velocity distribution indicates a thickening of the crustal material towards the north-eastern part of the model. These results confirm the trend of the Bouguer anomalies (Klingelé et al., 1992) indicating a thin crust in the western part of the model opposed to thicker crust beneath the Apenninic chain, at least for the area under study. Our findings are also in good agreement with the behaviour of the Moho, as derived from the European GeoTraverse studies (Giese and Buness, 1992). According to these research studies, the thickness of the crust reaches about 30 km under the Adriatic Sea, increases to more than 40 km under the Apennine chain and again decreases to 20 -25 km under the Tyrrhenian Sea and Tuscany (Negredo et al., 1999).

As previously pointed out, the tomographic resolution strongly decreases at depths of over 25 km, and a general distinction between poorly resolved and not-resolved areas only can be carried out. However, a deepening of the crustal material under the Apenninic chain and the relative deepening of the Moho (blue areas, 7.9-8.4 km/s) is visible within the limits of the resolving power. At this stage, it is not possible to infer whether this feature is connected to the subduction between the Adriatic and Tyrrhenian plates or not. A more complete data set, containing deep events to “illuminate” the area from below, is needed.

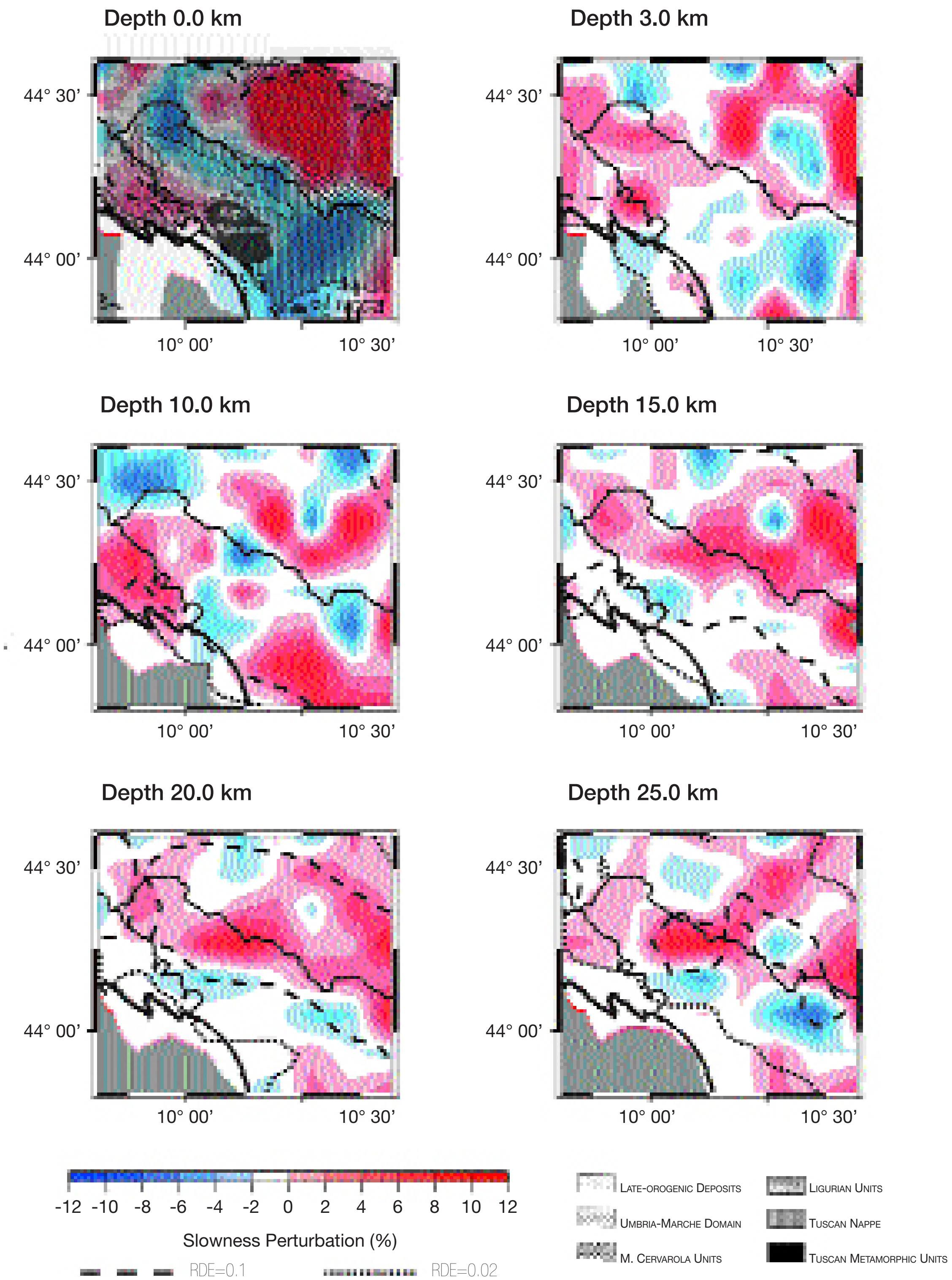

Fig. 7 - Slowness perturbation in percentage with respect to the average velocity of each considered layer for the depths 0, 3, 10, 15, 20 and 25 km. The dotted lines represent the area with 0.1 and 0.02 RDE values. On the shallower layer the structural setting of the area as proposed by Baldacci et al. (1992) is overlaid.

