

*Journée technique CFBR – CFMS –
SPTF FNTP du 16 mai 2019*

23 Avenue Condorcet, Villeurbanne



*La microstructure des
sols fins compactés*

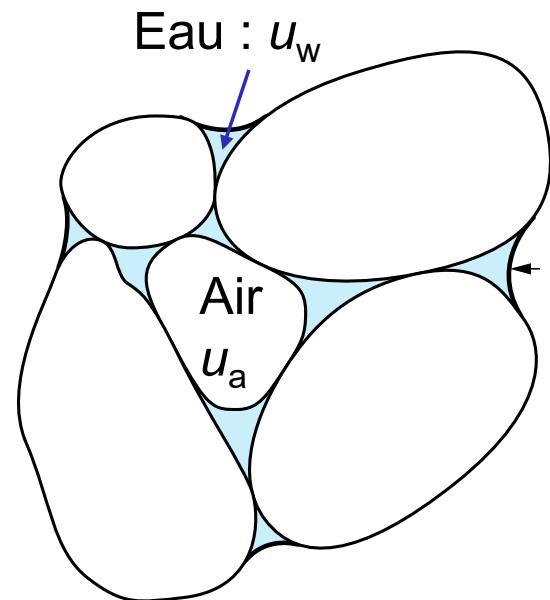
Pierre Delage, Ecole des Ponts ParisTech

Journée organisée par :



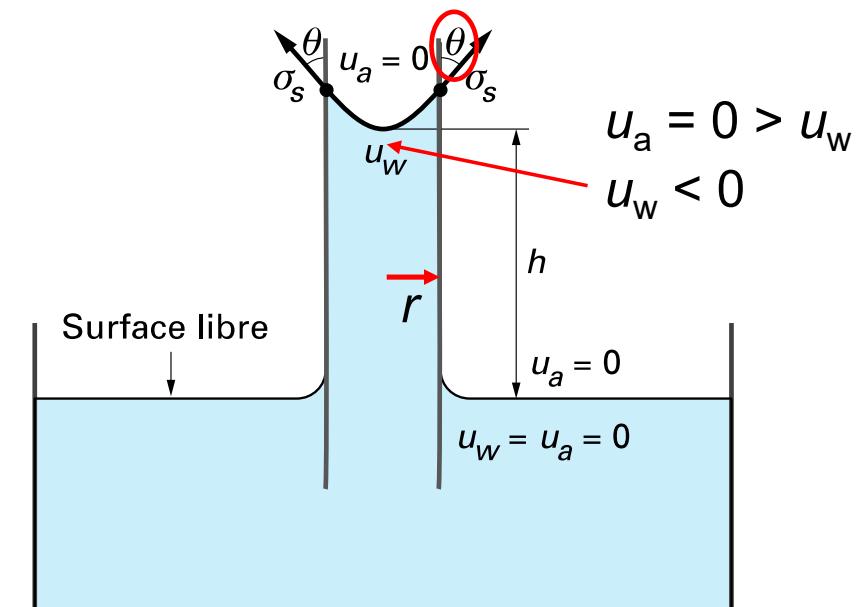
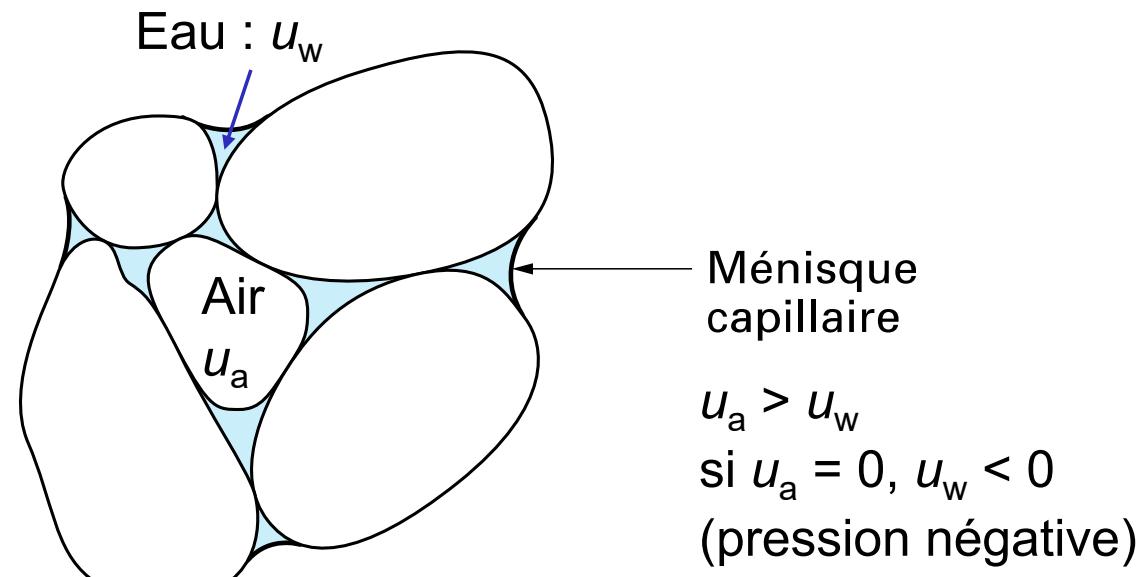
**CONCEPTION
ET CONSTRUCTION
des ouvrages en sols fins**

