Institut National des Sciences Appliquées

ACOUSTIC EMISSION AND GAS PERMEABILITY CONTRIBUTION TO STUDY ROCKS BEHAVIOUR

William PRINCE AGBODJAN

Professeur des Universités

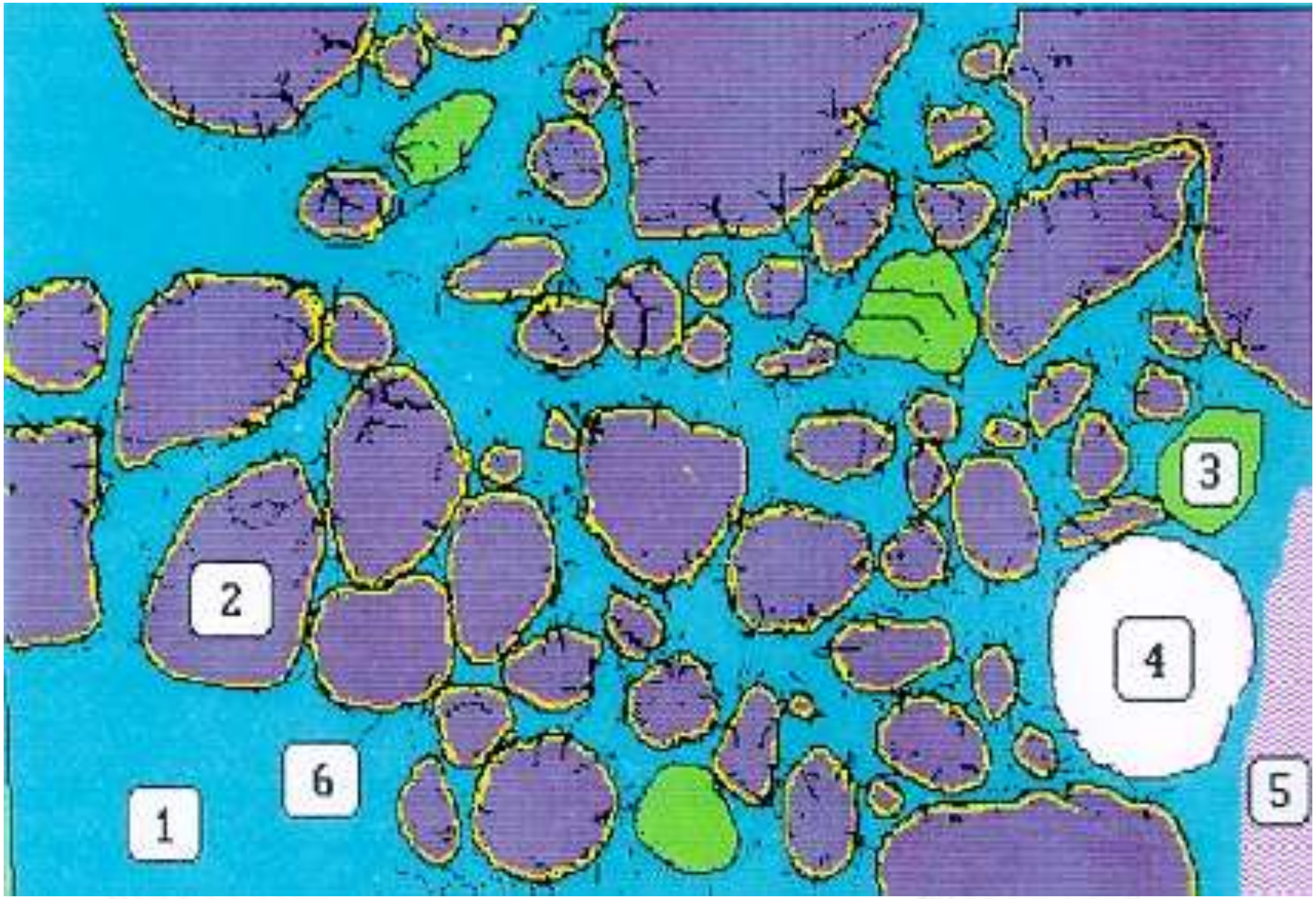
Directeur adj. du département Génie civil

INSA-Rennes

R. Pérami

Bridge of de île de Ré (France)

Bridge of Milhau (France)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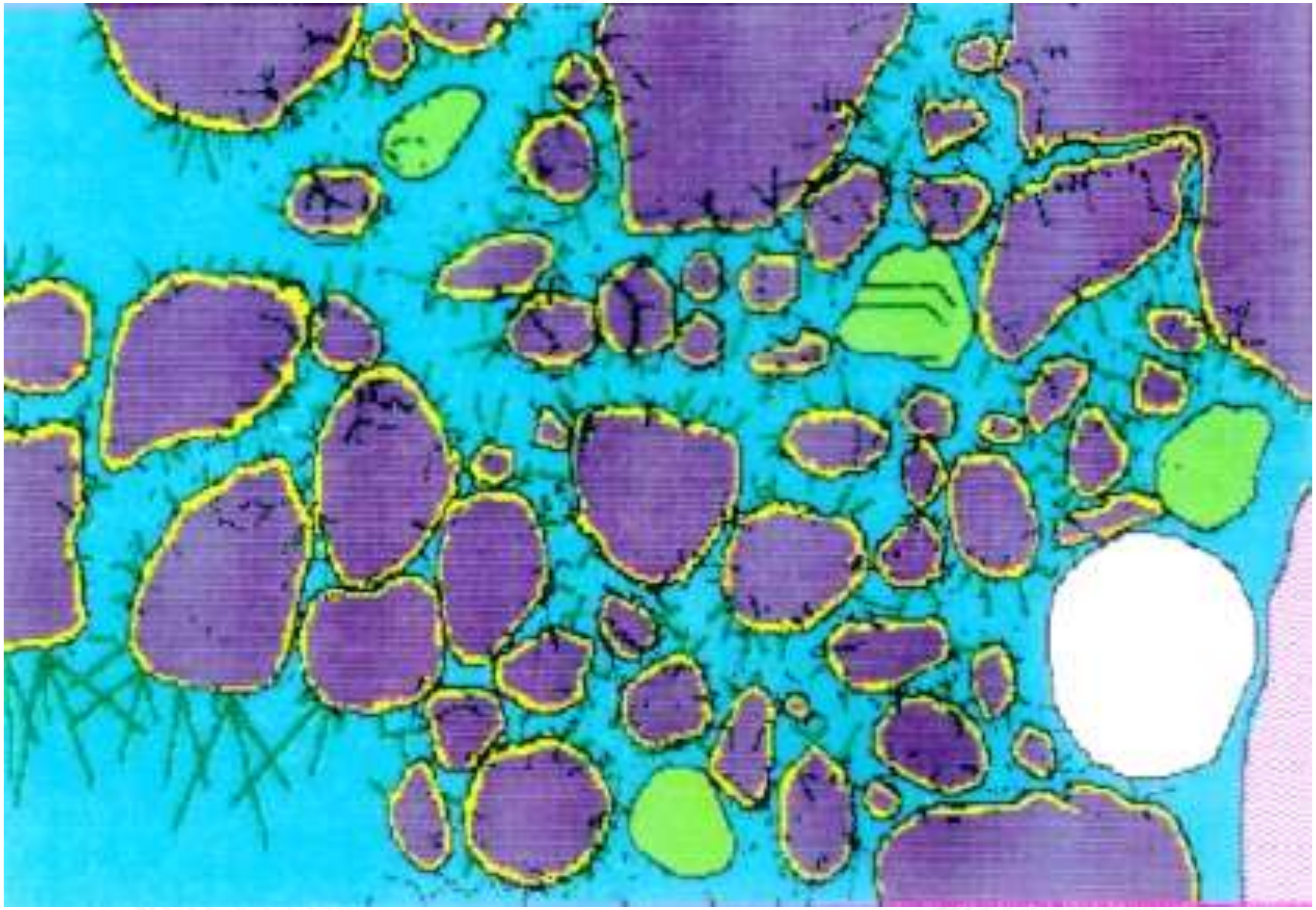

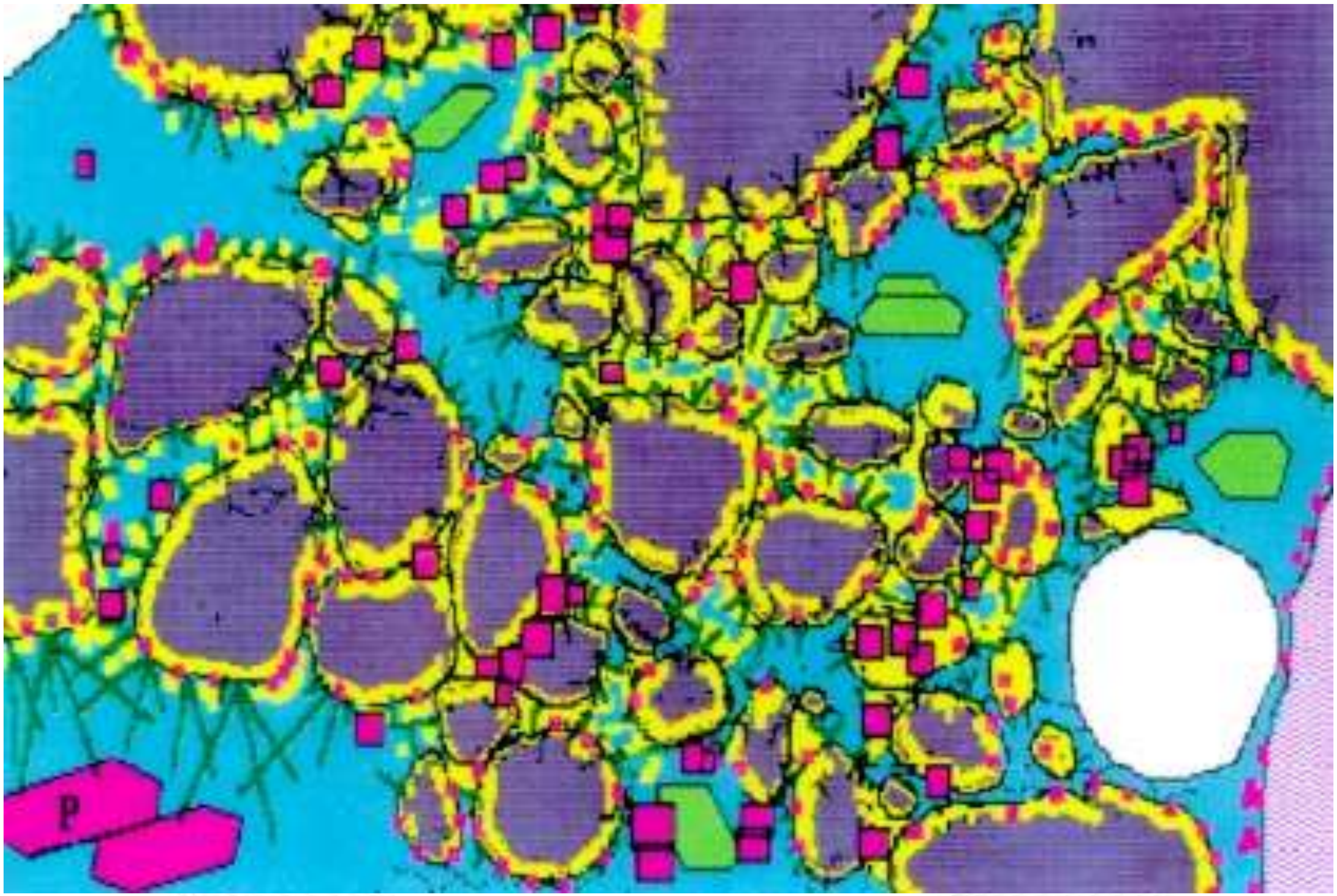
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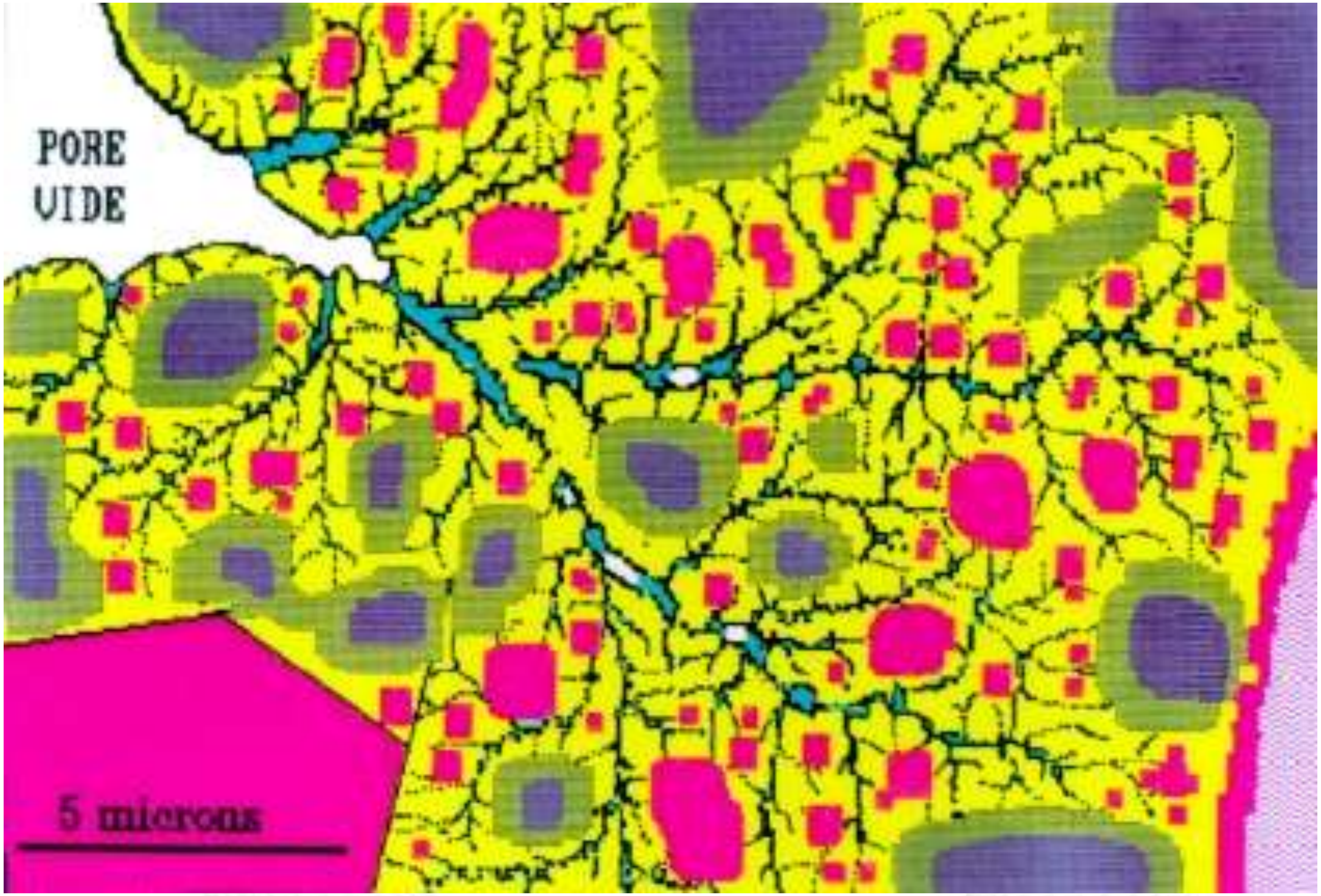
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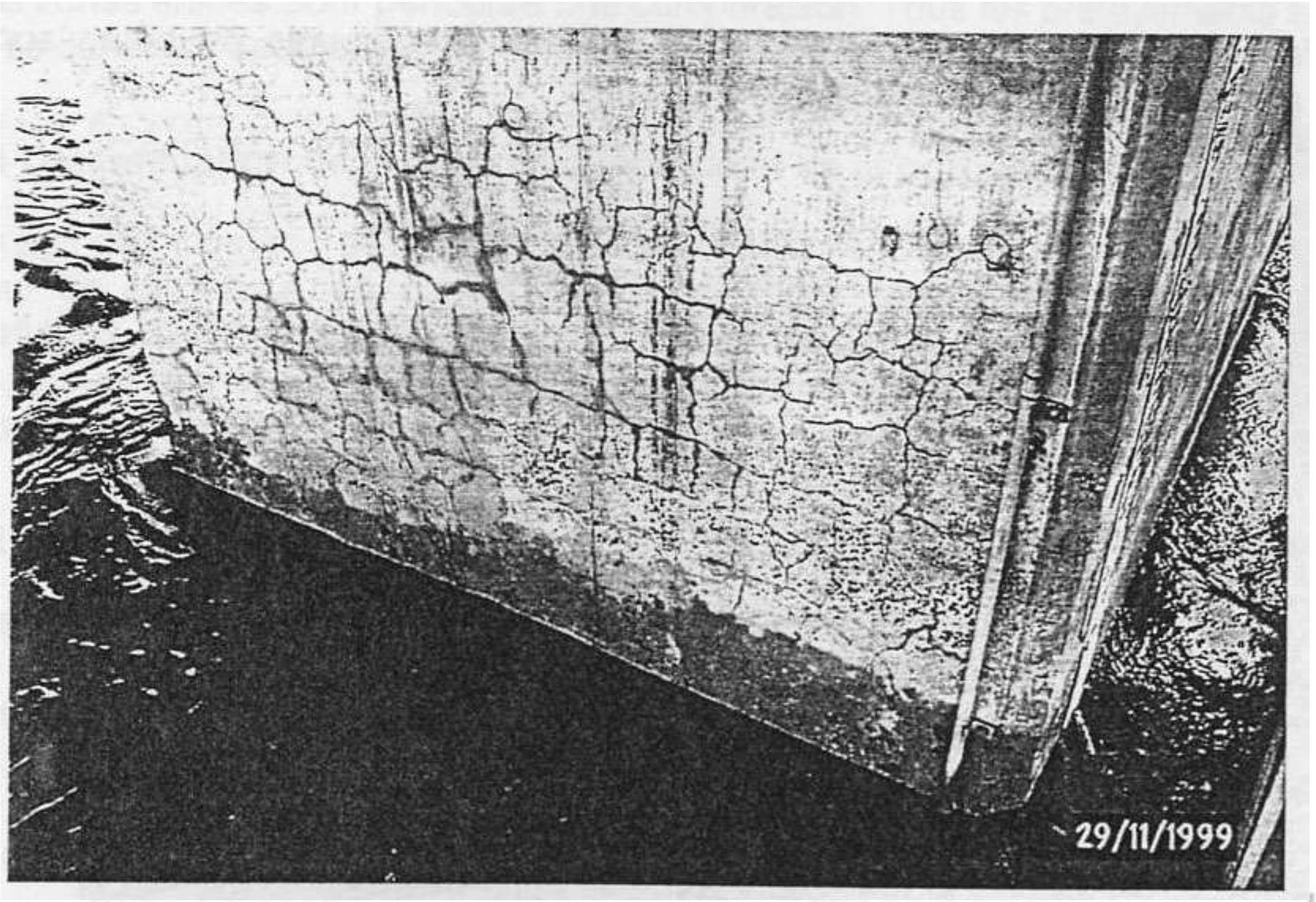
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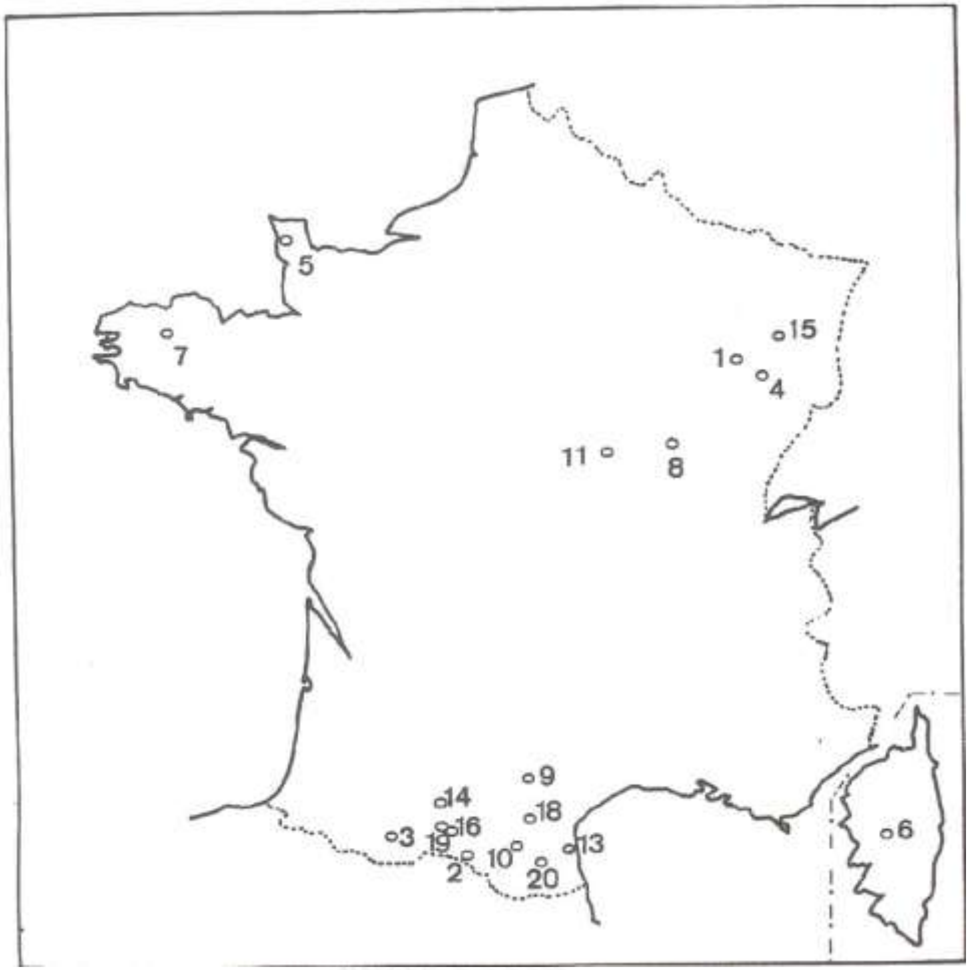
Geographical location of the samplings



PREMIER GROUPE : ROCHES MINERALOGIQUEMENT HETEROGENES

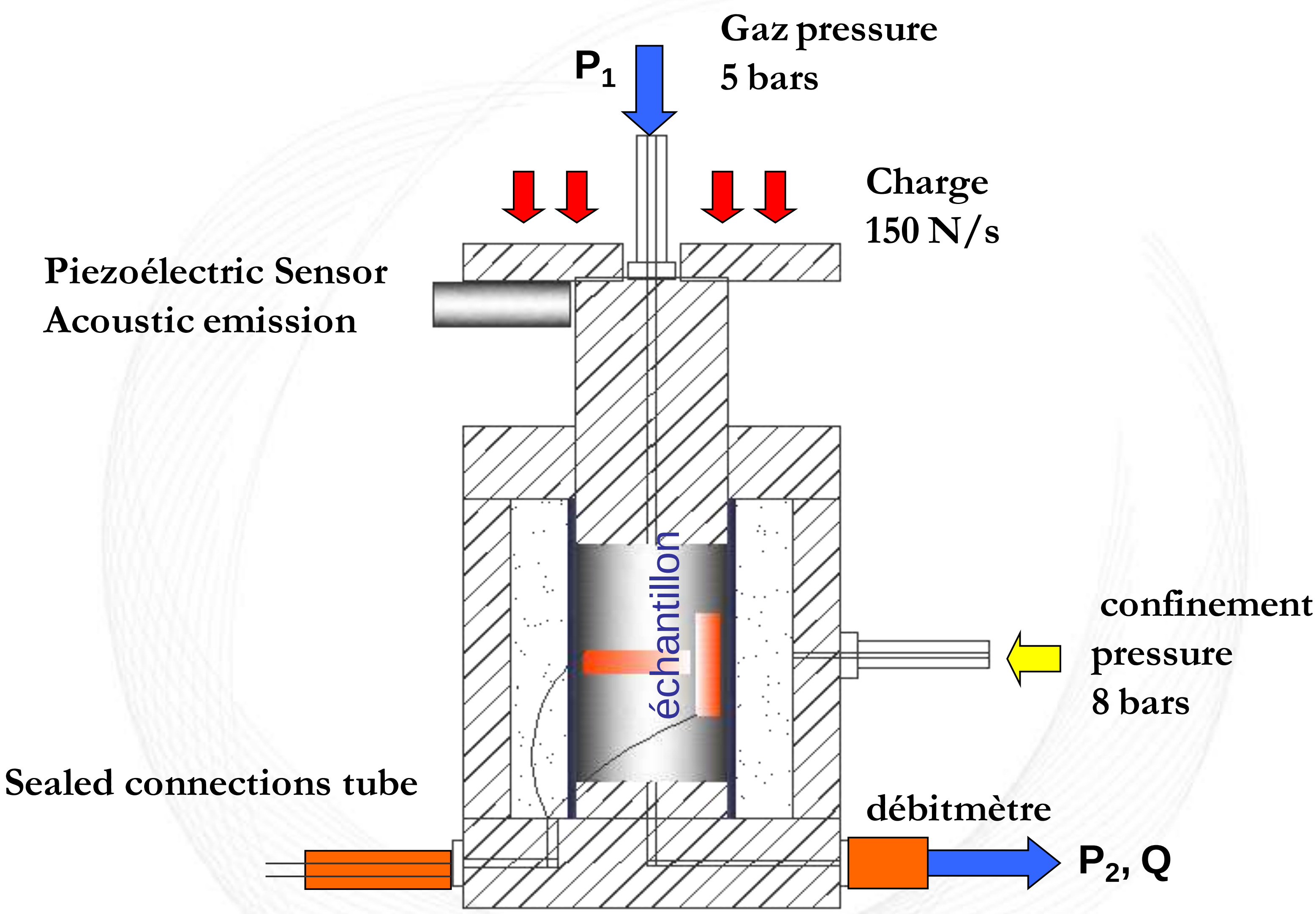
1 Granite de LA FORGE (A.C.)
2 Granite de SALAU (L.M.)
3 Granite de CAP DE LONG (A.C.)
4 Granite de LA BRESSE (A.C.)
5 Granite de FLAMANVILLE (A.C.)
6 Granite de CALACUCCIA (L.M.)
7 Granite de HUELGOAT (A.C.)
8 Granite de SAINT GERMAIN (A.C.)
9 Granite du SIDOBRE (L.M.)
10 Granite de QUERIGUT-MILLAS (L.M.)

11 Rhyolite de CORBIGNY (A.C.)
12 Syénite alcaline (Laurwickite) (L.M.)
13 Syénite néphélinique de FITOU (L.M.)
14 Ophite de SALIES DU SALAT (A.C.)
15 Basalte de RAON L'ETAPE (A.C.)

