In situ rock deformation and liquids under extreme conditions - the value of specialized LVPs at PETRA IV

M. J. Sieber

T. Katsura
Th 9:20 am

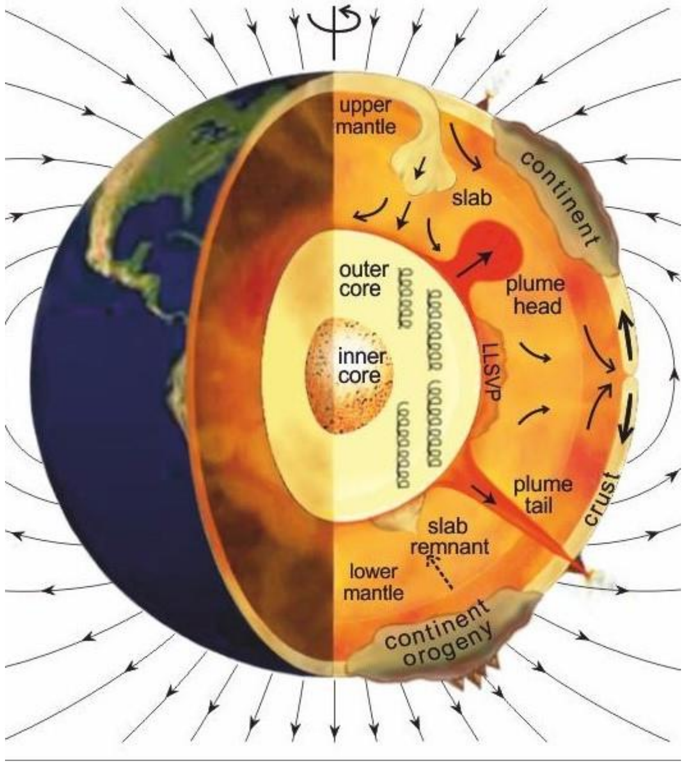
N. Hilairet
Th 9:40 am

R. Farla
Th 10:45 am

Rheology studies
in situ rock deformation

Why interesting?

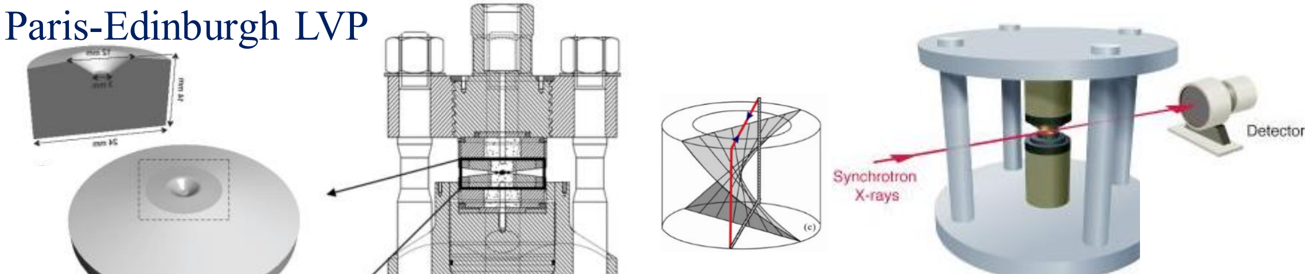
- ➢ mantle convections
  - ➢ driving tectonics, causing volcanic and seismic activities



Why are rheology studies under extreme conditions in a LVP needed?

- ➢ stress & strain can be monitored & measured
- ➢ sufficient number of grains
- ➢ uniform & stable PT-conditions over wide strain rates

