

# **FLUIDS IN INCLUSIONS and FLUIDS IN MINERALS OF GRANULITIC GARNETITES: CONFLICTS AND AGREEMENTS**

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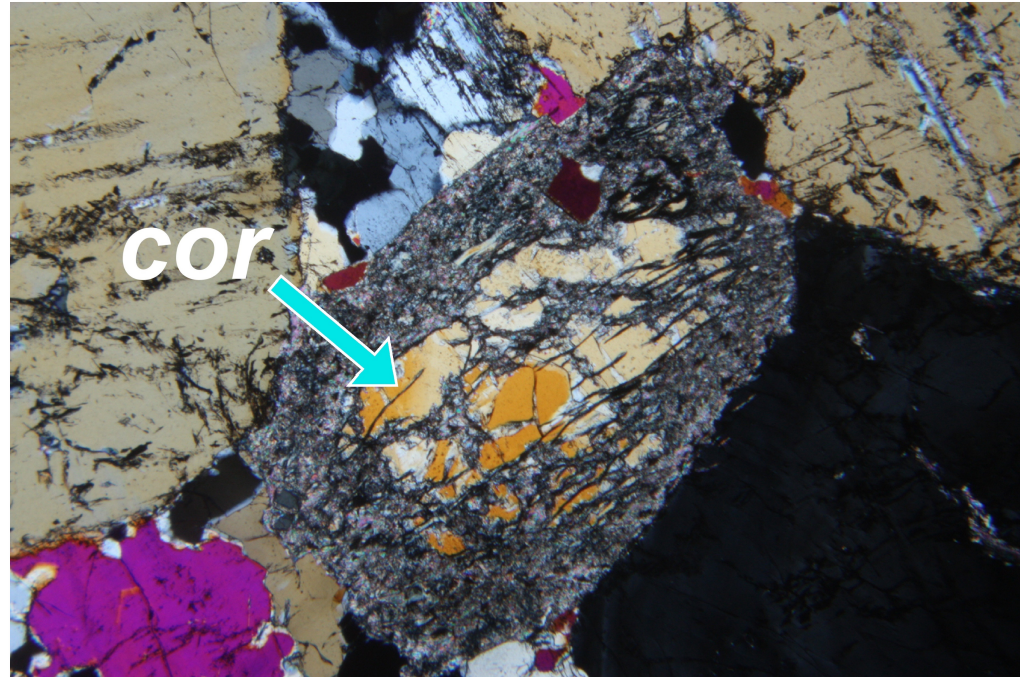
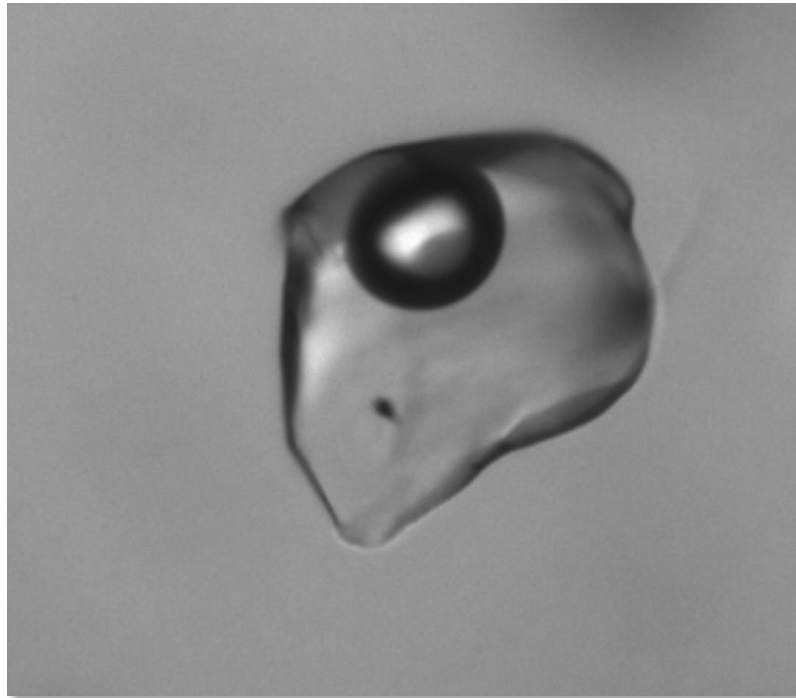
*Montanuniversity Leoben  
Austria*

Evgenii Pushkarev

*Russian Academy of Sciences  
Ekaterinburg  
Russian Federation*

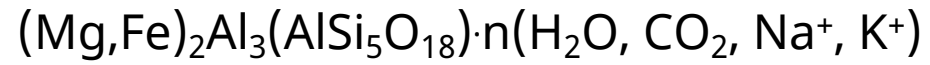
# Fluids in high-metamorphic environments

preserved in fluid inclusions?

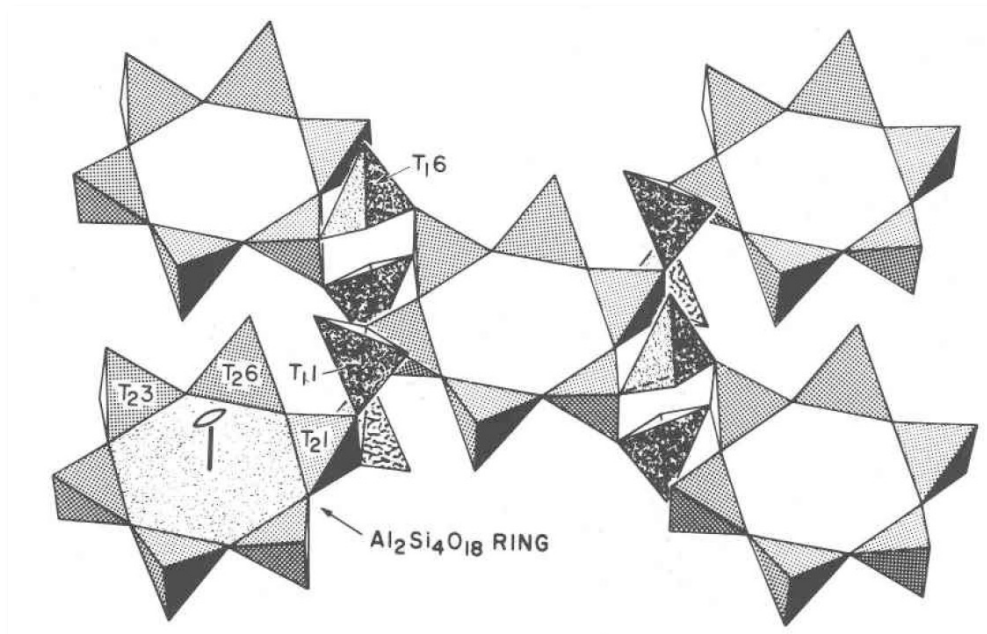


preserved in cordierite?