SECOND GROUPE : ROCHES MINERALOGIQUEMENT HOMOGENES

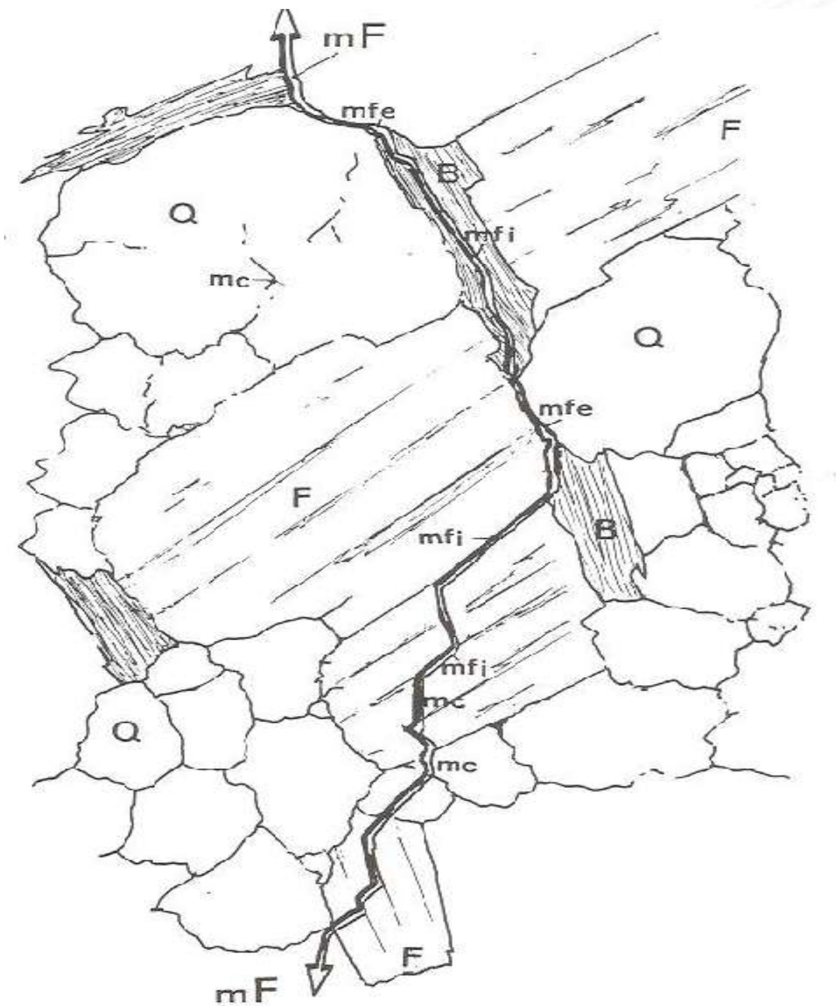
16 Calcaire microcristallin de SAINT BEAT (L.M.)
17 Calcaire grenu de SAINT BEAT (L.M.)
18 Calcaire à gros grain de MOSSET (A.C.)
19 Dolomie microcristalline de SAINT BEAT (L.M.)
20 Dolomie grenue de SAINTE COLOMBE sur GUETTE (L.M.)

Special device for compressive loading




protégez vos yeux

Microscopic discontinuities in rocks



mc : microcracquelure

mfi : microfissure intracristalline

mfe : microfissure intercristalline

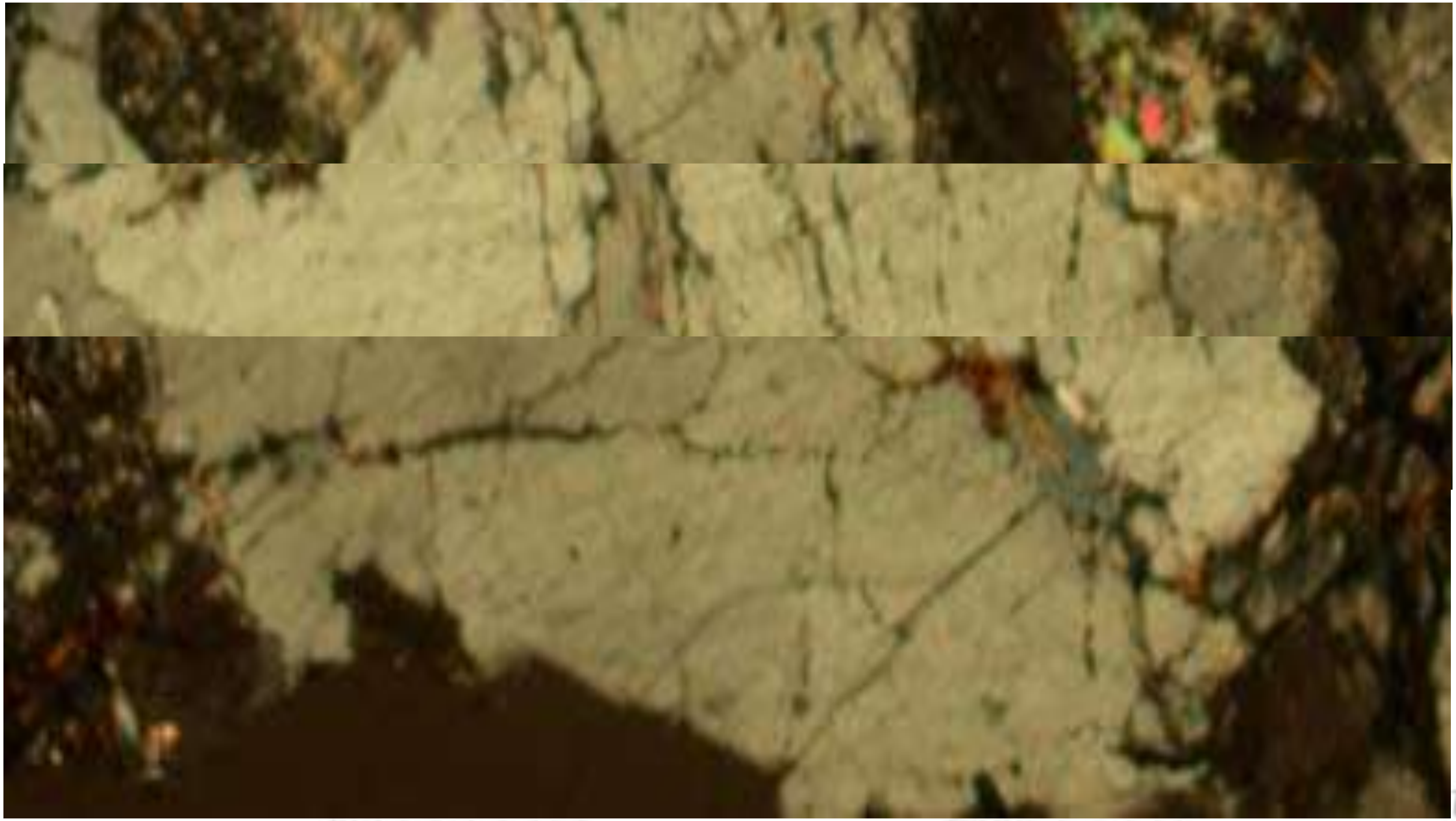
mF : microfracture

Q : Quartz

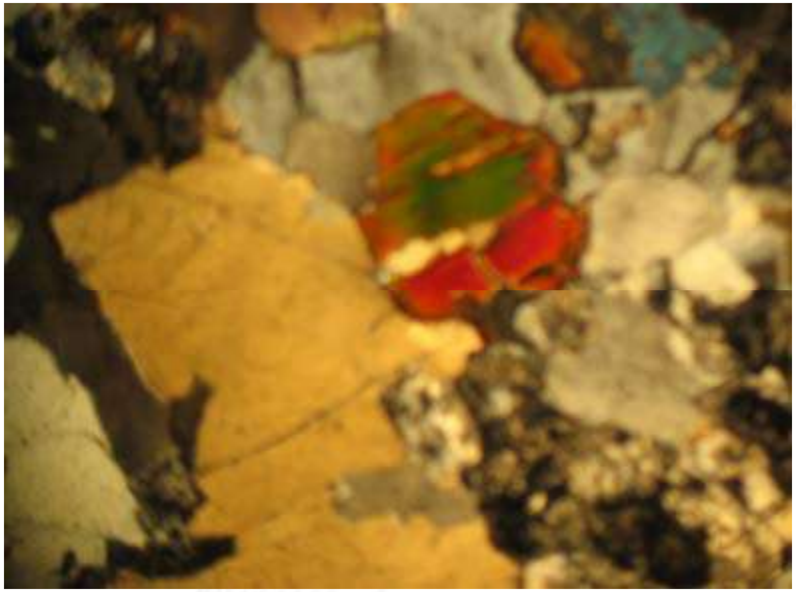
F : Feldspath

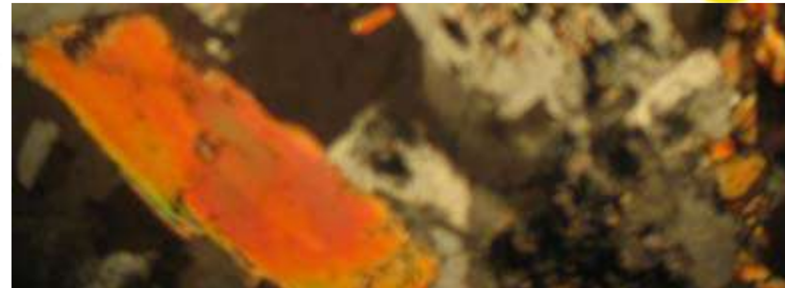
B : Biotite

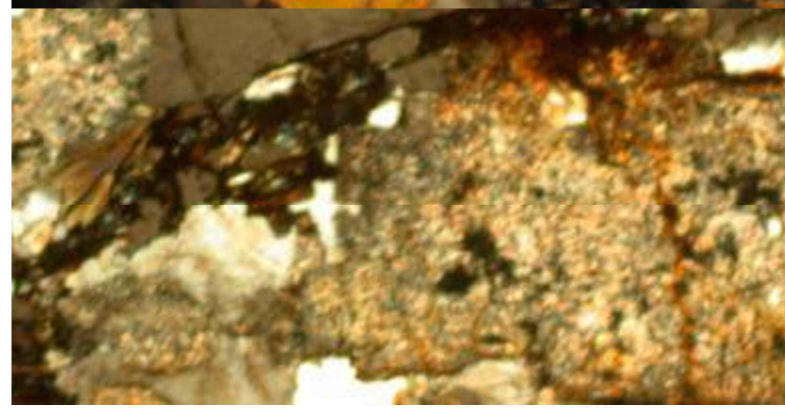
Quartz microcraquelé

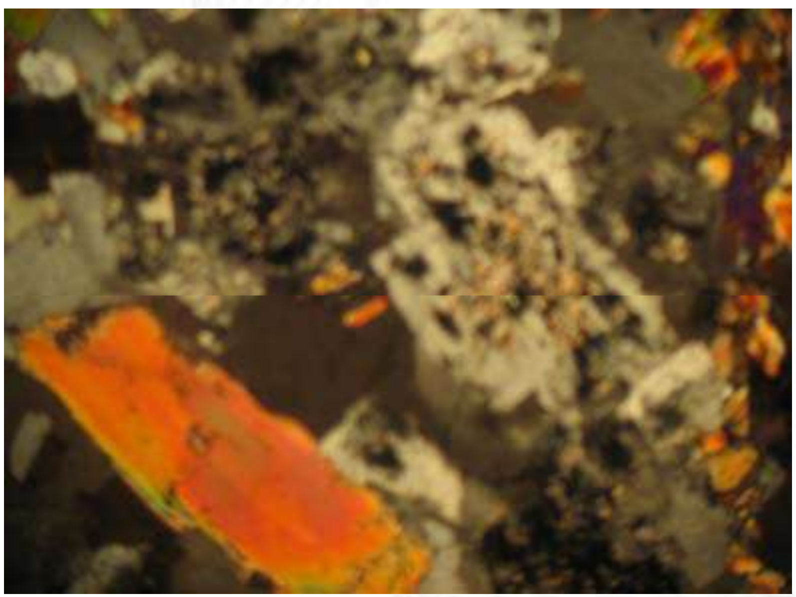


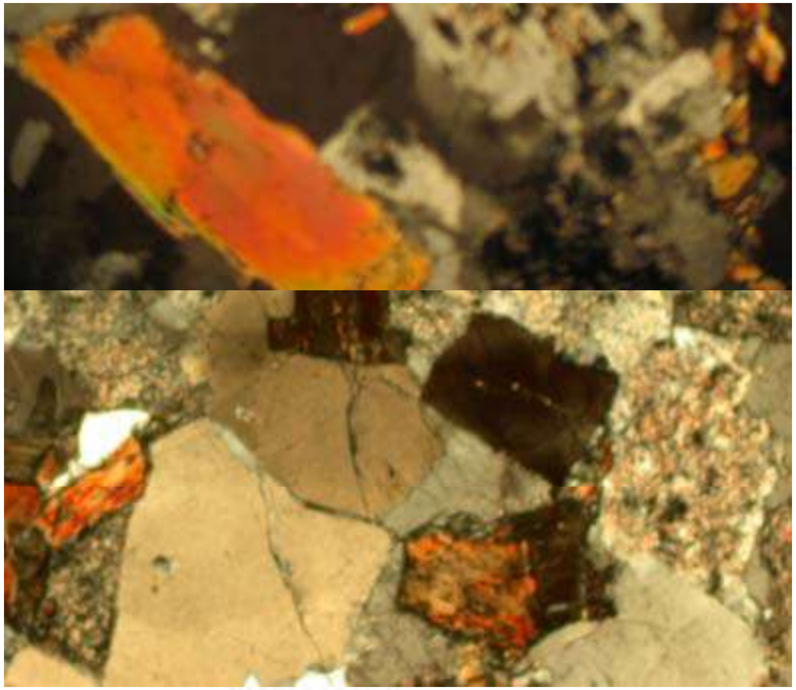
Lame mince granite

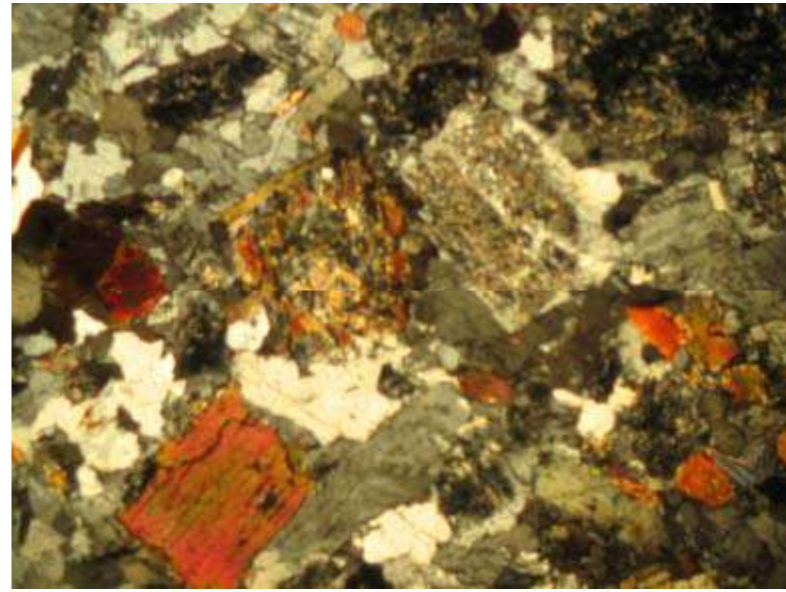




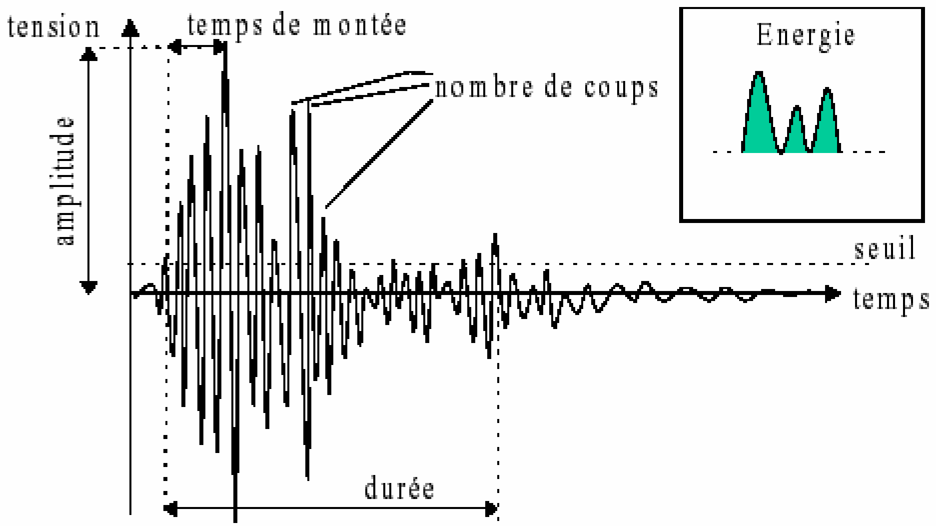






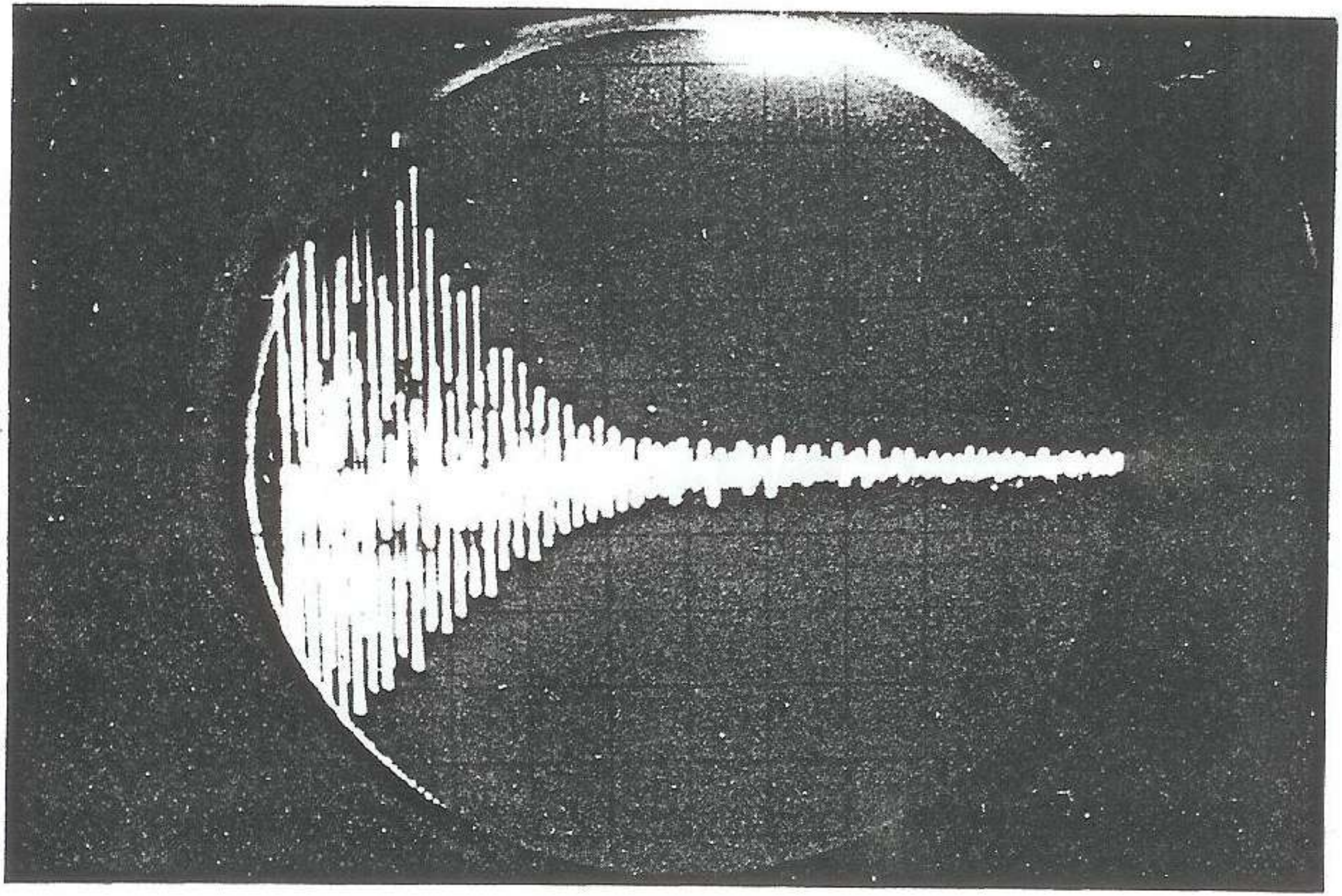


Caractéristiques d'une salve



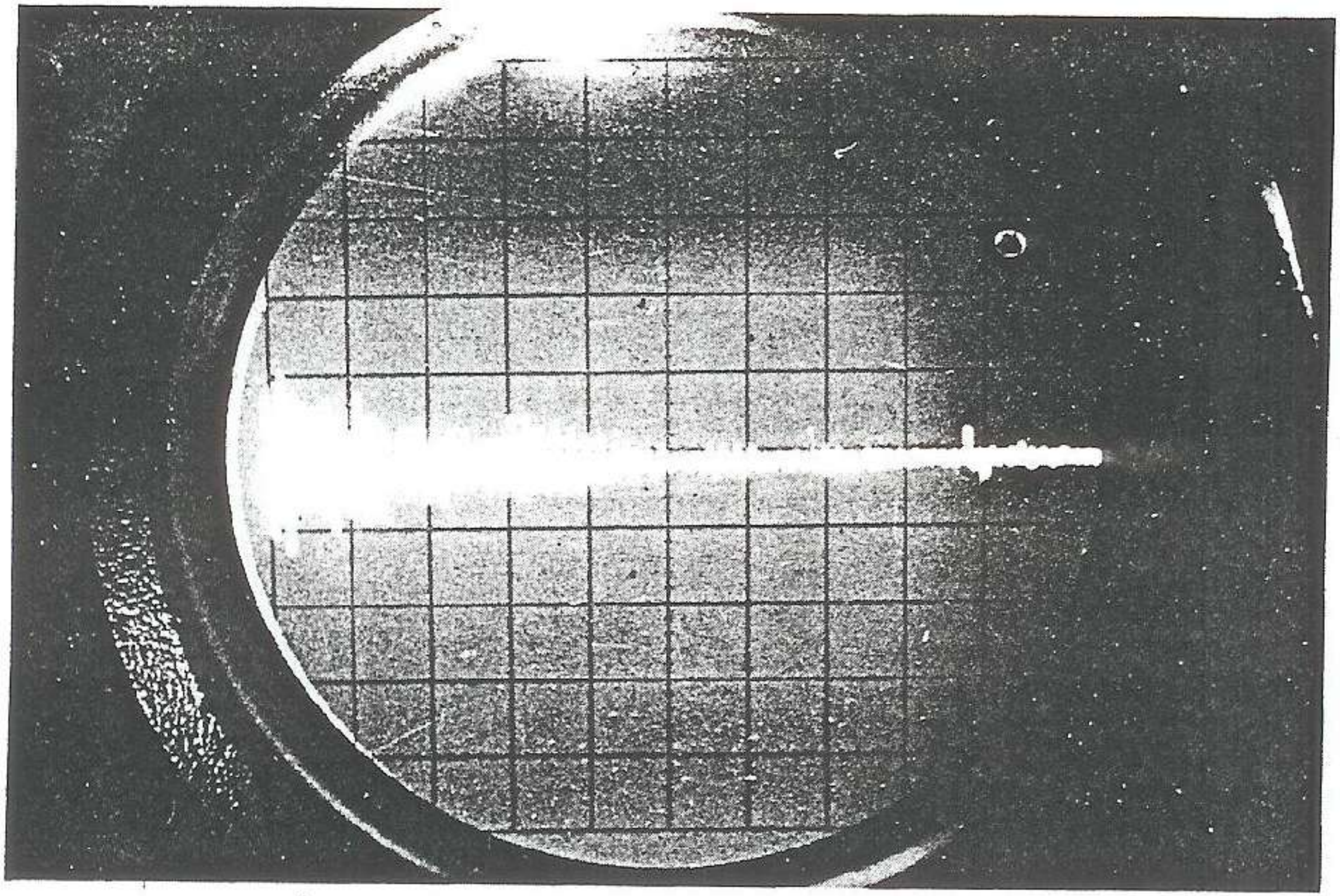
Acoustic salve

Stiff front and fast damping vibration due to quartz cracking and grain borderies opening



