PETROFABRIC, COMPOSITIONAL FEATURES AND SEISMIC PROPERTIES OF METAMORPHIC ROCKS: A MULTIPLE APPROACH

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Objectives

Our research focuses on the relationship between the compositional features, abundances and distribution of mineral phases of two paragneisses representative of the Peloritani Mountains, NE Sicily (Italy) and their petrophysical properties. The aim is to identify the similarities and differences obtained using various approaches, to better understand the petrophysical properties of rocks at elevated pressure and temperature.

Geological setting

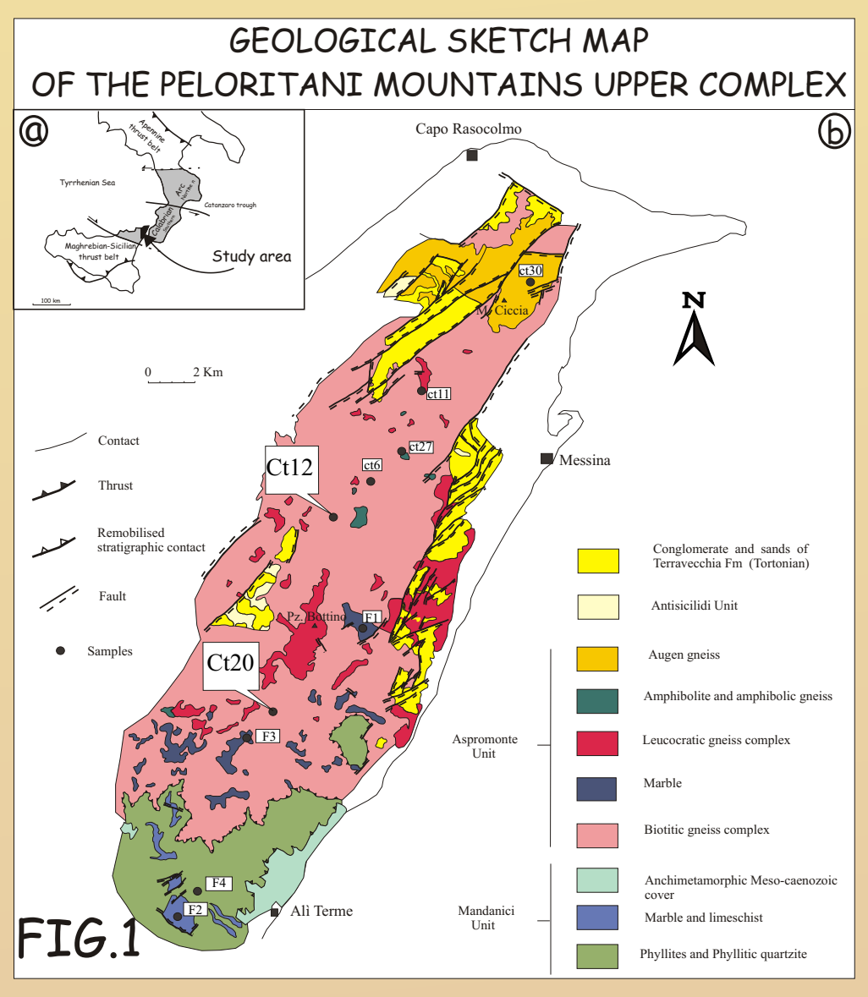


FIG.1

The Peloritani Mountain Belt constitutes the southernmost part of the Calabrian Peloritani Orogen (CPO), a segment of the Alpine orogenic belt located in the central Mediterranean area (Fig.1a). The actual structure of CPO is essentially characterised by a nappe-pile edifice, involving distinct tectonic slices of metamorphic basement rocks and passive margin Meso-Caenozoic sedimentary sequences. The basement units are both remnants of Hercynian chain and Alpine metamorphic rocks incorporated into the Alpine-Appennine nappe system of the western Mediterranean area (Fig.1b).

It is worth noting that the crystalline basement of the Peloritani Mountains was previously selected as a type area for investigating the Italian continental crust (Atzori et al., 2003).

Sample description

The two paragneisses chosen exhibitan anisotropic fabric with a single well developed foliation and single stretching lineation. They exhibit similar assemblages, except for higher muscovite content in sample Ct20 and sillimanite as well as abundant plagioclase occurrence in sample Ct12. Conventional geothermobarometry inferred P-T syn-kinematic metamorphic conditions at 3.6 +/- 0.3kbar and 823 +/- 25 K (Ioppolo & Puglisi, 1989).

