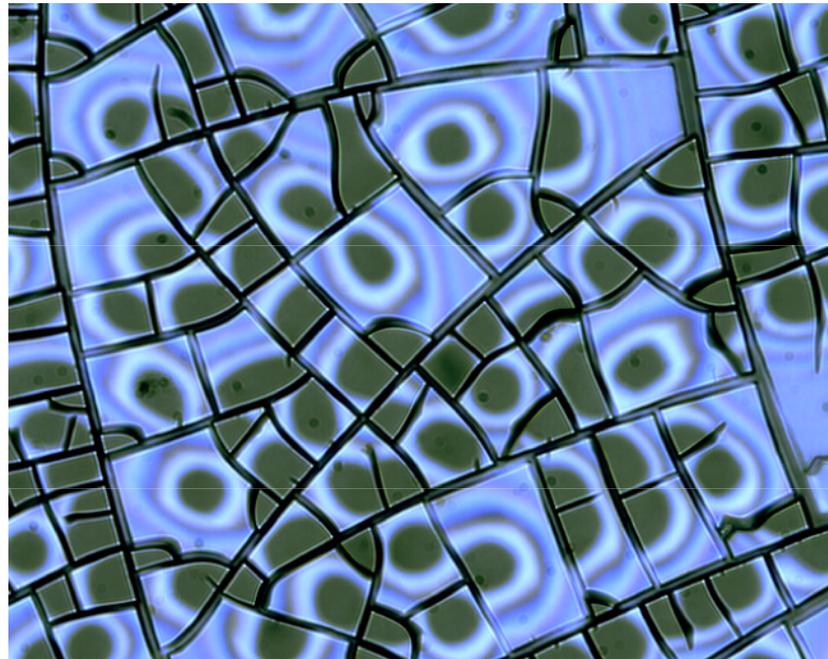
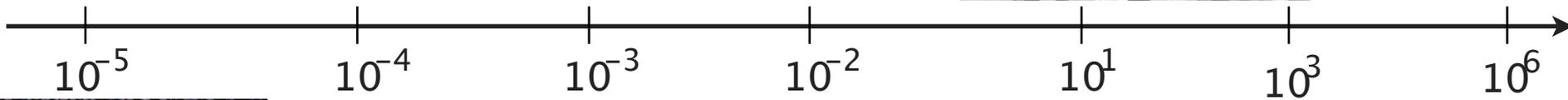
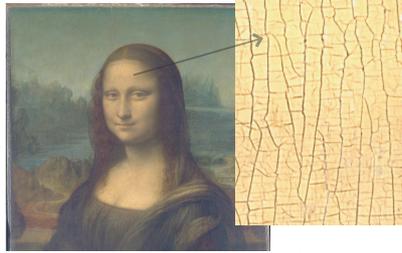
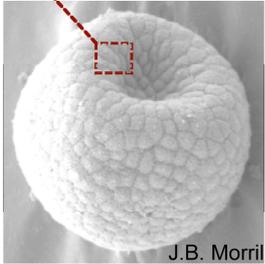
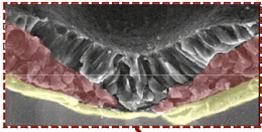
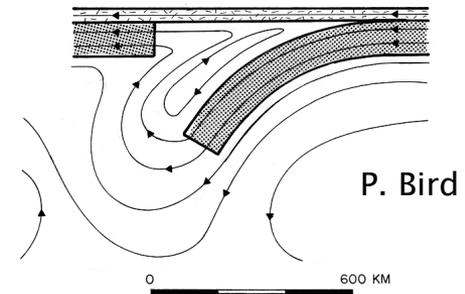


Instabilités dans les systèmes complexes

L. Pauchard
FAST – Orsay



Singularités

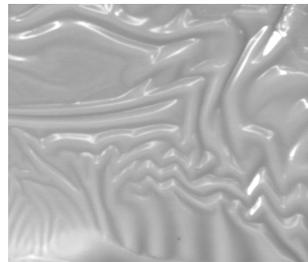
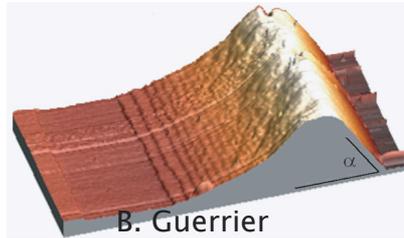
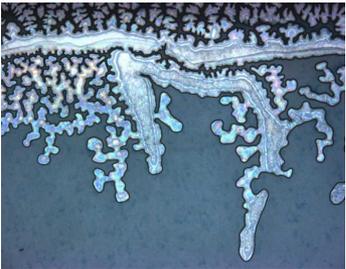


F. Giorgiutti

De Vinci

A. Davaille

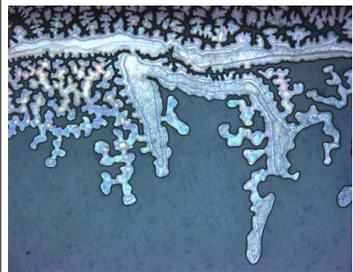
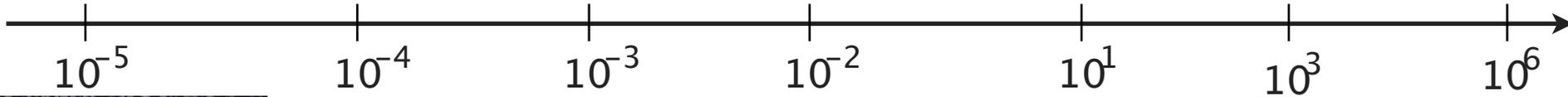
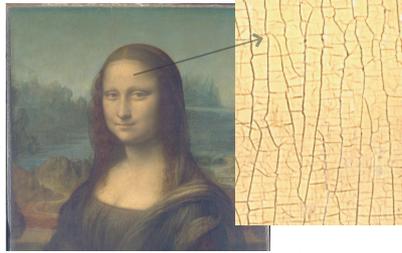
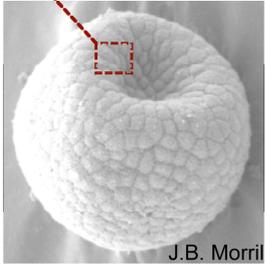
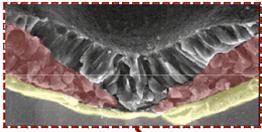
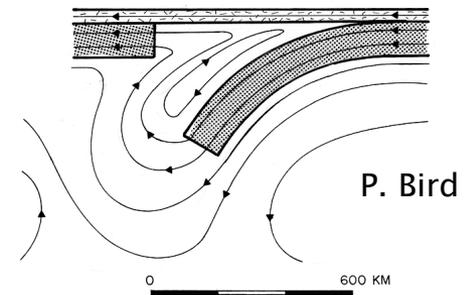
mètres



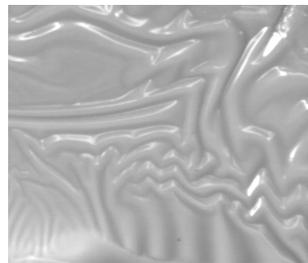
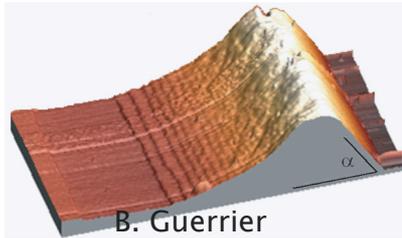
100 μm L. Pauchard

Lame traitée optiquement pour l'étude couplage exciton-photon (HYTEC)

Singularités



Lame traitée optiquement pour l'étude couplage exciton-photon (HYTEC)