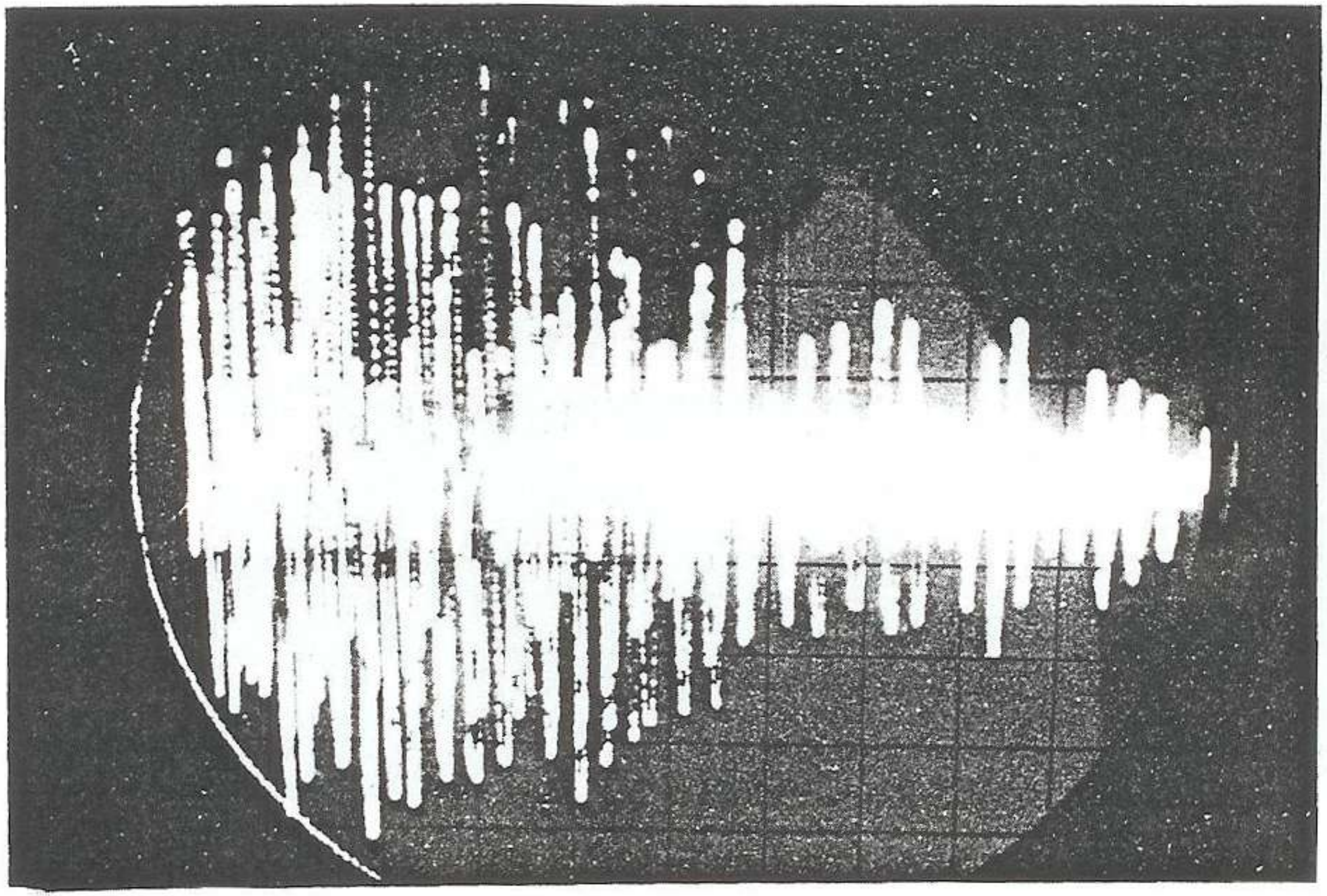
Acoustic salve

Very weak and slow damping vibration due to mineral cleavage

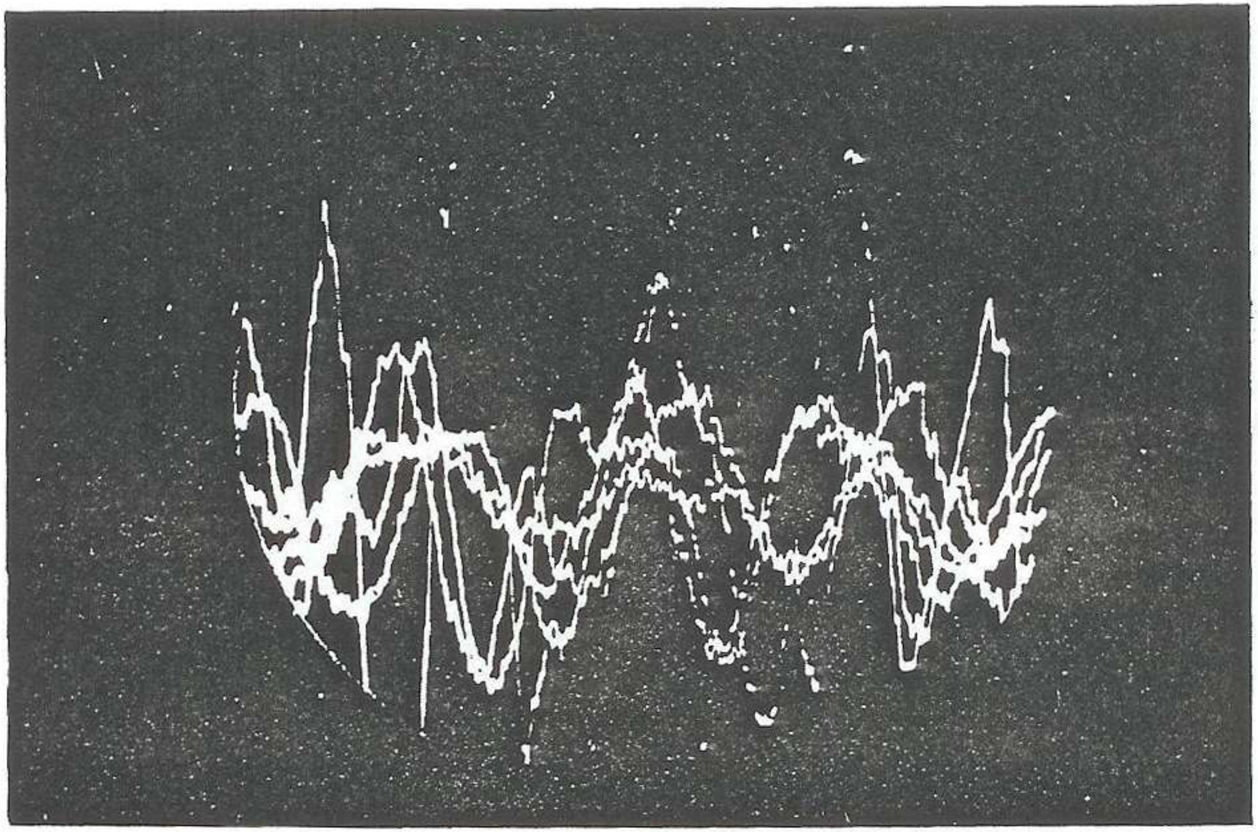


Acoustic vibrations

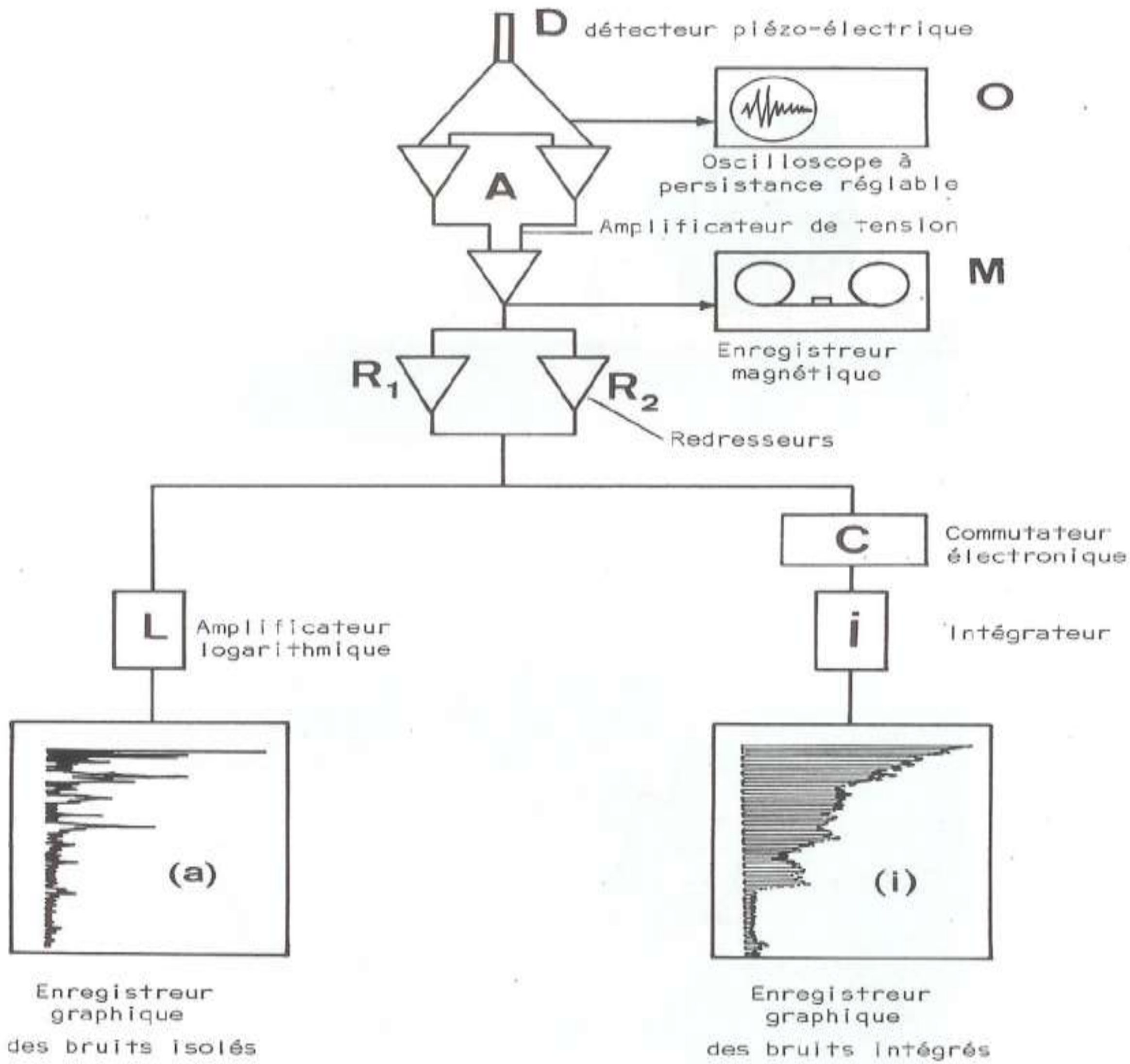
Long and complex vibration; simultaneous vibrations due to microfractures



Complexe justaposition of simultaneous vibrations due to microfractures



Results exploitation methodology

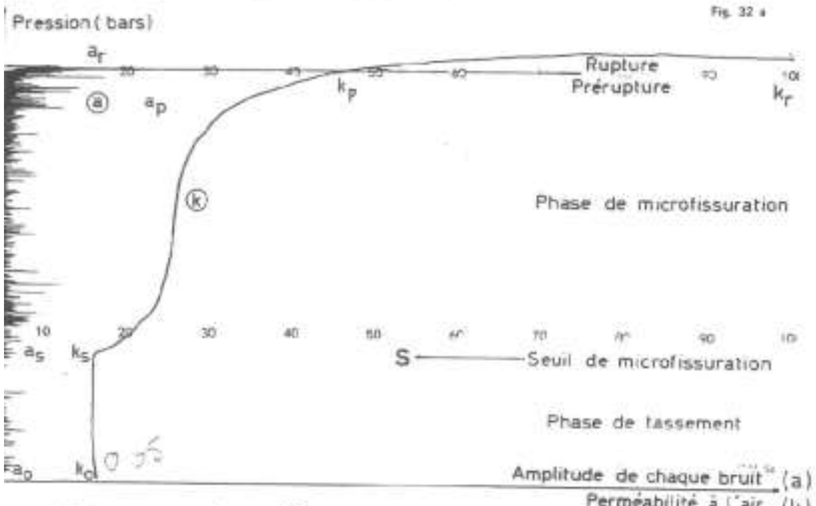


Results representation

- Strain-stress curve
- Strain– Permeability curve
- Strain–Microcracks intensity
- Colored thin plates

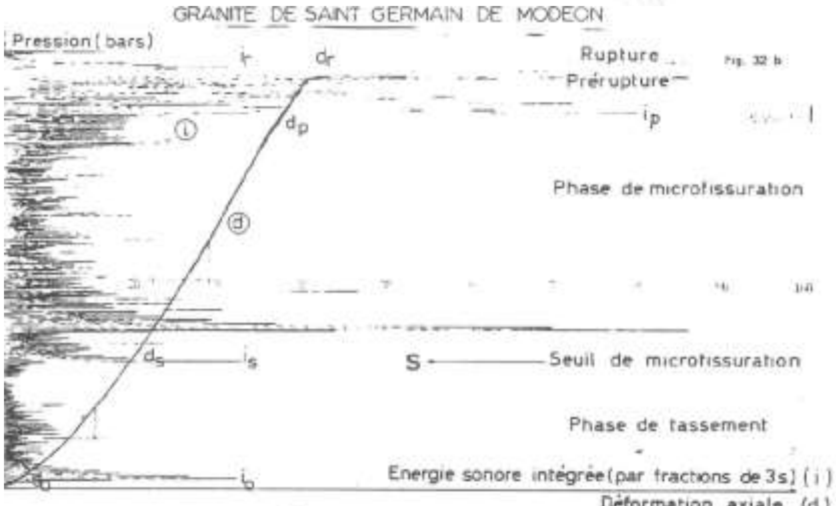
1st Example : Granite St germain de Modéon (Côte d'or)

- Permeability curve (k) and isolated noises (a)



Courbe de perméabilité (k) et diagramme d'amplitude des bruits (a)

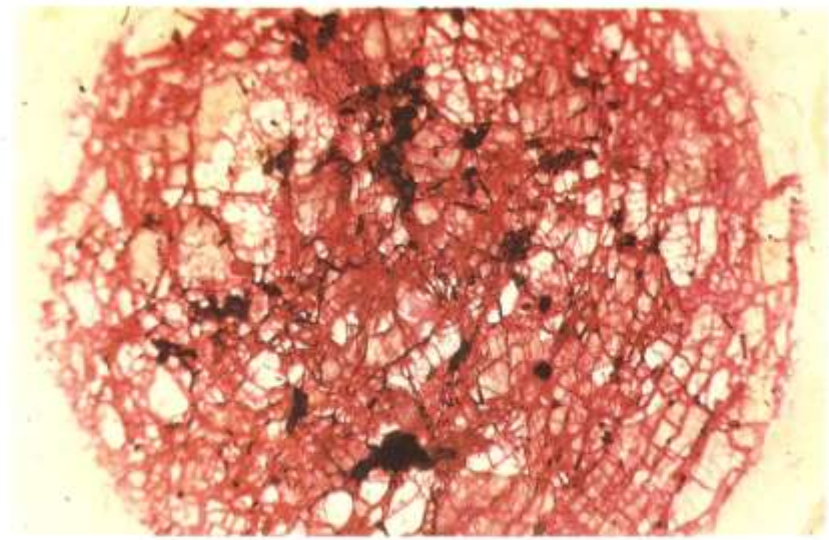
- Déformation curve (d) and integrated noises (is)



Courbe de déformation (d) et diagramme d'intégration des bruits (i)

Rocks microcracks caused by compression loading

Inter and intracristalline microcracks; cleavage microcracks



First conclusions

The two techniques are complementary: gas permeability represents the fluids transfer space but does not make difference between the opening of preexistent cracks and the creation of new cracks. Acoustic emission detects new cracking as well as the vibration generated by the internal crushing of the rock.

There exists a threshold beyond whose the rock ceases contracting and begins cracking and expansion.

Even in the elastic domain, and well before the rupture, some irreversible processes of microcracking occur in the sample whereas the curve of deformation still coarsely remains linear

LEXICON

A rock is said mineralogically **homogène** when it has only one minéral component (Example :calcaire or Dolomie)

It is said mineralogically **hétérogène** if it has différent minéral components (Example granite components are : quartz, feldspath, mica, etc)

A rock is said **« initially microfissurée »** when the initial permeability is high

It is said **microfissurable** if many microscopic cracks occur beyond the microcraking threshold

Tassement occured when the Compression loading closes the initial microcracks of the rocks and reduces it's gas permeability

Ecrasement : microcracks due to the internal crusching of the poral network

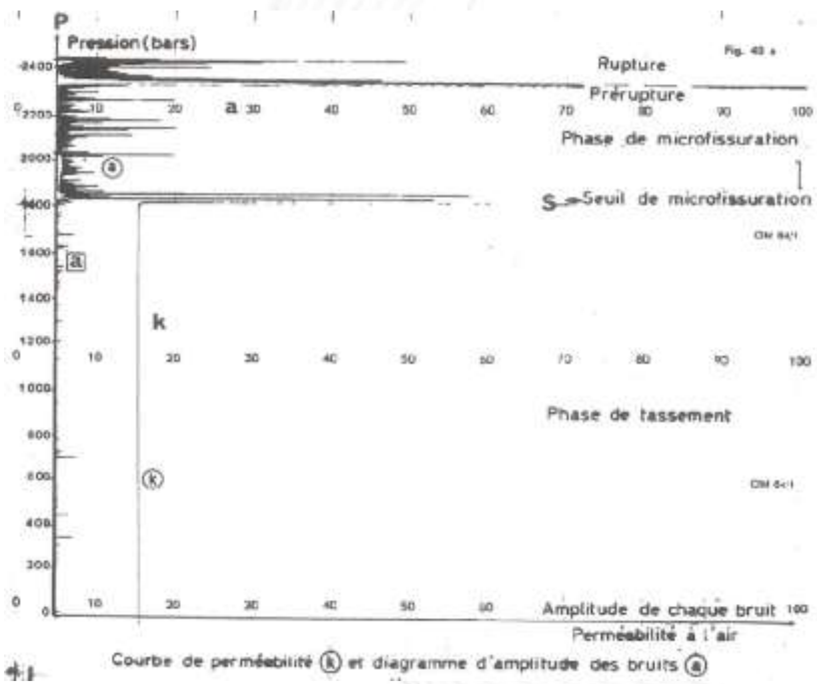
Behaviour of heterogeneous rocks submitted to uniaxial compression test (Granites)

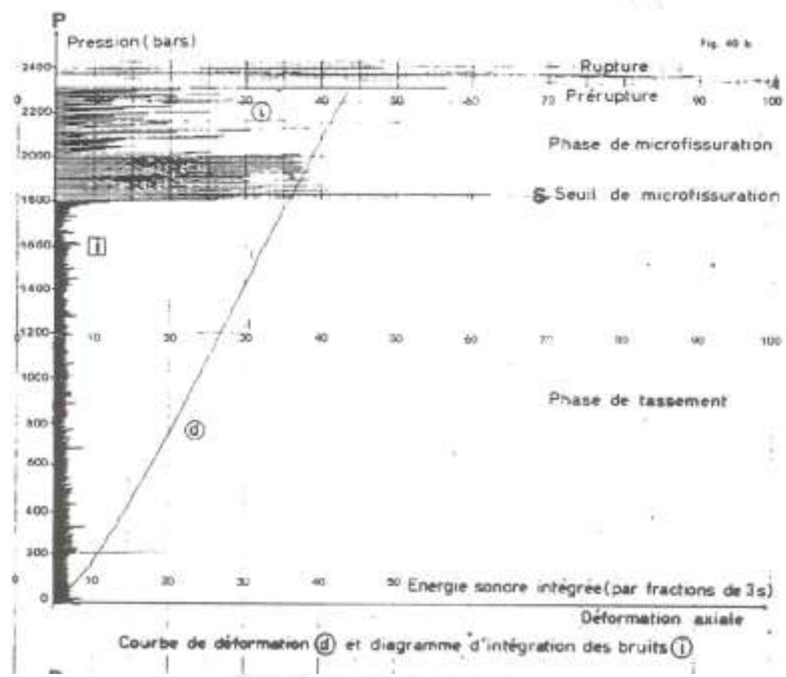
Type I

Granite of La Forge (Vosges) : very fine grains 1/10 mm.

Not microfissured initially No closing, no crushing.

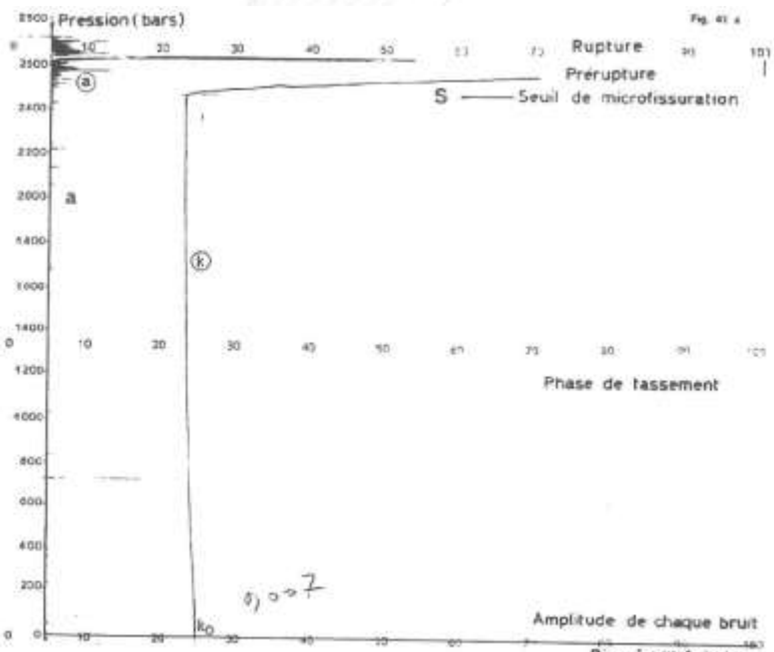
Brutal increase of the permeability by macrofissures formation.



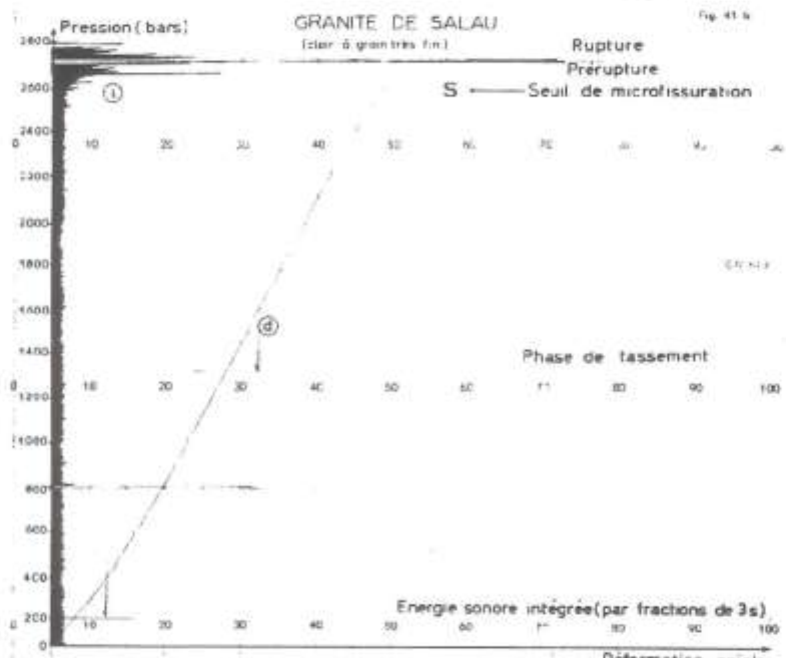


Type I

Granite of Salau (Ariège). Very fine grains **1/10 mm**. Fewly microfissured initially and no microfissurable. Brutal increase of the permeability.. **Fragile behaviour (microfragmentation).**



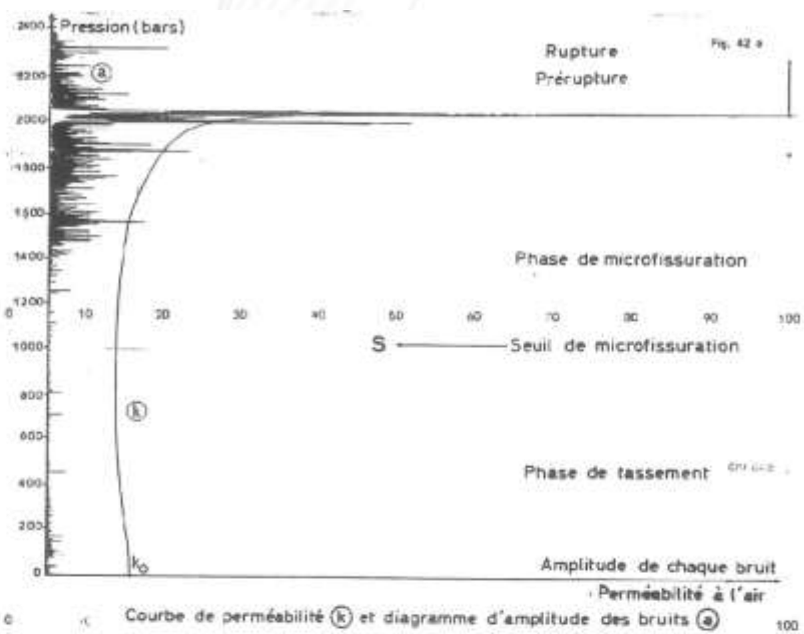
Courbe de perméabilité (k) et diagramme d'amplitude des bruits (a)

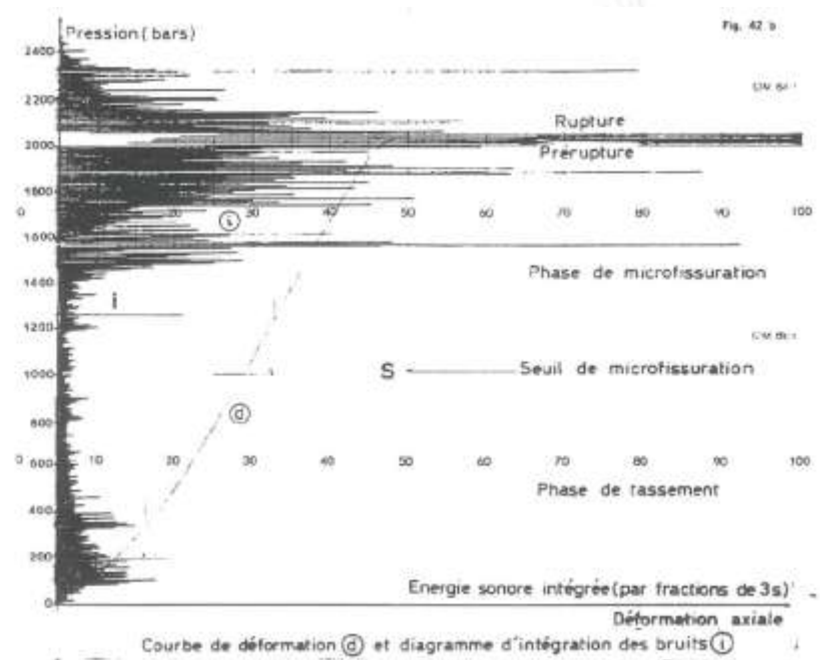


Courbe de déformation (d) et diagramme d'intégration des bruits (i)

Type II

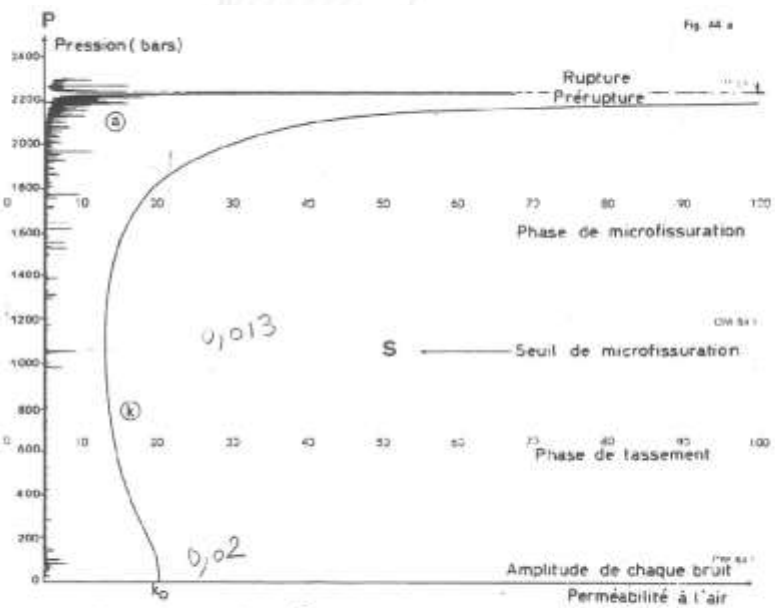
Granite of Cap de long (Htes Pyrénées). Fine grains (mm). Low initial permeability. Closing but no crushing. Progressive increase of the permeability by microfissuration;



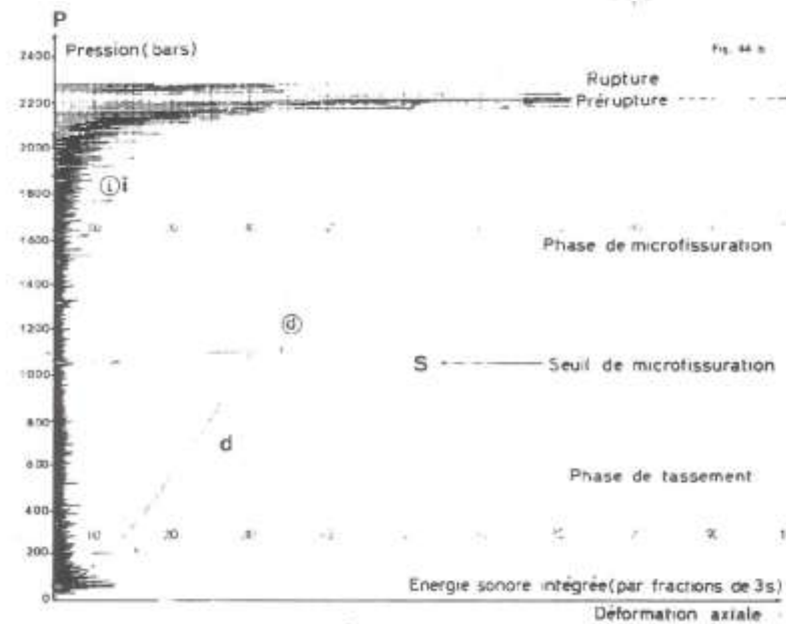


Type II

[Granite of Flamanville (Manche).](#) Coarse grains (cm) of feldspar associated with very fine quartz grains; low initial permeability; closing but no crushing; progressive increase of the permeability by microfissuring



