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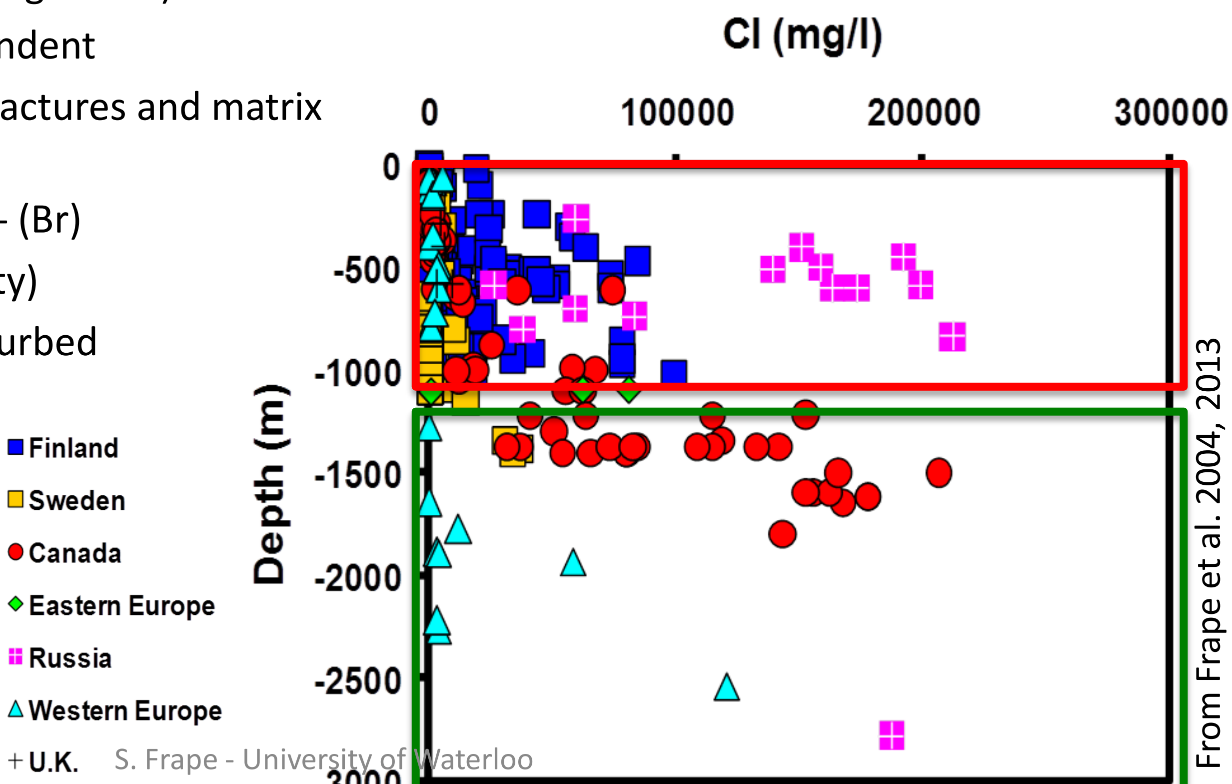
# Fluid or 'Groundwater' in Crystalline Rock

**Above 1km**

- Fresh to saline 0-100 $gL^{-1}$ TDS usually less than seawater (35 $gL^{-1}$ TDS)
- Composition: Ca-Na  $HCO_3$-Cl-$SO_4$

**Below 1km**

- Saline to Brine 10 - 350 $gL^{-1}$ TDS
- Reducing, pH (wide range 5 – 9)
  - often rock dependent
- Occurrence in open fractures and matrix porosity
- Ca-Na (Mg)  Cl-$SO_4$- (Br)
- Exceptions (low salinity)
  - Natural and disturbed

