

# Trapping of heterogeneous fluids

Ronald J. Bakker

Resource Mineralogy, Department of Applied  
Geosciences and Geophysics, Montanuniversity  
Leoben, Austria

bakker@unileoben.ac.at

In theory:

abundant temperature-pressure conditions in  
rock are defined within heterogeneous fluid  
systems according to specific fluid compositions,  
and heterogeneous entrapment must be a  
common process.

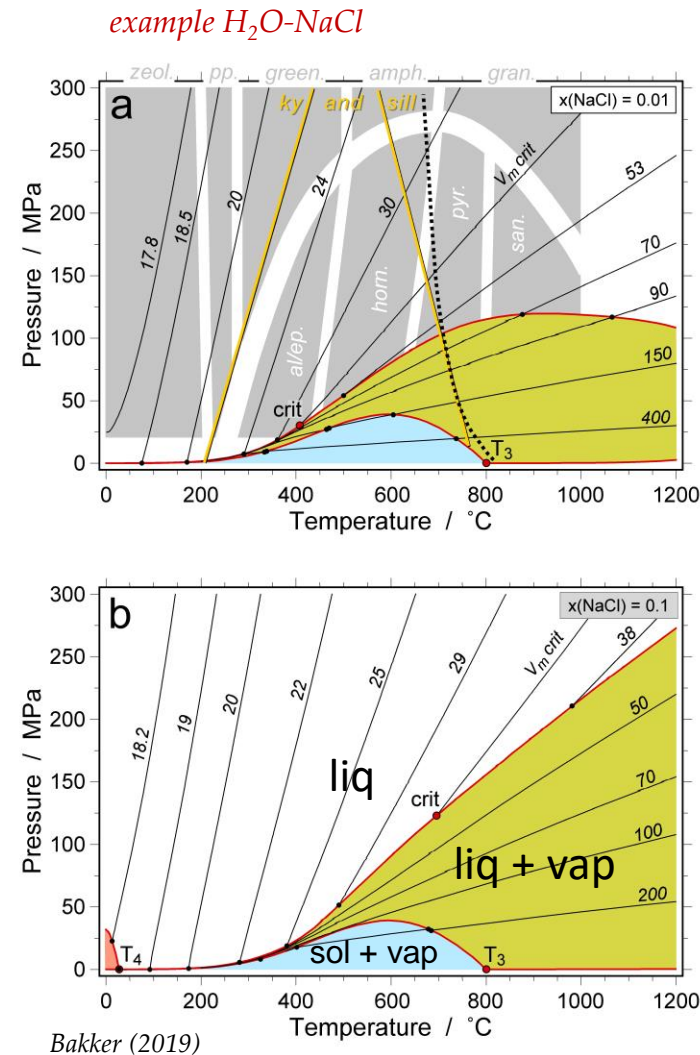
In practice:

Where are immiscible fluids located in the rock?

Do fluid inclusions form of both fluids?

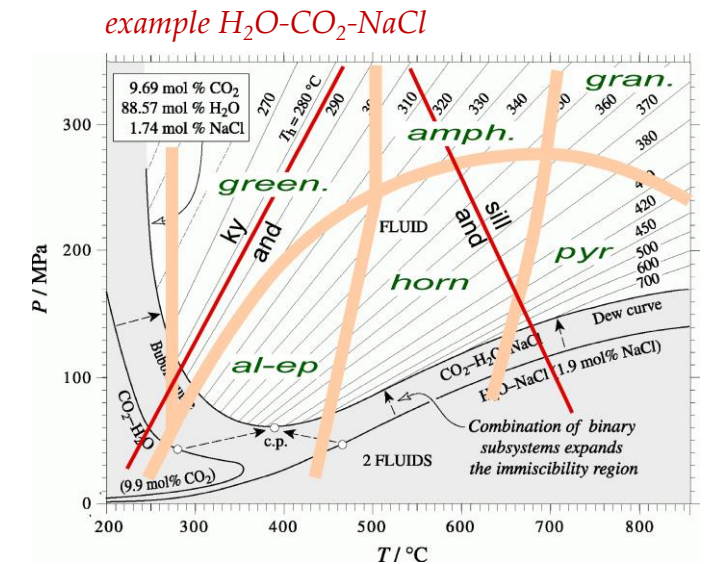
What are their properties?