Courbe de perméabilité (k) et diagramme d'amplitude des bruits (a)



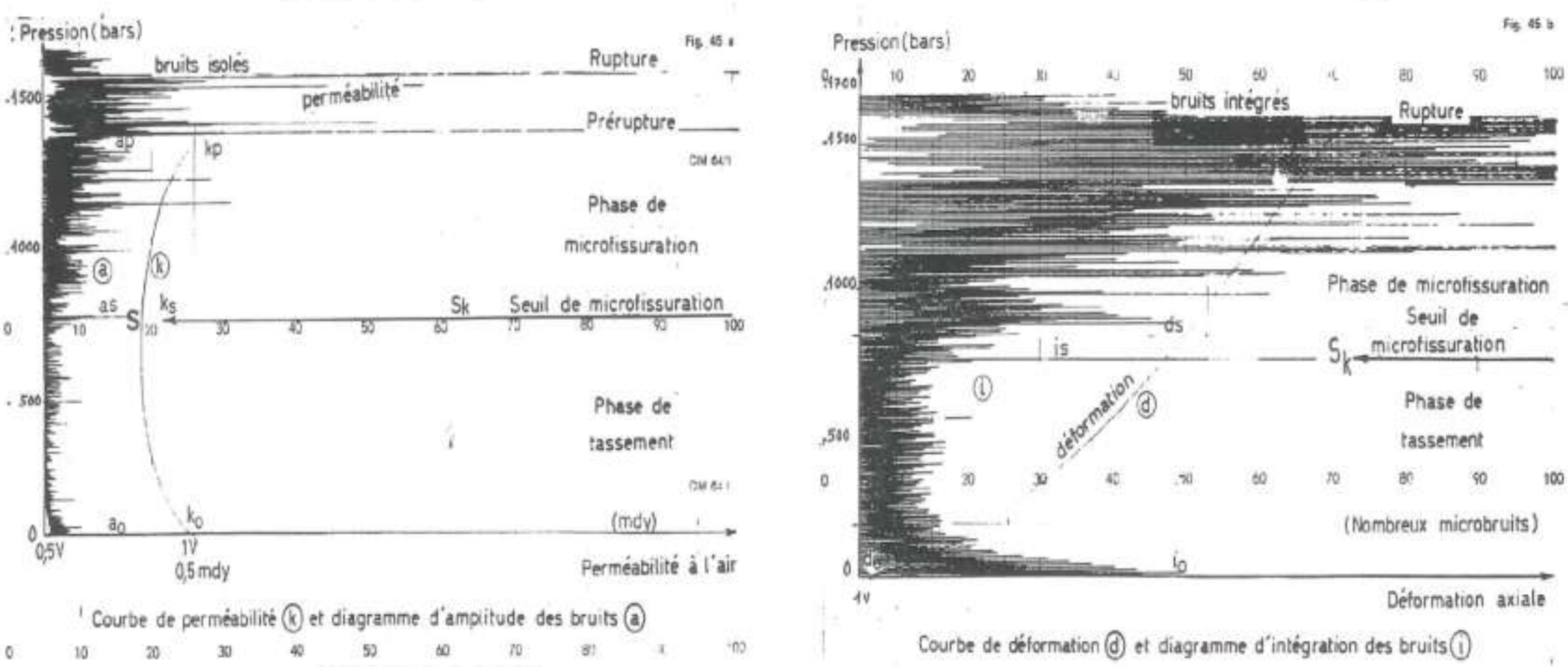
Courbe de déformation (d) et diagramme d'intégration des bruits (i)

Mechanical behviour of granites submitted to compression loading

Type III

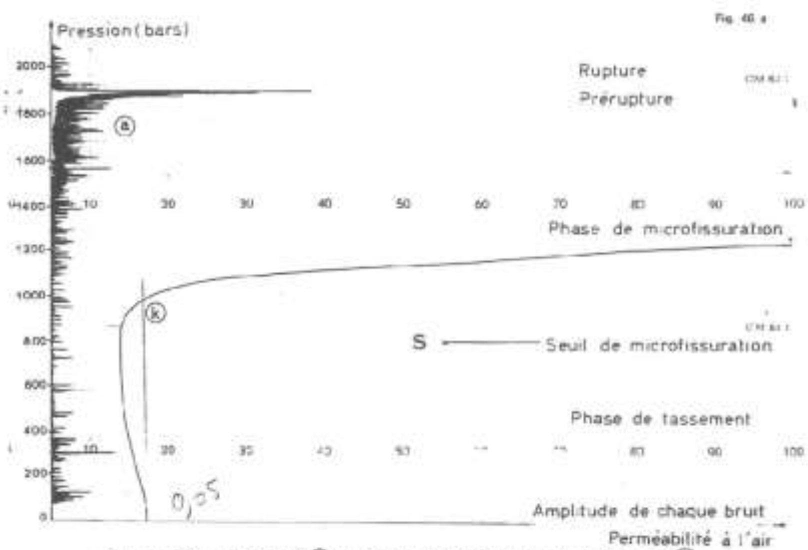
Granite of Calaccucia (Corse) : porphyroïde granite; coarse grains.

Initially microfissured; **Closing and crushing.** Progressive increase of the permeability by **microfissuration**;

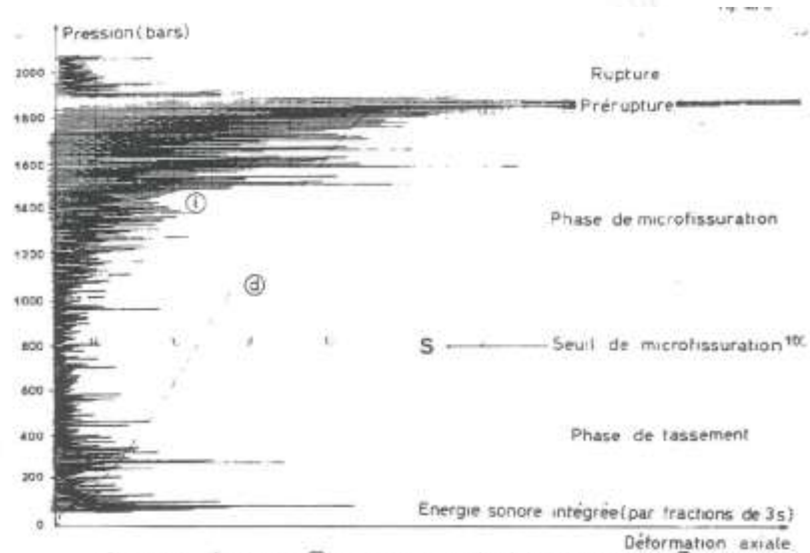


Type III

Granite of Huelgoat (Finistère). **Coarse grains ; quartz abondant (35à40%) initially microfissured; closing but no crushing; progressive Increase of the permeability by microfissuration;**



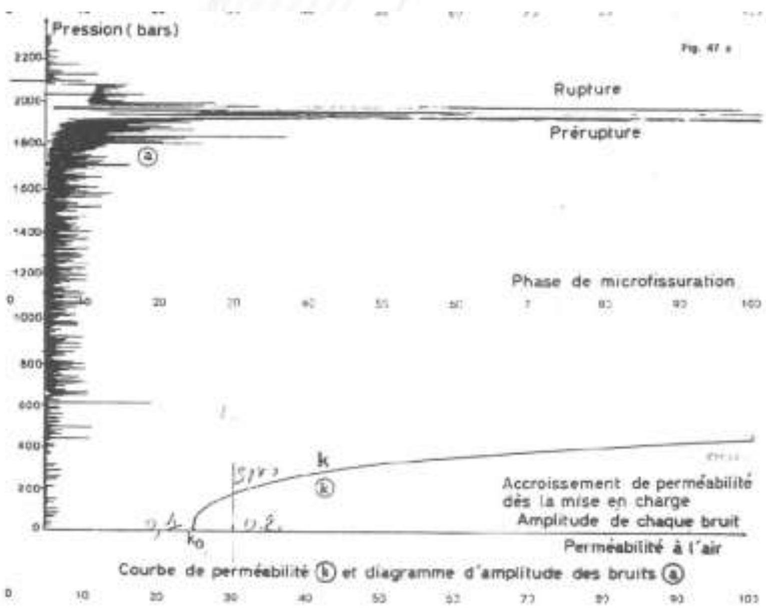
Courbe de perméabilité (k) et diagramme d'amplitude des bruits (a)

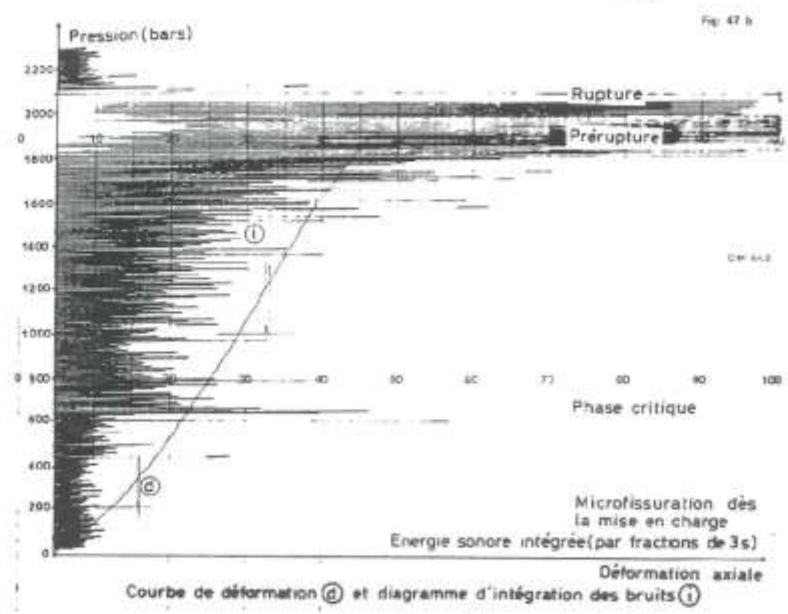


Courbe de déformation (d) et diagramme d'intégration des bruits (i)

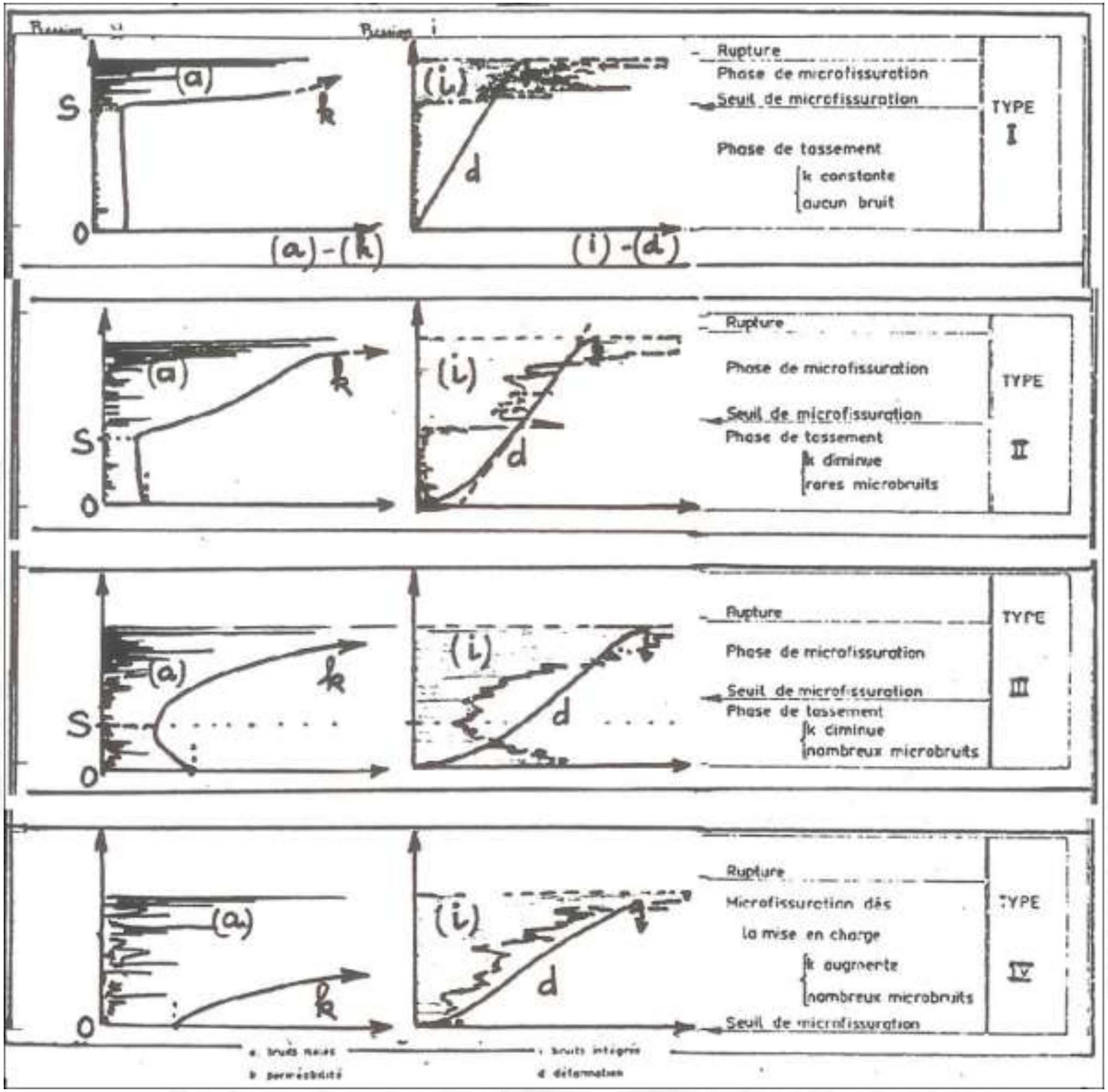
Type IV

Granite of St Germain de Modéon (Côte d'Or). Coarse grains; quartz abondant (35à40%). Initially microfissured; increase of the permeability since the beginning of the loading; expansion of the existing fissures parallel to the compression axis .



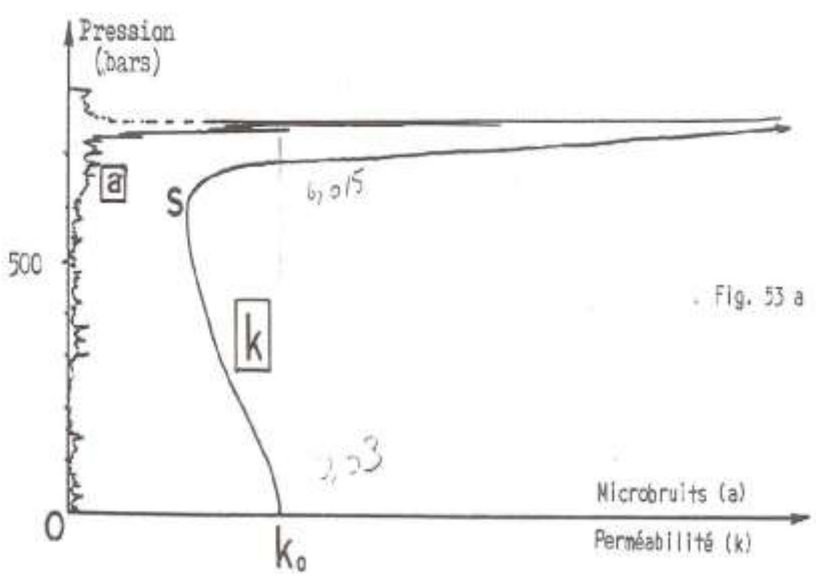


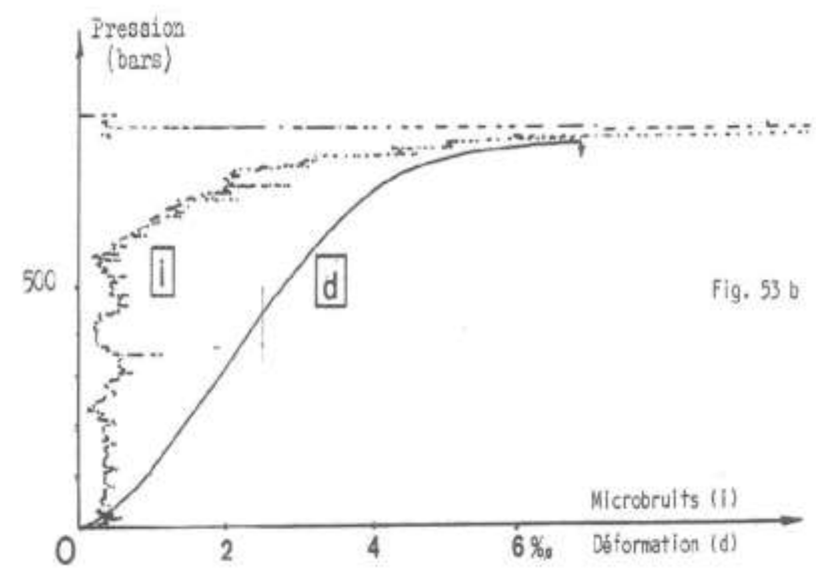
Comportement sous charge uniaxiale des principaux types de granites (Synthèse)



Mechanical behaviour of homogeneous rocks submitted to uniaxial compression test (Limestone and dolomie)

Cristalline limestone of Mosset. Coarse grains (cm). Important closing. High threshold; brutal increase of the permeability

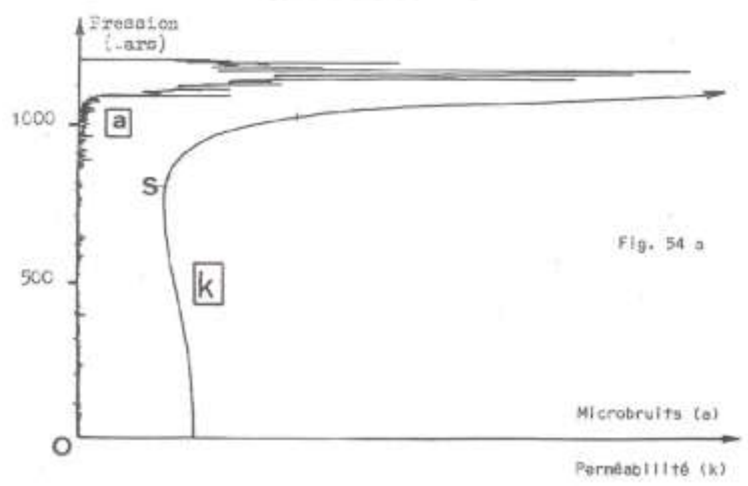


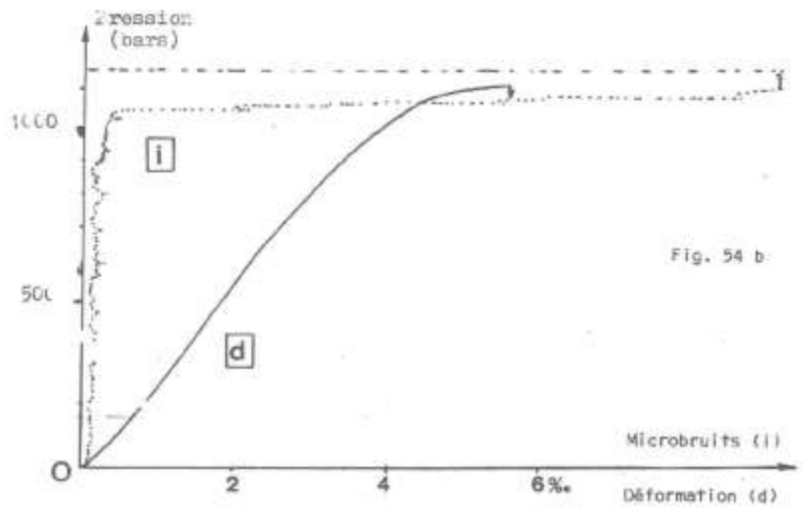


Perméabilité (k) et microbruits isolés (a)

Déformations (d) et microbruits intégrés (i)

Limestone of Saint Béat : Fine grains. No crushing. Microfracturable, fragmentation.





Perméabilité (k) et microbruits isolés (a)

Déformations (d) et microbruits intégrés (i)

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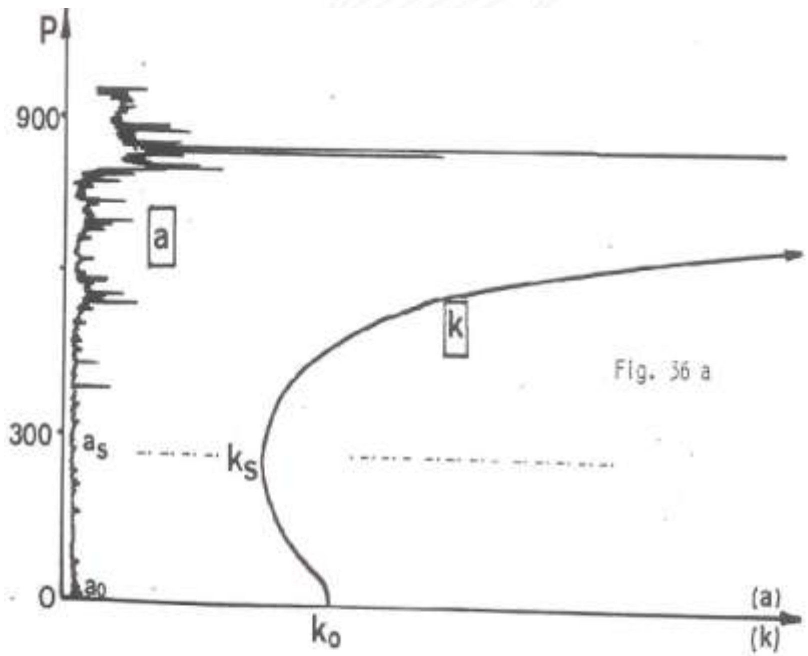
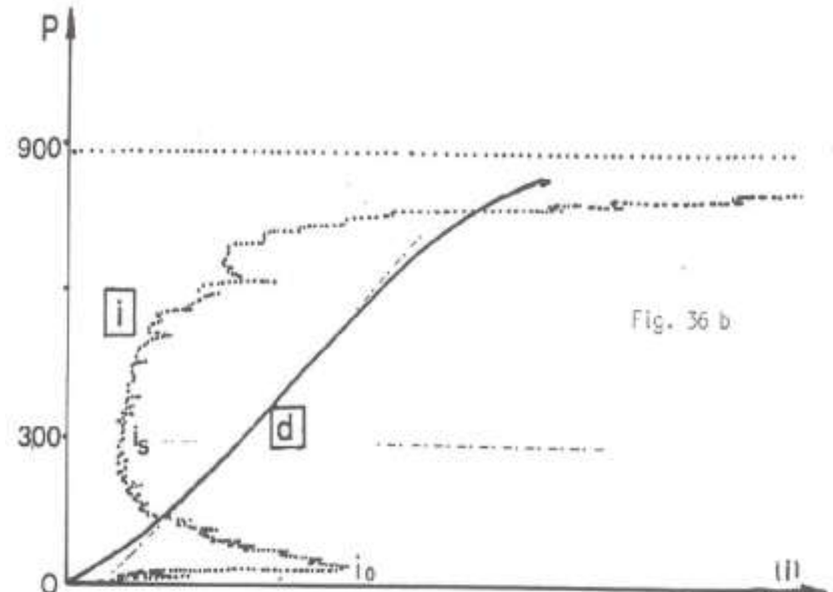
Dolomie Ste Colombe sur Guette. **Fine grains (mm). Important closing and crushing, microfissurable**



a) Courbe de perméabilité k et diagramme d'amplitude a des microbruits



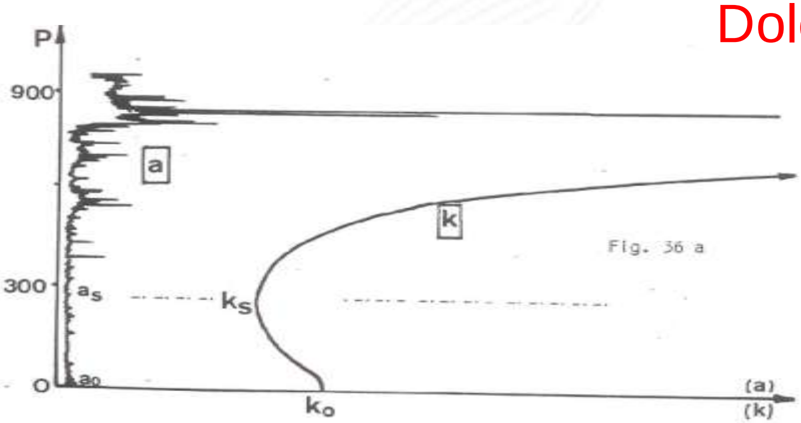
b) Courbe de déformation d et diagramme d'intégration i des microbruits

Dolomie de Ste colombe

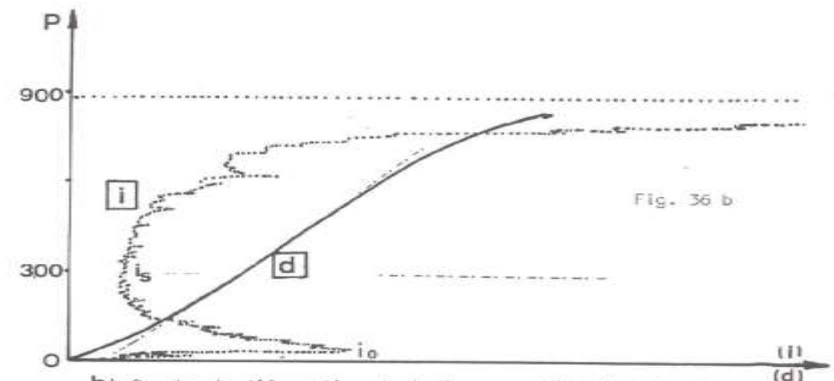
Comparaison of limestone and dolomie: Fine grains mm.

The grained limestone is more plastique est less microfissurable than the grained dolomie more fragile.

