Petrologic constraints on subduction zone metamorphism from a coesite-bearing metapelite in the Northern Appalachian Orogen

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Session TS7.11 The Caledonian orogen of the North Atlantic region: a natural laboratory for studying tectonic processes

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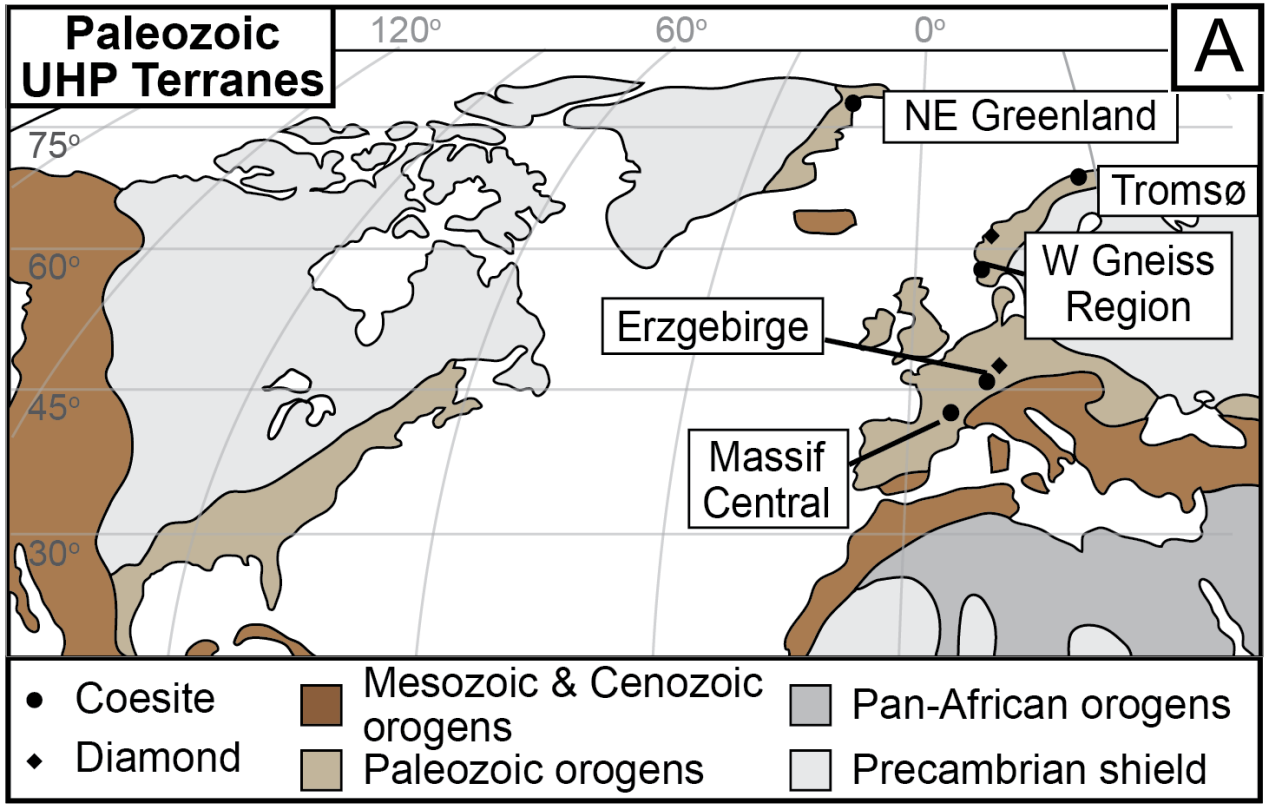
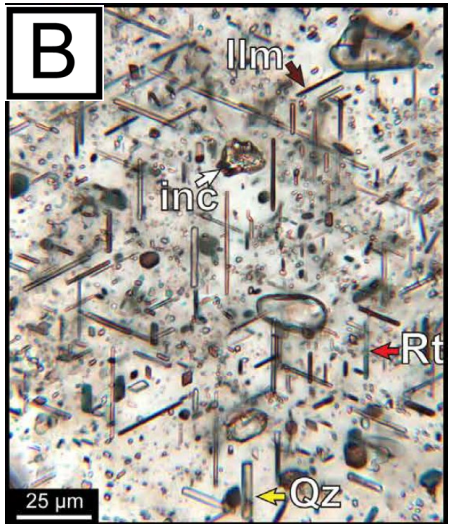
North Atlantic UHP terranes

- UHP metamorphism was previously interpreted to be absent from Appalachian orogen on the eastern North American continent
- Only proposed evidence of UHP metamorphism is from oriented inclusions in garnet from Acadian orogen rocks (*Figure B, Keller and Ague 2020*)
- Hypotheses for the absence of UHP
  - Pervasive metamorphic overprinting
  - Subduction occurred along a warm and shallow subduction zone
  - Paleozoic mantle upwelling produced a high-geothermal gradient under Laurentia
- **The question:** Did metamorphic rocks in the Appalachians reach UHP conditions? Or were peak UHP rocks formed but then completely retrogressed?

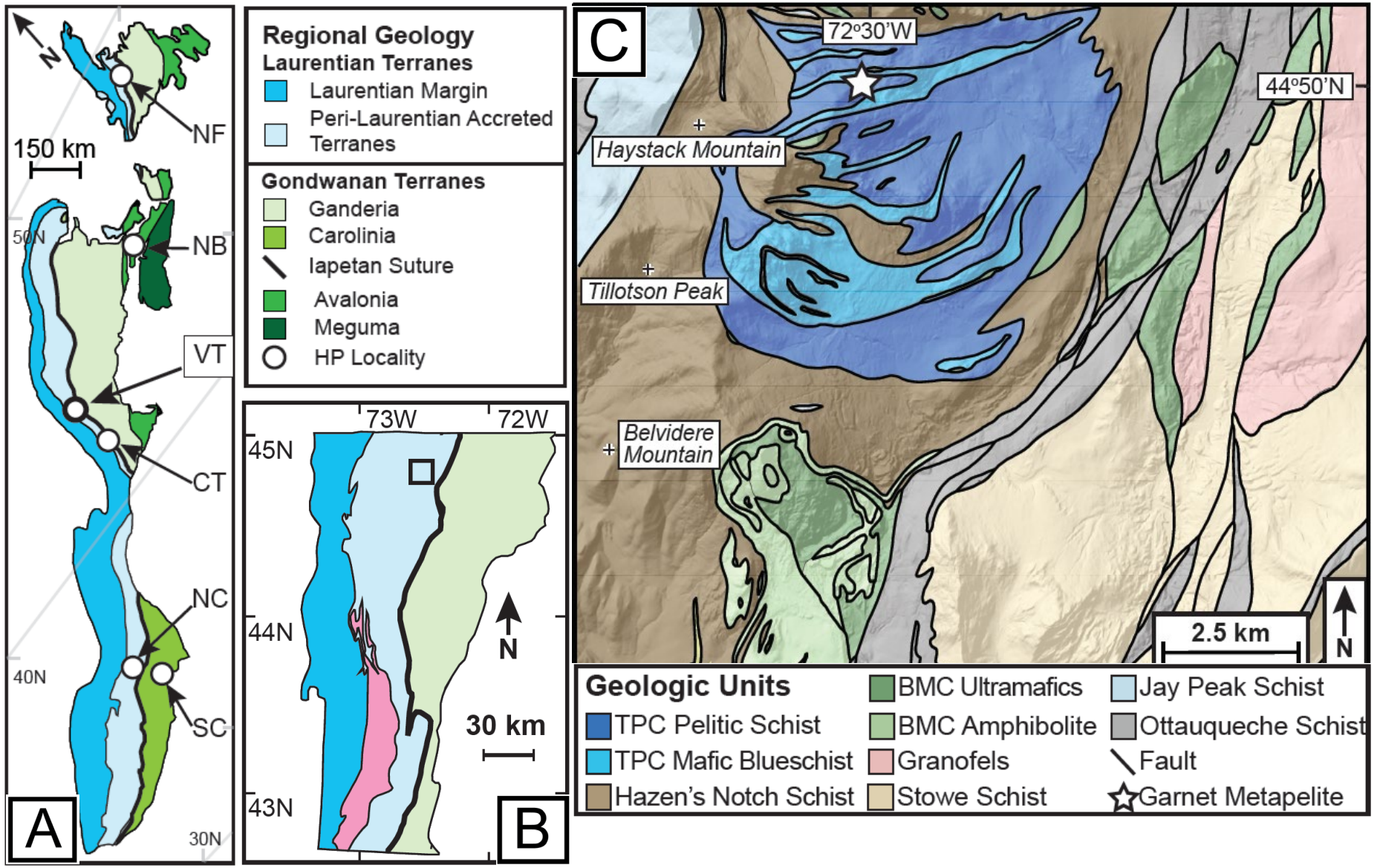




Top: *Gonzalez et al., 2020, modified from Gilotti 2013*
Right: *Keller and Ague 2020*

