Stresses* preserved in crystals

Measuring magmatic stresses with µXRD and Raman

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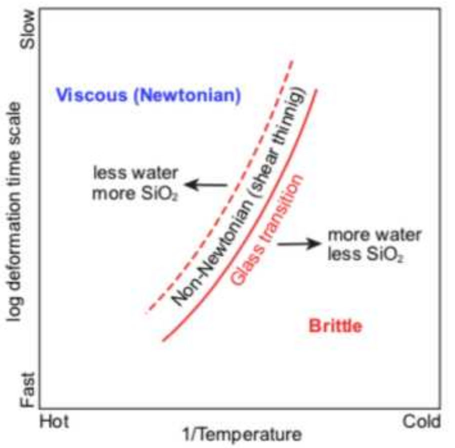
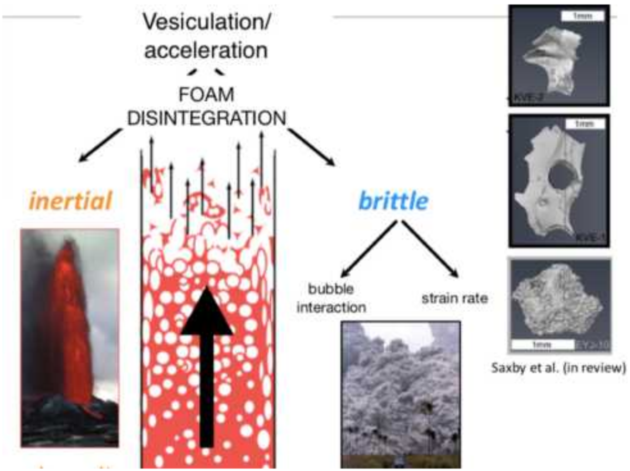
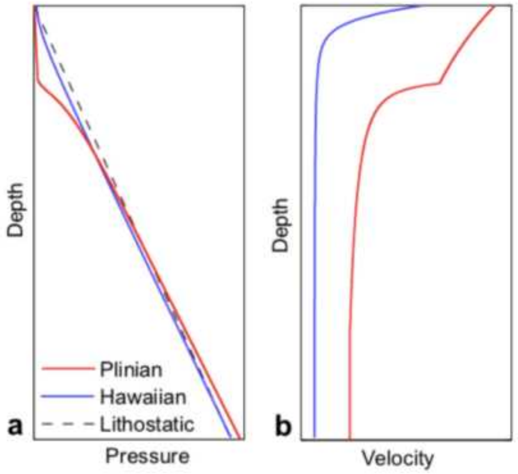
with collaborators Michael Manga (UC-Berkeley) and Miguel Cisneros (ETH)

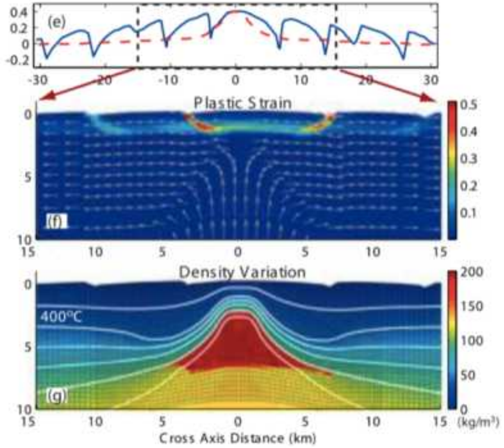
*strain

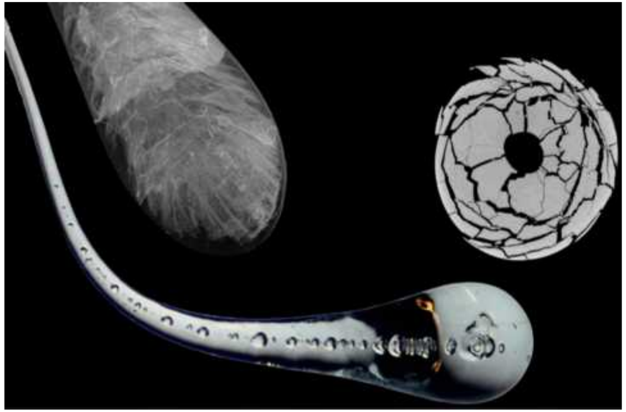
Forces matter. Maybe here too “crystals remember what the liquid and gas forgets.”