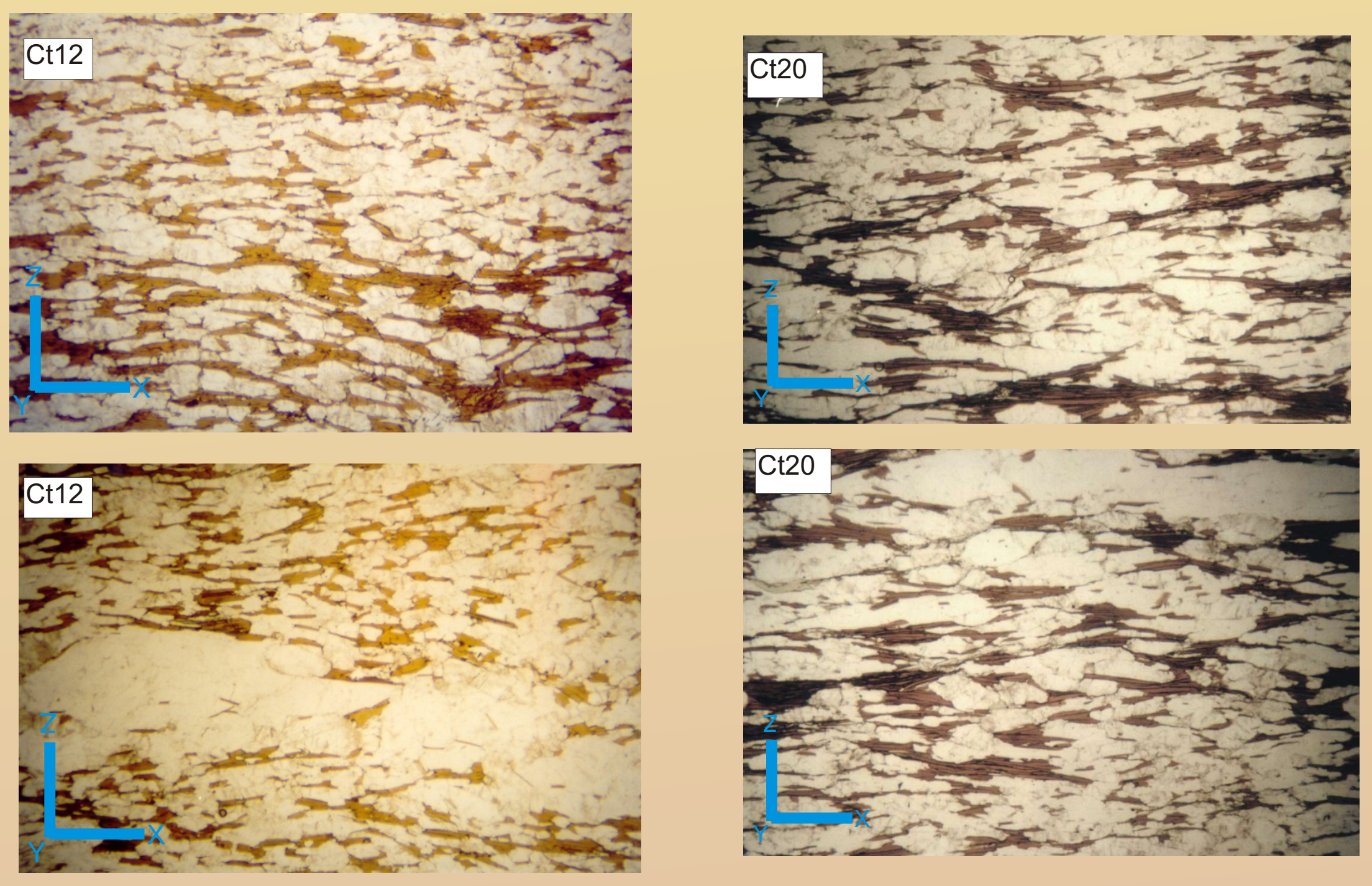


Fig.2. Microstructural features of paragneisses CT 12 and CT 20

Sample	Rock Type	Mineralogical abundance	Structures & microstructures
Ct 20	Paragneiss	42 Qtz, 27 Bt, 14 Ms, 2 Kfs, 2Ms, 1 Acc	Coarse-grained, grano-lepidoblastic texture
Ct 12	Paragneiss	36 Qtz, 25 Bt, 22 Pl, 2 Kfs, 7 Ms, 7 Sil, 1 Acc	Blastic structure, foliated
Abbreviations: Amph = amphibole; Bt = biotite; Cal = calcite; Kfs = K-feldspar; Ms = muscovite; Pl = plagioclase; Qtz = quartz; Chl = chlorite; Sil = sillimanite; Acc = accessories			

Tab. 1 .Petrographic features

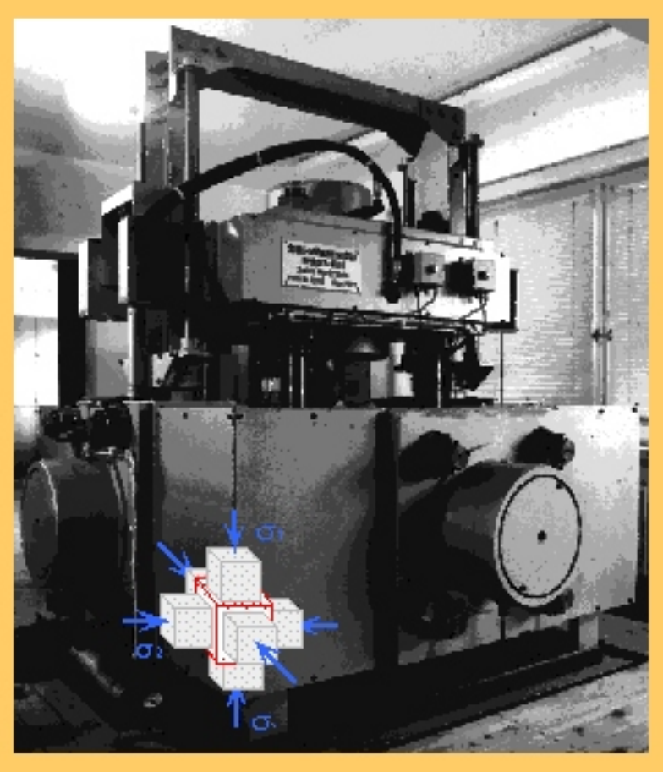
Wt%	Paragneiss **CT12**	Paragneiss **CT20**
SiO_2	65.08	64.93
TiO_2	0.79	0.65
Al_2O_3	15.09	14.46
Fe_2O_3	6.79	6.13
MnO	0.08	0.09
MgO	3.13	3.31
CaO	2.2	2.23
Na_2O	2.6	2.30
K_2O	2.88	2.82
P_2O_5	0.21	0.15
L.O.I.	1.36	1.44
ppm		
Cr	82	89
Ni	43	67
Zn	85	97
Rb	103	100
Sr	223	167
Zr	170	171
Ba	560	579