Theoretical fluid immiscibility at geological conditions:



Fluid immiscibility is not restricted to diagenetic conditions

Expansion of immiscibility field in multicomponent systems



Metamorphic facies:  
green. = greenschist  
amph. = amphibolite  
gran. = granulite  
al-ep = albite-epidote hornfels  
horn = hornblende hornfels  
pyr = pyroxene hornfels

## Two questions to be answered:

1. Do we have thermodynamic or/and purely empirical models to define the immiscibility field of multi-component fluid systems? What about the experimental data?

There are only few experimental studies that consider heterogeneous entrapment within the two-fluid phase field. These studies mainly investigated the boundary of the immiscibility fields in terms of temperature-pressure-composition ( $p$ - $T$ - $x$ ). The variability of individual fluid inclusions within assemblages in terms of  $p$ - $T$ - $V$ - $x$  that were formed by heterogeneous trapping was not analysed in literature. The systematics of distribution of distinct fluid inclusion types in healed micro-cracks has not been studied. Our knowledge of processes that accompany heterogeneous trapping are to a major extend unknown.

→ example Bodnar et al. (1985)

But ... What about those studies of experimental distribution of metals (e.g. Cu, Au, Mo) between liquid and vapour phases?

→ example Zajacz et al. (2017)

No knowledge about the immiscibility field of complex fluid systems (e.g.  $\text{H}_2\text{O}$ - $\text{NaCl}$ - $\text{KCl}$ - $\text{HCl}$ - $\text{S}$ )

Just a guess: "We defined the composition of the starting solutions so that they fell close to the expected position of the vapour limb of the *solvus* in the  $\text{NaCl}$ - $\text{H}_2\text{O}$  analogue system"

↑  
What is wrong with that?

2. How are unmixed fluids trapped in inclusions?

- little is known about formation processes of fluid inclusions in the two-fluid phase field (heterogeneous trapping)
- systematic analyses of fluid inclusion assemblages that contain both types of fluids were not performed
- there is only little knowledge about the variability within these fluid inclusion assemblages, because most analyses in literature included only 10 or less inclusions per experiment

→ theoretical consideration in  
Roedder (1984)

This is what we must consider:

different wetting properties of liquid-like and vapour-like fluids

→ Watson and Brenan (1987)  
Holness (1993)  
Gibert et al. (1998)  
Loucks (2000)

"trapping of variable proportions of both fluids may result in a variety of fluid inclusion properties, different wetting properties may result in the opposite effect"

"crystal growing from vapor-saturated solutions, ....., then most fluid inclusions should nucleate a gas bubble before sealing, and trap a heterogeneous mixture of gas and liquid"

H<sub>2</sub>O - NaCl

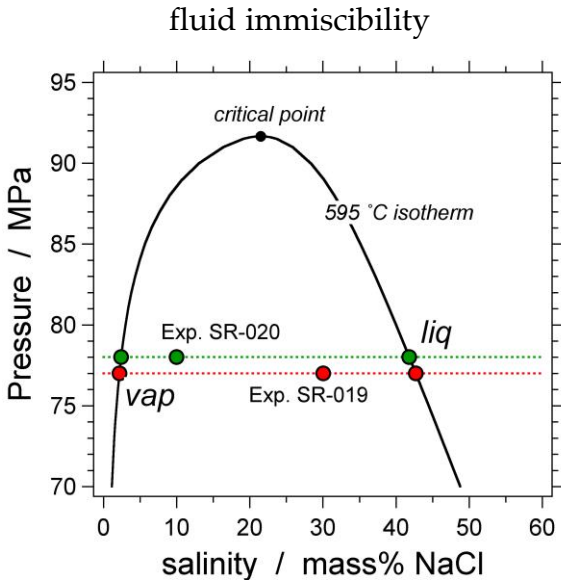
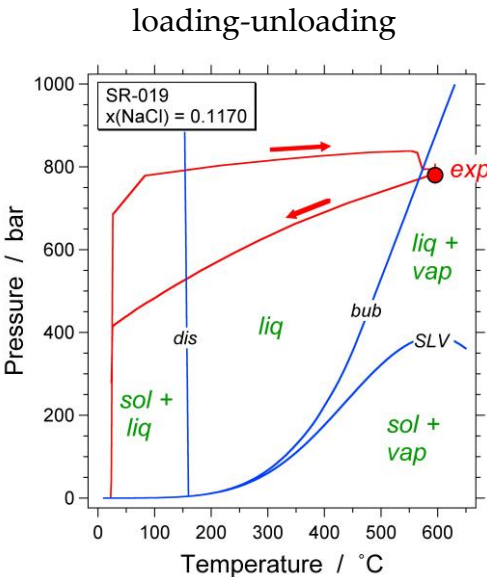
Synthetic fluid inclusions