Appalachian orogen

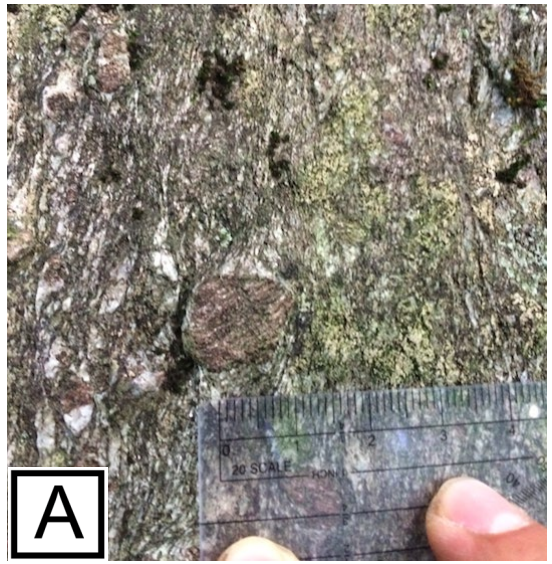
- Appalachian orogen is composed of a series of Paleozoic accreted terranes (*Figure A*)
- Rare high-pressure metamorphic rocks
- TPC is composed dominantly of blueschist, eclogite, and metapelite (*Figure C*)
- Taconic age: ~470 Ma (*Castonguay et al., 2012*)
- Interpreted as exhumed remnants of lapetan oceanic crust and overlying sediments
- Previous P-T: 12-14 kbar, 520-620 °C (*Laird et al., 1993*) from garnet – omphacite pairing

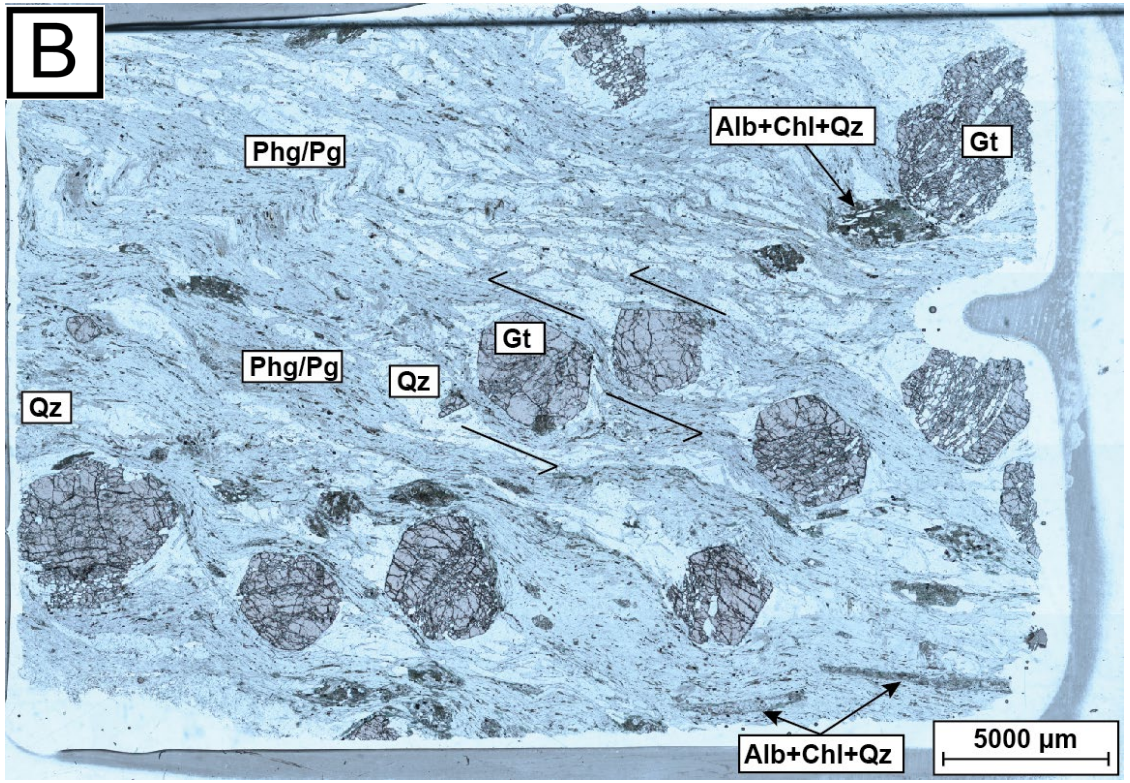


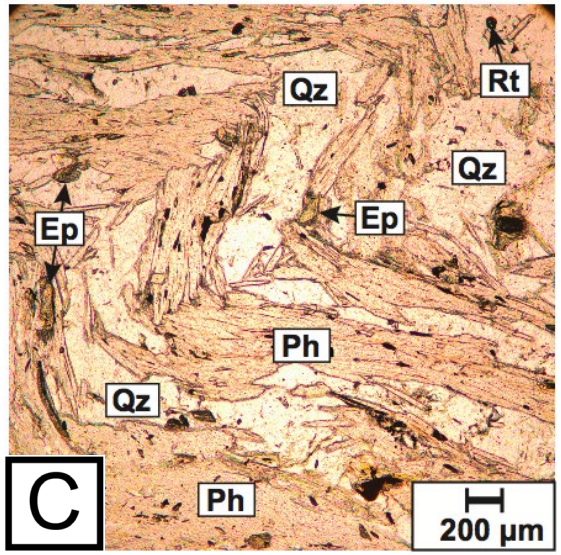
Modified from Gonzalez et al., 2020, Honsberger et al., 2017

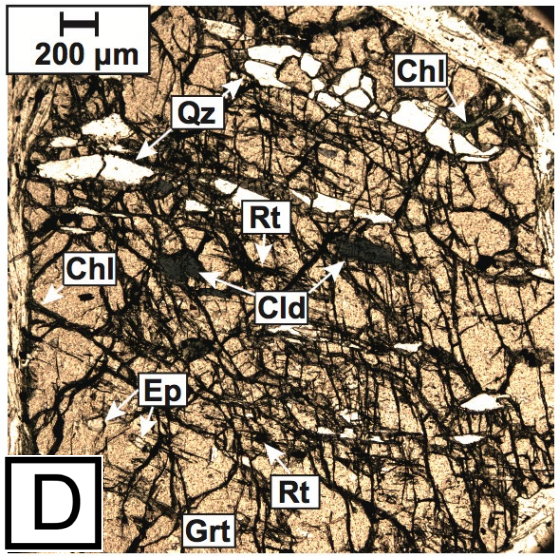
Petrographic analysis and inclusions in garnet

