Fluid assisted formation and deformation of eclogites - dislocation vs. dissolution-reprecipitation creep

universität wien

Anna Rogowitz[1] and Benjamin Huet[2]

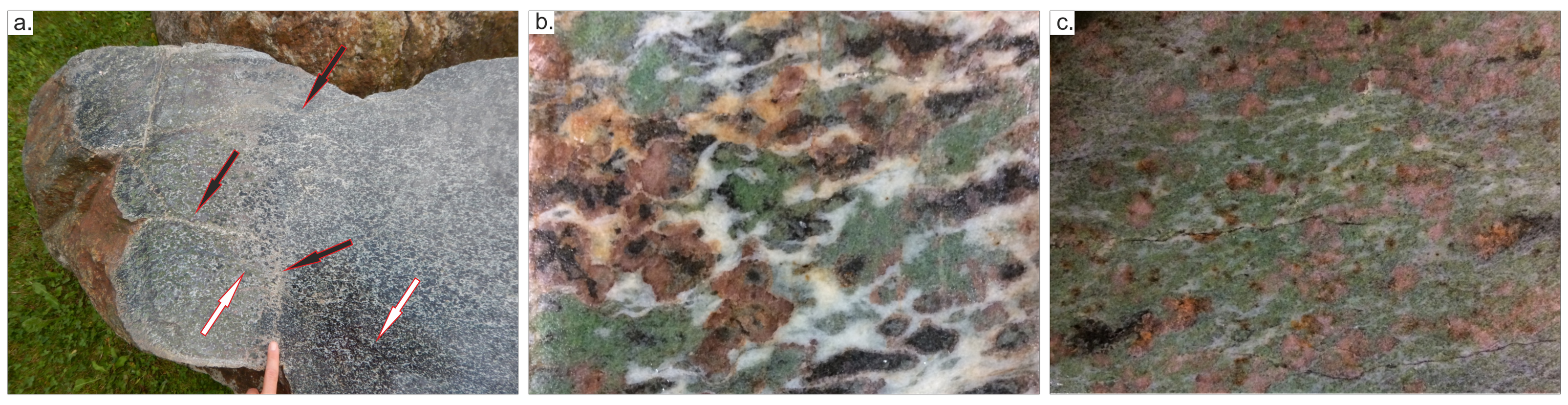
Department of Geodynamics and Sedimentology

Introduction

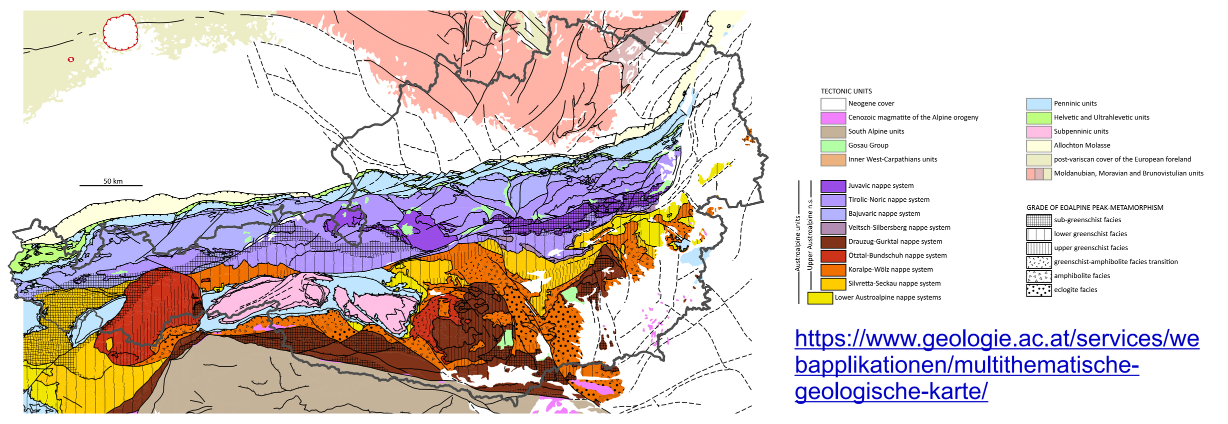
The classical eclogite mineral assemblage consists of the non-hydrous minerals garnet and omphacite. Nevertheless, it is widely accepted that the transformation of mafic rocks into eclogite requires fluid infiltration. The most common fluid pathway referred to are cracks acting as brittle precursor for fluid-supplied eclogitization, followed by subsequent strain localization, possibly enhancing further eclogitization. While this seems to be a common observation, it is still not fully understood by which processes fluids enhance the metamorphic processes. Herein a set of eclogites from the type-locality (Koralpe, Austria) representing three different strain stages has been analyzed by means of their microstructure and petrology. Additionally, thermodynamic forward modelling has been performed to constrain pressure, temperature and water activity during eclogitization.

