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Epidotisation and fluid flow in sheeted dyke complex : new field and experimental constraints

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Introduction

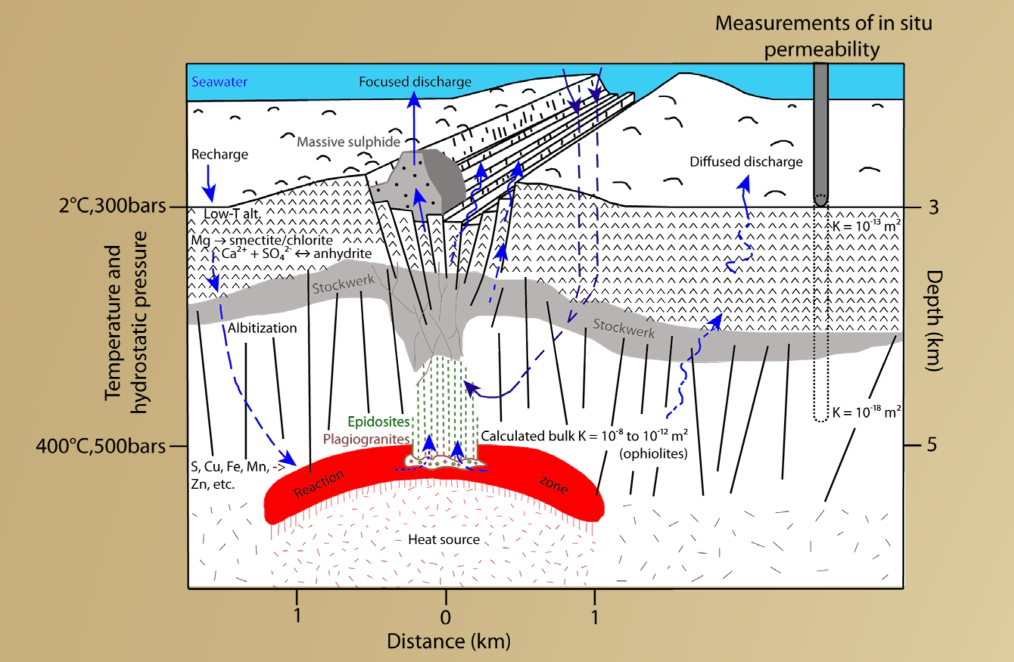


Diagram of a hydrothermal discharge area in the axial zone of a ridge from studies on several ophiolite complexes [3;4] and oceanic crust [5]

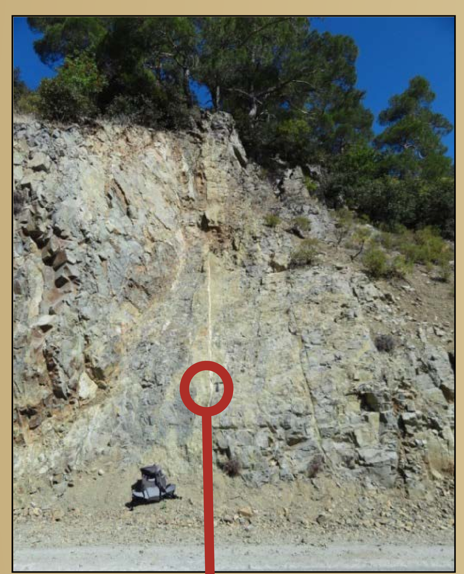
❑ Hydrothermal systems in oceanic crust are usually studied in situ via dredge samples and drilled holes.
❑ Their equivalents are also found in ophiolitic complexes (Cyprus, Oman). In the deepest zone, the fluids react with the sheeted diabase dikes at 400°C and 400 bars to form epidosites by enrichment in epidote and quartz [1]. Mineralogy and chemistry of epidosites have been widely studied on fields [1] and hydrology is generally studied using numerical models [2].

