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Comparison of laboratory and field measurements of P and S wave velocities of a peridotite rock

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ABSTRACT

In this study, surface seismic measurements in the field at a rock outcrop (peridotite) and laboratory high frequency seismic measurements of spherical rock samples were compared. Both the field and the laboratory velocities of P- and S- waves were determined using pulse-transmission technique. Special conditions at the field site enabled multi-directional measurement in three mutually orthogonal planes. The anisotropy of seismic P- and S- wave propagation was estimated. Special measurements using neutron diffraction were carried out making it possible to establish the influence of mineral crystallographic preferred orientations (CPOs) of bulk rock sample on elastic wave propagation and its anisotropy. It was determined that the deep peridotite rocks exhibit weak anisotropy. A good directional correspondence for different seismic waves (field/laboratory) even for 3D velocity calculated based on neutron diffraction was found.

1. Introduction

Research of the propagation of seismic waves through rock provides very important information for evaluating of its properties, especially data on heterogeneity, fracturing and anisotropy. The majority of commonly conducted seismic measurements however, primarily use P-waves only, measured in different directions.[1–4]

Expanding the research to monitor and interpret velocities of S-waves makes it possible to determine dynamic elastic moduli of the rock massif more accurately. In this paper we deal with the field and laboratory measurements of P- and S-wave velocities in various directions, over a broad frequency range of seismic signals.

Presented study is concentrated on seismic measurements of rocks from the Ivrea zone (Northwestern Italy) – Balmuccia region, where the dominant rock type of the peridotite massif is a medium- to coarse-grained, porphyroclastic spinel lherzolite.[5,6] This locality has been described in detail in Refs. 3,4,7 According to Lensch and Mehnert,[8,9] these peridotites were formed under conditions corresponding to the boundary between the upper mantle and the deep crust and they are characterized by high bulk density and high values of P- and S-wave seismic velocities.

The field measurements were performed on an outcrop of ultrabasic rocks in the area of Ivrea following up on previous measurements in this area.[4,10] Measurements were conducted in three nearly perpendicular planes – two vertical and one horizontal. This arrangement made it possible to estimate the spatial anisotropy of the propagation velocity of P- and S-wave.

Laboratory measurements were performed on rock samples taken from rock outcrops at the site of the field measurements. Sphere-shaped rock specimens (50 mm diameter) were measured using ultrasound pulse-transmission technique. Comparison of the laboratory ultrasonic measurements with the field measurements can quantify the effect of macroscopic rock damage and its inhomogeneity.

For a more comprehensive understanding of rock anisotropy, neutron diffraction texture measurements of the spherical samples were performed at the Joint Institute for Nuclear Research (JINR) in Dubna (Russia), with the SKAT texture diffractometer at the pulse reactor IBR-2. The texture-based calculation of the 3D velocity distribution of P- and S-wave velocities are compared with data measured on a sphere-shaped specimen in order to reveal the effect of microfracturing in the rock material.

The results obtained from the comparison of field and laboratory measurements can be useful in making better use of acoustic well-logging data for interpreting seismic data or for crustal stress determination.[11]

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2. Field measurement

The seismic field measurements in the Balmuccia region were performed in a deeply cut valley of the Sesia river on three, approximately orthogonal planar walls of a peridotite outcrop. The sub-horizontal plane (strike 40°/dip 18°) was roughly 2 m above the river level. The sub-vertical planes consisted of adjacent walls of the river corridor. One of these walls (2°/79°) was roughly parallel to the river flow and the second (82°/90°), considerably smaller in size, ran perpendicular to it (Fig. 1). The existence of these three planes clearly reflects the natural fracturing of the rock massif. Seismic measurements on individual areas were spaced roughly 3 m apart.

Ultrasound measurements followed up on previous measurements performed at the same location,[10] but they were expanded on measurements of S-wave velocities. The methodology of measuring P-waves was analogous to previous measurements. The ultrasound was generated by a V153-RM piezoceramic S-transducer with a natural frequency of 1 MHz, made by Panametrix, excited by an ultrasonic 5072PR pulser (Olympus). The high voltage electric pulse (up to 360 V) with a 5 ns rise time and exponential damping allows the generation of a broad-band high-frequency elastic wave. Due to frequency-dependent attenuation at roughly 25 and 50 cm from the seismic source, elastic waves with a frequency below 100 kHz were recorded. Therefore, to monitor P-waves, two 100 kHz V1548 Olympus piezoceramic S-sensors were used.

S-waves were recorded by two S-sensors and one 100 kHz P-sensor at a distance of approximately 50 cm. In the case of seismic measurement performed at a short distance directly at the rock surface the sensitivity of S-sensors to P-waves is significantly higher than that of P-sensors.[12] Similarly, when measuring the seismic transmission of S-waves at the rock surface, P-sensors exhibit higher sensitivity then S-sensors. Terrain measurement was conducted with a 4-channel oscilloscope. One channel registered the excitation pulse of the S-transducer (determining the origin time of the elastic wave), two channels were connected to two S-sensors and one channel was connected to a P-sensor (Fig. 2). During measurement, the central transmitting S-transducer was always oriented towards the measurement sensors, so it generated the particle movement in the direction of measurement. On each area tested there was a simple system for measuring the directional dependence of seismic wave velocity with an angular step of 45°. The travel time was measured for P- and S-waves propagation from the central source of seismic waves to two points on circles with radii of approx. 25 and 50 cm (Fig. 2).