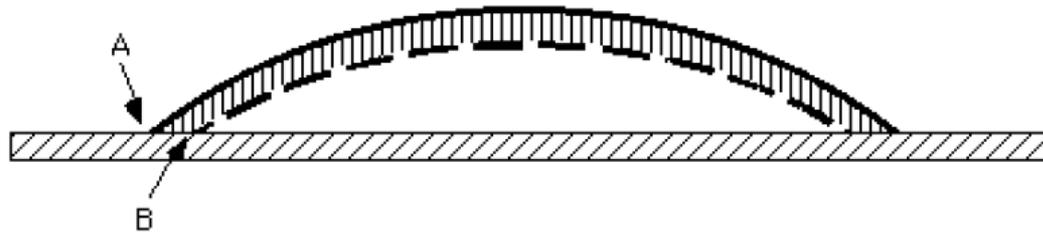
100μm L. Pauchard



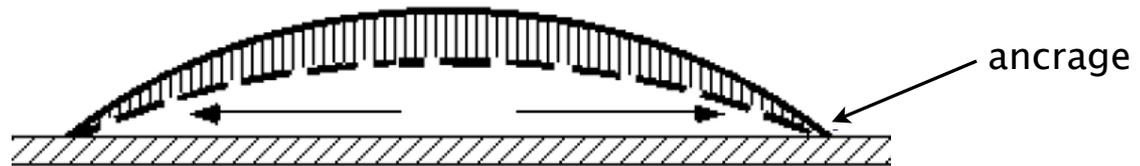
Séchage d'une goutte déposée sur un substrat



solvant pur

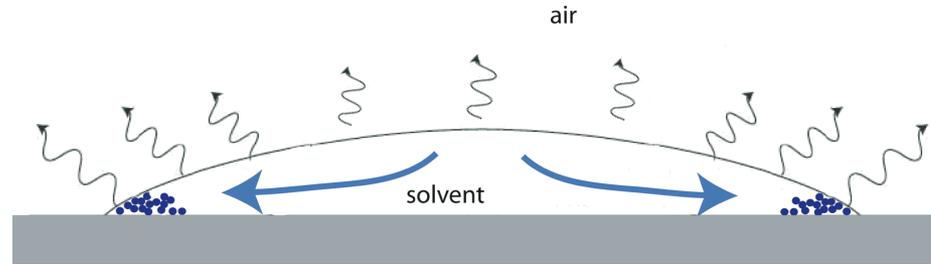


liquide complexe



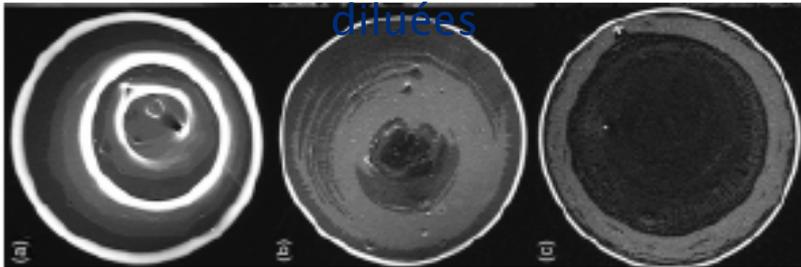
Deegan et al. Nature
(1997)

Séchage d'une goutte déposée sur un substrat



solutions diluées

figures de dépôts laissés par des gouttes de suspensions colloïdales diluées



Deegan et al. Phys Rev E (2000)

vues de dessus

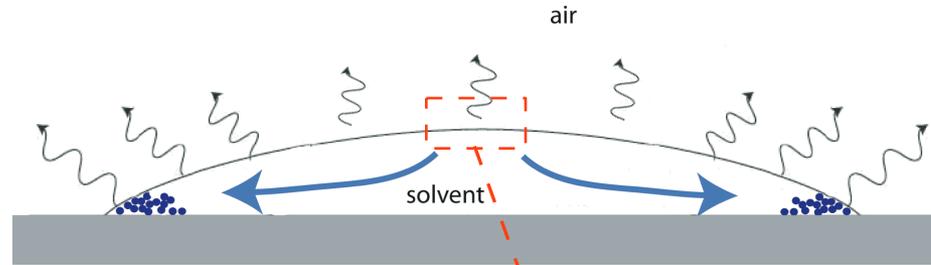
solutions concentrées

- 1- ancrage de la ligne triple
- 2- gradients de concentration

- 3- instabilités hydrodynamique (Rayleigh-Bénard ou Bénard-Marangoni) ou mécanique
⇒ formes de gouttes complexes

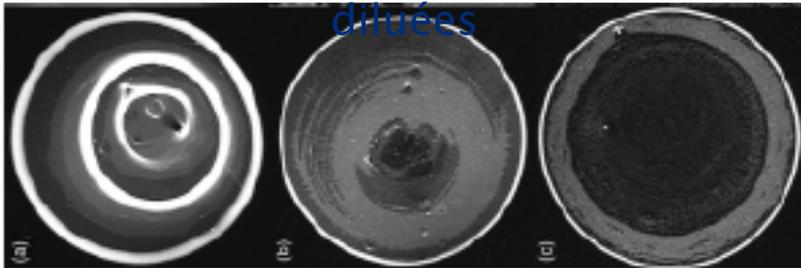


Séchage d'une goutte déposée sur un substrat



solutions diluées

figures de dépôts laissés par des gouttes de suspensions colloïdales diluées

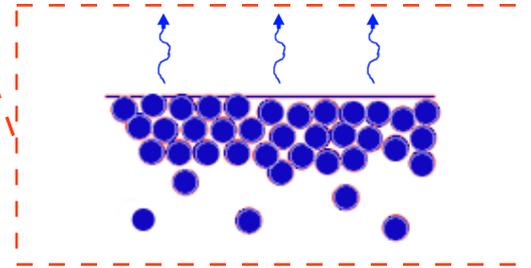


Deegan et al. Phys Rev E (2000)

vues de dessus

solutions concentrées

- 1- ancrage de la ligne triple
- 2- gradients de concentration

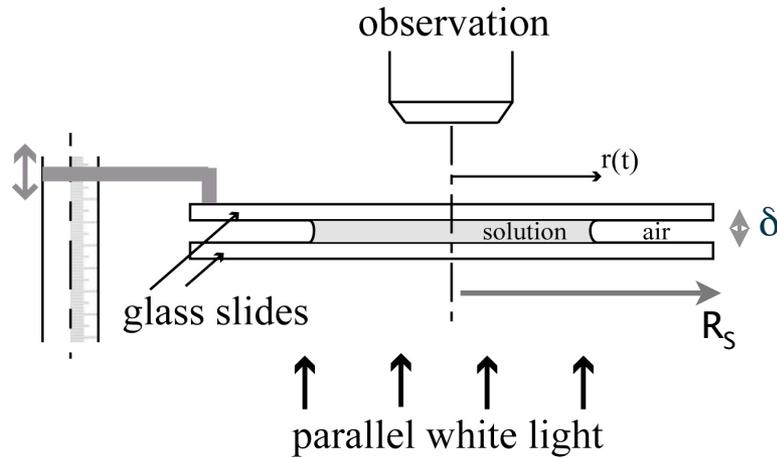


- 3- instabilités hydrodynamique (Rayleigh-Bénard ou Bénard-Marangoni) ou mécanique
⇒ formes de gouttes complexes

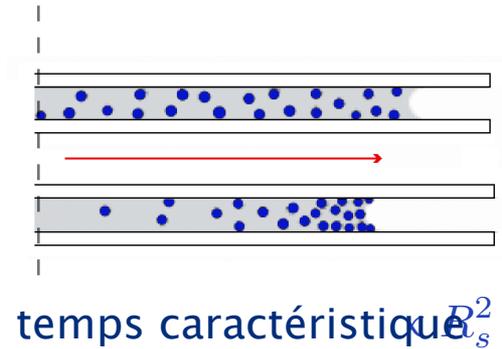


I. Séchage en milieu confiné

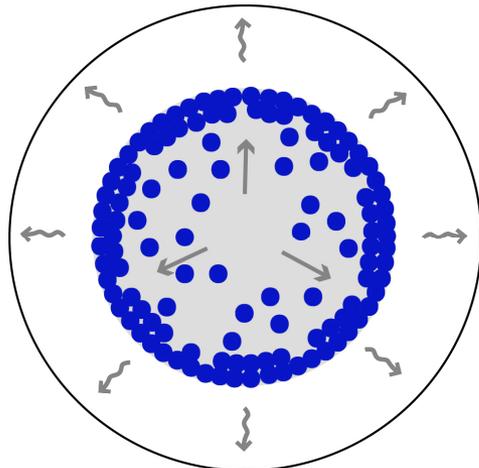
F. Giorgiutti-Dauphiné, L. Pauchard



séchage directionnelle



formation d'une enveloppe poreuse



paramètres expérimentaux:

- solution (colloïdes, polymères,...)
- conditions de séchage (géométrie, RH, T)
- conditions de mouillage (solutions, substrats)

Séchage en milieu confiné

suspension colloïdale

de nanolatex “dur”

$T_g = 100^\circ\text{C}$,

$\varnothing \sim 25 \text{ nm}$,

$\phi_{v0} \sim 30\%$,

$\eta = 8 \text{ mPa}\cdot\text{s}$,

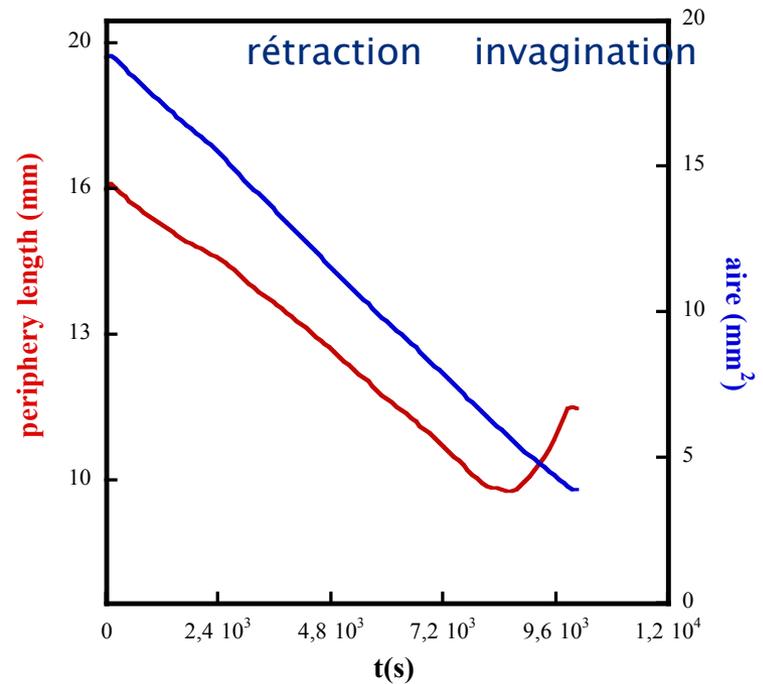
$\gamma = 62 \text{ mN/m}$

air

liquide

$r_0 = 2.4 \text{ mm}$

$\frac{\delta}{R_s} = 0.02$



flambement de l'enveloppe poreuse

d'après loi de Darcy:

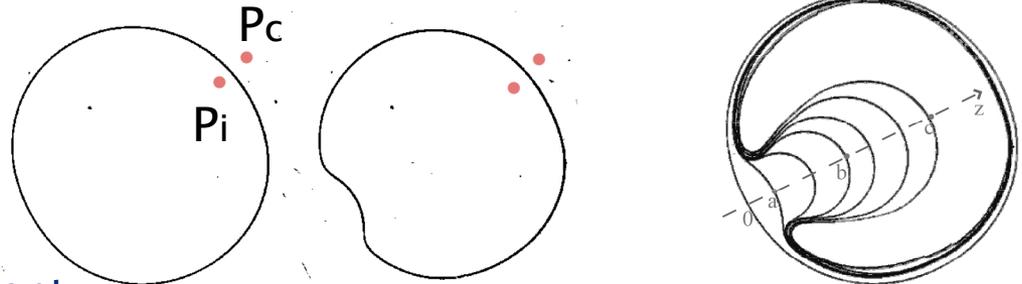
$$\Delta P_B = P_i - P_c = -\frac{1}{k} \eta V_E h_B$$

k: perméabilité (Carman-Kozeny)

η : viscosité solvant

V_E : vitesse d'évaporation

h_B : épaisseur enveloppe au flambement



Séchage en milieu confiné

suspension colloïdale

de nanolatex “dur”

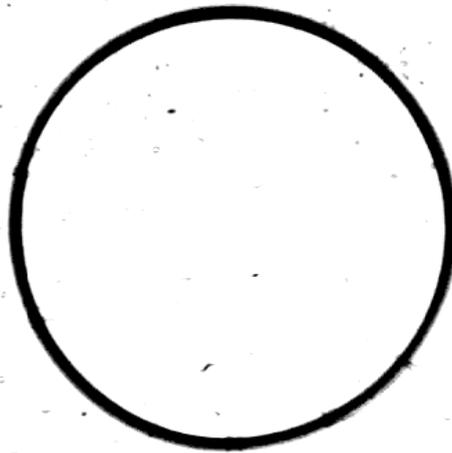
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$\varnothing \sim 25 \text{ nm}$,

$\phi_{v0} \sim 30\%$,

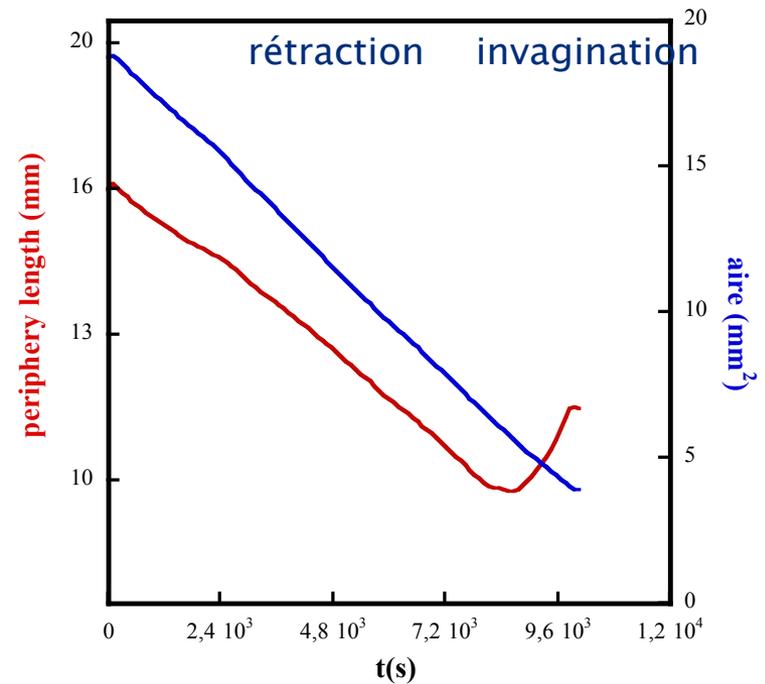
$\eta = 8 \text{ mPa}\cdot\text{s}$,

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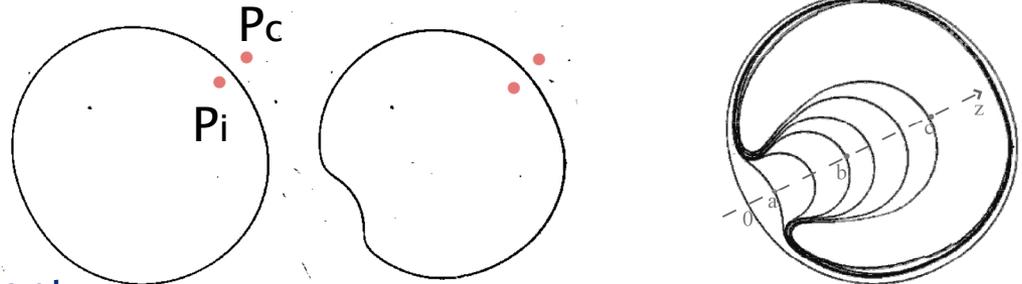
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Séchage en milieu confiné

suspension colloïdale

de nanolatex "dur"