Les sols compactés sont non saturés



a) sol granulaire

Les sols compactés sont non saturés



a) sol granulaire

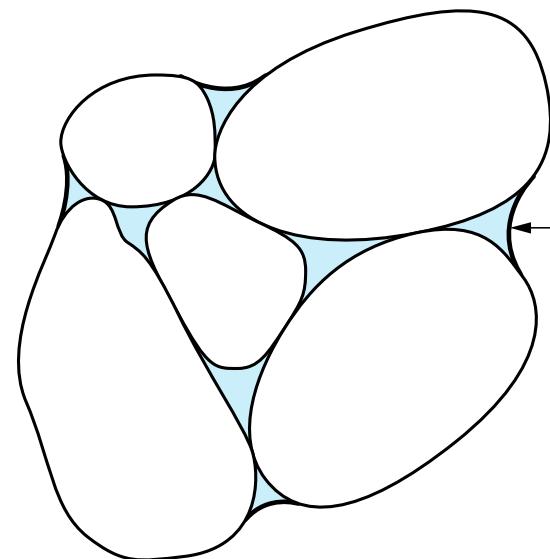
$$\text{Succion : } S = u_a - u_w = \frac{2\sigma \cos \theta}{r}$$

Eau
 $\sigma = 72,75 \times 10^{-3} \text{ N/m}$
 $\theta = 0^\circ$

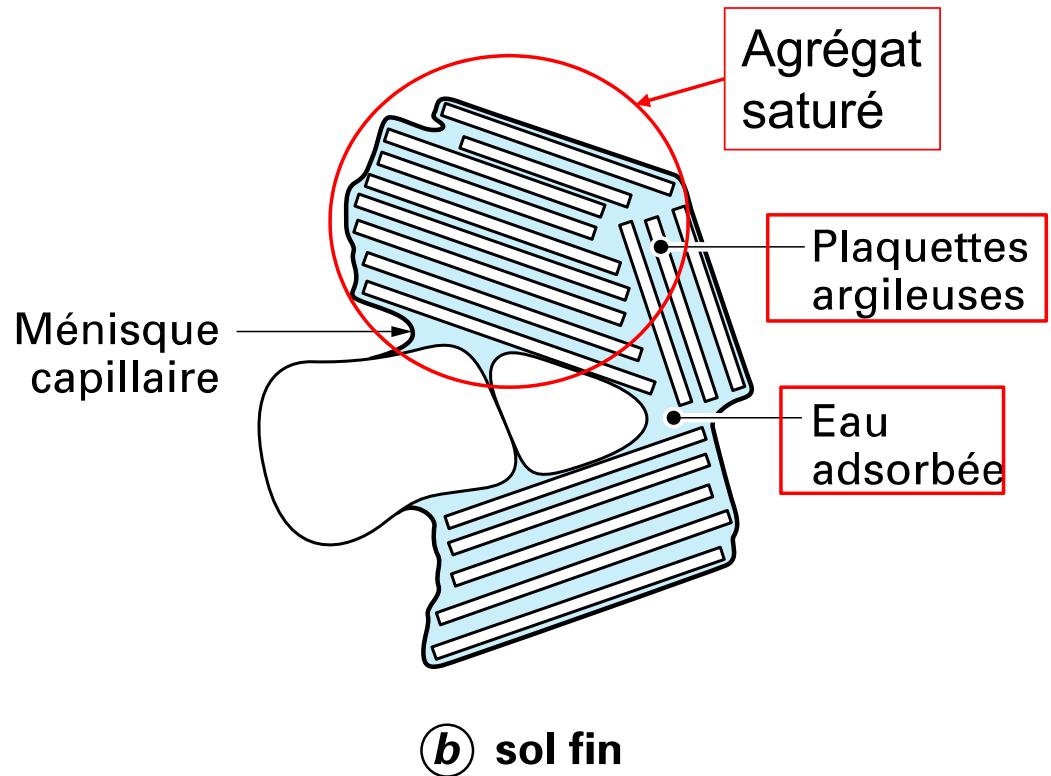
3

Delage & Cui 2000

Les sols compactés sont des sols fins



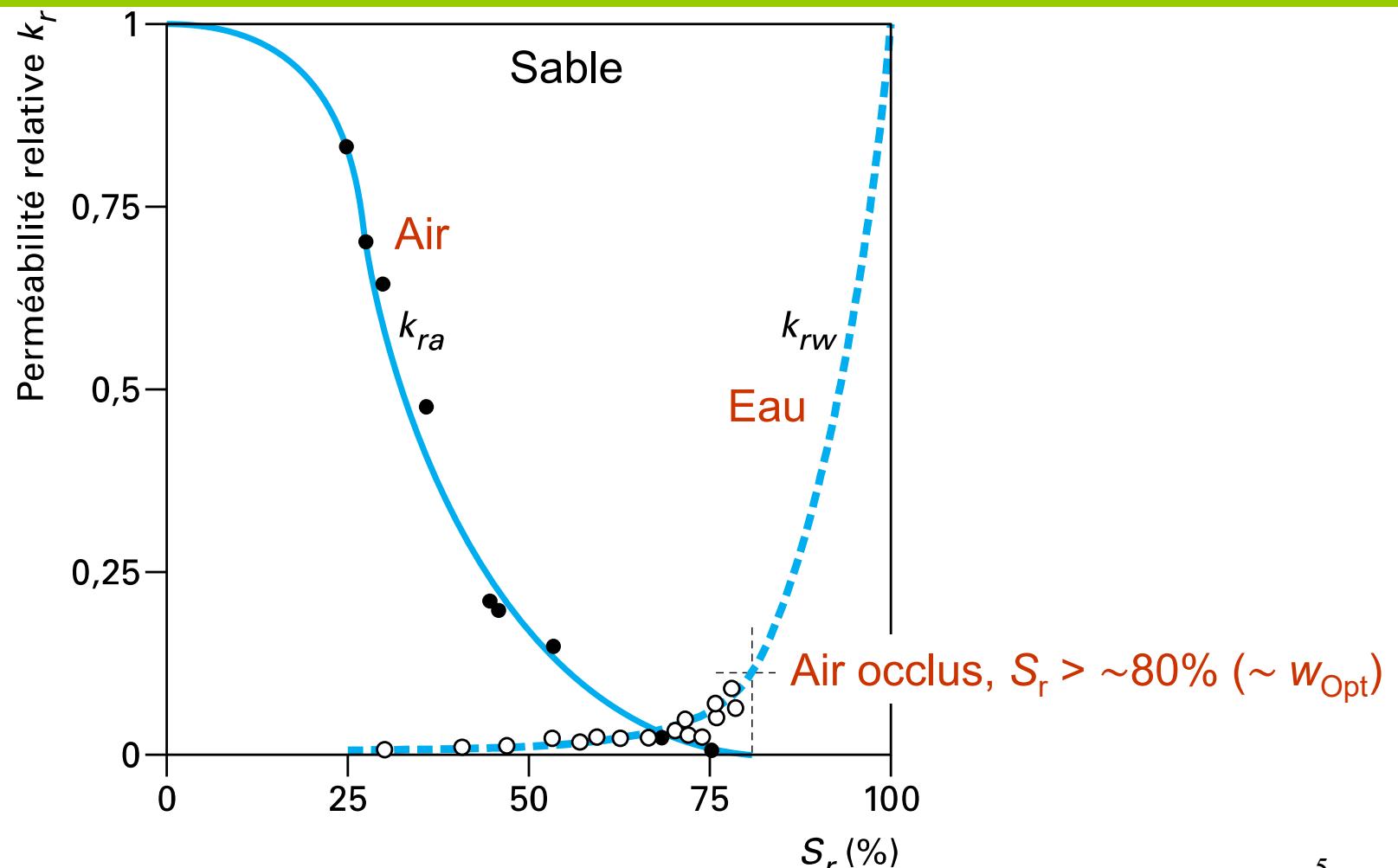