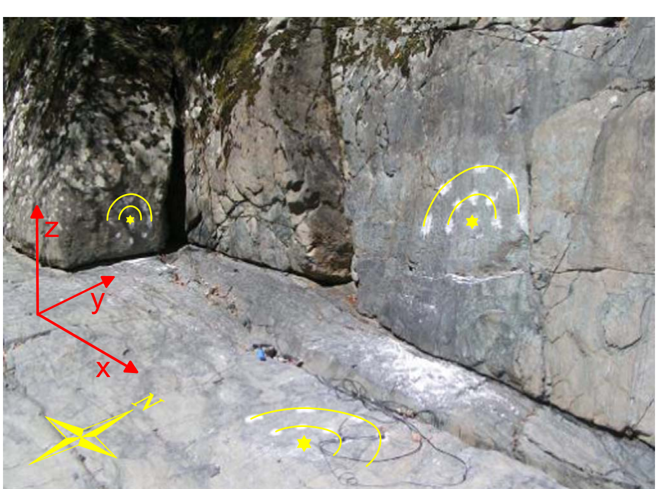

Fig. 1. Layout of the Balmuccia site. Position of three orthogonal planes of measurement.

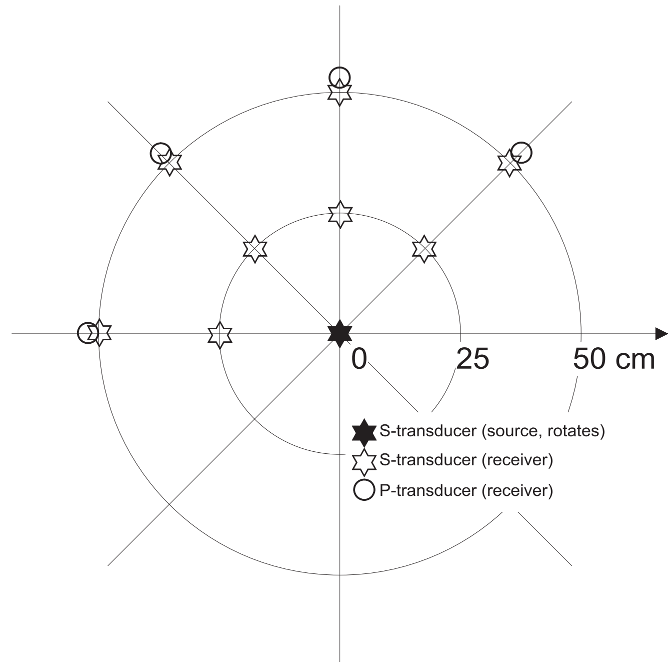

Fig. 2. Field measurement design. Positions of transducers for P- and S-wave measurement.

3. Laboratory measurements

Two rock samples were collected from Balmuccia region on the sub-horizontal plane close to Sesia river. The distance between samples extraction was about 3 m. These samples were used to prepare B15 and B16 spherical test specimens with 5 cm in diameter. The spherical specimens were dried under low pressure and increased temperature. The density was determined experimentally and was equal to 3500 kg m^{-3}. The orientation of the samples at the site was recorded, so that the laboratory coordinate system of samples was oriented to their original position in the field. Table 1 contains the mineral composition of specimens B15 and B16 determined by X-ray diffraction analysis. A relatively simple modal composition of the rock is shown in a classification diagram for peridotite and pyroxenite in Fig. 3, based on Ref. 13.

A pulse-transmission technique was used for measurements both P- and S-wave velocities. The measuring system used one pair of P-wave transducers, which can generate and record P-waves. A N51 Noliac piezoceramic pill, 4.5 mm in diameter and 0.5 mm thick, was used in these transducers. Simultaneously, one pair of shear wave transducers was installed for S-wave velocity measurement. In this case, N55 Noliac piezoceramic pills, 2.5 × 2.5 mm in size and 1 mm thick were used. All the transducers had flat contact surfaces; therefore they had only one point contact with the spherical specimen. This does not matter for P-waves registration. However, for shear wave transmission such point contact of transducer with the spherical specimen results in weak S-wave energy transfer. Therefore, the specimen surface was covered by a special shear wave gel with high viscosity. The

Table 1
Mineral composition of rock specimens (vol%) determined by X-ray analysis.

Specimen	Mineral			
	Olivine	Orthopyroxene (enstatite)	Clinopyroxene (diopside)	Chrysotile
B15	61.0	22.3	14.9	1.8
B16	56.2	25.3	16.3	2.2