Dolomie

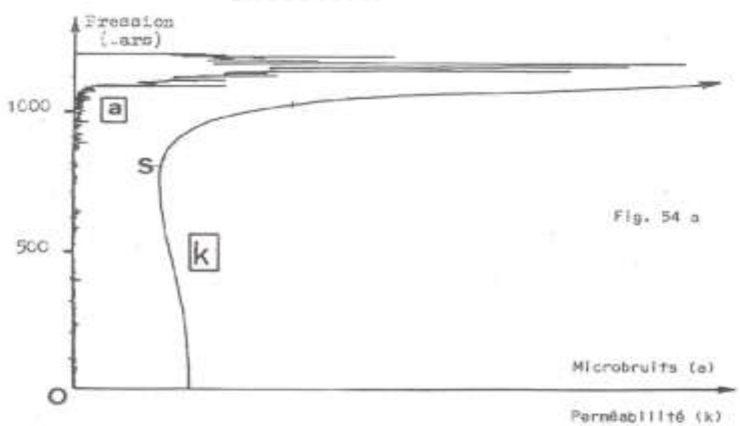


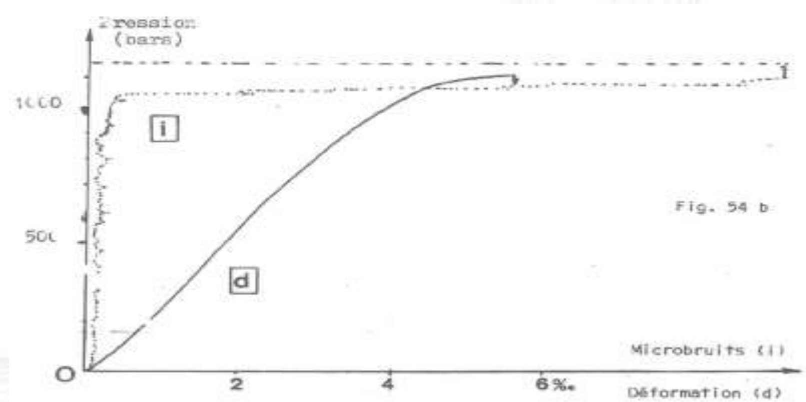
a) Courbe de perméabilité k et diagramme d'amplitude a des microbruits



b) Courbe de déformation d et diagramme d'intégration i des microbruits

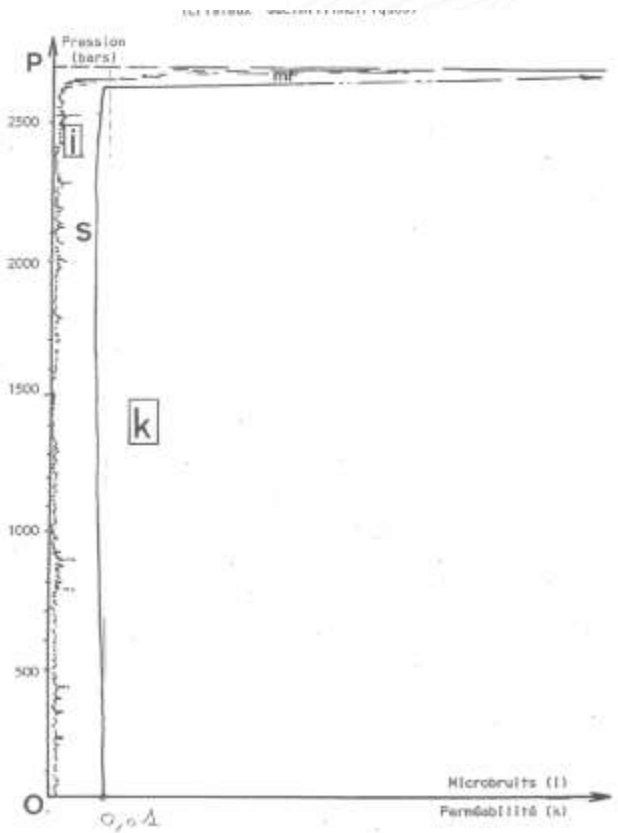
Calcaire



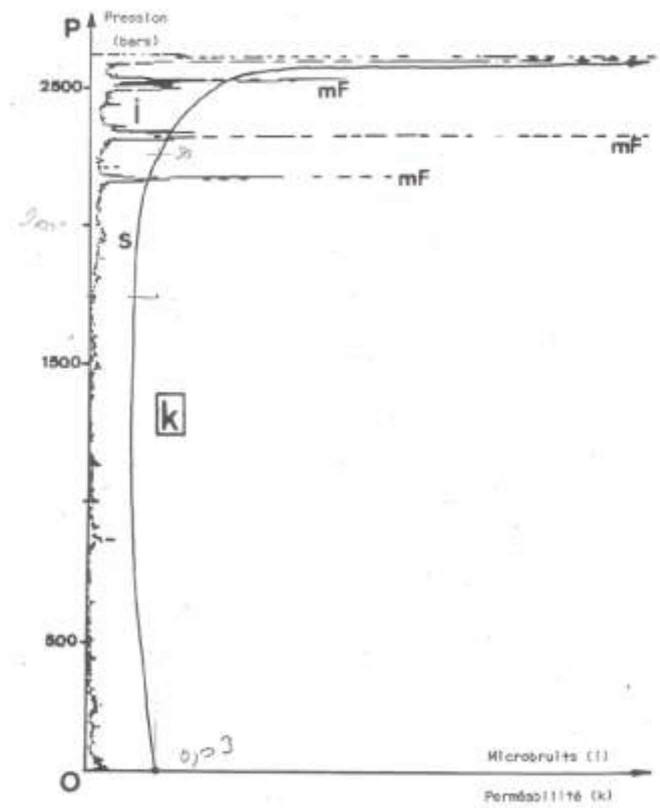


Comparaison calcaire-dolomie (1/10mm)

Comparaison of limestone et dolomie: grains 1/10mm
Both exhibit similar fragile behaviour but dolomie shows microfractures



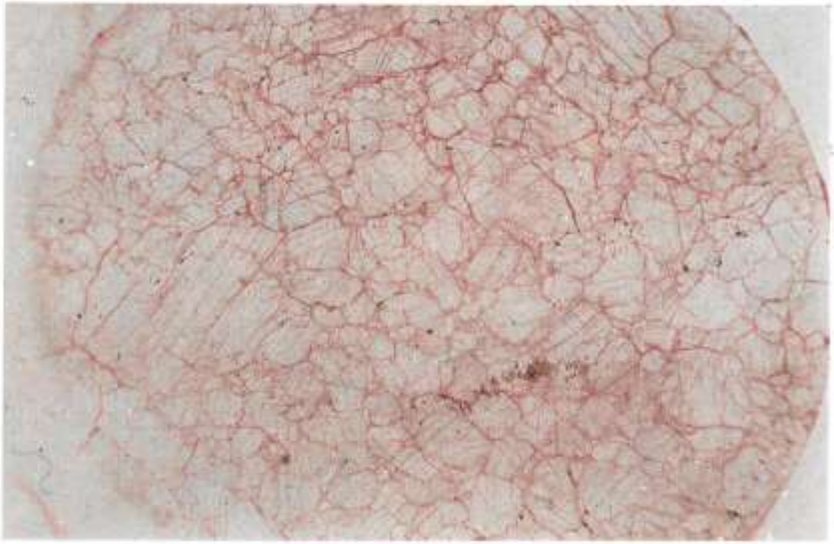
Calcaire microcristallin

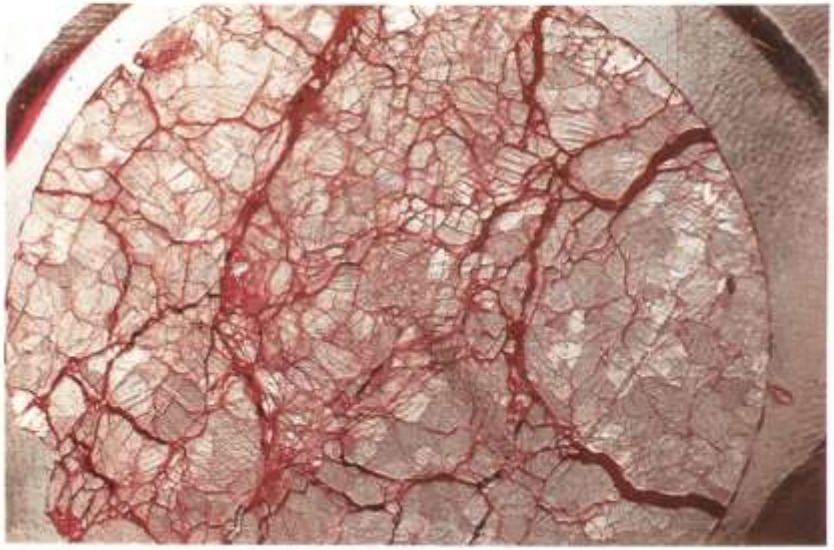


Dolomie microcristalline

Mechanical fissuration of a limestone

- Reference sample
- After mechanical compression





Titre de diapositive de contenu


A. RG


.A.RC

Synthèse des actions mécaniques

En définitive sur le plan mécanique, on peut distinguer trois types de comportements :

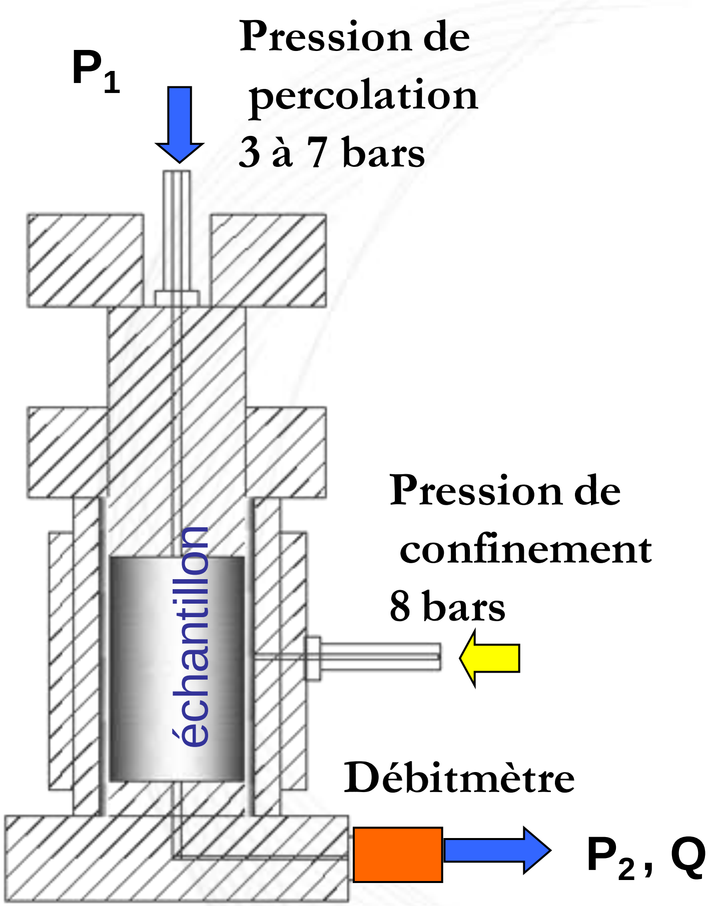
- **Les roches à comportement quasi fragile caractérisées par l'absence quasi-totale de microruptures jusqu'à la rupture; celle-ci survient de manière brutale et donne un petit nombre de fragments.**

- **Les roches microfracturables caractérisés par la formation d'un petit nombre de microdiscontinuités importantes qui s'étendent pour former une cassure principale. Celle-ci conduit à la rupture en donnant un nombre limité de gros fragments.**

- **Les roches microfissurables caractérisés par le développement d'un grand nombre de microfissures qui se multiplient, se rejoignent et conduisent à une rupture avec formation de nombreux éléments fins**

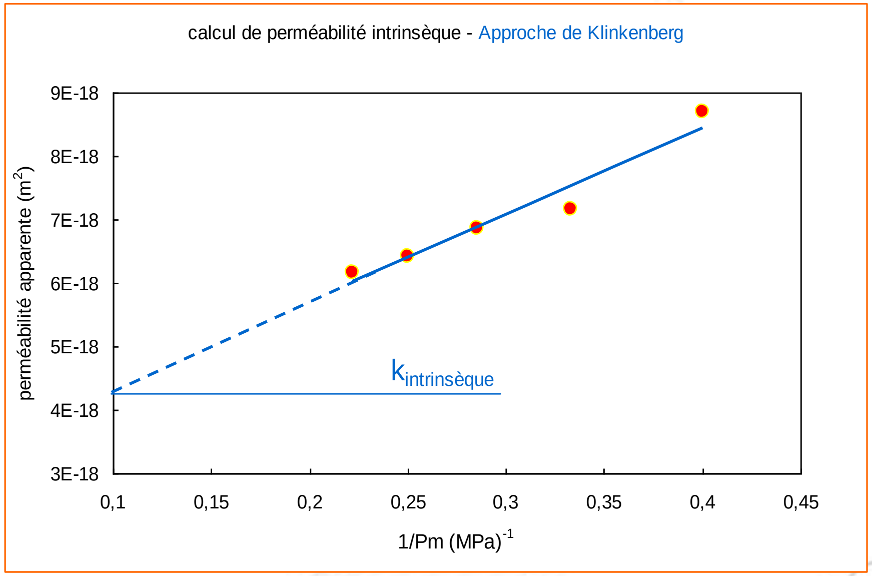
Rocks thermal microfissuration (Limestone, dolomie and granite)

Détermination of gas permeability $K_{intrinsèque}$



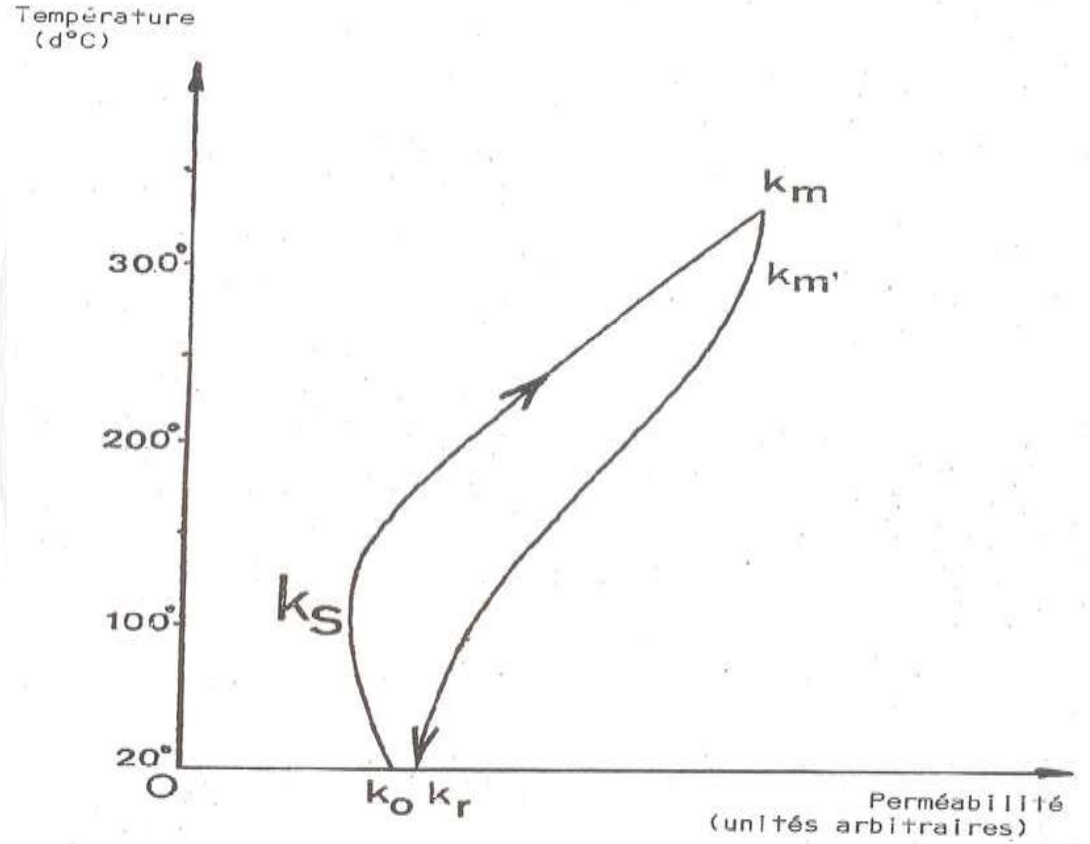
$$K_{apparente} = \frac{2Q\mu LP_2}{S(P_1^2 - P_2^2)}$$

$$\mu_{hélium} = 18{,}6 \times 10^{-6}\ \text{Pa.s}$$



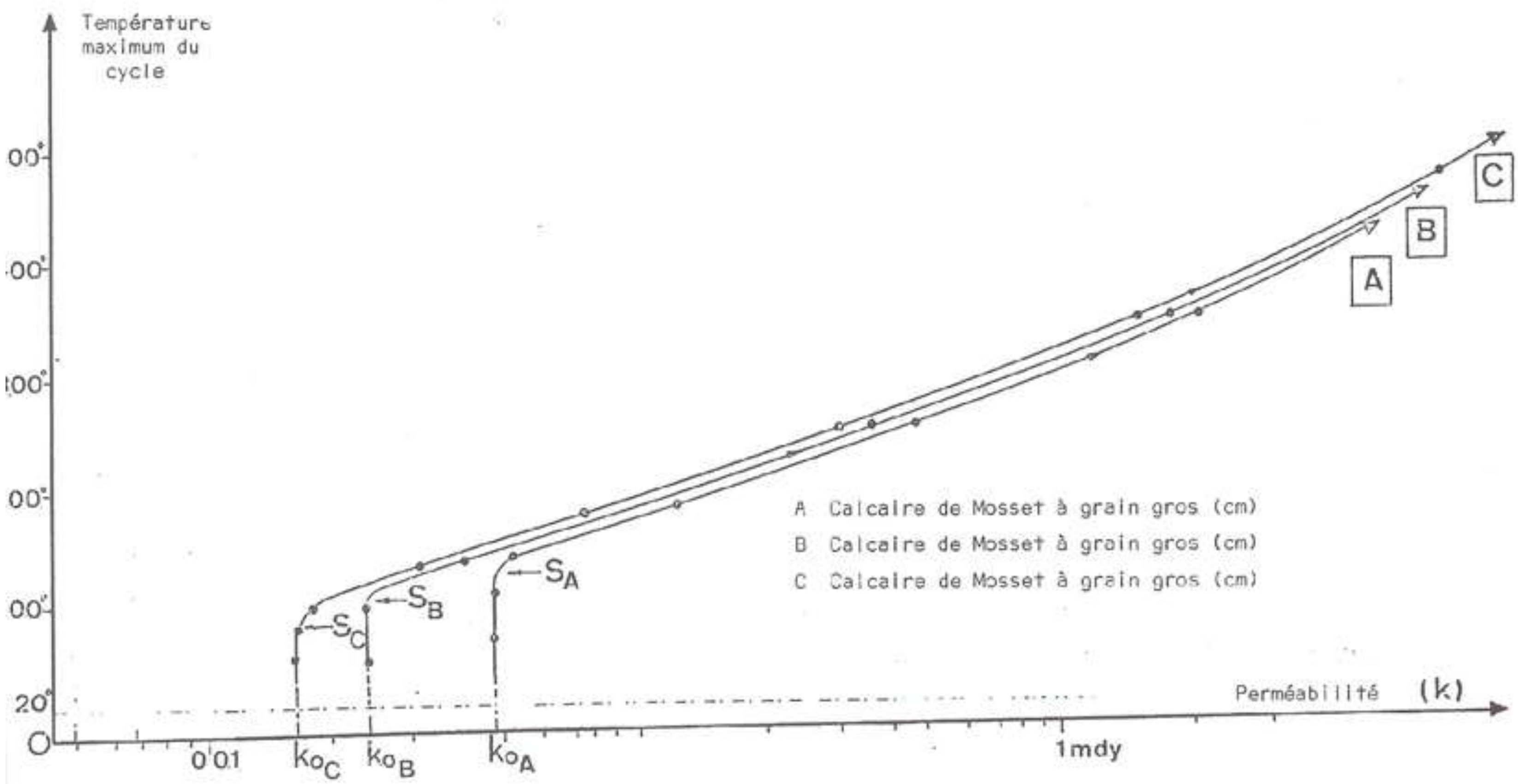
Approche de Klinkenberg

During the heating, tensions arise at the boundaries of the grains and cause microfissuration; the fissures enlarged and left residual permeability when the sample is cooled.



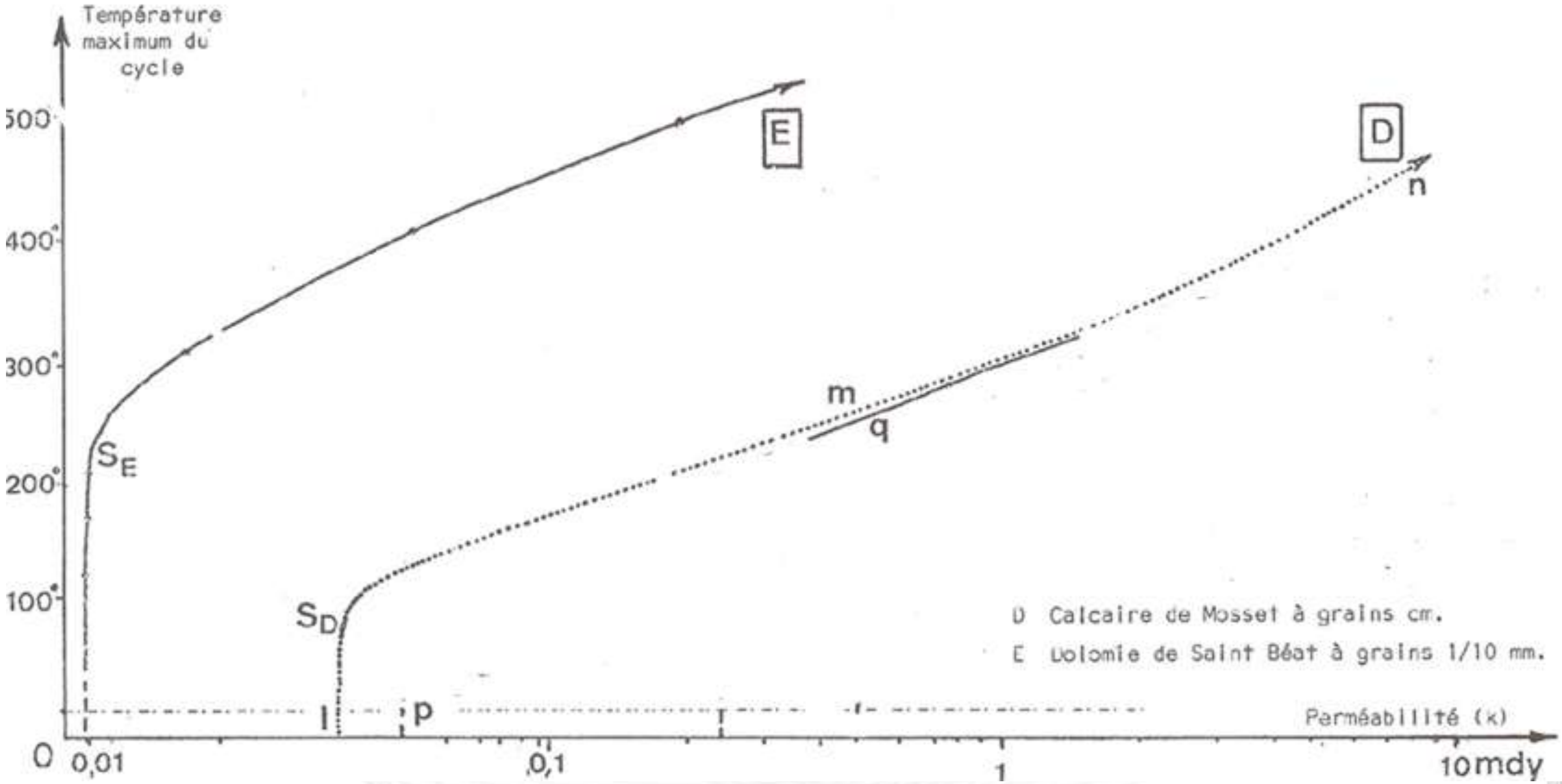
Limestone

Rôle of the initial permeability : limestone of Mosset (cm) grains; The existing fissures reduce tensions accumulation at the boundaries of the grains and delay new microfissuration.



