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Seismic properties of the upper crust in the central Friuli area (northeastern Italy) based on petrophysical data

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Abstract

The compressional and shear wave velocities have been measured at room temperature and pressure up to 450 MPa on 5 sedimentary rock samples, representative of the most common lithologies of the upper crust in the central Friuli area (northeastern Italy). At 400 MPa confining pressure the Triassic dolomitic rock shows the highest velocities (Vp ∼7 km/s, Vs ∼3.6 km/s), the Jurassic and Triassic limestones samples intermediate velocities (Vp ∼6.3 /s, Vs ∼3.5 km/s) and the Cenozoic and Paleozoic sandstones the lowest velocities (Vp ∼6.15 km/s, Vs ∼3.35 km/s). The Paleozoic sandstone sample is characterized by the strongest anisotropy (10%) and significant birefringence (0.2 km/s) is found only on the Cenozoic sandstone sample. We elaborated the synthetic profiles of seismic velocities, density, elastic parameters and reflection coefficient, related to 4 one-dimensional geological models extended up to 22 km depth. The synthetic profiles evidence high rheological contrasts between Triassic dolomitic rocks and the soft sandstones and the Jurassic limestones. The Vp profiles obtained from laboratory measurements match very well the in-situ Vp profile measured by sonic log for the limestones and dolomitic rocks, supporting our one-dimensional modelling of the calcareous-carbonatic stratigraphic series. The Vp and Vs values of the synthetic profiles are compared with the corresponding ones obtained from the 3-D tomographic inversion of local earthquakes. The laboratory Vp are generally higher than the tomographic ones with major discrepancies for the dolomitic lithology. The comparison with the depth location of seismicity reveals that the seismic energy is mainly released in correspondence of high-contrast rheological boundaries.

Keywords: Petrophysics; Laboratory measurements; Vp; Vs; Seismic properties; Seismicity; Sonic log

1. Introduction

The interpretation of geophysical results in terms of nature and structure of the lithosphere mainly relies on the physical properties of rocks measured on samples from exposed crustal sections (e.g. Fountain, 1976), boreholes (e.g. Siegesmund, 1996) or xenoliths (e.g. Kern et al., 1996). No direct correlation has been made between lithology, structure and, for instance, seismic velocity. Therefore the interpretation of seismic structures is not unique (Rudnick and Fountain, 1995). We know from laboratory experiments that several parameters affect the physical properties of rocks: some are intrinsic (e.g. rock

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fabric, mineralogy, microfracturing) and some are extrinsic (pressure, temperature and pore fluid pressure). In practice, a specific velocity of propagation of compressional wave can be obtained on different lithologies by applying different P, T or P_{fluid} conditions, or varying the intrinsic rock properties. Therefore a better definition of the effects that confining pressure, temperature and pore fluid pressure have on the physical properties of rocks is required for a better geophysical interpretation of crustal and lithospheric structures.

Recently, the upper crustal structure of the Friuli area was investigated by Gentile et al. (2000) using the tomographic joint inversion for hypocenters and 3-D velocity structure from local earthquakes and the modelling of gravity anomalies. This study related the 3-D Vp and Vp/Vs images to the main lithological units, the tectonic pattern and the seismicity. However, also in this case the geological interpretation is not unique since many rock types are characterized by similar velocities and the 3-D tomographic images are not well resolved everywhere. Furthermore, the seismic intrinsic properties of the rock units that compose the upper crust of the Friuli area involved with the seismicity are still unknown.

In the present paper we investigate the seismic properties of the most representative lithologies of the Friuli upper crust starting by the laboratory measurements of the compressional and shear wave velocities up to high confining pressure. The high pressures in laboratory measurements are necessary because they allow the separation between the crack-induced seismic properties from the matrix properties (e.g. Rasolofosaon et al., 2000). The seismic intrinsic properties are used to construct the synthetic profiles of seismic velocities, density, elastic parameters and reflection coefficients of 4 one-dimensional geological models, extended up to 22 km depth. It is often argued that the small samples used for the experiments might not be sufficient to represent the large scale properties. Therefore we compared the results with the sonic log data from a borehole in the area, in the same was as Dey-Barsukov et al. (2000) or Rasolofosaon et al. (2000), as well as from the tomography (Gentile et al., 2000). In the end, the synthetic profiles are compared with the depth profiles of the released seismic energy to explore the relation between the occurrence of seismicity and the crustal seismic properties.

2. Geological framework

2.1. Tectonic structure

The Friuli area is characterized by a complex tectonic pattern, resulting from the superposition of several Cenozoic-age tectonic phases (Fig. 1a). The structural framework is mainly characterized by two indented tectonic wedges, in which the outer surrounds the inner wedge (Fig. 1b); these wedges are outlined by NE–SW and NW–SE orientated paleo-fault systems (Venturini, 1991). They were formed from Paleozoic to the middle Eocene times by syn-sedimentary tectonic movements and they were re-activated during the compressional Cenozoic tectonic phases. The Mesoalpine (Dinaric) NE–SW compression was the earliest tectonic phase and generated NW–SE-orientated thrusts during the Middle–late Eocene, mainly in Slovenia and in the southeastern part of the Friuli area. During the middle to the earliest Pliocene, the north–south-trending Alpine compression caused severe shortening of the upper crust (Castellarin, 1979) and formed south-verging thrusts and backthrusts, orientated almost E–W, recognizable in the central part of the area. The last tectonic phase was a NW–SE-orientated compression during the Pliocene times. It generated NE–SW-trending thrusts and folds, mainly recognizable in the northwestern part of the area. Each tectonic phase inherited the deformations of the previous phase and fragmented the crust into different tectonic domains; this complexity is revealed by the strong lateral heterogeneities of Vp and Vp/Vs tomographic images of Gentile et al. (2000).

2.2. Geological setting

The geological setting of the Friuli area (Slejko et al., 1989) is characterized by sedimentary rocks ranging from Paleozoic to Quaternary age (Fig. 1a). The Paleozoic rocks, that outcrop in the northern part of the area, are mainly composed by terrigenous and volcanic deposits and minor limestones. The geologic units of the central part of the area are mainly made up of limestones and carbonatic rocks (Triassic–Cretaceous age), belonging to the thick shelf complex of the Friuli Platform (Bosellini, 2004). Flysch and molasse compose the Cenozoic and Quaternary deposits.

The central part of the Friuli area, where the synthetic profiles of seismic velocities and elastic moduli were elaborated, is mainly characterized by the Mesozoic limestones and carbonatic rocks. The Mesozoic cover is detached from the Paleozoic geologic units as consequence of the severe shortening caused by the north–south-trending Alpine compression. The dominant tectonic pattern is a south-verging embricated structure of folds and thrusts dipping 40° to 60° with some associated backthrusts (Fig. 1a). The thrusting caused alternations and repetitions of the Triassic dolomitic rocks and Jurassic limestones (Carulli and Ponton, 1992).