Tab. 2. Geochemical composition after XFR investigation

Experimental measurements and the nature of intrinsic seismic anisotropy

The laboratory measurements were performed in a multi-anvil pressure apparatus using the ultrasonic transmission technique with transducers (lead zirconium titanate) operating at 2MHz (Vp) and 1MHz (Vs) respectively. Simultaneous measurements of compressional and orthogonally polarized shear wave velocities (S1, S2) were done in the three structural directions X(parallel to lineation), Y(normal to lineation within the foliation plane) and Z (normal to foliation plane). Each set of results is composed of nine velocity values: three P-wave velocities and nine S-wave velocities.
Finally, length and resulting volume changes of the sample cubes are obtained from the piston displacement. The cumulative error in both Vp and Vs is <1%.

Triaxial multi-anvil apparatus



Six pyramidal pistons pressing onto the cube-shaped specimen (43 mm edge length) generate a near-hydrostatic stress. One end of each piston next to the specimen is surronunded by a furnace, and heat is transmitted from the pistons to the specimen

T max: 600°C P max: 600 M Pa

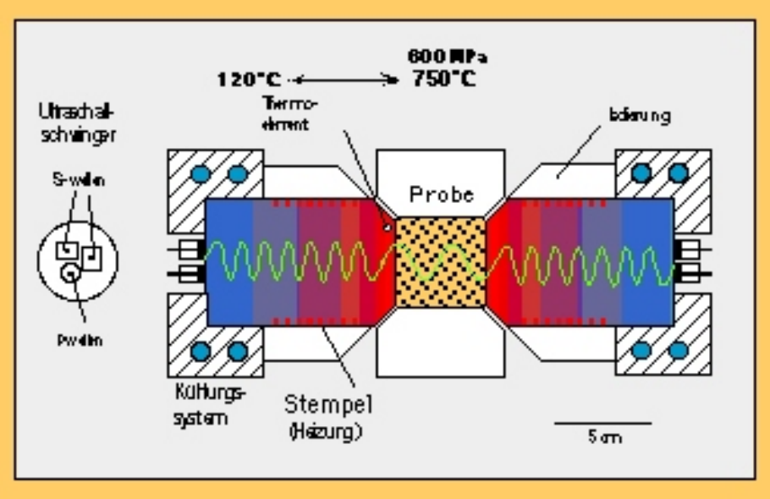


Fig.3 Sample cubes (43 mm edge length) oriented to structural directions X, Y and Z at P/T conditions.

Tthe directional dependences of P- and S- wave velocities in **paragneisses ct12** and **ct 20** as a function of pressure (at room temperature) and as a function of temperature (at 600MPa) are set out on Figs. 4 and 5,respectively. Increase of confining pressure gives rise to a non-linear increase of seismic velocities due to the progressive closure of microcrack. The crack-closing pressure is indicated by the transition from non linear to linear behaviour.
Moreover, the Vp and Vs measurements in the main structural directions (i.e. parallel and normal to foliation and lineation), allowed the determination of the coefficient of velocity anisotropy (A).

$$A= [(Vmax-Vmin)/Vmean]x100, \text{ where } Vmean \text{ is } (Vx+Vy+Vz)/3$$

	P(MPa)	Vp (km/s)	Vs (km/s)	Vp/Vs	Poisson's ratio	density (g/cm3)
ct 20	611	6.16	3.61	1.71	0.239	2.811
ct12	612	6.27	3.64	1.72	0.244	2.919

Tab. 3. Velocity average values along with Vp/Vs and Poisson's ratio and densities determined at room temperature conditions at P= 600MPa