All samples are composed of garnet (grt), clinopyroxene (cpx), quartz (qtz) and a fine grained polycrystalline mixture of kyanite (ky), clinozoisite (czo) and retrograde plagioclase (pl) which will be referred to as fgpa. While the general mineral paragenesis is similar in all investigated samples, we do observe minor variation in the volume fraction of each mineral, the specific mineral chemistry and the microstructure with respect to the different eclogite types. In the following microstructural and petrological observations on each eclogite type are described separately and discussed with regard to conditions and processes of eclogitization and deformation.

Geological setting



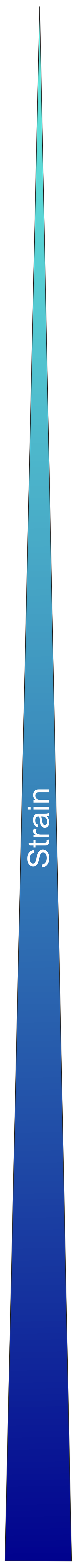
Photographs of the Koralpe eclogites. a. Polished rock at the Geopark Glashütten showing the transition from gabbro to eclogite. Gabbro and eclogite are crosscut by late fractures (black arrows) which are locally reactivated as shear zones (white arrow). b. Coronitic eclogite showing garnet coronae around pyroxene and amphibole in a matrix of sodium-clinopyroxene and clinozoisite (N 46°43′32″, E 15°08′44″). c. Highly strained eclogite showing elongated garnet aggregate in a sodium-clinopyroxene matrix with minor clinozoisite and quartz visible (N 46°43′32″, E 15°08′44″).