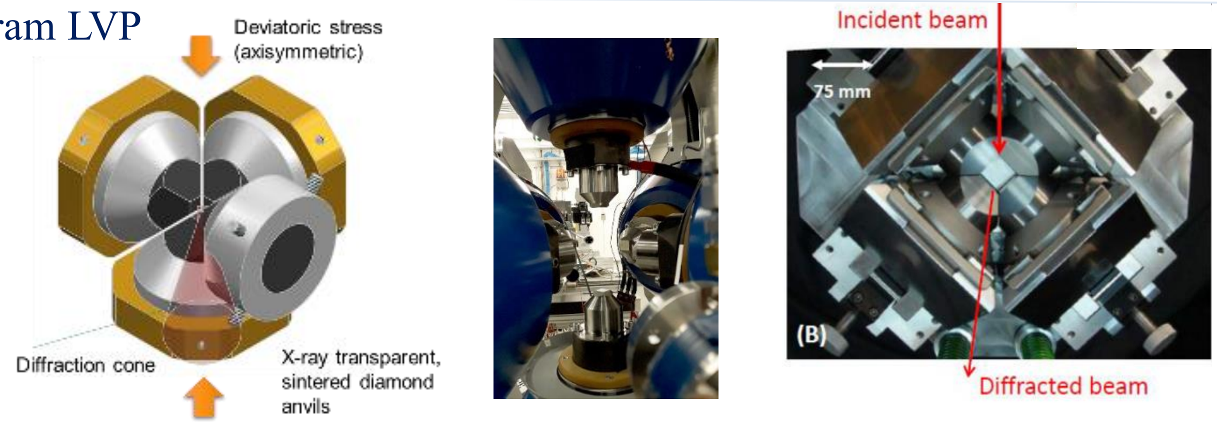
Paris-Edinburgh LVP



Shen & Wang (2014) Rev Min & Geochem, 78, 745-777

ESRF/Nigel Hawtin

6-ram LVP



in situ rock deformation
(2D) AD-XRD & radiographic imaging

Talk N. Hilairet
Th 9:40 am

Angle dispersive X-ray diffraction: stress
X-ray radiographic imaging: axial strain

Deformation of mantle olivine

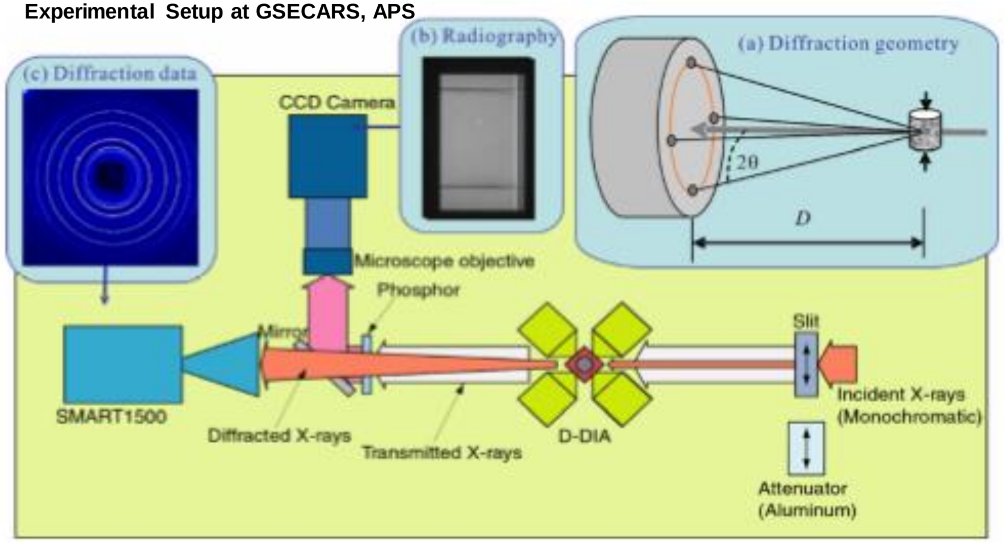
Hilairet et al. 2012

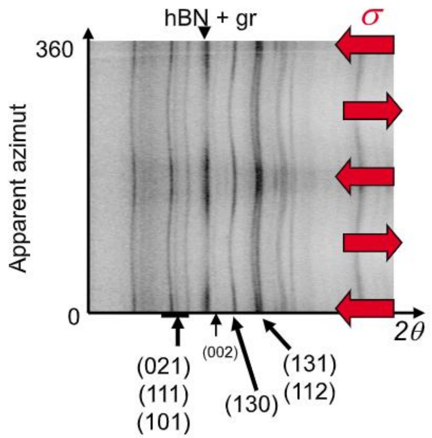
- polycrystalline olivine
- P=2.8-7.8 GPa; T~900-1400 °C
- stress rates: 7.10^{-6} to 3.10^{-5} s^{-1}