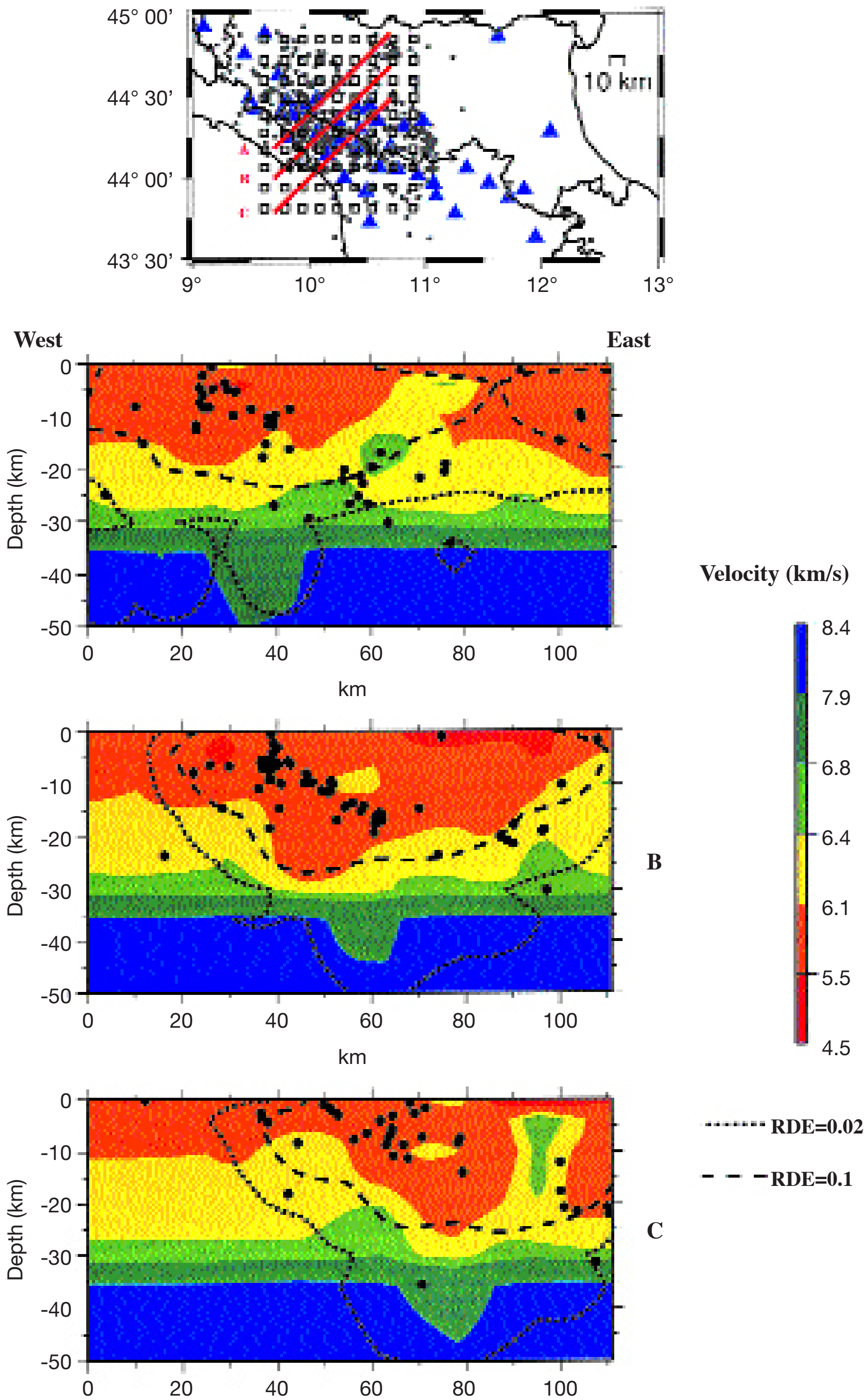

Fig. 8 - Top panel: the seismic events and the station distribution considered in the tomographic inversion. The position of the plotted cross-sections (A, B, C) is also indicated.
Bottom panels: seismic cross-sections (A, B, C) showing the P-wave velocity distribution as derived from the tomographic inversion. The events relocated by the joint inversion procedure are plotted. The dotted lines represent two RDE values used to assess the reliability of the inversion (see text for details).

5. Discussion and conclusion

The installation of the RSLG to monitor the seismic activity of the northern Apennines has been a remarkable incentive to develop and to improve the geophysical investigations of the crustal and subcrustal structure of this interesting region. The new stations (8 permanent, 4 temporary) provided a high quality data set that has been used to perform analysis on the seismotectonics and stress domain of the region and to compute, after integration with other seismic catalogues, a preliminary non-linear tomography.

The results have confirmed the geological and geophysical findings of previous studies, and have added new details to the knowledge of the area. In particular, the analysis of seismic activity conducted on the best locatable events showed that seismicity is confined to the first 35 km of depth and below 50 km. It seems that the layer in between is not interested by seismic activity, or at least it is of such magnitude as not to be detected or located. Regarding the distribution of hypocenters, seismicity is less frequent in a narrow band which could represent the transition between the inner and outer domains. A similar analysis conducted on a data set covering a larger area and a longer period, later used for tomography, partly confirmed the findings, in particular the lack of seismicity between a 35-50 km depth.

The analysis of focal mechanisms, though based on a small number of focal solutions and therefore not definitive, does not show the compressive regime that many authors attribute to the outer sector of the Apennines, at least in the area under study. Since the only two focal mechanisms with a compressive nature are found where the distensive domain is supposed to exist and at a depth greater than 40 km, we suggest that a more complicated stress