A new deep picture of the Alps-Apennines system derived from seismological data.

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The diverse studies carried out with geophysical and geodetic data in the last decades greatly improved the knowledge of the Alps-Apennines system. However, most of these studies were limited to portions of the system or to the shallow structures, and for these reasons reconstruction of the tectonic setting for a larger area and for the deeper layers is still open to different approaches and interpretations; in particular, very little is known about the deeper conjunction between the two chains.
One of the most powerful tools to investigate the deeper part of an earth's volume is seismic tomography. In fact, not only seismic tomography may reach depths that are far beyond those of many other methodologies, but it can provide information on very large areas (up to the entire earth) with a unique level of details.
In this study, we applied diverse tomographic techniques to perform a multi-approach investigation on the crustal structure of the North-Western part of Italy, in particular to obtain the under surface velocity structure and the attenuation distribution. An accurate analysis of seismicity and focal mechanisms complemented the study.
Seismic velocity tomography is an iterative technique to obtain a 3-D model of the distribution of both P and S velocities (or Vp/Vs ratio) from earthquake recordings. The method is based on the separate resolution of the coupled velocity-hypocentre problem. An initial likely velocity model must be provided and it is used to locate the earthquakes and to trace seismic rays in this "ideal" earth. The resulting travel times are compared with those observed, and the velocity model is adjusted to take into account the differences between computed and real phase readings. Each subdivision of the model is then attributed new velocity values. The whole cycle is repeated again until an acceptable solution minimum is reached. It is evident that some constrains interfere with the success computation. Among the others, the choice of the initial reference model and the kind of ray tracer used in the direct problem must be considered fundamental for the reliability of the final tomographic images.
In this study, an improved methodology has been used to take into account longer rays and, as a consequence, to increase the cross-firing and the sampling of the deep volumes. Moreover, the starting model has been obtained after the careful revision and selection of the available data. With these premises, a large volume including the whole Alps-Northern Apennines system down to 100 km depth has been investigated and imaged.
Several newly proposed issues can be derived from the observation and interpretation of the obtained results; in some cases they have rheologic implications. It is the case of the Ligurian Sea, where a high velocity anomaly extending down to 60 km depth is imaged, with a size dramatically reduced above 35 km depth. The

Vp/Vs ratio of this anomaly is lower by 4 to 6 % than imposed. The Ligurian Sea experiences heat flux above the average of the peninsula (of the order of 80 to 100 mW/m^2, [*Cermak et al.*, 1992]), therefore there must be some other conditions than the thermal status to justify such an anomaly. According to *Zhang et al.*, [2004], the Vp/Vs ratio for Japan of the same order and at depth comparable with the one we found may be a consequence of petrological – petrophysical changes. A more complete discussion of this topic requires knowledge of the P,T conditions and is beyond the scope of this paper, but the rheological implications deserve thorough investigation.

The tomographic images show, both in plane and depth views in nice details, the shape and extension of the Ivrea body. The roots of the Apennines down to 30-35 km depth and the low velocity area corresponding to the Po Plain are noteworthy.

The lateral complexity of the region, as derived from velocity tomography, suggests that a 2-D attenuation study might provide important information, that will integrate the other seismological studies to better understand this complicated region.

The structural heterogeneity of northern Italy makes the region an ideal test area to apply a 2-D Q tomography technique. The approach we use has been developed by Phillips et al. (2005) and is an extension of previous amplitude ratio techniques to remove source effects. The method requires some assumptions such as isotropic source radiation which is generally true for coda waves.

We used more than 400 earthquakes with magnitude larger than $M_L \sim 3.0$. The data set is composed of recordings coming mainly from 19 three-component stations of the RSNI network (Regional Seismic network of Northwestern Italy, Genova). In addition, we supplemented this dataset to gain better path coverage by using waveforms from the RéNaSS (The French National Network of Seismic Survey, Strasbourg), OGS network (Istituto Nazionale di Oceanografia e di Geofisica Sperimentale, Trieste, Italy) and GRSN network (Germany).

For each frequency band in the range of 0.3 – 15 Hz we imaged quality factor variations with respect to an average computed over the region using the same events for both direct and coda waves. Using a checkerboard test analysis for an input model with cell size of 0.5 by 0.5 degrees, and low and high attenuation input cells of Q=500 and 50 respectively, we estimated the resolution area.

Attenuation tomography results revealed the complexity of northern Italy since the study region comprises the Alps-Apennines junction zone and the foredeep basin (Po plain) of both chains. Within this area we observe the similar Q variation at different frequency bands for coda and direct waves. In particular, the low attenuation in the southern part of the western Alps coincides with the area characterized by the massifs, where *Eva et al*. (1991) obtained similar results. Moreover, a high Q zone is highlighted in correspondence of the Po plain, extending to the very northern part of the Apennines, close to Parma. In this case an interpretation is not simple given the complex geological setting and geometric crustal relationships. In fact, the northern Apennines front is buried under the Po plain sediments and the Po plain is the foreland basin of both the Alps and Apennines (*Doglioni*, 1993). This complexity might be the origin of strong lateral heterogeneity in the crust where we observe a high attenuation anomaly related to this buried front. Moreover, *Ciaccio and Chiarabba* (2002) observed a shallow, high velocity anomaly in the same area and interpreted that as an effect of heterogeneity due to uplifted Mesozoic carbonaceous rocks.