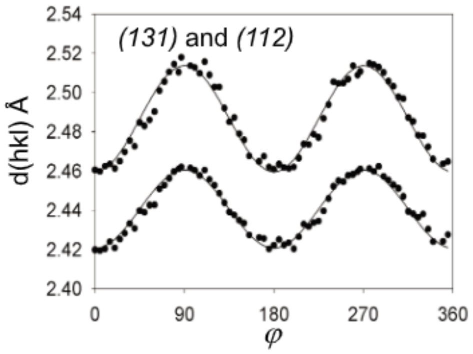
D-DIA

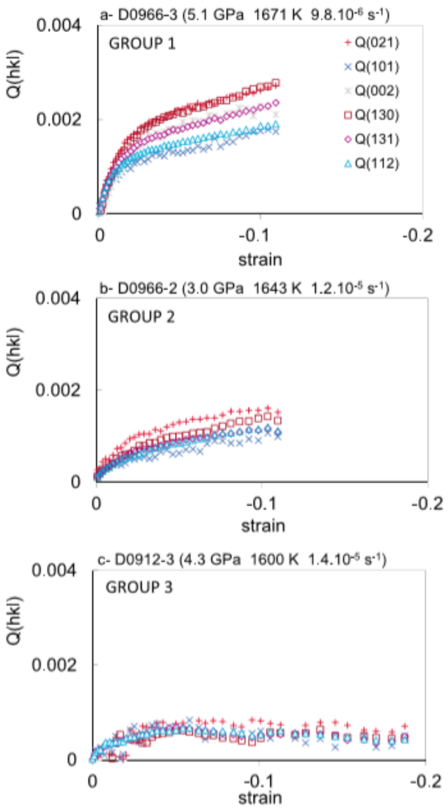
installed @ GSECARS, APS

Experimental Setup at GSECARS, APS









Wang Y. B., et al. (2010). *Journal of Earth Science* **21**, 495-516.
Hilairet N., et a. (2012). *Journal of Geophysical Research* 117, B01203.

Large Volume Press @ PETRA IV

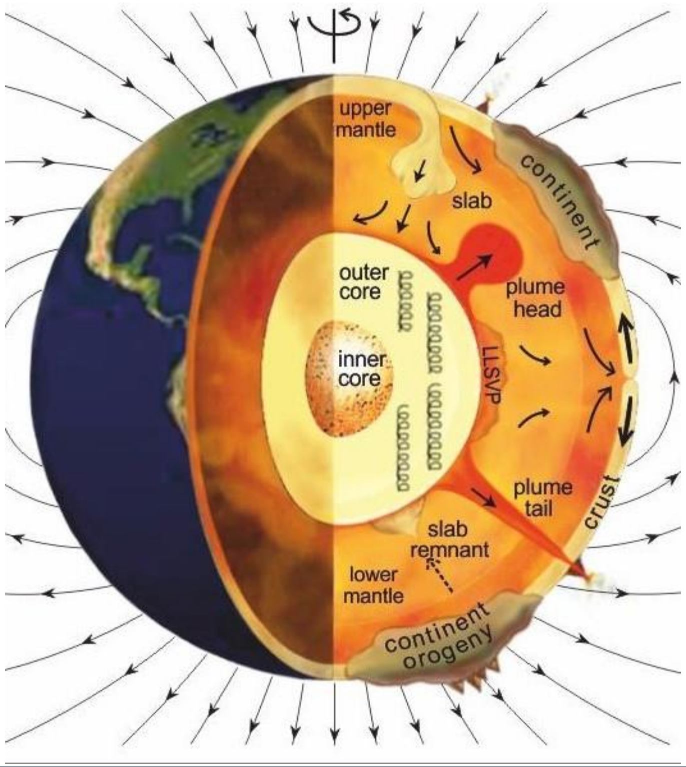
	**6-ram MA (P61.B)** 20 GPa, 2000 K (40 GPa; 2000 K)
	➢ axial deformation (rheology)
	➢ (2D) AD-XRD ➢ imaging (radiography)

	➢ improved resolution in stress and strain measurements (also for rocks)
	➢ directional, monochromatic X-ray beam with high coherence and low-emittance
	    ➢ ΔE/E ~ 10^{-3} to 10^{-4}
	    ➢ 40-100 keV
	    ➢ large-radius area detector
	    ➢ highly focused beam

Liquids under extreme conditions

Why interesting?