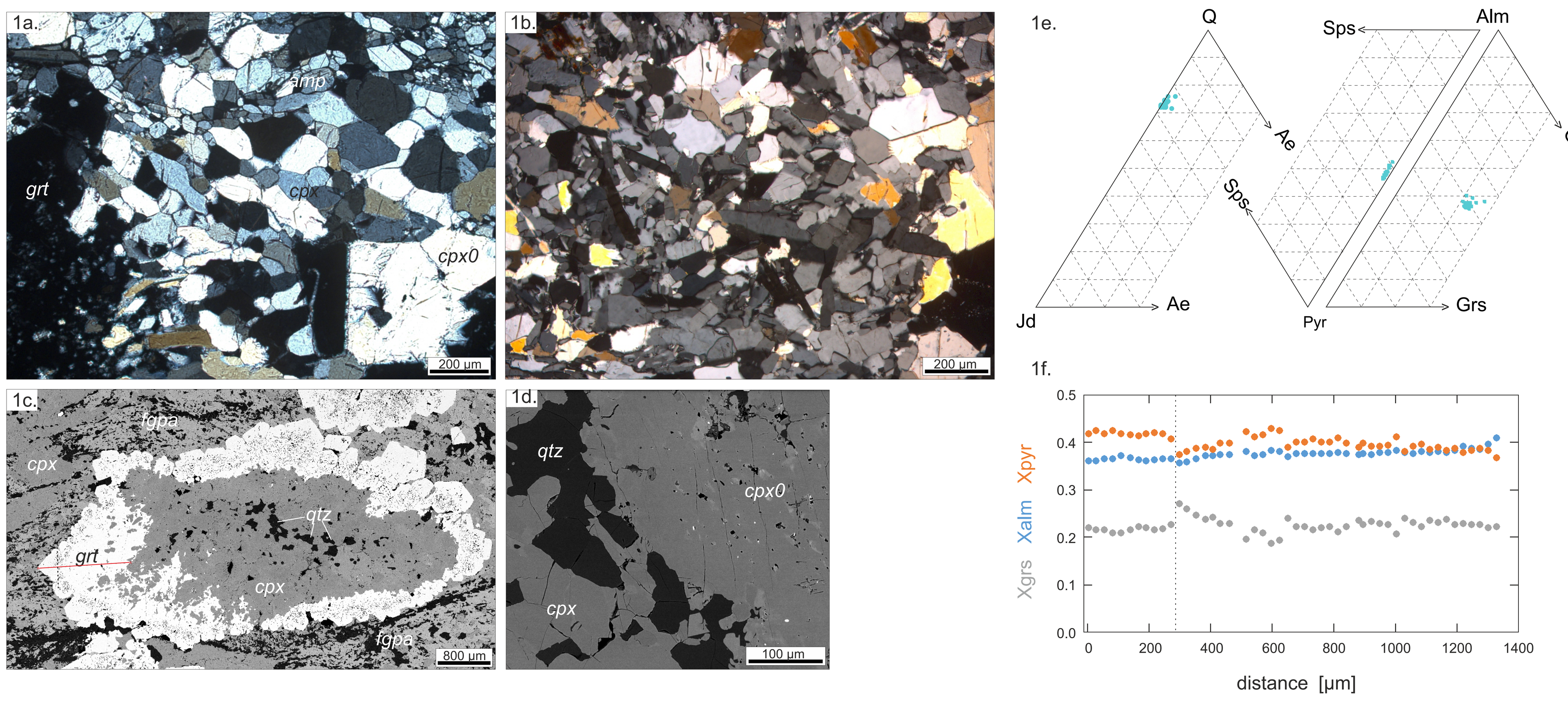


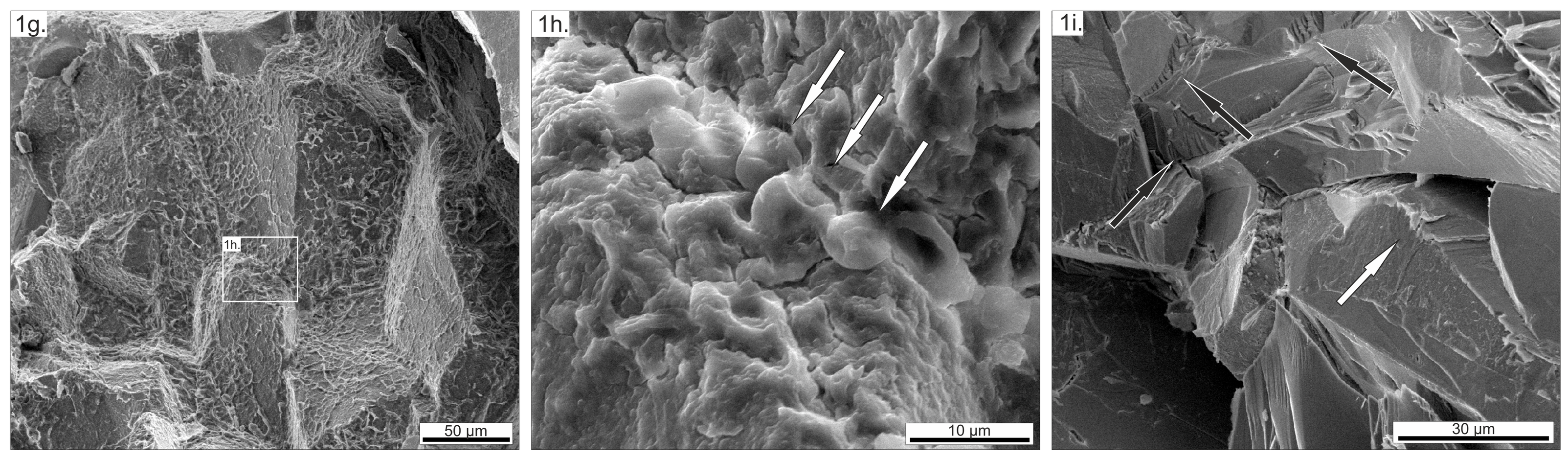
Combined metamorphic and tectonic map of Austria showing the eclogite type locality in the framework of the Eastern-Alps. The green star marks the Koralpe.

https://www.geologie.ac.at/services/webapplikationen/multithematische-geologische-karte/