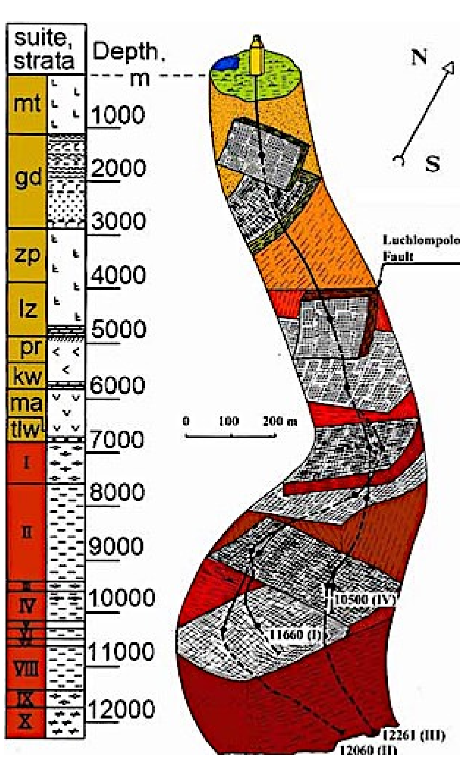



From Frape et al. 2004, 2013

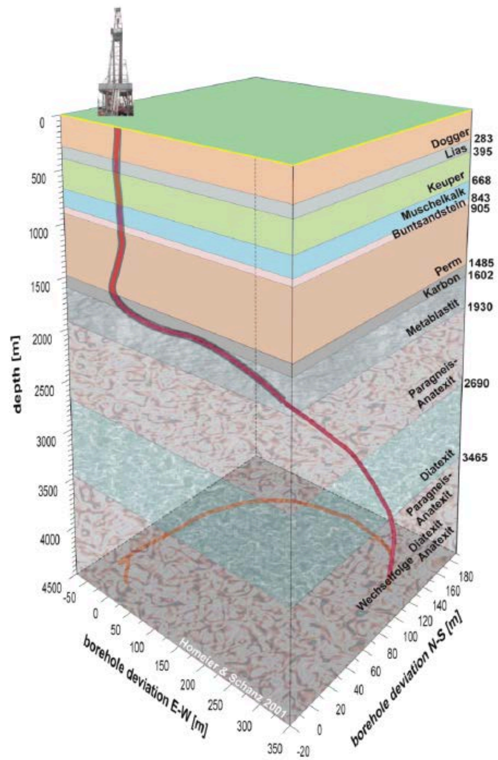
# Fluid or 'Groundwater' in Crystalline Rock

## (Below 2km) - Only a limited number of deep boreholes in crystalline environments

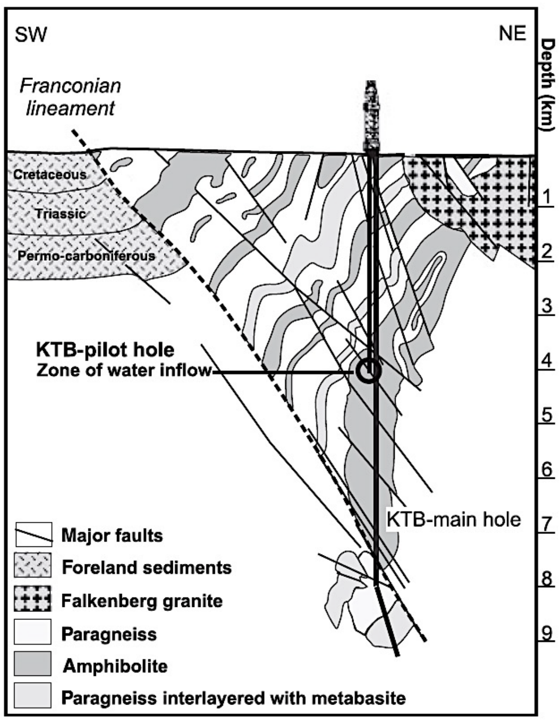
- In some cases sparse data due to sampling difficulties
- Often drilling fluids are involved in many of the samples
- Samples often representative of long borehole intervals and potentially from multiple fracture systems




Kola Super Deep Hole ~13 km




Urach-3 ~4.5 km




German Deep KTB ~9 km

# Fluid or 'Groundwater' in Crystalline Rock

(Below 2km) - Only a limited number of deep boreholes in crystalline environments