a sol granulaire



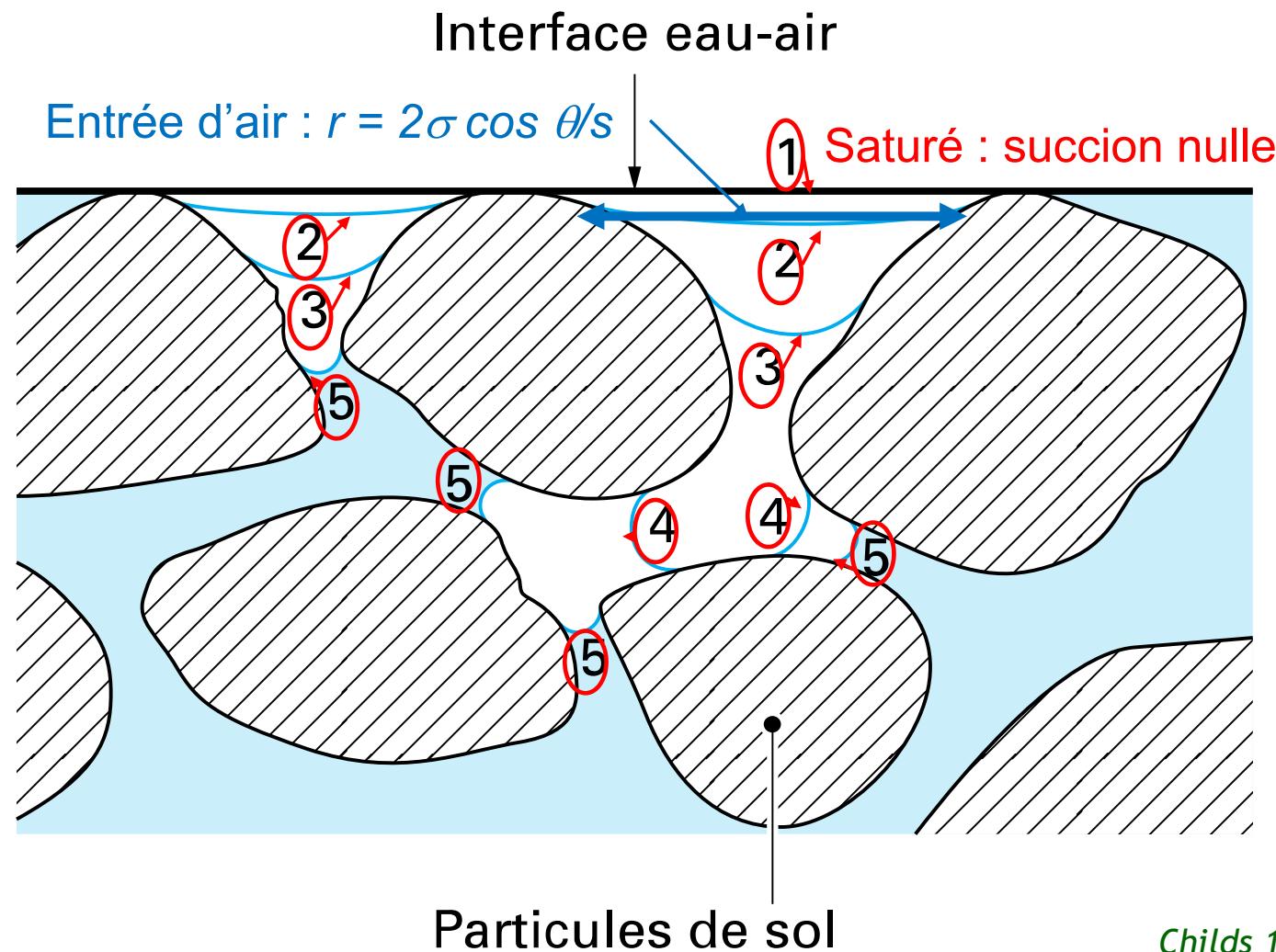
b sol fin

Continuité de la phase gazeuse

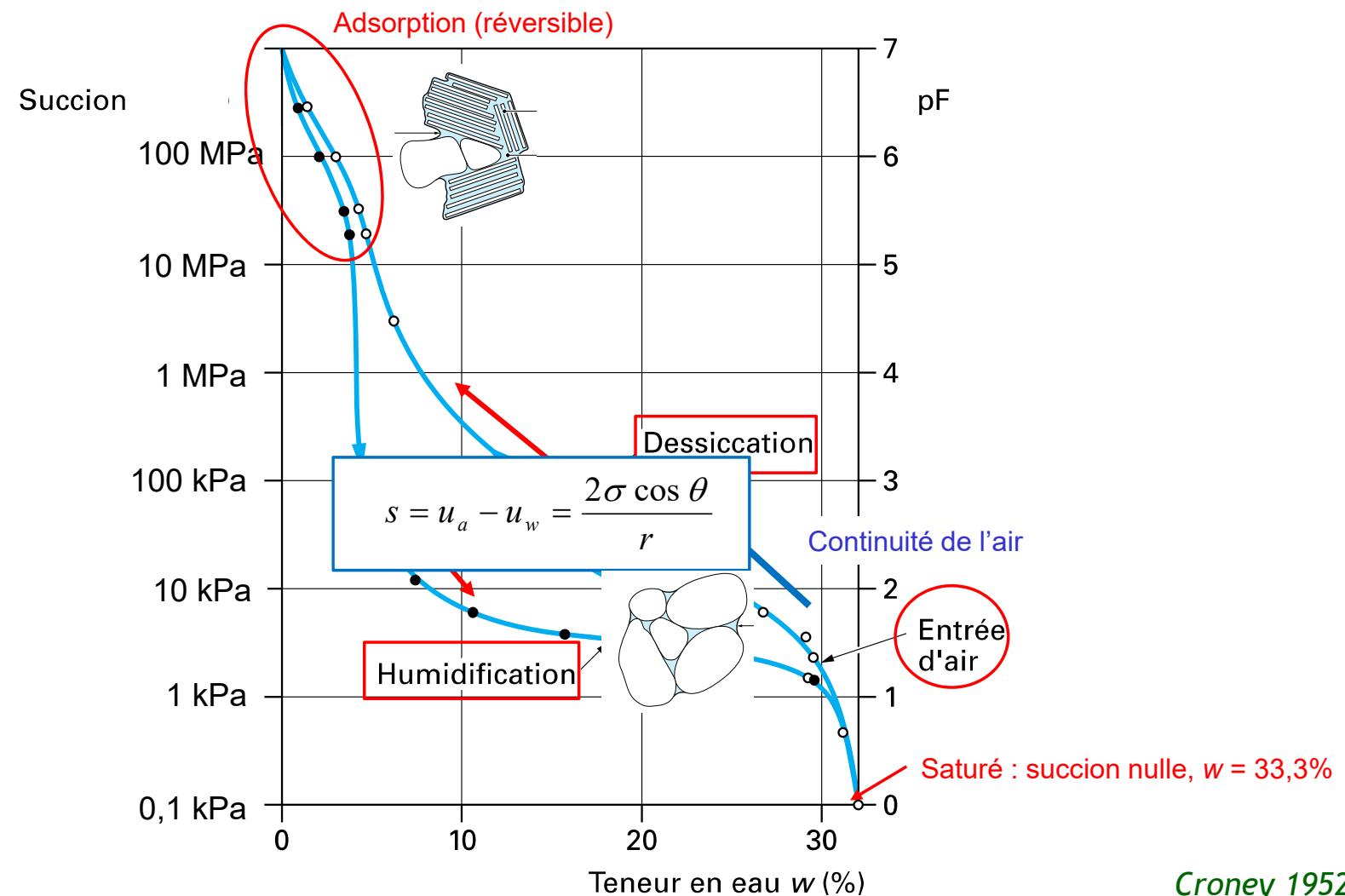
Perméabilités eau/air en non saturé