Thermal microfissuration of homogeneous rocks :

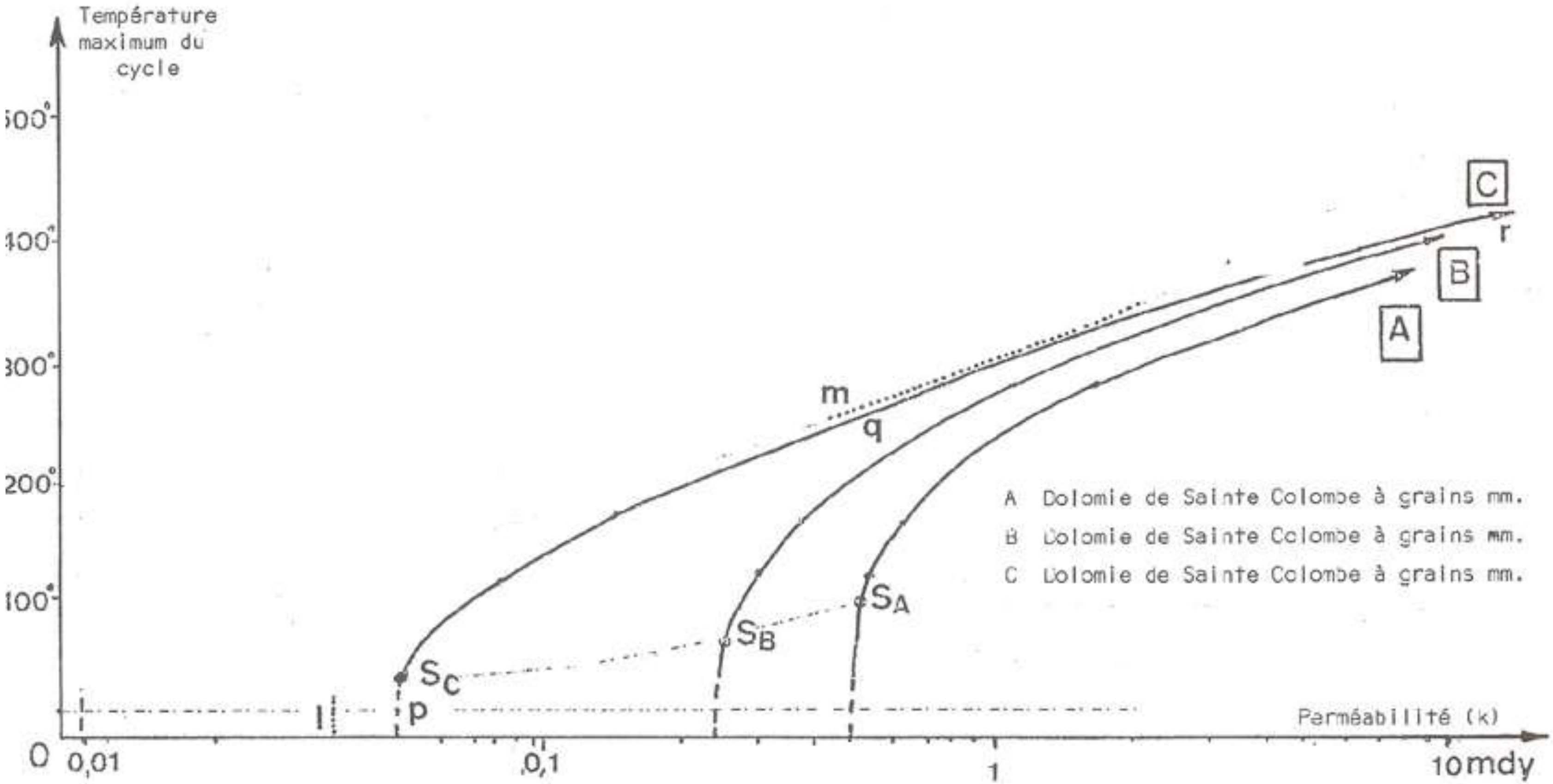
Rôle of the size of the grains : comparaison of two size of grains mm (curve D) et 1/10mm (curve E). Tension at boundaries are lower for fine grains



Thermal microfissuration of homogeneous rocks :

Dolomie

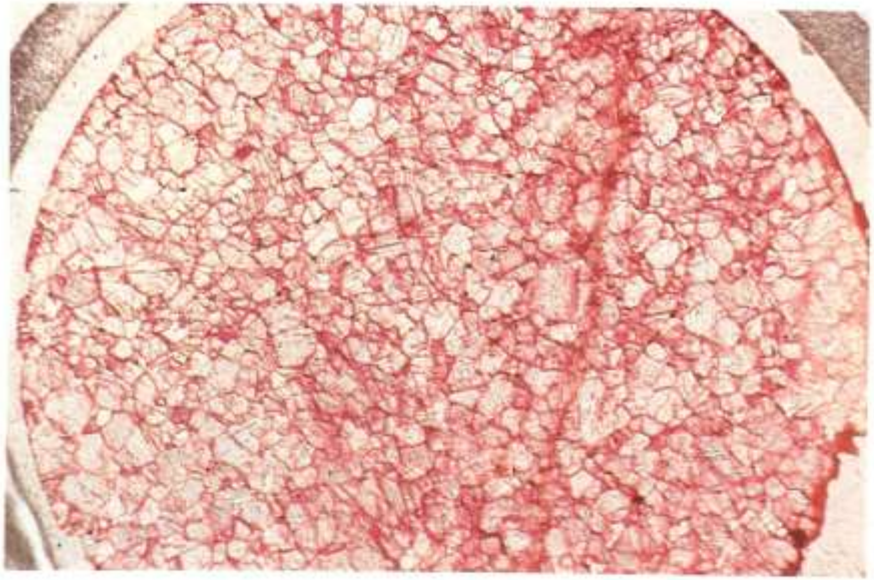
The existing fissures postpone new cracks formation and increase the microfissuration threshold



The new microfissures are mainly intercristalline

- Reference sample

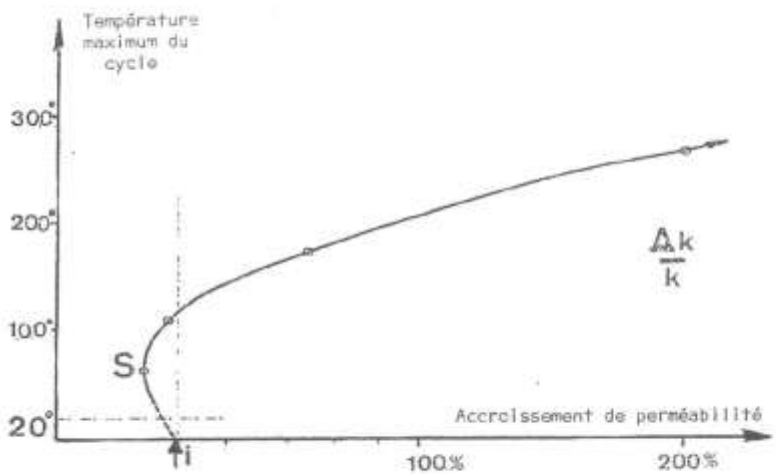
- Sample heated at 300 °C

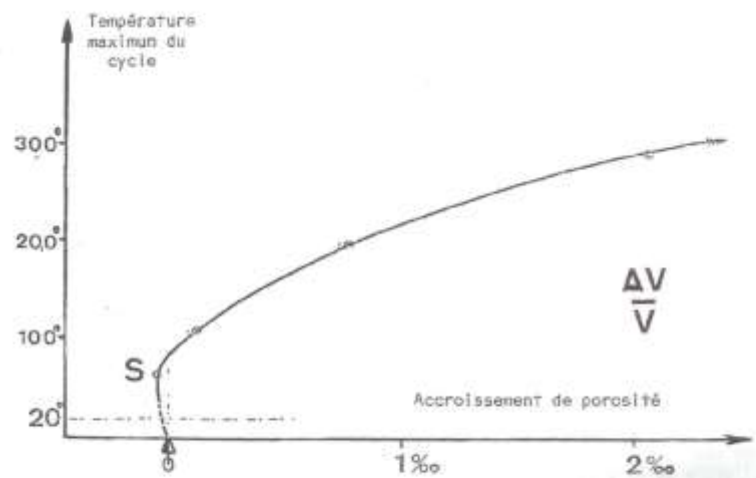


Granite of Querigut Millas

Residual permeability ΔK/K

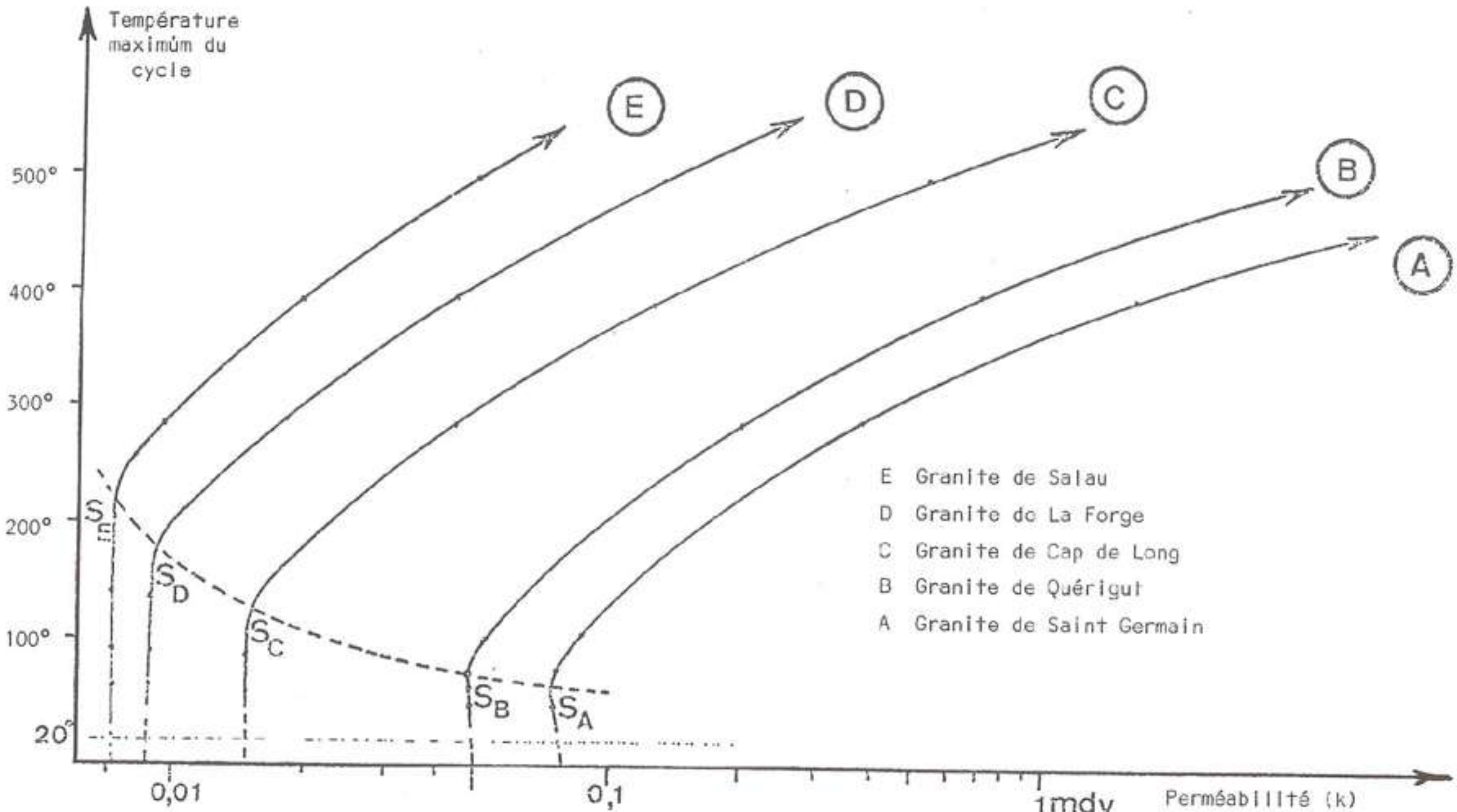
Residual porosity ΔV/V





Role of the grain size and the initial permability

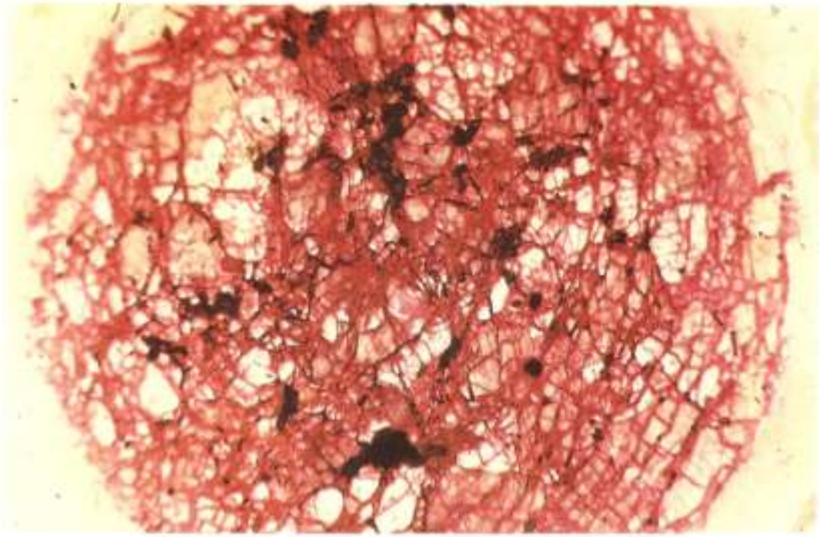
The microfissuration threshold increases when the grains are fine and the initial permeability low. Laforge and Salau (E and D, very fine grains, 1/10 mm) Cap de Long (C, fine grains mm) ; Saint Gremain and Querigut (A and B, coarse grains, cm)



Mechanical and thermal microfissuration : comparaison

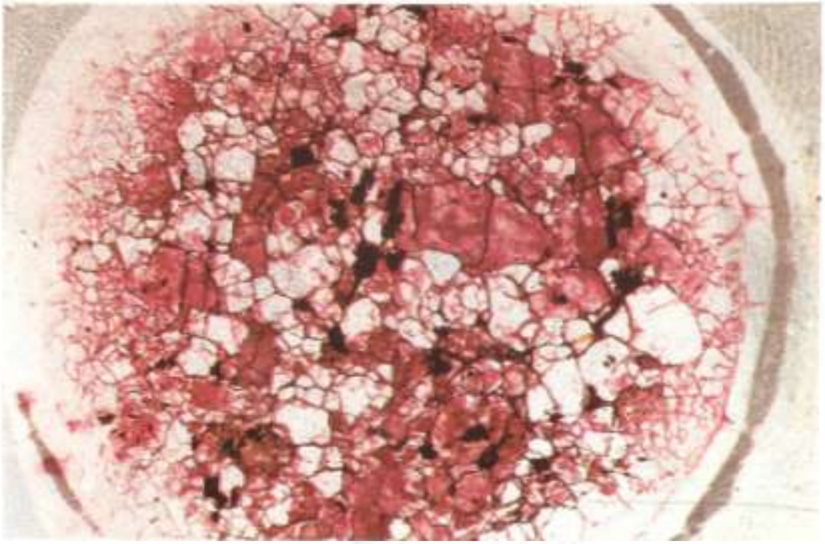
Mechanical action

Intra-cristallines microfissures



Thermal action

Inter-cristallines microfissures



Synthèse

Globally, heat treatment causes mainly inter-cristalline fissure compare to mechanical action.

During the heat treatement the limestone mineral more plastique than dolomite mineral reduce the residual permeability.

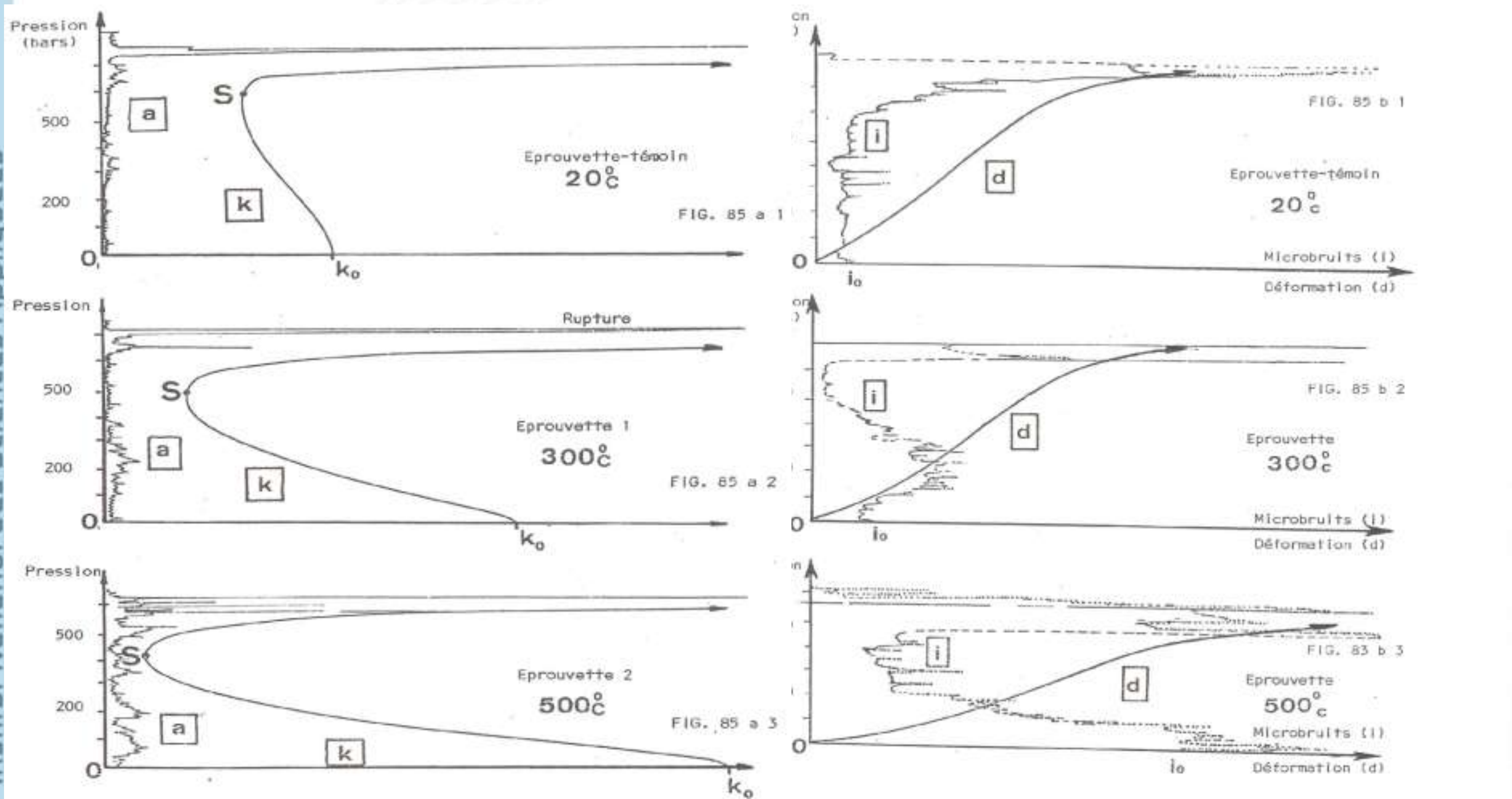
Generally, granites rocks easity microfissurable mechanically are also microfissurable thermically. Indeed, quartz mineral mainly responsible of the mechanical microcracking exhibit also the strongest thermal dilations that causes new cracking.

Successive actions of temperature and mechanical compression (limestone and dolomie)

Thermal action followed by mechanical compression

Limestone of Mosset

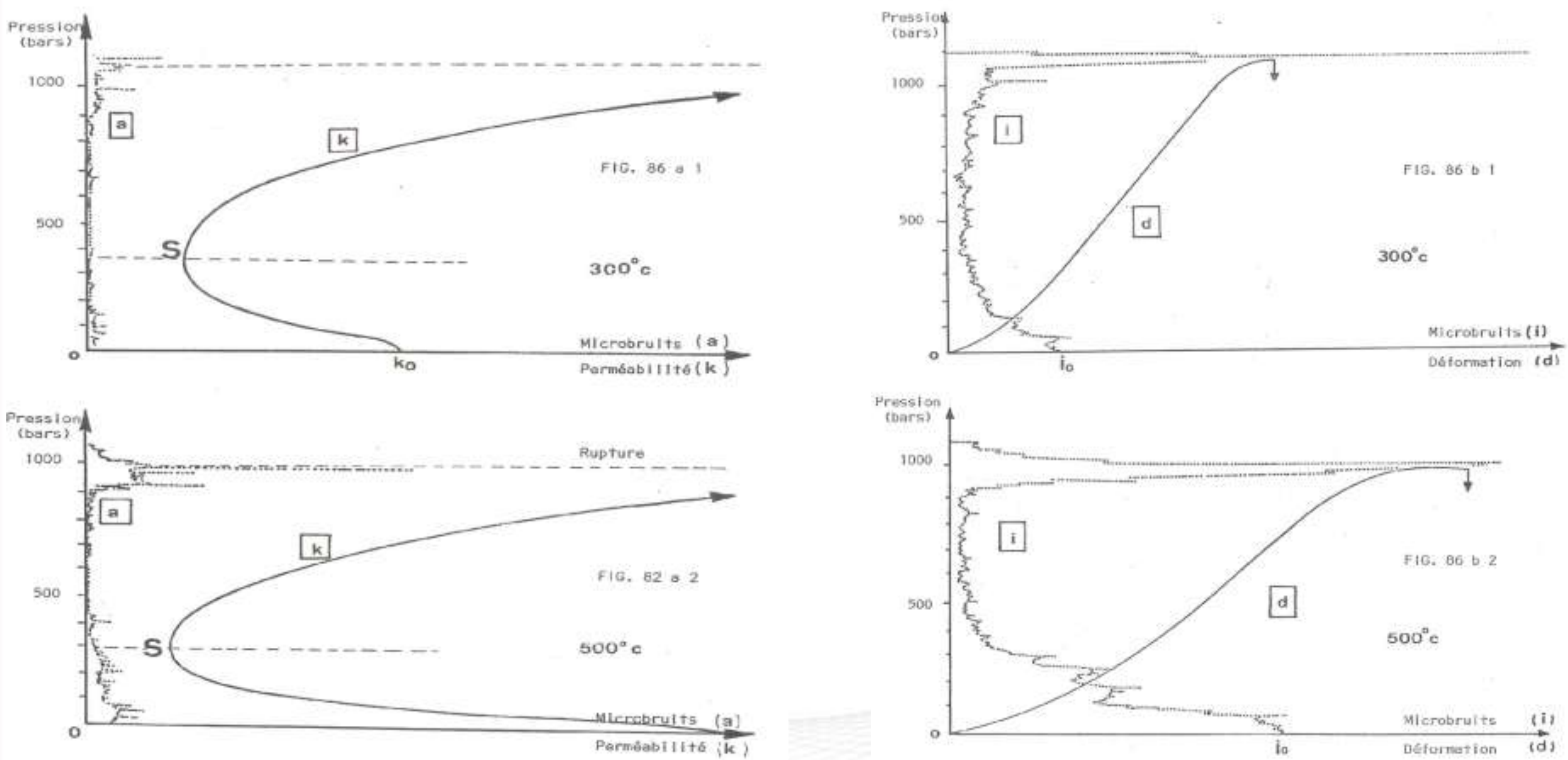
1) Increase of the **closing** and **crushing** phenomena 2) a weak lowering of the **threshold** and the failure load



Thermal action followed by mechanical compression

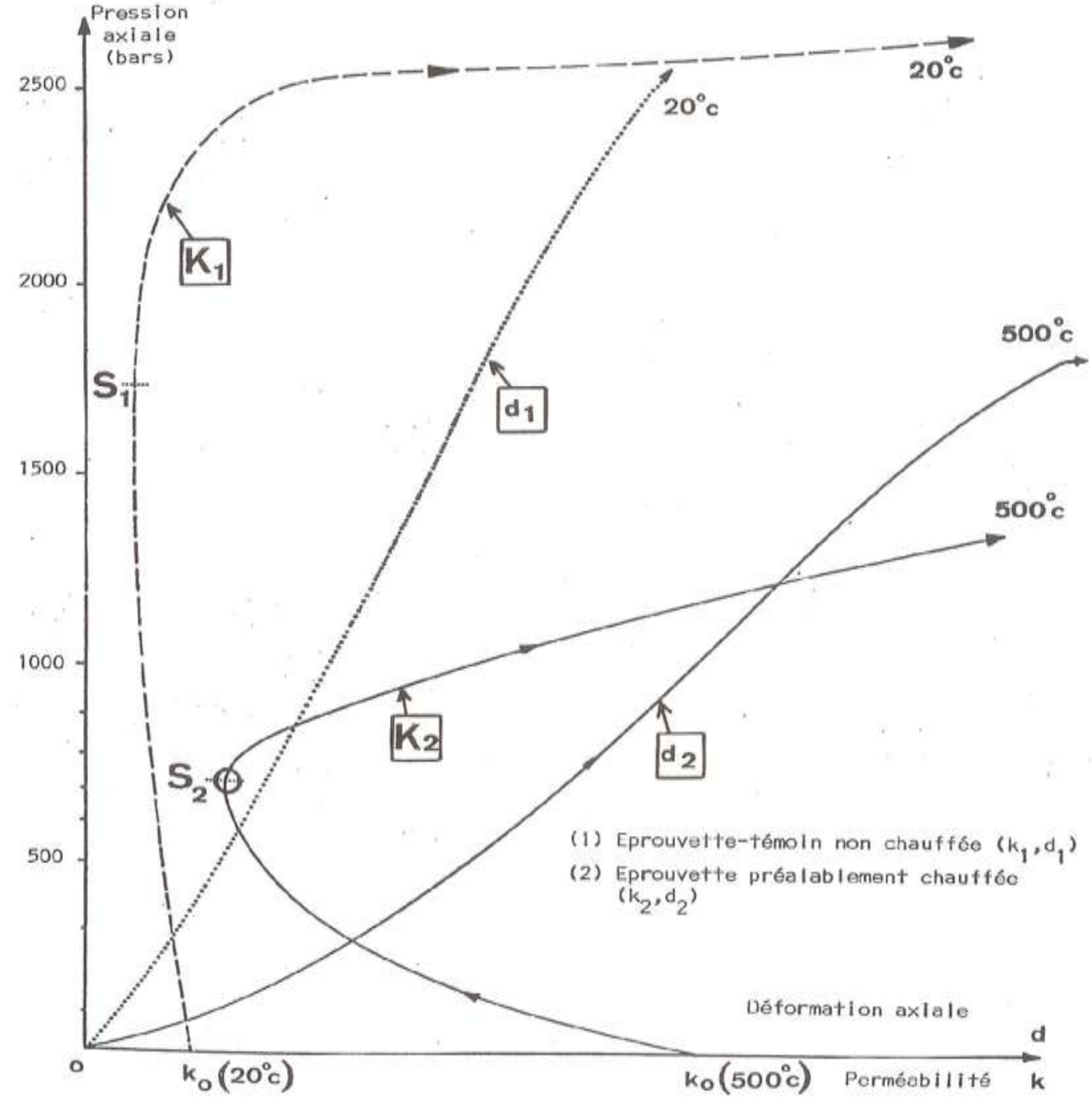
Dolomie de Ste Colombe

1) Increase of the **closing** and **crushing** phenomena 2) lowering of the **threshold** and the failure load.



