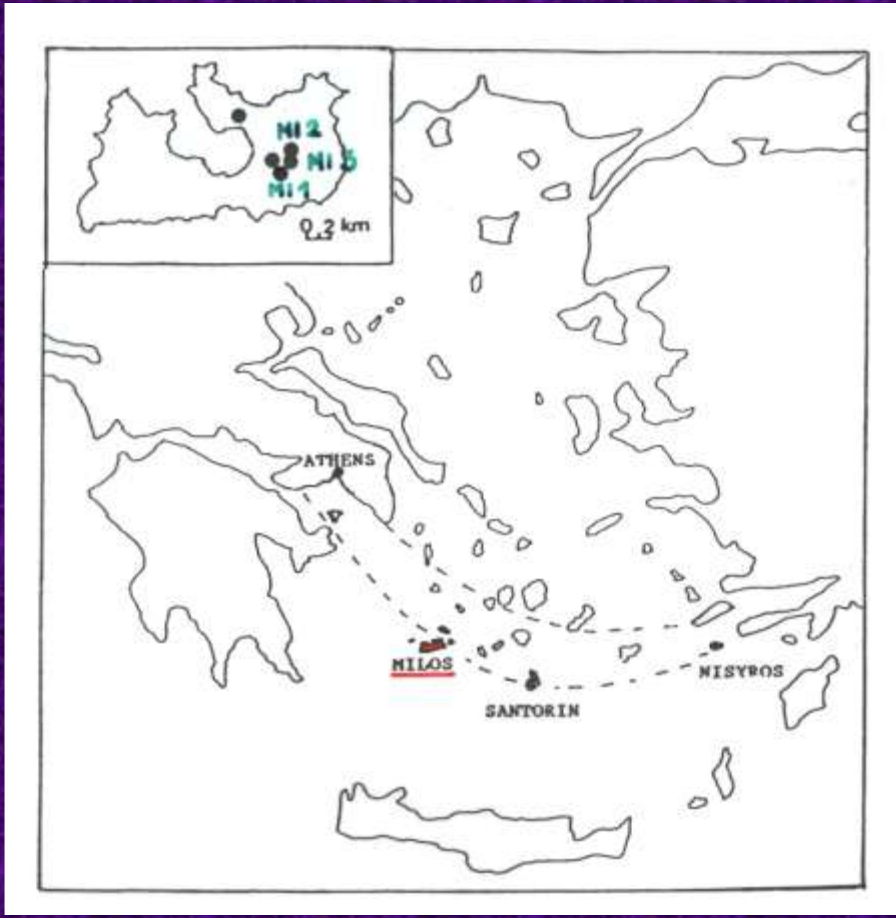
Summary

In other active geothermal systems

example of Milos

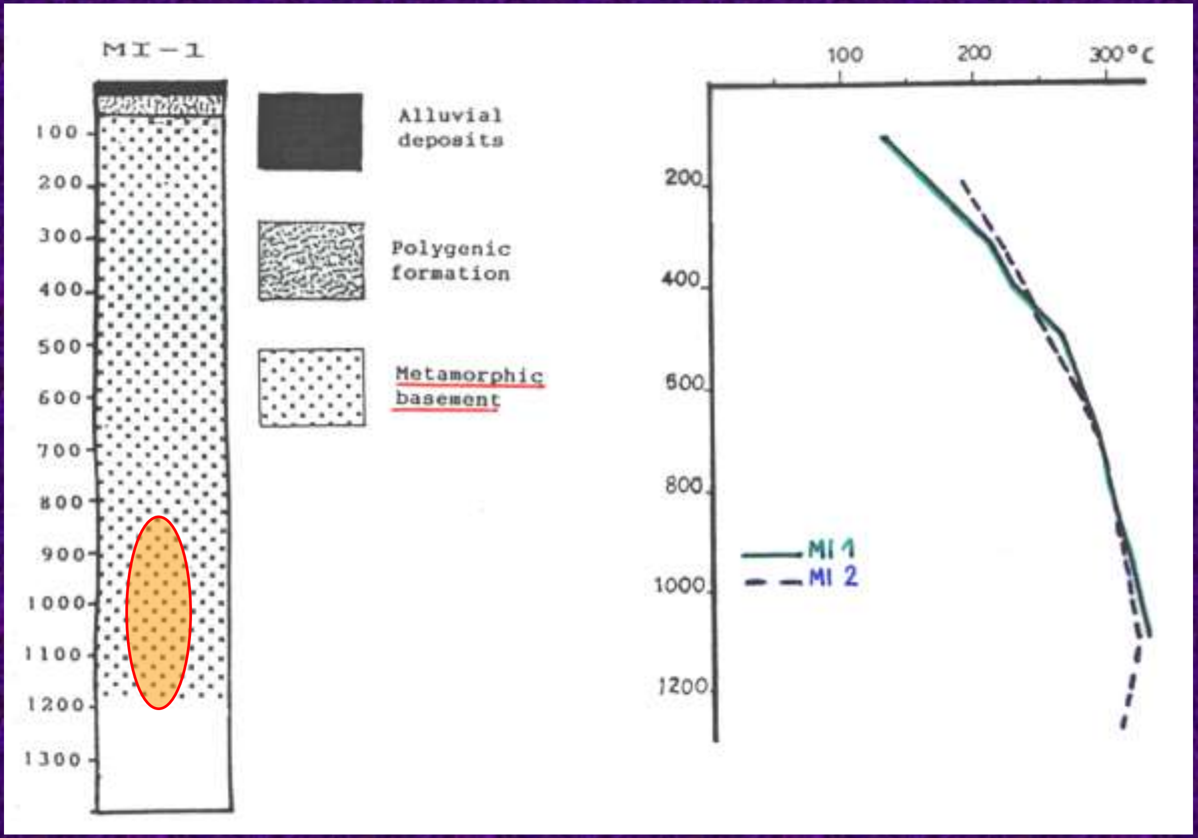
Aegean arc :
Subduction of the african plate under the hellenic one



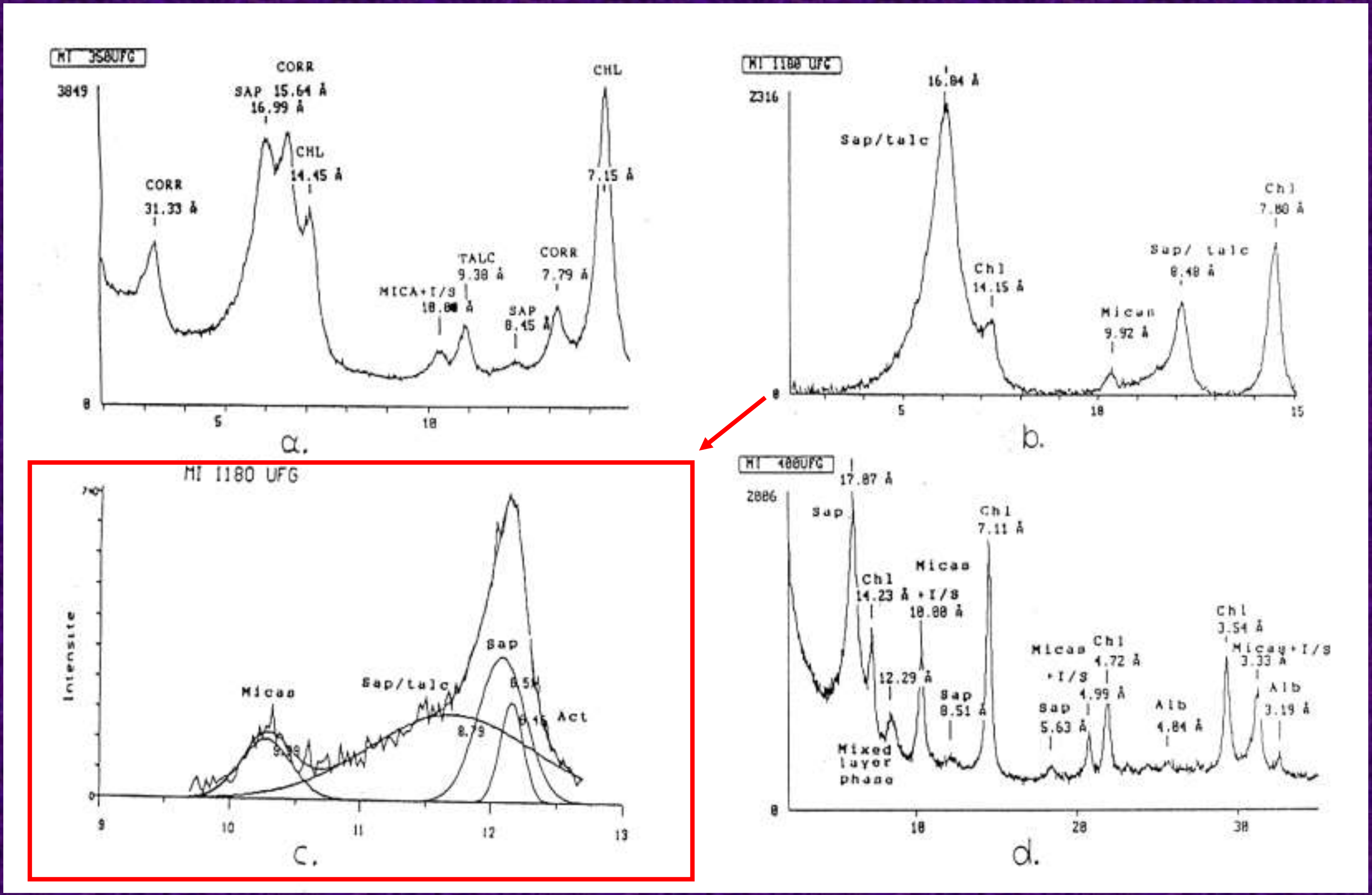
example of Milos

HT: 200-300 °C

Fluids : sea water = main component



example de Milos

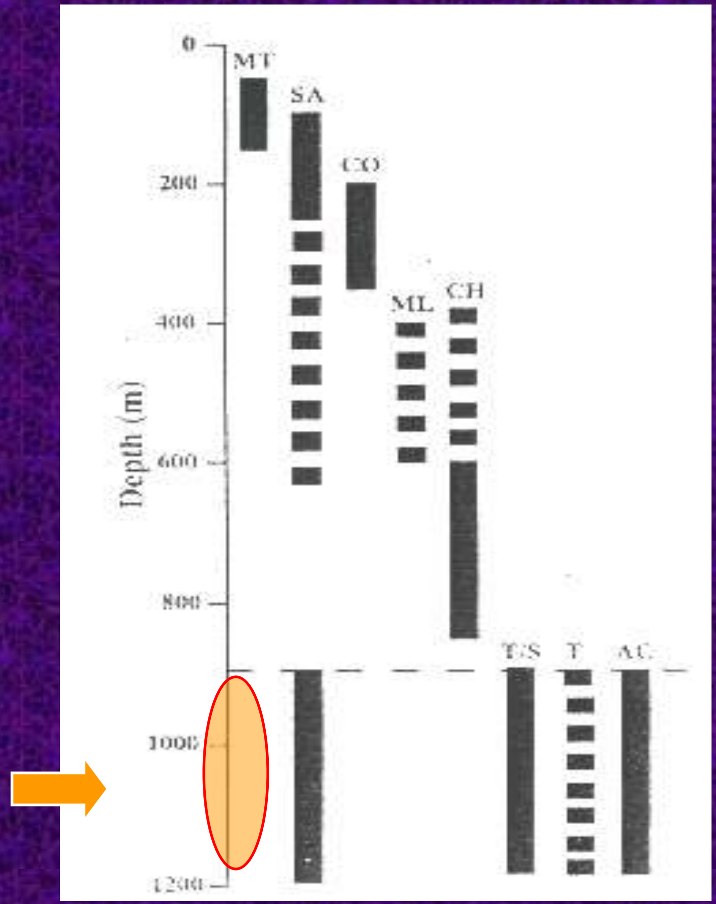


Example de Milos

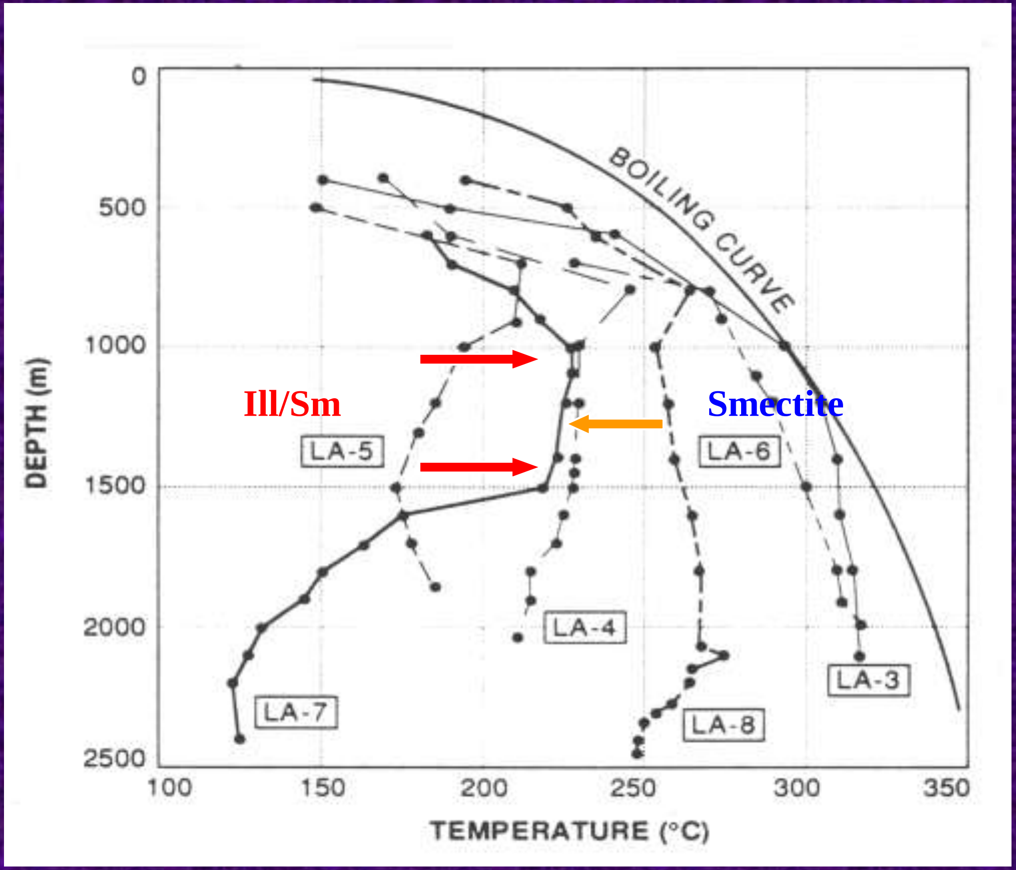
Mainly trioctahedral clay minerals:

Saponite
Talc/Saponite
Talc

(Actinolite)



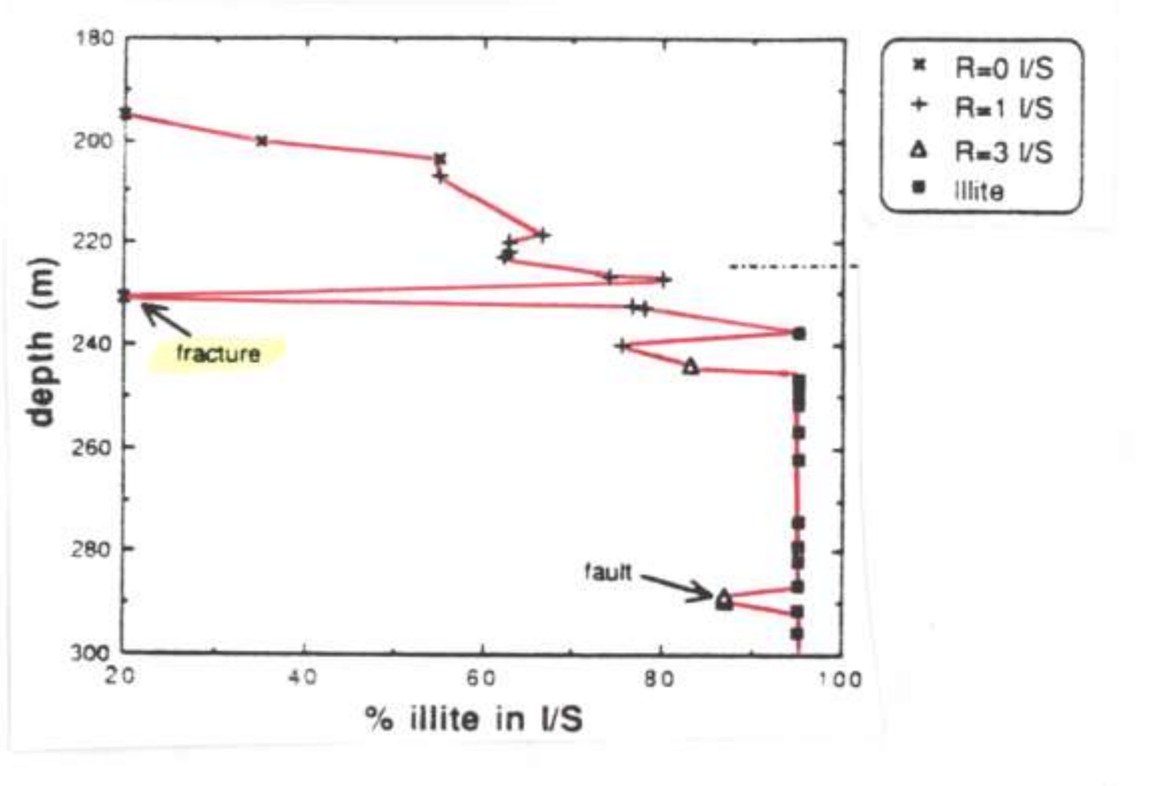
In other active geothermal systems



Aluto-Langano

(Teklemariam et al., 1996)