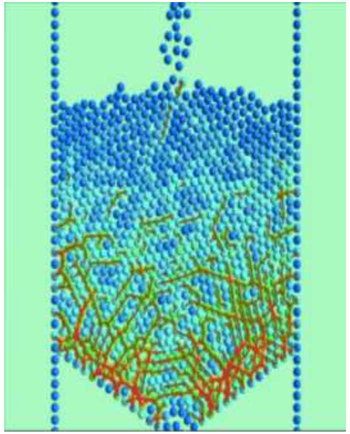




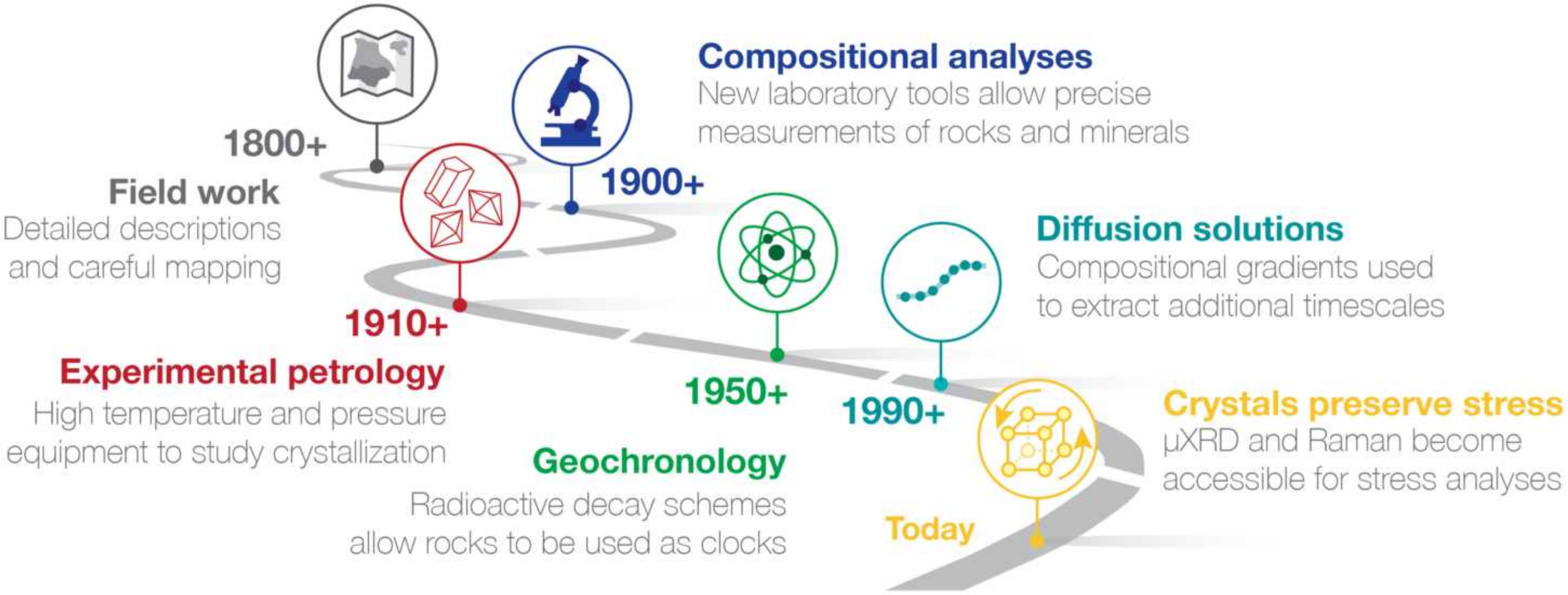






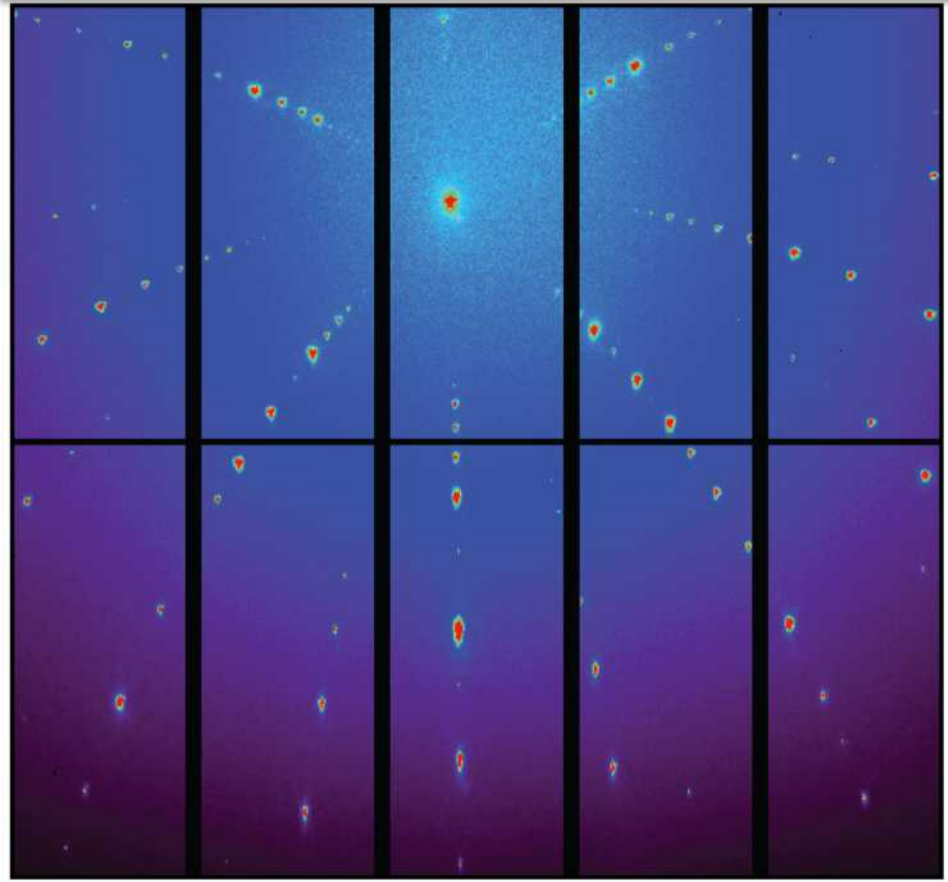


Technological advances push petrology forward

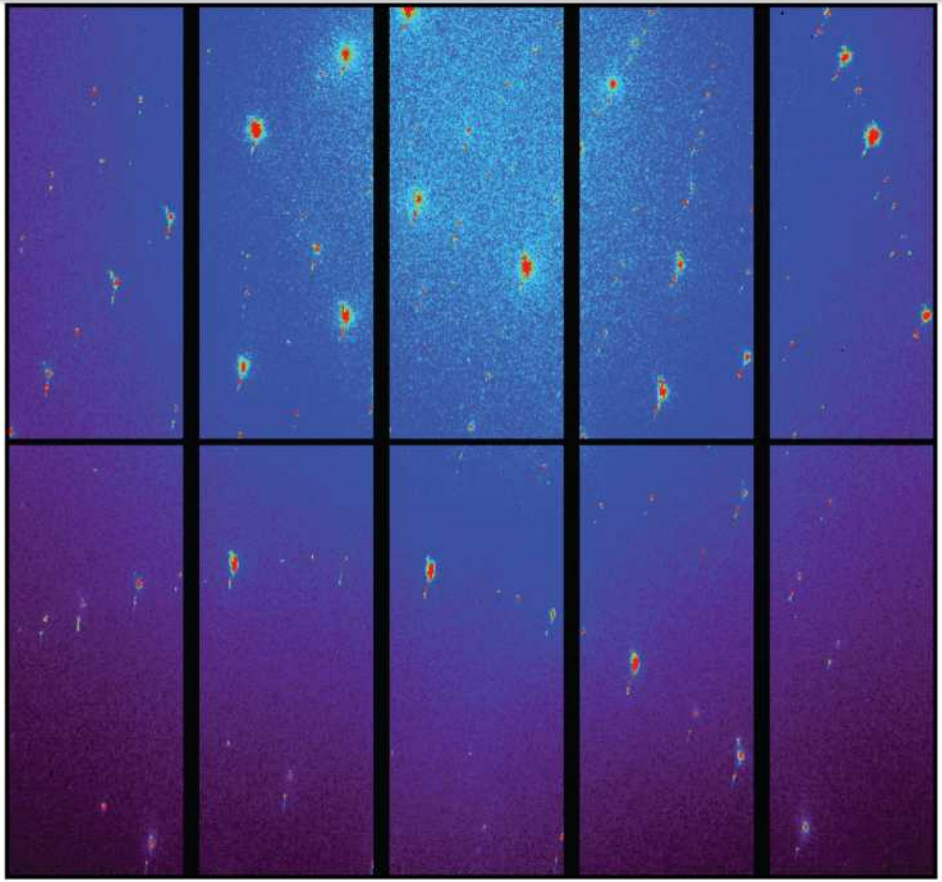


Synchrotron µXRD at the Advanced Light Source, Lawrence Berkeley National Lab

μXRD in Laue diffraction mode produces pattern of spots that relate to lattice spacing



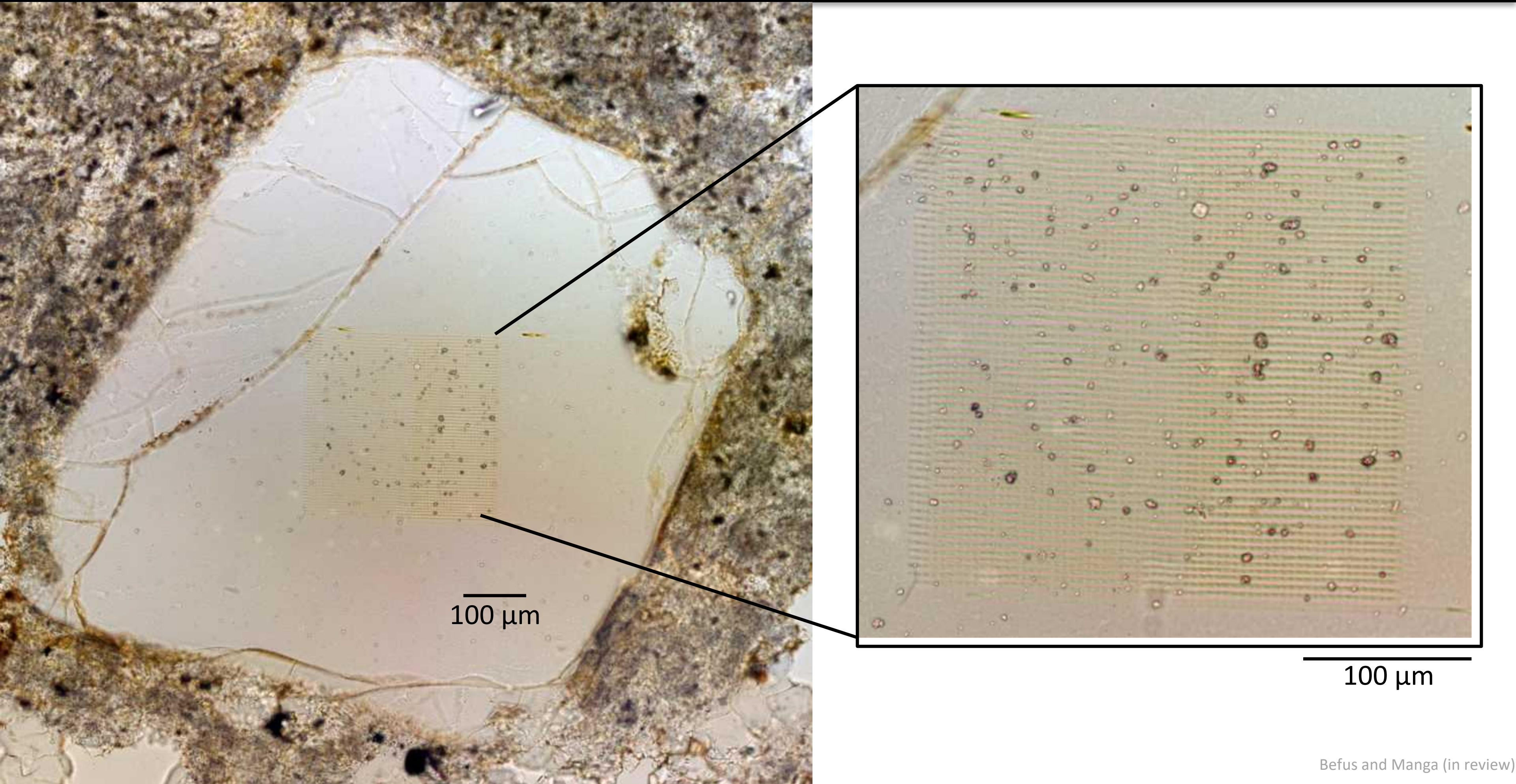
Quartz standard



Quartz from Tuff of Bluff Point, Yellowstone

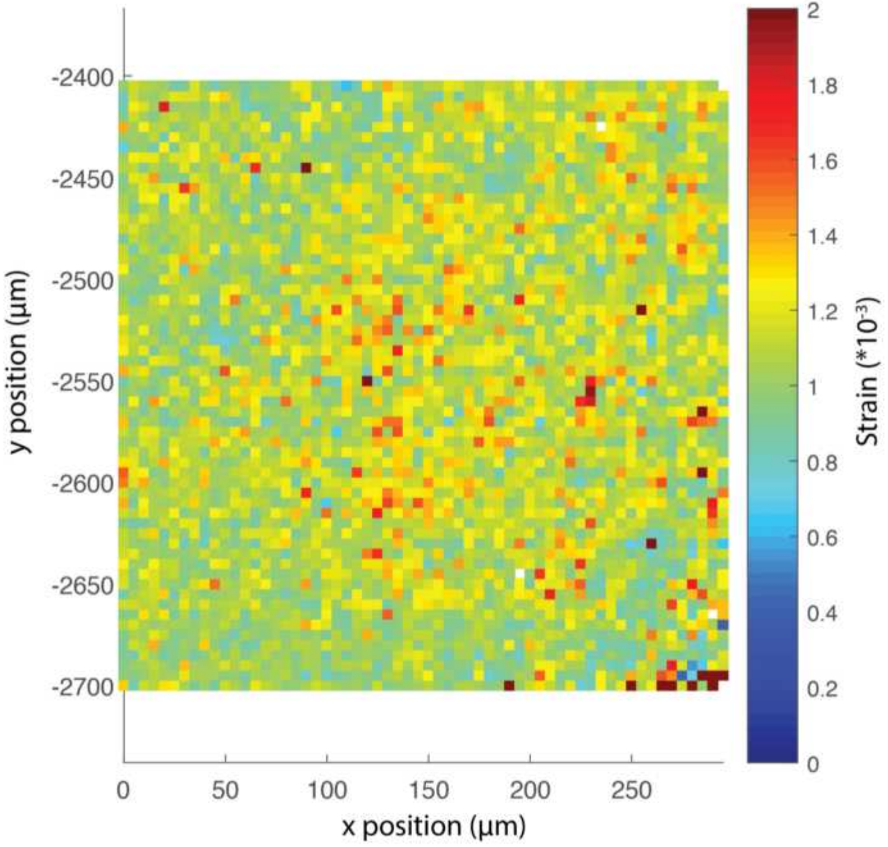
Befus and Manga (in review)

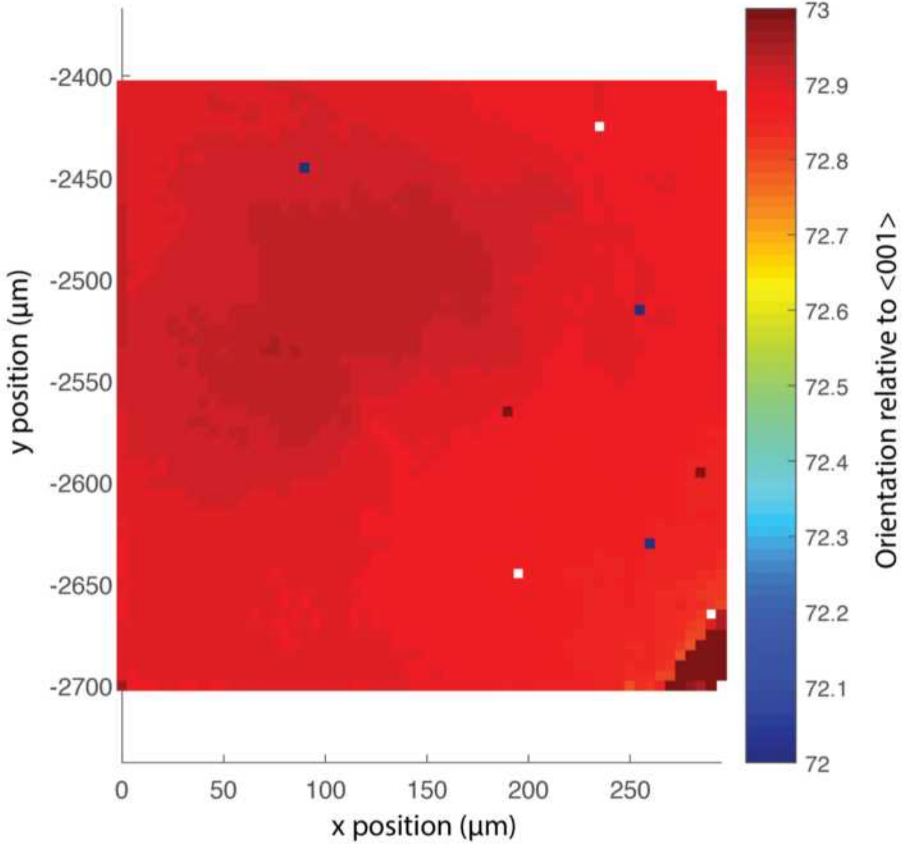
Example measurement from Huckleberry Ridge Tuff quartz from Yellowstone caldera



Befus and Manga (in review)

µXRD measures many crystallographic parameters. Here strain and orientation are shown.