Objectives

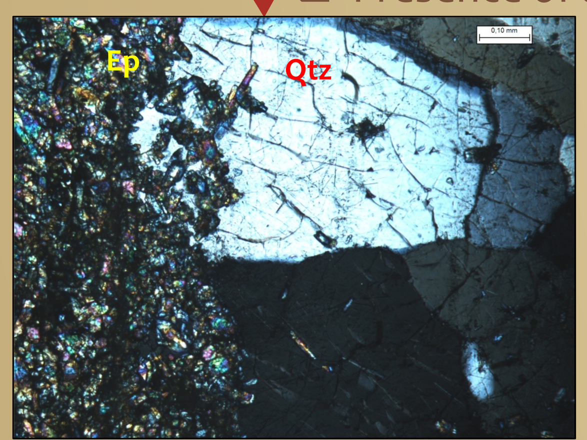
❑ **Problem** : relations between the emplacement of diabase dikes, their alteration in epidosites and deformation.
❑ **Experimental approach** : I) stress the P-T-fO_2 conditions of the reaction of epidotisation and, II) quantify interrelations between the permeability and the epidotisation during deformation.

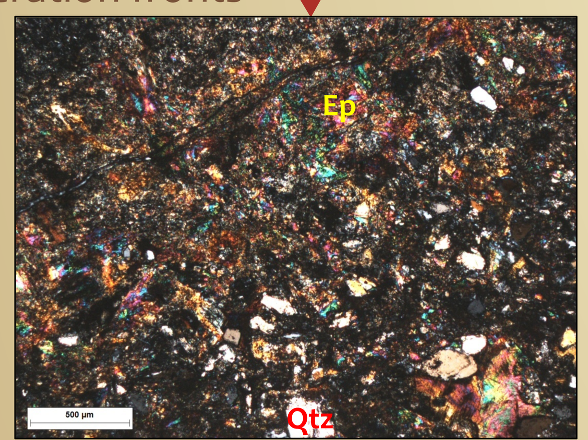
I. Field observations : two types of epidotisation

Hydrothermal epidote in fractures VS Pervasive epidosite in core of dikes

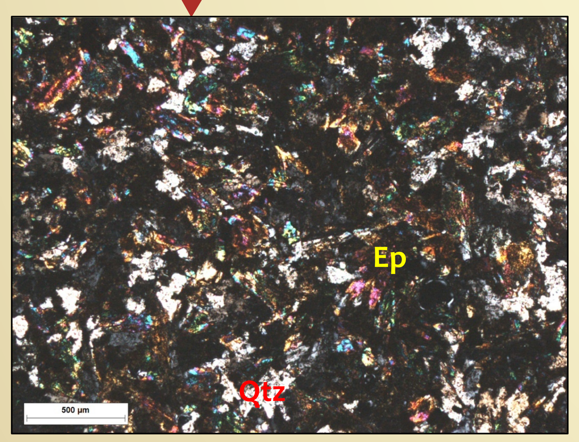

Epidotised cooling joint planes

❑ Presence of alteration fronts









❑ Dikes are hydrogeologically distinct.
❑ Magmatic texture is absent.

II. Experimental study of the reaction of epidotisation

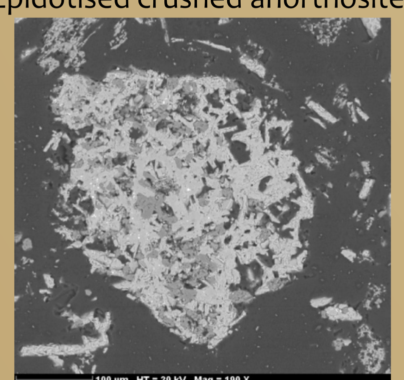
Materiel & methods

❑ Static autoclave with external heating.
❑ Duration of each experiment : 1 month.
❑ Fluid/rock ratio = 5.
❑ fO_2 controlled by a hematite-magnetite buffer.