In other active geothermal systems



Long Valley caldera

(Flexser, 1991)

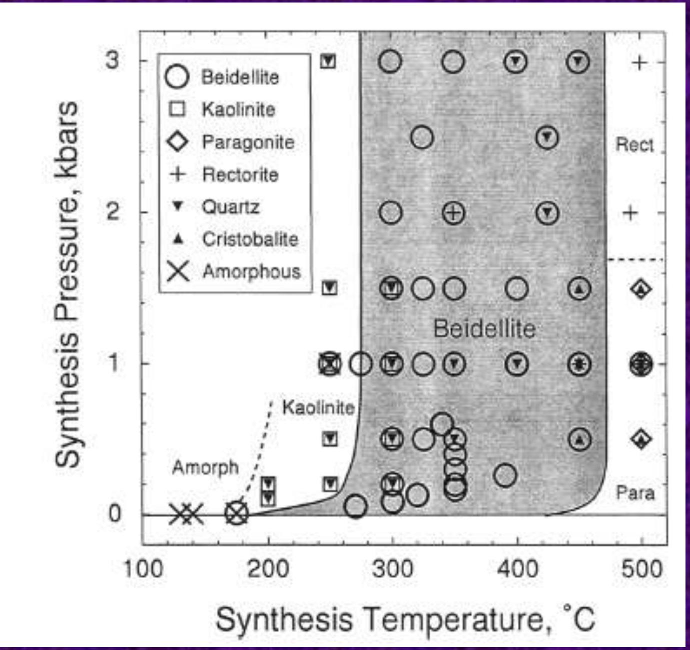
Experimental synthesis...

- Smectites frequently formed outside their thermodynamic stability domain (Kloprogge et al, 1999)

They evolve towards more stable phases

Ex. Saponite → talc/saponite, chlorite/saponite…

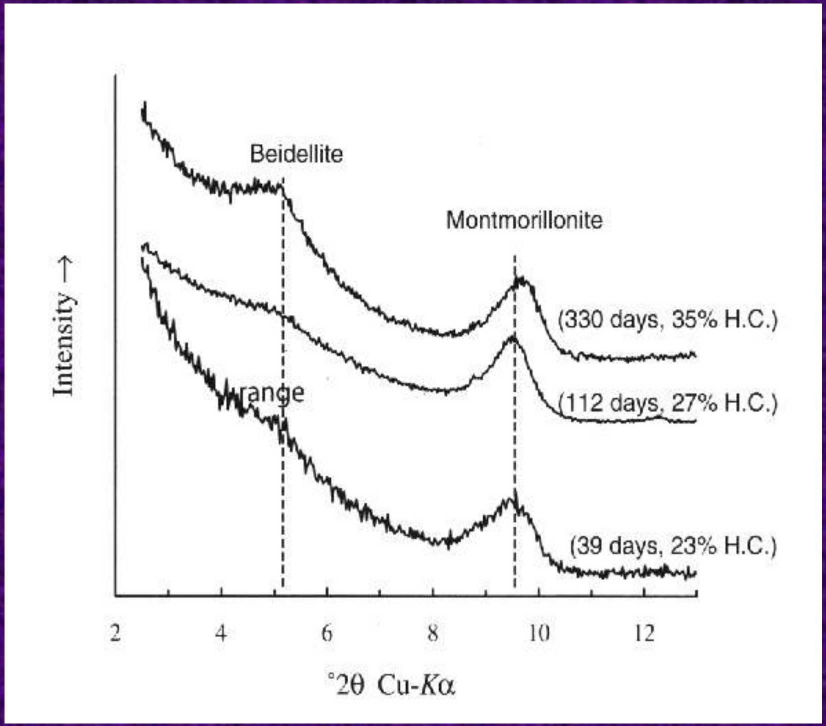
200 days at 400°C



- Mixed layer minerals = transitory metastable state

(Jiang et al., 1994 ; Essene et Peacor, 1995…)

Experimental synthesis...



Yamada et Nakazawa (1993):

- Beidellite stable at higher temperature than montmorillonite

Favored in environments of high energy

Beaufort et al (2001) : hydrothermal treatment of Mt at 200 °C (with sanidine, + quartz)

Summary

Study of active geothermal systems

Distribution and properties of clay minerals are controlled by the dynamic of the systems

<u>crystallisation kinetics (time x temperature) must be handled</u>

Very important factor in these contexts where fluids mixing, boiling often generate strong disequilibria

Inadequacy between models based on thermodynamic equilibria and the mode of functioning of these systems

Numerous informations can be deduced from clay minerals (reactivity, N/G, duration of the conversion series…)

Clay minerals...

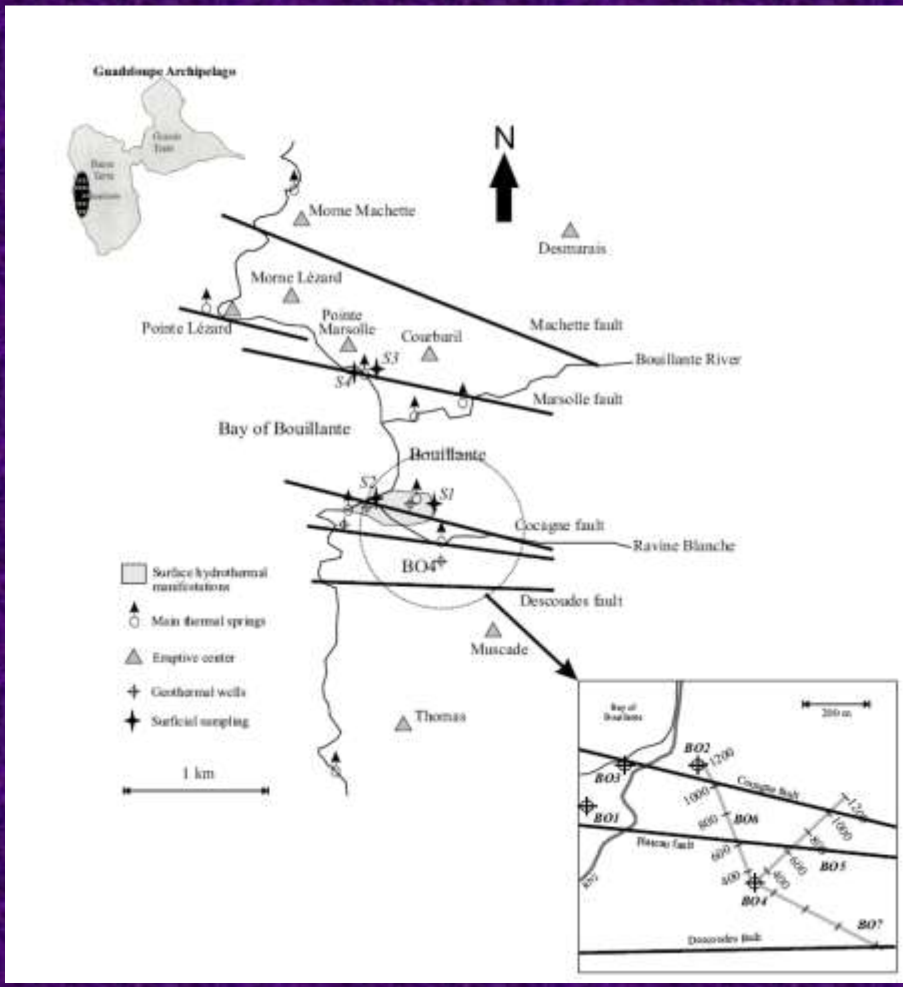
Textural, crystal-chemical, microstructural properties...

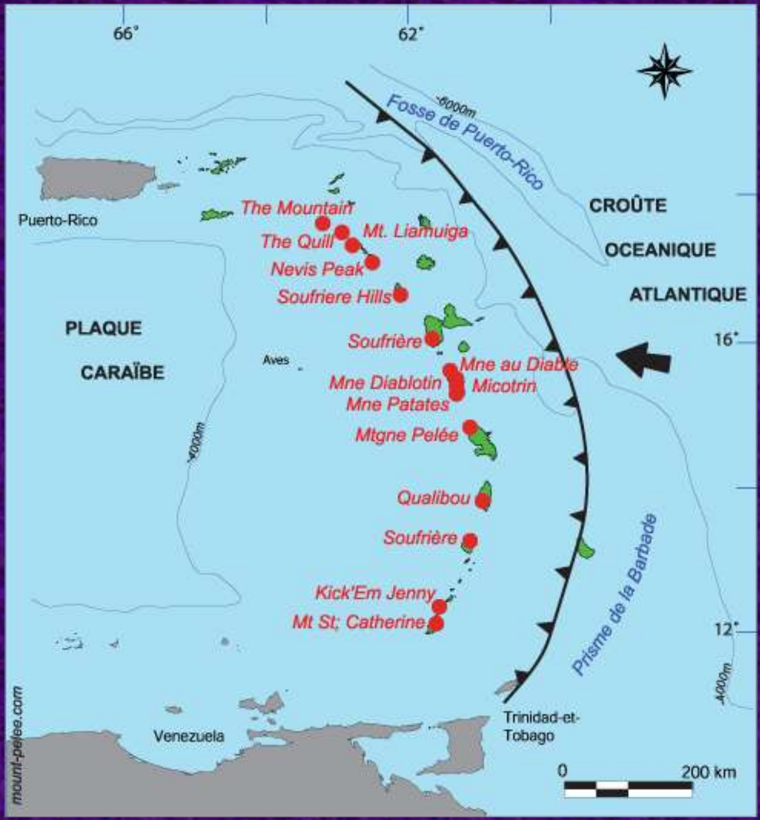
- Recognition of geothermal areas by surface investigation
- Location of permeable levels, characterization of the hydrological regime
- Nature of hydrothermal fluids + fluid state
- History of the hydrothermal activity (location, duration…)

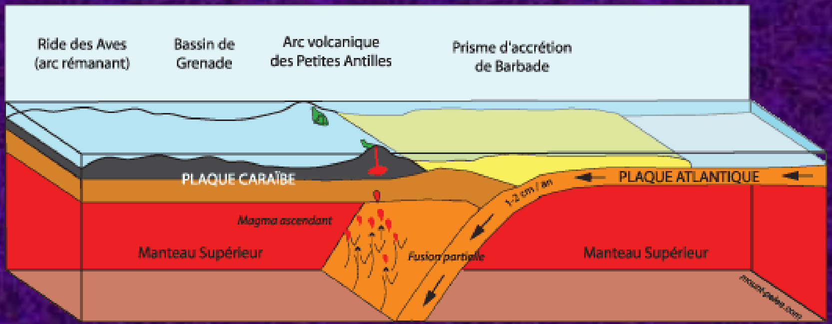
- Better understanding of ancient systems

Lesser Antilles Guadeloupe :

Bouillante geothermal field

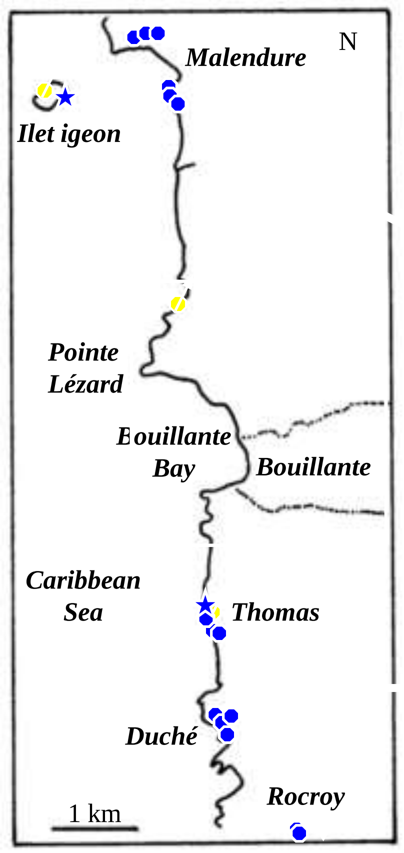


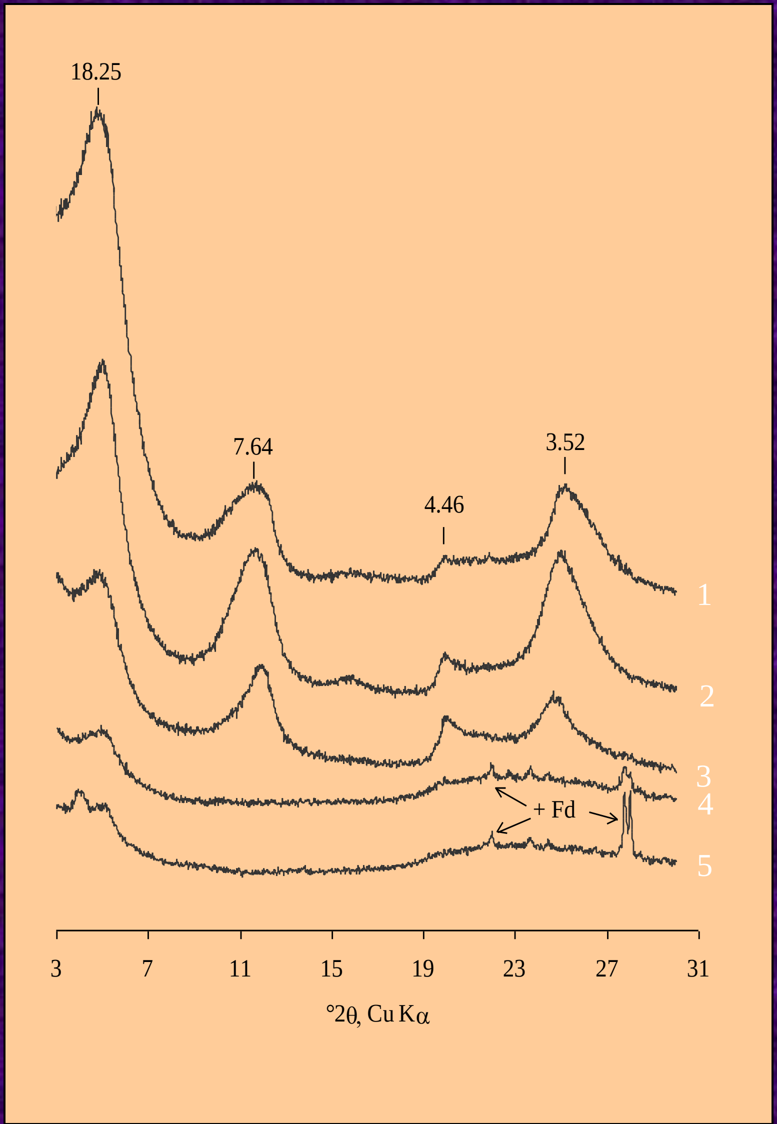




Mineralogy

Recognition of geothermal area by surface investigation… example of *Bouillante geothermal field*