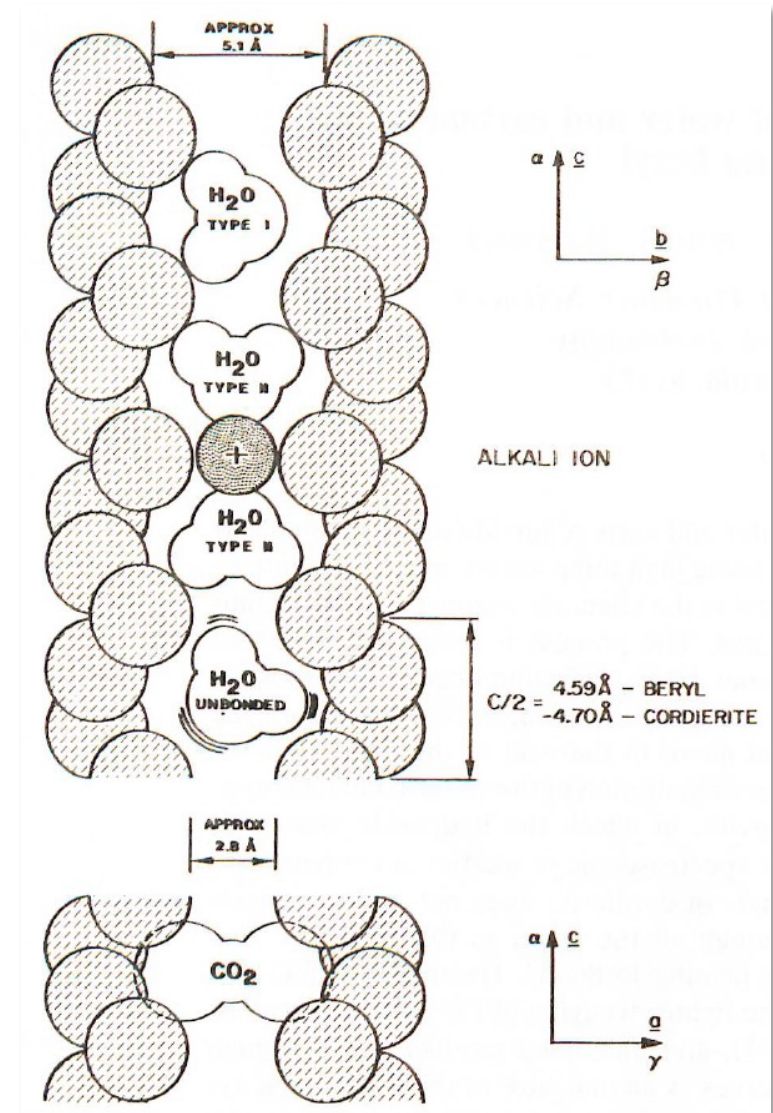
# Fluid components in cordierite



Fluids: C-O-H-N, noble gases



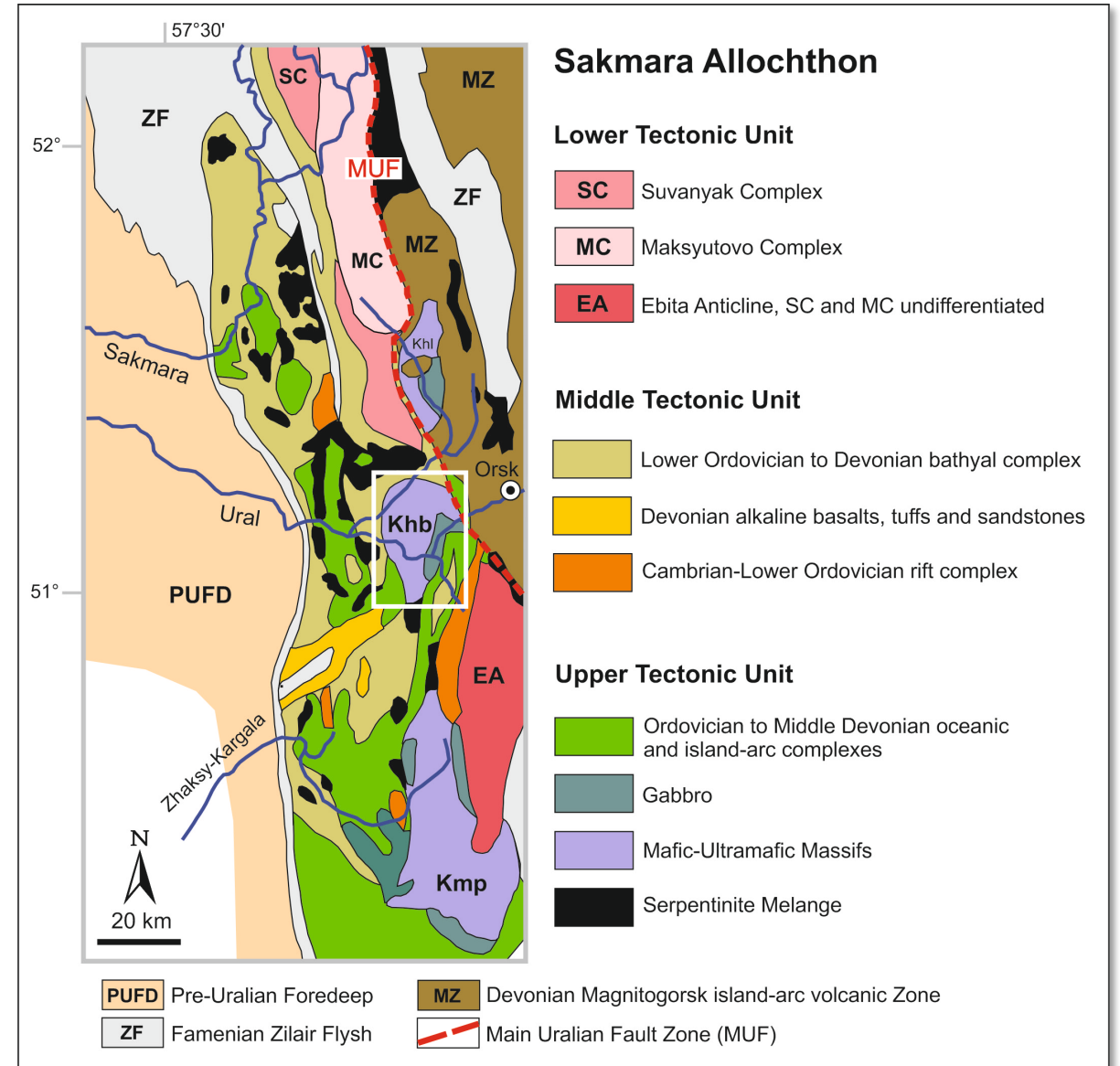
Armbruster & Bloss (1982)