Finally a low Q zone is observed in the western side of the Alps, the same region where *Campillo et al.* (1993) noticed an extinction of L_g waves effect. In addition, the area presents a positive Bouguer anomaly which is interpreted as an effect of a shallow slice of mantle known as the Ivrea body (*Kissling* 1993; *Di Stefano et al.* 1999). *Campillo et al.* (1993) explain this attenuation effect as a result of strong heterogeneity of the surface geology which is characterized by interwoven mantle and crustal rocks.

In the light of our new analysis of velocity tomography, attenuation tomography and focal mechanisms a more in deep interpretation of the characteristics of the Alps-Apennine system is now possible.

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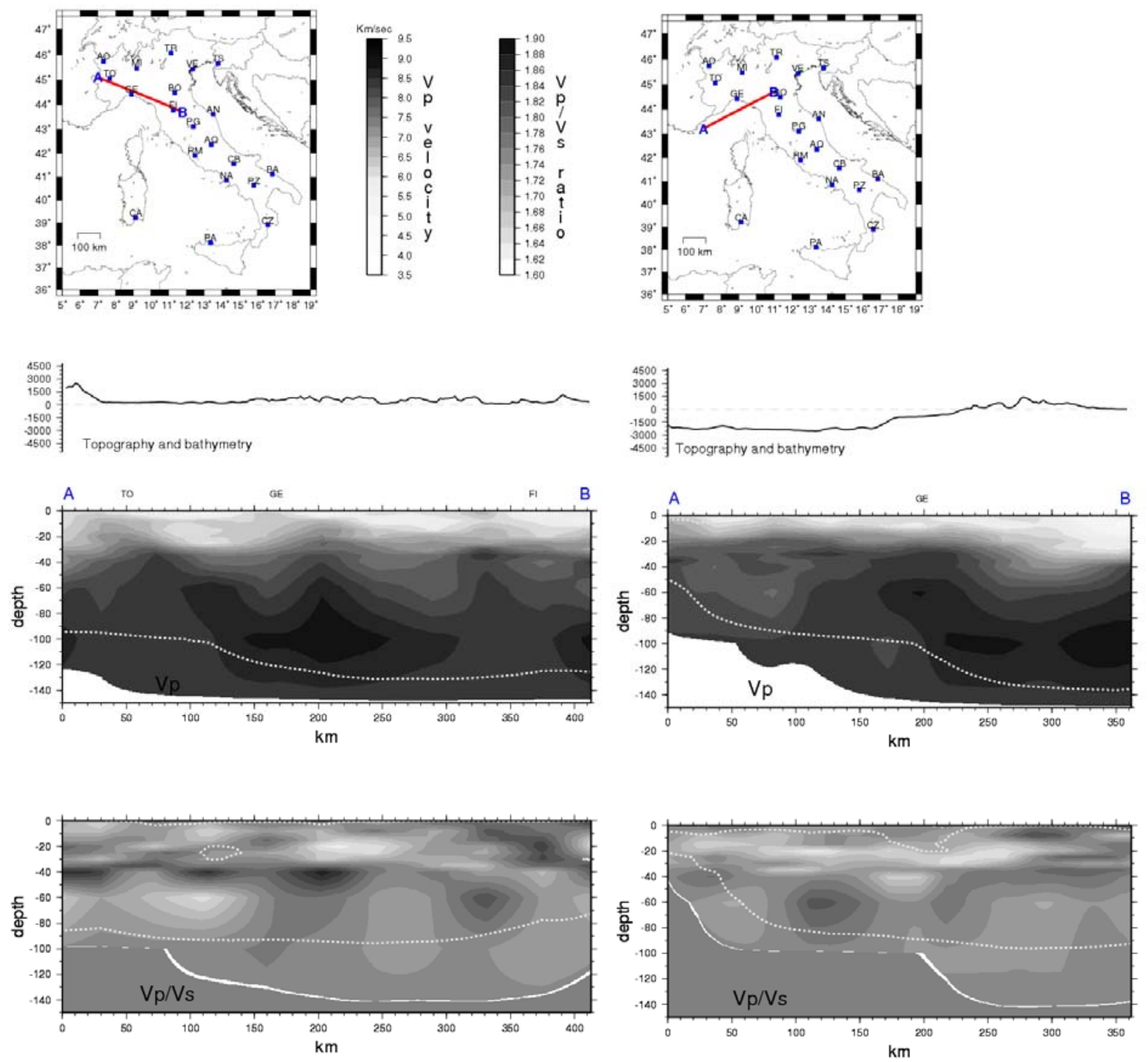

Figure 1- Two orthogonal tomographic cross-sections are presented. The upper section refers to P waves tomography, whereas in the lower section the variation of Vp/Vs ratio is shown. The different gray shades indicate the main velocity and Vp/Vs contrasts. The dotted white lines mark the resolution limits in depth of the tomographic images.