Befus and Manga (in review)

Convert strain to stress using Hooke's Law and the elastic stiffness of quartz

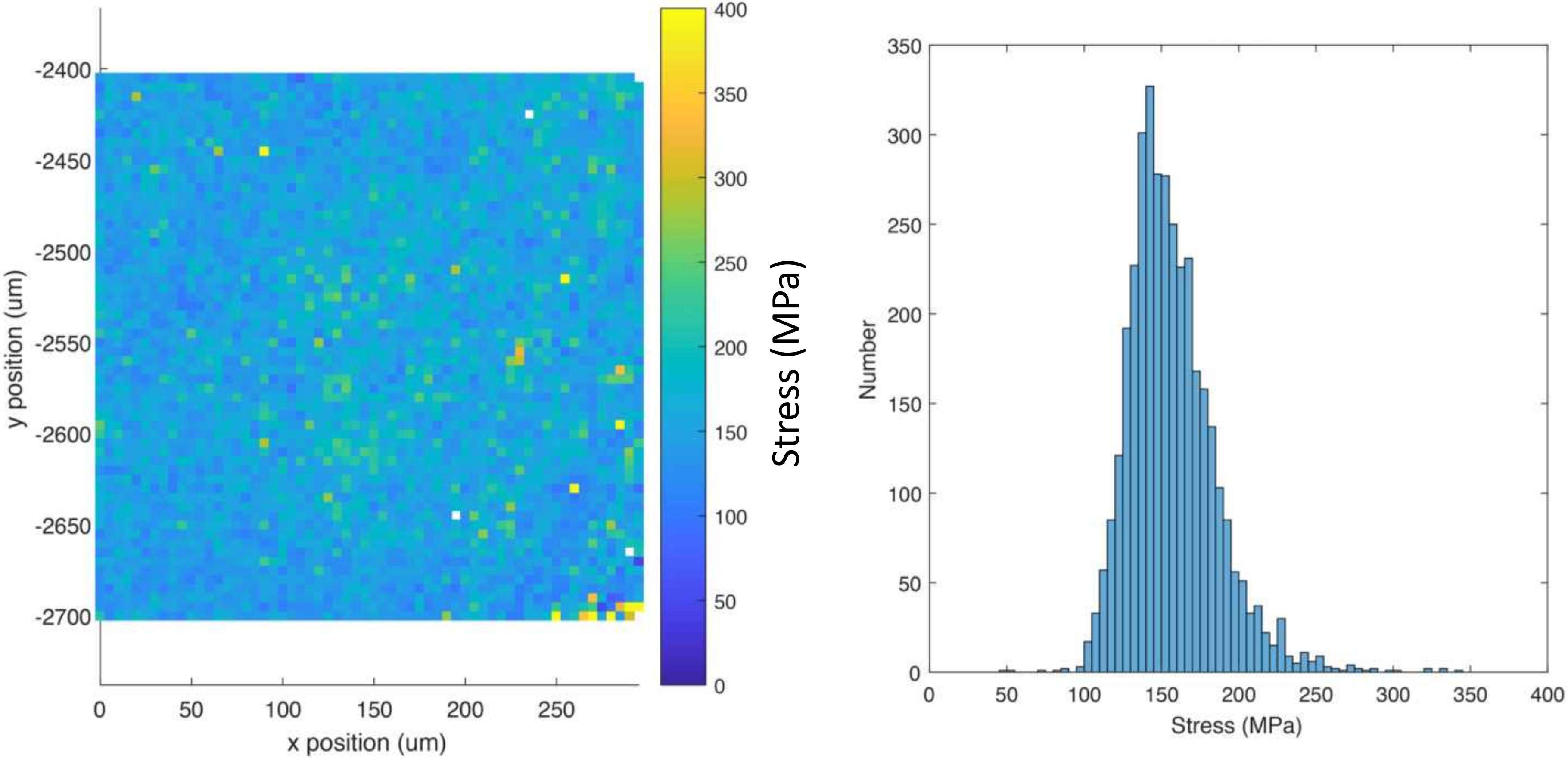
	Unit cell (Å)		Axial angles (°)		
	a_o	c_o	α	β	γ
β quartz	4.997	5.457	90	90	120

Hooke's Law: $\sigma'_{ij} = c_{ijkl} * \varepsilon'_{kl}$

σ = deviatoric stress tensor
c = elastic stiffness tensor
ε = measured strain tensor

	Elastic stiffness constants (GPa)						
	c11	c12	c13	c14	c33	c44	c66
β quartz	120	10	35	-	116	40	50

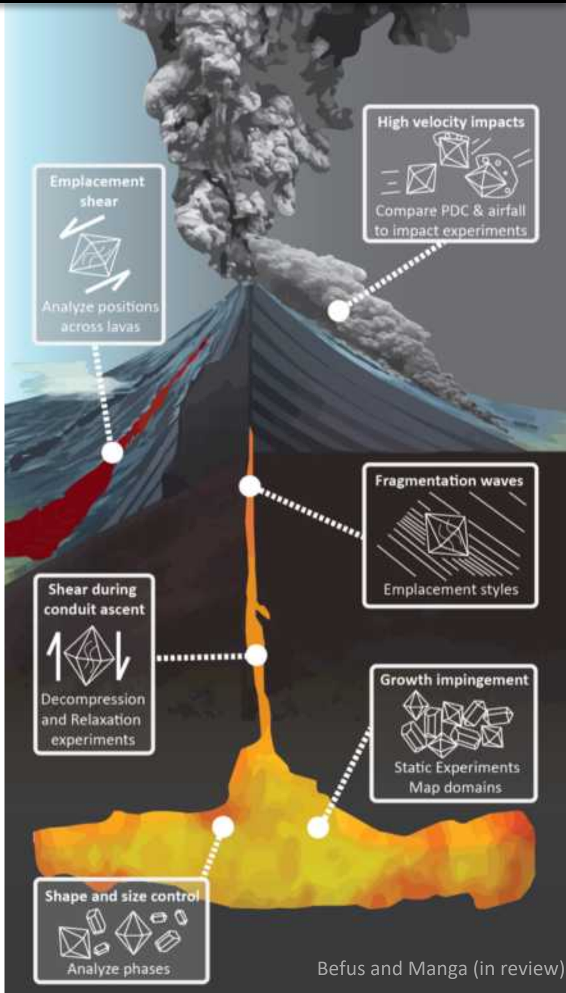
Huckleberry Ridge Tuff preserves a homogenous distribution of residual stress



Befus and Manga (in review)

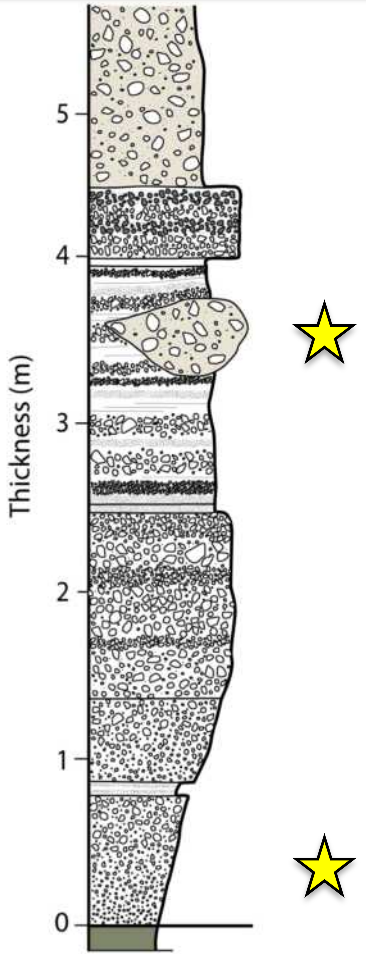
What forces make volcanoes eruption?