Thermal action followed by mechanical compression

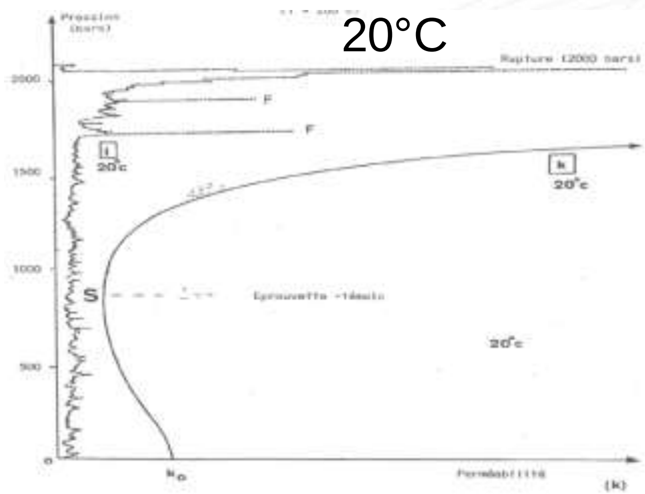
Microcristalline dolomie of St Béat

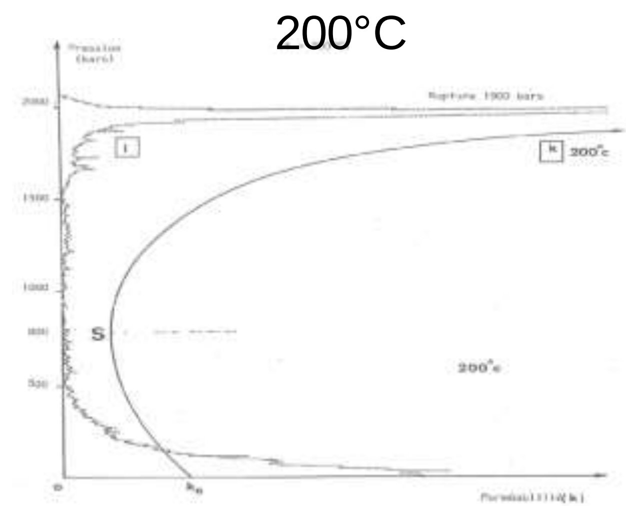


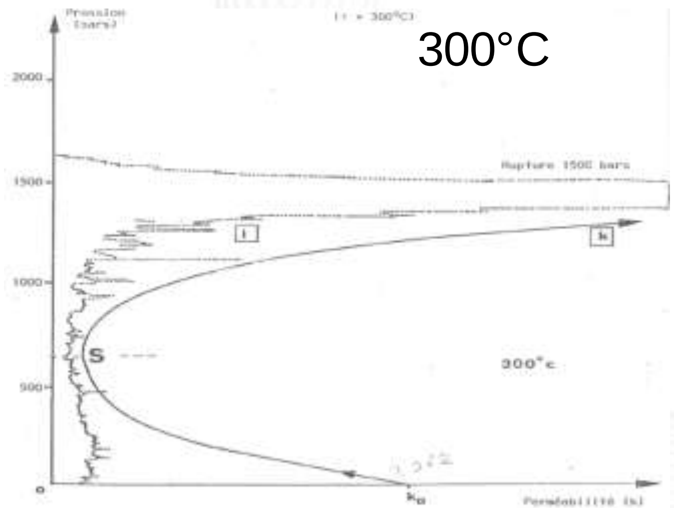
Thermal action followed by mechanical compression

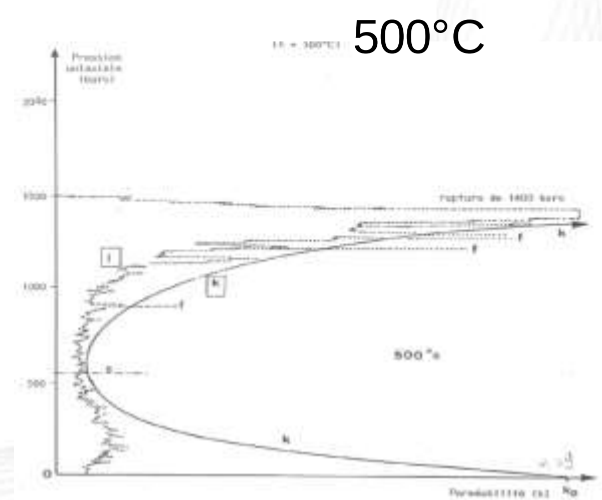
Granite of Sidobre

1) Increase of the closing and crushing 2) lowering of the thrshold; 3) lowering of the failure load



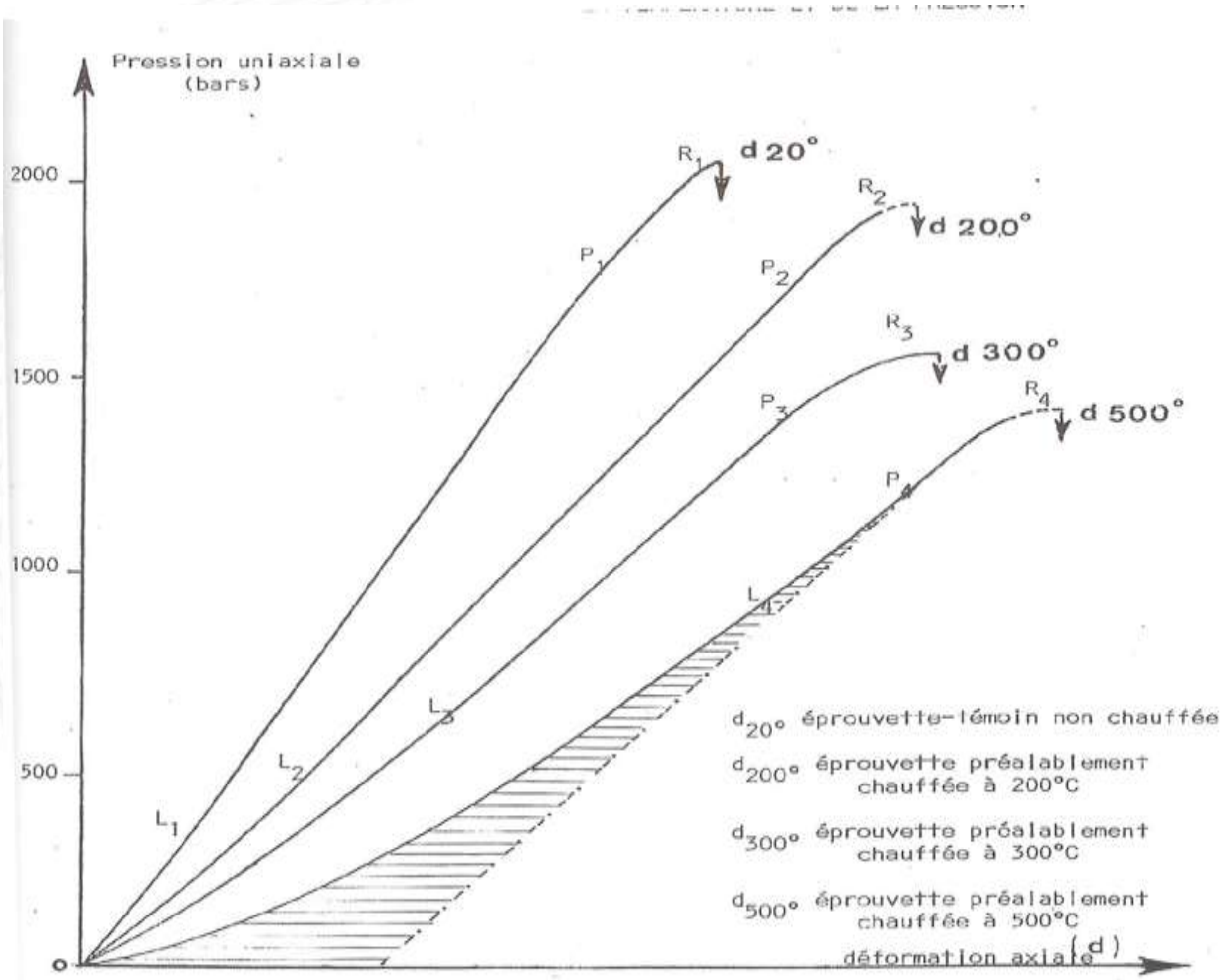






Thermal action followed by mechanical compression
Granite du Sidobre

1) Decrease of the young modulus 2) un accroissement de la déformation de tassement 3) diminution de la portion rectiligne 3) une accentuation de la courbure prérupture 3) lowering of the failure load



Synthèse

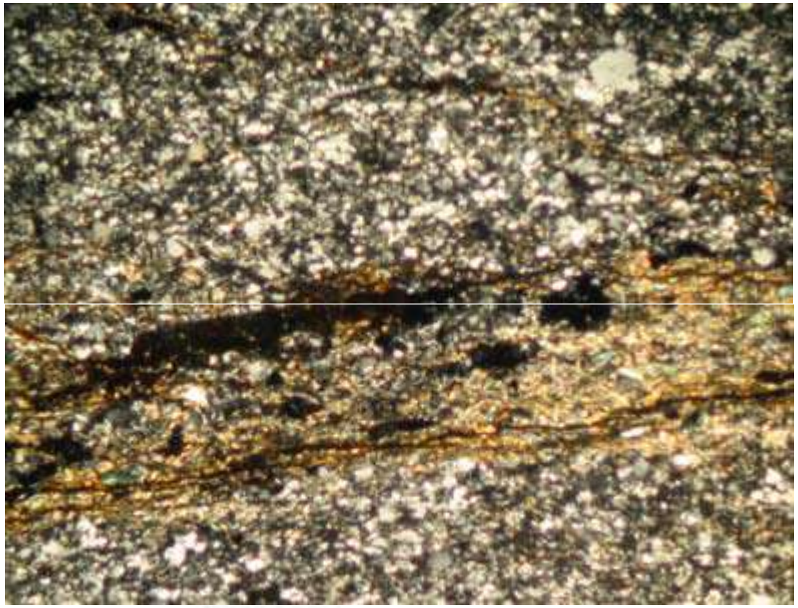
Finally, the heating treatament modifies many mechanical behaviour of the rocks :

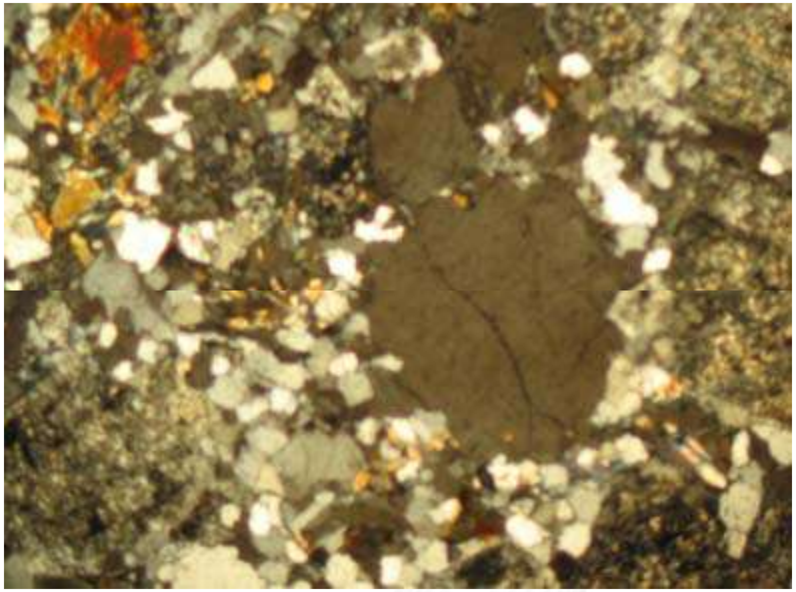
1) It cause an important closing and crushing at the beginning of the loading.

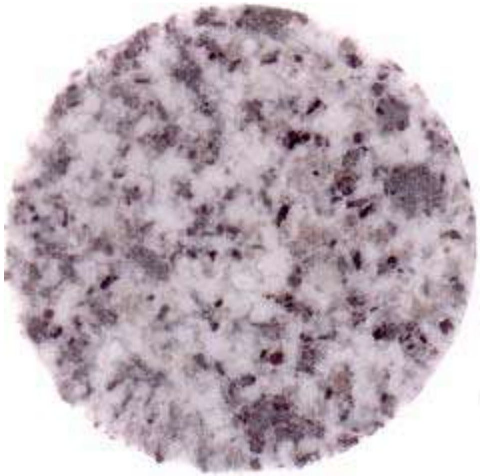
2) If the rock is made of fine grains and is initially not microcracked, the heat treatment creates a network of fewly open intercrystalline microcracks which decreases the cohesion of the rock and causes a considerable lowering of the microfissuration threshold and the failing load.

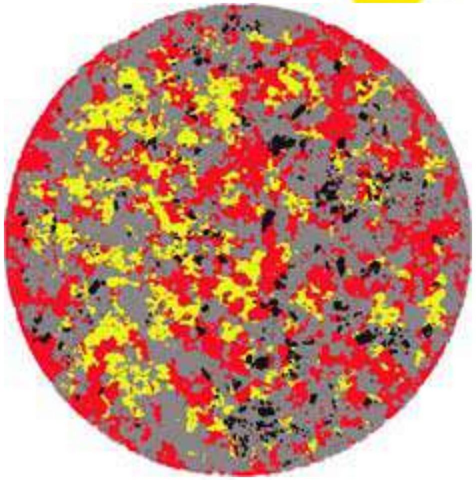
3) If on the contrary the rock made of coarse grains is already microcracked, the heat treatment enlarges the existing cracks and causes increase of the permeability but the microfissuration threshold and the failing load are not modified..

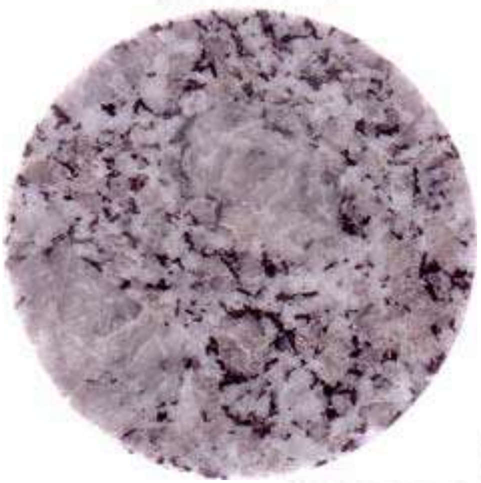
4) The initial microcracks due the heating of the rocks absorbs strain concentration at the boundaries of the grains and postpone new cracking formation

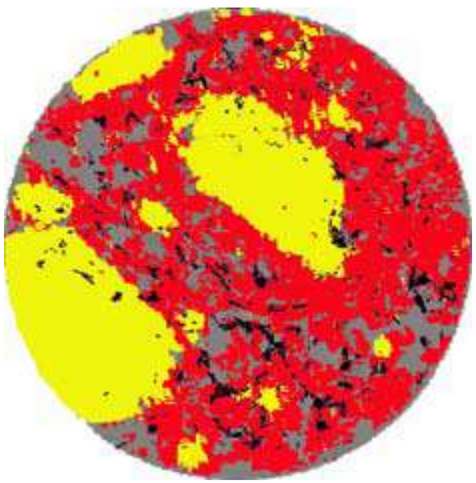












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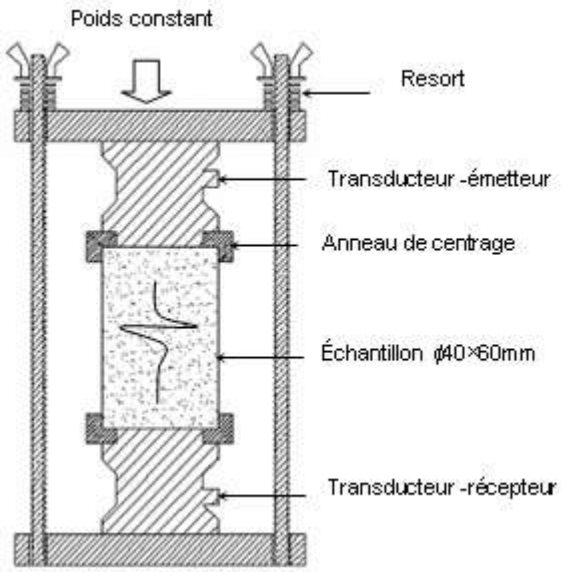

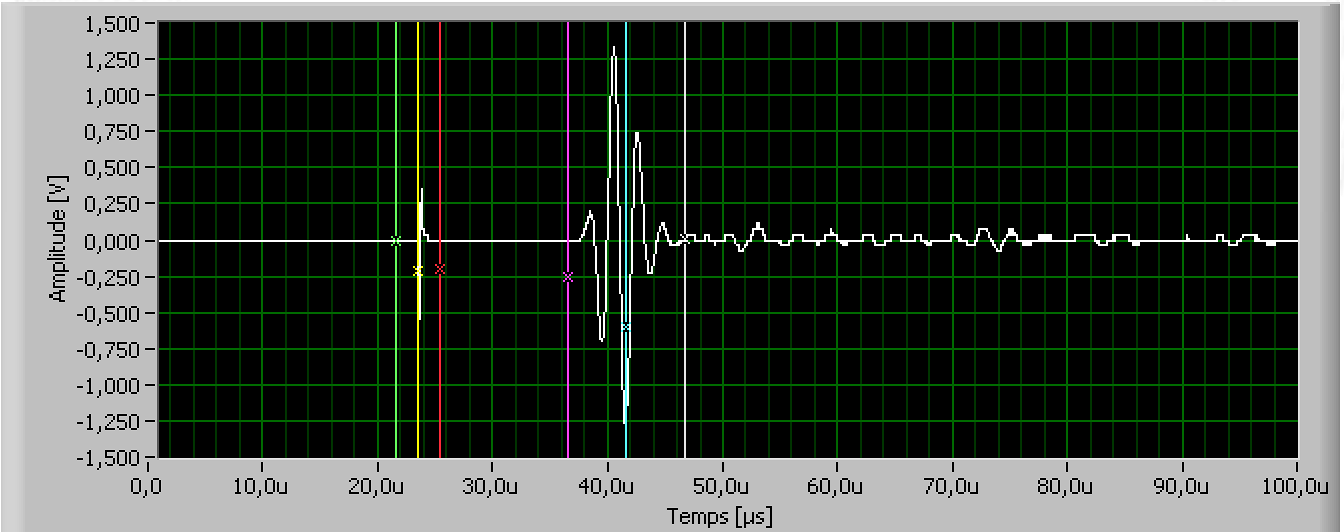

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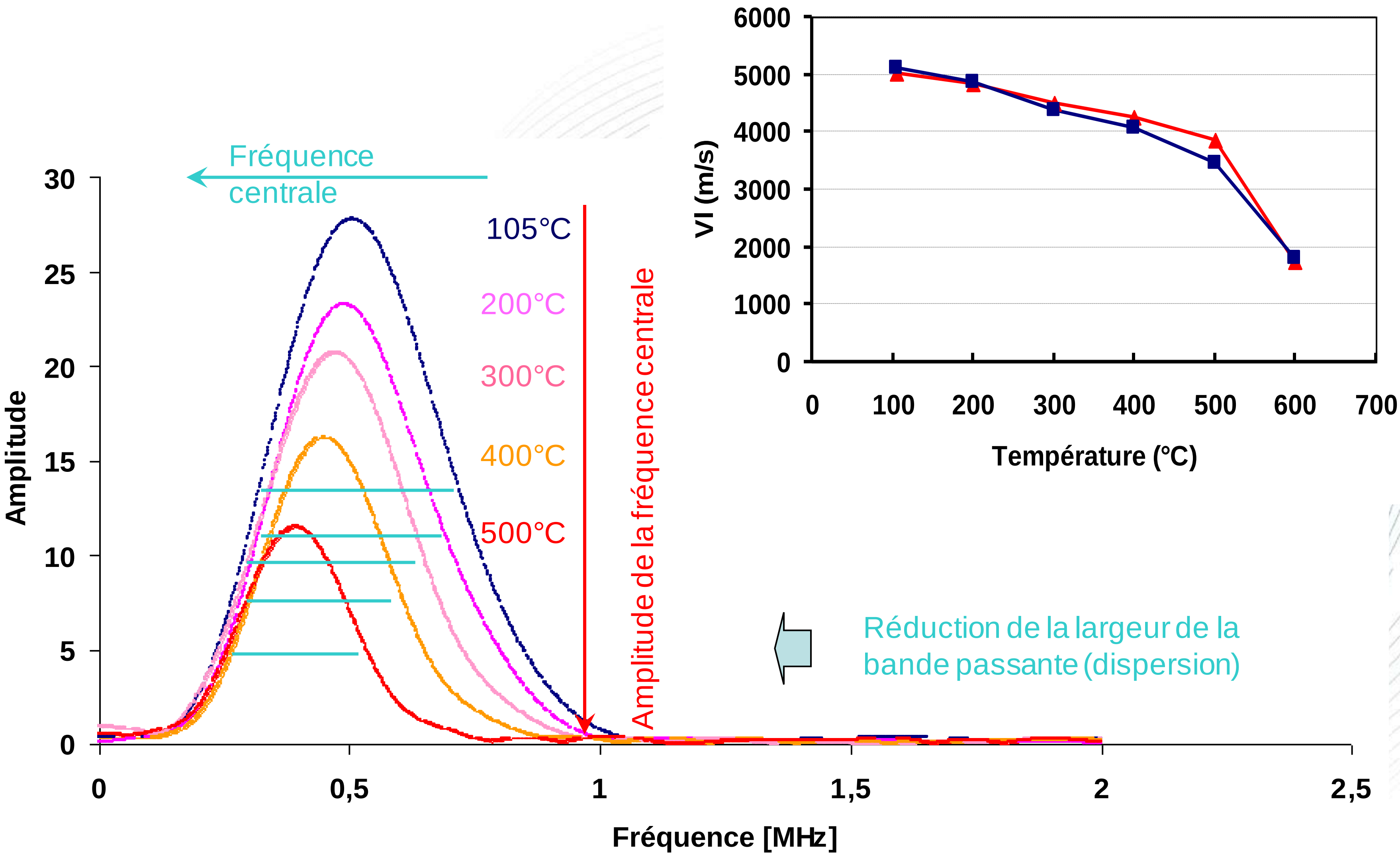
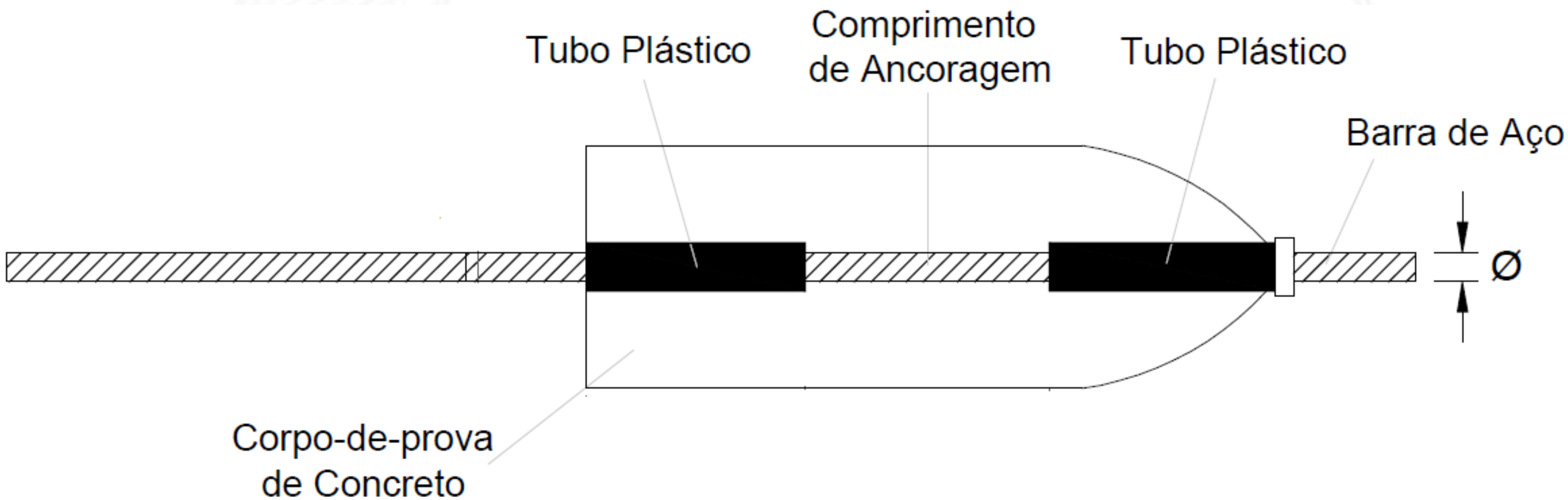
Résultats expérimentaux

Sensibilité des mesures ND

❖ Ultrasons



Réduction de la largeur de la bande passante (dispersion)


Tubo Plástico
Comprimento
de Ancoragem
Tubo Plástico
Barra de Aço
Ø
Corpo-de-prova
de Concreto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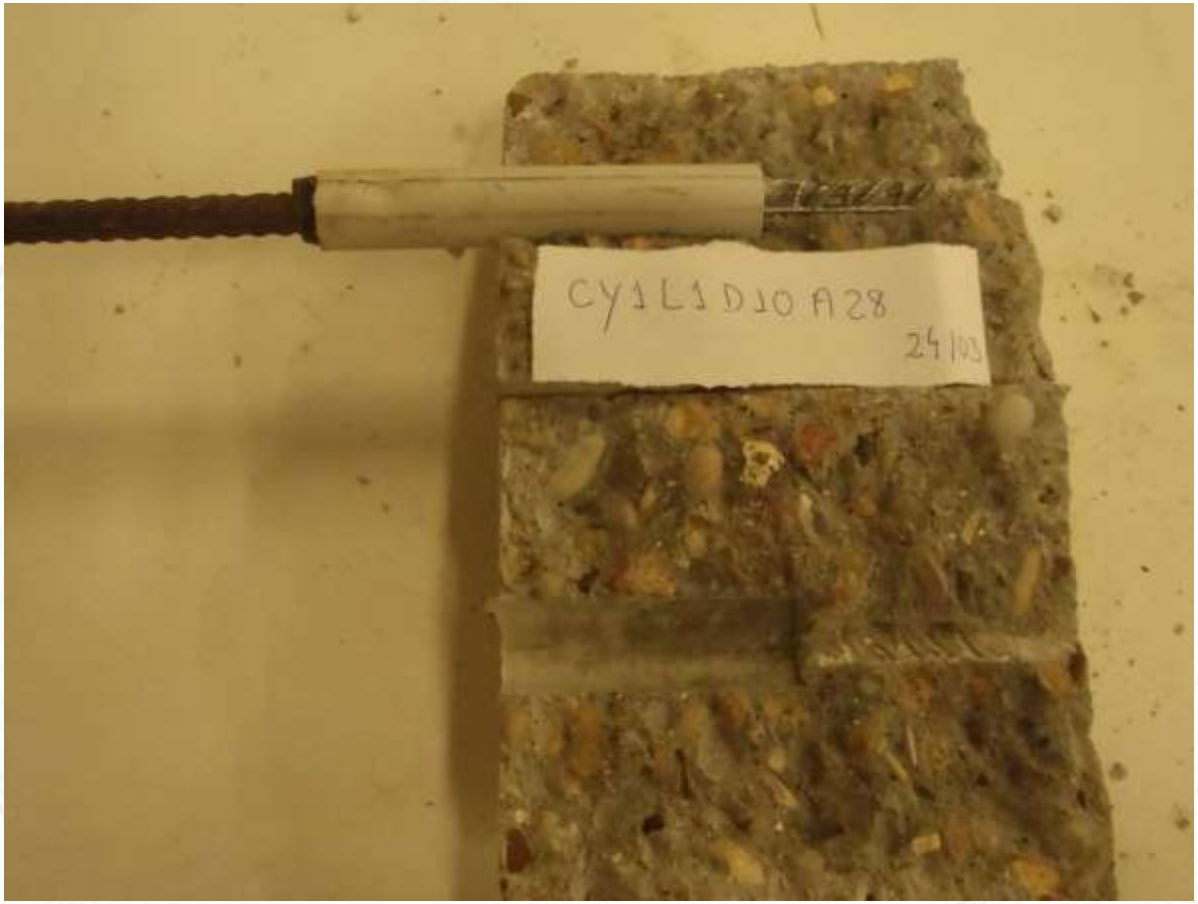
24/03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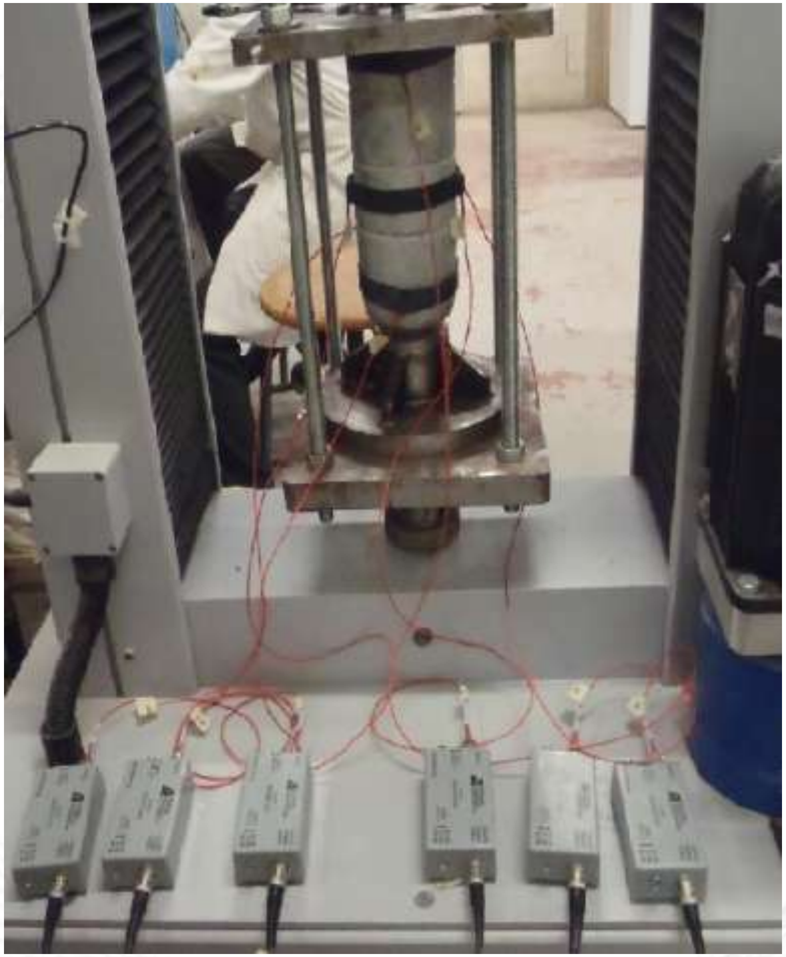