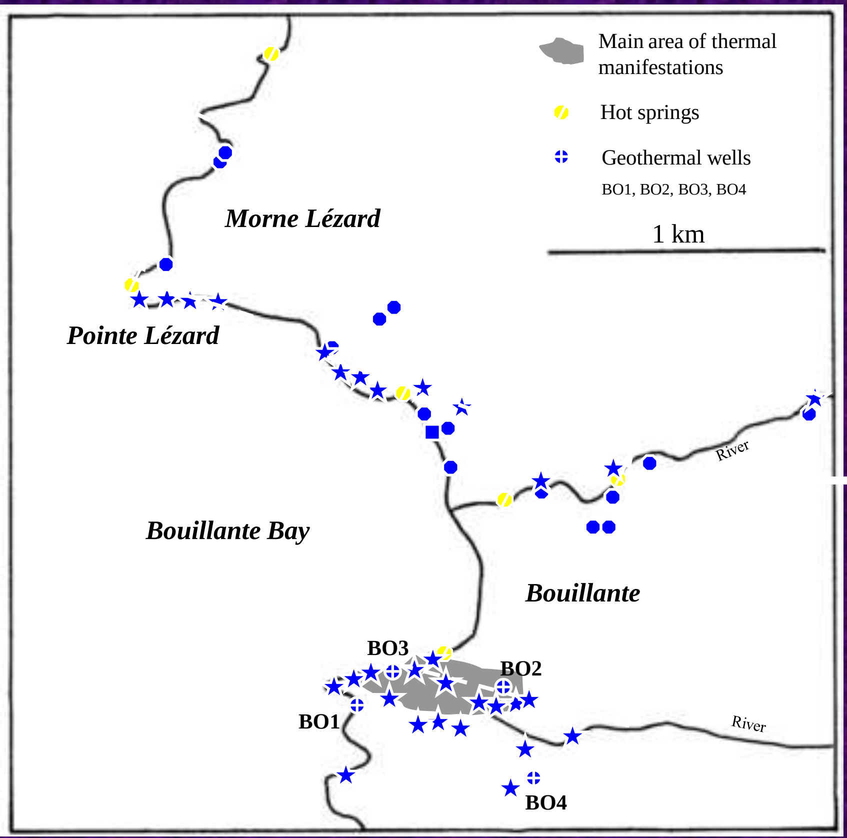


- **Outside the Bouillante Bay:**

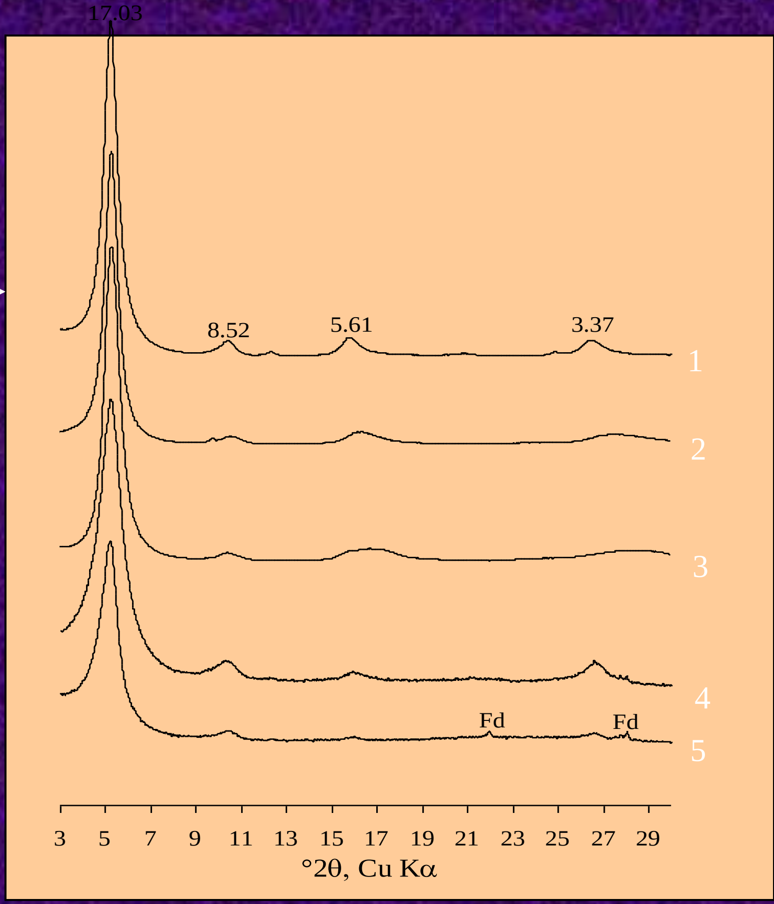
Kaolinite/smectite (± halloysite, allophanes)

Weathering in tropical environnement

Mineralogy



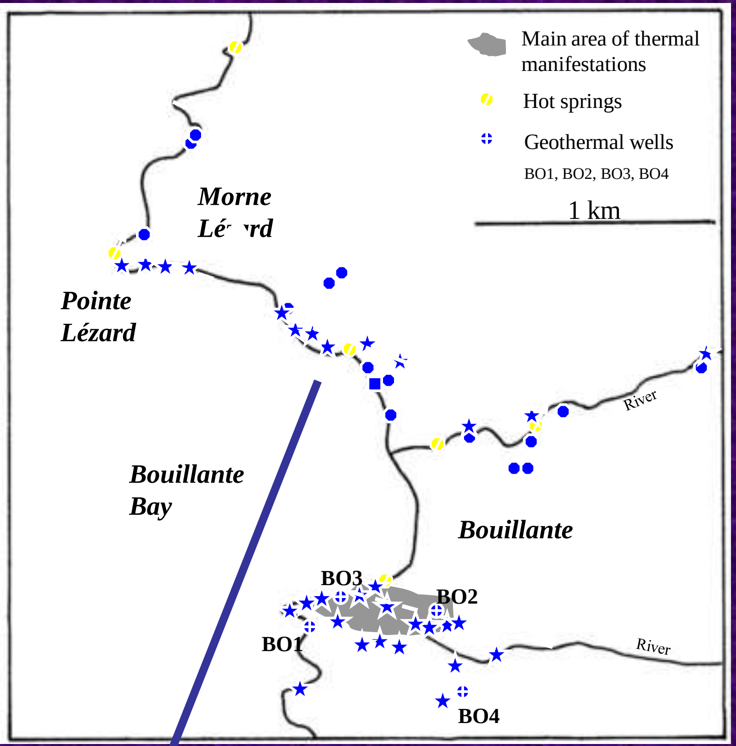
Surface investigations… *Bouillante*

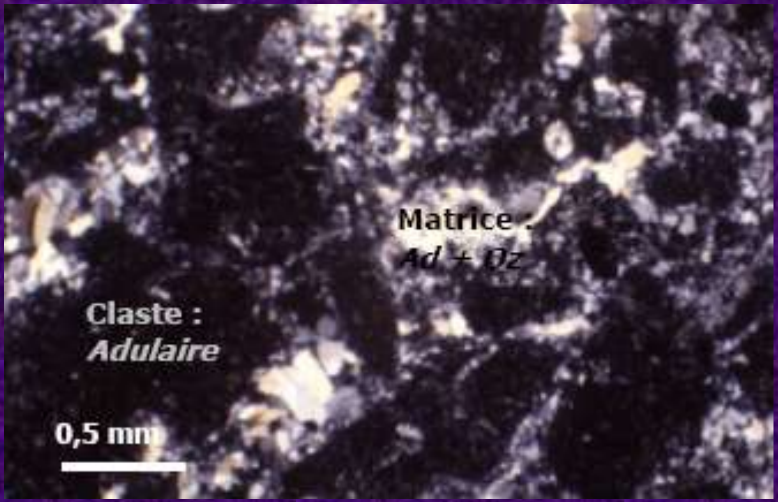


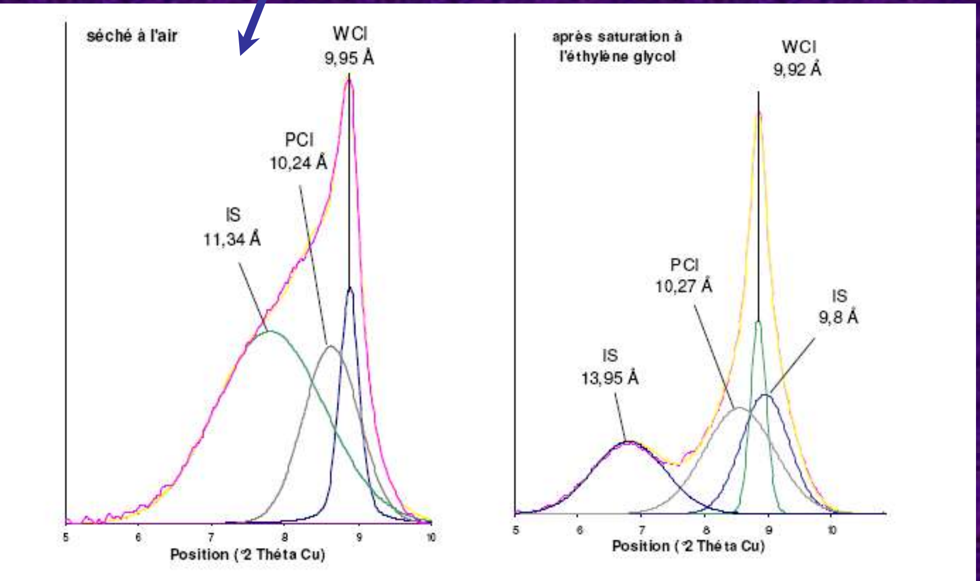
Prospection guide
Cheap and easy

- **In hydrothermalized area :**
Smectite : beidellite (montmorillonite)

Recognition of geothermal area by surface investigation



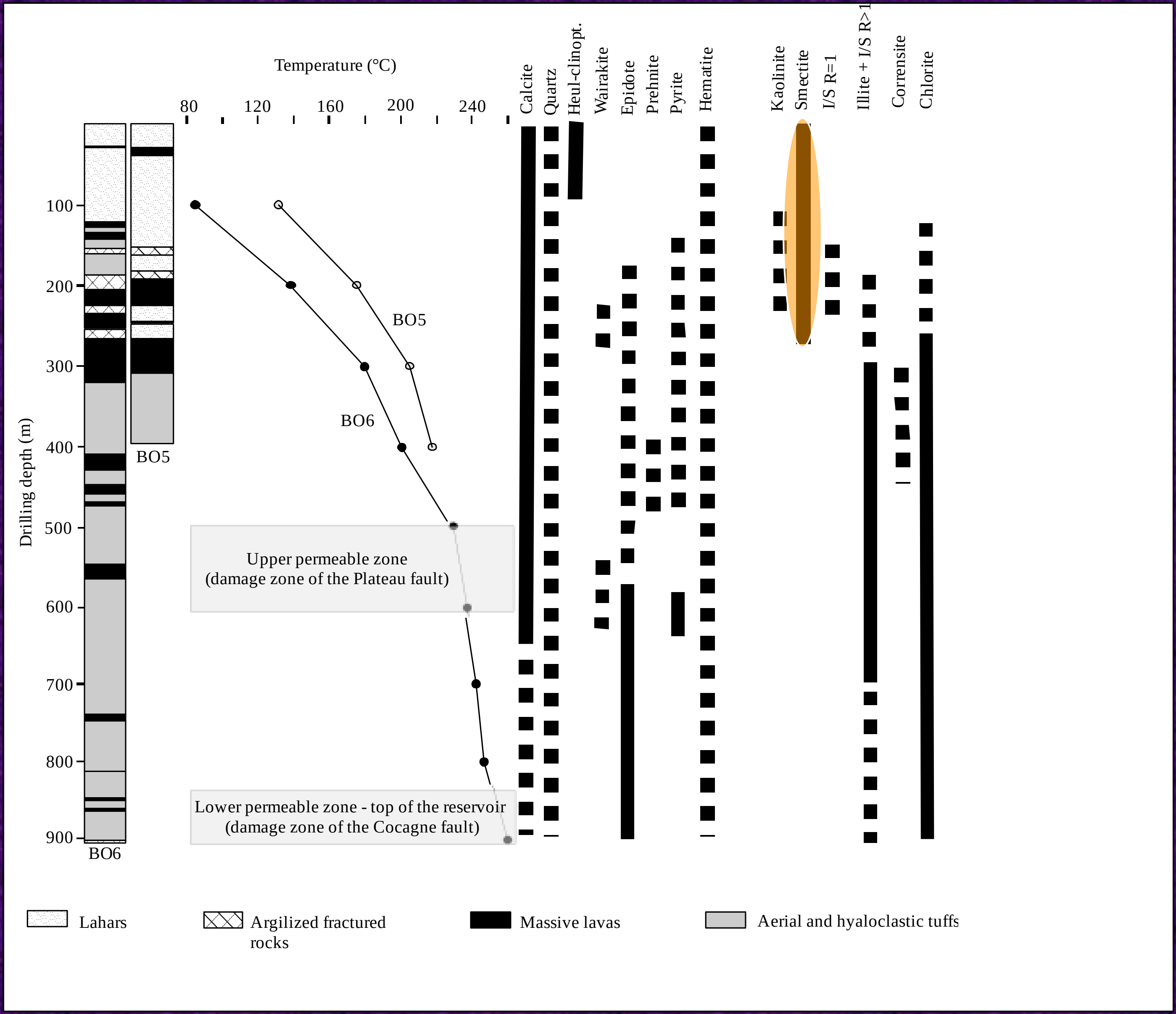




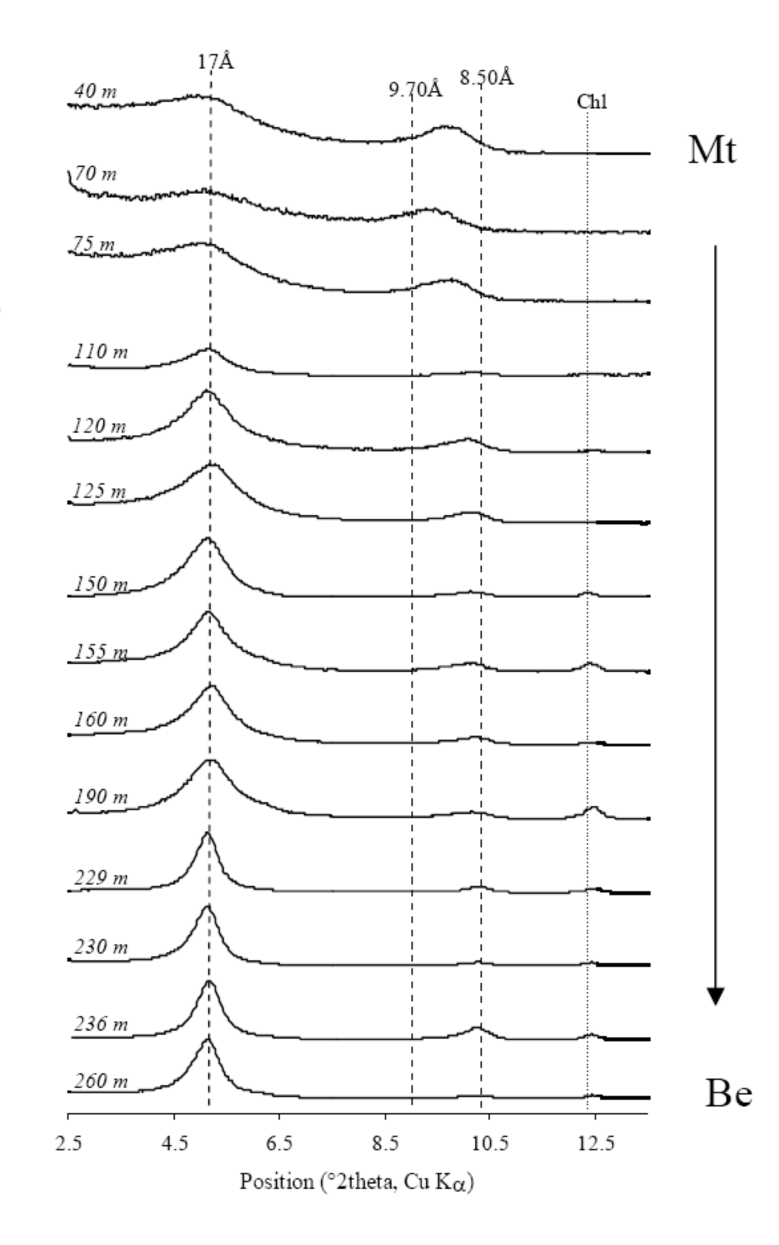
- <u>Epithermal breccia</u>
Illite/smectite mixed-layers