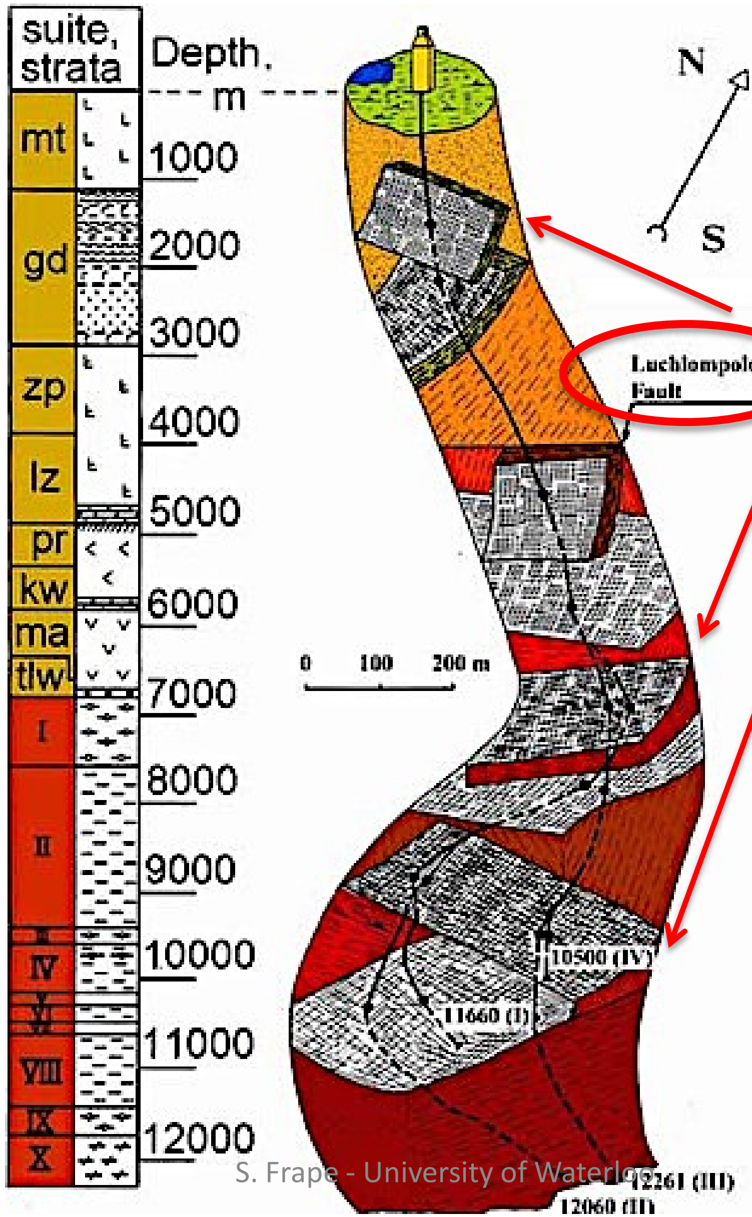
<$2gL^{-1}$ $Ca\text{-}HCO_3\text{-}SO_4$
$E_H$: -20mV; pH=9.4

Flow: Ca-Cl

Dilute

$Na\text{-}Cl\text{-}HCO_3$
pH=8.5

Ca (Na) Cl
200 – 300 $gL^{-1}$
**T~300 °C**




Note:
Variable Chemistry

**Faults**

Kola Super Deep Hole ~13 km

From http://www.dailykos.com/

# Fluid or 'Groundwater' in Crystalline Rock

(Below 2km) - Only a limited number of deep boreholes in crystalline environments

Note:

Temperatures & Salinity

Sedimentary Rocks

Crystalline Rocks

(1978) 97°C
Na-Cl; TDS= 27 gL$^{-1}$

(2004) 150°C
Na-Cl; TDS= 70 gL$^{-1}$
pH=5.6-5.9

Urach-3 ~4.5 km

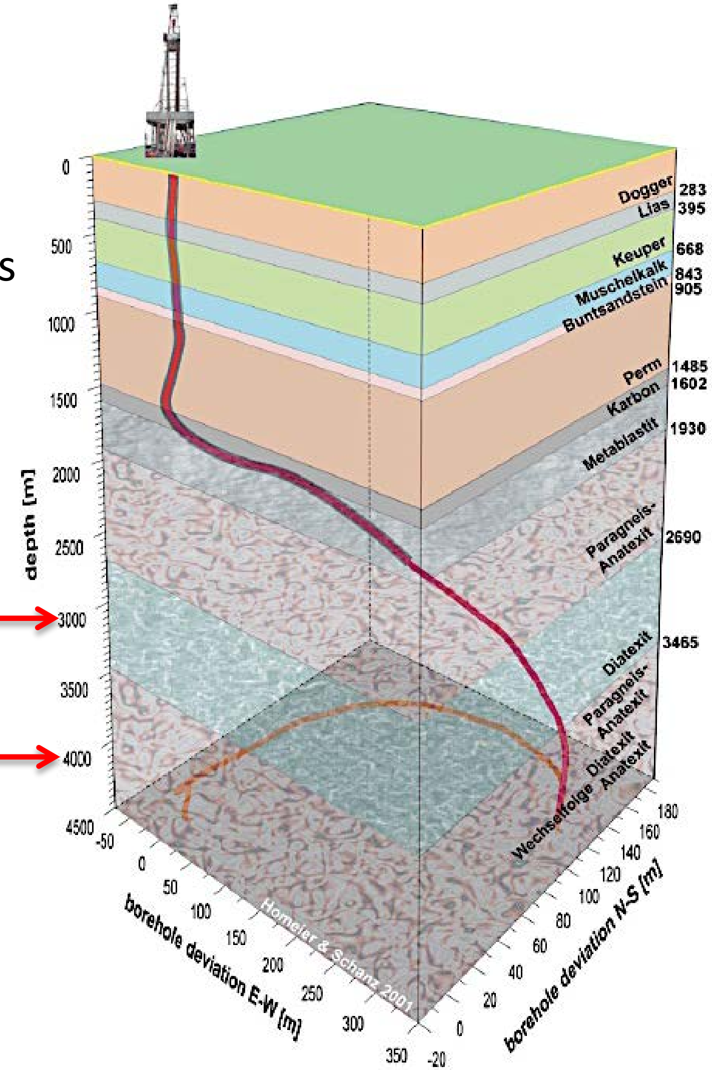



*Fig. 1: Three-dimensional view of the drillhole Urach 3 trajectory and the geological formations (v:h ≈ 1:9).*

From Schanz et al. 2003

# Fluid or ‘Groundwater’ in Crystalline Rock

(Below 2km) - Only a limited number of deep boreholes in crystalline environments