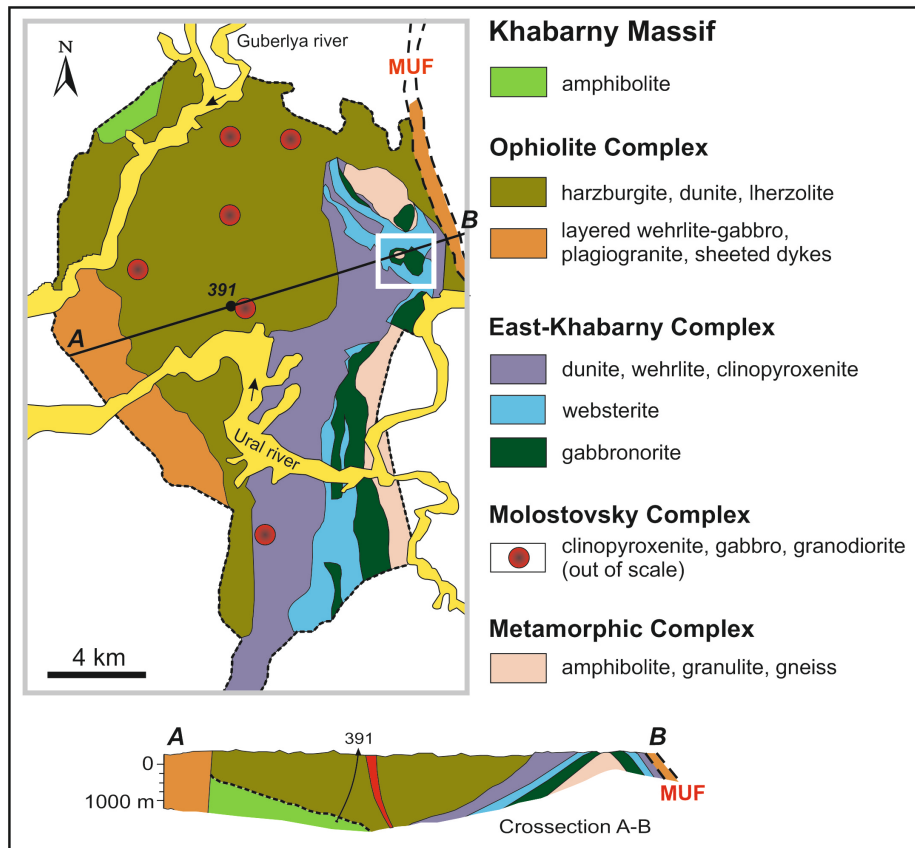
Aines & Rossman (1984)



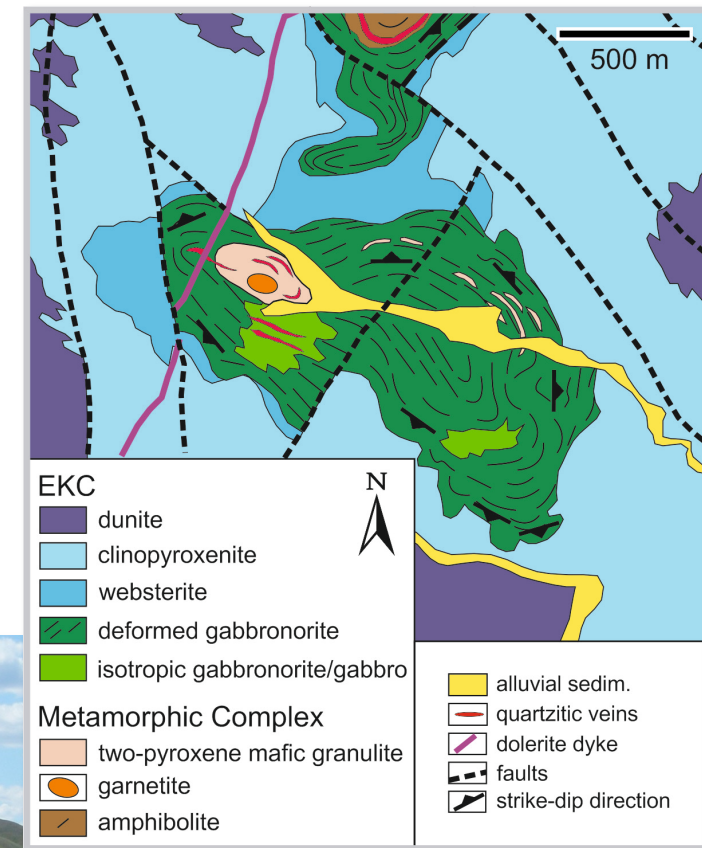
# Khabarny Ultramafic Massif (Southern Ural)







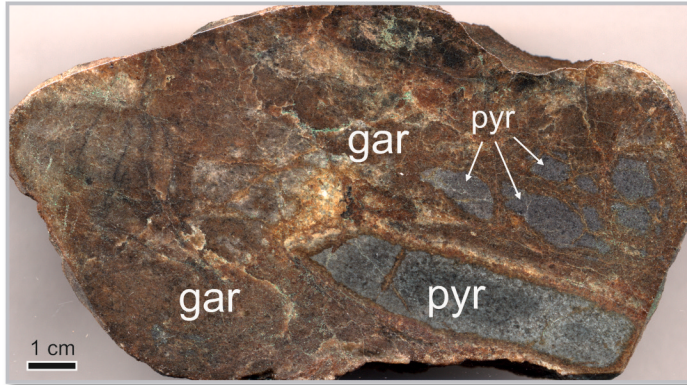
# Khabarny Ultramafic Massif



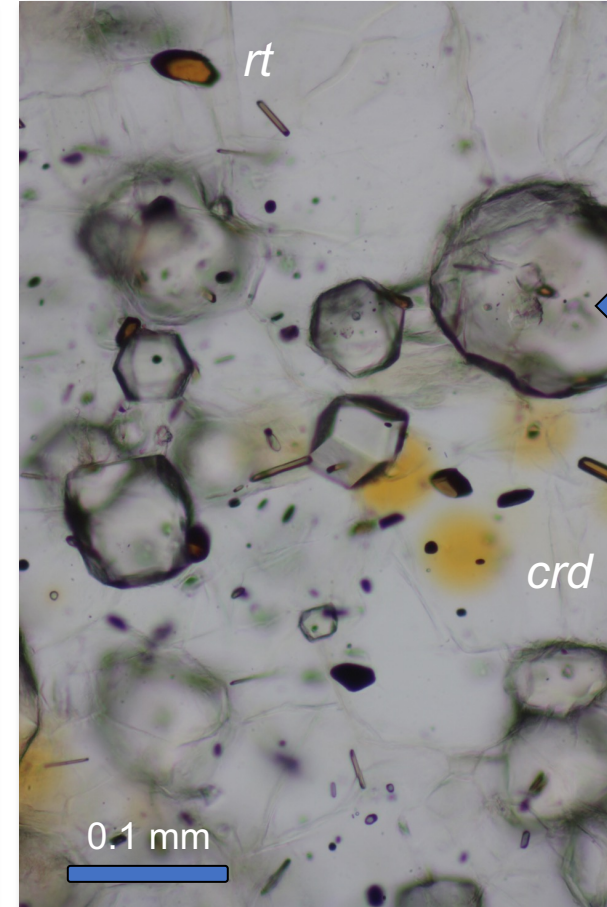
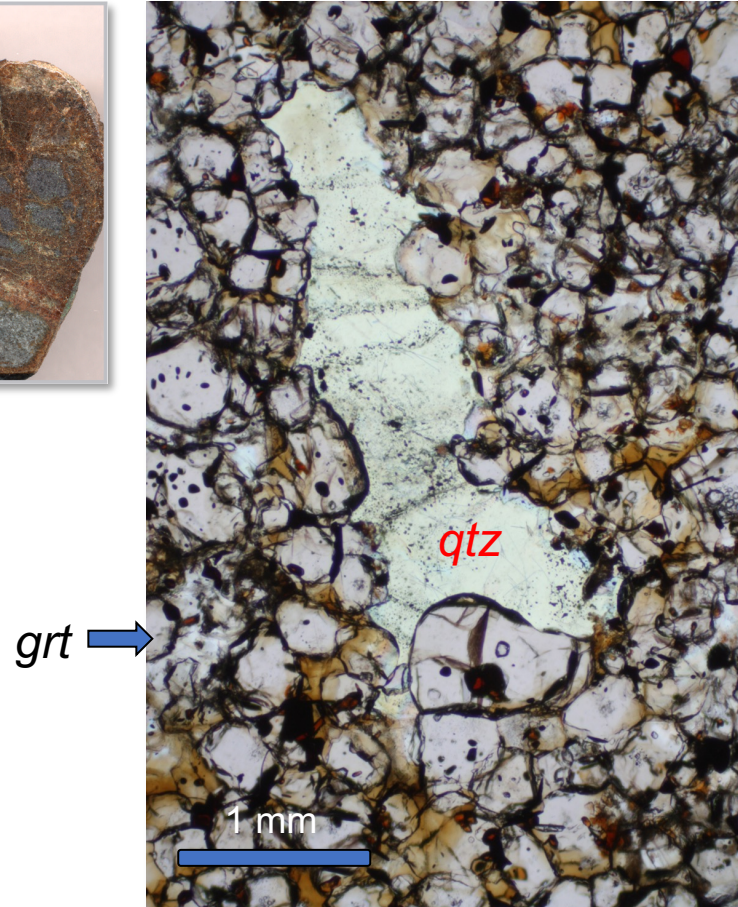