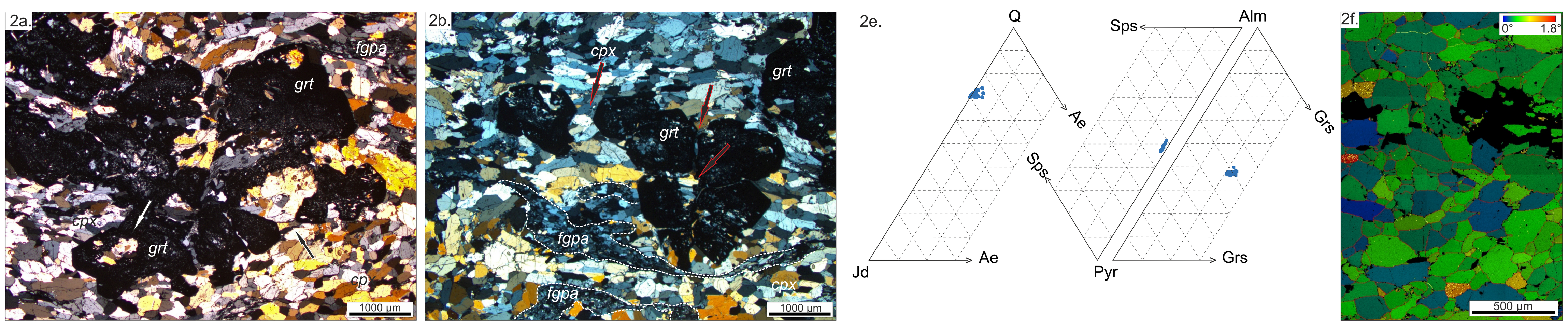
Microstructural and petrological observations