Stober et al. 2005

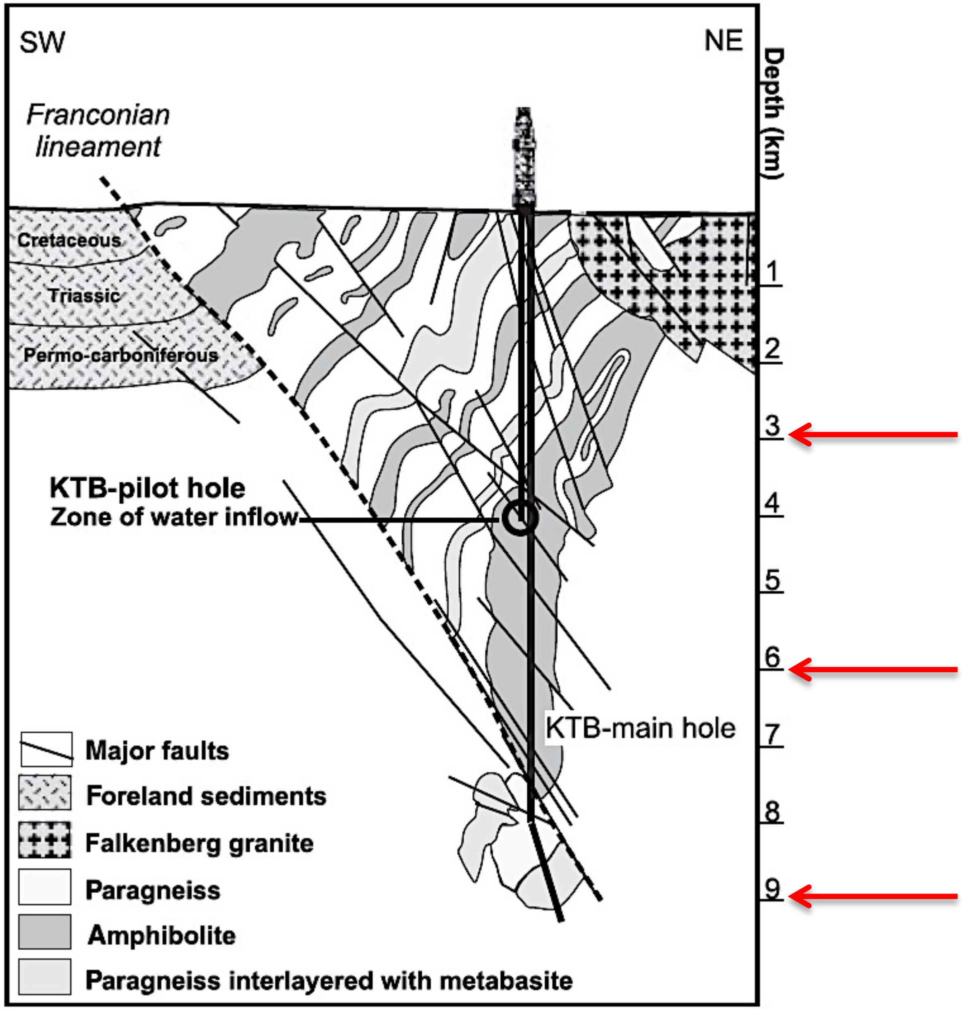



**Fig. 2.** Cross section through the continental crust at the KTB drill site (modified from Harms *et al.* 1997). Section is normal to the Franconian lineament (Fig. 1). Data from KTB pilot hole are reported in this paper. Horizontal scale–vertical scale.

Note:
Temperature & Salinity

70°C
Na-Cl; low TDS

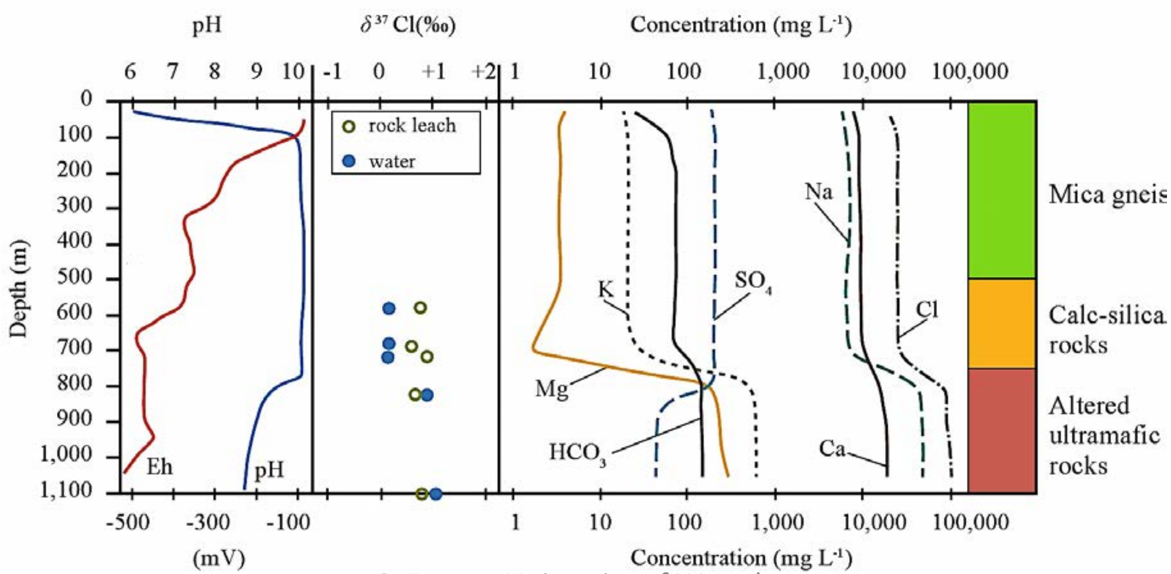
150°C

270°C
Ca-Na-Cl; TDS= 68 $gL^{-1}$
$CH_4$- $N_2$ gases

German Deep KTB ~9 km

# Other Characteristics of ‘Groundwaters’ from Deep Crystalline Environments

- Stable isotopes of water ($^{18}O$ - $^{2}H$) unique compared to sedimentary fluids (could be used as a tracer to distinguish crystalline fluids from other fluids e.g. overlying sedimentary fluids or meteoric waters)
- In many cases associated with gases – discussed by Jennifer McIntosh
- Individual fault systems or rock types retain distinct fluid geochemical signatures
- Dual porosity (fracture = primary; small pores & fluid inclusions = secondary)
- Water/Rock interaction causes fluids to vary with rock type
  - Long time period due to slow reaction times dependent on T-P conditions