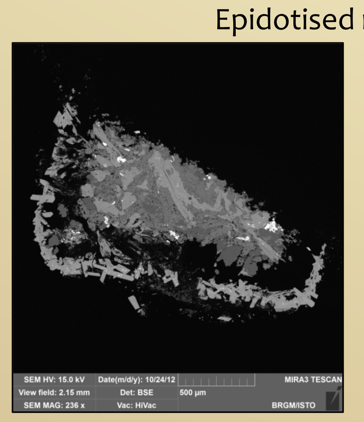
Results at 400°C/400 bars

Products = hedenbergite
▪ Literature : epidote has never been synthesized below 2 kbars (possible from germs : [6]).
▪ Problem : kinetics or nucleation (too high activation energy ?).

Results at 500°C/2500 bars

Epidotised crushed anorthosite


Epidote formation	Starting material	Hematite	HM buffer	Fluid
Yes	Anorthosite (50% An)	Yes	Yes	30 wt. % $CaCl_2$
No (hedenbergite)	Anorthosite	Yes	No	30 wt. % $CaCl_2$
No	Anorthosite	Yes	Yes	3.5 wt. % NaCl
No	Anorthosite	No	Yes	30 wt. % $CaCl_2$
Yes	Albite	Yes	Yes	30 wt. % $CaCl_2$
Yes	Metadiabase (Troodos)	Yes	Yes	30 wt. % $CaCl_2$
Yes	Metabasalte (Troodos)	Yes	Yes	30 wt. % $CaCl_2$

Epidotised metadiabase



6 albite + 1 anorthite + 2 hematite + 7 Ca^{2+} + 6 H_2O $\longrightarrow$ 4 epidote + 8 quartz + 6 Na^+ + 8 H^+
or 6 albite + 1 anorthite + FeO (Fe from silicates) + 7 Ca^{2+} + 8 H_2O $\longrightarrow$ 4 epidote + 8 quartz + 6 Na^+ + 8 H^+ + 2 H_2

Variation of molar volume : $\Delta V = [V(\text{products}) - V(\text{reagents})] / V(\text{reagents}) \times 100 = -3{,}3\,\%$ ➡ porosity ↗

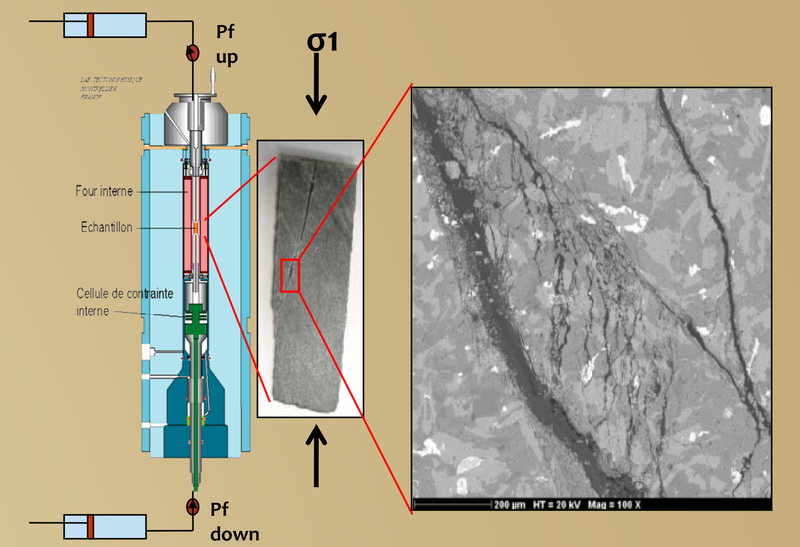
III. Interrelations between permeability-deformation-alteration