Record of the opening stage

In depth…



Example de Bouillante



Subst. in octahedral sheet

Subst. in tetrahedral sheet

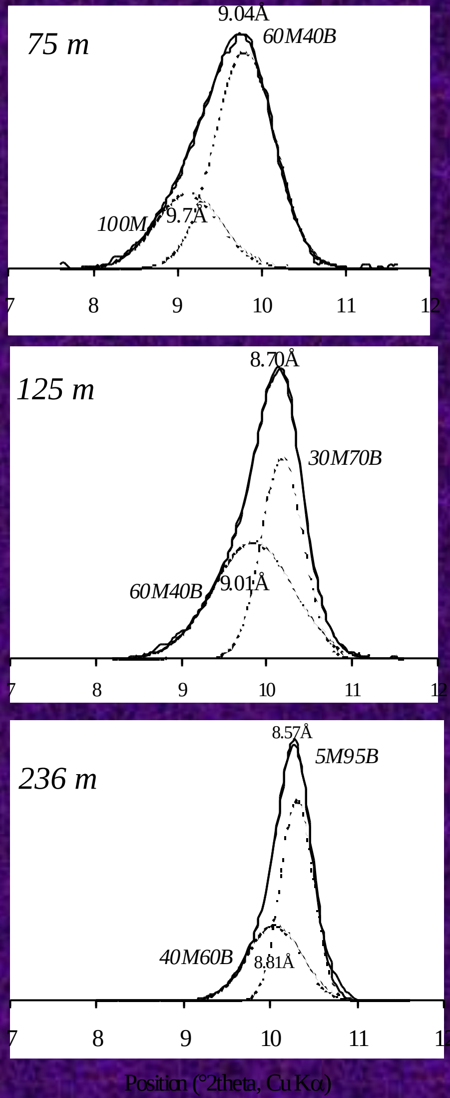


Figure 8, Guisseau *et al.*

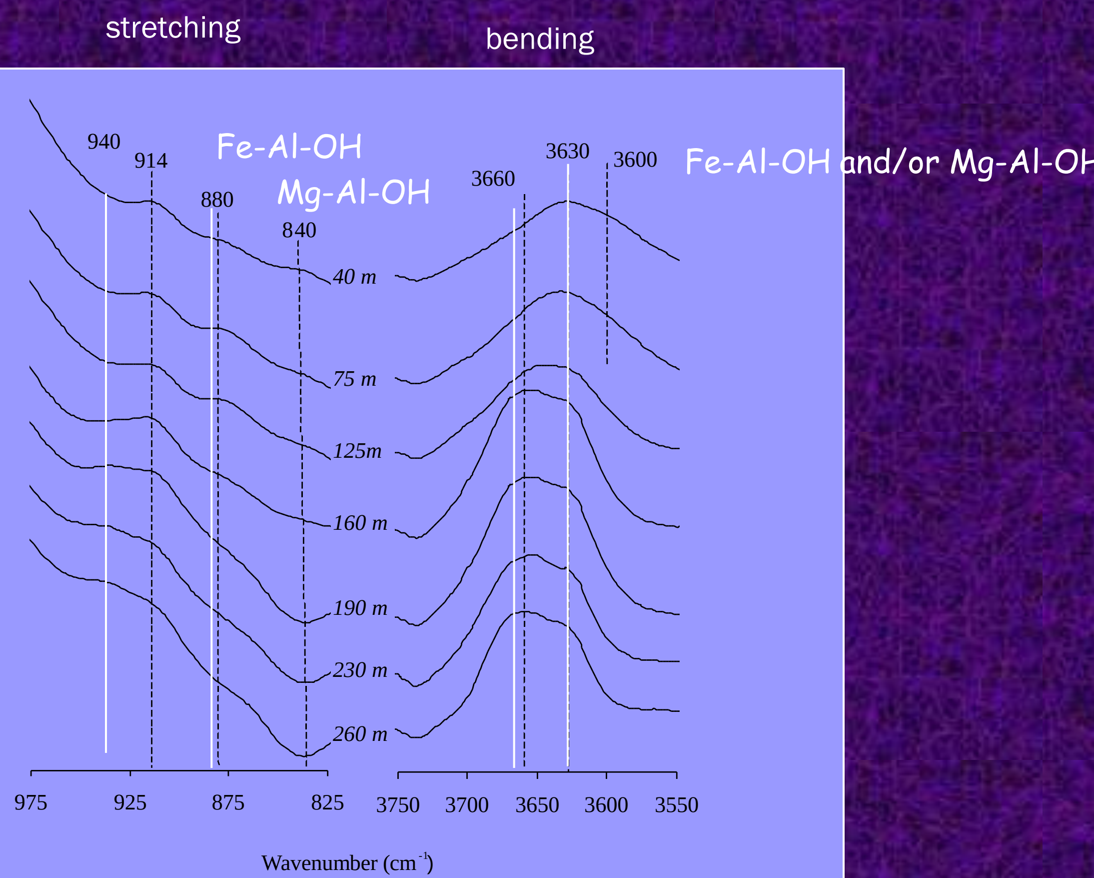


Figure 4, Guisseau *et al*

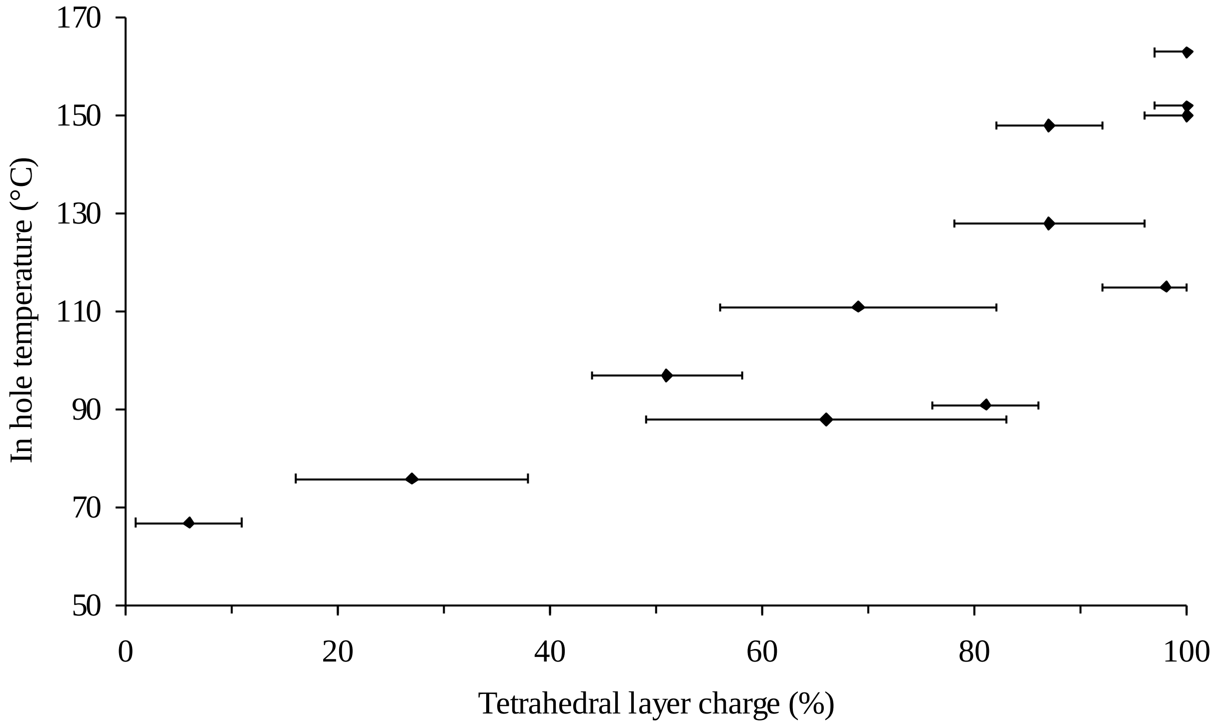


Figure 10, Guisseau *et al.*

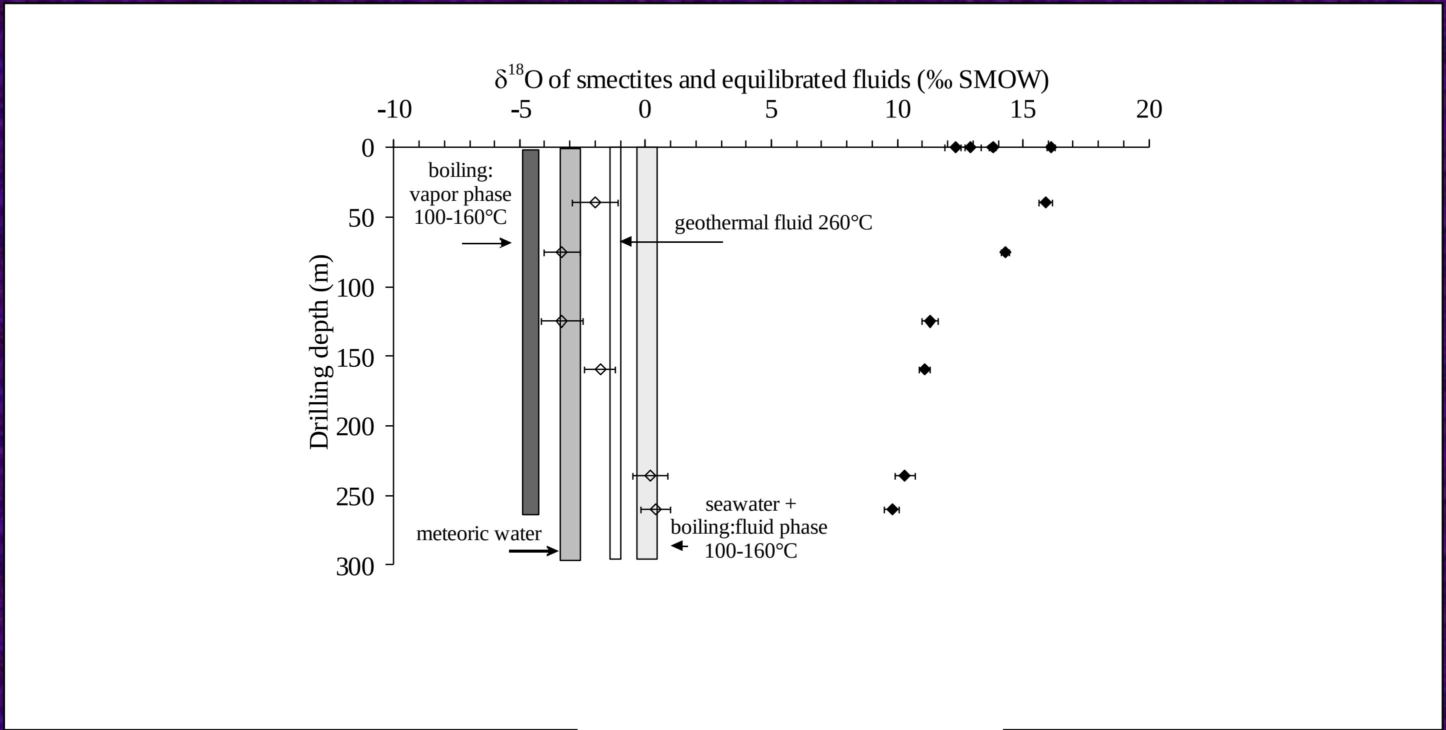
Bouillante

Isotopic composition of clay phases…

$10^3 \ln \alpha_{\text{smectite-eau}} = 2{,}55 * 10^6 * T^{-2} - 4{,}05$ (Sheppard et Gilg, 1996)

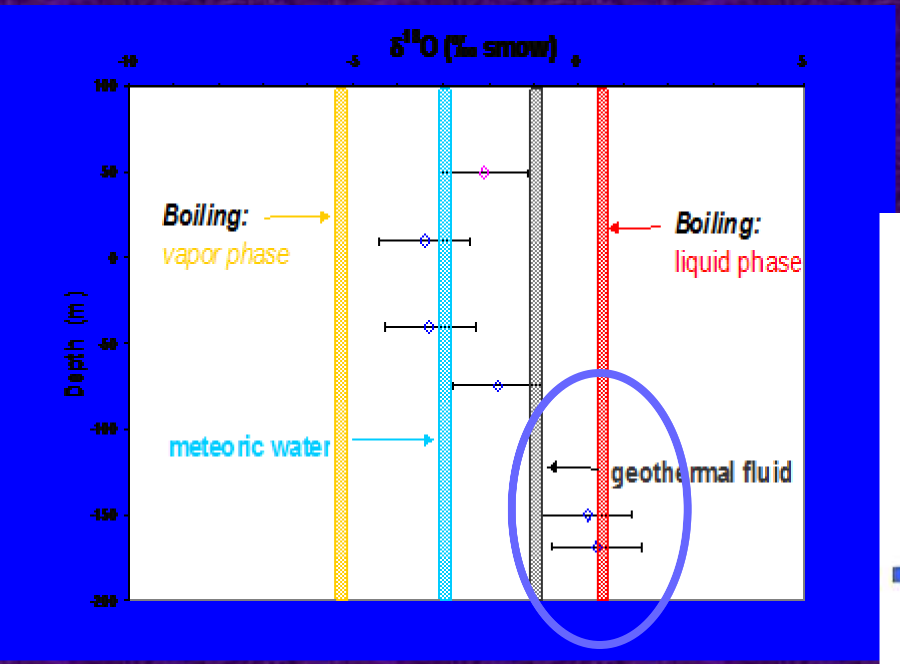
$10^3 \ln \alpha_{\text{illite-eau}} = 2{,}39 * 10^6 * T^{-2} - 3{,}76$ (Sheppard et Gilg, 1996).

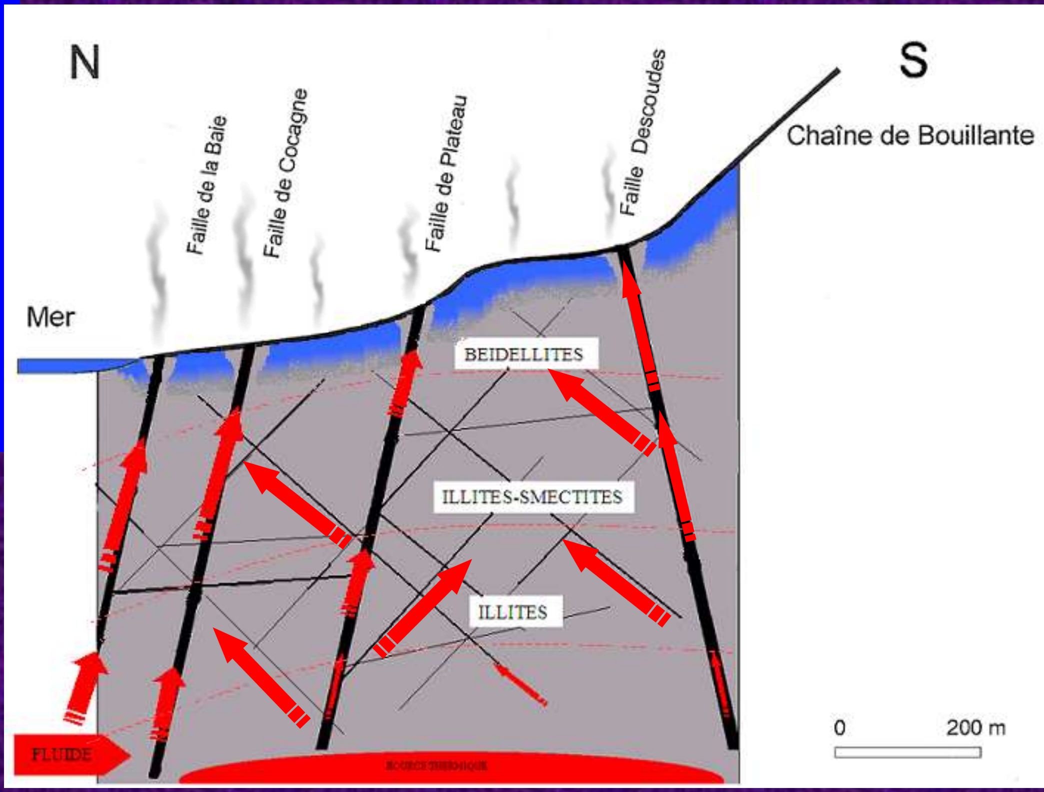
$10^3 \ln \alpha$ minéral-eau = ^{18}Ominéral - ^{18}Oeau, pour ^{18}Ominéral - ^{18}Oeau<10‰.