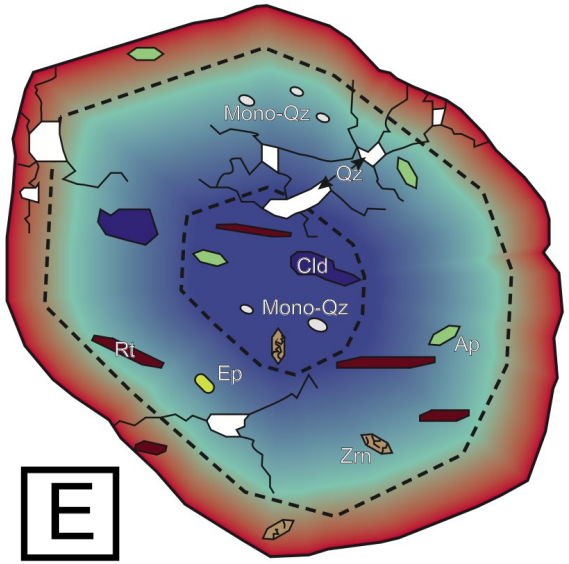
- Primary mineral assemblage (*Figure A-B*)
  - Garnet, phengite, paragonite, quartz, epidote, rutile, Na mineral
- Retrograde mineral assemblage (*Figure A-B*)
  - Chlorite, albite, titanite
- Inclusions in garnet (*Figure D-E*)
  - Rutile, apatite, zircon (metamict)
  - Chloritoid (only in garnet core-mantle region
  - Epidote
  - Quartz (3-200 µm)
- Large quartz inclusions associated with fractures
- Small elastically isolated inclusions only in the core and mantle of garnet





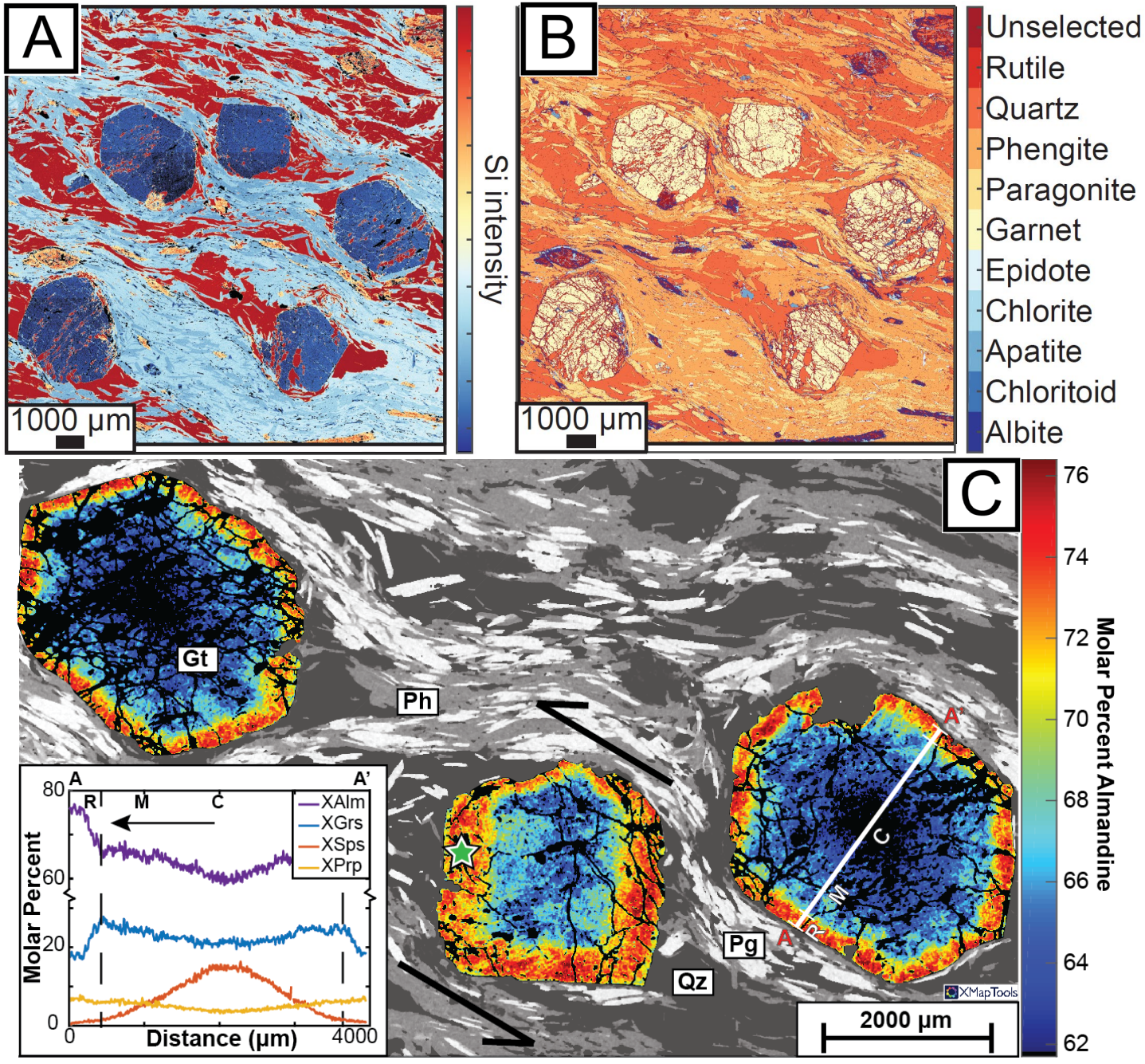






Electron microprobe analysis

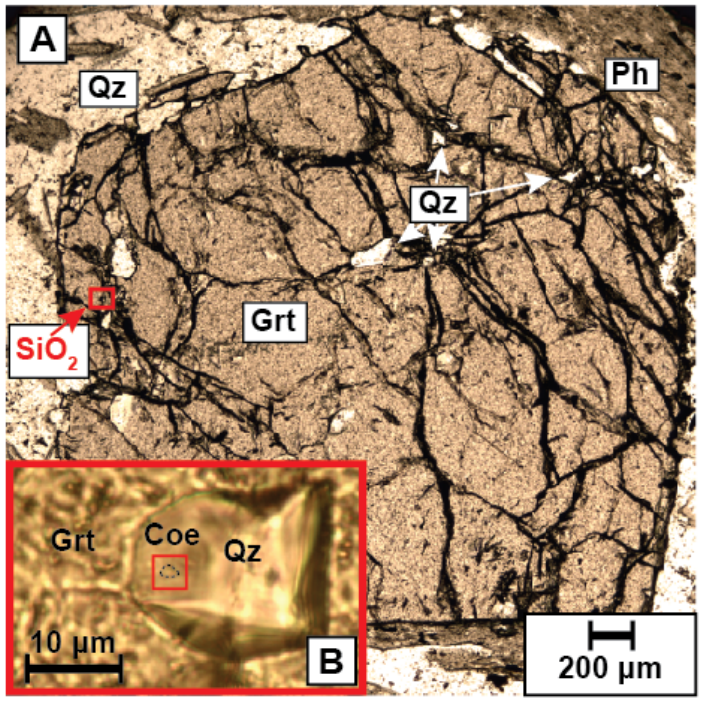
- Collected a series of major element WDS X-ray maps and spot analyses to create quantitative compositional maps (*Lanari et al., 2014; Figure A*)
- Mineral compositions and zoning patterns were determined (*Figure C*)
- Defined two zones in the garnets: core-mantle, and rim
- Single generation of compositionally homogeneous phengite (3.5 Si p.f.u.)
- From these maps we can extract local bulk compositions to calculate mineral phase equilibrium diagrams