Materiel & methods

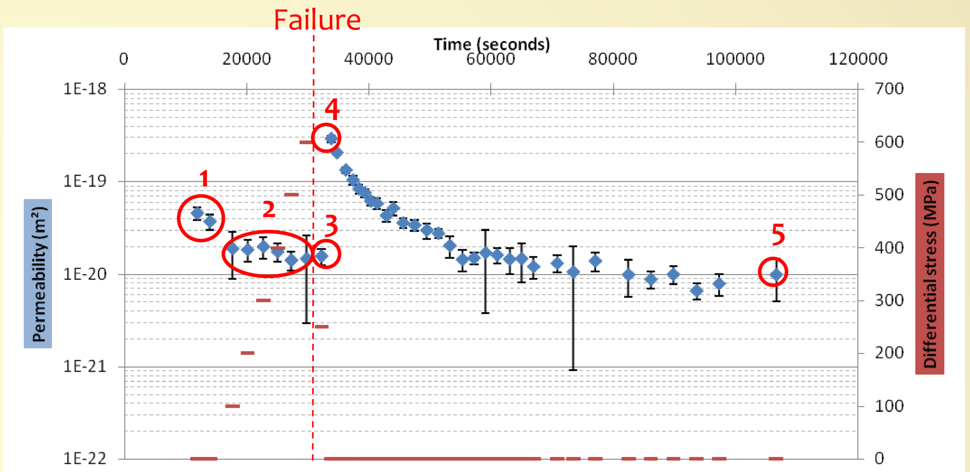

Paterson apparatus

❑ Samples : metadiabase (quartz, actinolite, chlorite, plagioclase feldspar) and epidosite (epidote, quartz, chlorite) from Troodos.
❑ Temperature : 400°C.
❑ Confining pressure : 1000 bars (argon).
❑ Pore pressure : 500 bars (water VS argon).
❑ Permeability was measured before, during and after coaxial deformation using the steady state flow method for Darcian flow :