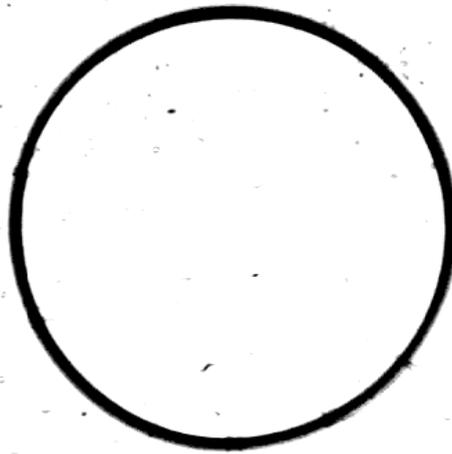
$T_g = 100^\circ\text{C}$,

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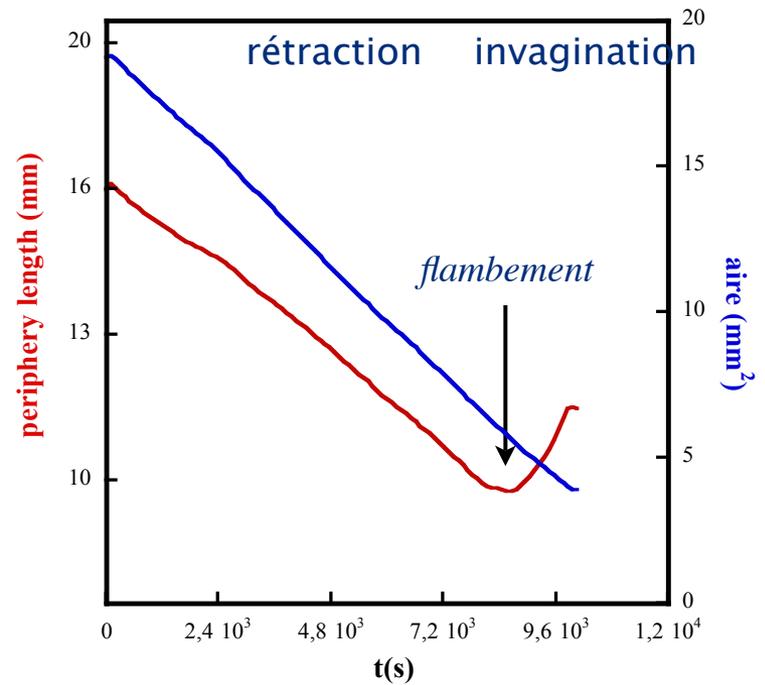
$\eta = 8 \text{ mPa}\cdot\text{s}$,

$\gamma = 62 \text{ mN/m}$



$r_0 = 2.4 \text{ mm}$

$\frac{\delta}{R_s} = 0.02$



flambement de l'enveloppe poreuse

d'après loi de Darcy:

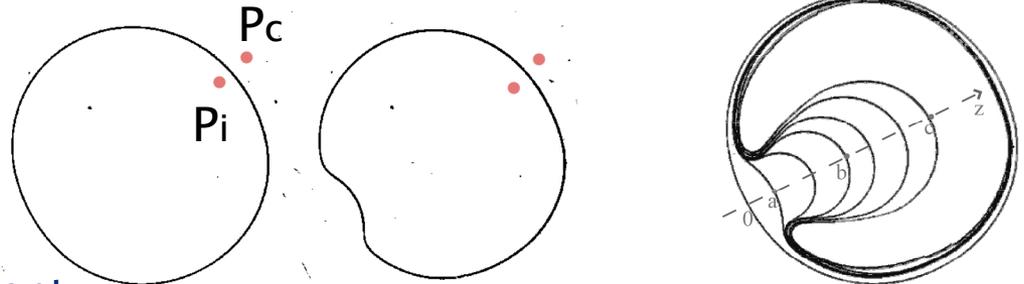
$$\Delta P_B = P_i - P_c = -\frac{1}{k} \eta V_E h_B$$

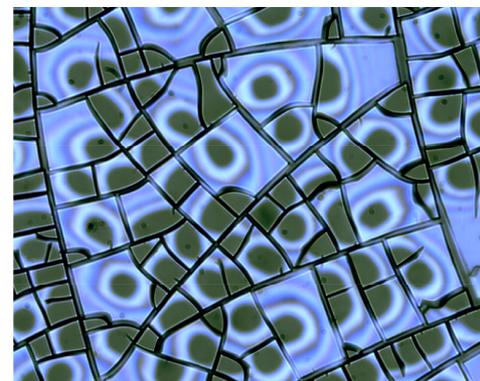
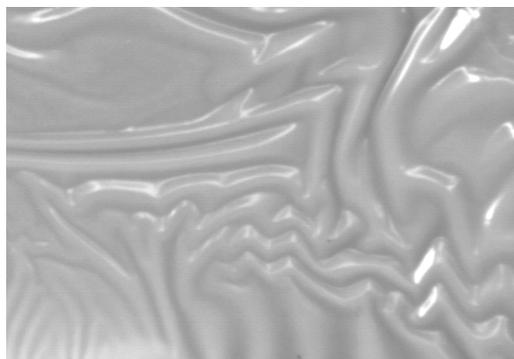
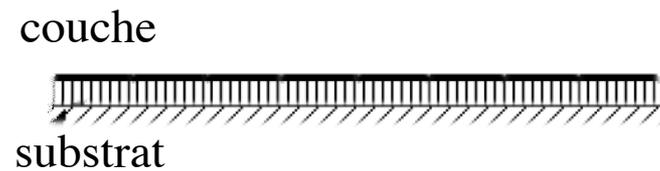
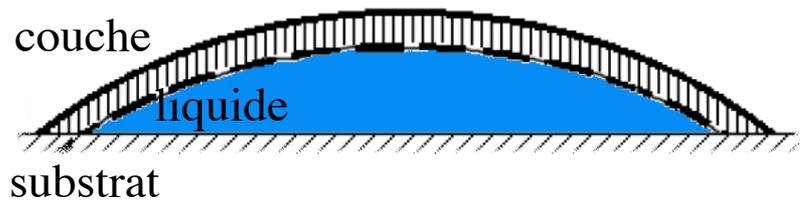
k: perméabilité (Carman-Kozeny)

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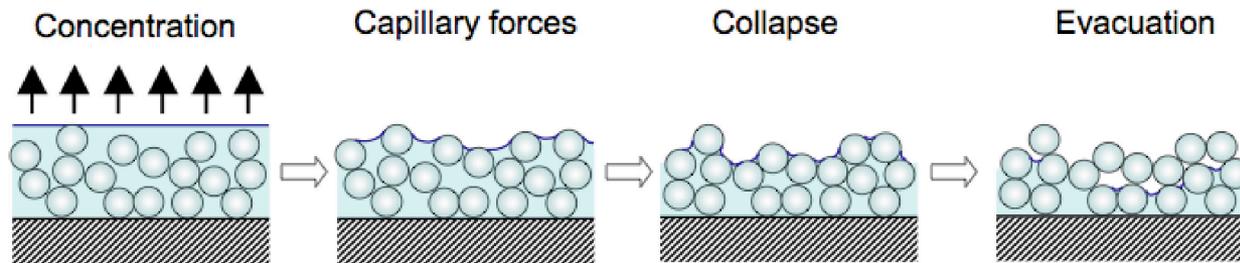




II. Morphologies de fractures induites par séchage

G. Gauthier, V. Lazarus, L. Pauchard

séchage d'une suspension concentrée de particules colloïdales



gel colloïdal = matrice poreuse solide saturée en solvant

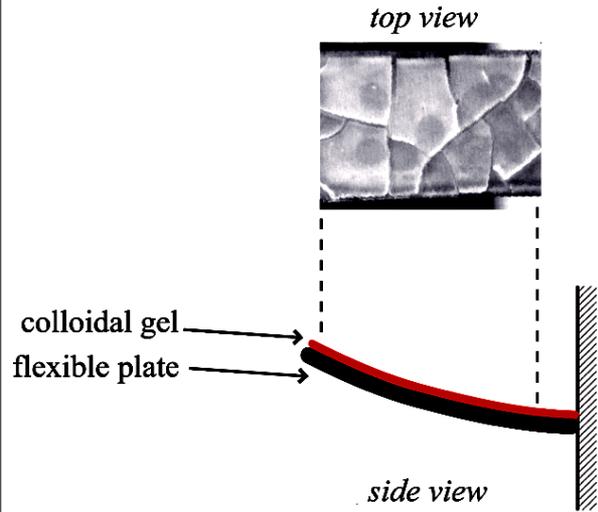
évaporation \Rightarrow **contraintes d'origine capillaire**

$$P_{cap} = \alpha \frac{\gamma_{solvant/air}}{r_{pore}} \cos\theta \sim 10^7 Pa$$

rétraction limitée par l'adhésion sur le substrat

Contraintes mécaniques induites par séchage

thèse M. Chekchaki



déflexion (μm)