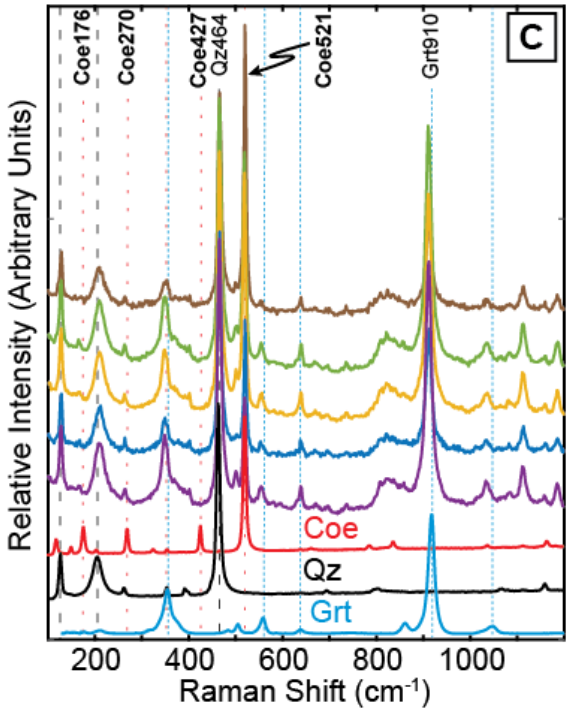


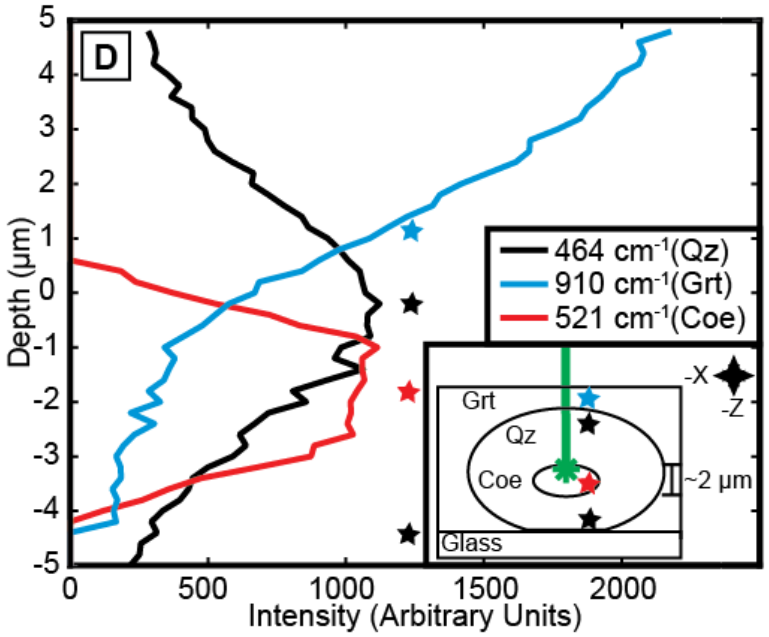
Gonzalez et al., 2020

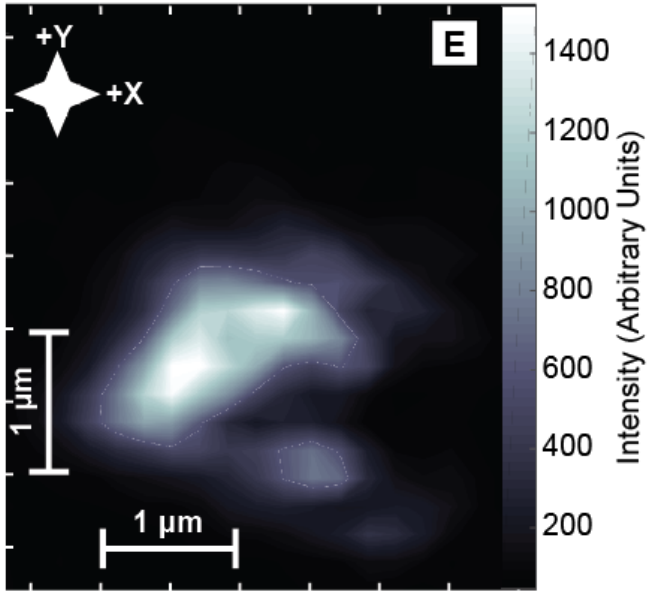
Raman spectroscopy

- Inclusions contained in fractured garnet porphyroblasts were analyzed by Raman spectroscopy for:
  - Phase identification/confirmation
  - Quartz-in-garnet elastic thermobarometry
- Fractured ~20 µm inclusion targeted for Raman spectroscopy (*Figures A-B*)
- Raman spot analyses
  - Coesite Raman bands at 521 cm^{-1}, 270 cm^{-1}, 176 cm^{-1} (*Figure C*)
- Depth profile (0.2 µm step size) to approximate the thickness of the inclusion (*Figure D*)
- Raman 2-D (X-Y) mapping of 521 cm^{-1} band (*Figure E*) with a 0.2 µm step size over a 20.25 $µm^2$ area
- **These results confirm that the inclusion is bi-mineralic SiO_2 with α-quartz and relict coesite and fully**