Beidellite

Surficial clay mineral in equilibrium with the geothermal fluid



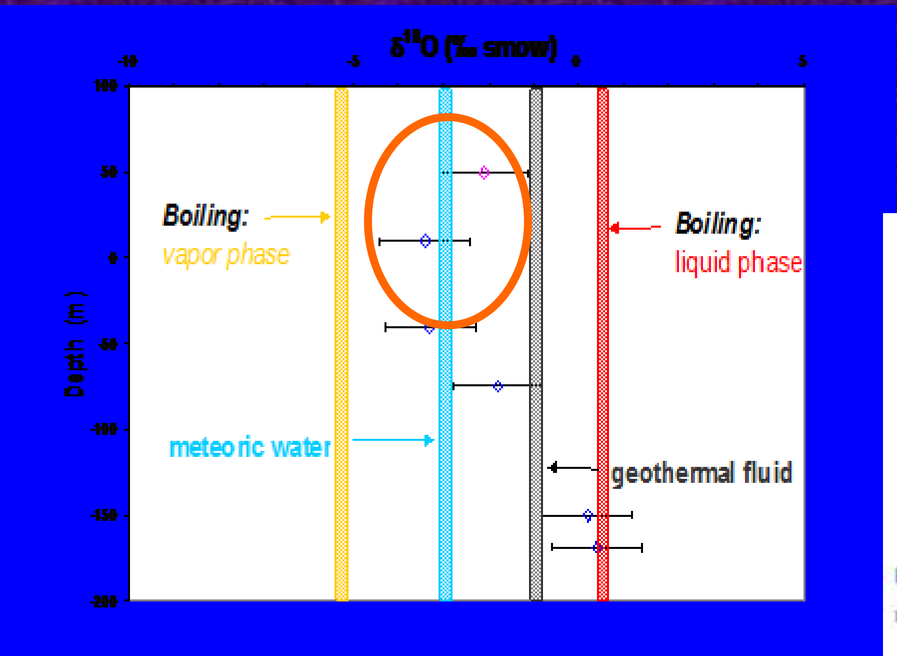


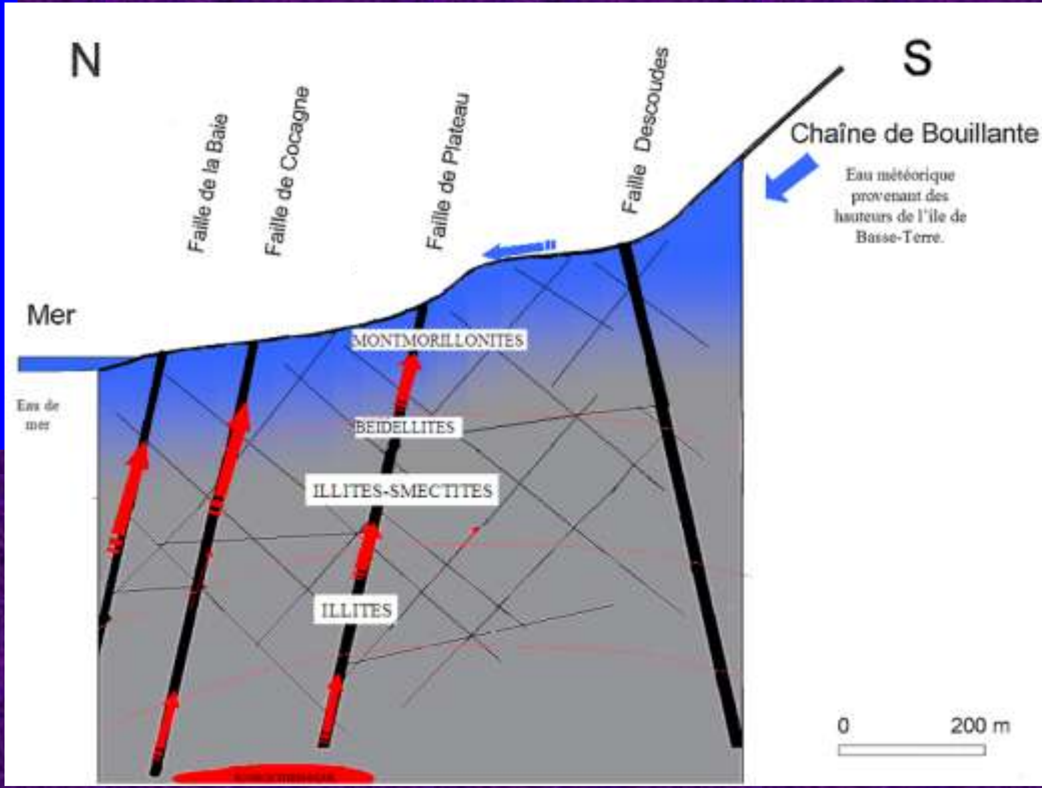
Ascending hydrological regime

(ancient and present hydrothermal vents)

Montmorillonite

Surficial clay mineral in equilibrium with the geothermal fluid mixed with meteoric water