1. Shear during lava transport
2. Shear during conduit transport
3. Impacts during pyroclastic processes
4. Energic fragmentation, or lack thereof
5. Crystal-crystal impingement

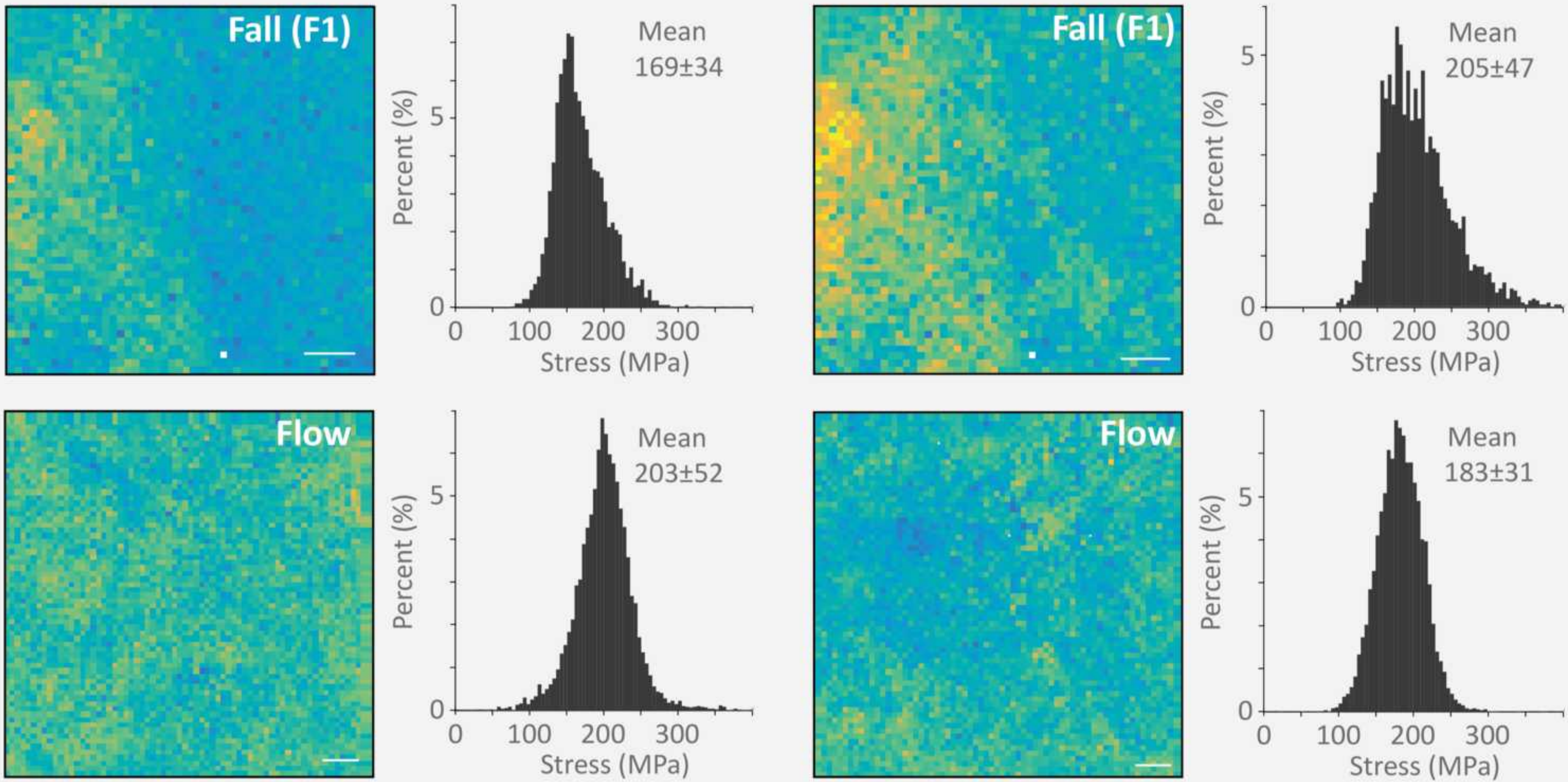


Befus and Manga (in review)

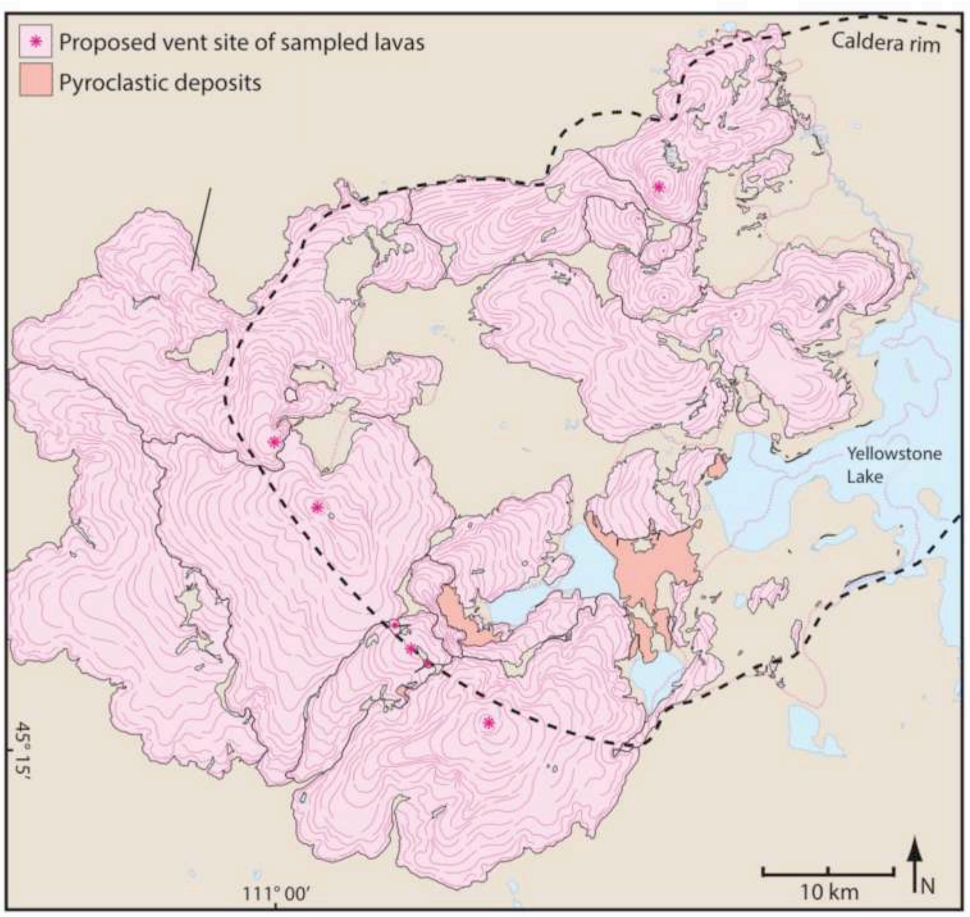
Test influence of pyroclastic processes using quartz from the Bishop Tuff, CA

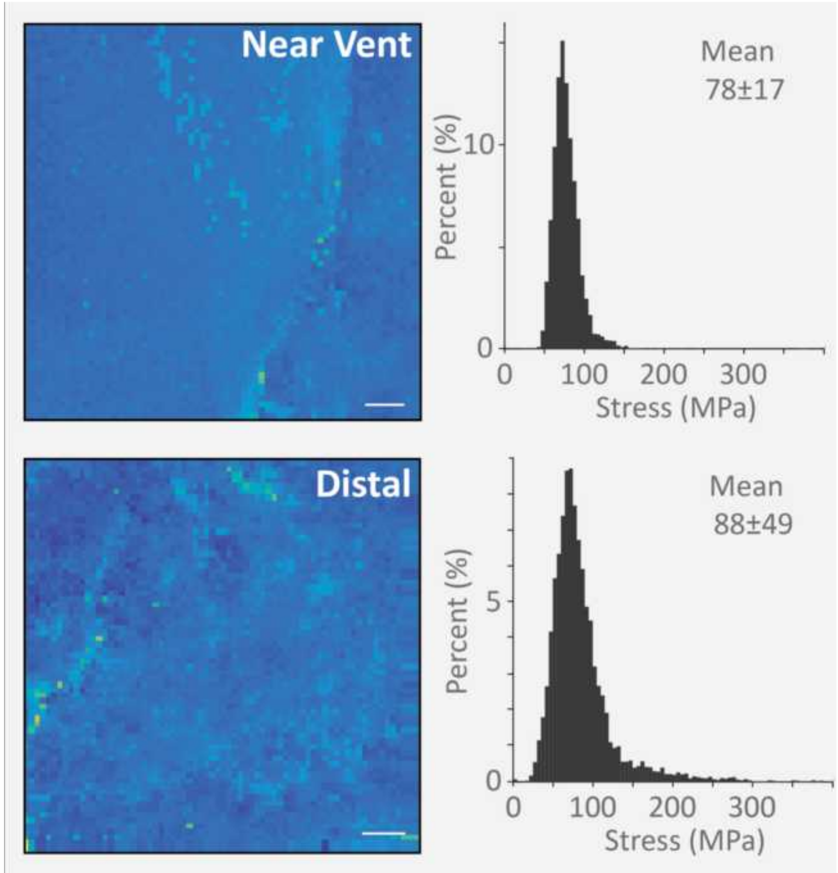


Pyroclastic processes do not modify residual stresses in the Bishop Tuff



Test influence of surface emplacement using quartz from Summit Lake lava flow





What forces make volcanoes eruption?