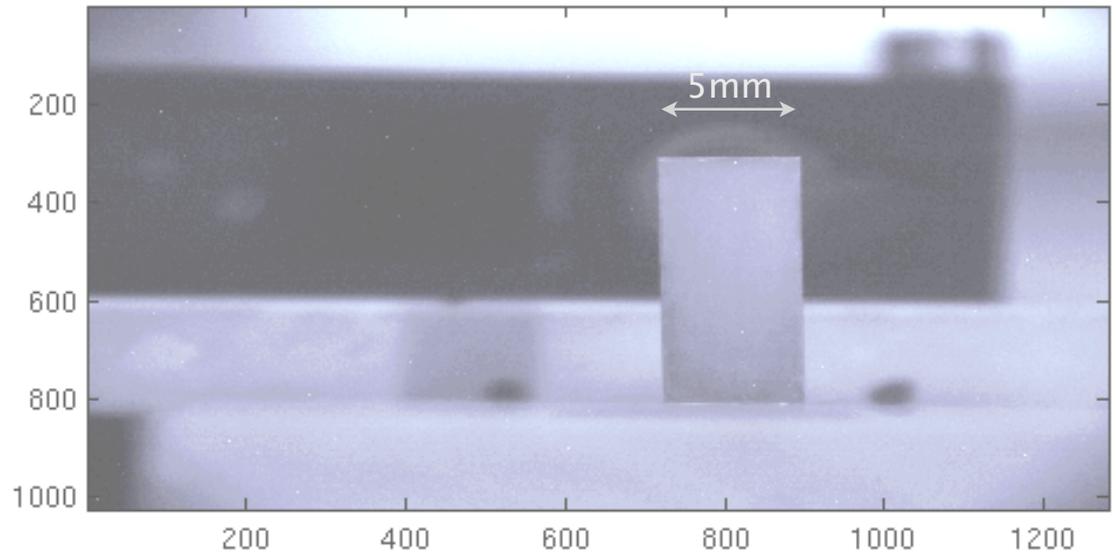
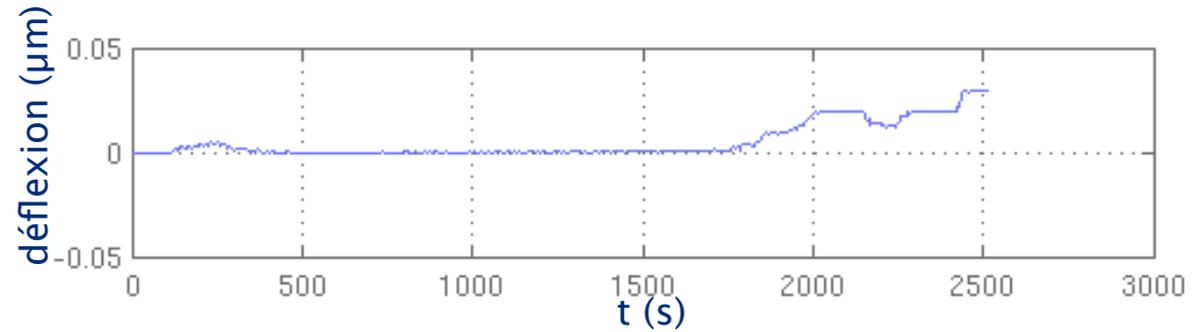
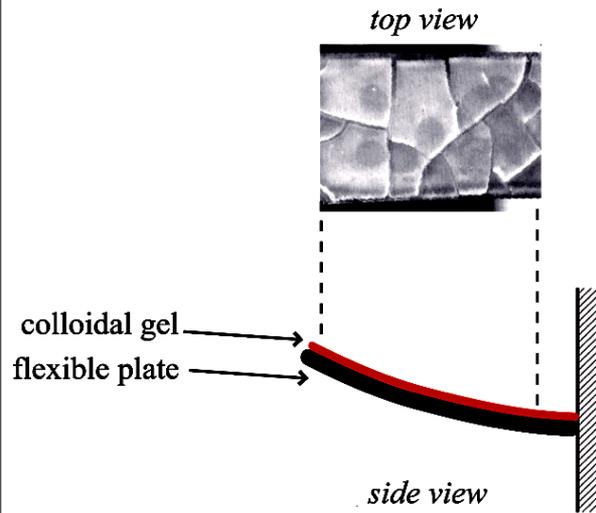
t (s)

5mm


$$\sigma_{film} \sim \frac{E_{substrat} h_{substrat}^2}{6h_{film} L} \gamma \quad (\text{formule de Stoney})$$