Paragneiss Ct 12

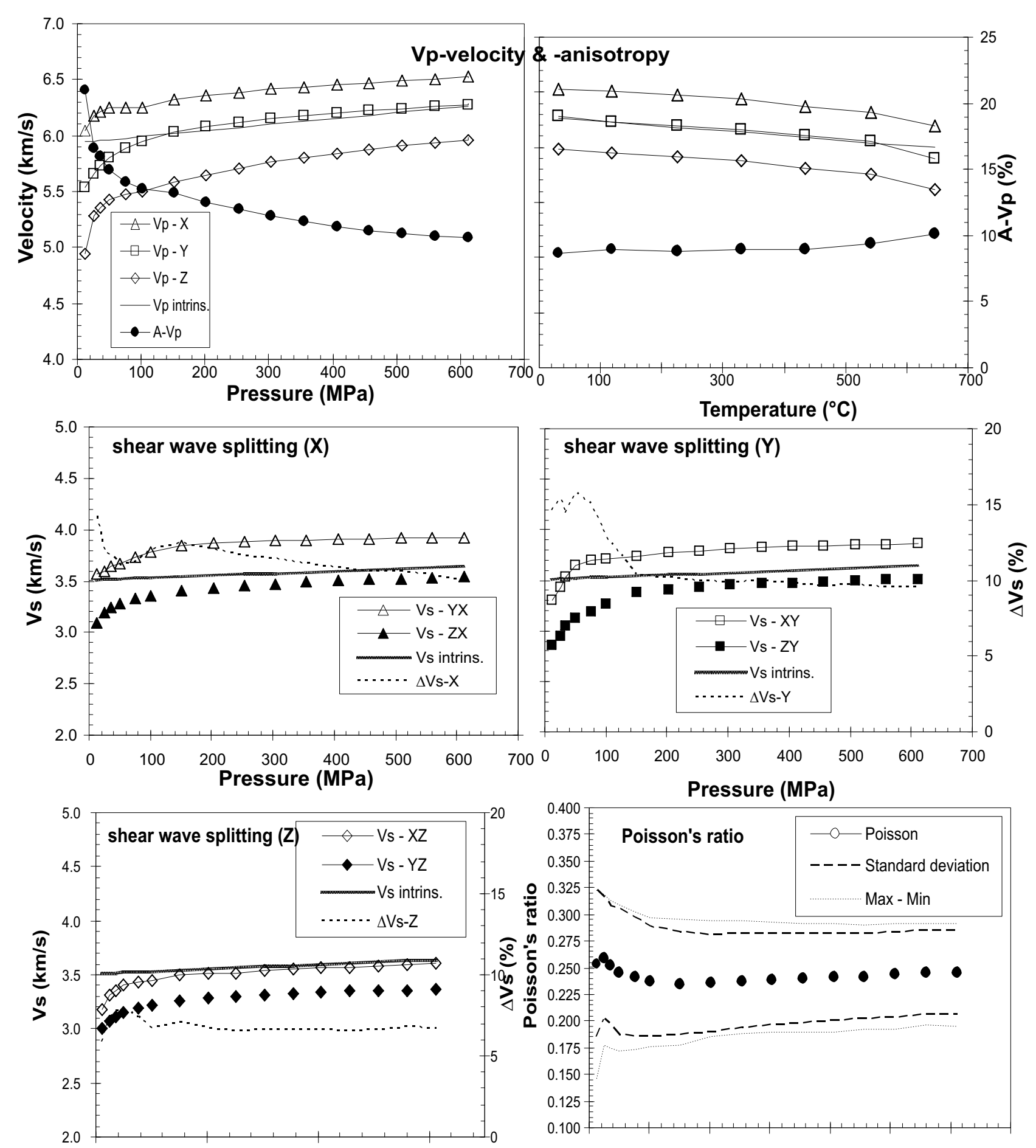


Fig.4

Paragneiss Ct 20

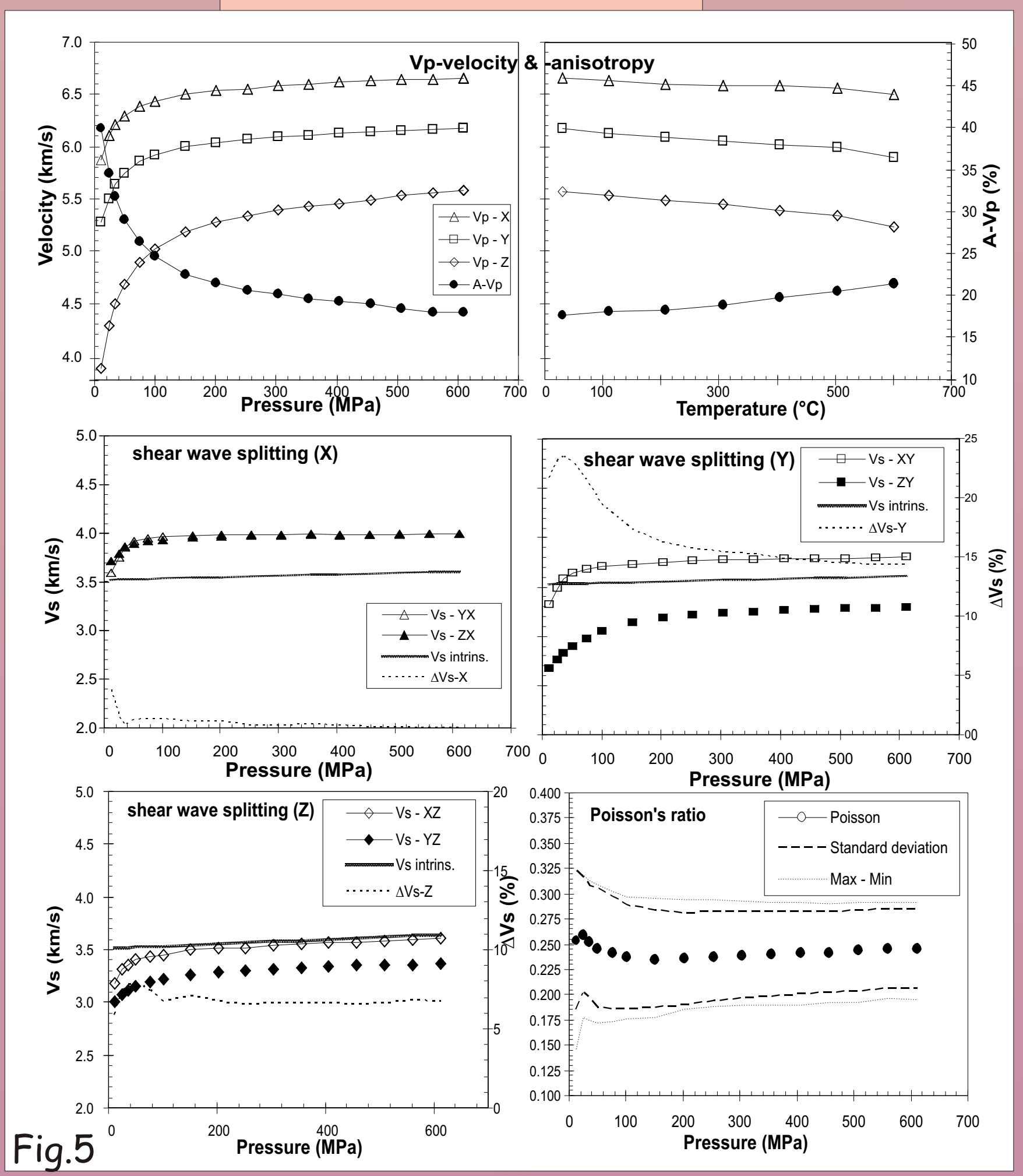


Fig.5

LPO-based velocity calculations

Thise approach is based on the Christoffel equation which combines the velocity (V), the single stiffness coefficients (Cijkl), the density (ρ) and the LPO-derived Orientation Distribution Function (ODF) of the mineral phases in their modal proportions. The Voigt-Reuss-Hill averaging was used for calculations.The measurements of LPOs in the paragneisses were performed with an U-stage equipped optical microscope.