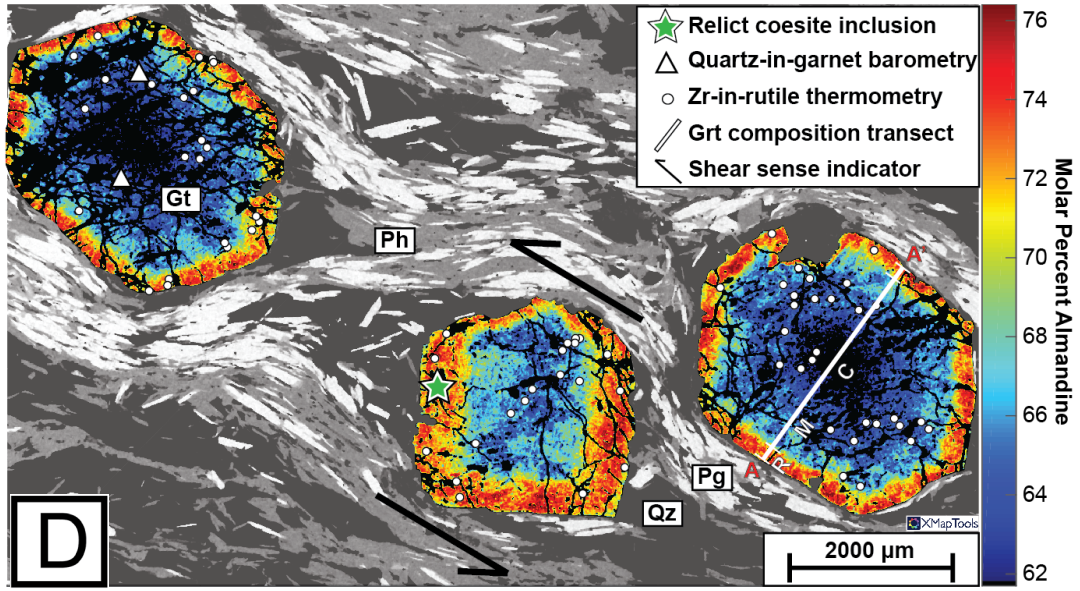


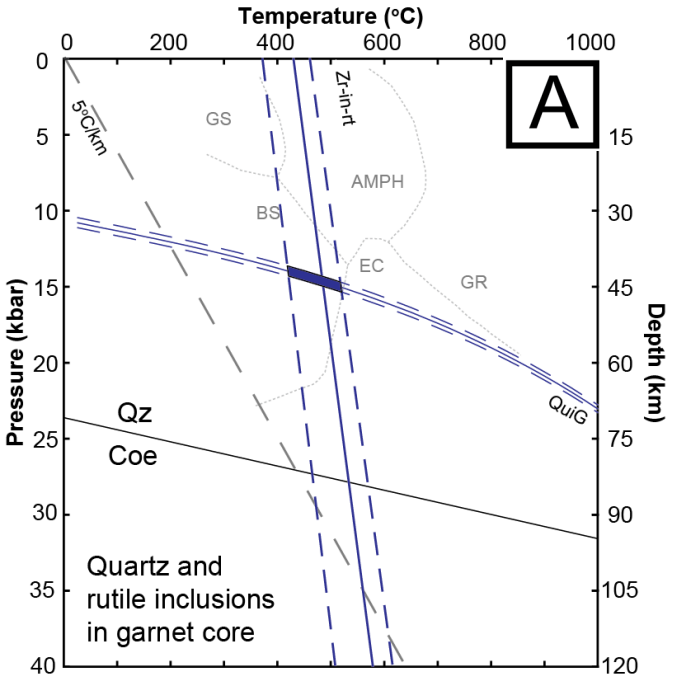


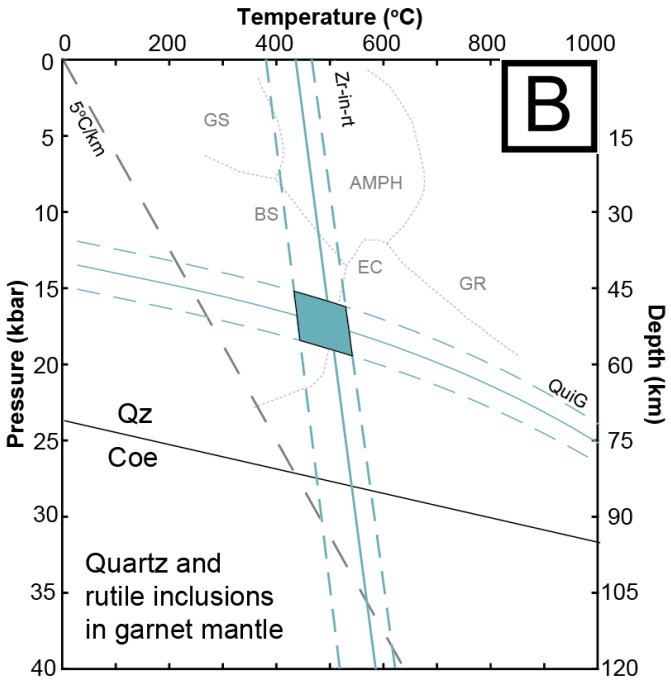
Gonzalez et al., 2020

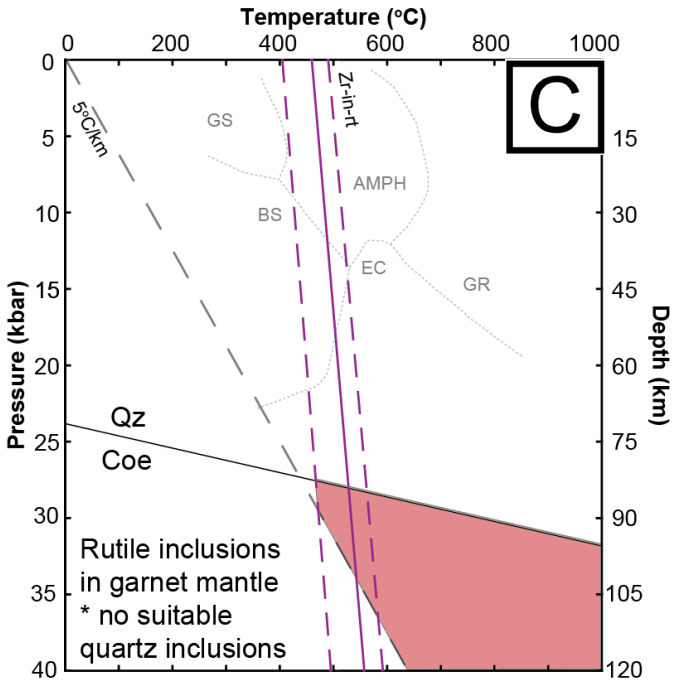
Thermobarometry

- Coesite provides a minimum constraint on peak metamorphism
- Elastic and trace element thermobarometry was used to constrain P-T conditions of garnet growth
- Quartz-in-garnet
  - Core: P_{inc} = 6.3 ± 0.2 kbar; Mantle: P_{inc} = 8.1 ± 0.6 kbar
- Zr-in-rutile
  - Average of 16 ± 8 ppm Zr (n = 79)
  - Used highest Zr concentration in each zone
- **P-T conditions of prograde garnet growth**





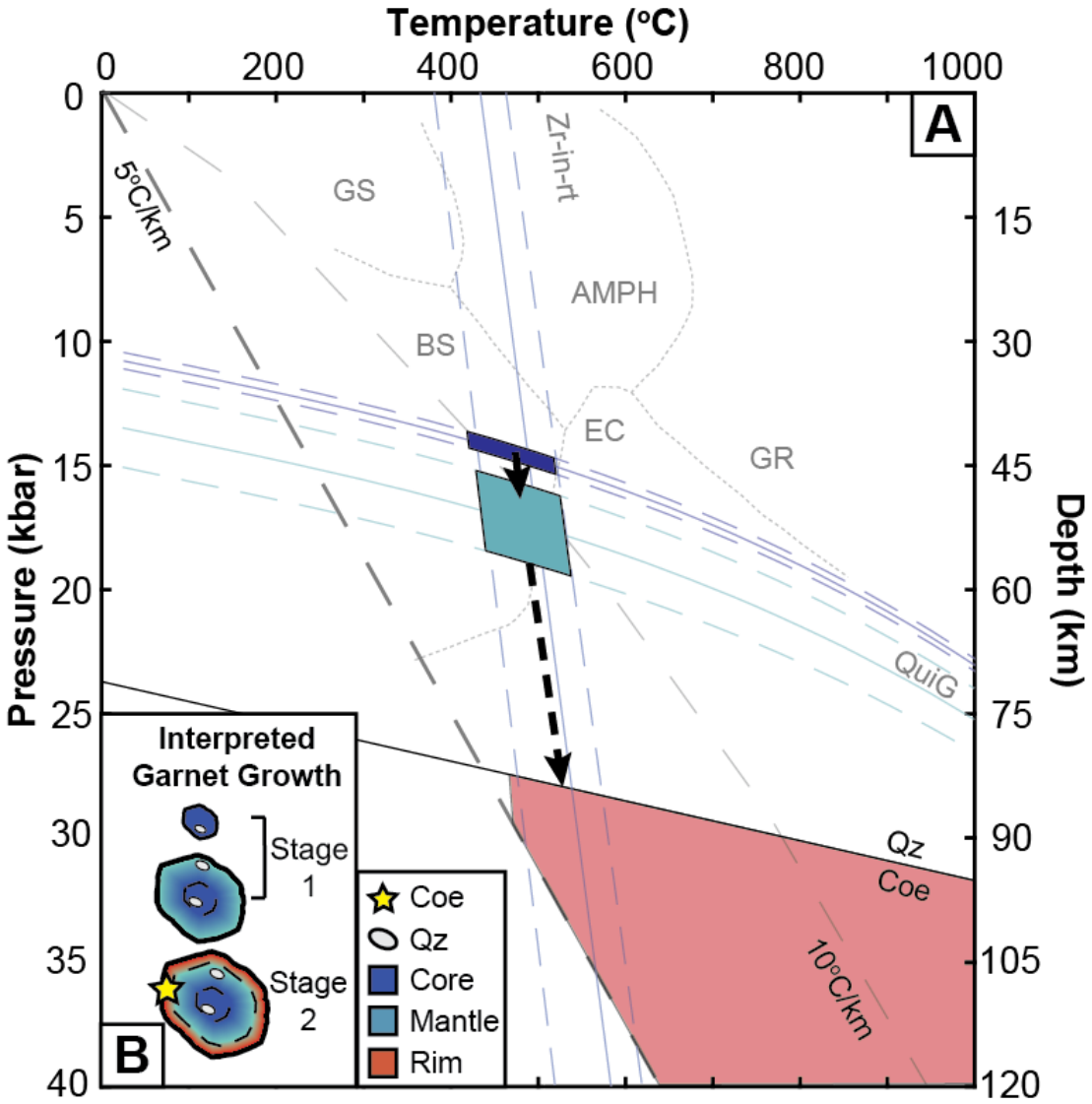




Modified from Gonzalez et al., 2020

Garnet growth during subduction zone metamorphism

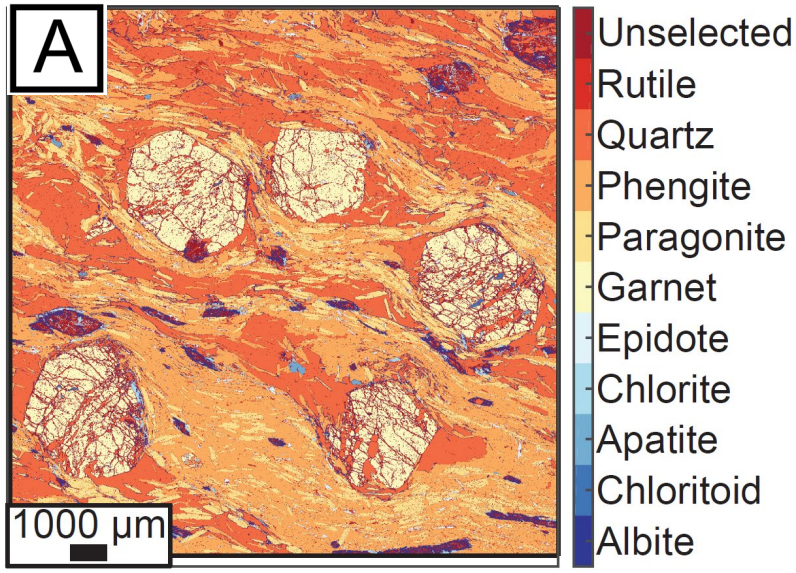
- Current conclusions
  - Garnet growth is interpreted to have formed during two primary stages
    - Prograde metamorphism and garnet growth in the blueschist facies
    - Peak metamorphism at UHP metamorphic conditions
  - The first finding of coesite in the Appalachians suggests that some Laurentian sediments were subducted to UHP metamorphic conditions.
    - P-T data shows that sediments were subducted along relatively cold (6 – 8 C/km) geothermal gradients
- Additional questions
  - What is the retrograde/exhumation P-T path of the UHP metapelite?
  - What are the peak metamorphic conditions preserved in other nearby metamorphic units, such as the Tillotson Peak mafic blueschist?