# Petrography and mineralogy of garnetite

- main phases
- fine-grained almandine-pyrope-spessartine-rich garnets (75%)
  - magnesian-rich cordierite (10%)
  - quartz (12%) nodules and inclusions



Garnetites with relicts of two-pyroxene mafic granulites



*grt*

48.5% almandine ( $\pm 3.9$ )  
34.7% pyrope ( $\pm 3.3$ )  
10.3% spessartine ( $\pm 1.1$ )  
1.8% grossular ( $\pm 1.5$ )  
1.5% andradite ( $\pm 1.5$ )

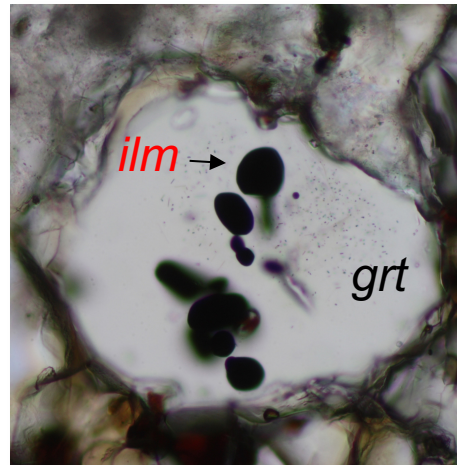
*crd*

#Mg = 0.787

# Solid inclusions in garnet

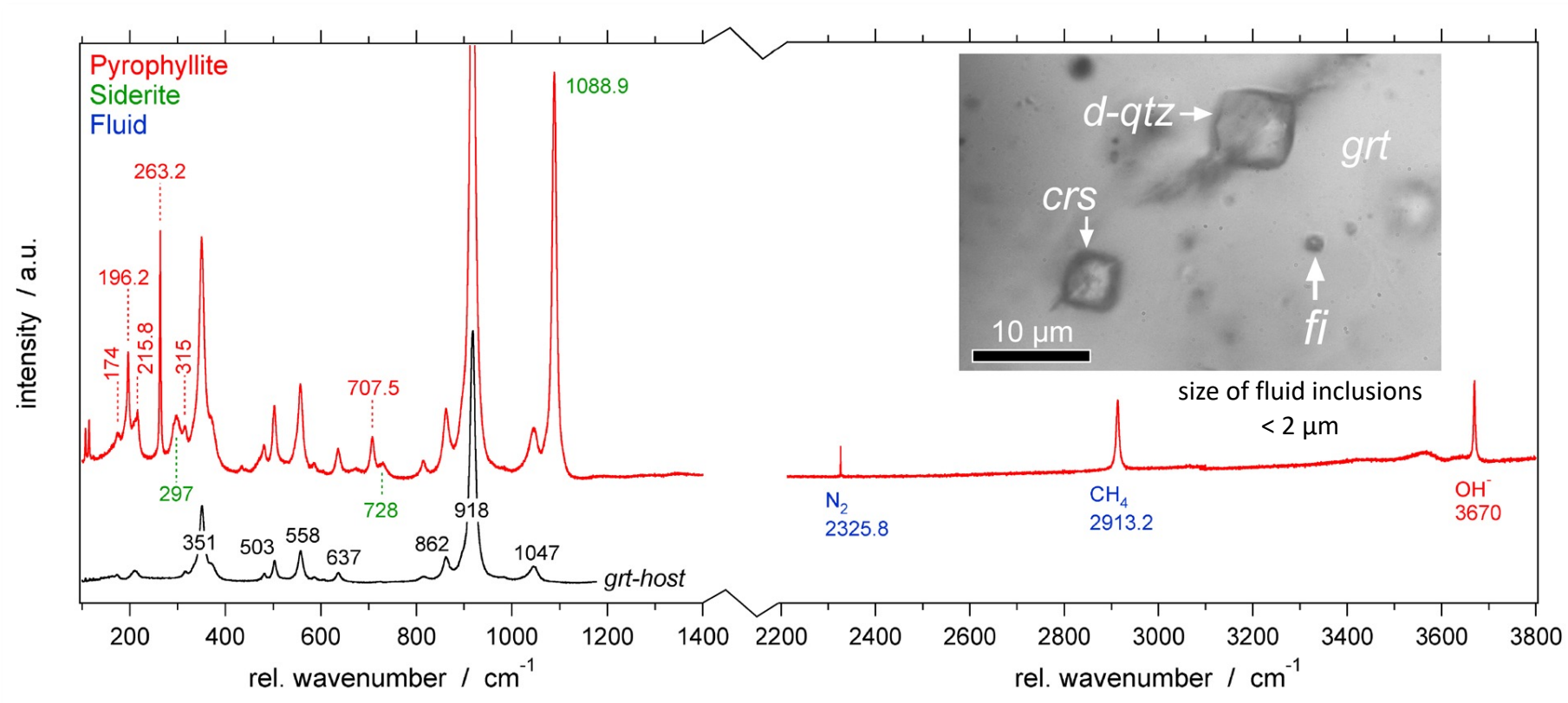


- quartz (90%)
- ilmenite
- rutile
- graphite
- plagioclase (variable Na-Ca content, albite to labradorite)
- magnetite,
- cordierite
- phlogopite
- zircon