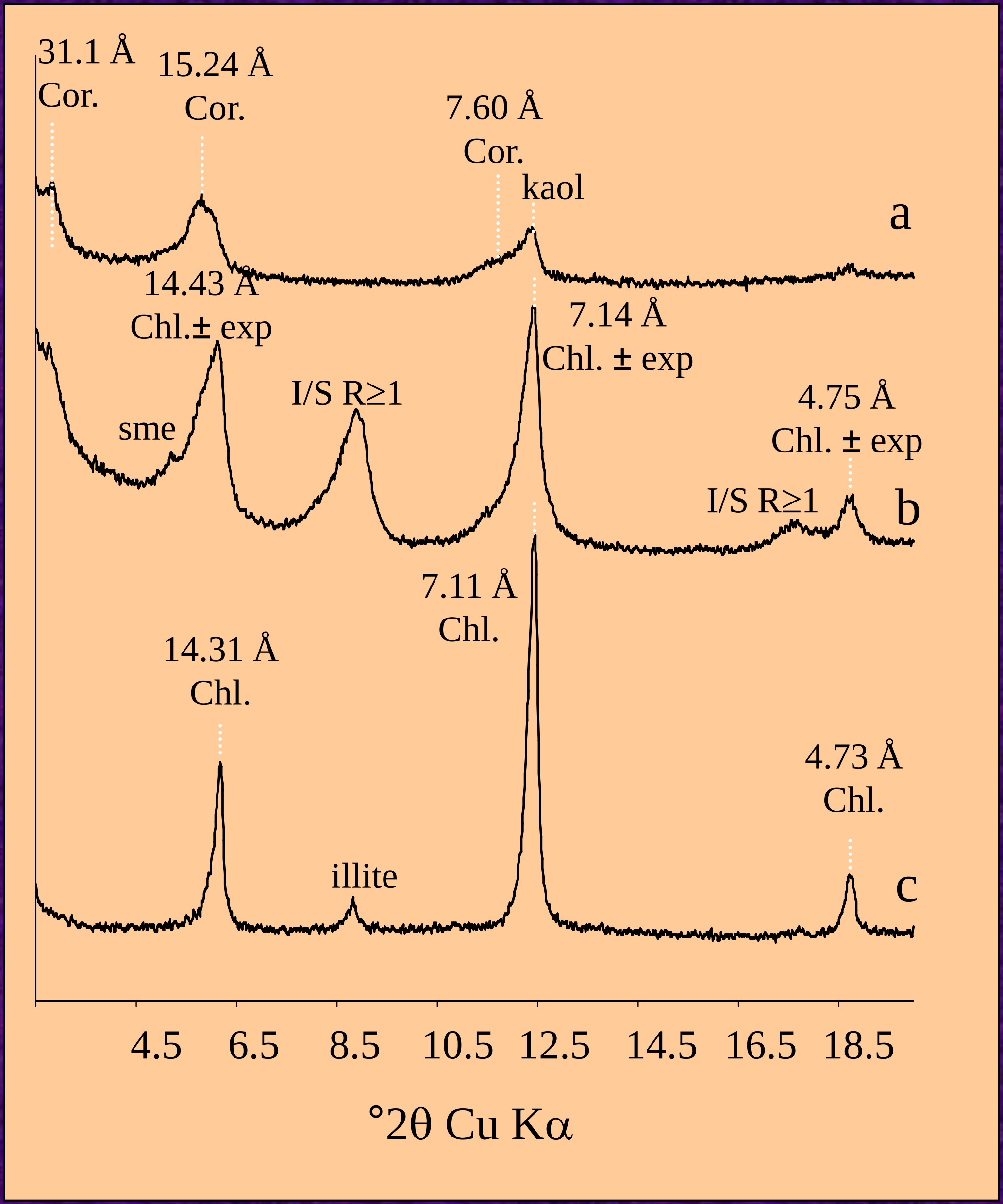




hydrological regime : downward infiltrations

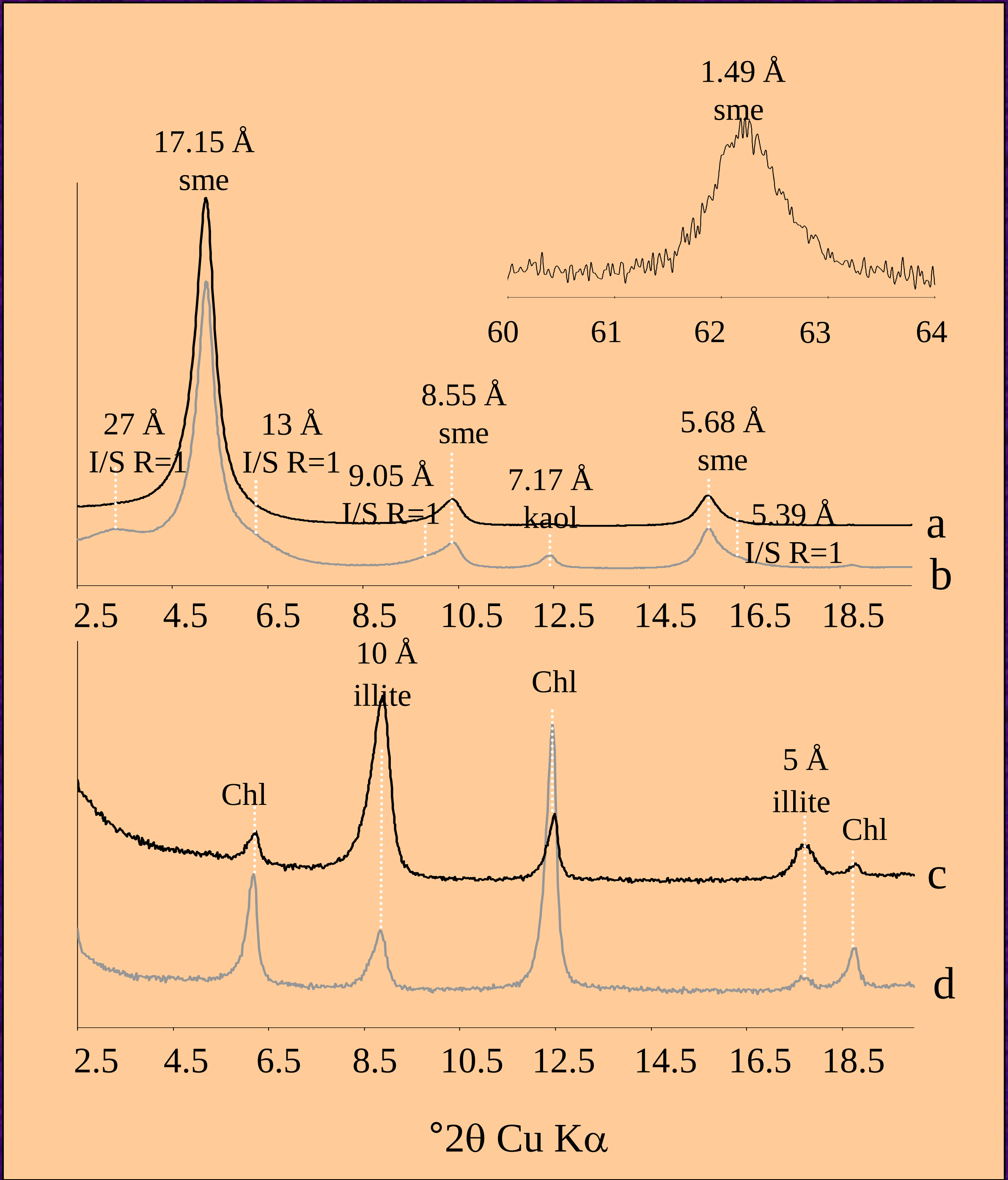
↘ Hydrostatic pressure

In depth…

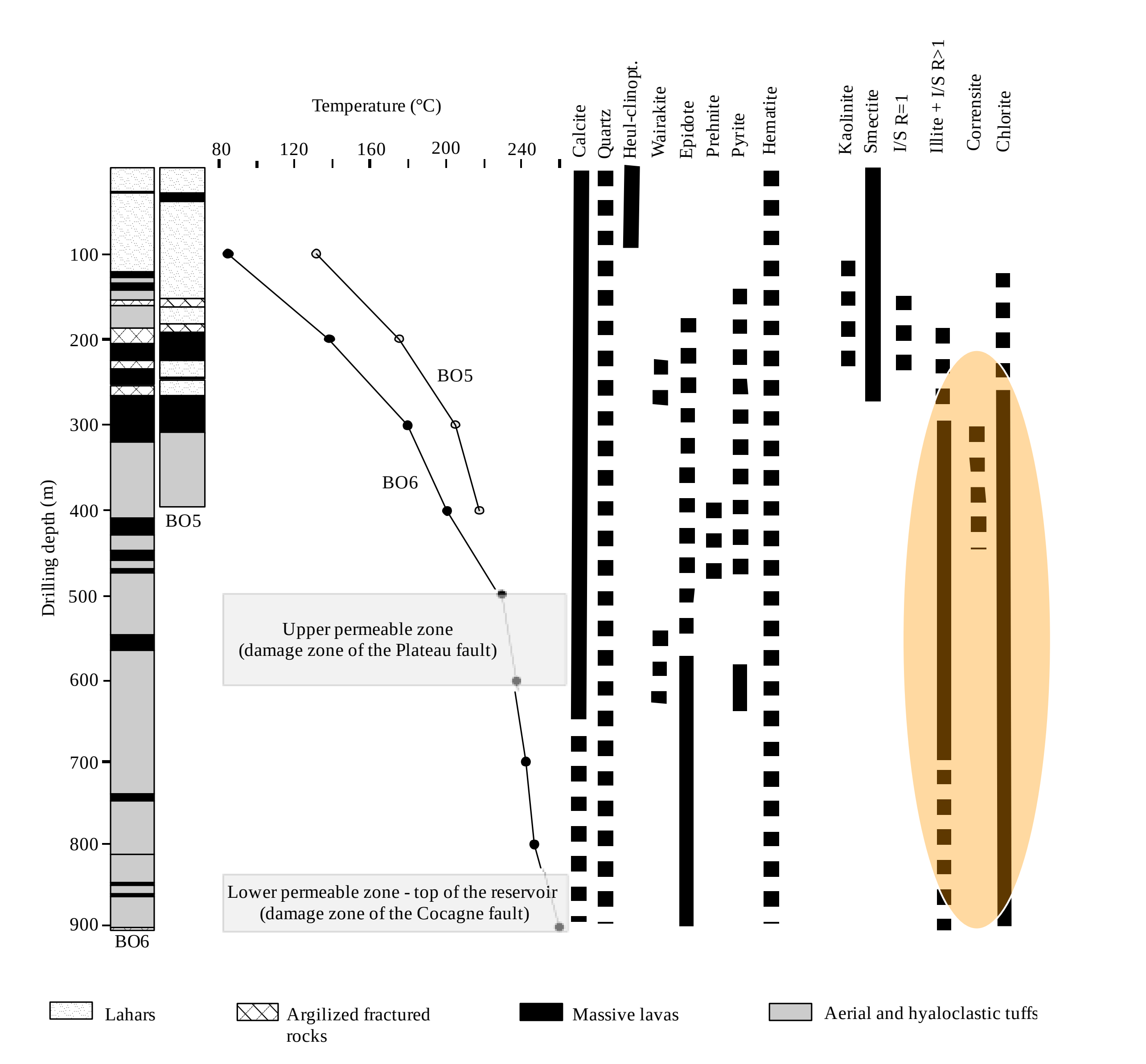


Bouillante

In depth…

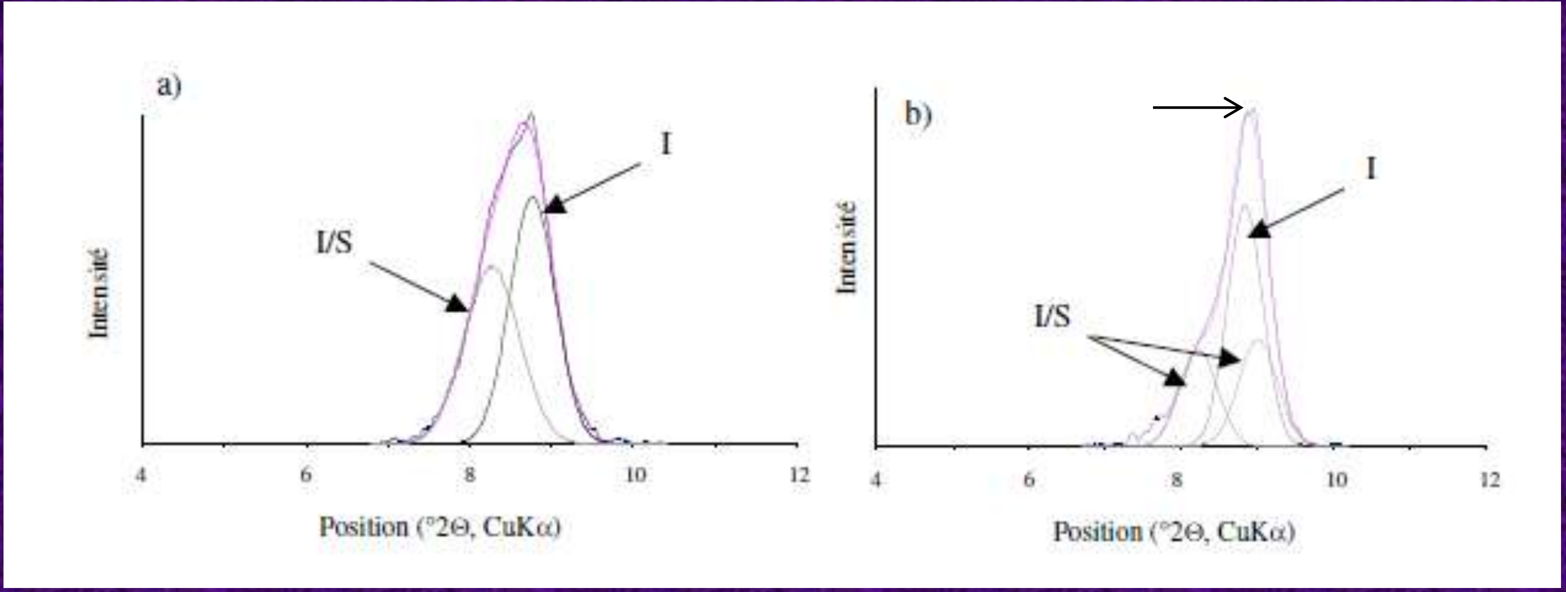


Bouillante



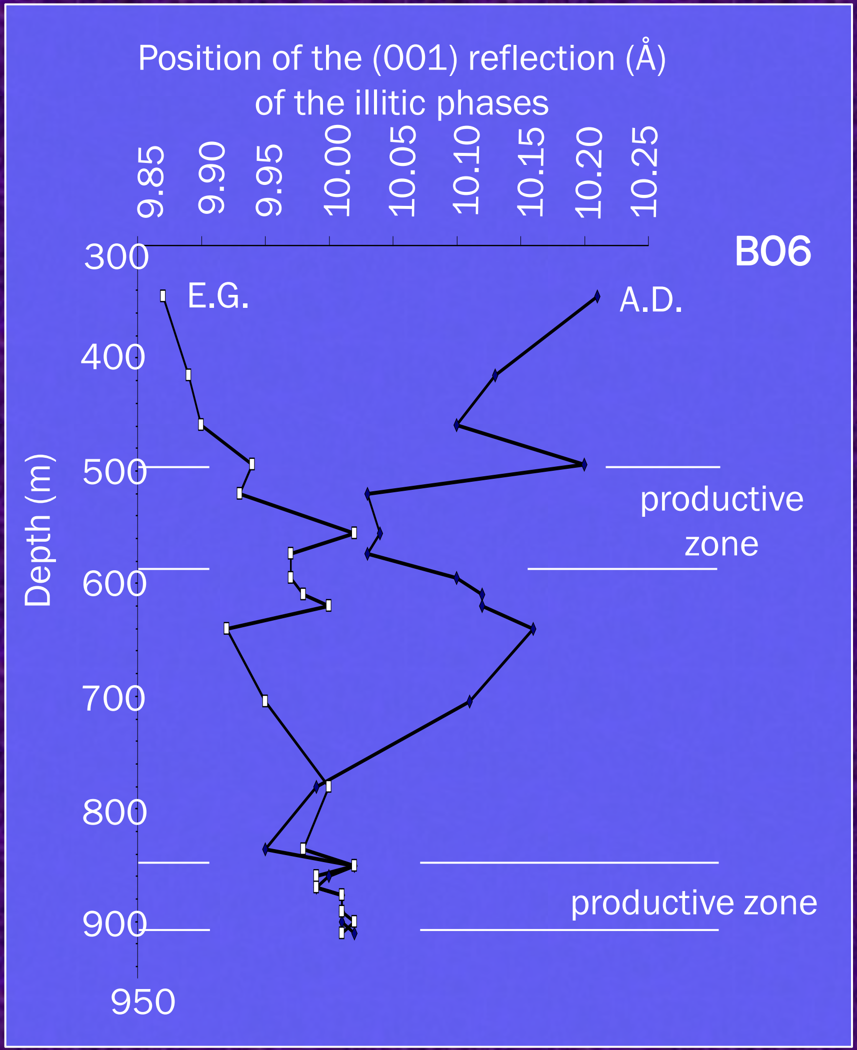
Temperature (°C)
80
120
160
200
240
Calcite
Quartz
Heul-clinopt.
Wairakite
Epidote
Prehnite
Pyrite
Hematite
Kaolinite
Smectite
I/S R=1
Illite + I/S R>1
Corrensite
Chlorite
Drilling depth (m)
100
200
300
400
500
600
700
800
900
BO5
BO6
BO5
BO6
Upper permeable zone
(damage zone of the Plateau fault)
Lower permeable zone - top of the reservoir
(damage zone of the Cocagne fault)
Lahars
Argilized fractured rocks
Massive lavas
Aerial and hyaloclastic tuffs

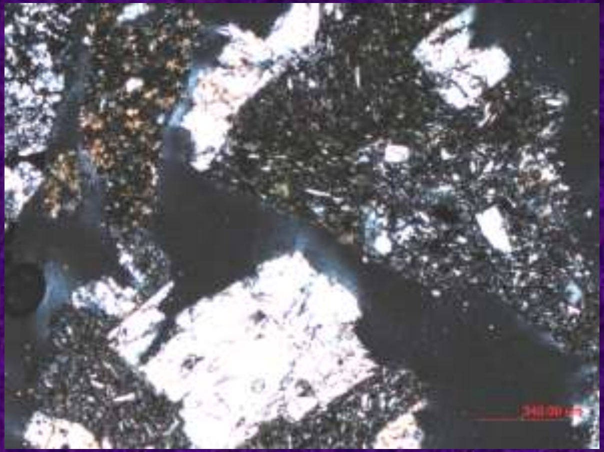
Air dried EG

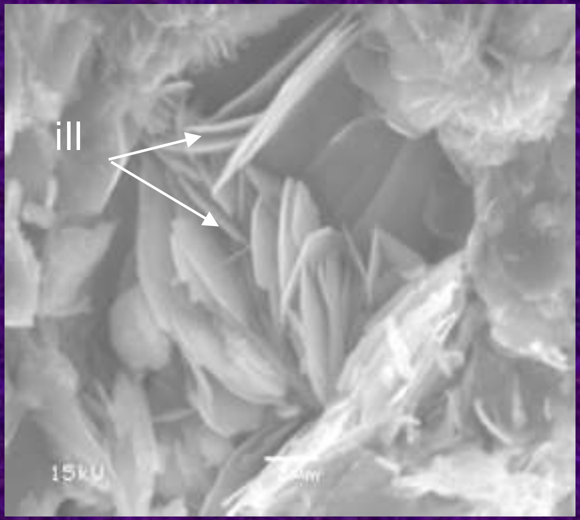


a)
I
I/S
Intensité
4
6
8
10
12
Position (°2Θ, CuKα)
b)
I
I/S
Intensité
4
6
8
10
12
Position (°2Θ, CuKα)

Reservoir zone: weak argilization





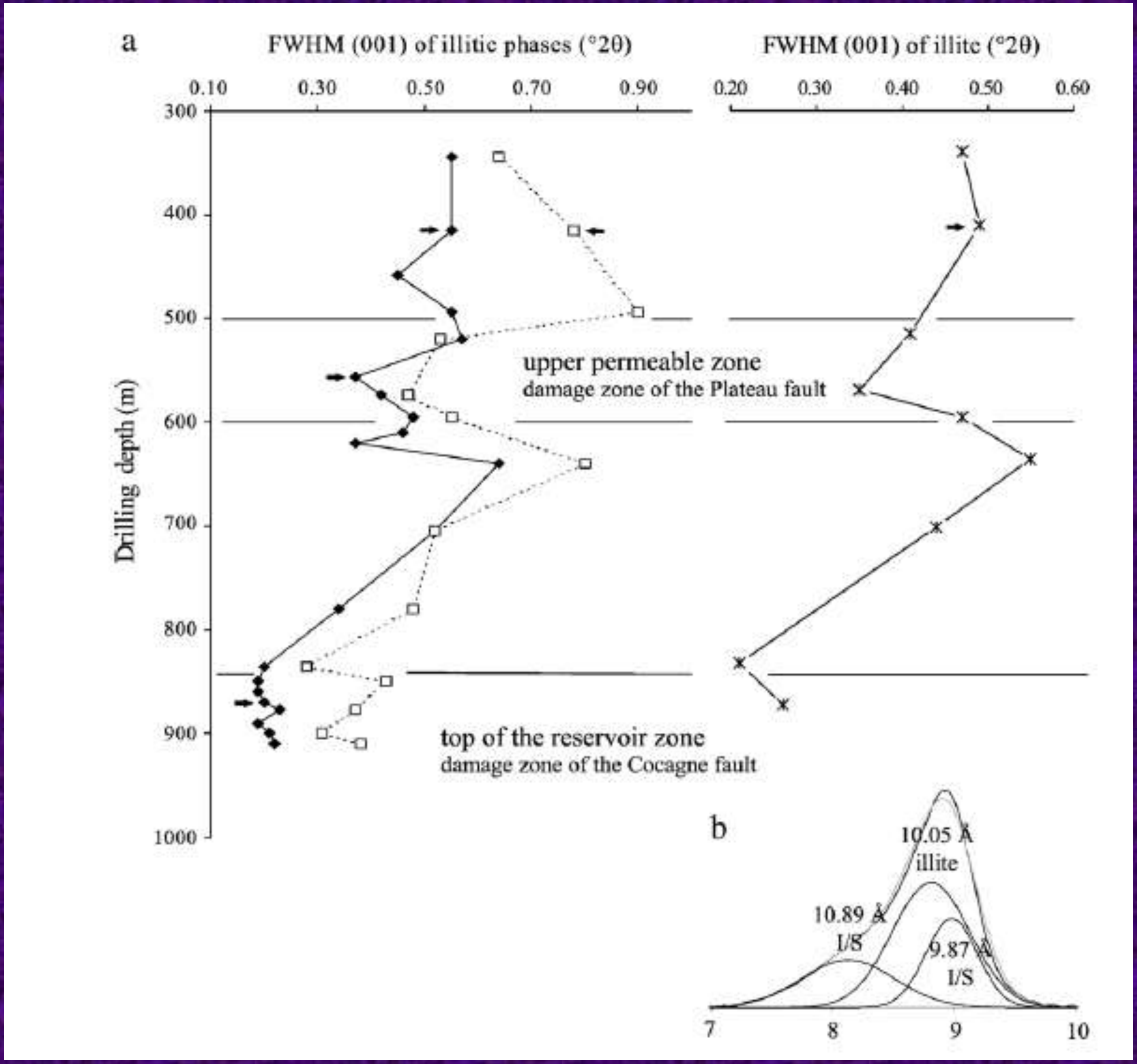


clay minerals approached equilibrium with the geothermal fluids

Specific textural and microstructural properties (interstratification rate, …)

N/G rates

Reservoir zone: weak argilization

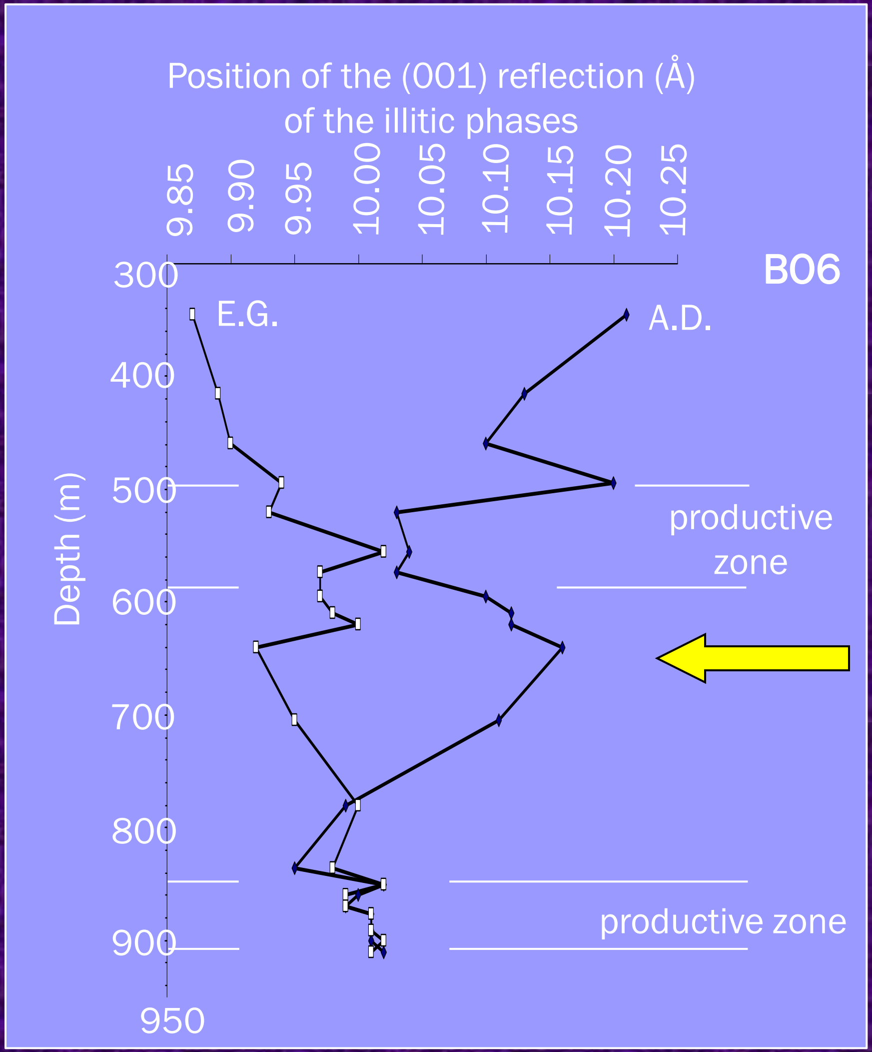


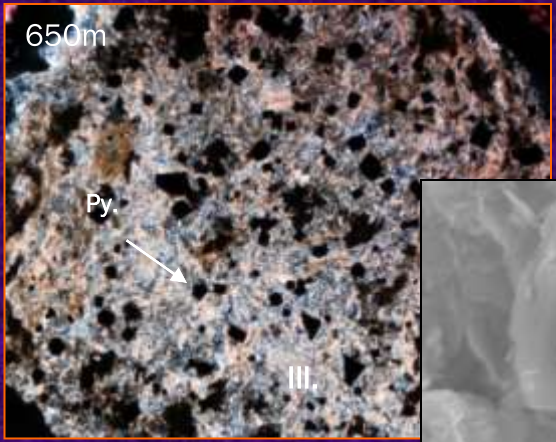
Specific textural and microstructural properties (cristallinity…)

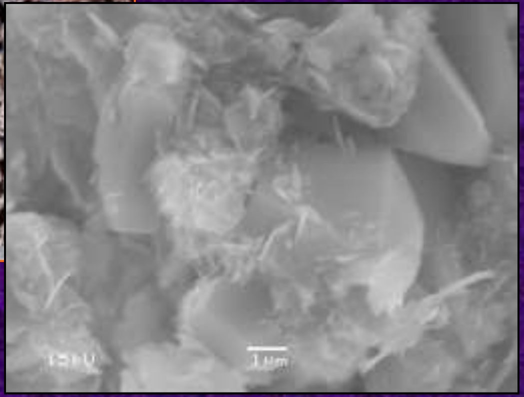
High CSD size

High CSD size

Massive argilization in impervious zones







Ancient permeable levels

Paragenesis richer in smectite

In the past: Strong oversaturation of geothermal fluids (boiling, confirmed by bladed calcite)

Reservoir zones : 2 argilization schemes

Rapid ascending of geothermal fluids and abrupt changes in physical and chemical conditions

Strong argilization
Rapid nucleation and growth

Parageneses rich in smectites controlled by fluid chemistry, independant of temperature beidellite (saponite)

⬇

Ancient reservoir zones of Bouillante… Examples of Milos, Chipilapa

Slow ascending of geothermal fluids which are close to equilibrium with the host rock

Weak argilization

- Parageneses controlled by T…

Predicted clay phases : mixed layers, chlorite, illite...