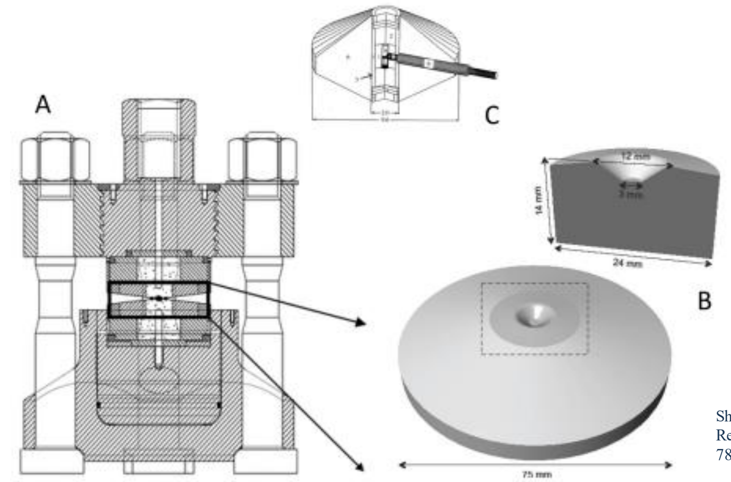
- relevant to the origin and evolution of planets
- heat and mass transfer influence the chemical and thermal history of Earth's interior



Why are studies of liquids under extreme conditions in a (PE) LVP needed?

- some liquids are non-quenchable
- e.g. viscosity, density, structure of a melt but also melting point and melt propagation can best be studied in situ
- precise PT control (over time)
- post mortem characterization possible
- composite materials (multi-grain rocks)

Paris-Edinburgh LVP advantage: wide opening angle



Shen & Wang (2014) Rev Min & Geochem, 78, 745-777

Liquids under extreme conditions
X-ray absorption imaging / tomography

X-ray absorption imaging / tomography

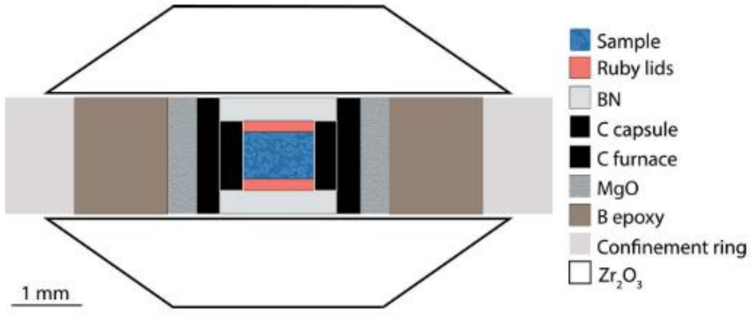
Rhyolite melt percolation through the mantle

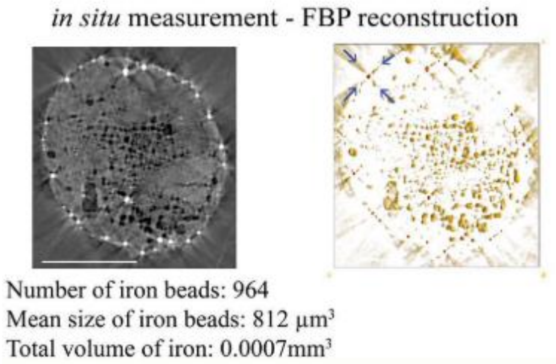
Boulard E., *et al.* 2018

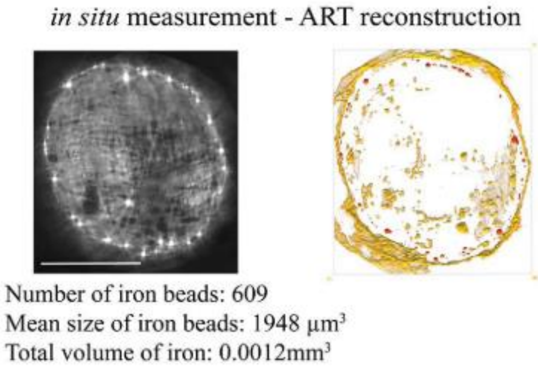
- finely ground rhyolite & olivine crystals
- P=3 GPa; ≤1600 K
- **rotation 135º**, 10 msec exposure time
  → **10 sec for a tomogram**