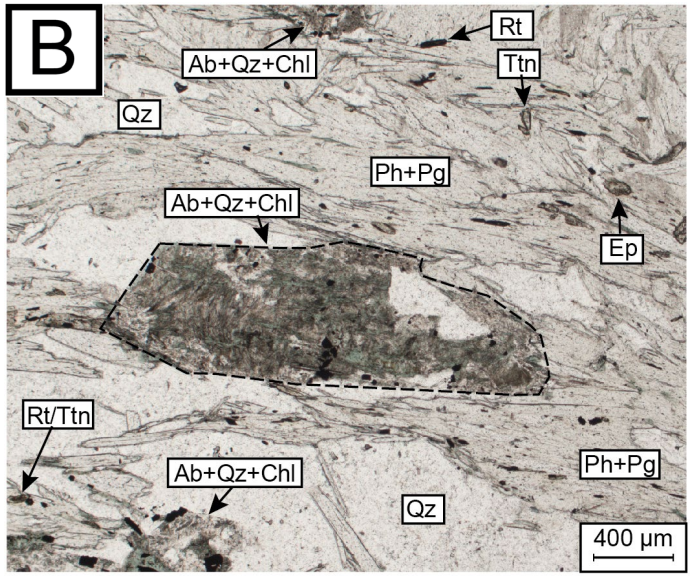


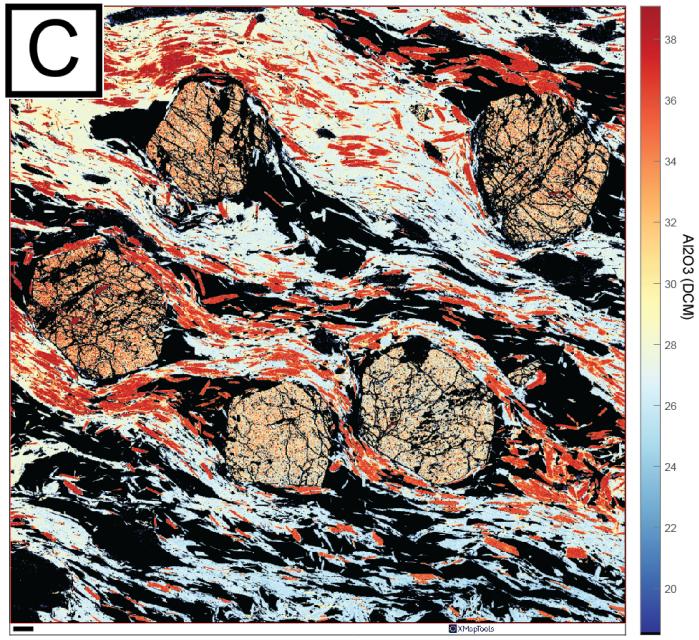
Gonzalez et al., 2020

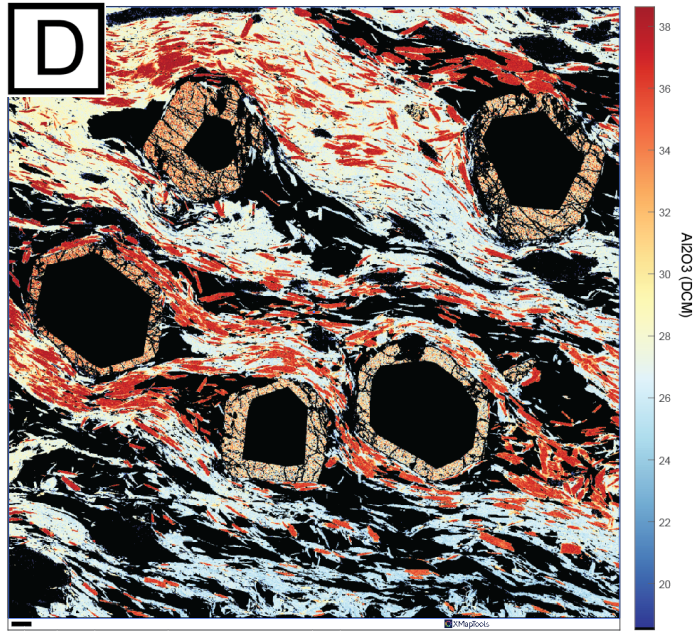
Ongoing work: Constraining retrograde P-T conditions

- From the compositional maps, we extracted local bulk rock assemblages for equilibrium phase modeling in Theriak-Domino (*Figure A; De Capitani and Petrakakis 2010, Lanari and Engi 2017*) that we can use to:
  - Evaluate the prograde P-T path results
  - Provide additional constraints on peak metamorphism
  - Constrain the metamorphic conditions during retrograde metamorphism or metamorphic overprinting (*Figure B*)
- Two bulk rock compositions
  - Total bulk rock composition (*Figure C*)
  - **Fractionated bulk rock composition with garnet core-mantle region removed (*Figure D*)**