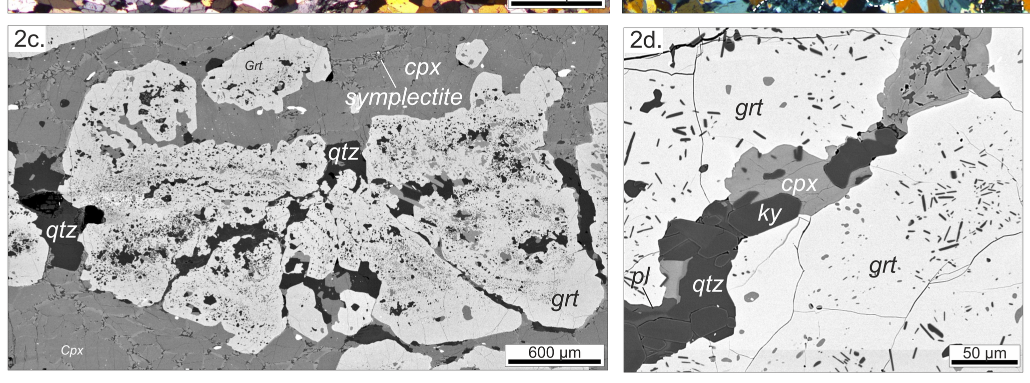


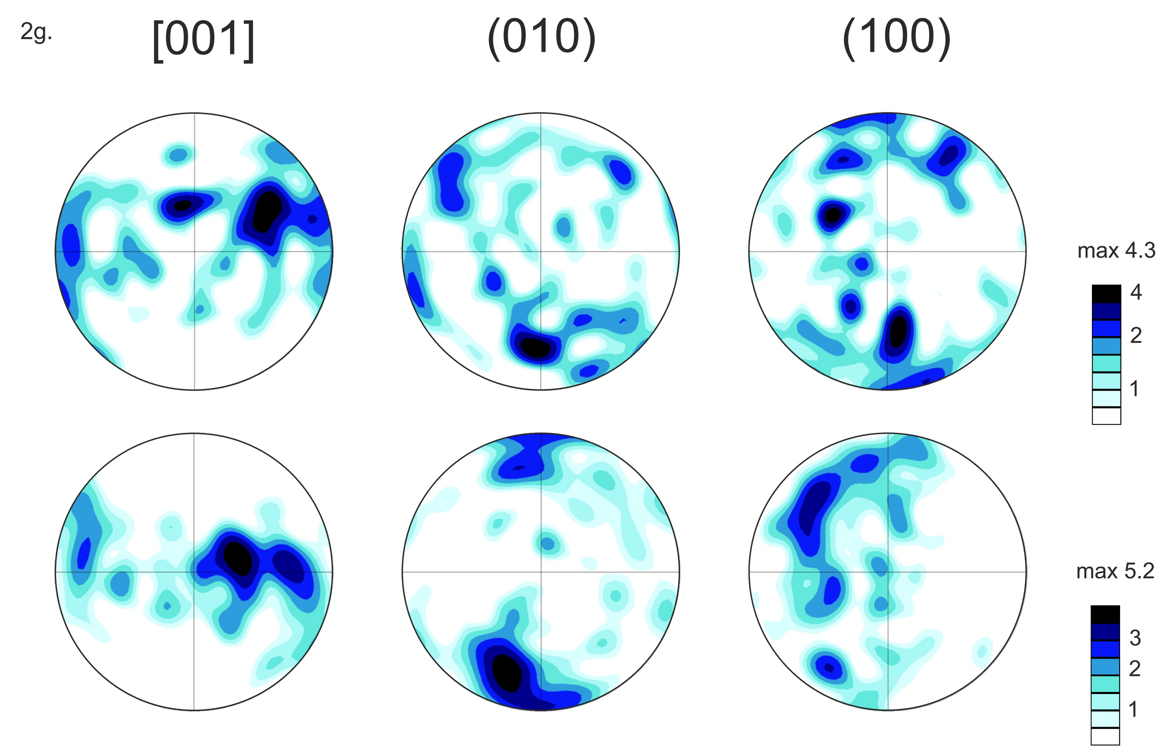




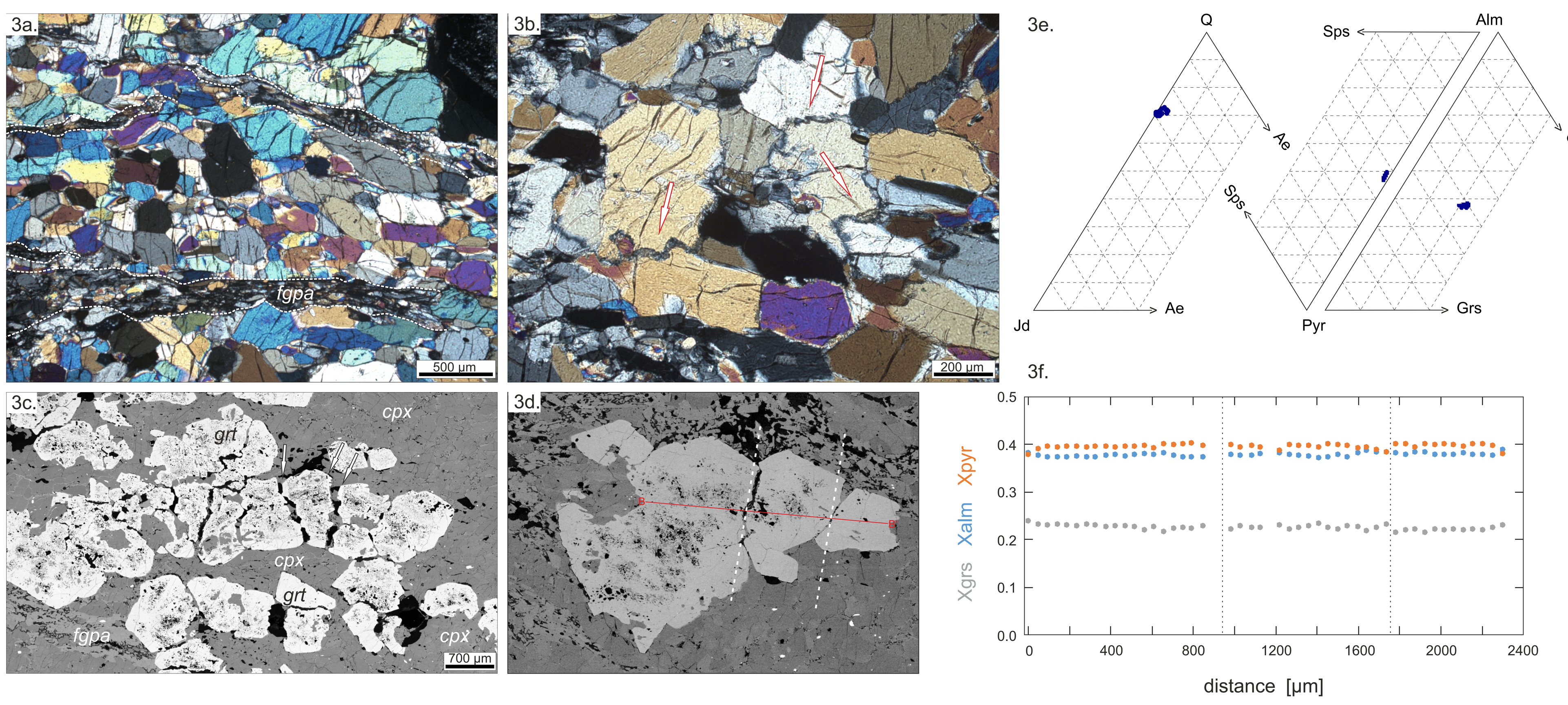
1a. Foam texture in cpx and minor amphibole in coronitic eclogites. Left side of the image shows a grt-cpx intergrowth (crossed polarized light). 1b. Fine grained mixture of fgpa and retrograde pl. Note the random shape orientation of the minerals(crossed polarized light). 1c. Grt corona around cpx, hornblende and qtz surrounded by a fine grained matrix and local enclaves of cpx. Grt shows inclusion-free coarse grained crystal faces towards the matrix while cpx-grt intergrowths can be observed towards the corona center. Red line (A-A') shows the locality of chemical composition profile in 1f (electron backscatter image). 1d. Reaction front between older cpx0 and cpx, qtz and hornblende. Note the micro-pores in cpx0 often located close to rutile inclusions. 1e. Composition of cpx and grt. 1f. Chemical composition profile (A-A' in c.). Black dotted line separates coarse grained grt with crystal faces and fine grained aggregate. 1g. Vein like network of reprecipitate on grt grain surface. The white rectangle marks a close up shown in 1h (secondary electron image). 1h. Close up of reprecipitate on grt surface revealing small crystal nuclei on grain boundaries (white arrows). 1i. Smooth cpx grain surfaces revealing huge open pores at grain triple junctions (white arrow).