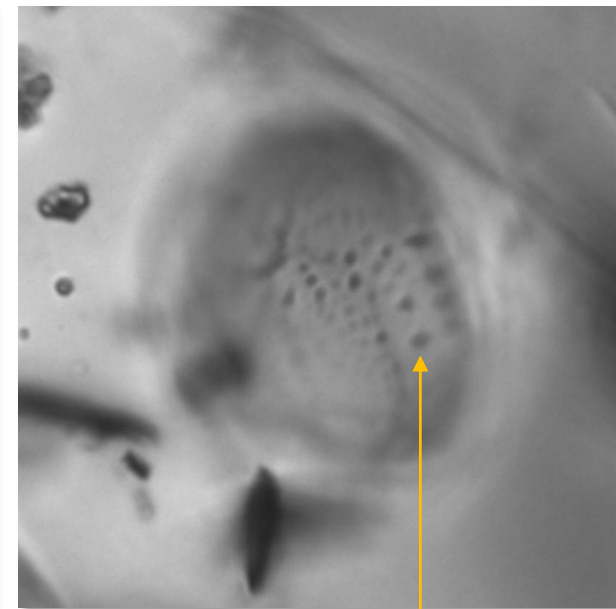
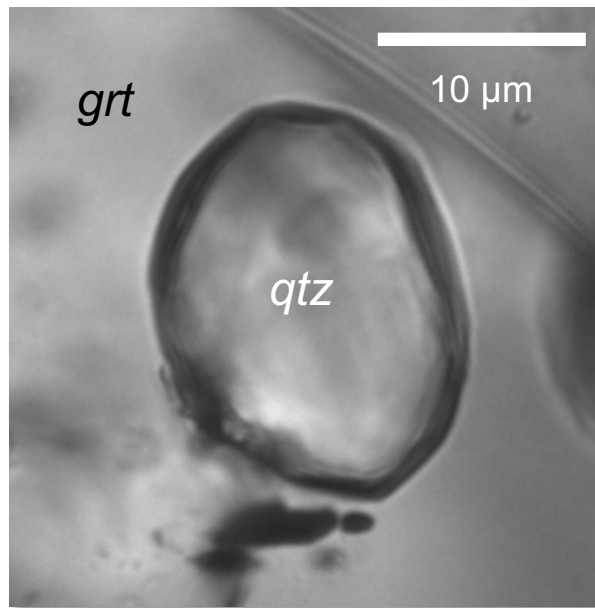
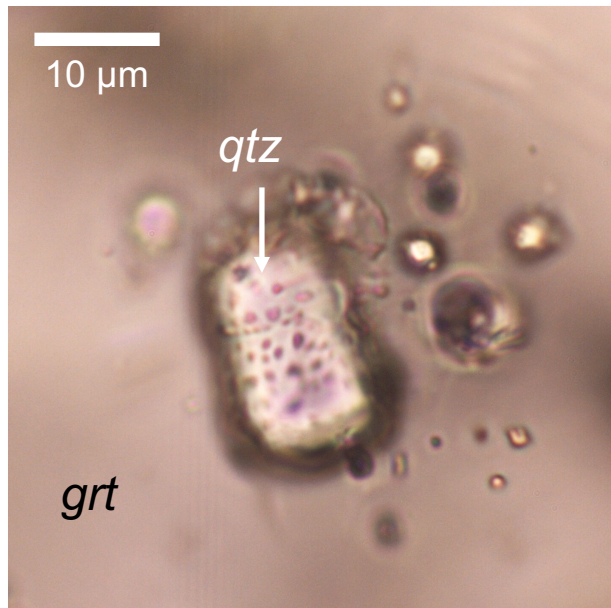
# Fluid inclusions in garnet 1



$79 \pm 4$  mole%  $\text{CH}_4$   
 $21 \pm 4$  mole%  $\text{N}_2$

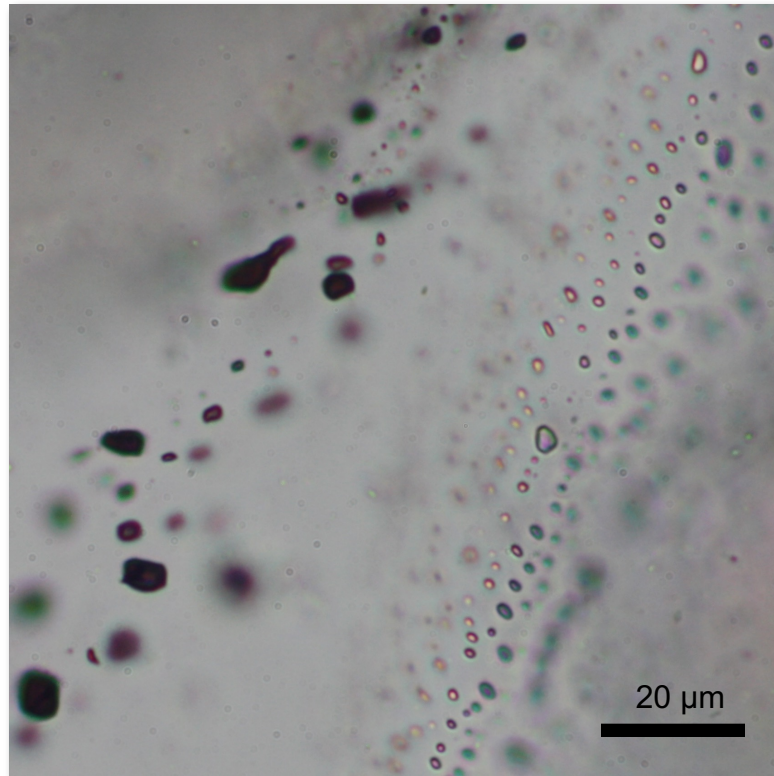
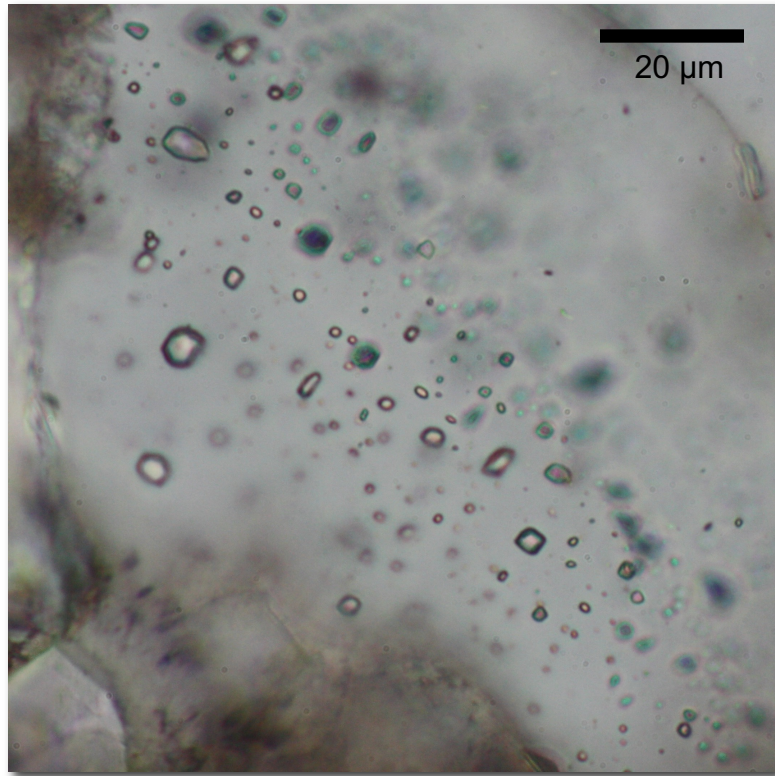
# Fluid inclusions in garnet 2