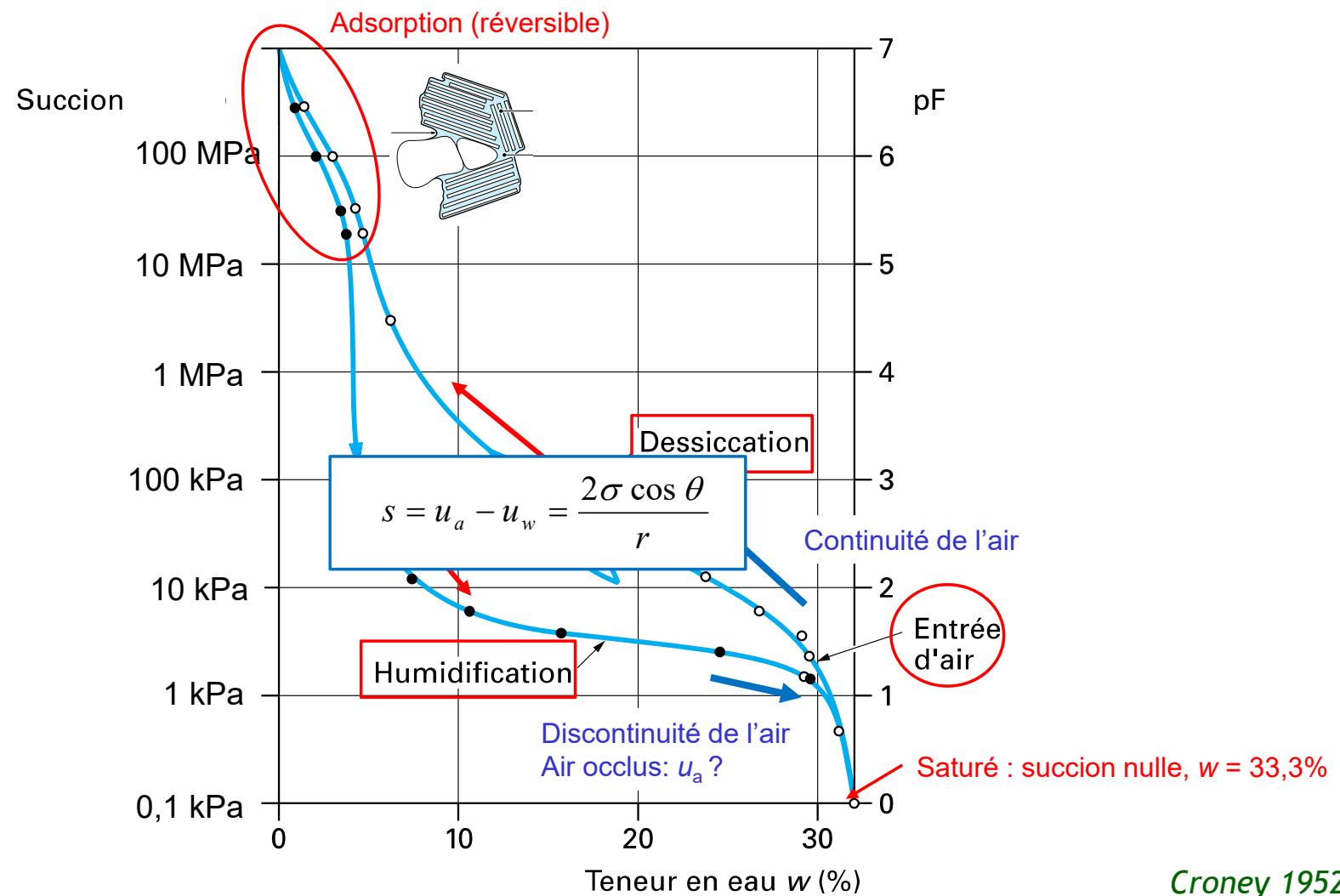
Début de désaturation : entrée d'air



Désaturation d'un sable argileux



Désaturation d'un sable argileux

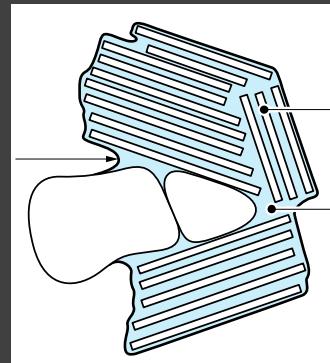
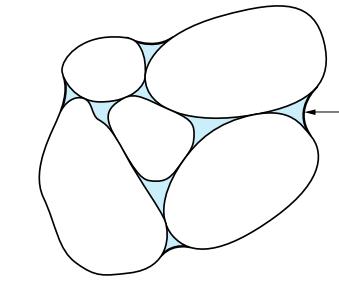