Experimental conditions: 595 °C  
78 MPa (SR-020) and 77 MPa (SR-019)

expected results:

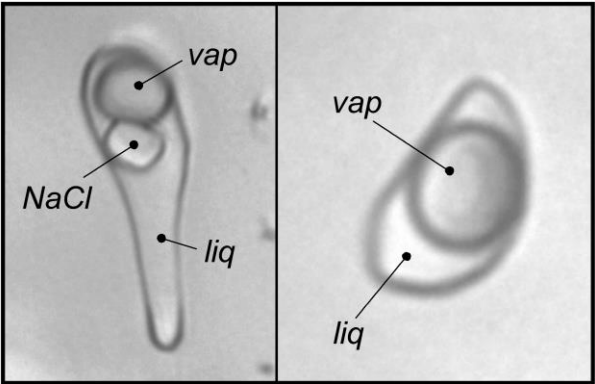
experiment	loaded fluid	immiscibility at experimental conditions					
		liquid-rich fluid			vapour-rich fluid		
	NaCl mass%	NaCl mass%	$V_m$ cm <sup>3</sup> /mol	vol.%	NaCl mass%	$V_m$ cm <sup>3</sup> /mol	vol.%
SR-019	30.07	41.40	29.34	47.0	2.41	58.51	53.0
SR-020	10.00	40.42	29.44	8.3	2.71	57.10	91.7

calculated with AqSo\_NaCl (Bakker, 2019 and 2020)

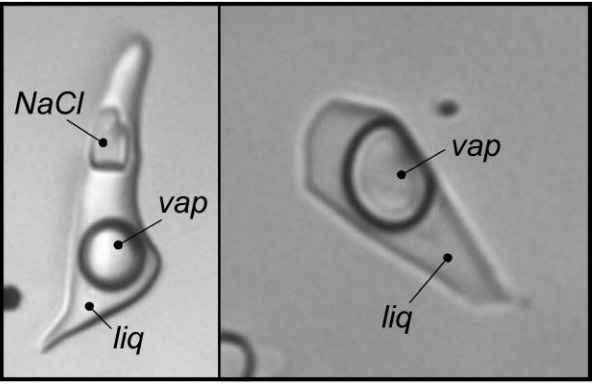


optical microscopy: two types of synthetic fluid inclusions per experiment

SR-019



SR-020



are these heterogeneous assemblages?

# Microthermometry:

mechanical mixtures: evidence of trapping variable proportions of both fluids (liquid and vapour) in fluid inclusions?

model		model
1 vol.% vapour bubble in liquid-rich fluids	→	$T_h$ increase up to 601.5 °C Salinity decrease $T_m$ (halite) decrease down to 335.4 °C
0.1 vol.% liquid in vapour-rich fluids	→	$T_h$ increase up to 608 °C Salinity increase $T_m$ (ice) „decrease“ down to -1.7 °C

this is inconsistent with observations!

experimental artifacts?