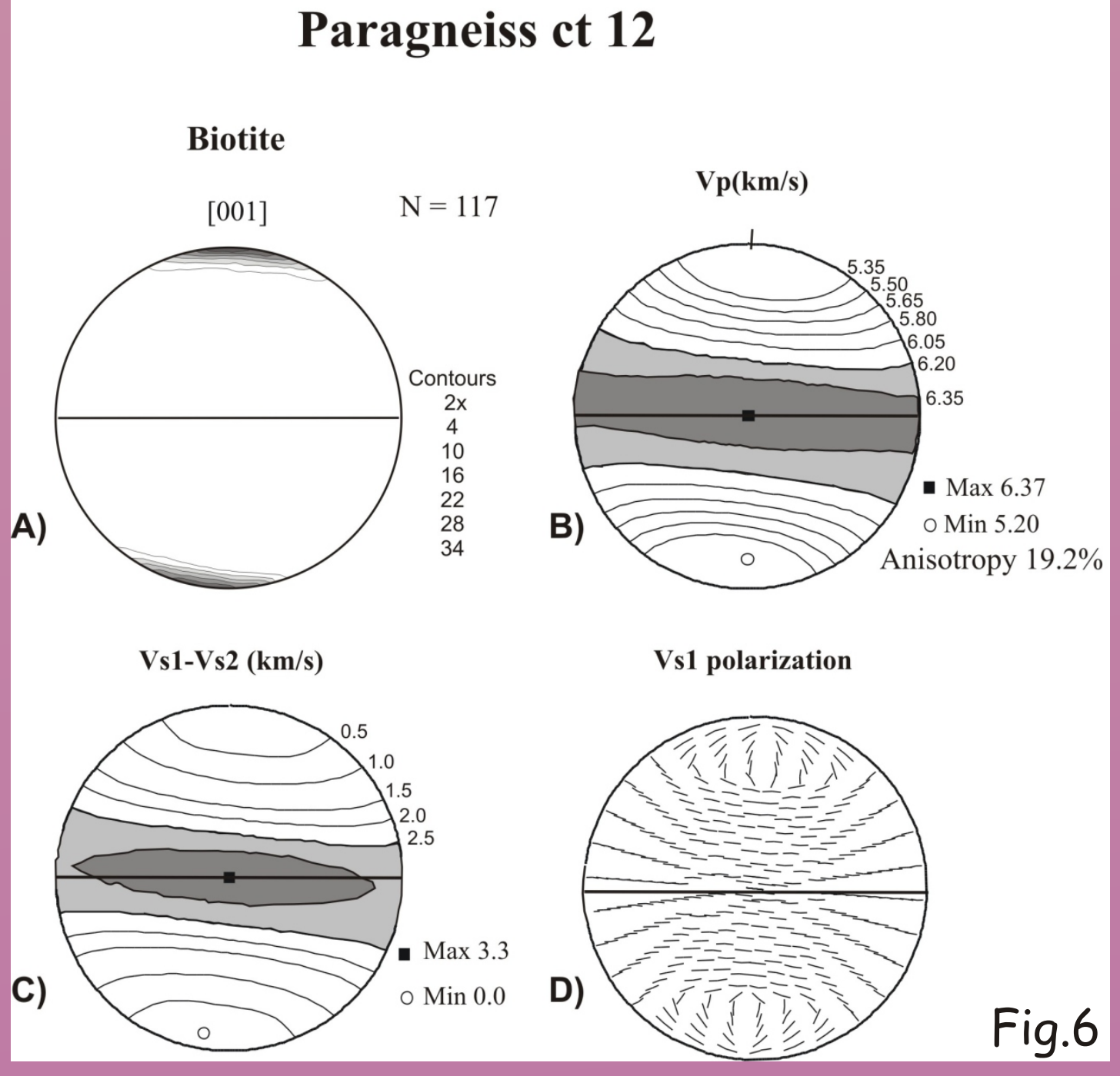


Fig.6

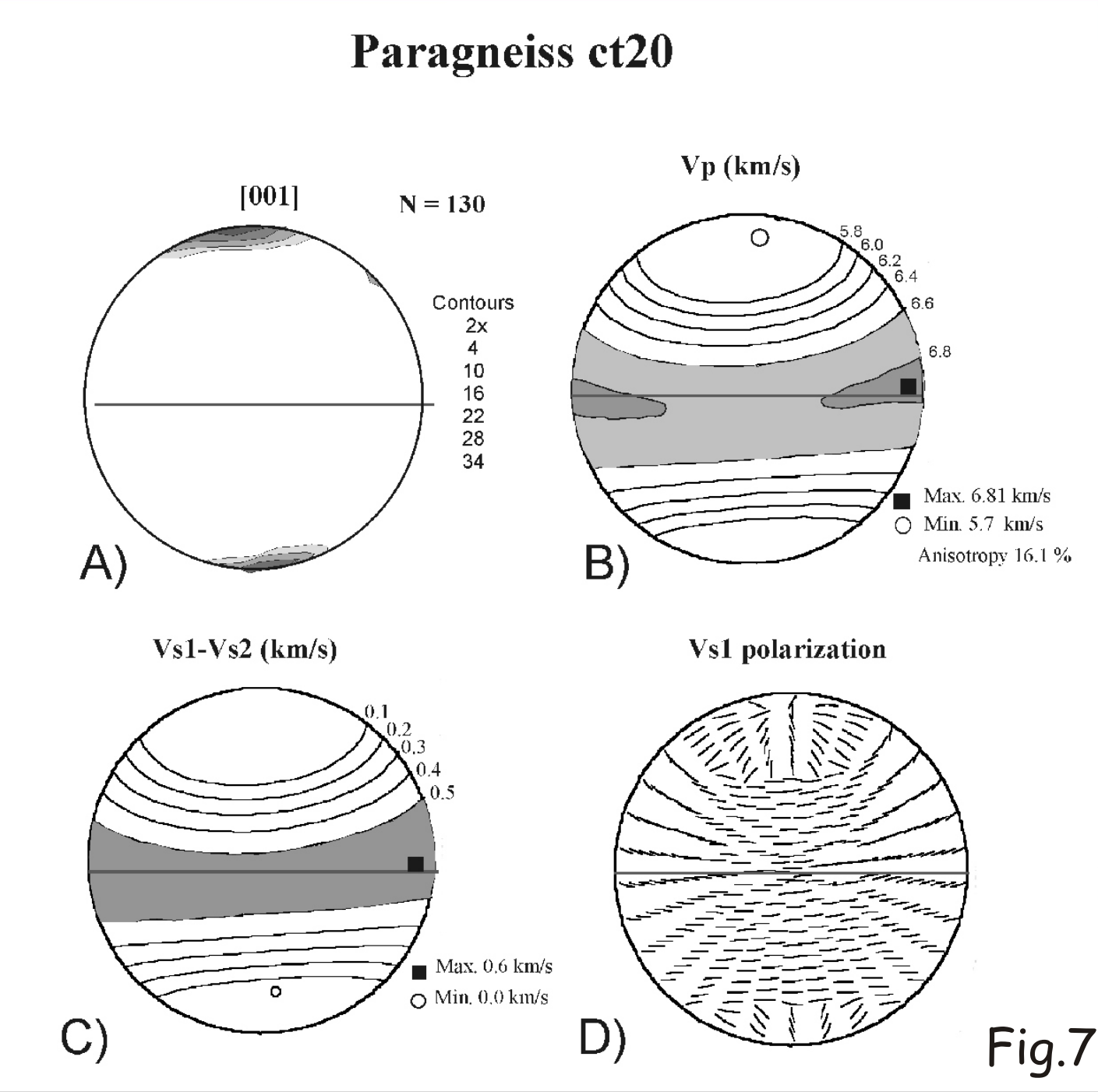


Fig.7

Figs. 6 and 7. Maximum and minimum P- and S- wave velocities as well as shear wave splitting are strongly related to biotite LPO and to foliation.

Petrophysical properties from thermodynamic approach

For both paragneisses, fixed bulk rock compositions were used in the calculation of pseudosections and elastic properties over the P-T space.
Assemblages, mode and compositions of the constituent minerals were determined by free energy minimization using the Perplex software package, which consists of a suite of programs for calculating phase diagrams and thermodynamic equilibria.Bulk moduli were calculated by Voigt-Reuss- Hill averaging, and then these are used to calculate bulk velocity of the aggregate, by also taking into account the volume proportion of the respective phases. With this approach, average elastic properties of the aggregate are calculated without any dependence on the textural features. Properties were computed in the MnO, Na_2O, CaO, K_2O, FeO, MgO, Al_2O_3, SiO_2, H_2O chemical system (MnNCKFMASH); H_2O was considered in excess.