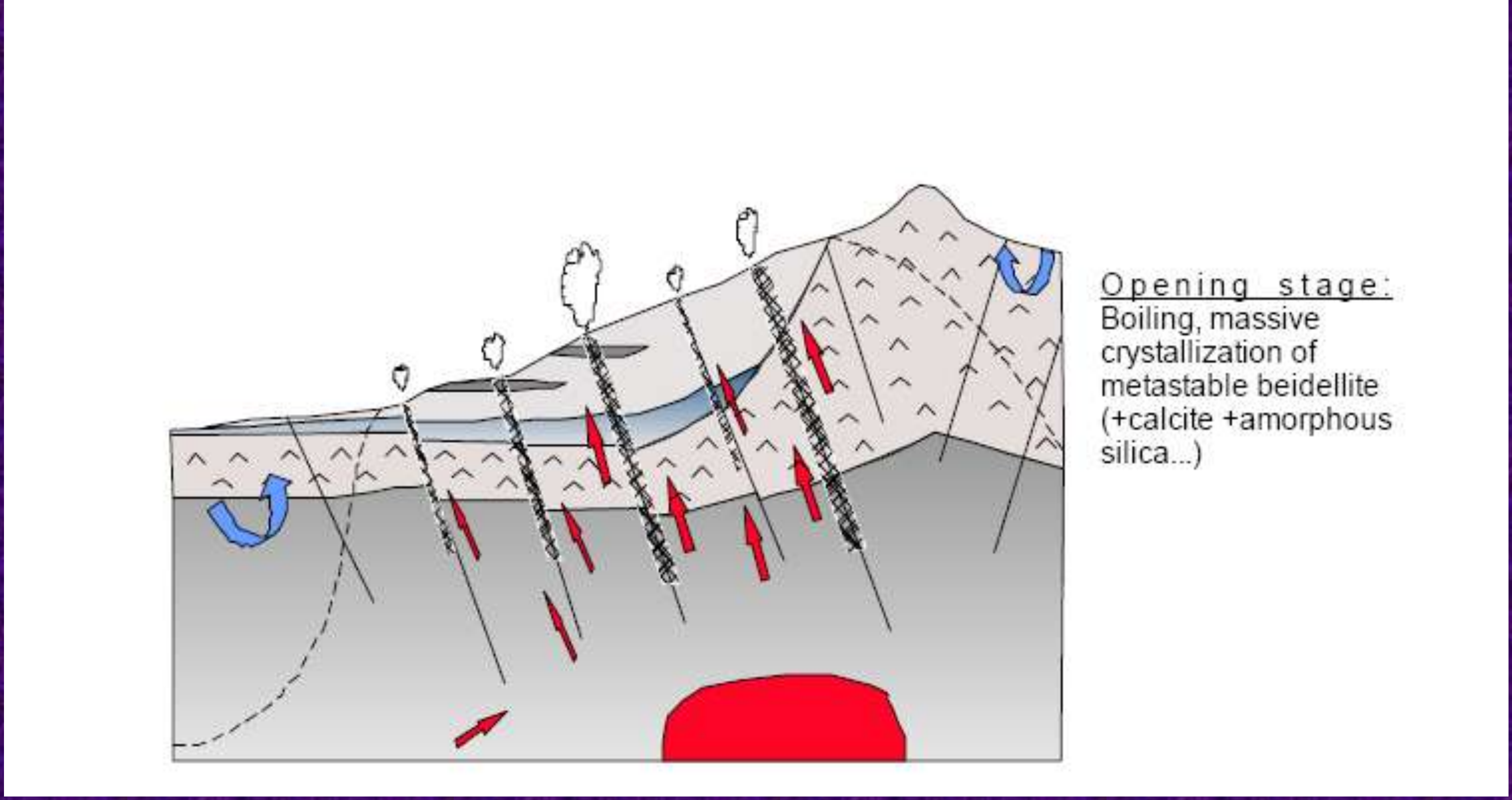
⬇

Present reservoir of Bouillante…

Texture and crystal structure of clay minerals could be a potential indicator of the hydrodynamic of fluids in the reservoir zones (past and recent)

General sketch : example of Bouillante geothermal field…

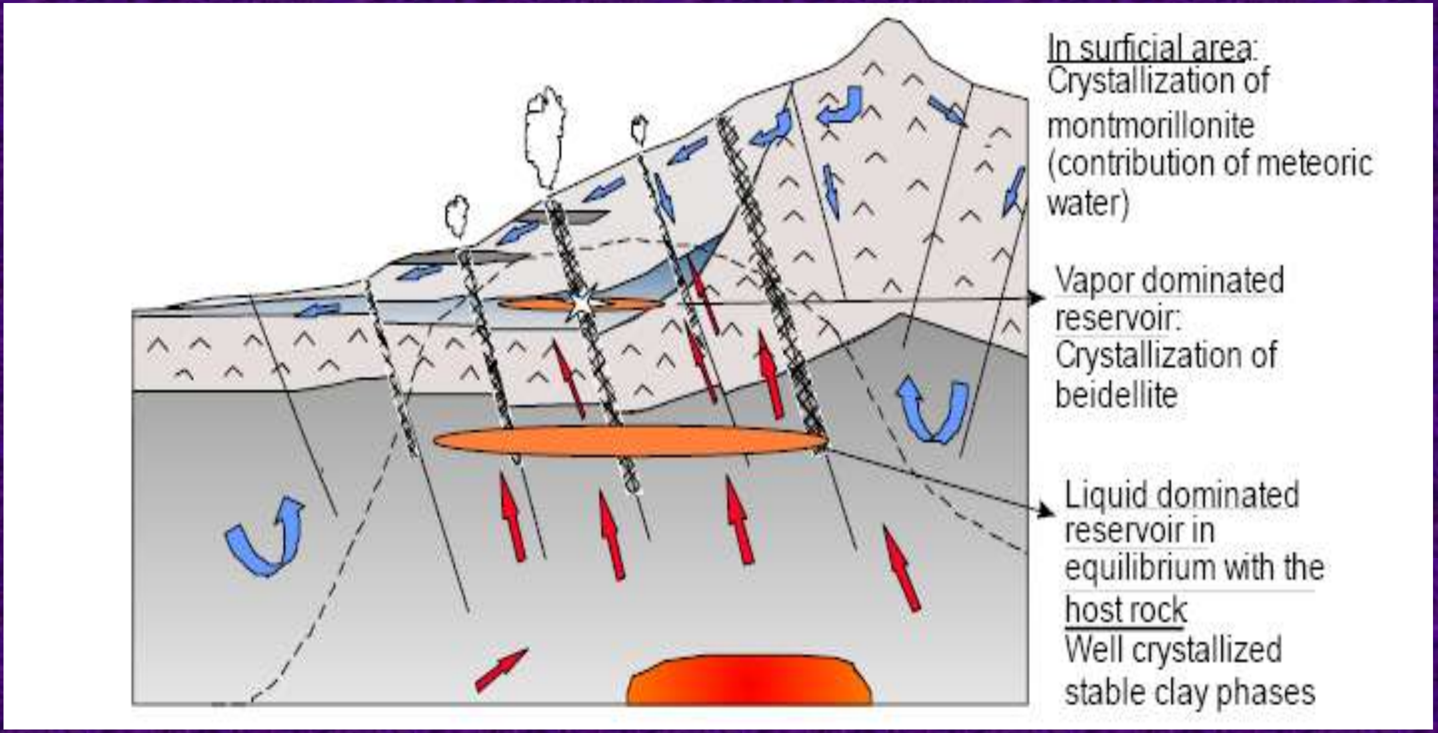
Opening : dramatic change in flow regime (extensive fracturing, tectonic reactivation)



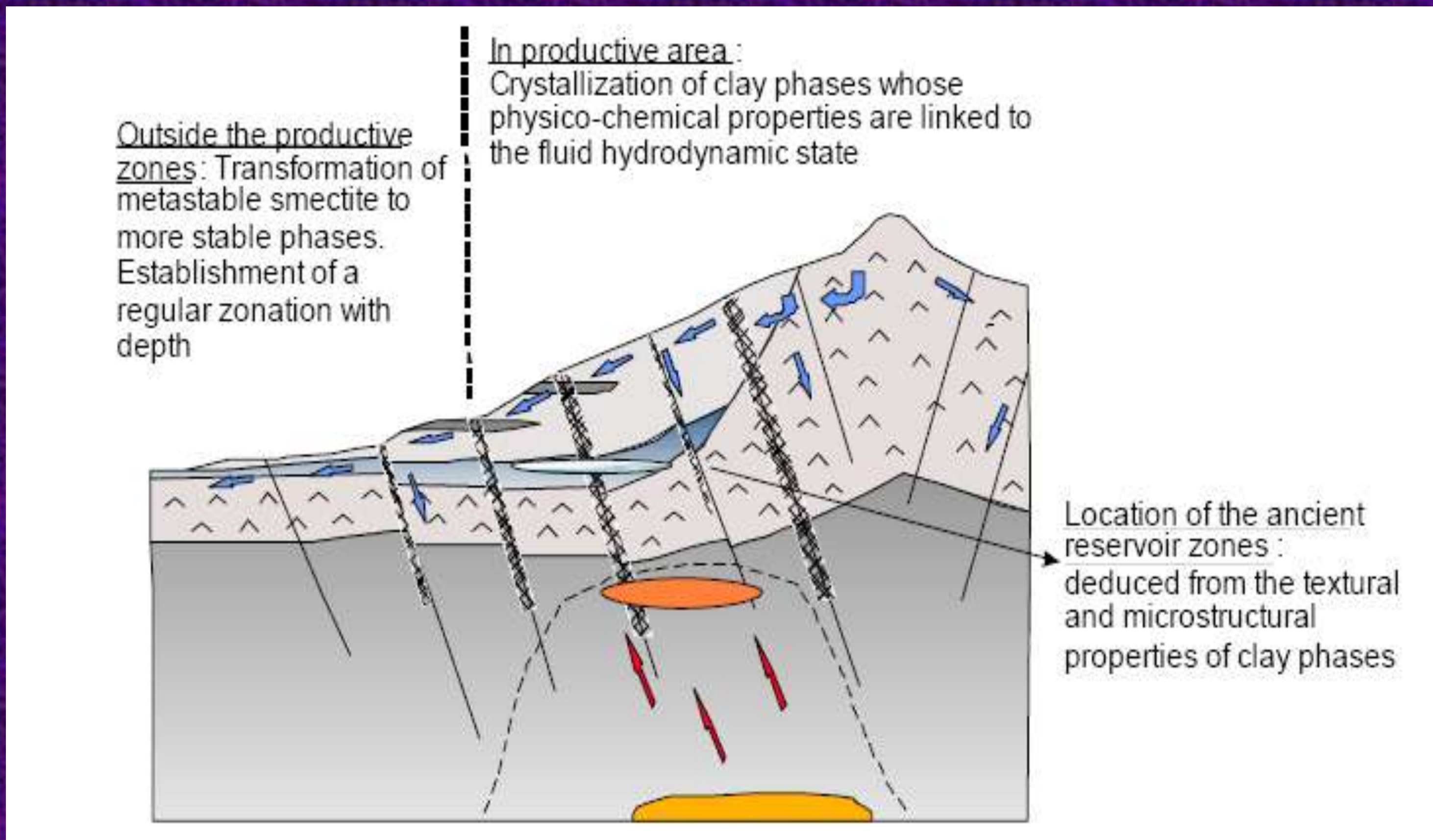
Per ascendum hydrological regime

General sketch

Progressive sealing
Progressive collapse…



General sketch



Collapsing of the hydrothermal activity in the system lead to a change in heat flow regime

Clay minerals...

Besides of their hypothetical use as accurate geothermometers, crystal-chemical and textural properties of clay minerals are a interesting tool to better understand the whole functioning of hydrothermal systems

In low to medium enthalpy geothermal systems
Plaine du Lamentin

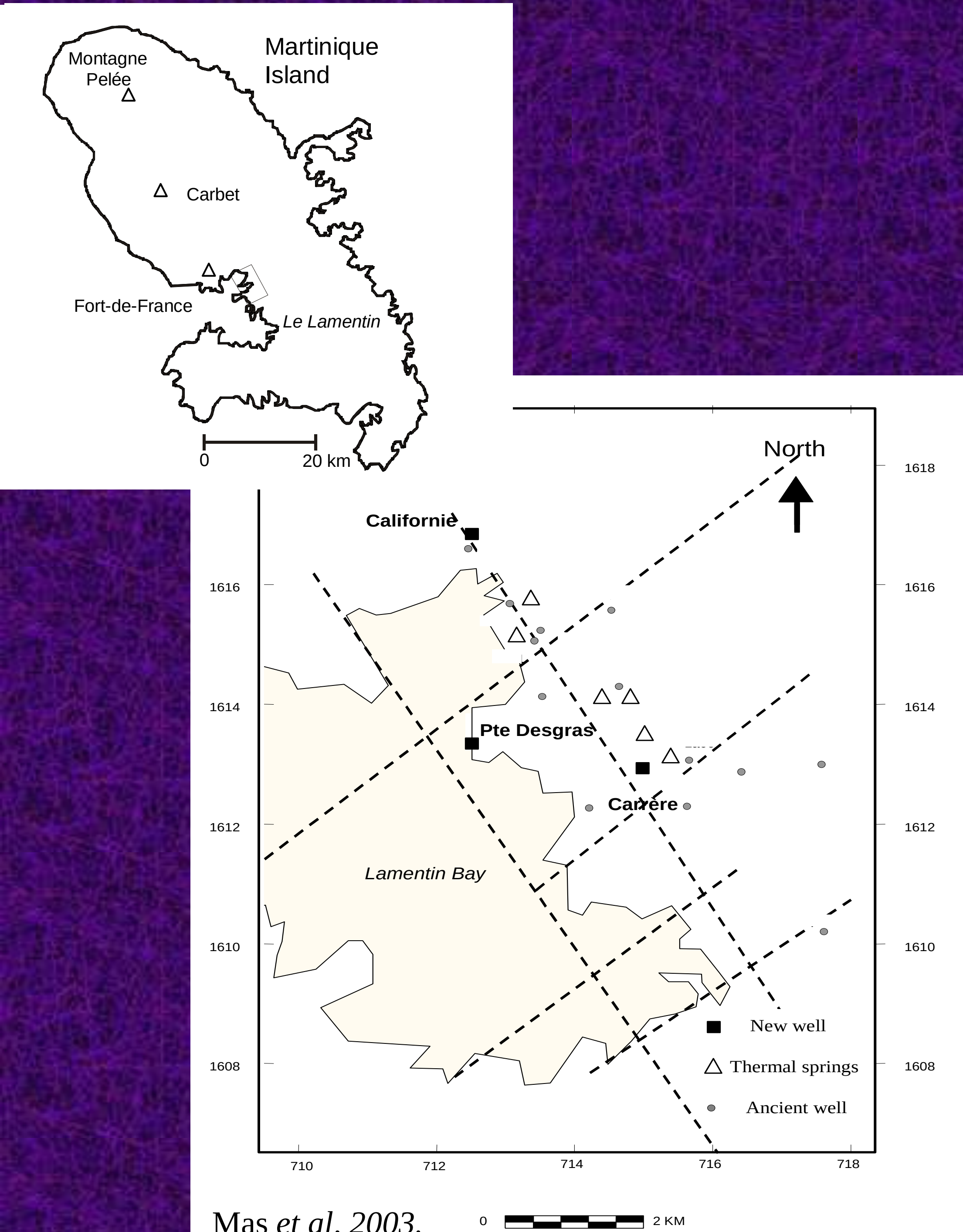
Clay minerals poorly studied in low to medium temperature geothermal systems :

- Studies focus on secondary minerals in high enthalpy reservoirs
- Clays minerals are quite similar to clay minerals formed during weathering
-Clay minerals superimposed on HT parageneses formed during arlier events

but

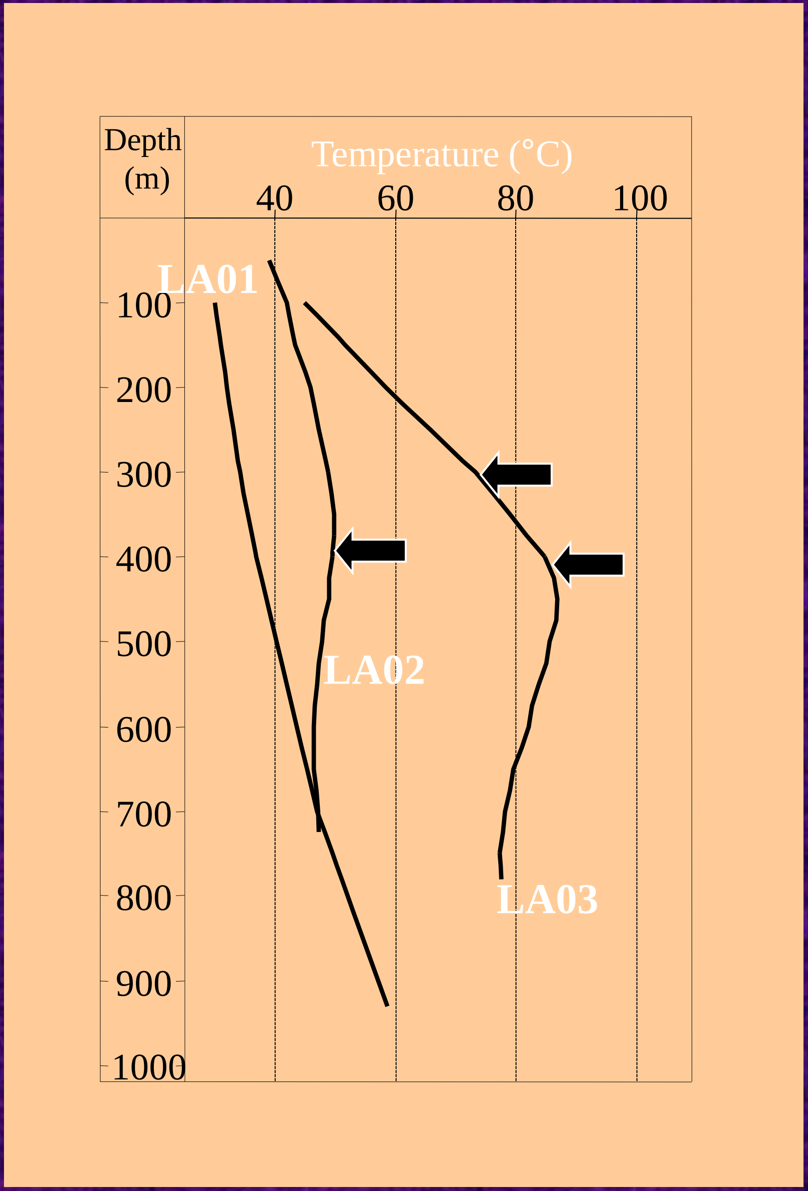
Most surficial part of geothermal field
Interest for prospection