PE

installed @ PSICHE, SOLEIL







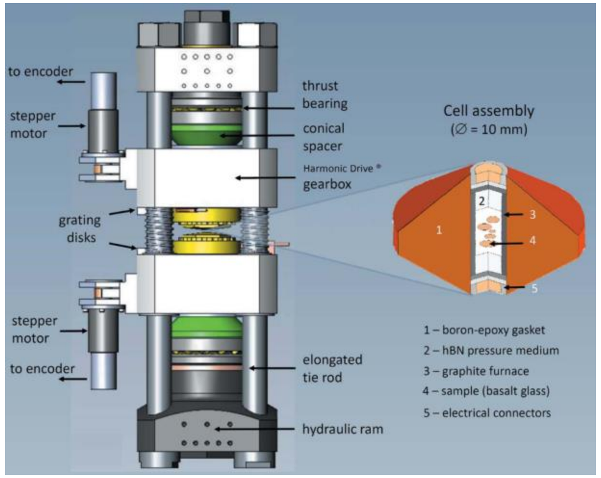
Boulard E., et al. (2018). *Journal of Synchrotron Radiation* **25**, 3, 818-825.

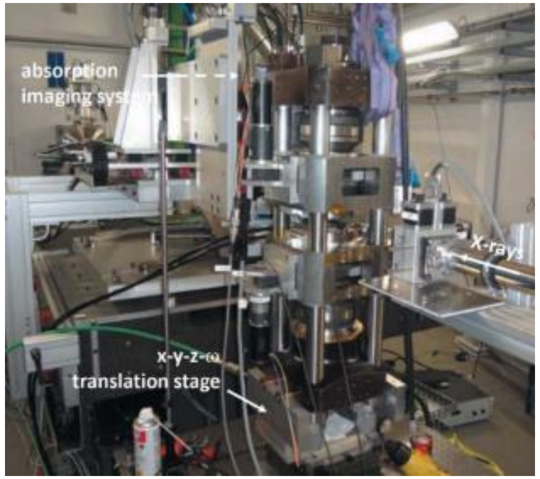
Liquids under extreme conditions
X-ray absorption imaging / tomography

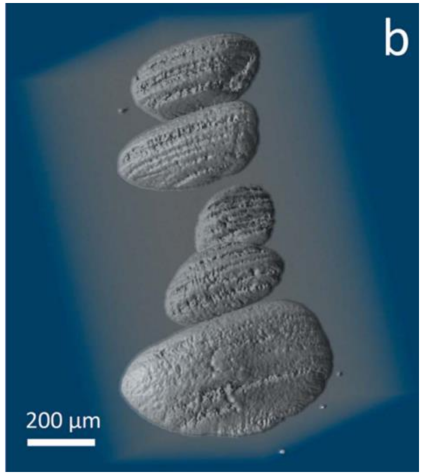
X-ray absorption imaging / tomography

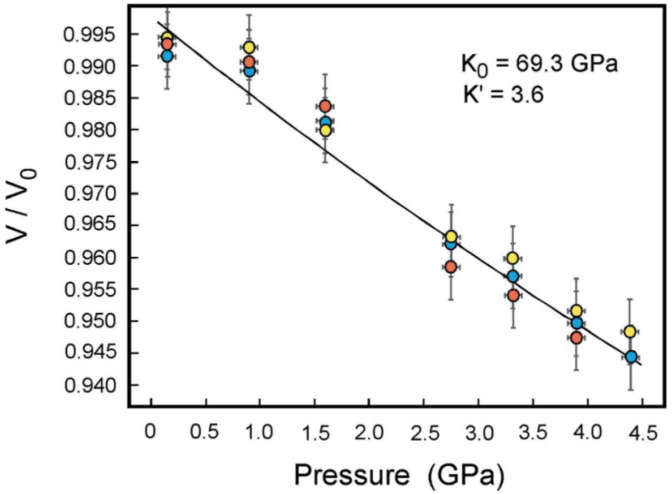
Compressibility of basaltic glass
Álvarez-Murga M., *et al.* 2017
- 5 basaltic glass beads in h-BN
- P=0-4.4 GPa; RT
- **rotation 180º**, 0.15º s^{-1}
  → **20 min for a tomogram**

RoToPEc
installed @ PSICHE, SOLEIL









Álvarez-Murga M., et al. (2017). *Journal of Synchrotron Radiation* **21**, 1, 240-247.