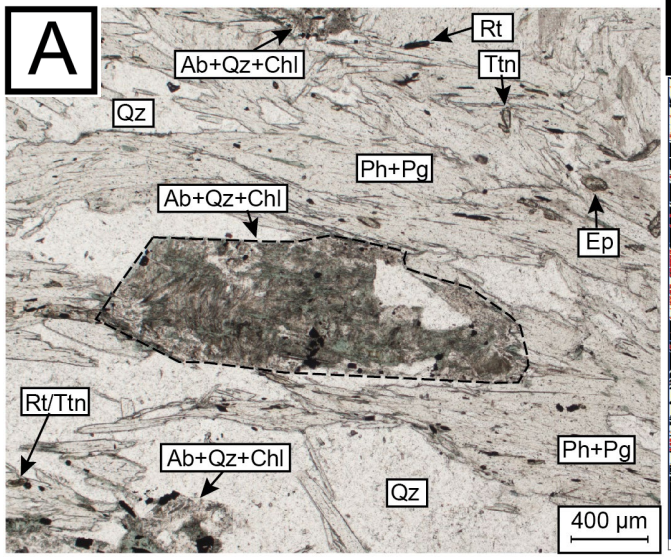


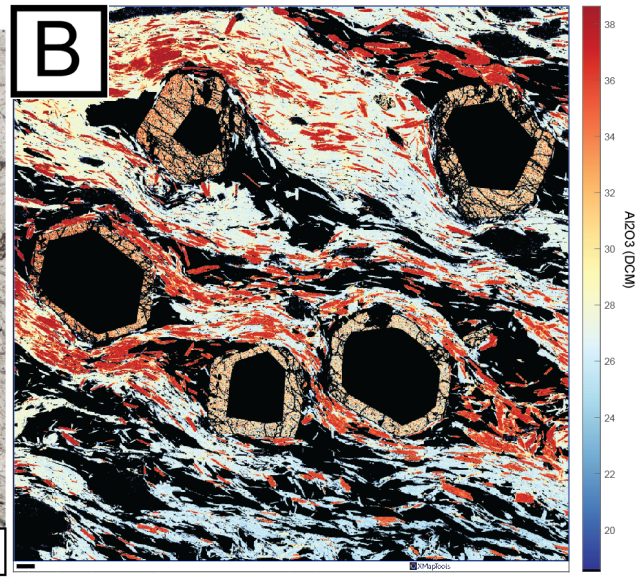


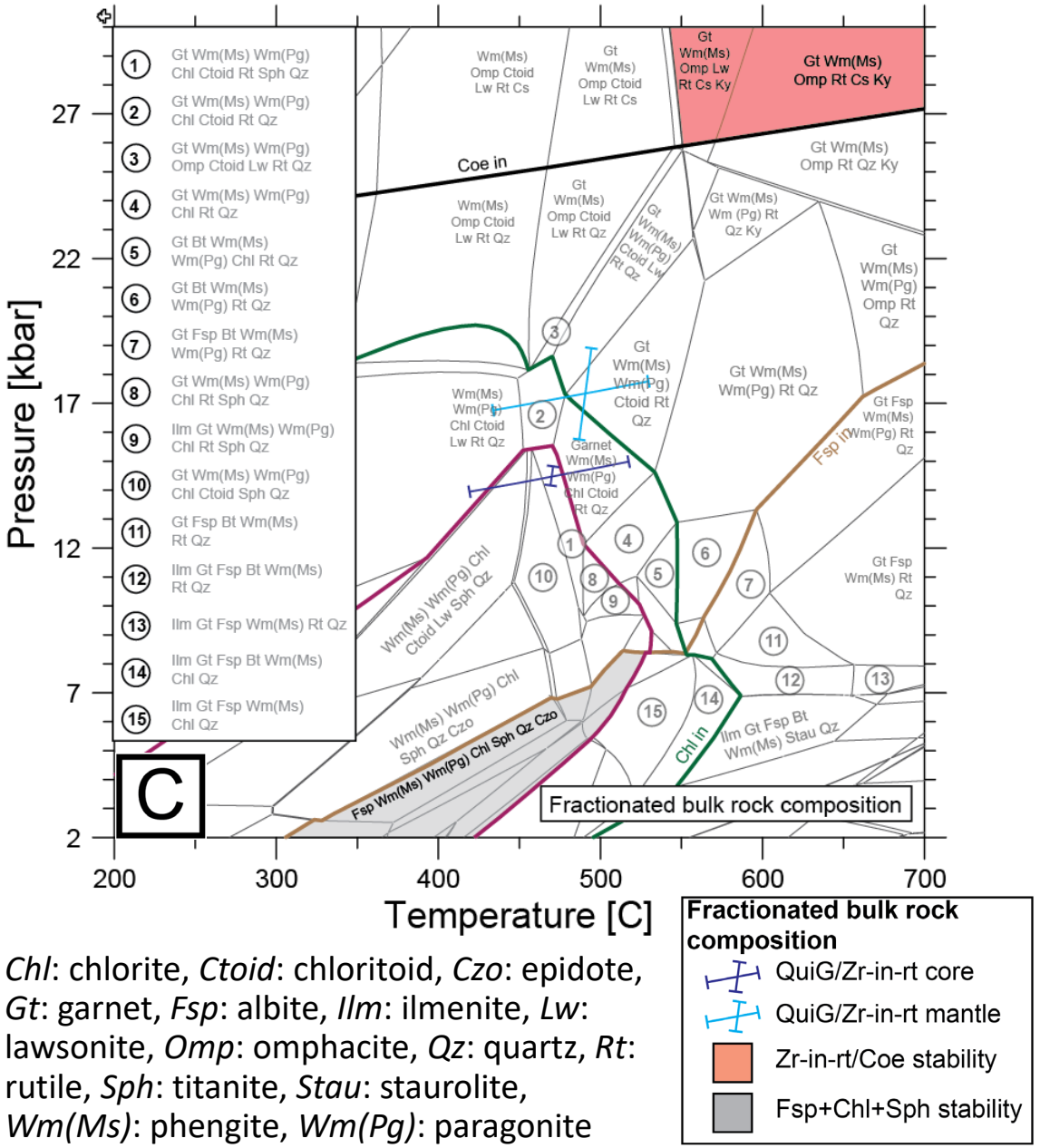


Ongoing work: Constraining retrograde P-T conditions

- Provide additional constraints on peak metamorphism
- Fractionated bulk rock composition
  - Used to estimate the mineral assemblage stable at peak metamorphic conditions (*Figure C, red shaded area*)
- Greenschist facies P-T conditions of metamorphic overprinting
  - < 8 kbar, 525 °C (*Figure C, gray shaded area*)
  - Due to Salinic or Acadian orogen?



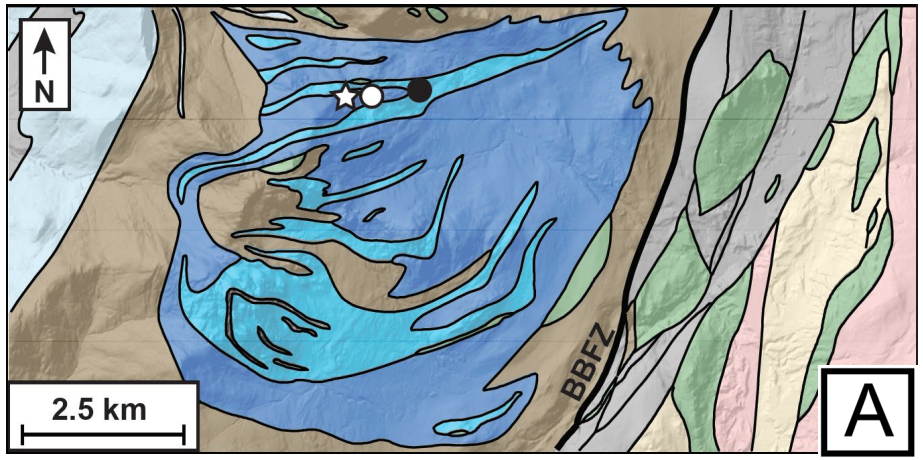




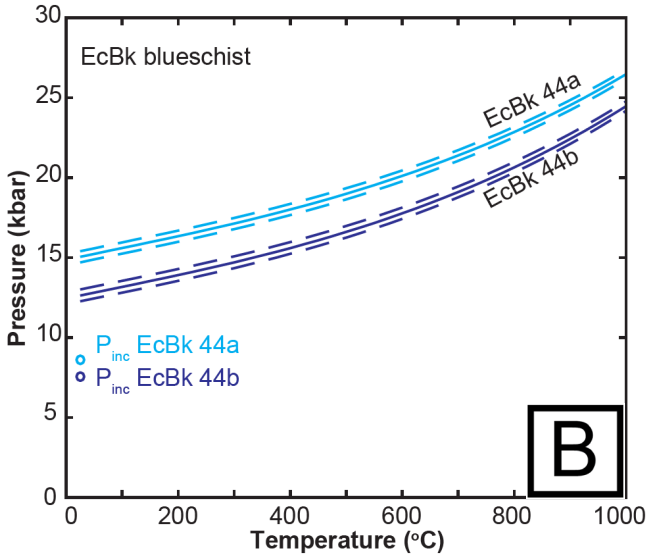
Chl: chlorite, *Ctoid*: chloritoid, *Czo*: epidote, *Gt*: garnet, *Fsp*: albite, *Ilm*: ilmenite, *Lw*: lawsonite, *Omp*: omphacite, *Qz*: quartz, *Rt*: rutile, *Sph*: titanite, *Stau*: staurolite, *Wm(Ms)*: phengite, *Wm(Pg)*: paragonite