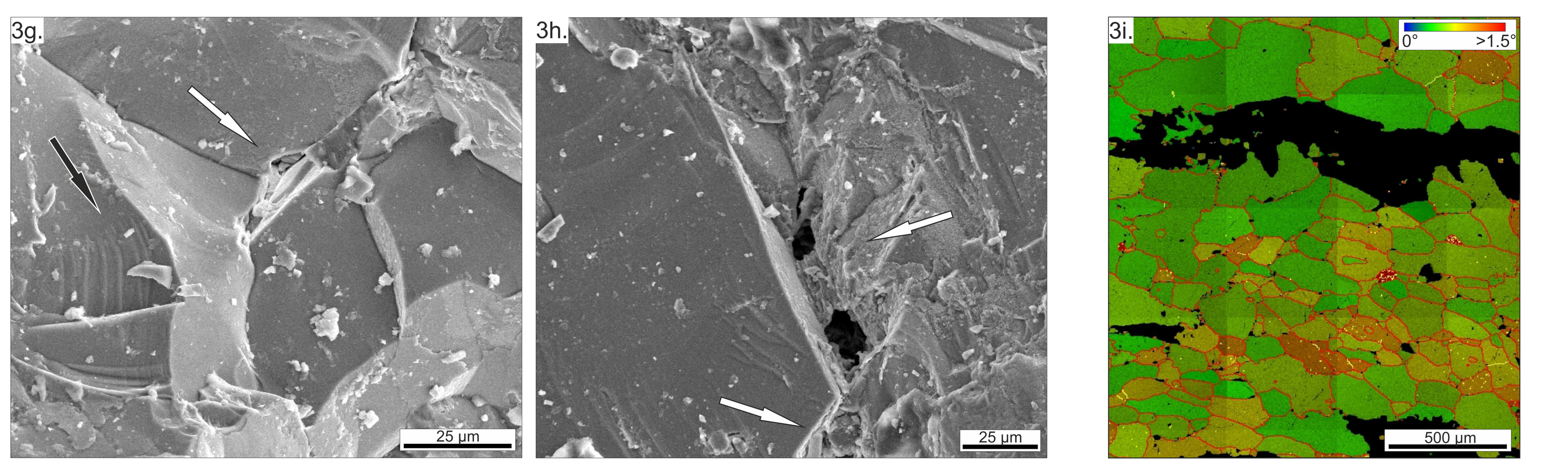




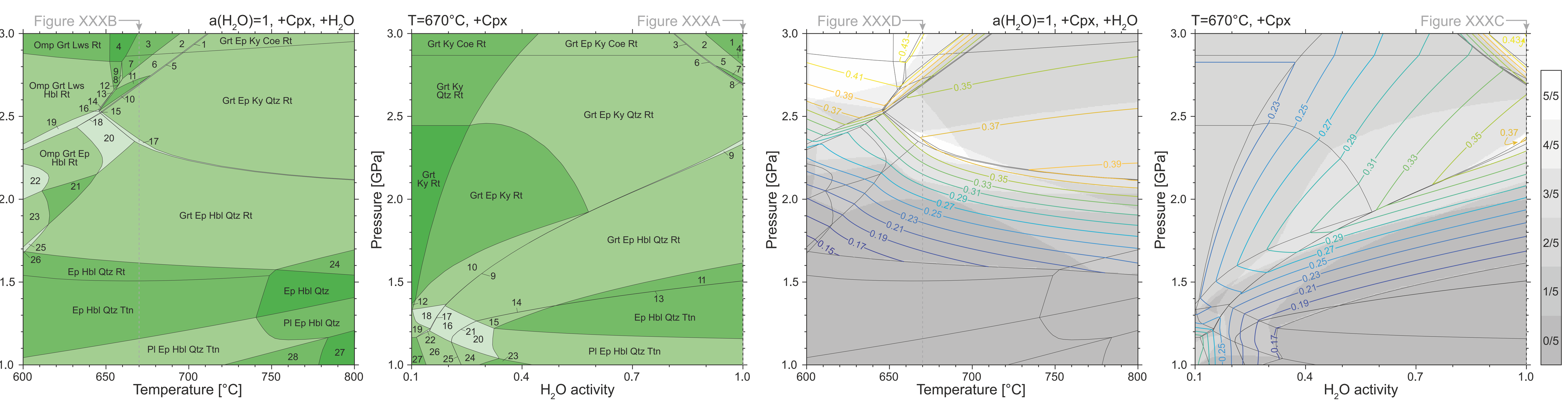


2a.Onset of grt-aggregate disaggregation. Locally you can still notice the former grt-corona structure (arrows; crossed polarized light). 2b. Grt-aggregate disaggregation in a cpx dominated matrix. At areas of disaggregation newly reprecipitated cpx and qtz can be observed. Note the well pronounced shape preferred orientation of cpx (arrows; crossed polarized light). 2c. Elongated inclusion-rich grt aggregate in a cpx matrix. Locally retrograde pl-di symplectites occur along cpx grain boundaries (electron backscatter image). 2d. Grt interphase showing eclogitic mineral paragenesis composed of cpx, ky and qtz. Locally pl-di symplectites can be observed at cpx grain boundaries and retrograde pl surrounding qtz (electron backscatter image). 2e. Composition of cpx and grt. 2f. Grain-average orientation map of cpx from intermediate strained eclogite revealing that the crystal lattice is almost unstrained. High-angle grain boundaries (>10°) are coloured in red, low-angle grain boundaries (3-10°) in yellow. 2g.Stereographic projection of [001] axis, (010) and (100) poles of cpx in eclogites with increasing strain (from top to bottom). Equal area, upper hemisphere projection.





3a. Clpx showing a strong shape preferred orientation parallel to the foliation. The fgpa is intercalated in sub-parallel to parallel layers (marked by white dashed lines). Foliation perpendicular cracks are visible in cpx (crossed polarized light). 3b. Indenting cpx grains traced by symplectites (arrows). 3c. Flattened and elongated inclusion-rich grt aggregate adumbrating former coronitic structure. Grt aggregates are preferentially disaggregating perpendicular to the foliation nevertheless you can trace inclusion trails through several grt fragments. Separated fragments show a inclusion-free garnet rim (white arrows; electron backscatter image). 3d. Dissagregating grt-aggregate surrounded by elongated cpx grains and patches of fgpa (electron backscatter image). 3e. Composition of cpx and grt. 3f. Chemical composition profile B-B‘ in 3d. Dotted lines represent locality of grt disaggregation (electron backscatter image). 3g. Smooth cpx grain surfaces with straight grain boundaries. Small, partly filled pores occur at grain triple junctions (white arrow; secondary electron image). 3h. Open cpx grain boundary with reprecipitate and symplectite (white arrows; secondary electron image). 3i. Grain-average orientation map of cpx from highly strained eclogite showing a strong SPO while the crystal lattice is almost unstrained. Only very few subgrains occur. High-angle grain boundaries (>10°) are coloured in red, low-angle grain boundaries (3-10°) in yellow.