Contraintes mécaniques induites par séchage

thèse M. Chekchaki

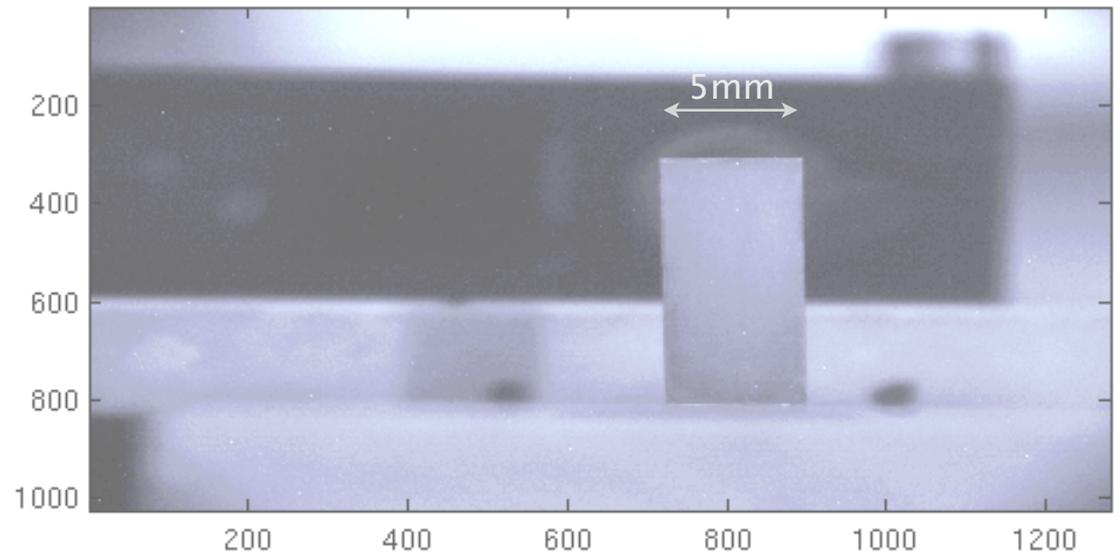
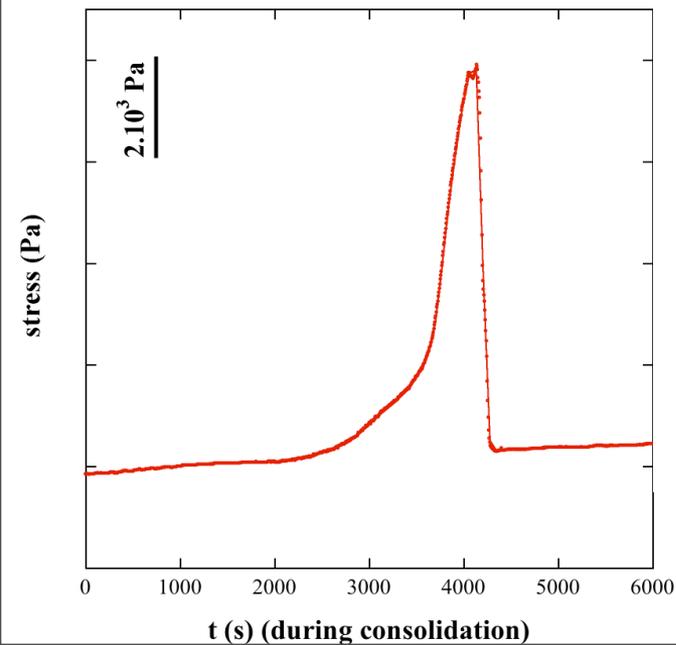
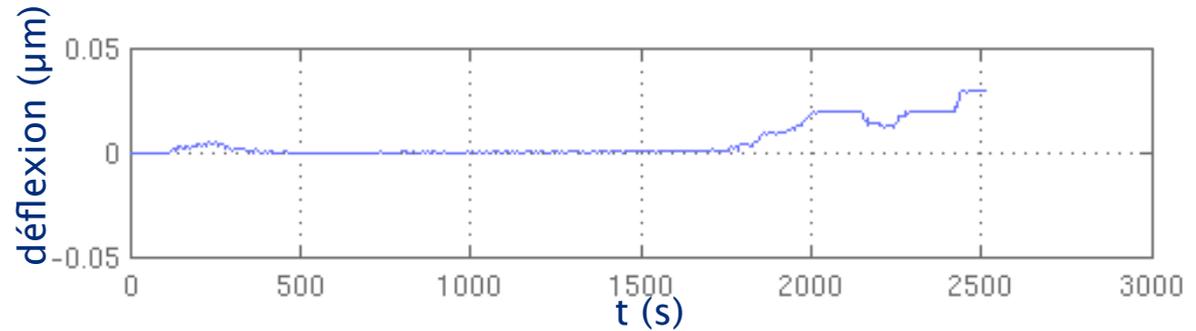
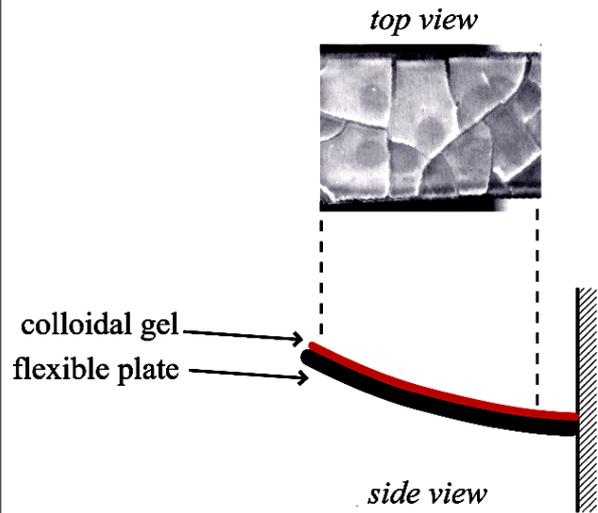


←

$$\sigma_{film} \sim \frac{E_{substrat} h_{substrat}^2 \gamma}{6 h_{film} L} \quad (\text{formule de Stoney})$$

Contraintes mécaniques induites par séchage

thèse M. Chekchaki



$$\sigma_{film} \sim \frac{E_{substrat} h_{substrat}^2 \gamma}{6 h_{film} L} \quad (\text{formule de Stoney})$$

Contraintes mécaniques induites par séchage

contraintes influencées par:

- perméabilité de la structure poreuse
- effets de la présence de surfactants (réduction de la pression capillaire)
- rigidité de la structure poreuse
- cinétique de séchage

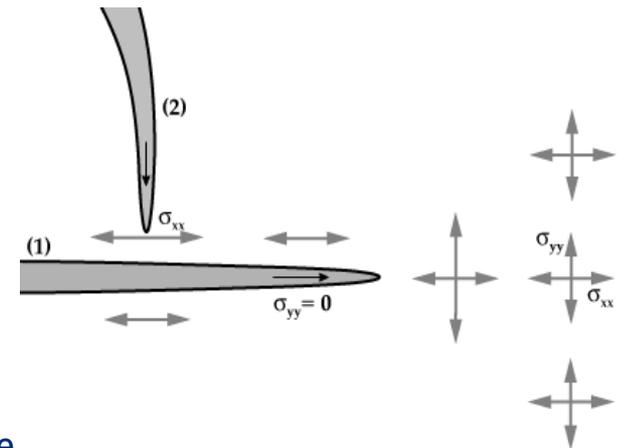
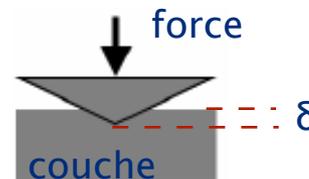
$$P_{cap} = \alpha \frac{\gamma_{solvant/air}}{r_{pore}} \cos\theta \sim 10^7 Pa$$

propagation d'une fracture:

facteur d'intensité des contraintes: $K = \sigma\sqrt{h}K_{fissure}^*$

$$\begin{cases} K < K_c & \text{pas de propagation} \\ K \geq K_c & \text{propagation} \end{cases} \quad (\text{critère d'Irwin})$$

K_c : ténacité du matériau \Rightarrow micro-indentation

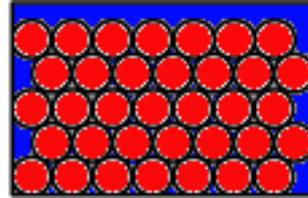
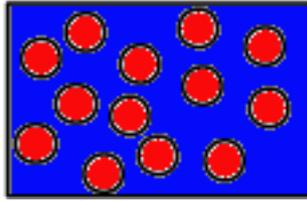


Contraintes mécaniques induites par séchage

latex

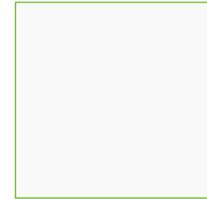
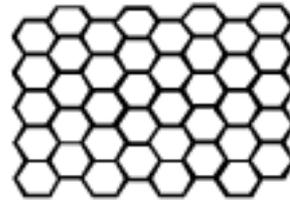
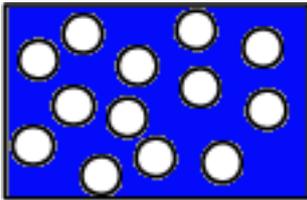
suspension de particules colloïdales rigides

$T_{amb} < T_g$

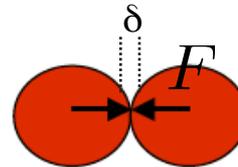


suspension de particules colloïdales déformables

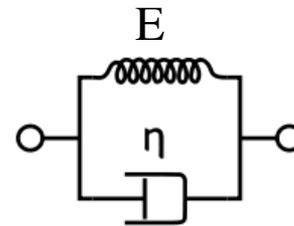
$T_g < T_{amb}$



modèle de Kelvin-Voigt



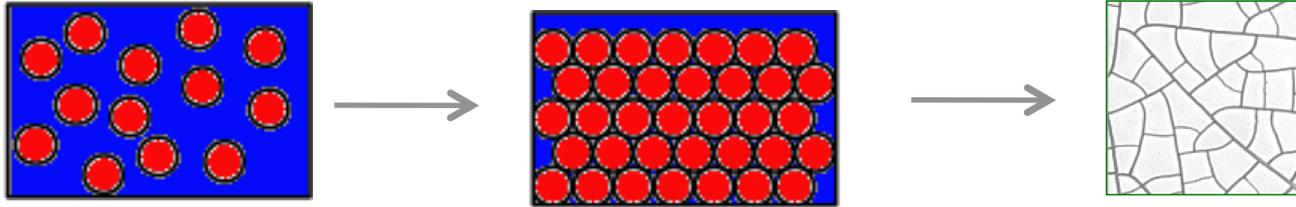
$$\delta^2(t) \propto \frac{1}{E} \left(1 - e^{-\frac{Et}{\eta}}\right)$$