1. ~~Shear during lava transport~~
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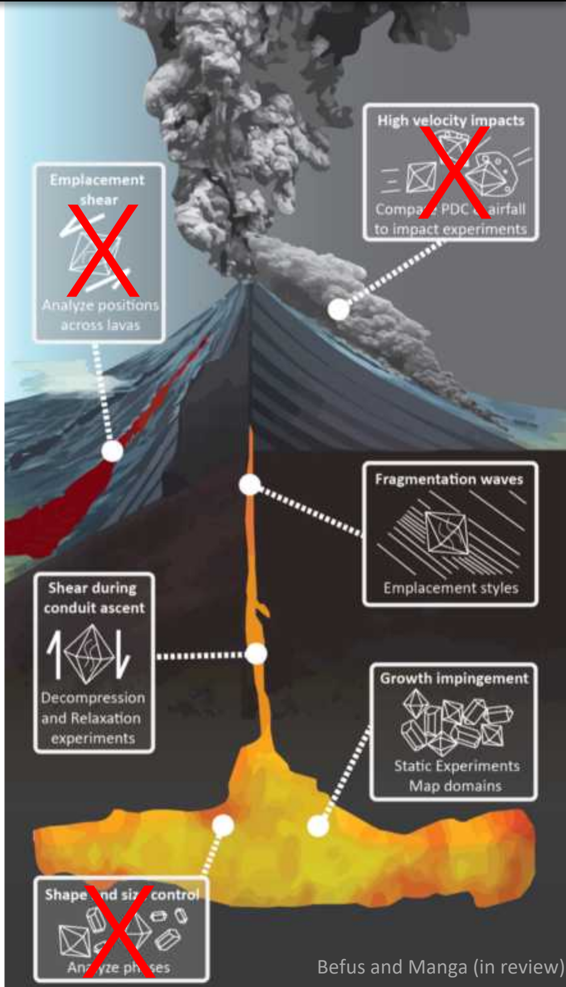
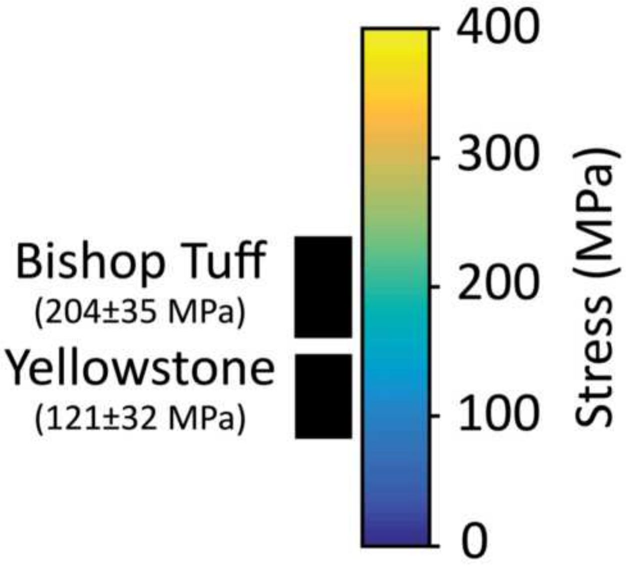
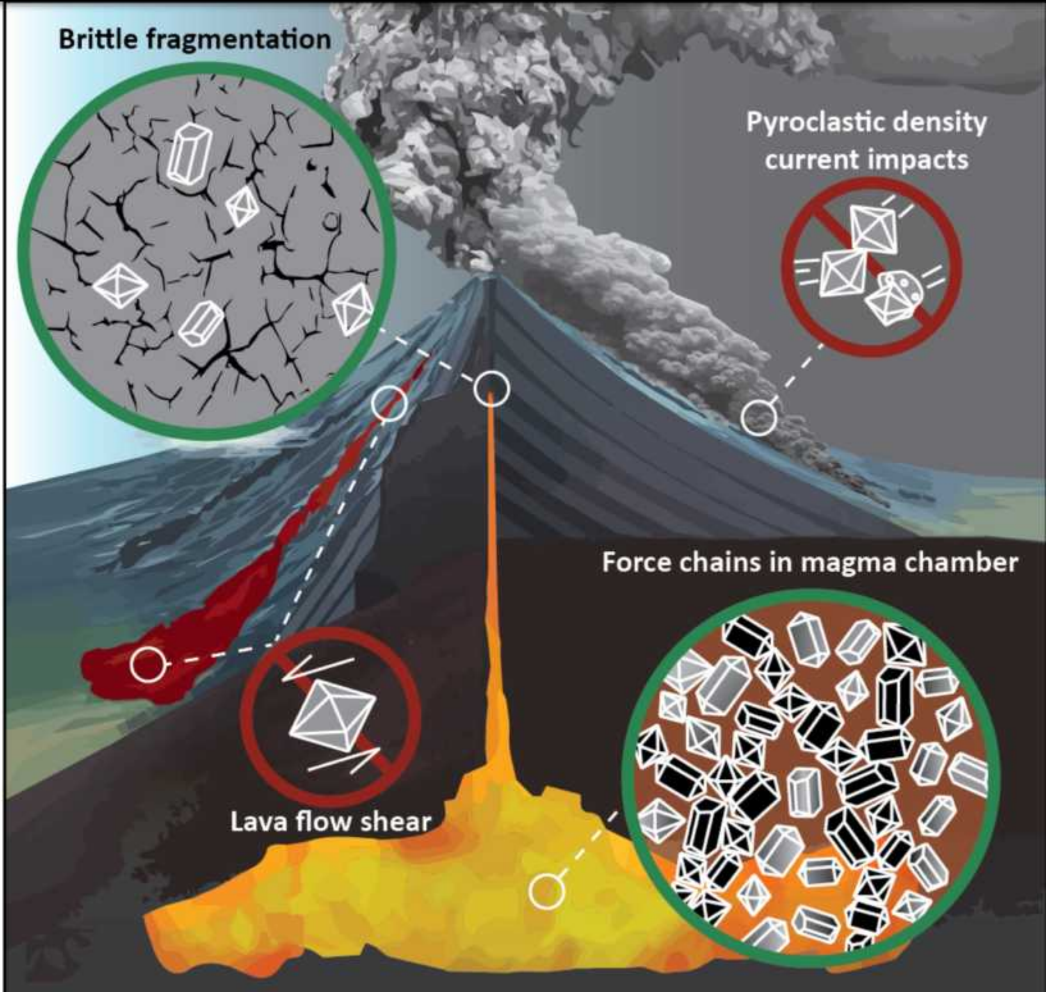


Befus and Manga (in review)

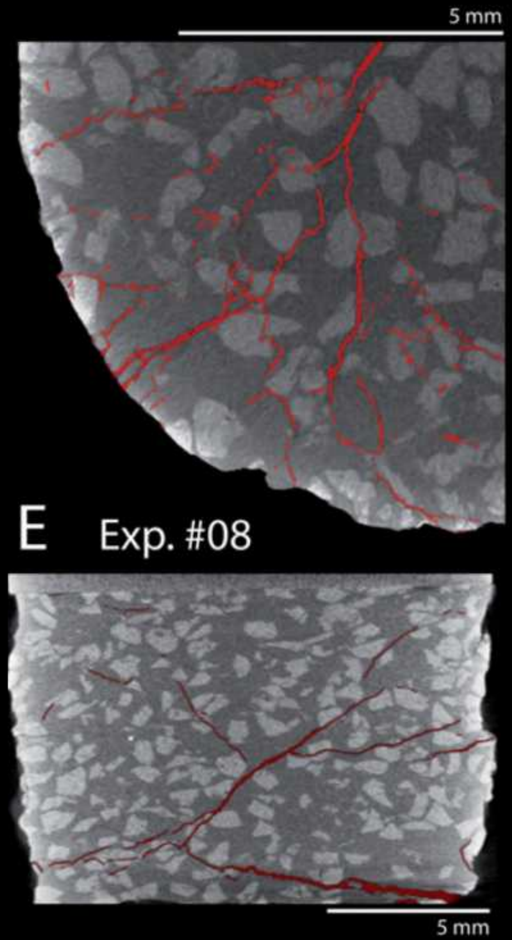
Possibility #1: Force Chains in a crystal mush

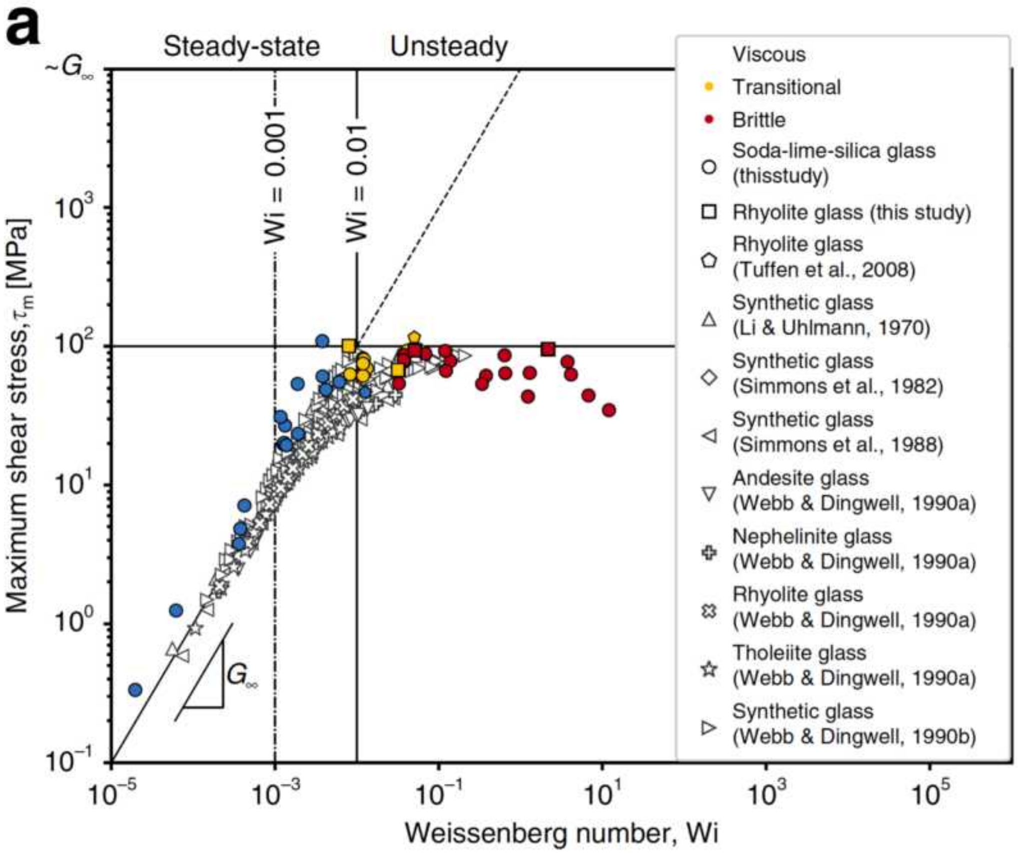




Befus and Manga (in review)

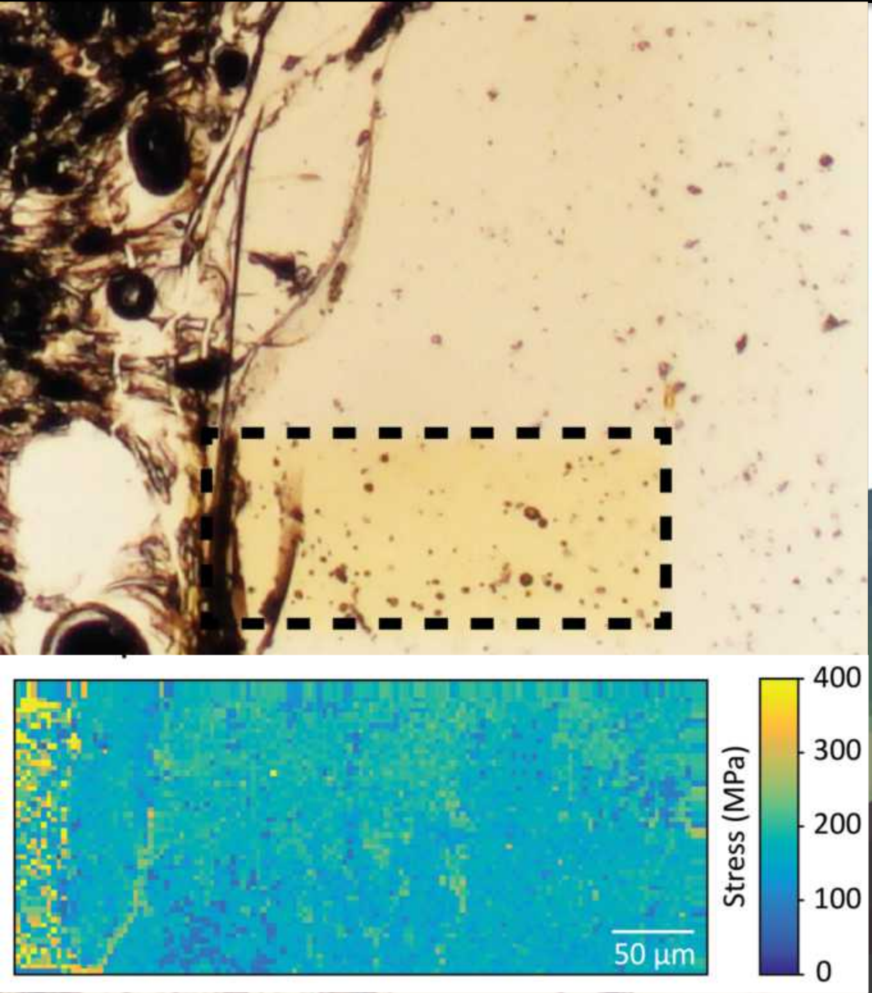
Possibility #2: Stresses during brittle fragmentation