CH<sub>4</sub> fluid inclusions at surface of quartz inclusions in garnet

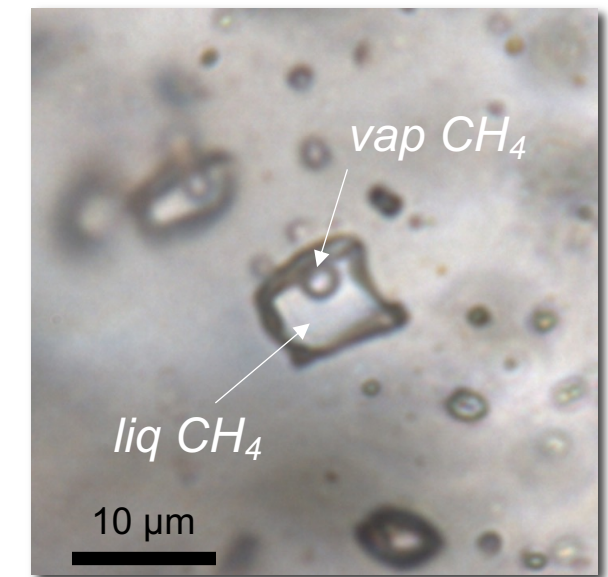
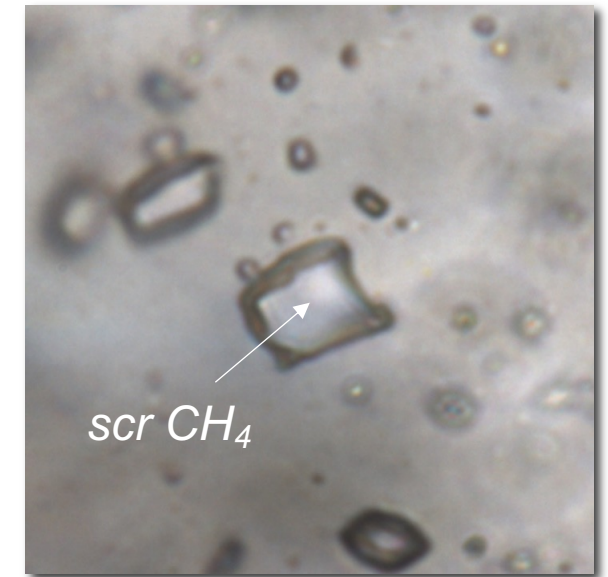


size of fluid inclusions < 1 μm

# Fluid inclusions in quartz nodules



*microthermometry*





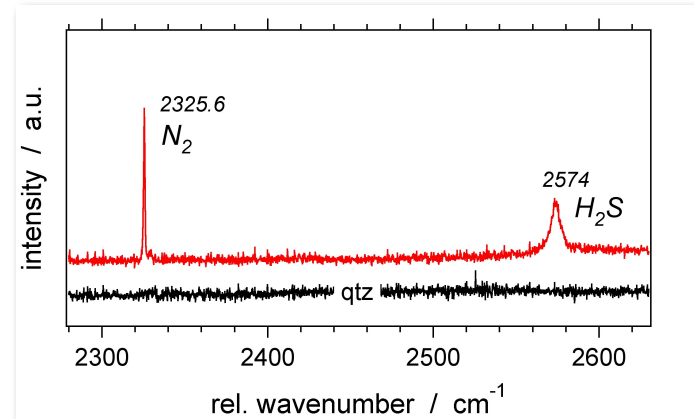
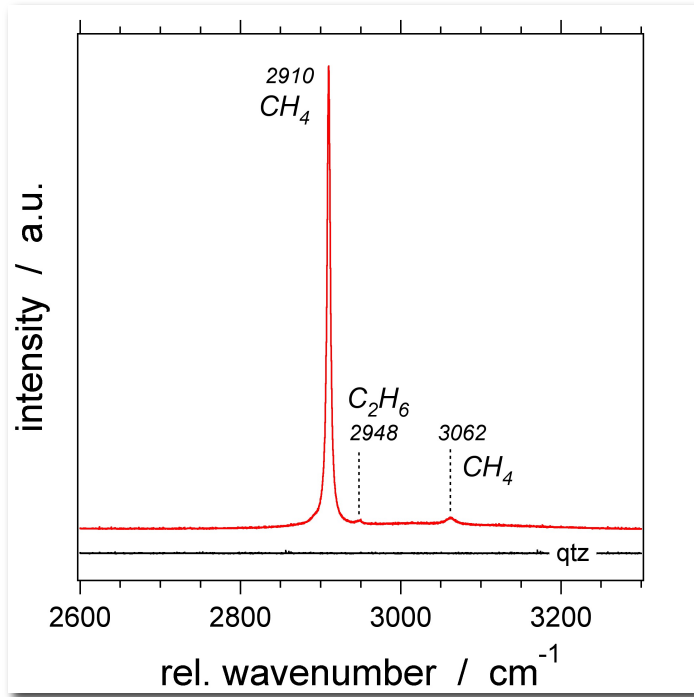
# High density CH<sub>4</sub>-rich fluid inclusions in quartz

CH<sub>4</sub> > 96 mole%

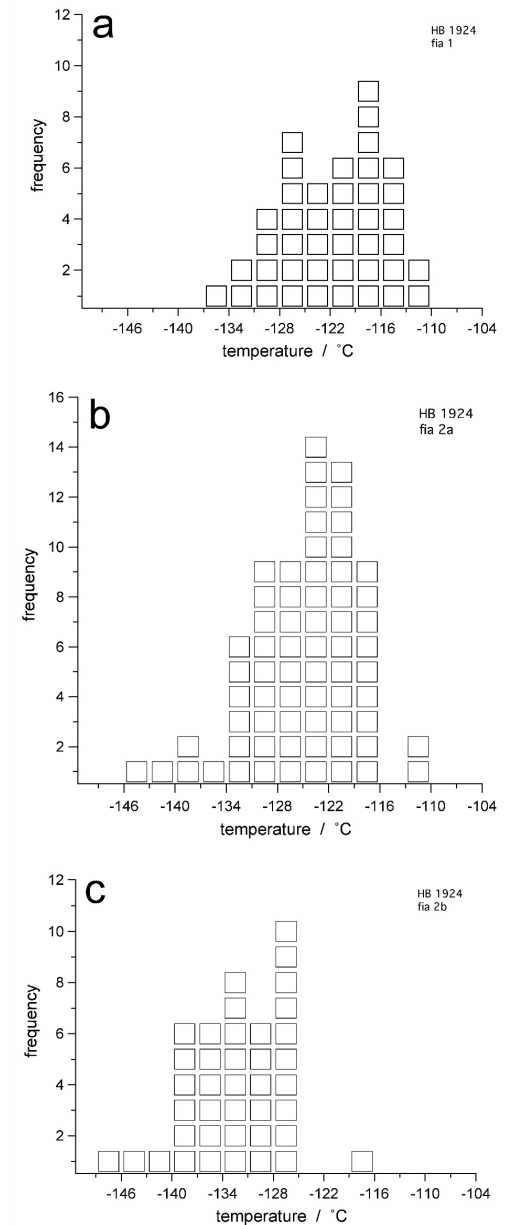
minor amounts of C<sub>2</sub>H<sub>6</sub>, N<sub>2</sub> and H<sub>2</sub>S