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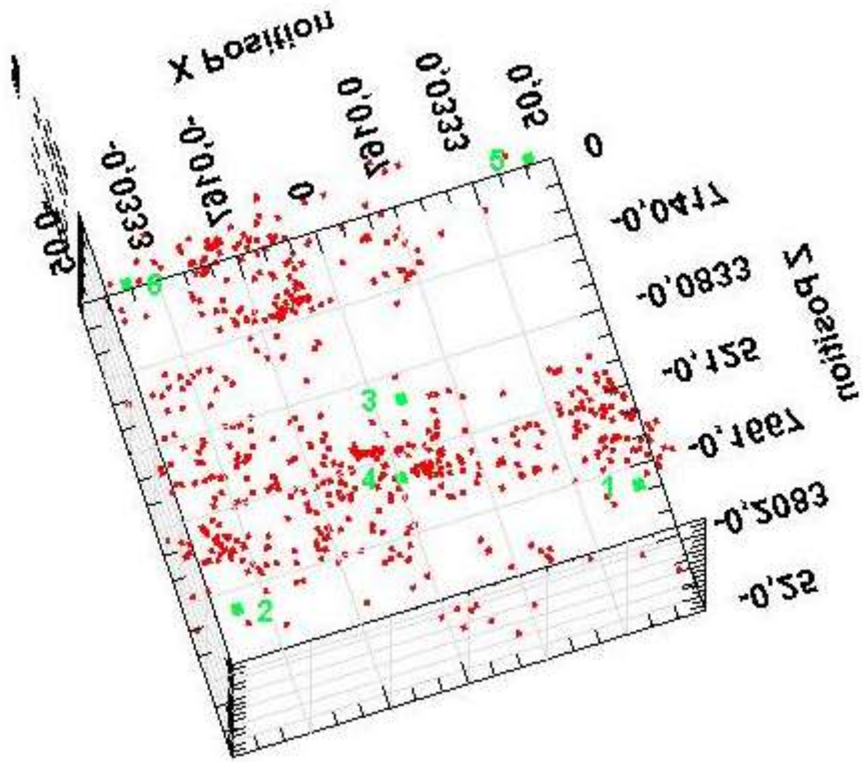

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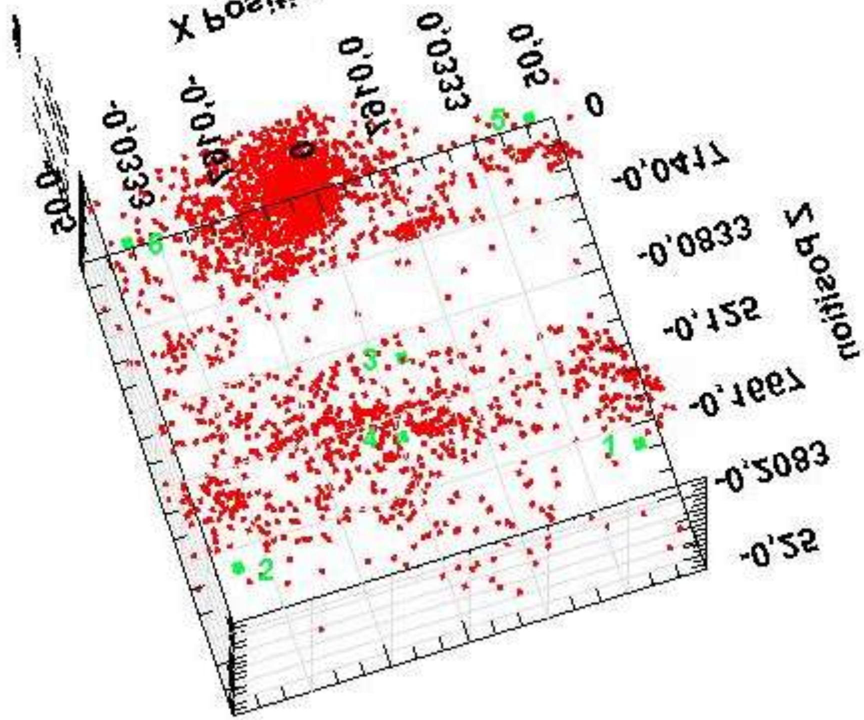

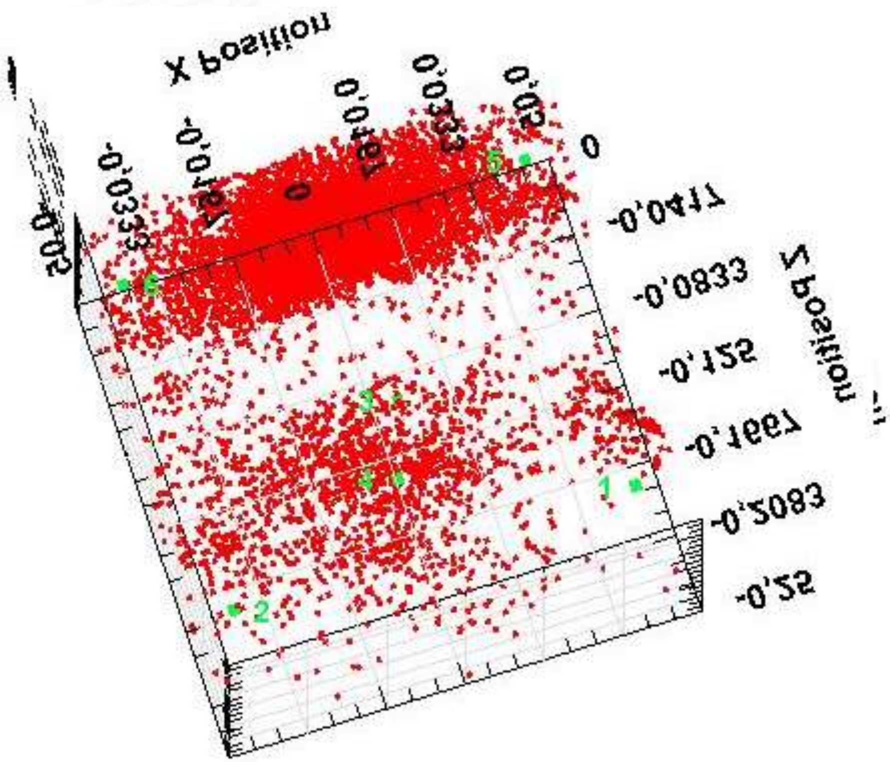
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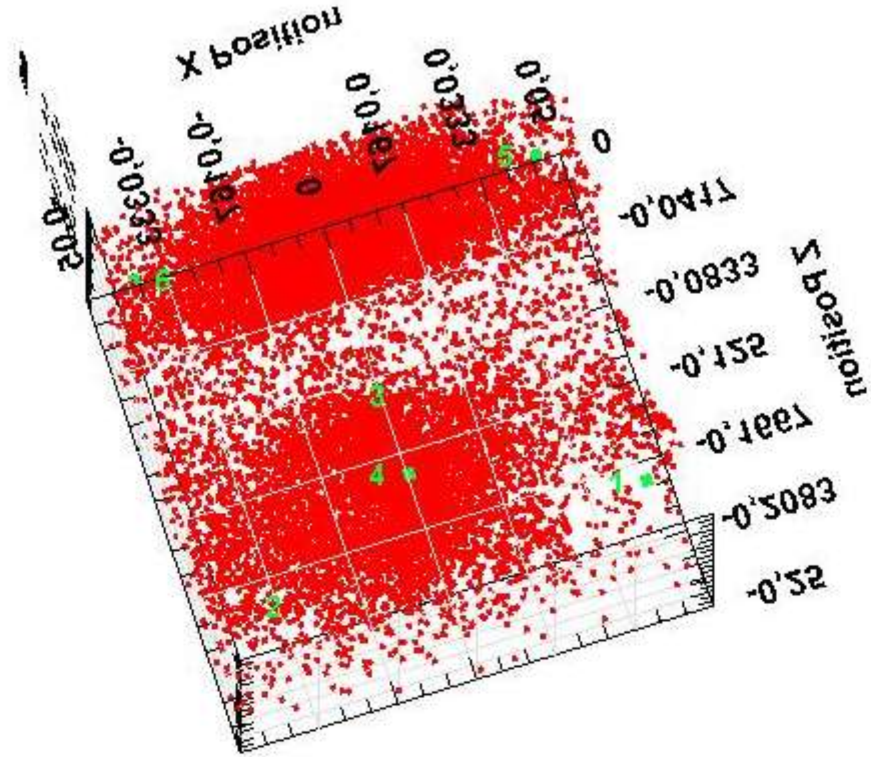

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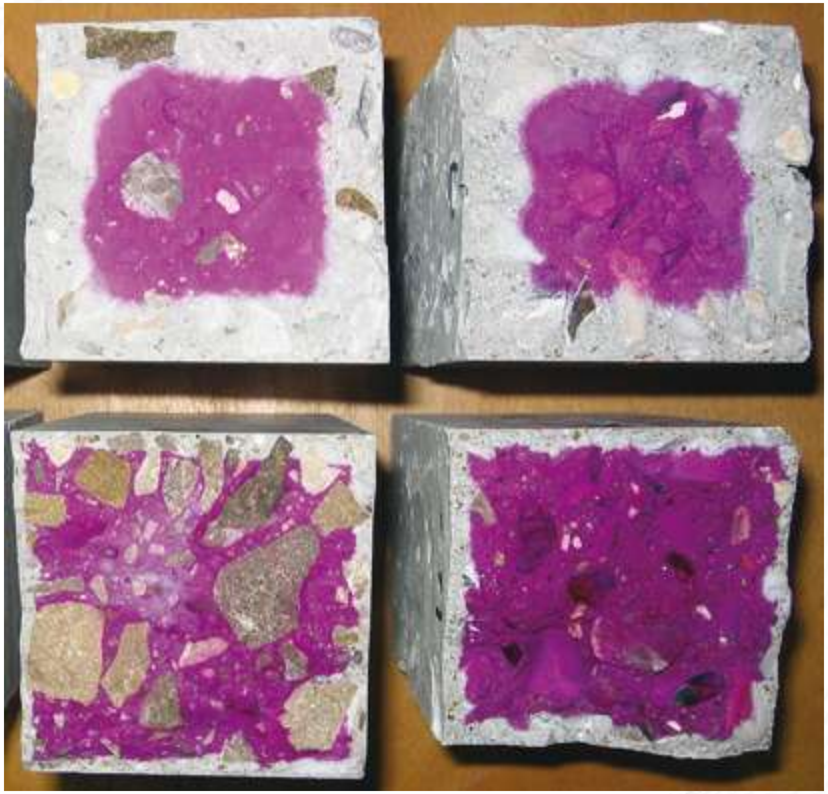
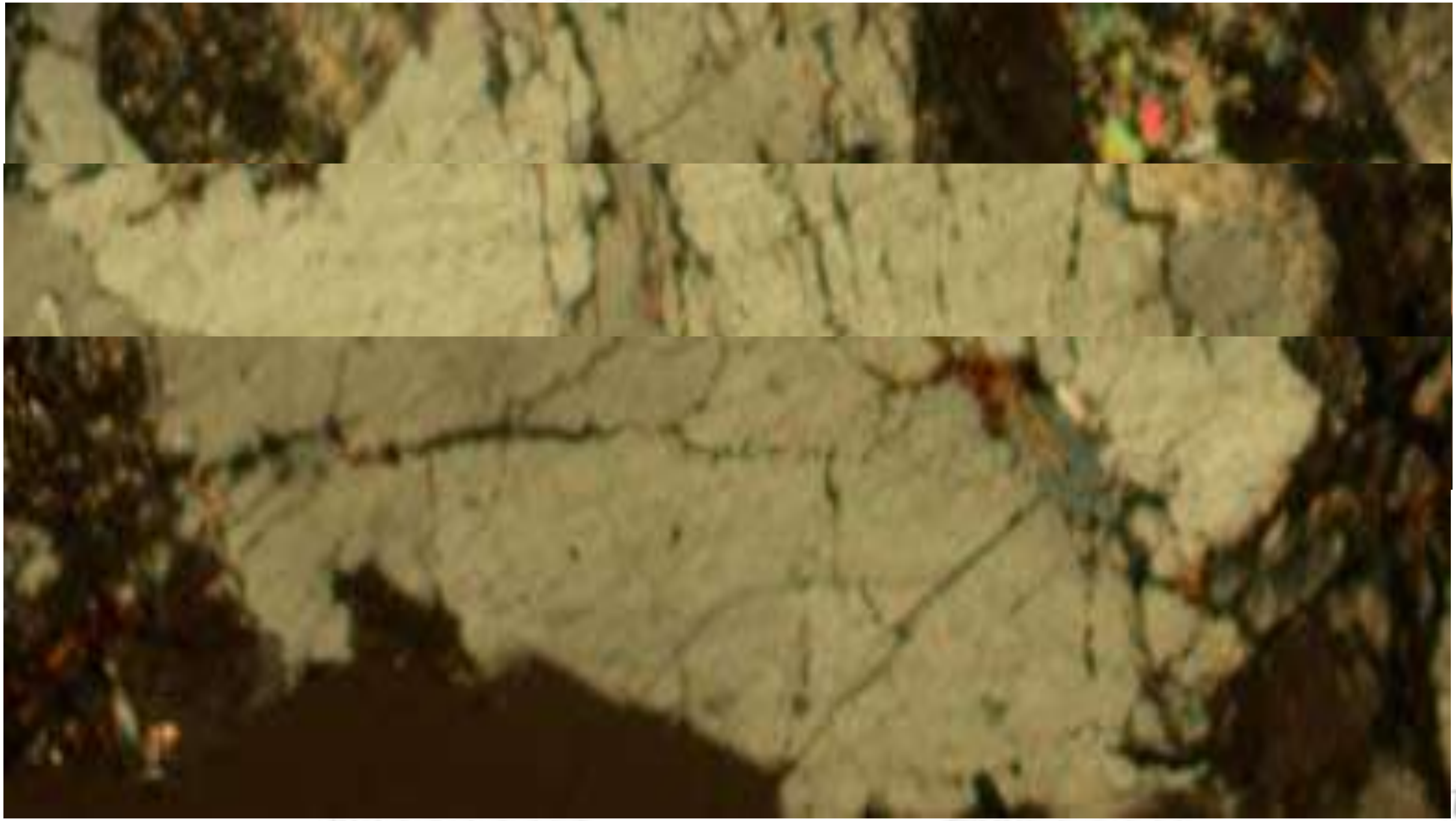


Quartz microcraquelé



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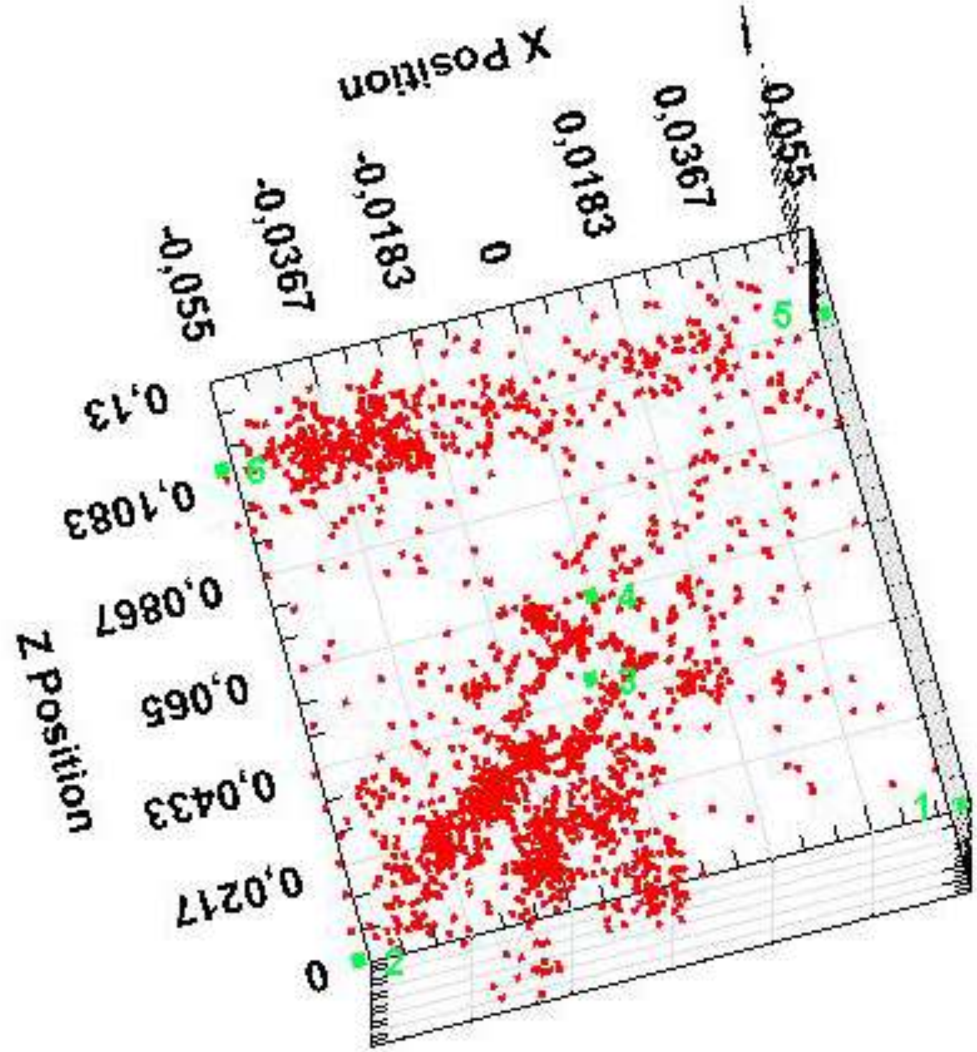

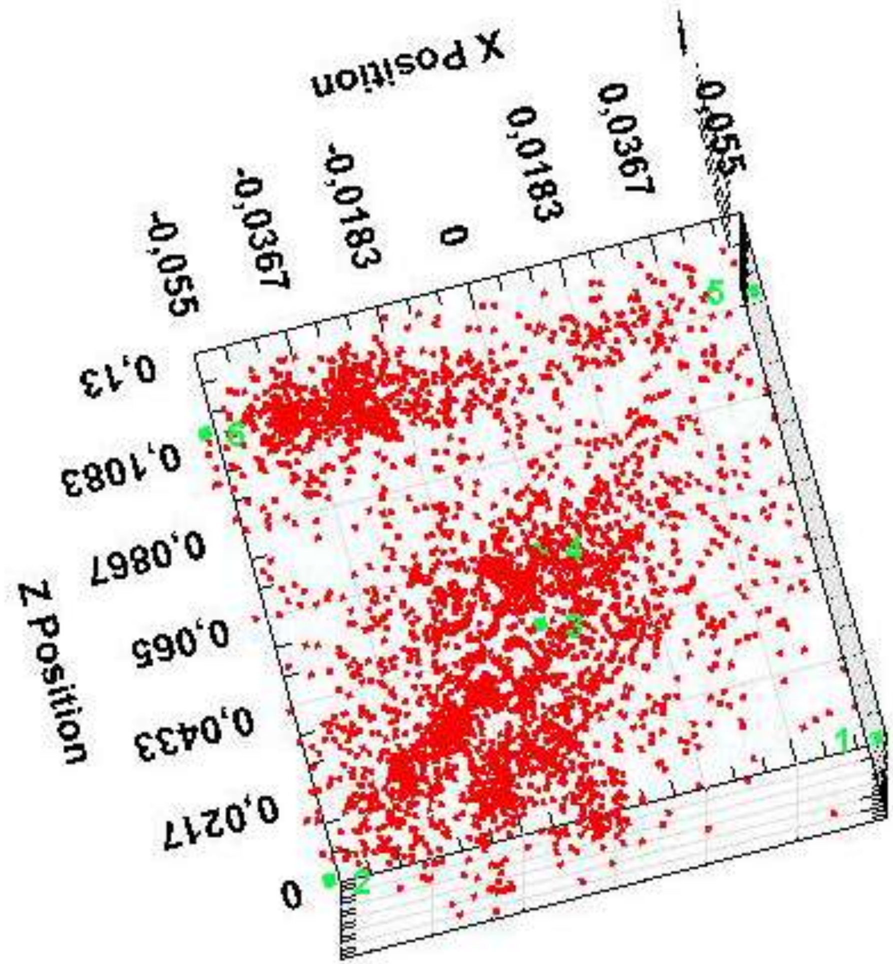
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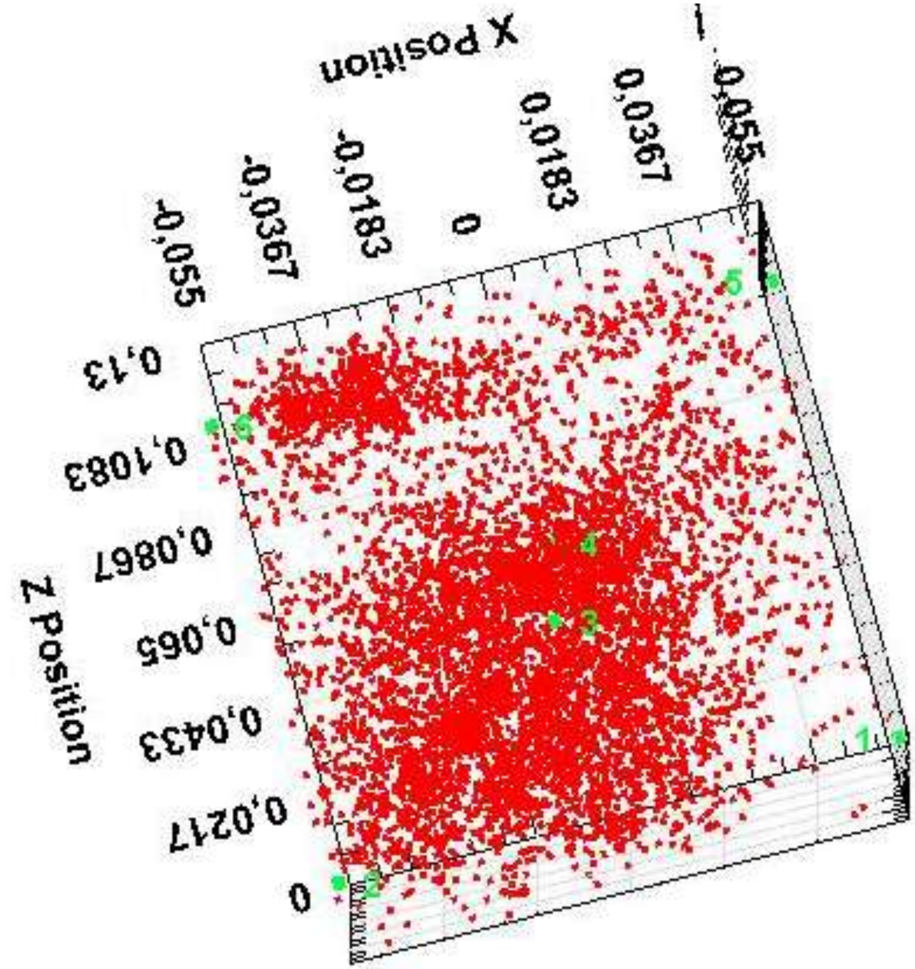
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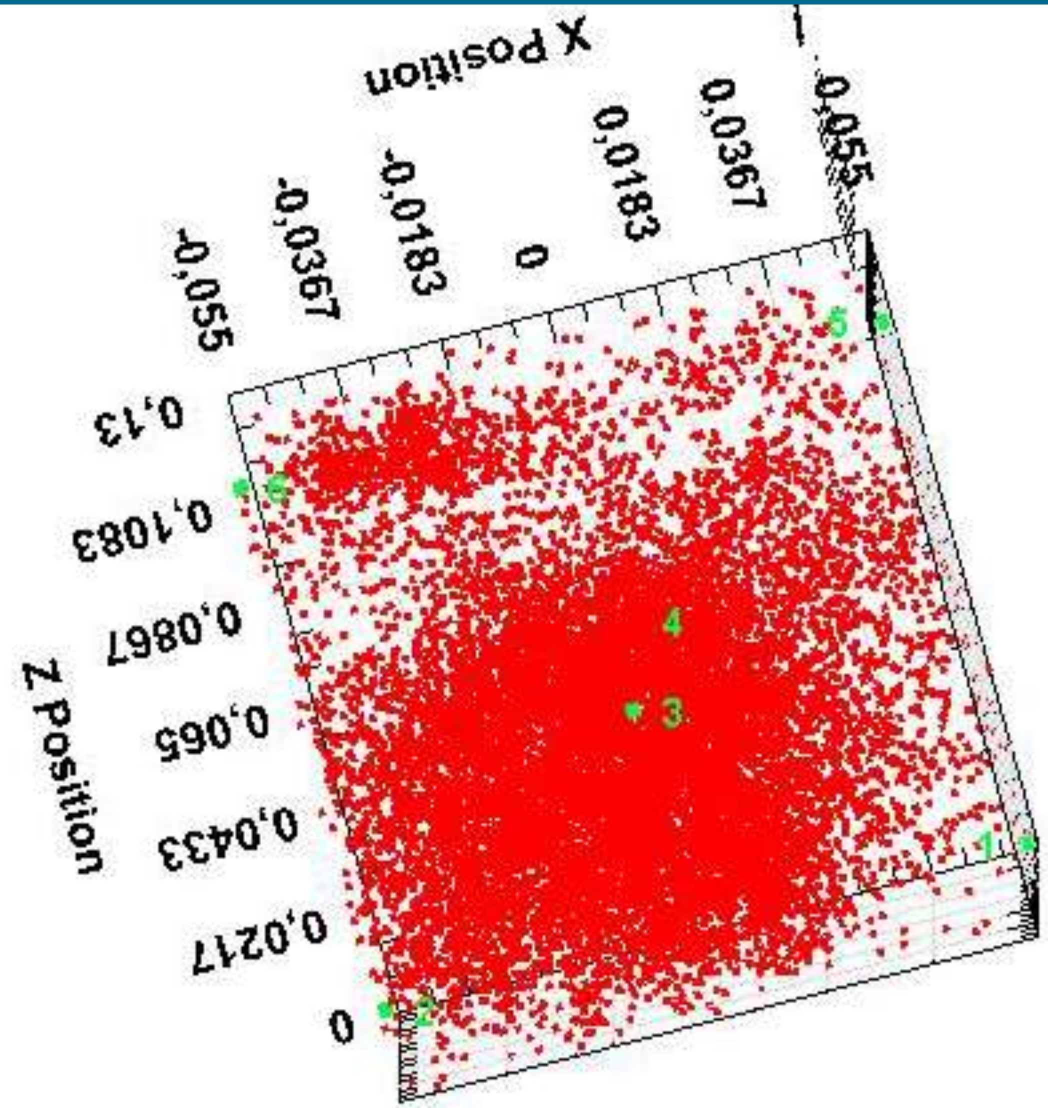
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