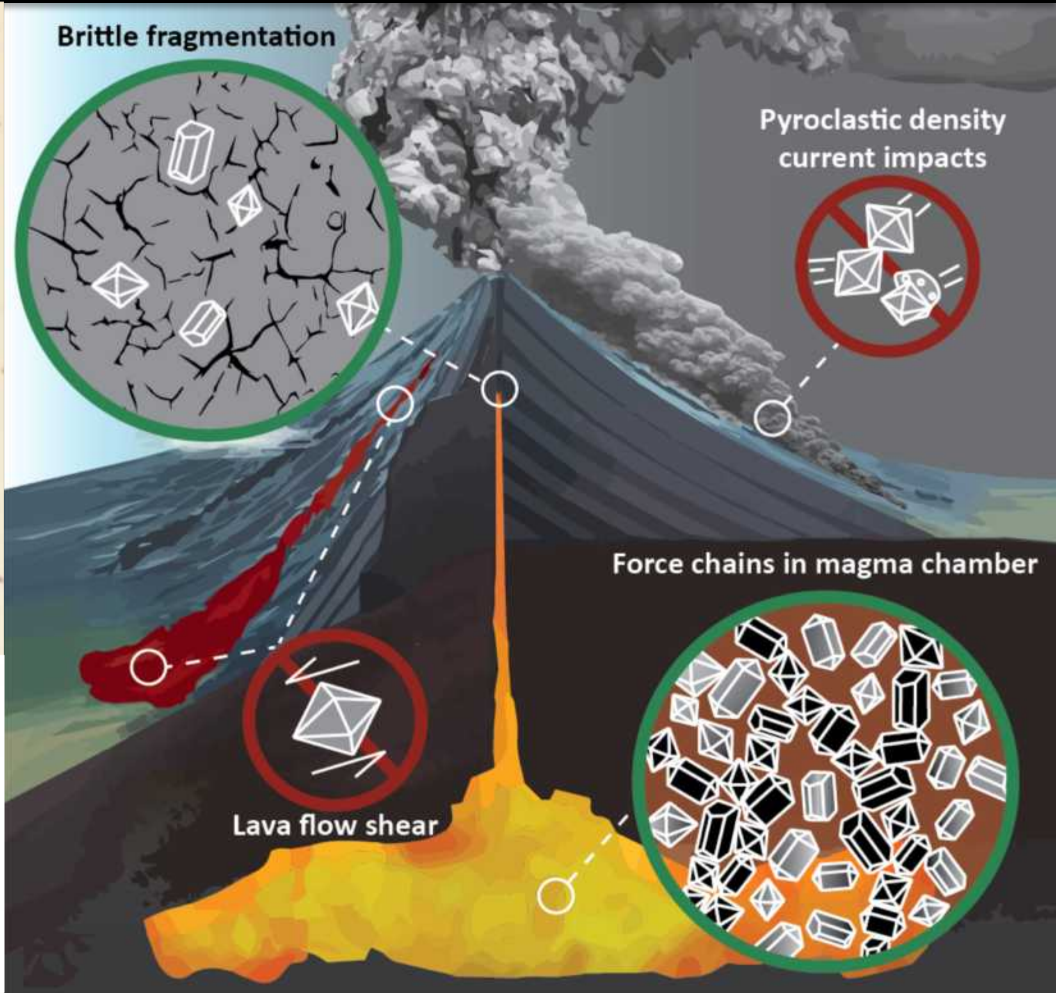




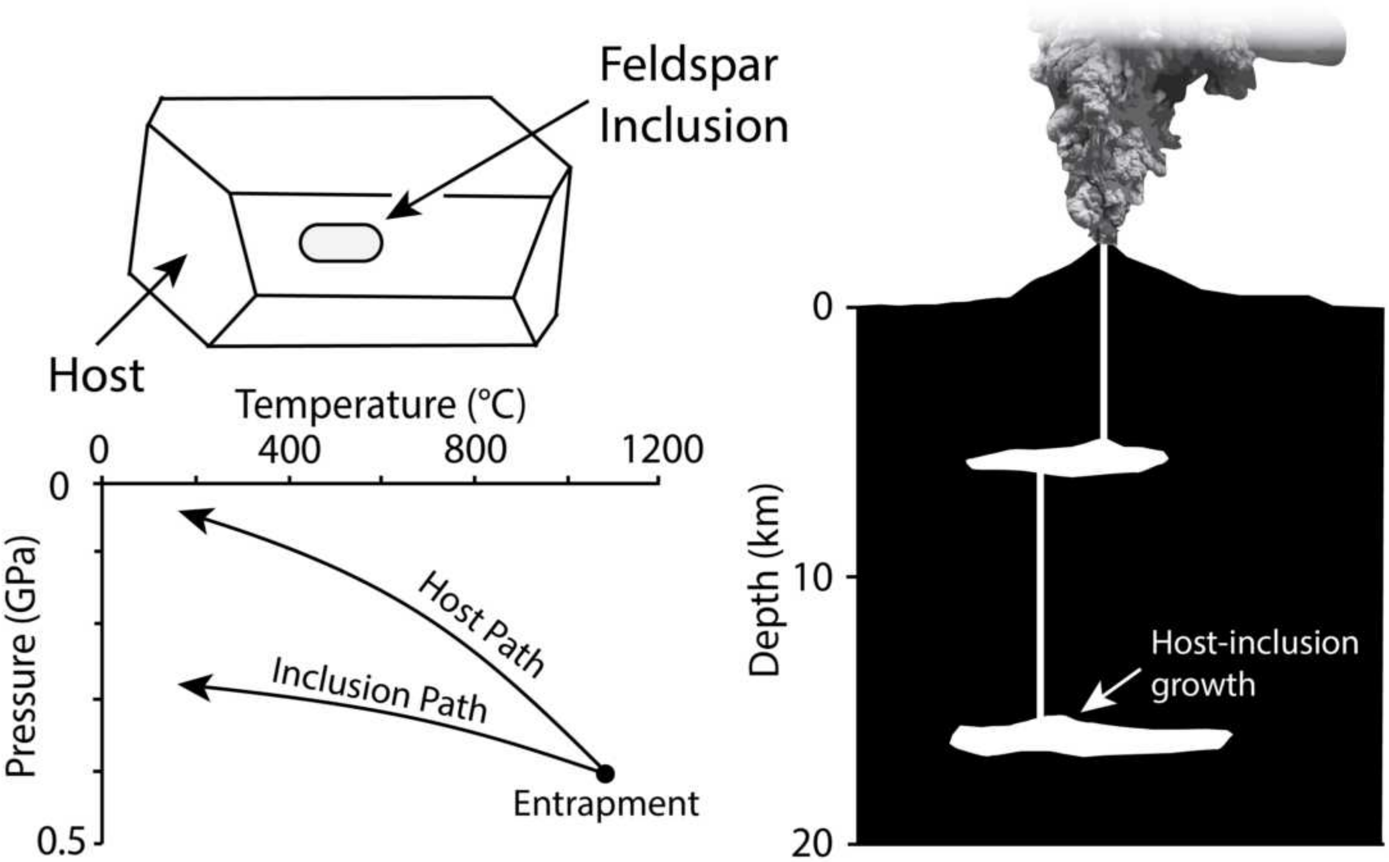
Cordonier et al (2012)
Wadsworth et al (2018)

Timing of brittle fragmentation



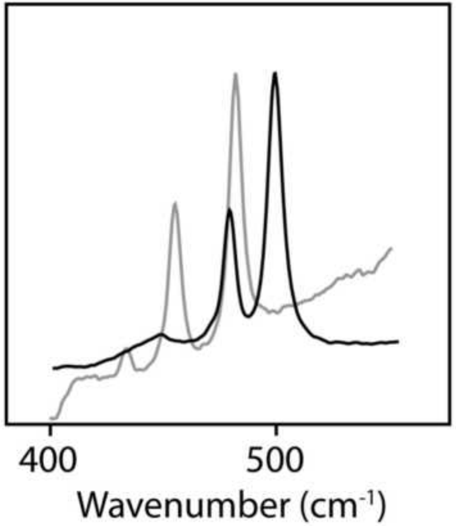


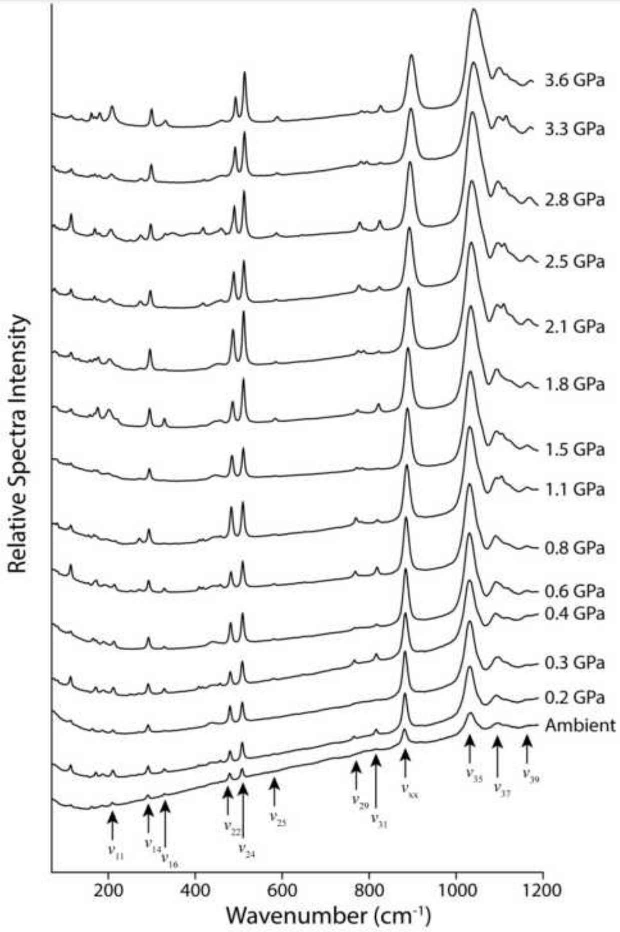
Raman thermobarometry: Imagine how the inclusion feels