setting must govern the area. The complex structural setting of the northern Apennines would in fact justify a distensive regime in the shallow crust and a compressive behaviour at greater depth where an active or passive (gravitational?) subduction is going on. The small number of computed focal solutions leaves an open question regarding the relationships between the very deep compressive mechanisms under the Garfagnana area and the much shallower compressive fault-plane solutions computed for the Reggio Emilia area, situated some 50 km north-east of the area under study.

An attempt to display the complex crustal structure of the area has finally been conducted by doing a preliminary non-linear inversion of a joint seismic catalogue. As a summary, the 3-D reconstructed velocity model helps to improve our knowledge of the crustal structure of the Lunigiana-Garfagnana area down to 20-25 km. The shape and position of the anomalies reconstructed at these depths can be considered accurate since the tools to estimate the reliability of the solution, within the limits of the arbitrary choice of the upper and lower values, confirm it is trustworthy. Conversely, the poor resolution obtained for the deeper layers does not allow us to investigate in detail the features and the geometry of the subcrustal structures.

The shallower tomographic plane views show a good agreement with the position of the main tectonic units of the northern Apennines. An interesting feature, confirmed by the tomographic cross-sections, is the thickening of the crust under the Apenninic chain. Although the reliability of the tomographic reconstruction is very poor under a 25 km depth, making any interpretation very subjective and incomplete, the cross-sections show a deepening of the Moho under the Apennines. To overcome the problem of lack of data biasing the detailed interpretation of this feature, an approach able to sample the area from below is needed; in this sense, a teleseismic inversion, characterised by a low power of resolution for lateral inhomogeneities but perfectly tuned to investigate deep, wide and elongated structures, will be also taken up in order to focus our attention on the geometry and shape of the subcrustal structure and possibly their relationships with the subducting slab.

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