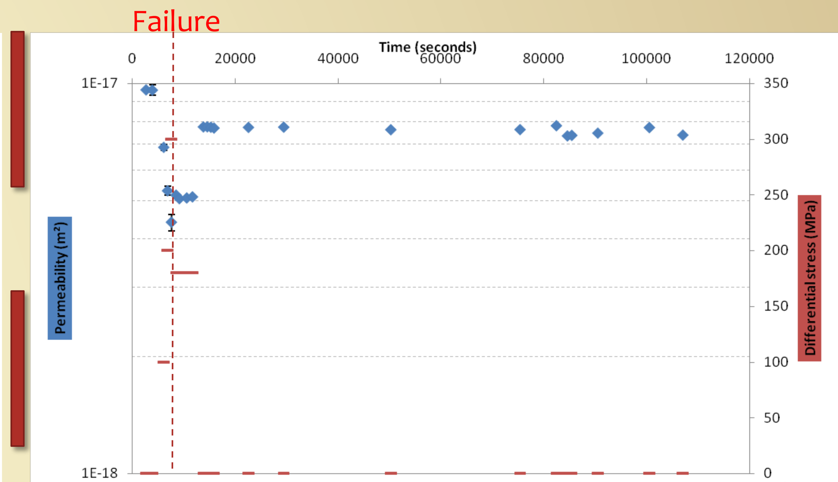
$$K = \mu L Q / A \Delta P$$



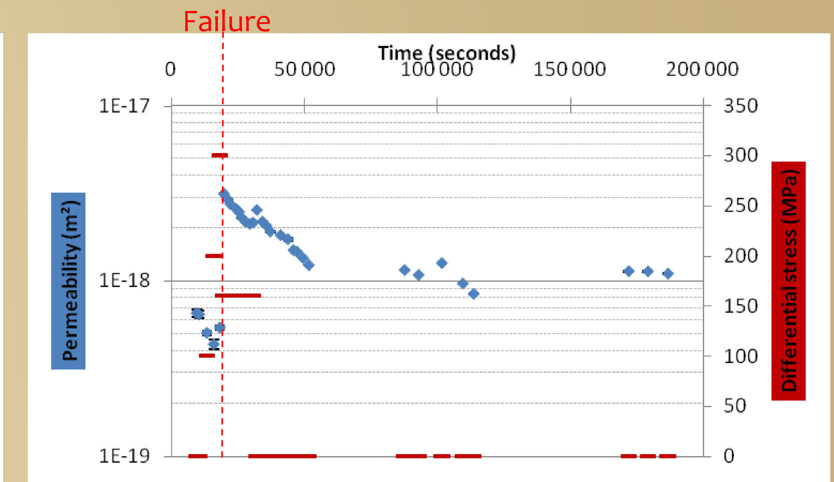
Results



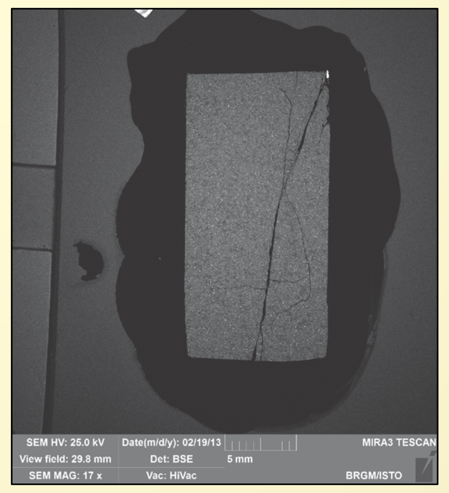
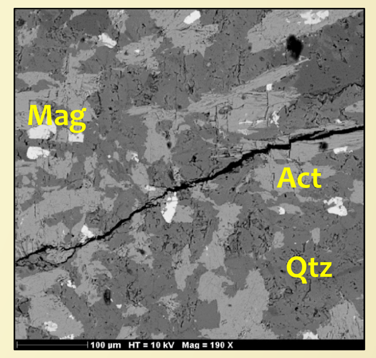
Evolution permeability on **metadiabase** with **water** as pore fluid

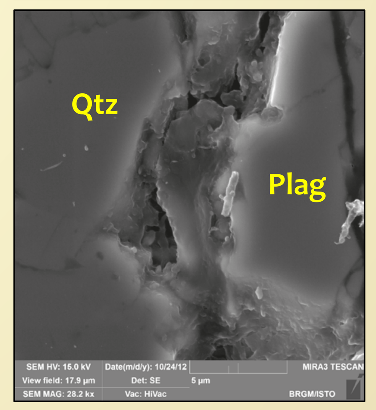


Evolution permeability on **epidosite** with **argon** as pore fluid

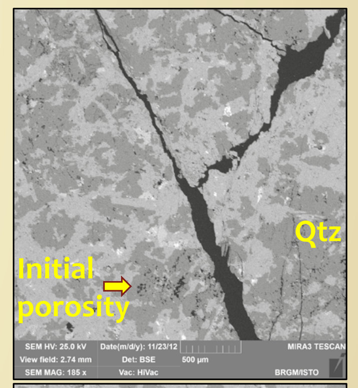


Evolution permeability on **epidosite** with **water** as pore fluid

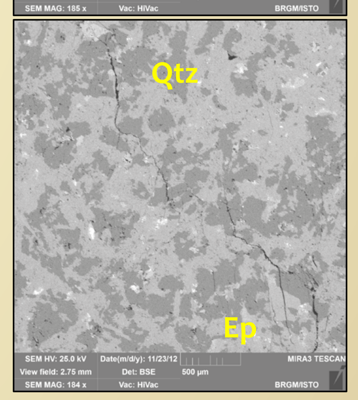





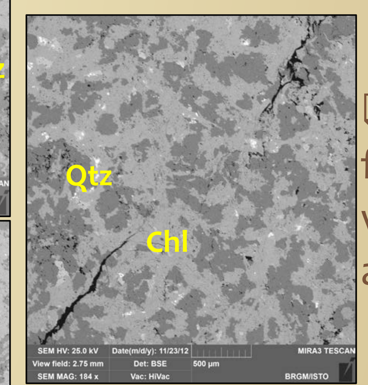
❑ Microcracks parallel to σ1 and micro fractures perpendicular to σ1.
❑ Presence of silica gel within grain boundary microcracks.