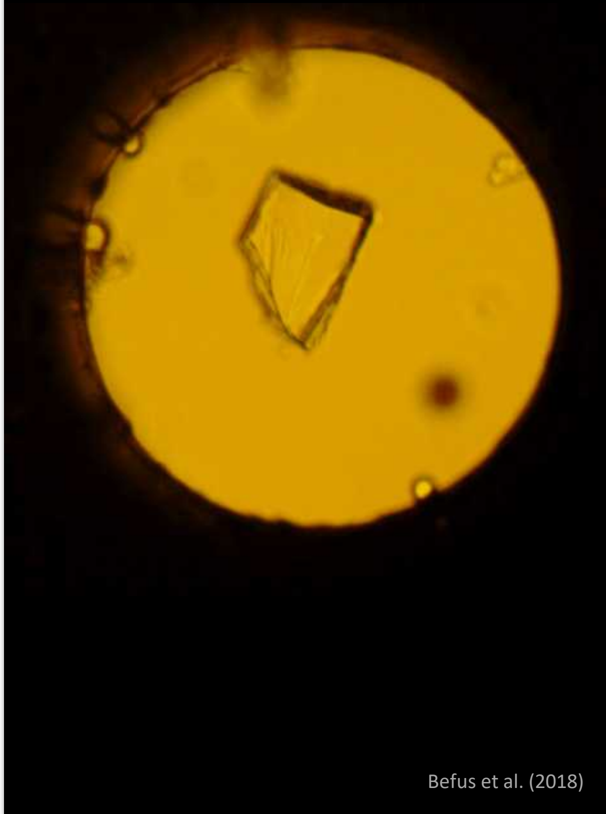


Befus et al. (2018)

Raman spectra of albite measured in a diamond anvil cell

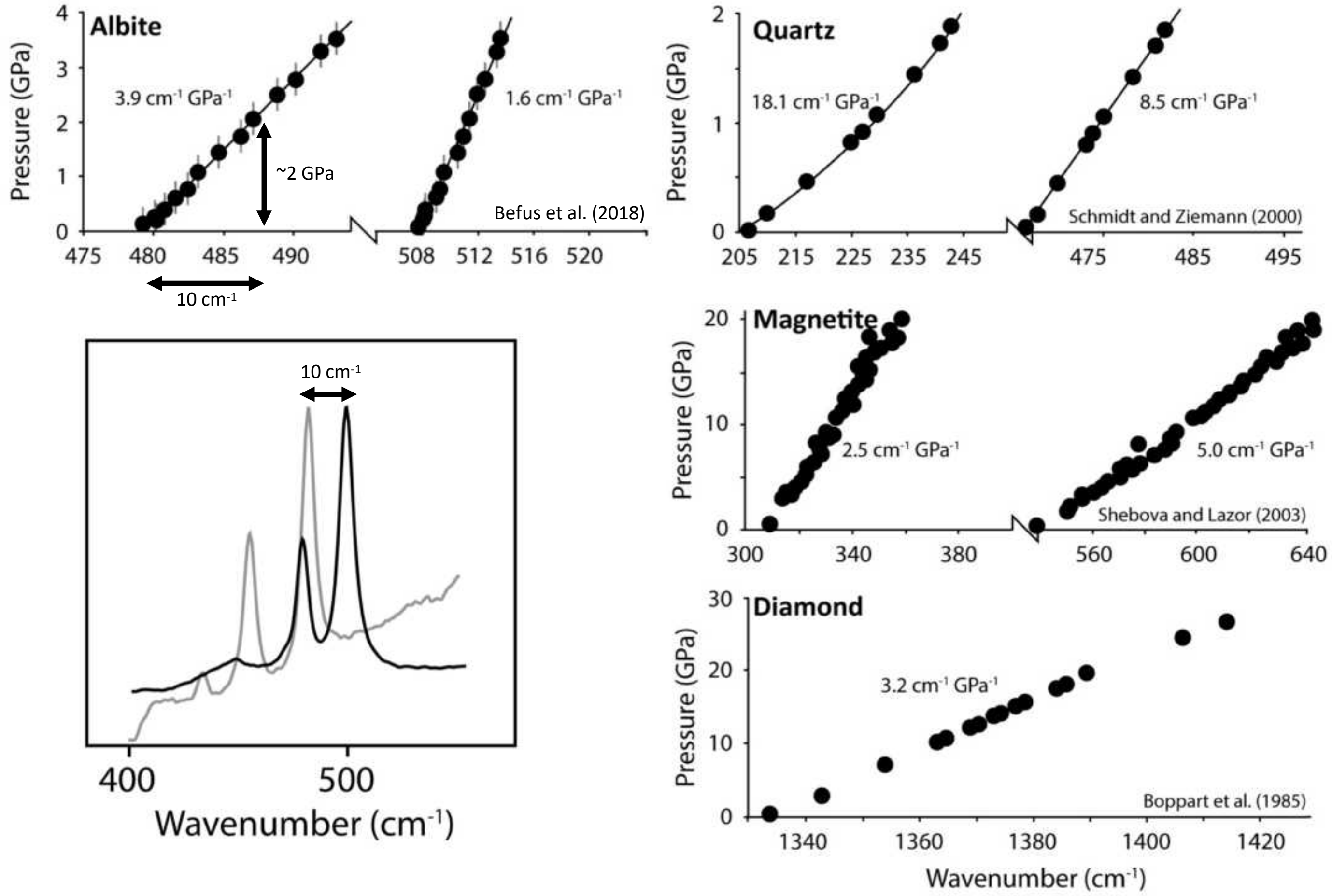






Befus et al. (2018)

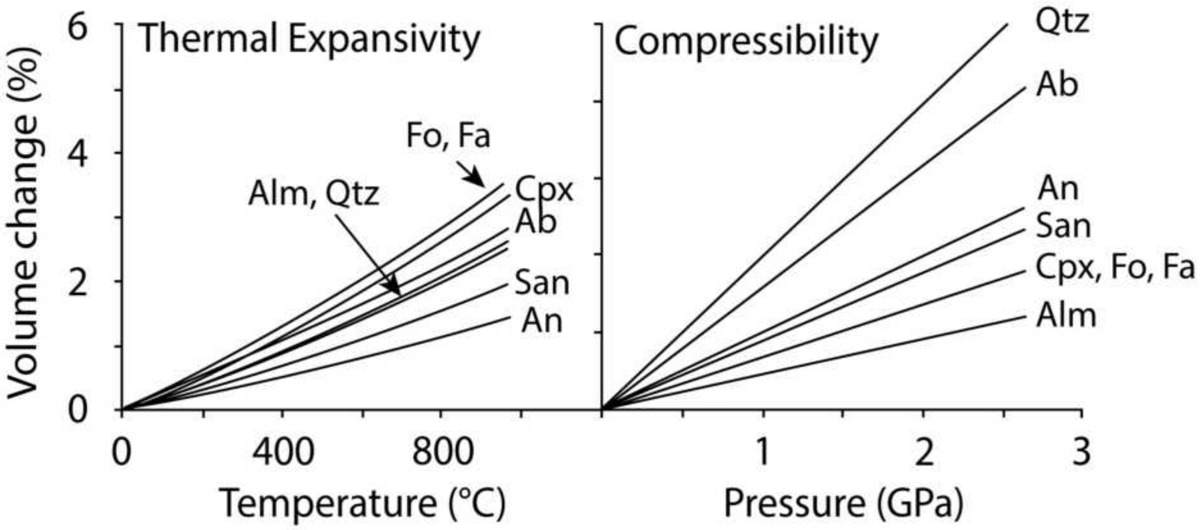
Minerals display systematic wavenumber shifts with increasing pressure



The math part: elastic model to calculate entrapment conditions

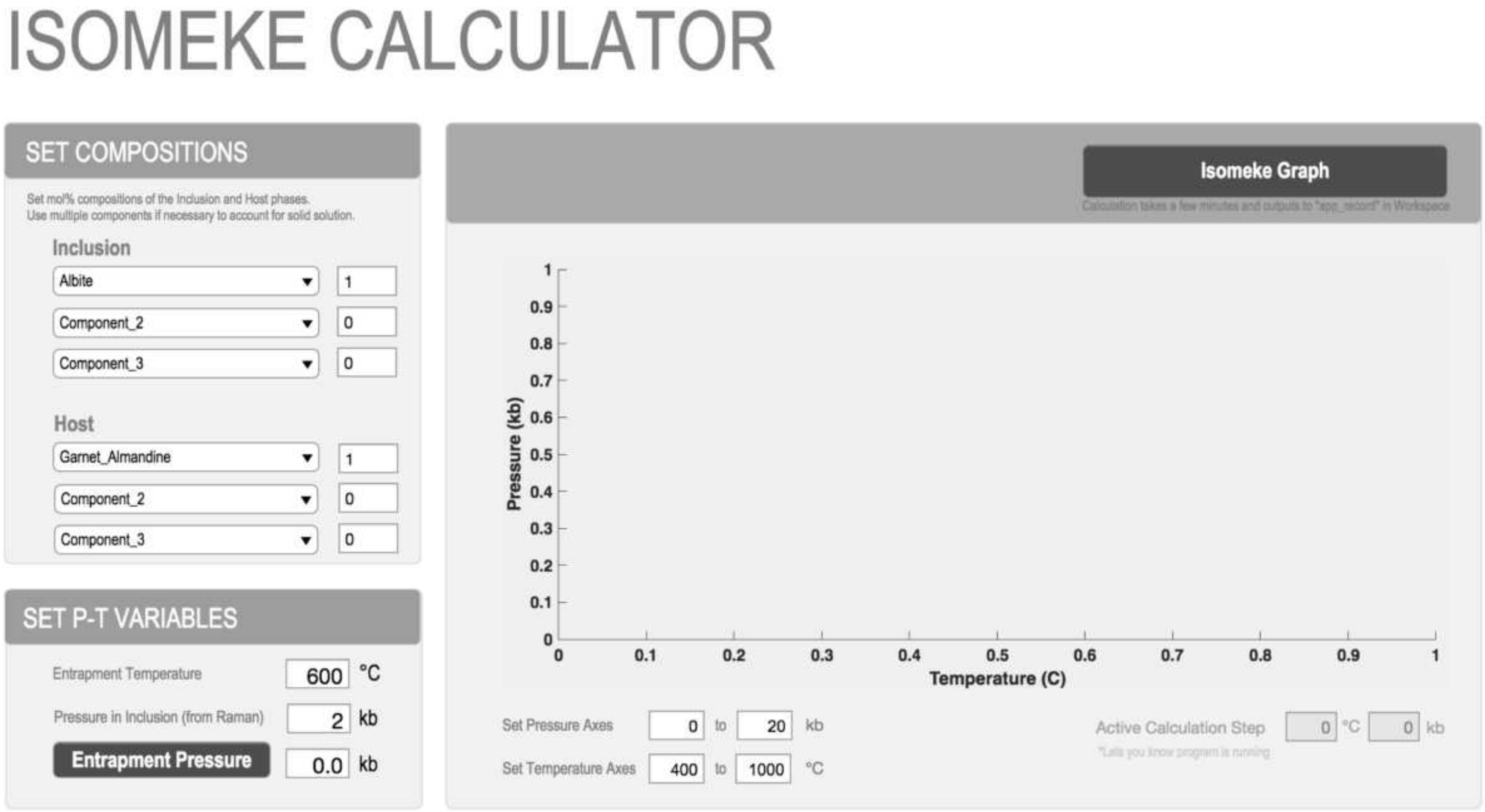
$$P_{\text{incl}} = 1 - \frac{4\mu}{3}\left(\frac{V_{\text{host}}^{298,\,1\text{ bar}}}{V_{\text{host}}^{T,P}} - \frac{V_{\text{incl}}^{298,\,P_{\text{incl}}}}{V_{\text{incl}}^{T,P}}\right)$$