In low enthalpy hydrothermal systems



Mas *et al*, *2003.*

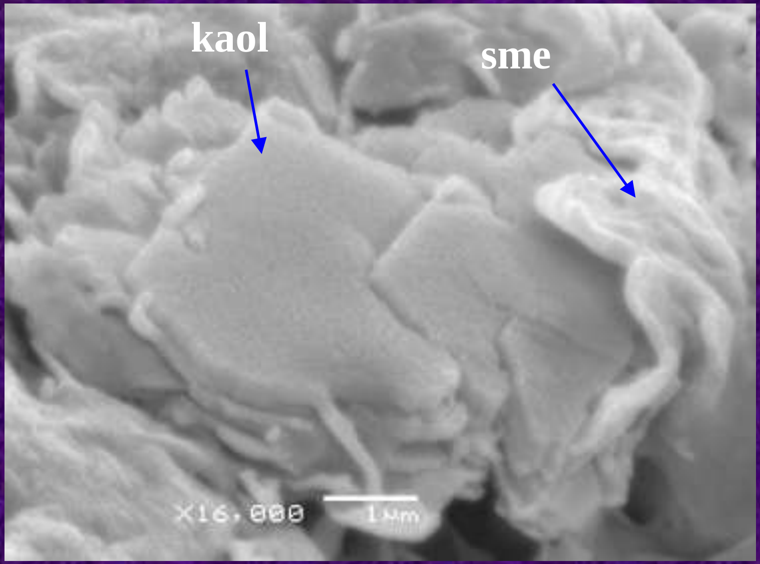
Lamentin area


Depth (m)
Temperature (°C)
40
60
80
100
100
200
300
400
500
600
700
800
900
1000
LA01
LA02
LA03

Lamentin

Textural/microstructural parameters

Different events of kaolinite crystallization occurred

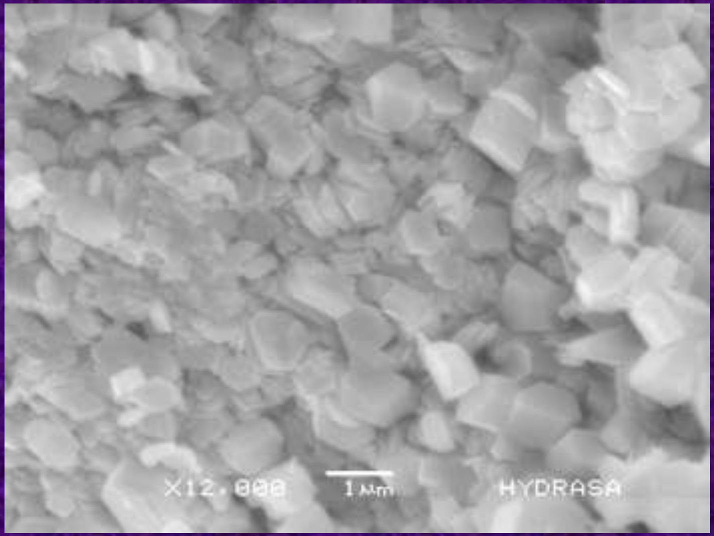


- « Early kaolinite »

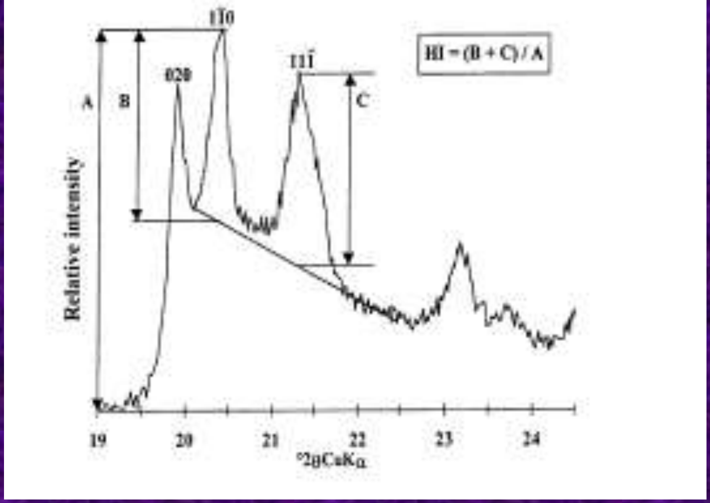
Dissolution features,
replacement by **smectite (Mt/Bei)**

- « Present » kaolinite

Euhedral crystals
No dissolution features

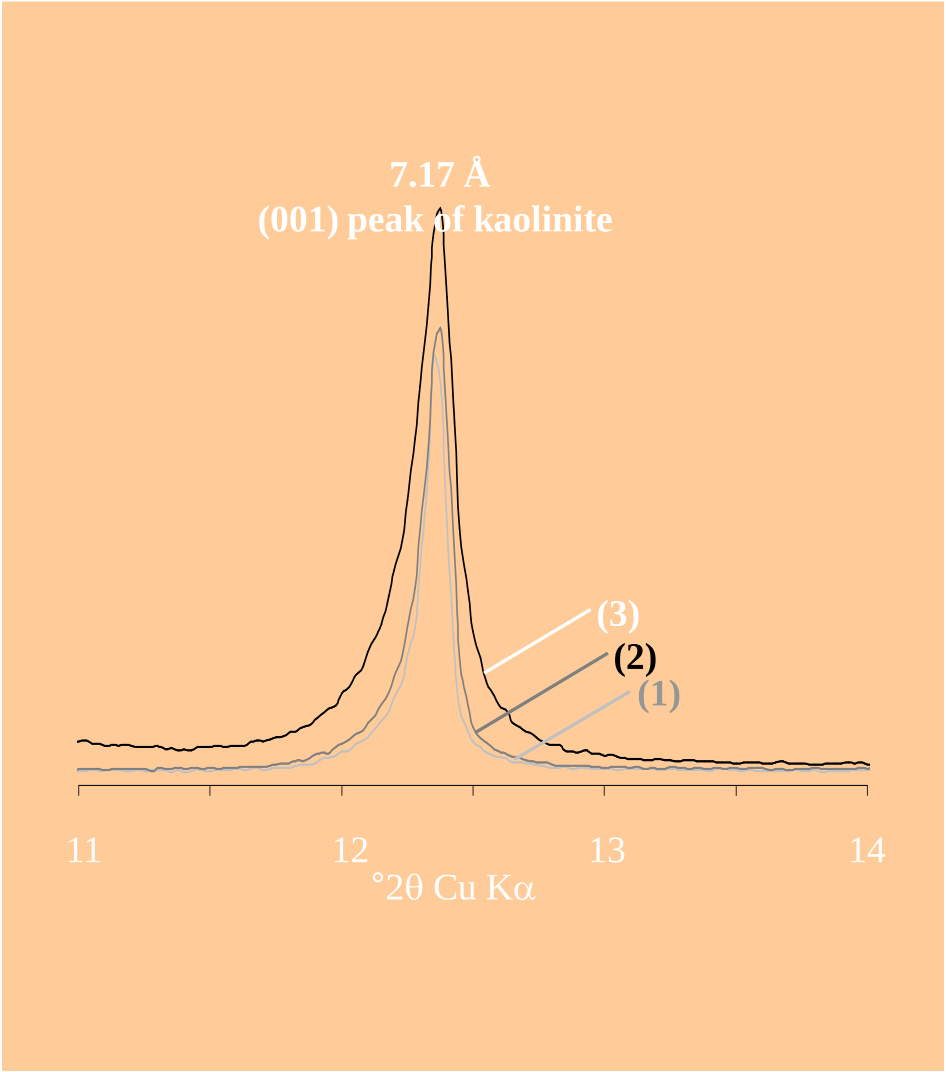


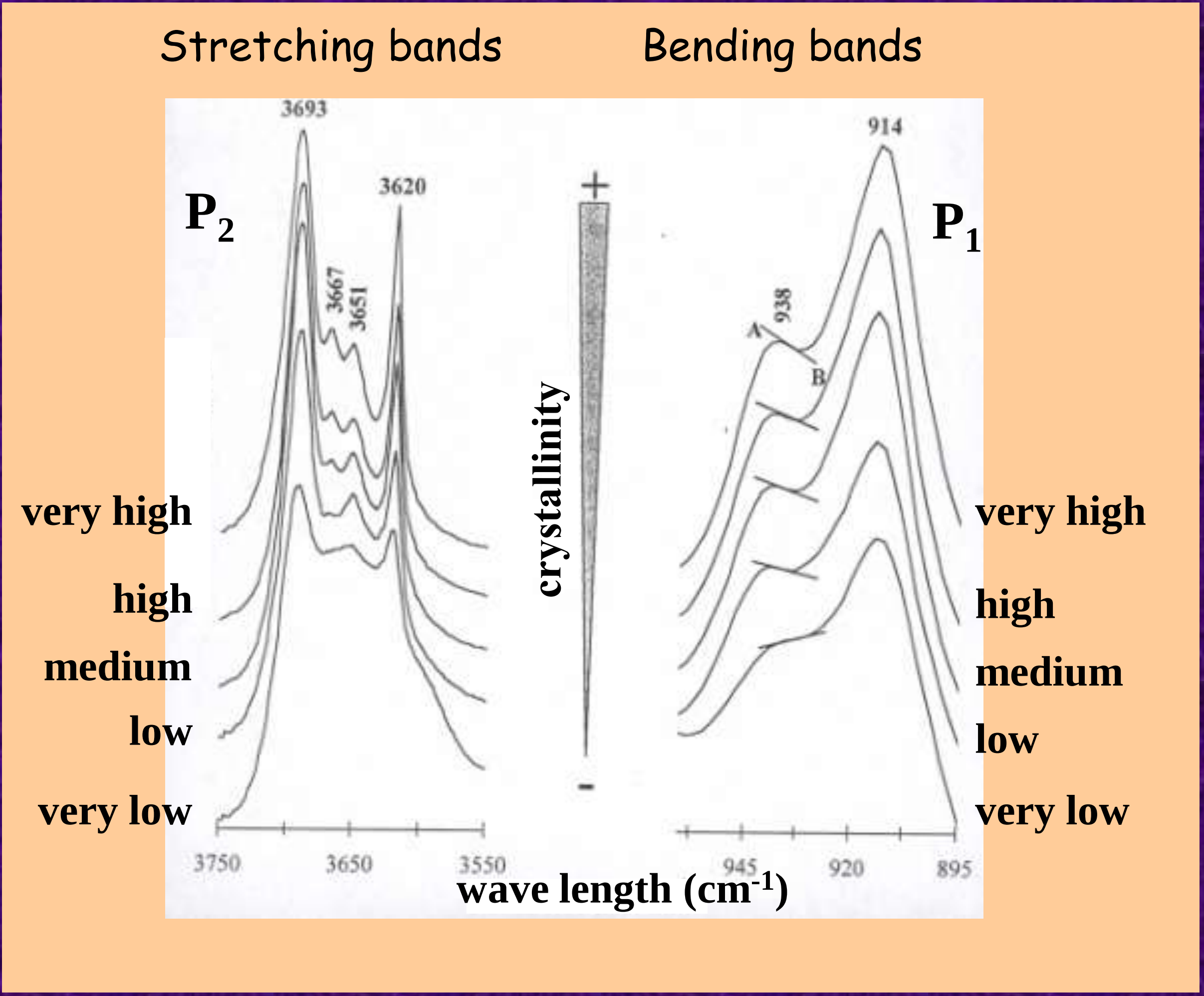
- Microstructural properties of kaolinites in present circulation zones as a function of hydrothermal fluid temperatures
3 : 50 °C - 2 : 70 °C - 1 : 90 °C



Hinckley index, 1963

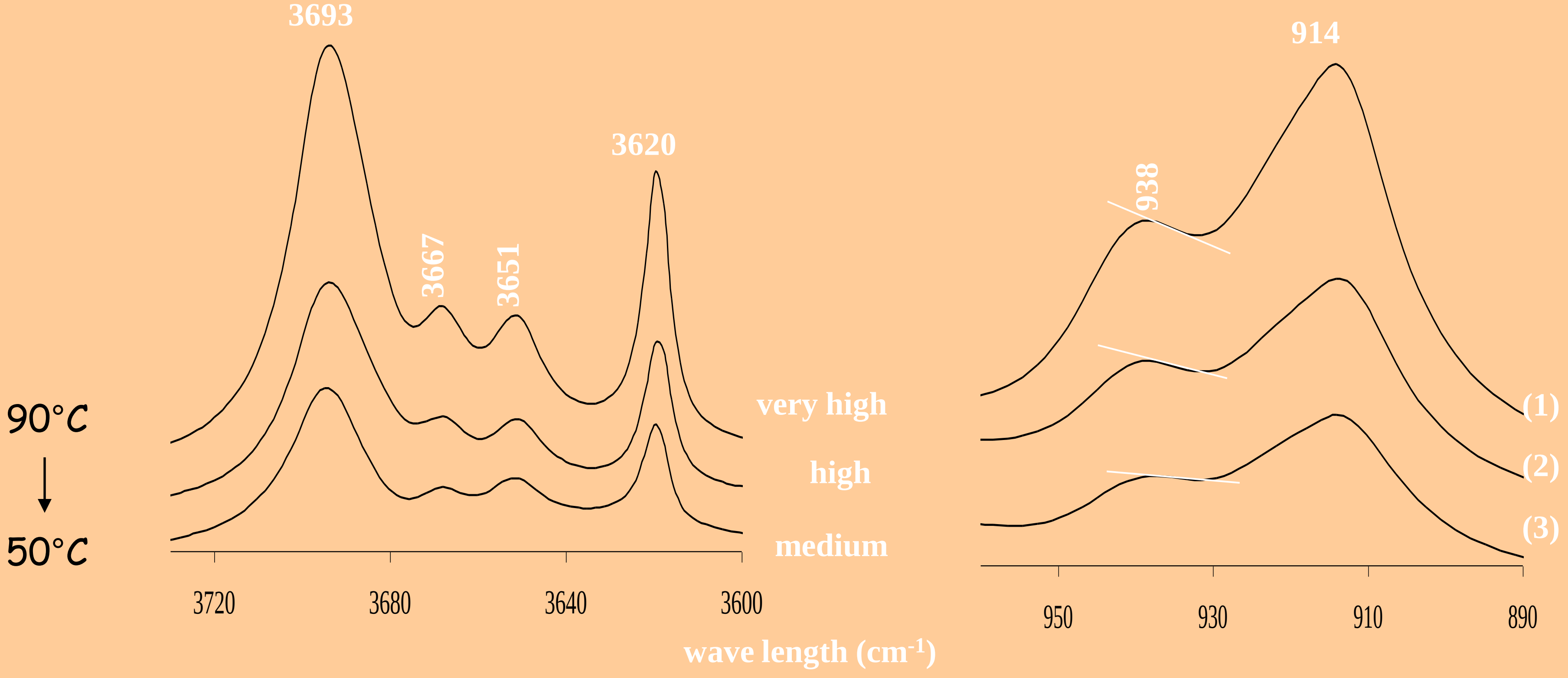
This index can vary between 0.20 (for the more disordered kaolinite) and 1.50 (for the most ordered kaolinite).





Lietard, 1977

Present day paragenesis - kaolinite



- Microstructural properties of kaolinites vary with hydrothermal fluid temperatures

- Different properties than supergen kaolinites

kaolinite crystallinity	–			+
well	LA02	LA03	LA03	LA03
depth (m)	390.60	311.00	410.15	405.60
FWHM (°2θ)	0.32	0.15	0.11	0.10
HI	0.51	0.80	1.27	1.32
P_1 and P_2	medium	medium	very high	very high
T fluid (°C)	50	70	90	90

Conclusion …

According to their kinetic control, clays minerals occurring in hydrothermal systems cannot be used in most cases as absolute geothermometers

Crystal-chemical , textural, microstructural properties…

Reaction rate, degree of transformation towards more stable phases

depend on

F/R (permeability), dT/dt,

Dynamic of the system

Prospection

Ready to explore hydrothermal systems…