density:  
0.349 to 0.367 g/cm<sup>3</sup>

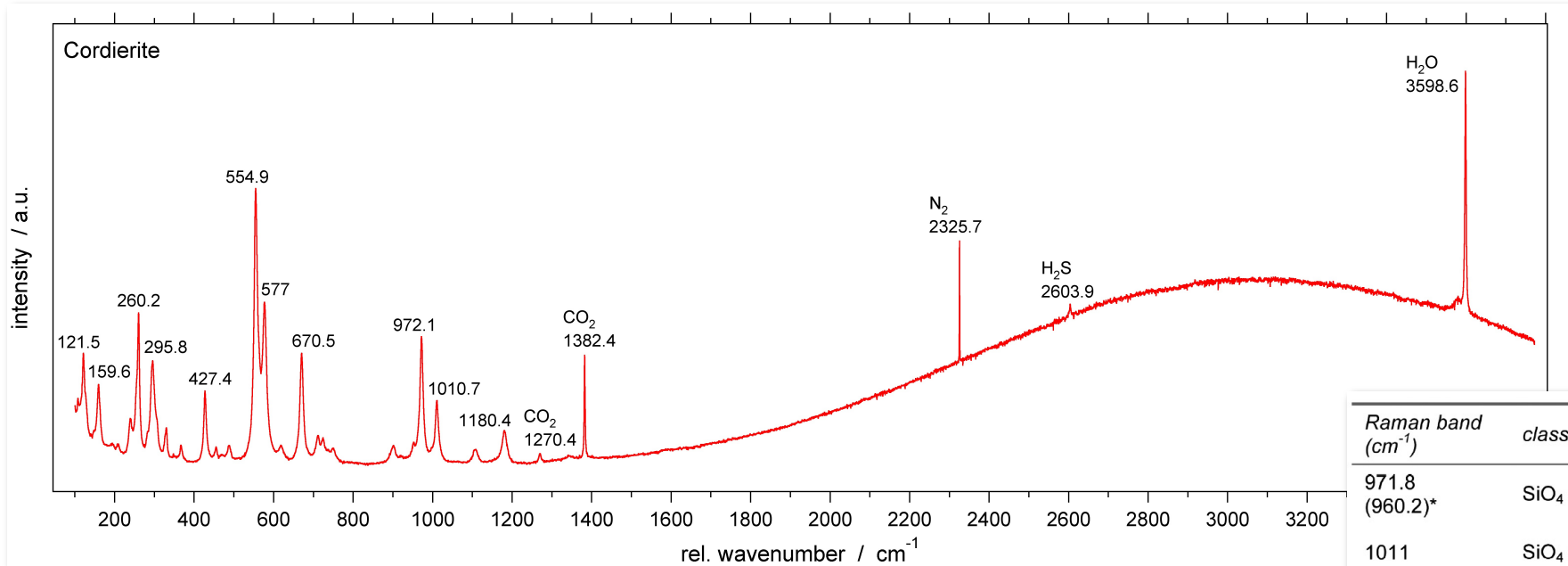
molar volume:  
43.7 to 45.9 cm<sup>3</sup>/mol



homogeneous fluid inclusion assemblages



# Fluid components in cordierite



H<sub>2</sub>O – CO<sub>2</sub> - rich fluid  
minor amounts of N<sub>2</sub> and H<sub>2</sub>S

Raman band (cm <sup>-1</sup> )	classification	area (a.u.)	amplitude (a.u.)	width (cm <sup>-1</sup> )	Gauss factor
971.8 (960.2)*	SiO <sub>4</sub> (v <sub>1</sub> )	14673.8 (1940.2)	1162.5 (70.9)	8.4 (25.7)	0.0883 (1.0)
1011	SiO <sub>4</sub> (v <sub>2</sub> )	1052.7	94.4	10.3	0.9373
1179.9 (1167.9)*	SiO <sub>4</sub> (v <sub>3</sub> )	15483.8 (1954.3)	846.1 (55.4)	12.8 (33.2)	0.2034 (1.0)
1269.6	CO <sub>2</sub> (v <sub>1</sub> )	2645.2	261.8	7.3	0.0345
1369.8	<sup>13</sup> CO <sub>2</sub> (v <sub>1</sub> )	50.2	23.0	2.1	1.0
1382.2	CO <sub>2</sub> (2v <sub>2</sub> )	9165.9	2191.0	2.8	0.1304
1394.9	CO <sub>2</sub> (base)	1627.3	38.6	27.9	0.0811
2325.5	N <sub>2</sub> (v <sub>1</sub> )	1362.8	1004.3	1.0	0.2646
2603.2	H <sub>2</sub> S (v <sub>1</sub> )				
3598.2 (3585.4)*	H <sub>2</sub> O (v <sub>1</sub> ) Class I and II	6853.3 (2144.8)	1226.4 (55.0)	3.8 (25.8)	1.0 (1.0)

# Fluid phase contradictions?

Methane  
(fluid inclusions)

IW-buffered oxidation state

typical oxidation state of the mantle

fluid is completely dissolved in melt fractions of the asthenosphere

Carbon-dioxide  
(cordierite)

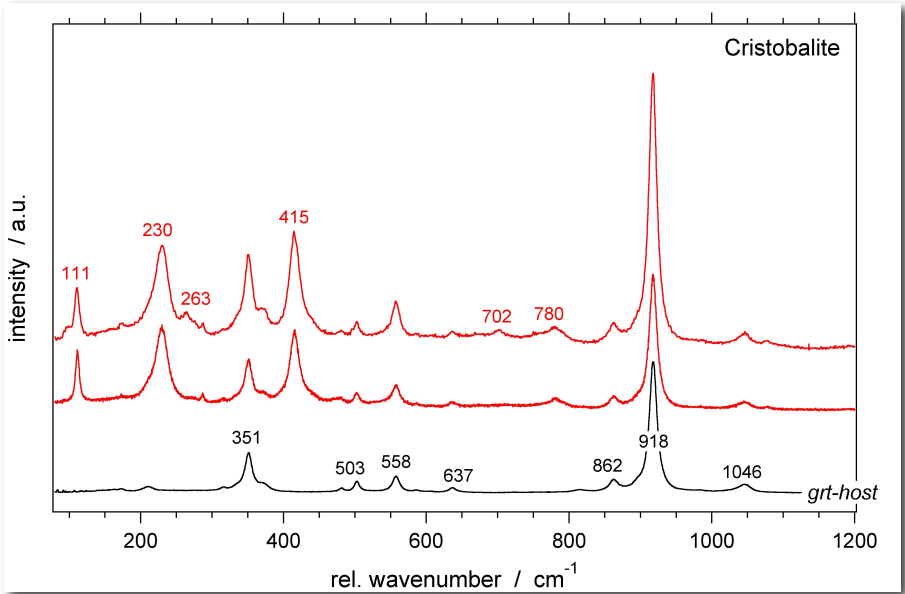
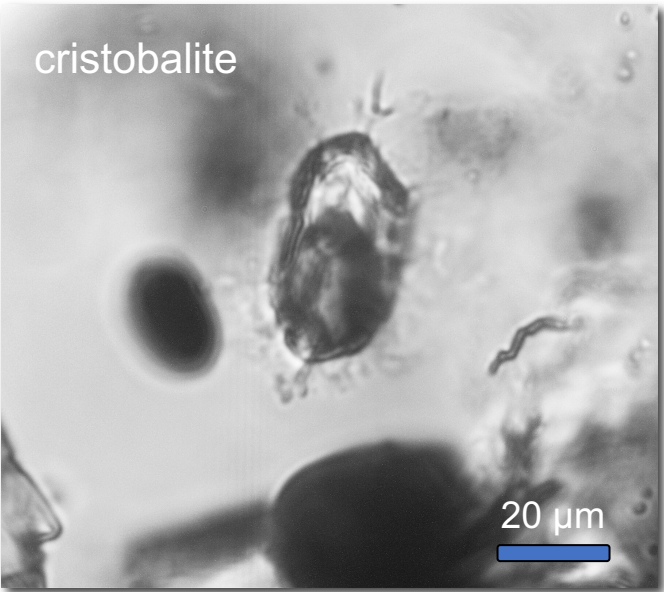
Typical fluid in granulite-facies rock (lower crust)

