Seismic properties of continental mantle xenoliths at the garnet-spinel transition. An experimental study.

L. Burlini*, H Kern**, I.V. Ashchepkov***

*Centro per lo Studio della Geodinamica Alpina e Quaternaria, CNR, Via Botticelli 23, I-20133 Milano, Italy

**Mineralogisch-Petrographisches Institut, Universität Kiel, 24089 Kiel, Germany

***United Institute of Geology, Geophysics and Mieralogy, SD,RASc, Novosibirsk, Russia.

Seismic properties of some mantle xenoliths from the Vitim volcanic plateau (Siberia) were measured in a triaxial pressure apparatus at pressure up to 600 MPa and temperature up to 600°C and compared with calculated velocities based on the crystallographic preferred orientation (LPO) of olivine and orthopyroxene determined by U-stage measurements, the modal composition measured with a computer-imaging technique and the single crystal stiffness coefficients.

P and T of equilibration has been calculated from the mineral composition of many samples, allowing the reconstruction of a lithological column spanning from 40 to 90 Km depth. The samples studied have been equilibrated at temperature of 1050-1150°C and represent the middle part of the mantle column, in which the spinel- garnet transition in the upper continental mantle occurs, at the starting time of the Vitim lava plateau formation.

The velocity measurements were done on sample cubes (43 mm edge length) using the ultrasonic pulse transmission technique. The measurements of P- and S-wave velocities along the three principal axes of the sample cubes permit the estimation of maximum and minimum velocities and thus the coefficient of anisotropy. This, particularly, holds for the case that the sample reference system has been related to inherent fabric elements such as the lineation (X), the normal to the foliation plane (Z) and the normal to these two directions (Y). Two sets of shear wave transducers with perpendicular polarization planes alowed the measurement of shear wave splitting. The compressional (V_P) and shear wave velocities (V_S) measured as functions of pressure and temperature (up to 600°C at 600 MPa) shows a marked increase in wave velocities as pressure is increased. Quasi-linear behaviour indicating closure of most of the inter-and intragranular cracks is approached between 200 and 400 MPa. Increase in temperature at a constant pressure of 600 MPa, gives rise to further increase of velocities. The temperature-induced velocity increase is most pronounced in samples (313/802, 314/380) exhibiting more quenched melts along grain boundaries, suggesting that both temperature >600°C and pressures >600 MPa are required to completely close porosity in the xenoliths which are in general more decompacted than mantle peridotites from massifs brought to the surface by tectonic events.

All the studied samples exhibit pronounced anisotropies of V_P and V_S. The fastest P-wave velocities were measured within the foliation plane parallel to lineation (X) and the slowest normal to it (parallel to Z). The near-parallel slopes of the velocity curves above about 300 MPa, where the mayor part of cracks is closed, suggest that the velocity anisotropy is mostly related to preferred orientation of major minerals. It is clear from the parallel slopes of the velocity vs temperature curves that velocity anisotropy is not significantly affected by temperature. P-wave anisotropies (at 600 MPa) vary between 3.98 and 6.37% and average P-wave velocities are in the range 6.98 to 7.92 km/s. Elastic anisotropy is also documented by shear wave splitting up to 0.17 km/s

The calculation of the directional dependence of the elastic wave velocities in the rocks is based on the LPO's of olivine (413-801, 314-303) and of olivine and orthopyroxene (samples 313-802 and 314-380) making up more than 68% and 80% of the total volume, respectively In the samples 313-801, 314-303 the LPOs of ortho- and clinopyroxenes are assumed to be random. The minor minerals such as garnet and spinel are cubic and, therefore, do not contribute much to the velocity anisotropy of the rock. The melt has been ignored in the calculation because never exceed 0.5%, and the thin kelyphitic rim around garnet has been assumed as garnet.

In Fig.1 we present the crystallographyc fabrics as pole figures (equal area, lower hemisphere) and, in Fig.2 we present the P- and S-wave velocities in the form of contour stereograms. In addition, the mode of the rocks used for the calculations is indicated. The vertical line represents the trace of the folitation plane, and lineation is N-S.