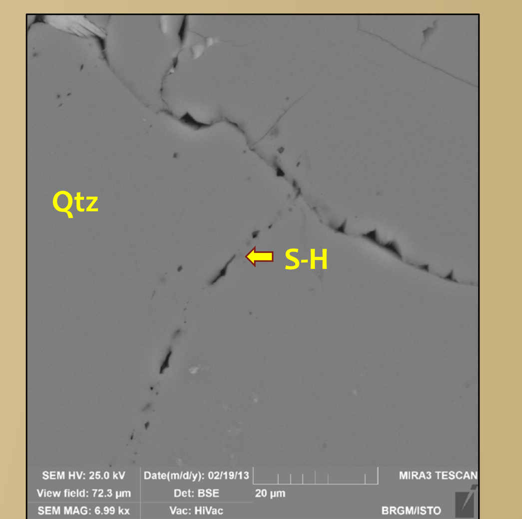
❑ Conjugate fractures.



❑ Micro fractures along epidote grains.



❑ Discontinuous fractures (gouge) where chlorite is abundant.

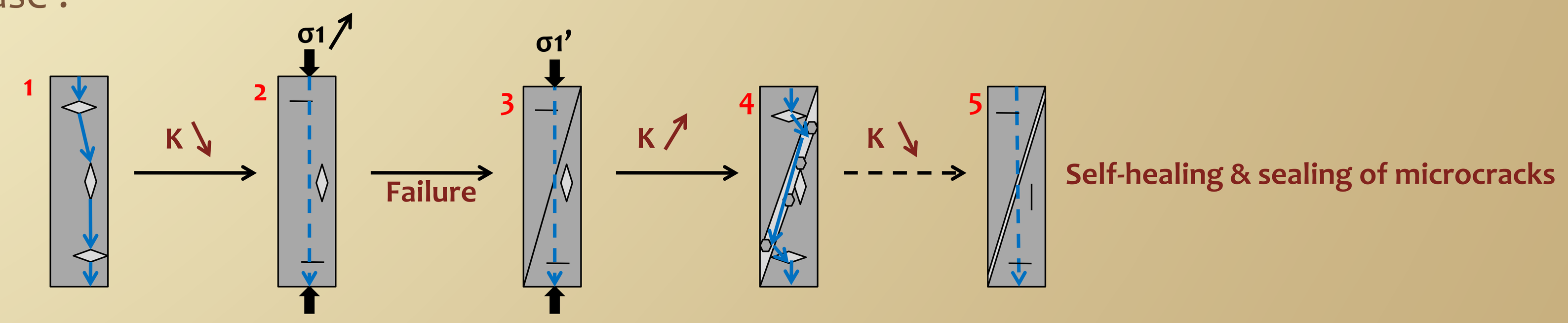


❑ Textures suggestive of self-healing (S-H) in quartz grains from water experiments.

Conclusion

❑ Mechanical behavior of metadiabase :

Permeability reduction after failure is explained by mineral precipitation.



❑ Non-epidotised sheeted diabase dikes present very low permeability (10^{-20} m²) ➡ Main problem = initiation of the circulation of hydrothermal fluid : 2 possibilities : 1) fluid flow via fracturation (permeability increases by at least one order of magnitude) and, 2) fluid flow in a late magmatic stage via segregation of porosity during introduction of dyke [7].
❑Positive feedback : epidotisation creates porosity.
❑ Other problem : No nucleation of epidote à 400°C and 400 bars ➡ The system needs more energy : 2 possibilities : 1) boiling (explosion in the roof of the magma chamber) or, 2) nucleation enhanced at higher temperature via a volcanic glass (deuteric alteration).
❑ So 2 types of epidotisation that can be explained by the timing between the activity of magma chamber and the reaction of epidotisation.
❑ Massive epidotisation is enhanced by an increase of fO_2 in the reaction zone and a fluid enriched in Ca and Fe.
❑ Deformation of abundant chlorite ➡ Formation of gouges.

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