Miihkali 116 Borehole 0-1.1 km – Eastern Finland

From Frape et al. 2004, 2013

# 'Age' of Deep Crystalline Fluids

a) Noble Gases (Residence Times)

- Gases derived from radiogenic decay (closed vs. open systems)
- Gas isotopes unique to early earth atmosphere (e.g. Xenon calculations; Holland et al. 2013)
  - ➢ Xenon isotopes Canadian Shield waters from 2.4 km deep calculated to be 1.5 billion years

b) Chemical Constituents

- In situ water-rock interaction
- Time it takes to derive high salinity and compositions "Could the fluids be the age of the rock?"

c) Age dating highly saline deep fluids is challenging

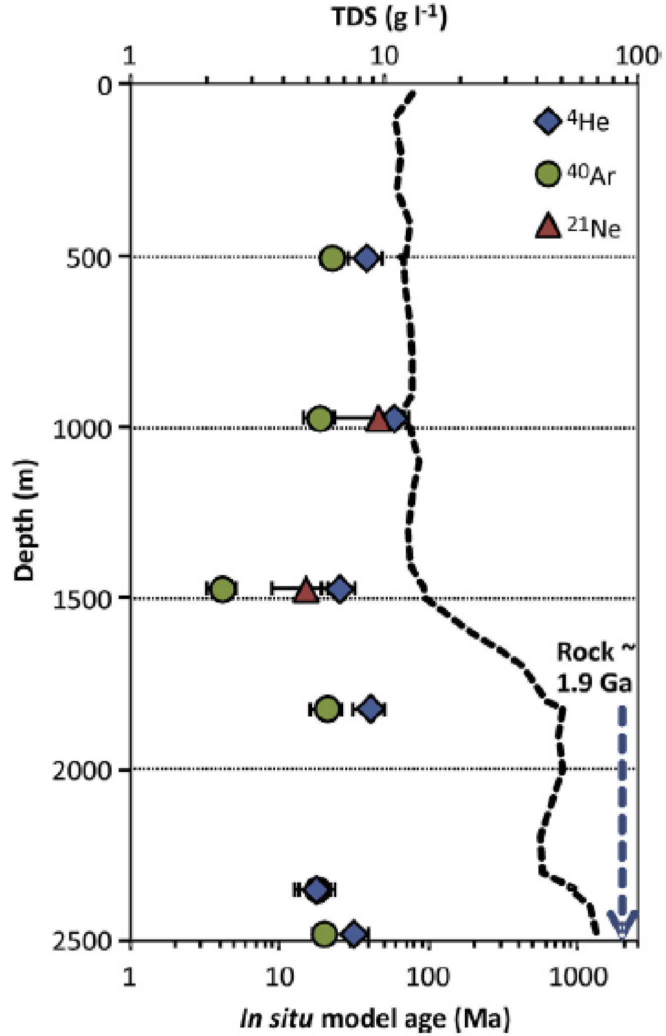
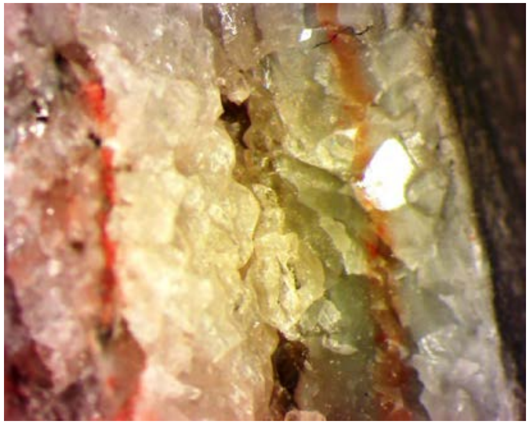



Fig. 4. *In situ* noble gas residence times and salinity expressed as total dissolved solids (TDS) along the Outokumpu Deep Drill Hole. The TDS values (dashed line) are from Kietäväinen et al., (2013).