Equilibrium assemblage diagrams calculated for the average eclogitic Al-Mg-rich metagabbro composition. Mineral abbreviations after Whitney & Evans (2010). A. Pressure-Temperature pseudosection calculated with a(H2O)=1 (i.e. excess H2O). H2O and a disordered clinopyroxene (sodic at high pressure and calcic at low pressure) are stable in all fields. The green shade indicates the field variance. The assemblage of numbered fields is 1: Grt Ep Lws Ky Coe Rt, 2: Grt Lws Ky Coe Rt, 3: Grt Lws Coe Rt, 4: Grt Lws Rt, 5: Grt Ep Lws Ky Qtz Rt, 6: Grt Lws Ky Qtz Rt, 7: Grt Lws Qtz Rt, 8: Grt Lws Hbl Qtz Rt, 9: Grt Lws Hbl Rt, 10: Grt Ep Lws Ky Rt, 11: Grt Lws Ky Rt, 12: Grt Lws Ky Hbl Qtz Rt, 13: Grt Lws Hbl Ky Rt, 14: Omp Grt Lws Hbl Ky Rt, 15: Grt Ep Lws Hbl Ky Qtz Rt, 16: Omp Grt Ep Lws Hbl Ky Rt, 17: Grt Ep Hbl Ky Qtz Rt, 18: Omp Grt Ep Lws Hbl Qtz Rt, 19: Omp Grt Ep Lws Hbl Rt, 20: Omp Grt Ep Hbl Qtz Rt, 21: Grt Ep Hbl Rt, 22: Omp Grt Ep Hbl Gln Rt, 23: Grt Ep Hbl Gln Rt, 24: Grt Ep Hbl Qtz, 25: Grt Ep Hbl Gln Qtz Rt, 26: Ep Hbl Gln Qtz Rt, 27: Pl Hbl Qtz, 28: Pl Hbl Qtz Ttn. B. Pressure-H2O activity pseudosection calculated at 670°C. A disordered clinopyroxene (sodic at high pressure and calcic at low pressure). The green shade indicates the field variance. The assemblage of numbered field is 1: Grt Lws Coe Rt, 2: Grt Lws Ky Coe Rt, 3: Grt Ep Lws Ky Coe Rt, 4: Grt Lws Qtz Rt, 5: Grt Lws Ky Qtz Rt, 6: Grt Ep Lws Ky Qtz Rt, 7: Grt Lws Ky Rt, 8: Grt Ep Lws Ky Rt, 9: Grt Ep Hbl Ky Qtz Rt, 10: Grt Ep Hbl Ky Rt, 11: Ep Hbl Qtz Rt, 12: Grt Hbl Ky Rt, 13: Ep Hbl Qtz Rt Ttn, 14: Grt Ep Hbl Qtz Rt Ttn, 15: Grt Ep Hbl Qtz Ttn, 16: Grt Pl Ep Hbl Qtz Rt, 17: Grt Pl Ep Hbl Ky Qtz Rt, 18: Grt Pl Ep Hbl Ky Rt, 19: Grt Pl Hbl Ky Rt, 20: Grt Pl Ep Hbl Qtz Ttn, 21: Grt Pl Ep Hbl Qtz Rt Ttn, 22: Grt Pl Hbl Ky Qtz Rt, 23: Pl Hbl Qtz Ttn, 24: Grt Pl Hbl Qtz Ttn, 25: Grt Pl Hbl Qtz Rt Ttn, 26: Grt Pl Hbl Qtz Rt, 27: Grt Pl Hbl Rt. C. XMg isopleth of garnet calculated for the diagram in A. D. XMg isopleth of garnet calculated for the diagram in B. In diagrams C and D, the grey shade in background indicates the number of positive tests on garnet and clinopyroxene composition

Conclusion

Thermodynamic modelling yield eclogitization conditions of approximately 2.4 GPa, 670 °C and a H2O activity slightly lower than 1 suggesting that fluid supply did play an important role during eclogitization and deformation. Microstructural and petrological investigations reveal the formation of a micro-porosity along new developed grain boundaries allowing fluids to migrate to the reaction front, slowly consuming the original gabbroic protolith and replacing it with the stable eclogitic mineral paragenesis. This rather static-type of eclogitization is dominated by dissolution-reprecipitation processes and resulting in a volume reduction of about 11.8 %. Subsequent volumetric strain is further accommodated by dissolution-reprecipitation resulting in the development of foliated eclogites. Lack of chemical zoning in minerals indicated that formation and deformation of eclogites in the Koralpe occurred rather quickly at almost stable conditions.

[1] University of Vienna, Department for Geodynamics and Sedimentology, Althanstrasse 14, 1090 Vienna, Austria.
[2] Geological Survey of Austria, Department of Hard Rock Geology, Neulinggasse 38, 1030 Vienna, Austria.

FWF Der Wissenschaftsfonds.