Sol non saturé naturel

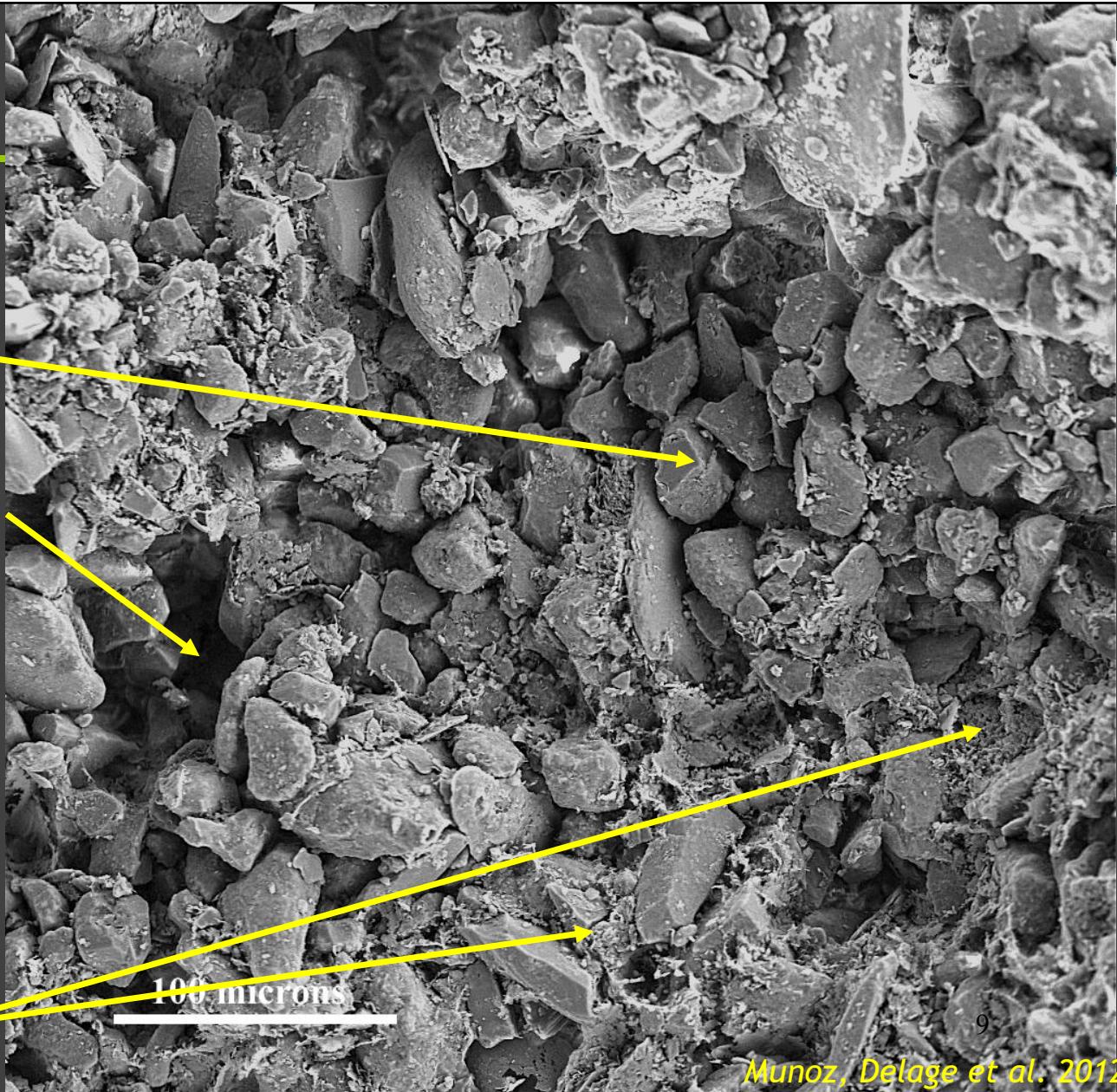
Loess de Picardie $I_p = 9$

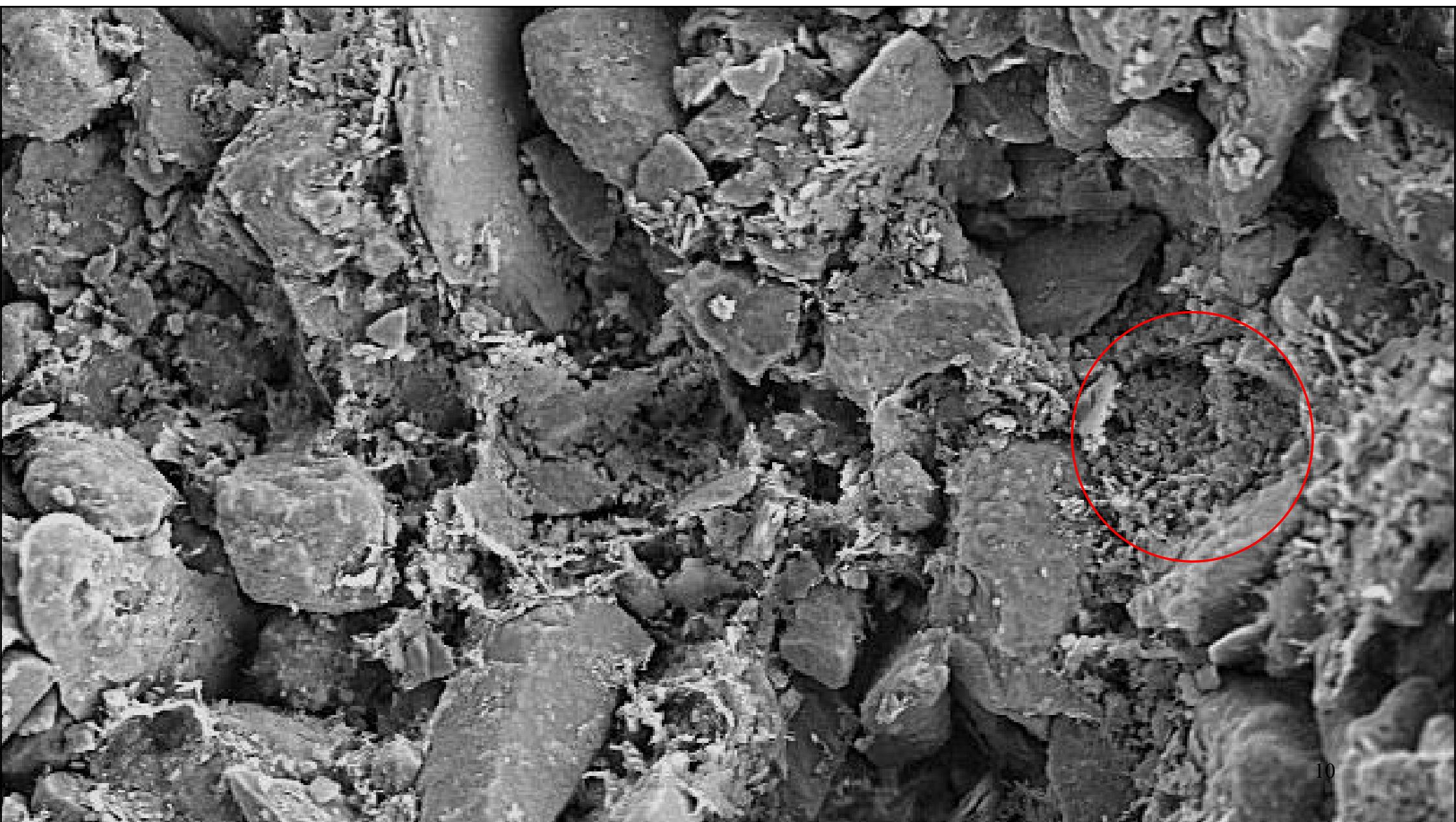
Grains propres, arrondi

*Gros pore entre grains propres,
30 µm, rempli d'air à l'état naturel
Pression d'entrée d'air*