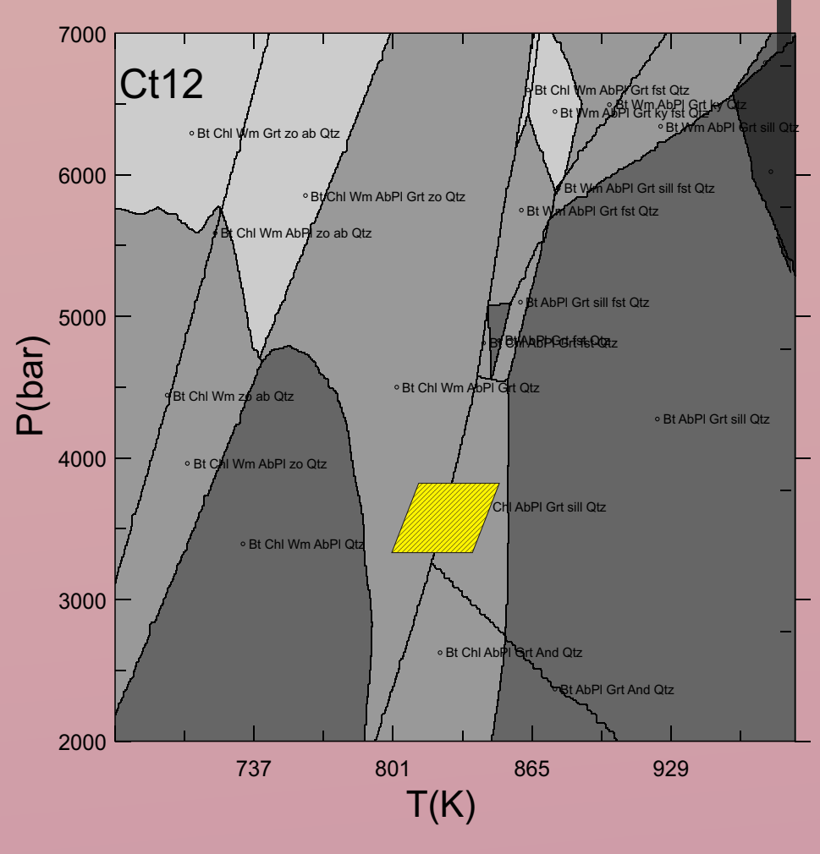
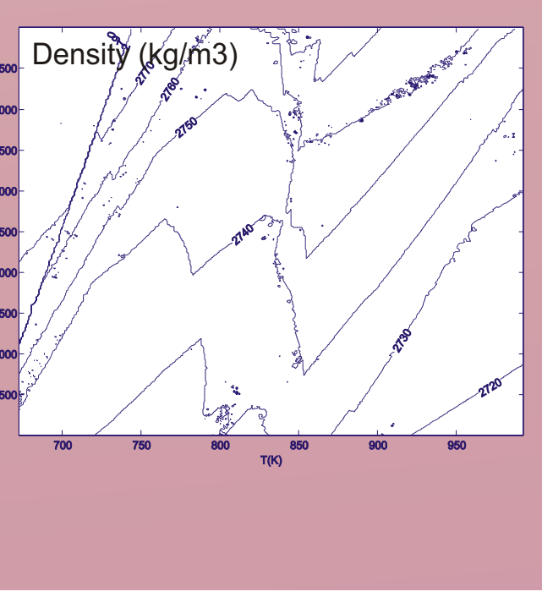
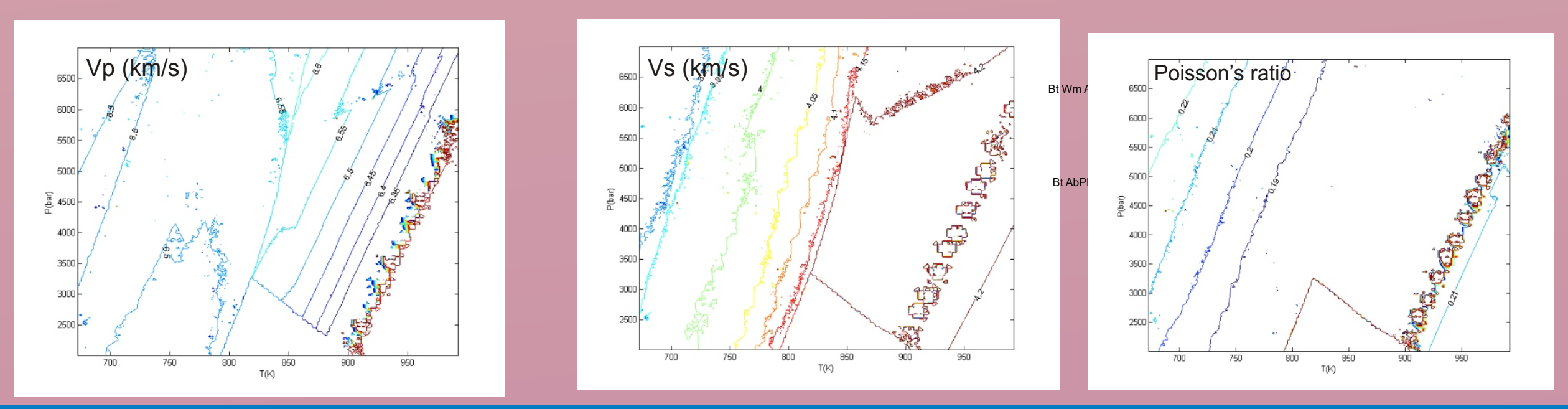


Fig.8. Computed pseudosection and seismic properties of sample Ct12



Sample ct12

T (K)	823	848
P(bar)	3600	3300
Density (kg/m3)	2734	2738
Grueneisen ratio	0.62	0.63
Adiabatic Bulk Modulus (bar)	489496	469805
Shear Modulus (bar)	479727	491630
P-Wave velocity (km/s)	6.52	6.51
S-Wave velocity (km/s)	4.16	4.21