Contraintes mécaniques induites par séchage

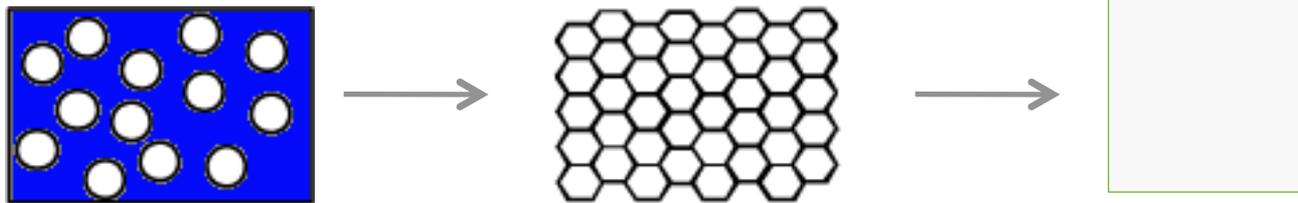
latex suspension de particules colloïdales rigides

$T_{amb} < T_g$



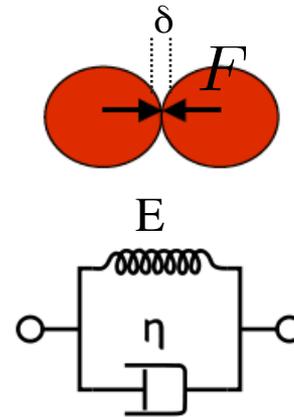
suspension de particules colloïdales déformables

$T_g < T_{amb}$

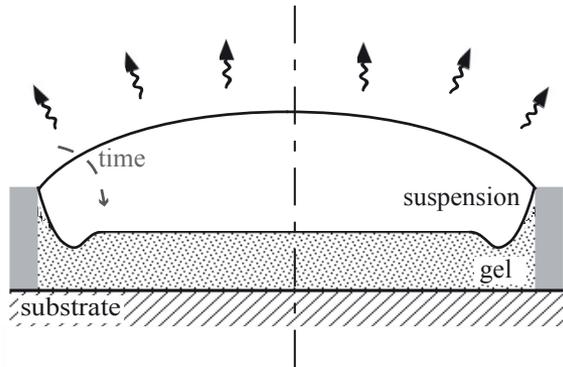


modèle de Kelvin-Voigt

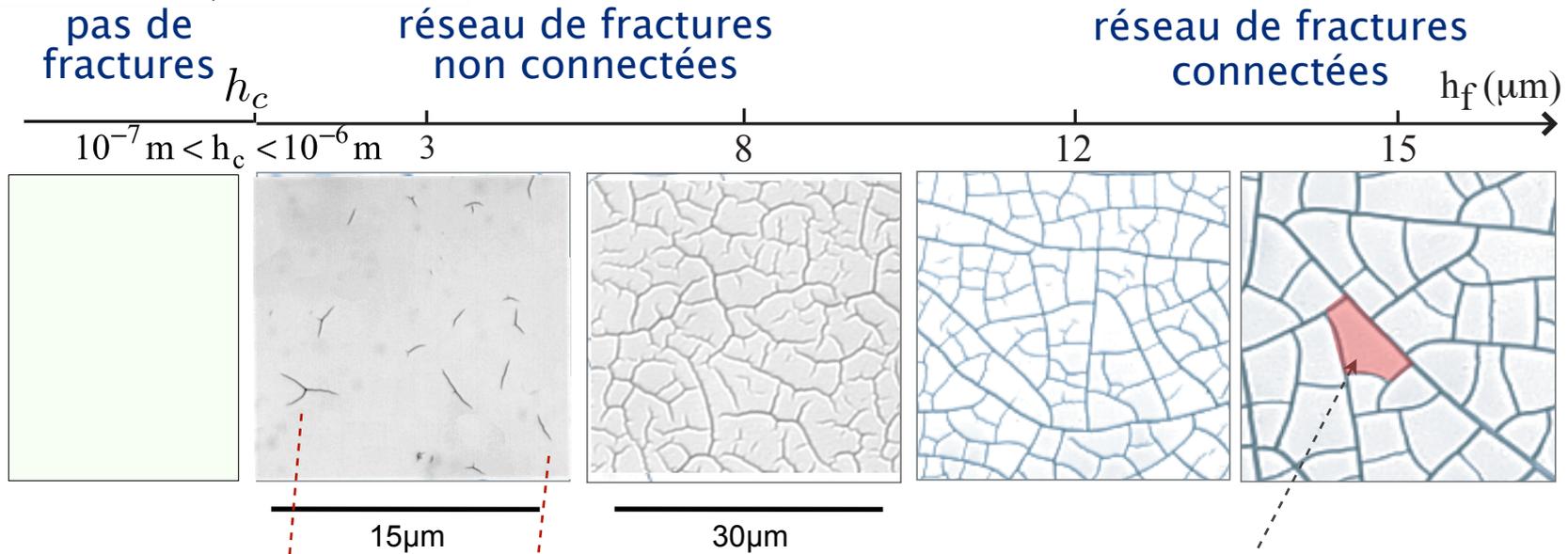
$$\delta^2(t) \propto \frac{1}{E} \left(1 - e^{-\frac{Et}{\eta}}\right)$$



Morphologies à la fin du processus de fracturation

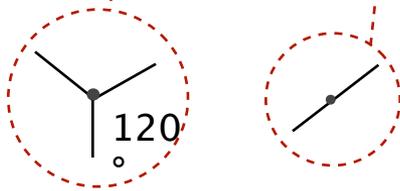


influence de l'épaisseur de la couche



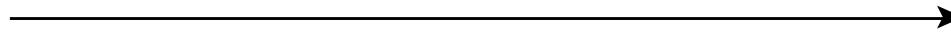
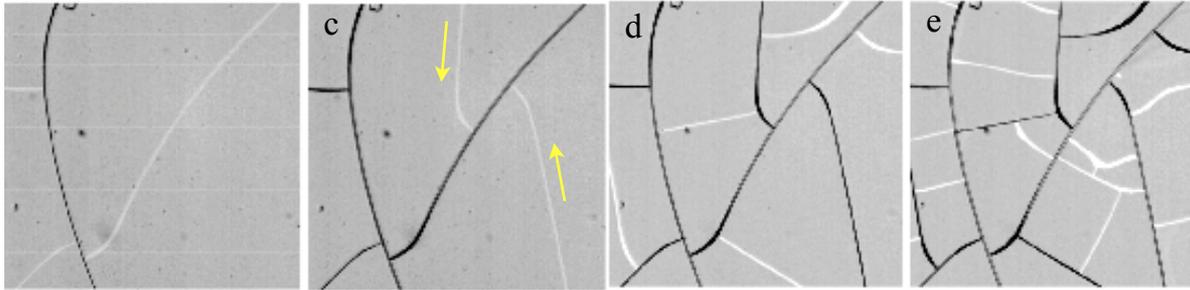
nanolatex "dur"

$T_g = 100^\circ\text{C}$,
 $\varnothing \sim 25 \text{ nm}$,
 $\phi_{v0} \sim 30\%$,
 $\eta = 8 \text{ mPa}\cdot\text{s}$,
 $\gamma = 62 \text{ mN/m}$



$$A_{cell} = f \left(\begin{array}{l} \text{élasticité matrice poreuse} \\ \text{adhésion} \\ \text{séchage} \end{array} \right) \cdot h_f^2$$