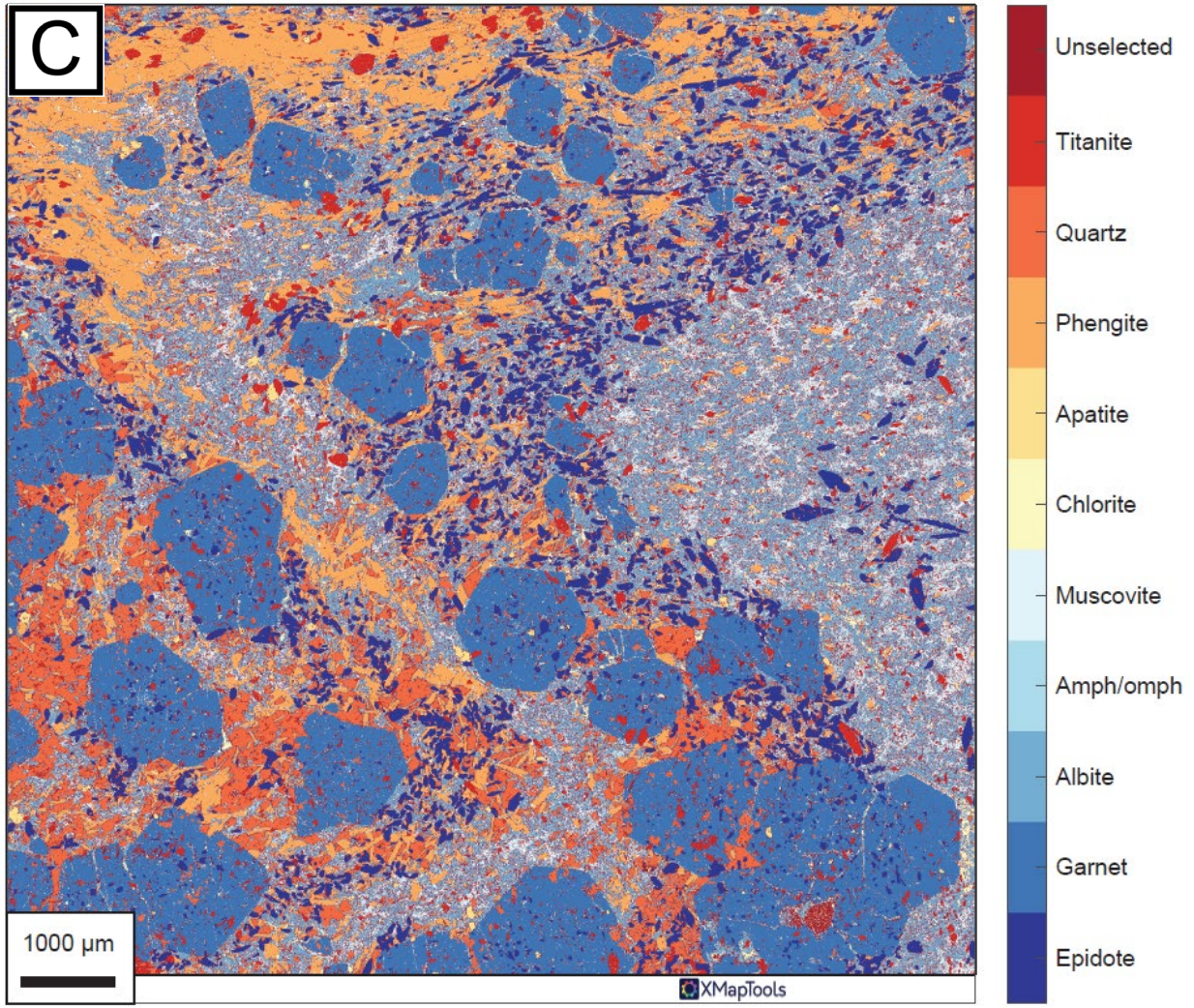
Ongoing work: P-T history of other units

- What were the peak P-T conditions of the TPC blueschist? (*Figure A*)
- Preliminary thermobarometry suggest high-pressure history (*Figure B*)



Geologic Units
- TPC Pelitic Schist
- TPC Mafic Blueschist
- Hazen's Notch Schist
- Ultramafics
- Jay Peak Schist
- Ottauqueche Schist
- Fault
- Garnet Metapelite
- VT87
- ECBK

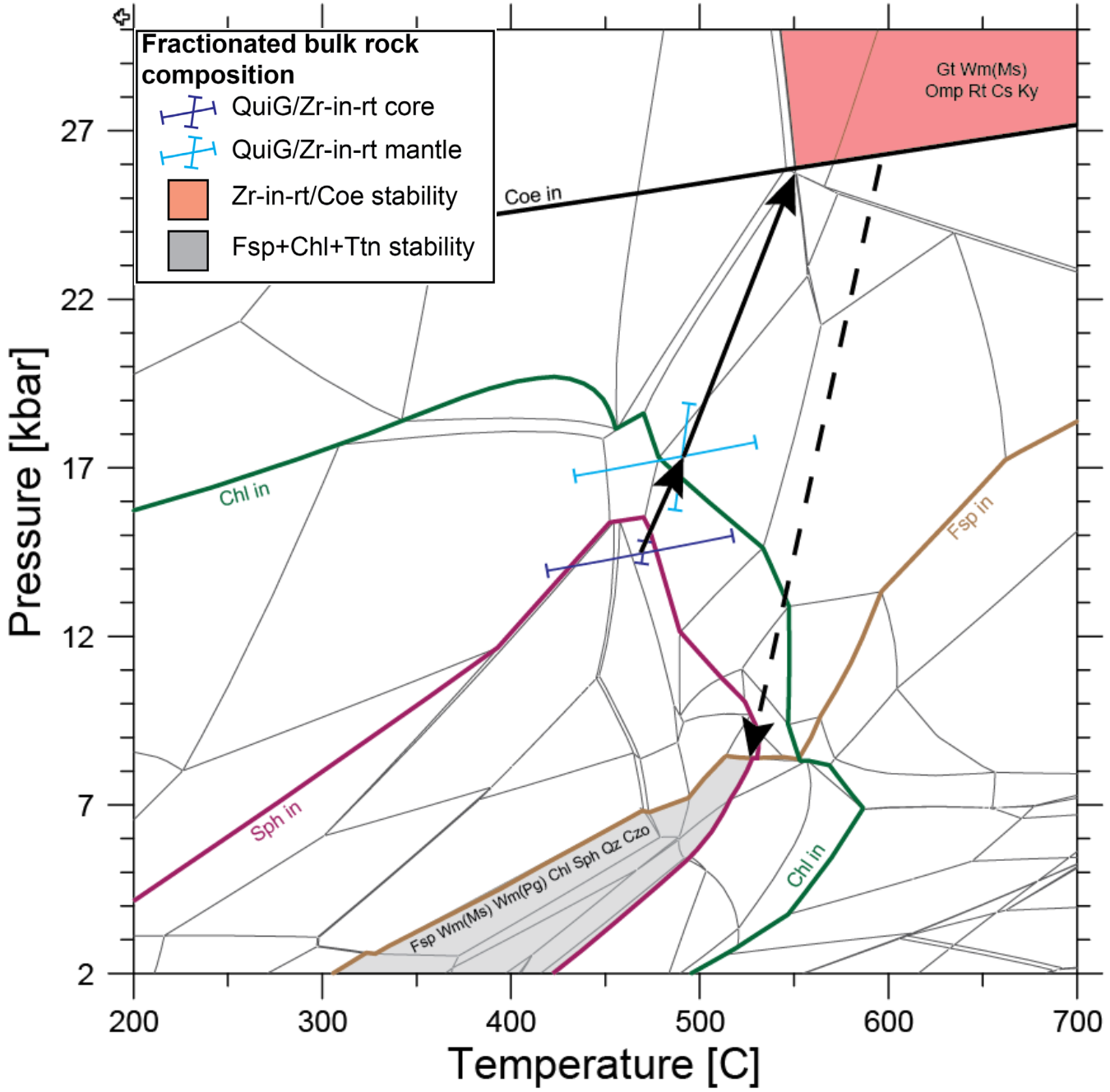




- Mask calculated in XMapTools of mineral assemblage in retrogressed blueschist (*Figure C*)

Summary

- Results suggest that evidence for UHP metamorphism may only exist as µm-scale inclusions in overprinted metamorphic rocks in the Appalachian orogen
- Sediments were metamorphosed along relatively cool geothermal gradients in the blueschist – eclogite metamorphic facies
- Integrated thermobarometry can be used to constrain the complex P-T evolution of poly-metamorphosed rocks in the Northern Appalachian orogen.
- Future studies are focused on determining the peak metamorphic conditions of the nearby mafic blueschist, and constraining the P-T conditions of metamorphic overprinting of the coesite bearing metapelite



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