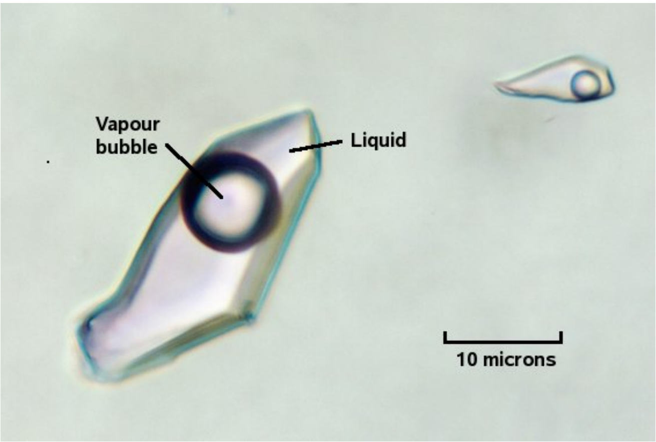
From Kietäväinen et al 2015

# Fracture Minerals (Many Uses)

- Redox Controls
  - Oxygen consumed by redox sensitive minerals
  - Can trace redox fronts or paleo redox history using minerals
- Direct? and Indirect Age Dating
- Fluid/Geochemical History
  - $^{18}O$ geothermometry, Calcites ($CaCO_3$) when combined with fluid inclusion data constrain temperatures and salinity of formation fluids
  - Indirectly used as age indicator (Blyth et al. 2009)
    - e.g. Higher temperature events reflected in fluid inclusions are related to the last high temperature geological episode (most likely known)



a) Fracture calcites – temperature-pressure




b) Fluid inclusion

From www.appliedminex.com/

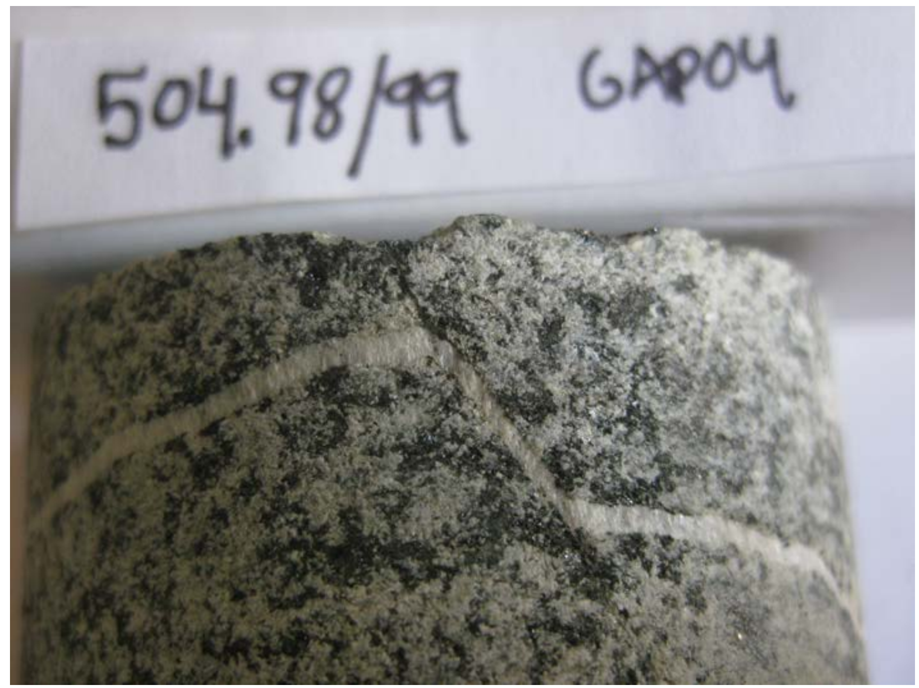
# Fracture Minerals (Many Uses)

- Control on Fluid Transport
  - Fracture minerals precipitate and limit flow or dissolve and enhance flow
    - e.g. calcites, gypsum and zeolites

From Stober and Bucher 2015

c) Hydrothermal zeolite - precipitate and reduce flow


d) Laumontite on fracture surface




From Henkemans 2015

e) Hydrothermal Gypsum/Anhydrite – soluble, but stable under an ice sheet in Greenland