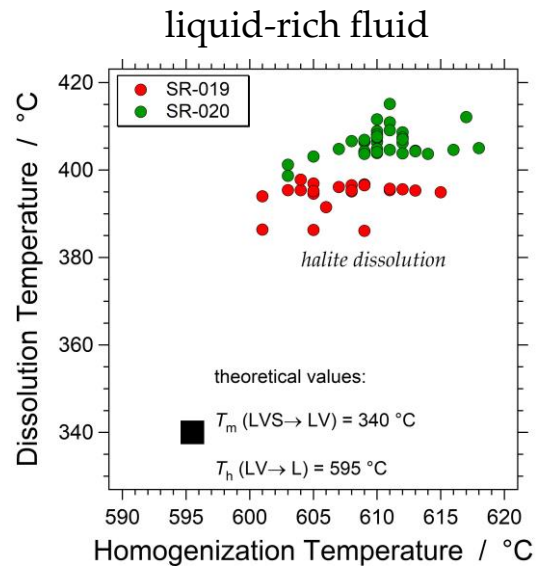
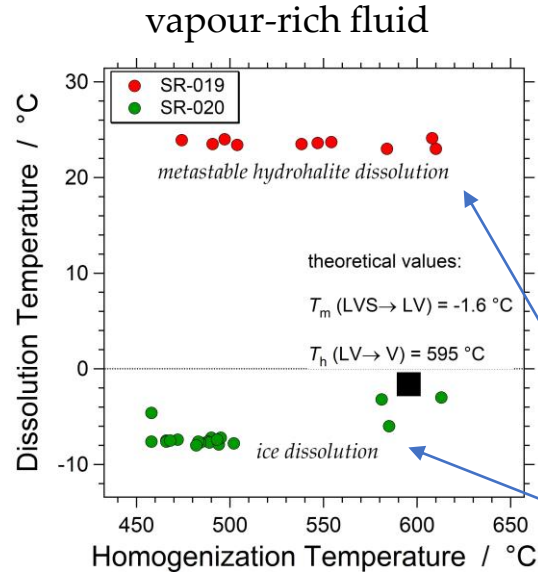
1. most of the vapour-rich inclusions contain the original fluid, trapped during the loading sequence

SR 020  $T_m$  (ice)  $\approx$  -7 °C corresponding to approximately 10 mass% NaCl  
 $T_h$  460 – 500 °C trapping pressure at approximately 80 MPa (loading path)

SR 019  $T_m$  (HH)  $\approx$  +24 °C corresponding to approximately 30 mass% NaCl  
 $T_h$  470 – 590 °C trapping pressure at approximately 80 MPa (loading path)

← metastable dissolution!

2. all of the liquid-rich inclusions contain mechanical mixtures of solid NaCl and the unmixed liquid-rich phase ( $\pm$ 41 mass% NaCl)



model		model
1 vol.% solid NaCl in liquid-rich fluid	→	$T_h$ up to 602.1 °C $T_m$ (halite) up to 353 °C
4 vol.% solid NaCl in liquid-rich fluid	→	$T_h$ up to 619.9 °C $T_m$ (halite) up to 394 °C

this is consistent with observations!

*experimental trapping of heterogeneous fluids in synthetic fluid inclusions**conclusions*

experimental difficulties, trapping of fluid before experimental T, P is reached, before immiscibility field is reached

unmixed vapour-rich phase is seldomly trapped (wetting difference)

mechanically mixing of unmixed liquid phase and solid NaCl crystals at conditions of undersaturation



enigmatic

Where are these crystals coming from?

Are salt crystal preferentially nucleated on crack surfaces, during the process of unmixing?

the trapped fluids do not correspond to the theoretically calculated immiscibility

---

the preliminary results of these experiments illustrate that heterogeneous trapping is not as simple as expected from theoretical considerations and experimental studies. The variety of fluid inclusions properties within an assemblage cannot be explained by applying simple equilibrium thermodynamics. These experiments also indicate that careful analyses of the fluid inclusion assemblages is needed, and may lead to the observation of regularities in deviations, that may have been caused by processes in addition to simple crack healing.