In the Vitim samples, the LPOs of the olivine fabric are very similar. Maximum concentrations of [100] poles are observed subparallel to foliation and linetation. Compared to the spinel peridotite (314-380), the [100] directions in the garnet peridotites show a tendency for a N-S girdle. The poles of the [001]- axes exhibit maximum concentrations supparallel to foliation and perpendicular to lineation. The [010] directions tend to girdles with maximum concentrations more ore less normal to the foliation plane.

The marked fabric anisotropy measured in the xenolith samples gives rise to pronounced velocity anisotropy as is documented in the stereograms of the calculated P- and S-wave velocities. The symmetry of all V_P patterns is more or less orthorhombic with a tendency for axial symmetry around [010] in the garnet peridotites, and reflects the symmetry of the orientation patterns. Directions of highest P-wave velocities are found to be subparallel to lineation and foliation and closely related to the maxima of olivine [100], which is the fast direction in olivine single crystals. Directions of slow P-wave velocities are perpendicular to foliation and correspond to maximum concentration of [010]. [010] is the slowest direction for P-wase in olivine single crystals.

Conclusions

(1) Seismic anisotropy in the mantle peridotites is primarily a result of olivine preferred orientation. Measured and calculated velocity anisotropies of the mantle peridotites from the Vitim xenoliths compare fairly well. The correspondence between the measured and calculated shear wave splitting data is generally less pronounced, probably because the LPOs of the cpx fraction have not been included in the calculation. In addition, grain boundary effects (interstitial quenched melt, uncomplete crack closure) could have an effect on shear wave polarization.

(2) The experimentally determined P-wave anisotropies of the mantle xenoliths are in the same range as the P-wave anisotropies measured on mantle peridotites from massifs.

(3) The seismic properties of the few Vitim xenoliths examined seem to indicate a very slight increase of Vp and a significant decrease of Vp anisotropy and shear wave birefringence across the transition spinel to garnet peridotite.

FIGURE CAPTIONS

Fig. 1: Pole figures of olivine [100]-, [010]-, and [001]-axes for the Vitim tuff xenoliths presented on equal area projection.

Fig. 2: 3D calculations of P- wave velocities (left), variations of shear wave splitting (middle), and orientations of the polarization plane of the fast split shear wave (right); each short arc segment is a part of a great circle corresponding to the orientation of the polarization plane. Also shown is the modal composition of the rock.

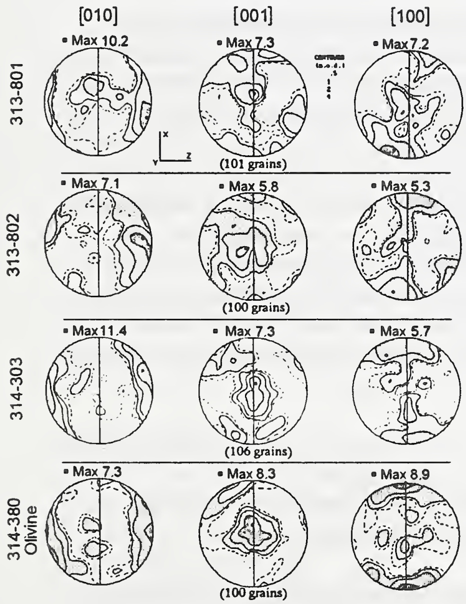

Fig.1

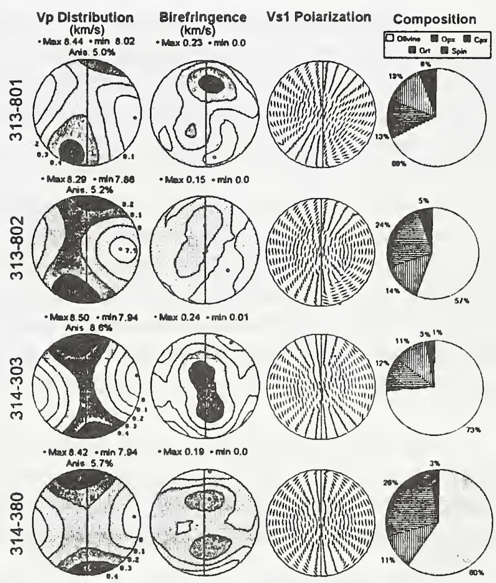

Fig.2