Guirard and Powell (2006)
Kohn (2014)
Ashley et al. (2017)



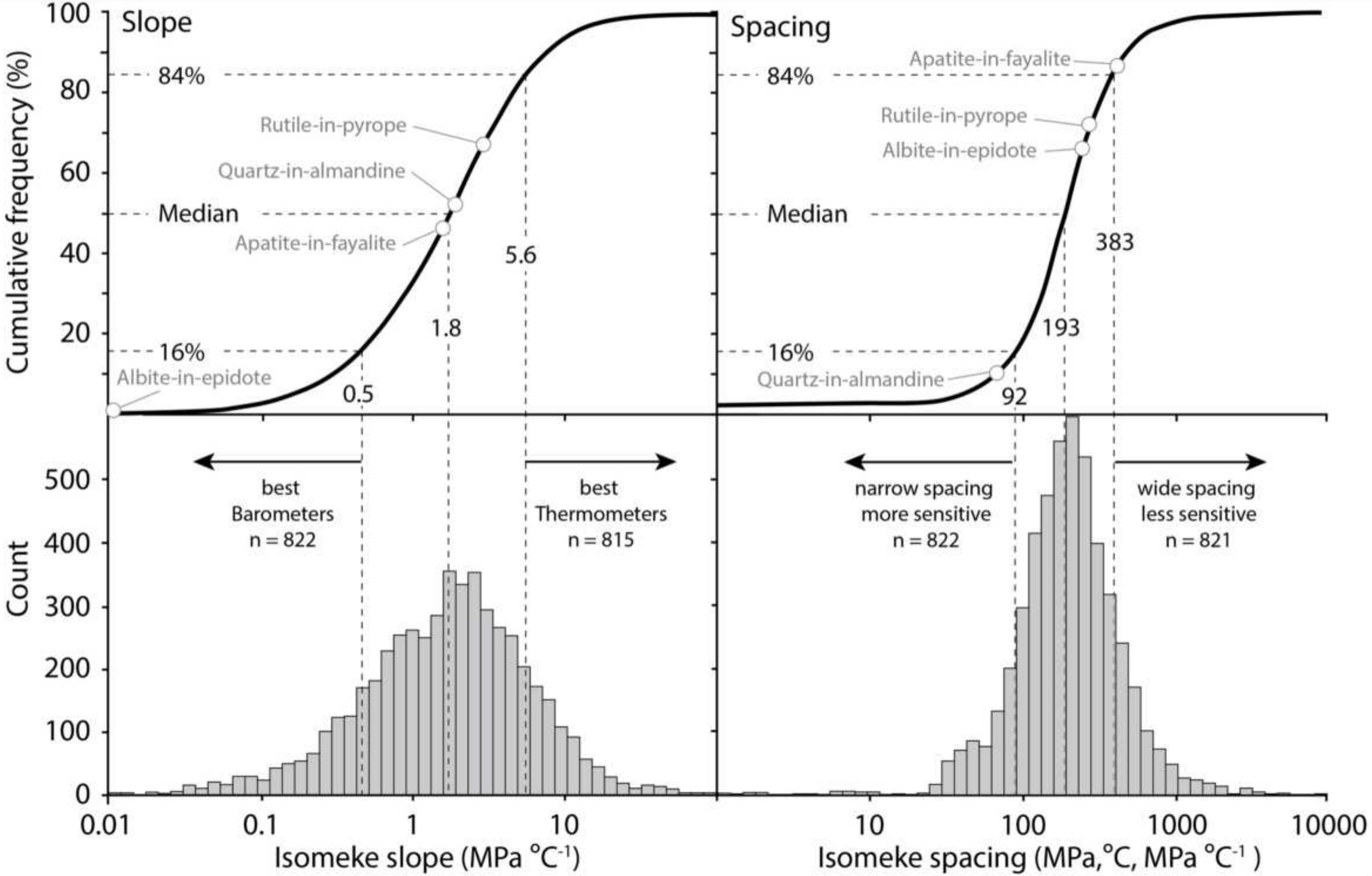
Befus et al. (2018)

Software to calculate any inclusion-host pair



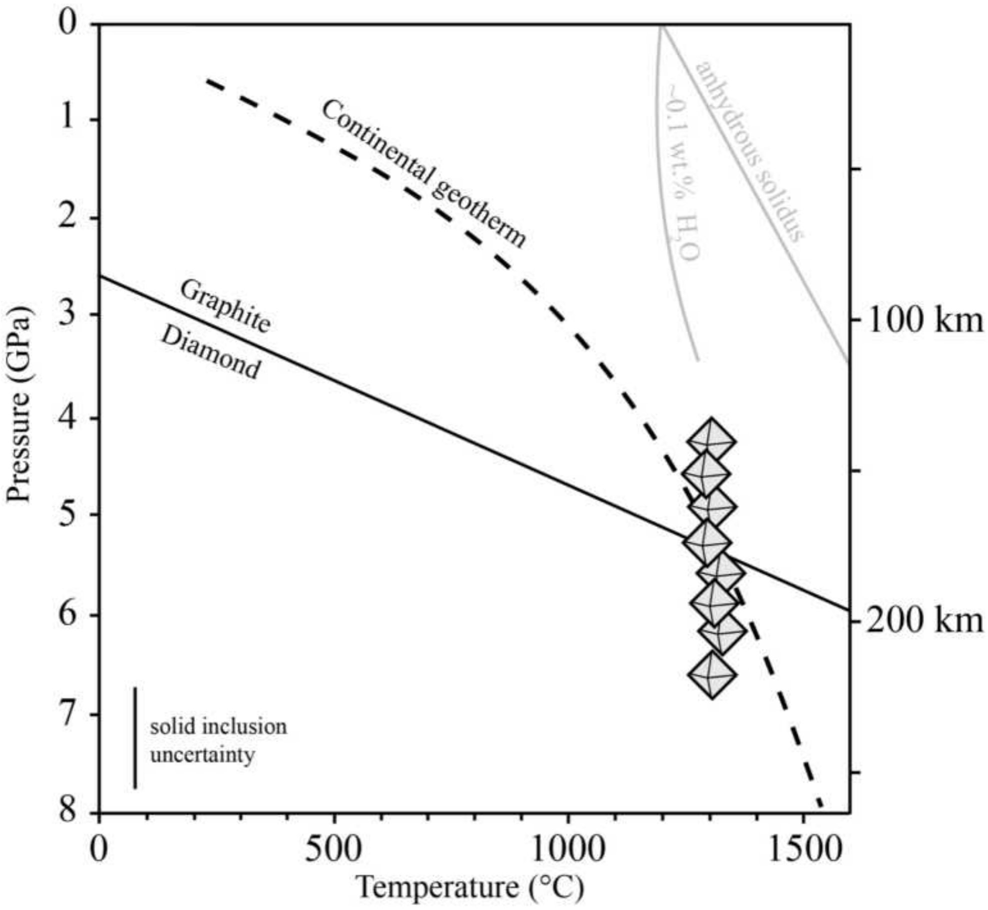
Cisneros, Befus, Darnell (in revisions)

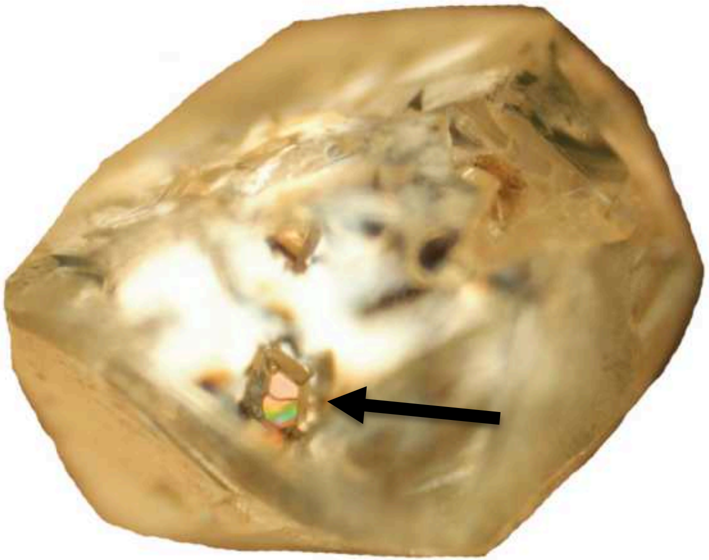
In context of ~5000 combinations of solid mineral inclusion thermobarometry



Cisneros, Befus, Darnell (in revisions)

Case study: Diamonds from the world's last wild place (Guiana Shield, Guyana)





Conclusions:

Stresses in crystals

1. Solid mineral inclusion thermobarometry is approaching wide applicability.
2. Volcanic crystals preserve residual elastic stresses giving new insight to subsurface processes.
3. Exciting new technologies to apply to challenging geologic problems.