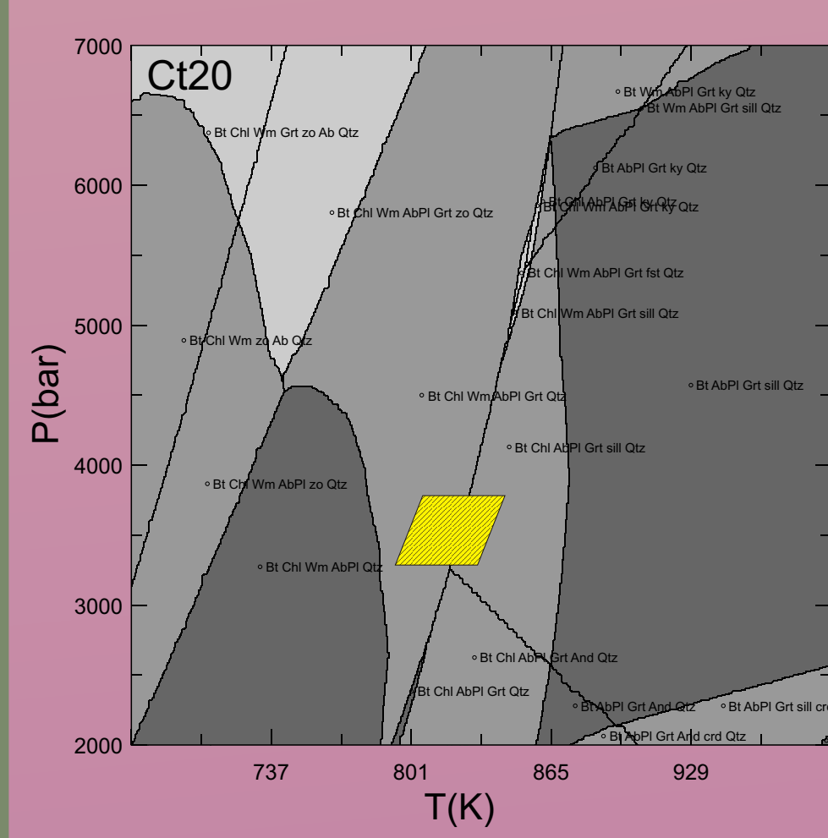
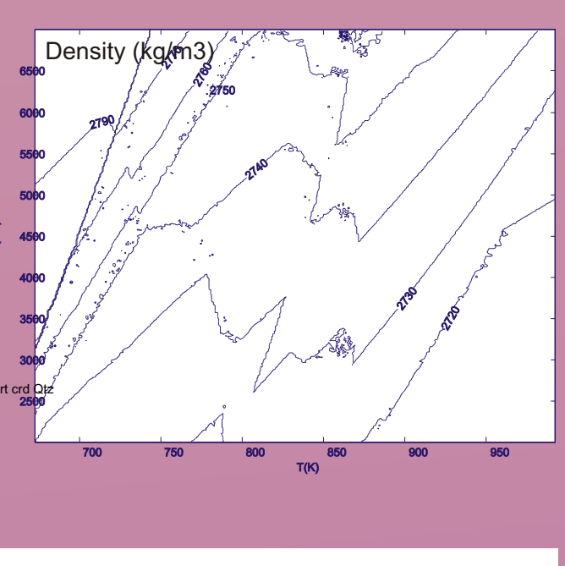
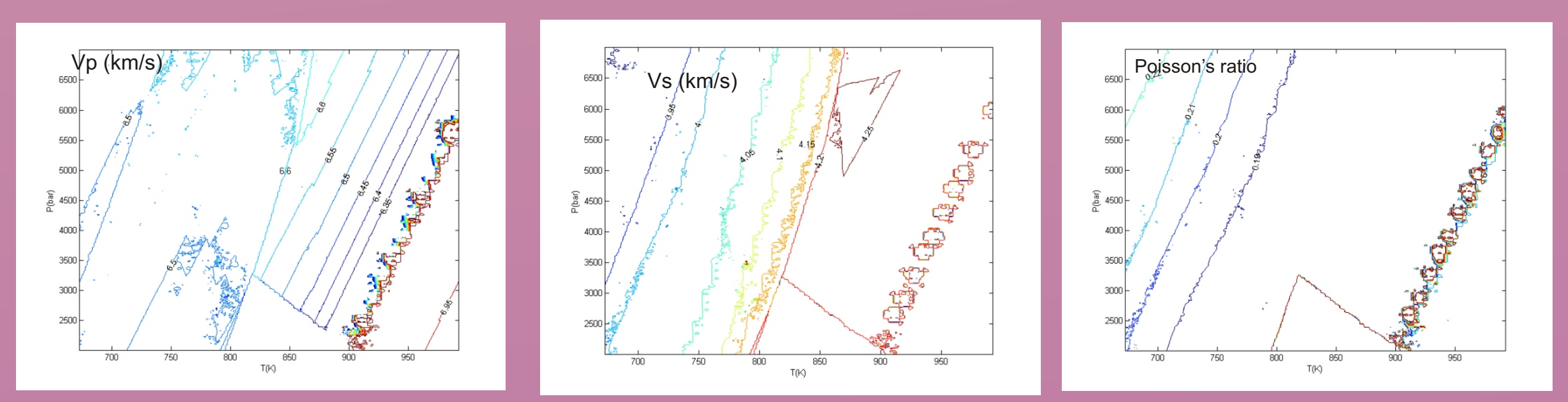


Fig.9. Computed pseudosection and seismic properties of sample Ct20



Sample ct20

T (K)	823	848
P(bar)	3600	3300
Density (kg/m3)	2729	2731
Grueneisen ratio	0.625	0.64
Adiabatic Bulk Modulus (bar)	486394	468886
Shear Modulus (bar)	478764	495536
P-Wave velocity (km/s)	6.51	6.51
S-Wave velocity (km/s)	4.16	4.24



Conclusions

Calculated velocities result to be systematically higher than the values obtained experimentally.
This may be interpreted as the effect of occurring microcracks and secondary minerals which are not taken into account in both LPO- and Perplex- based computation.
On the other hand, velocity calculations were done in simplified systems, in terms of: a) chemical composition; and b) modal proportions.
Direct measurements may be therefore regarded as the basis on which seismic calculations must refer to, in order to put into evidence the influence of texture on the development of seismic anisotropy as well as the average elastic behaviour of a rock with given chemical composition over the P-T space.