QFM-buffered oxidation state

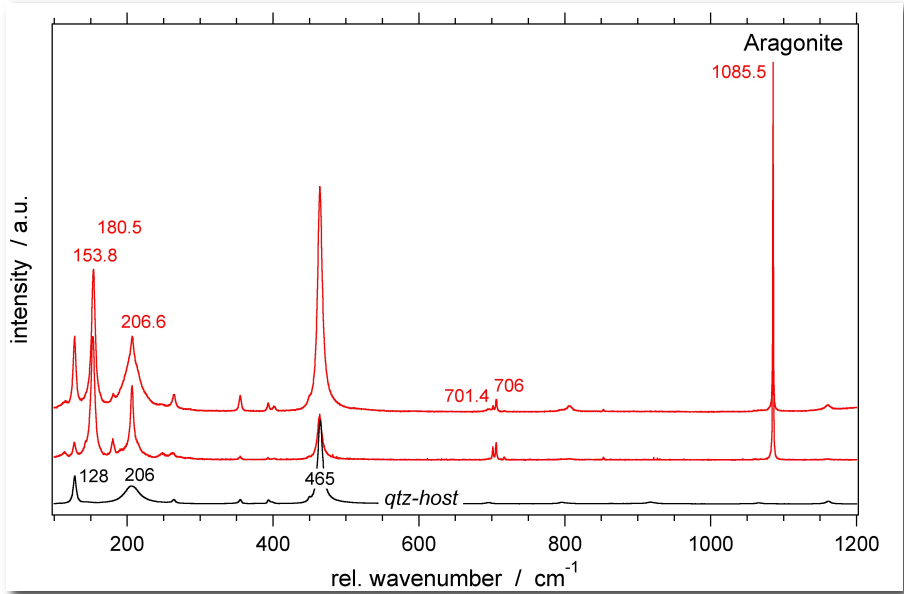
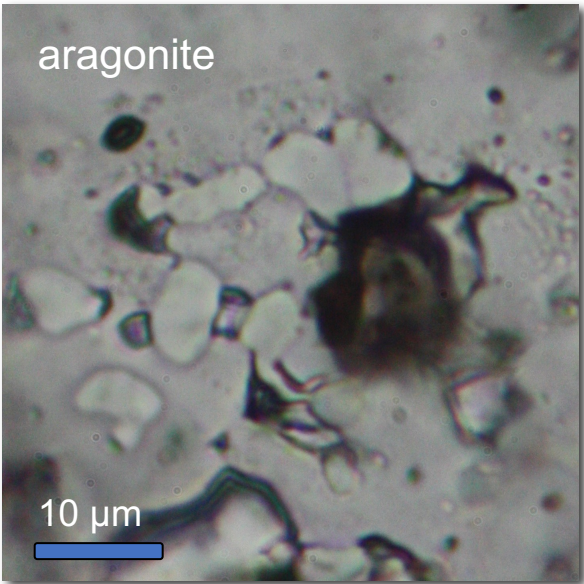


# Specific solid inclusions

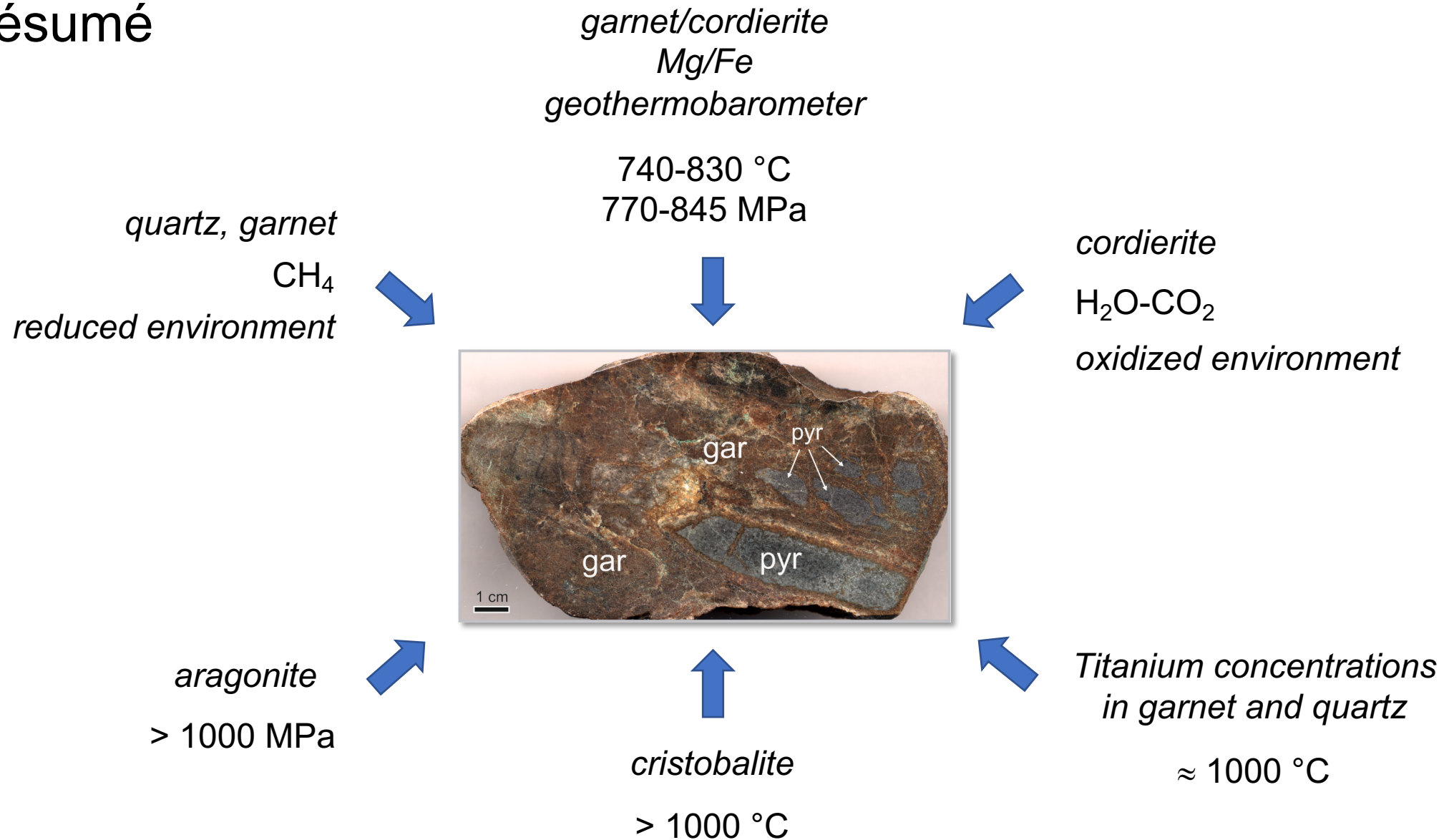
high-temperature metamorphism?



high-pressure metamorphism?



# Résumé



# Conclusions

- Metamorphic complex: amphibolite to granulite facies (lower crust)  
relatively oxidized lower crust system at granulite facies conditions (QFM buffered)  
minor amounts of H<sub>2</sub>O-CO<sub>2</sub>-rich fluids (only preserved in cordierite)
- Magmatic underplating intrusion of large masses of high temperature ultramafic-mafic mantle melts  
➡ strong positive thermal anomaly at the lower continental crustal level  
(formation of two-pyroxene granulites and garnetites, cristobalite, Ti-content Qtz, Grt)
- Mantel CH<sub>4</sub> abundant CH<sub>4</sub>-H<sub>2</sub> rich fluids (IW buffered) are produced upon cooling of this intrusive mafic-ultramafic magmatic complex in the lower crust  
flushing the metamorphic complex (tectonics)  
➡ formation of abundant CH<sub>4</sub>-rich fluid inclusions

*Ref.: Bakker et al. (2020) Journal of Petrology, vol. 61, issue 6, egaa006*