Formation hiérarchique d'un réseau de fractures connectées

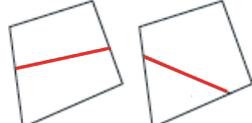
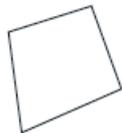


génération n

3



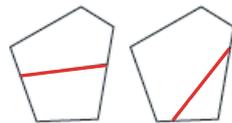
4



4,4

3,5

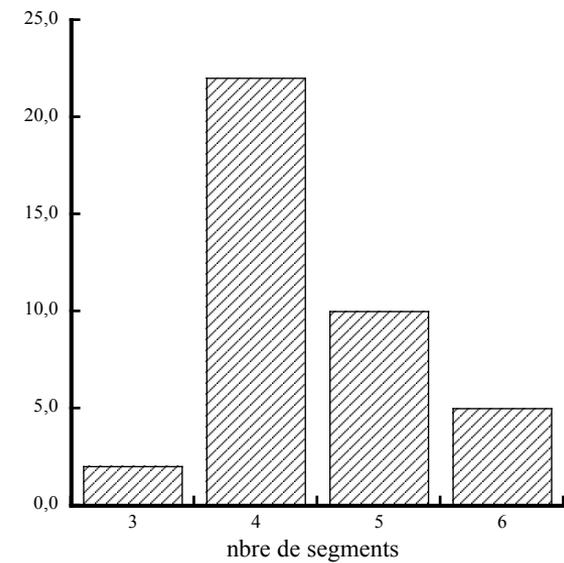
5



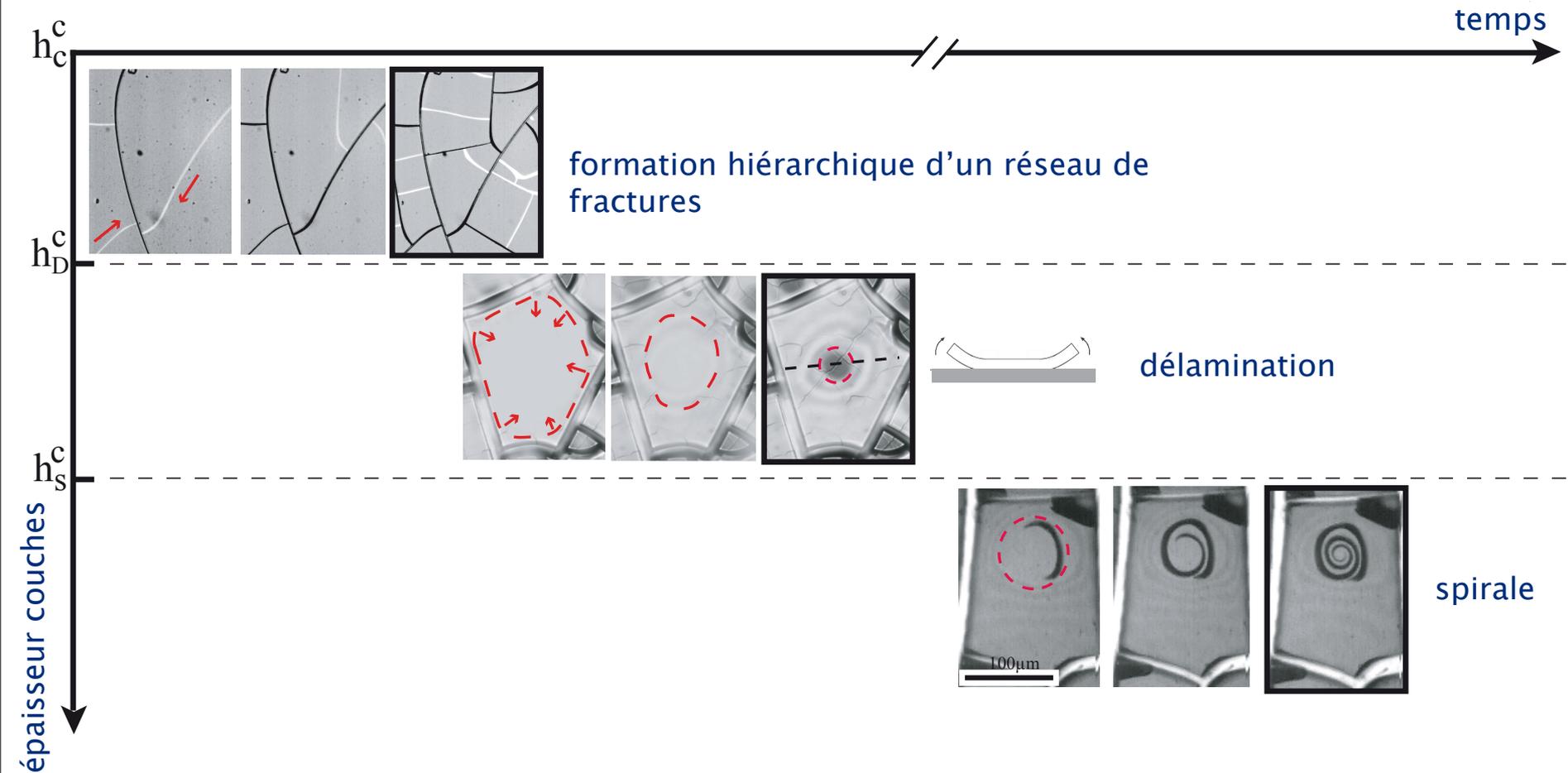
4,5

3,6

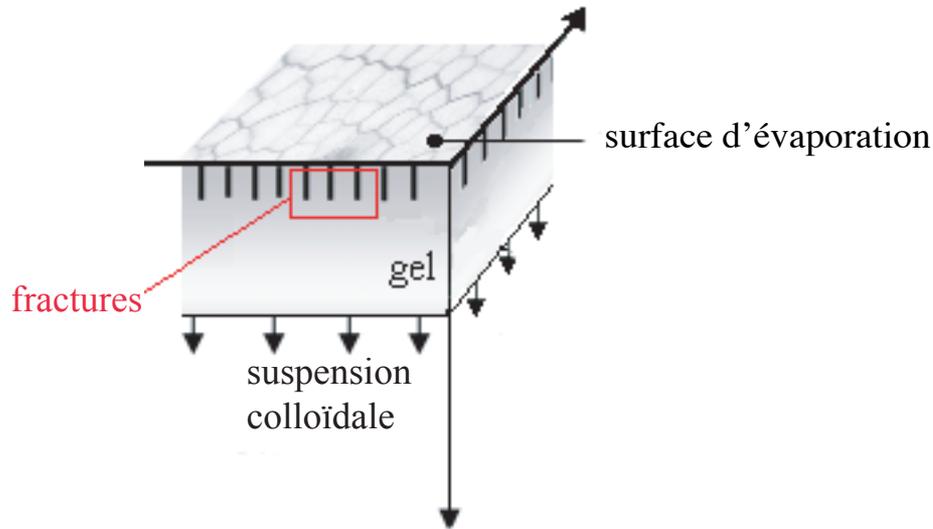
génération n+1



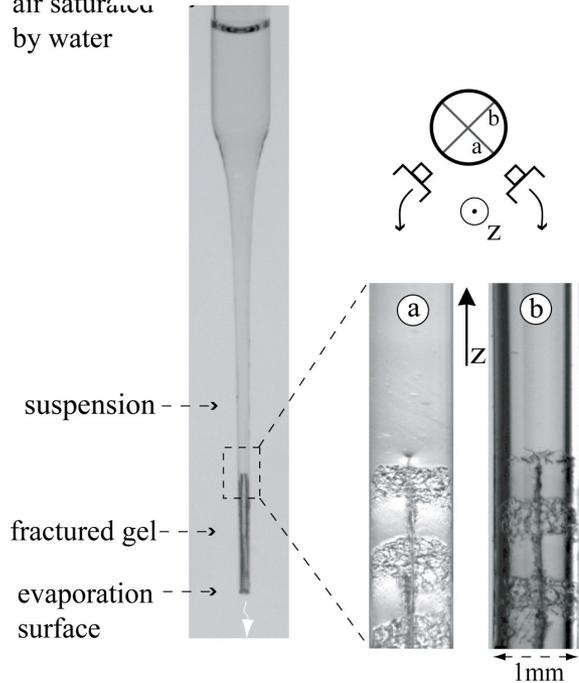
Formation successive de fractures



Croissance directionnelle de fractures



air saturée
by water



orgues basaltiques



Conclusion

Exemples de problèmes couplant

- hydrodynamique
- rhéologie
- mécanique
- physico-chimie
- mouillage

Aspect multi-échelles