Liquids under extreme conditions
X-ray absorption imaging / tomography

Universität Potsdam

X-ray absorption imaging / tomography

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RoToPEc

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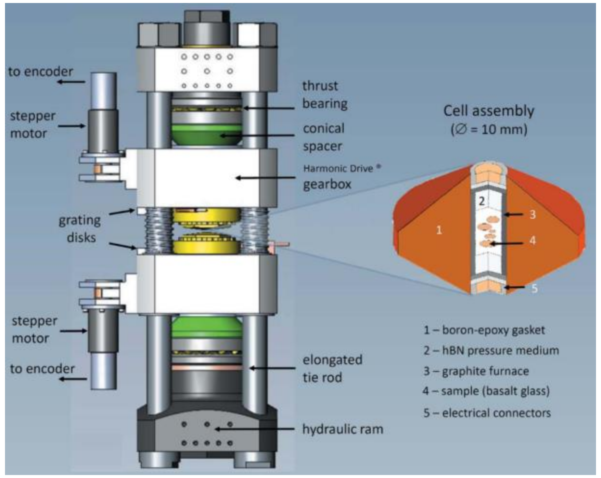
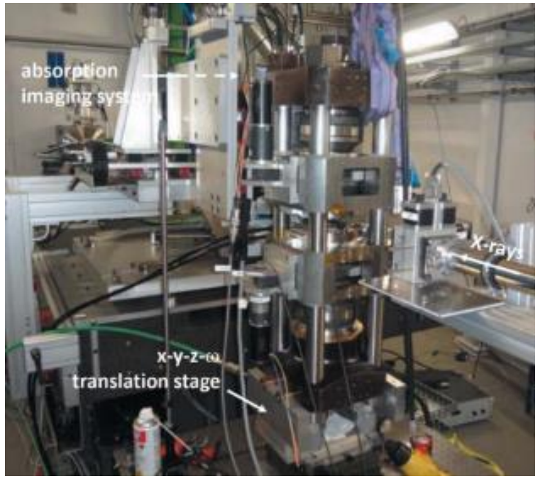
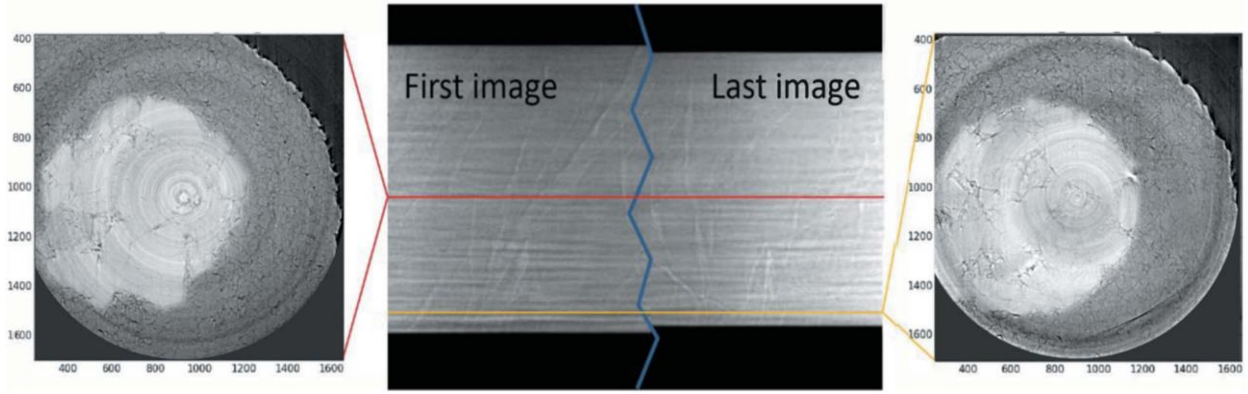




3 GPa 1800 K



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Liquids under extreme conditions
X-ray phase contrast imaging

X-ray phase contrast imaging

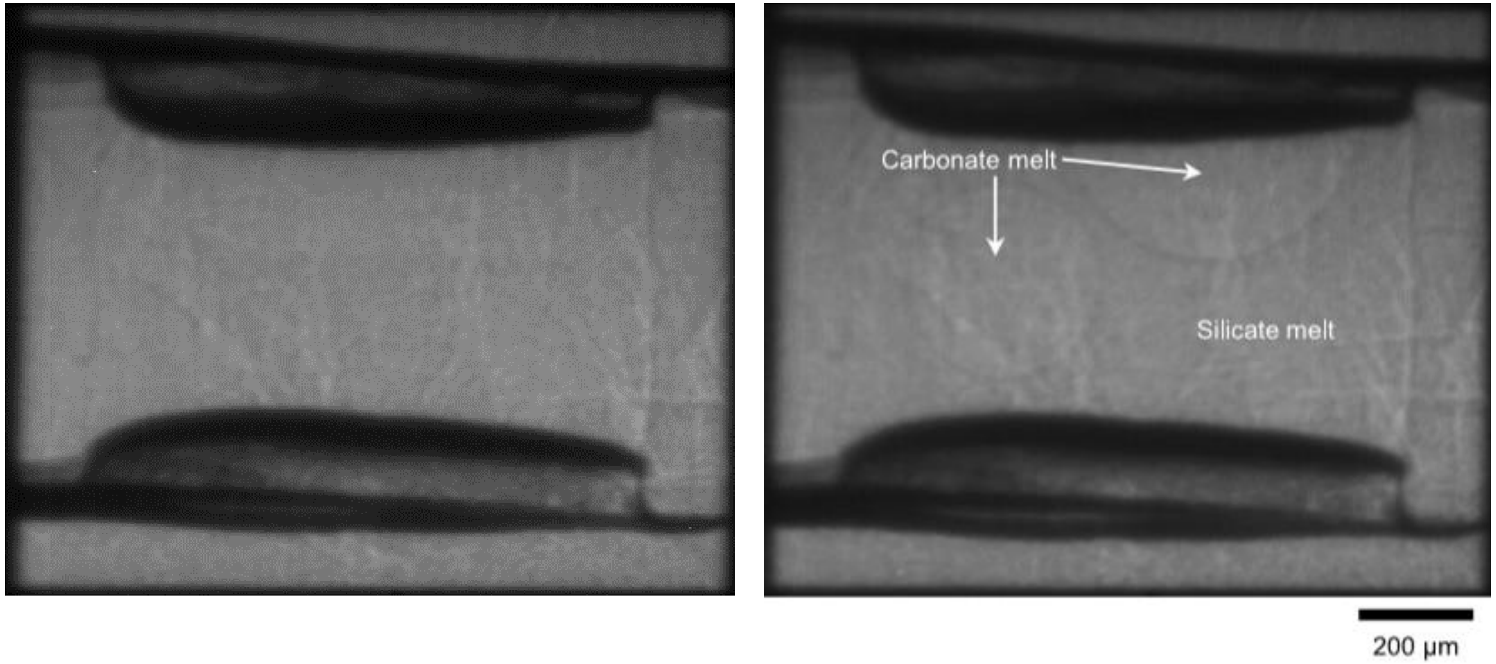
Liquid phase separation and liquid-liquid immiscibility

Kono Y., *et al.* 2015

- 40 wt% albite & 60 wt% calcite
- P=2.5 GPa; 1350-1500 °C
- movie: 60 frames/sec

PE

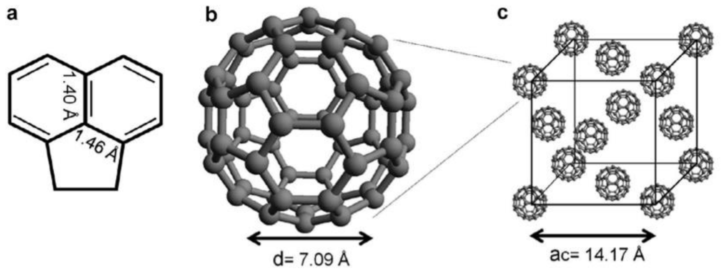
installed @ 16-BM-B, APS

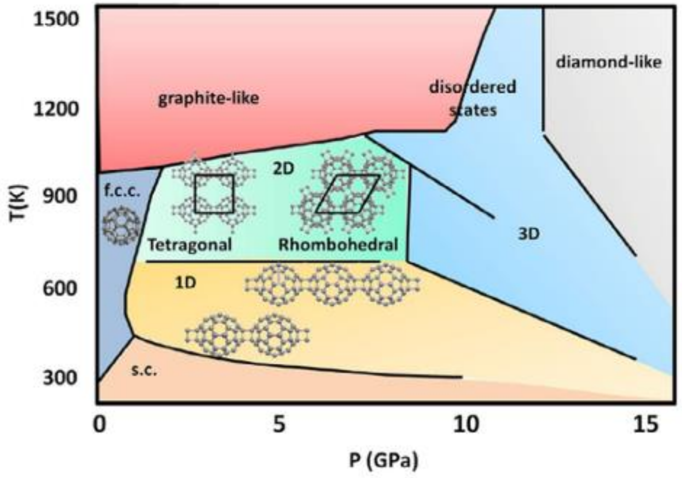


Kono Y., et al. (2015) *Review of Scientific Instruments*. 86, 072207, 1-8

X-ray diffraction / scattering µ-tomography

X-ray diffraction / scattering µ-tomography





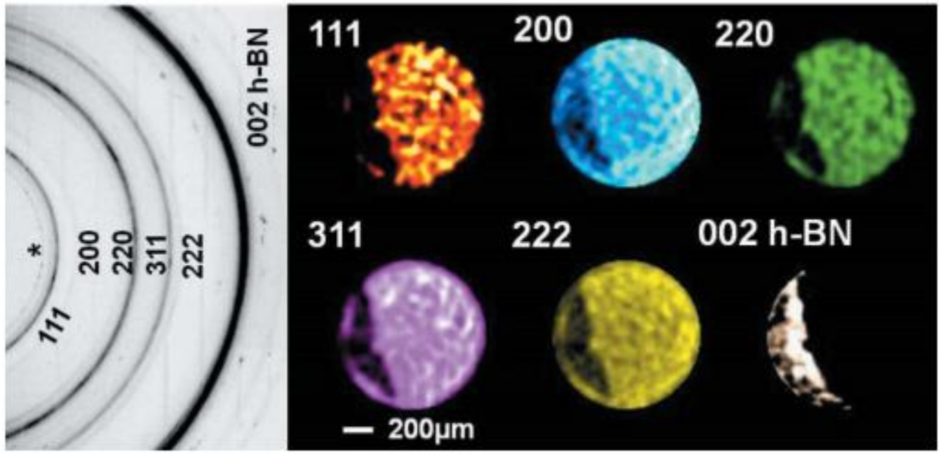
C_{60} polymerization & phase transitions

Álvarez-Murga M., *et al.* 2017

- fullerene
- monochromatic beam
  - 2.4 µm x 2.0 µm; 4.0 mm x 2.0 mm
- for 1.35 mm profile: 2350 2D-XRD patterns → **8h**

RoToPEc

installed @ ID27, ESRF



Álvarez-Murga M., et al. *Journal of synchrotron radiation* ***24, 240-247*** **(2017).**

Large Volume Press @ PETRA IV

		**PE-LVP (former P02.2); RoToPEc (new)** 10 GPa, 1700 K (20 GPa, 1700 K)
		➢ structure, density and viscosity of liquids
		➢ (4D) AD-XRD ➢ DSCT (Diffraction Scattering X-ray Tomography) ➢ imaging (µ-tomography & radiography & phase contrast)
		➢ improved energy resolution (10^{-4} for E>40 keV) ➢ fast acquisition and high resolution (for 4D imaging) ➢ tunable spot size (~1x200 µm to ~2x2 mm) ➢ large radius area detector ➢ X-ray microscope (for radiography/tomography)
		➢ big data-storage: ~1 TB/day (more?)

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Large Volume Press @ PETRA IV

	**6-ram MA (P61.B)** 20 GPa, 2000 K (40 GPa; 2000 K)	**PE-LVP (former P02.2); RoToPEc (new)** 10 GPa, 1700 K (20 GPa, 1700 K)	**Uniaxial LVP UHP**
	➢ structural charaterization & phase transitions of e.g. hydrous minerals and carbonates ➢ axial deformation (rheology)	➢ structure, density and viscosity of liquids ➢ shear deformation (rheology) ➢ evolution of microstructures & phase distribution	➢ pushing the pressure limit
	➢ (1D/2D) AD-XRD ➢ ED-XRD ➢ imaging (radiography & phase contrast)	➢ (4D) AD-XRD ➢ DSCT (Diffraction Scattering X-ray Tomography) ➢ imaging (µ-tomography & radiography & phase contrast)	➢ ED-XRD
	➢ improved energy resolution (10^{-4} for E>40 keV) ➢ fast acquisition and high resolution (for kinetics / 4D imaging) ➢ tunable spot size (~1x200 µm to ~2x2 mm) ➢ large radius area detector ➢ X-ray microscope (for radiography/tomography)		T. Katsura Th 9:20 am
	➢ additive in situ characterization (e.g. ultrasound-velocity, electrical-conductivity measurements)	➢ big data-storage: ~1 TB/day (more?)	

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Thanks

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