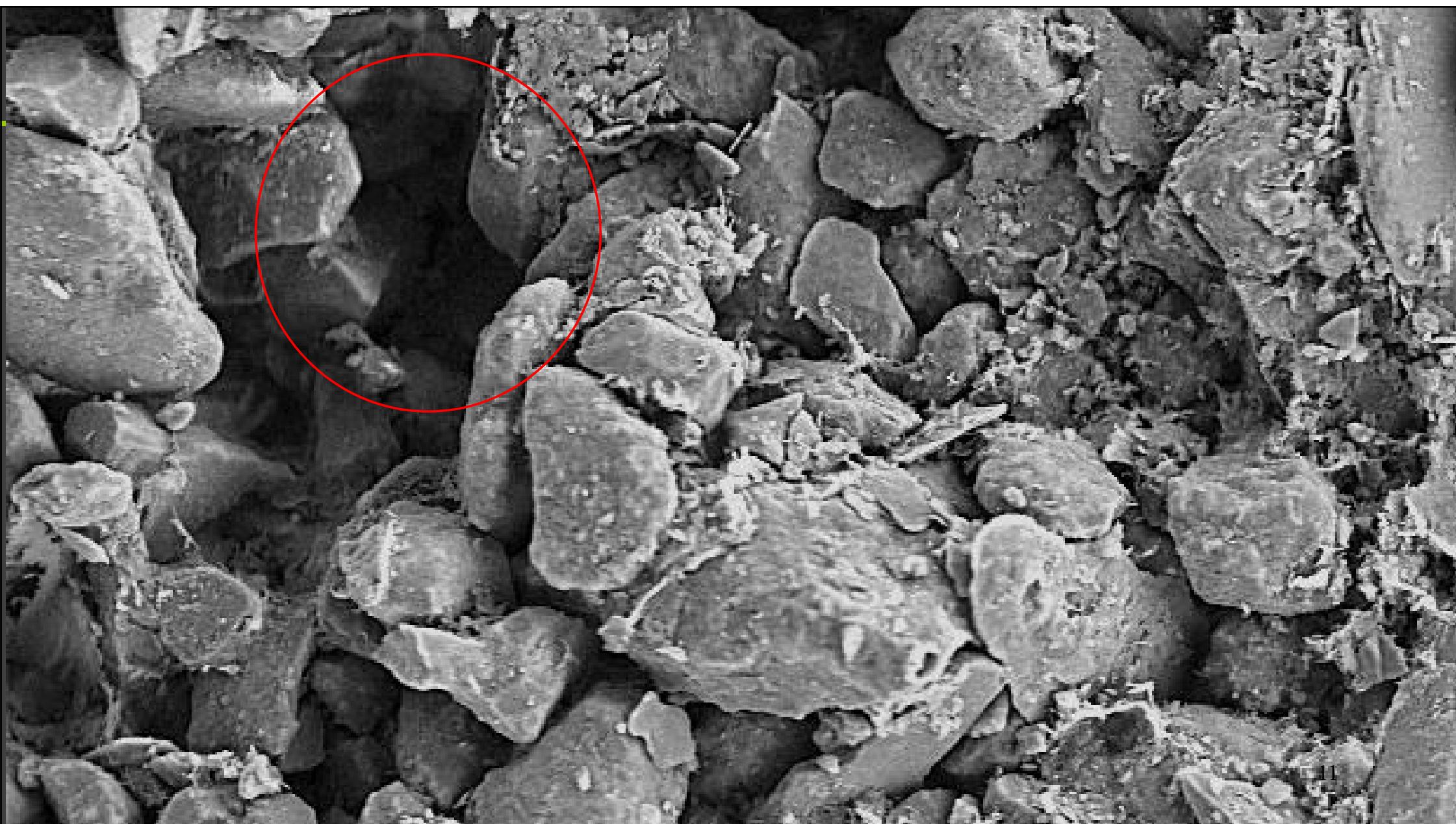


*Remplissage d'agrégats argileux
(saturé) entre les grains*

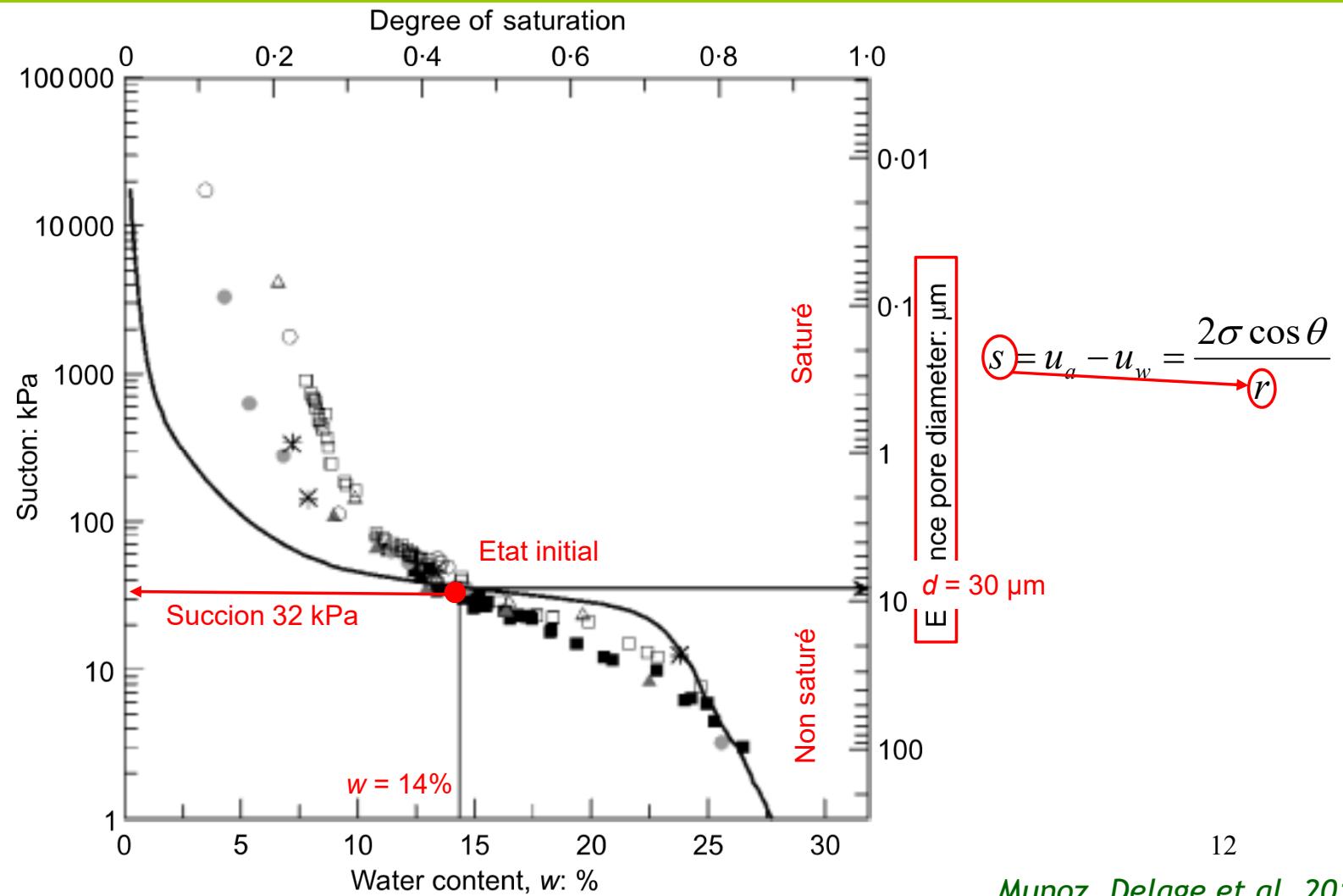
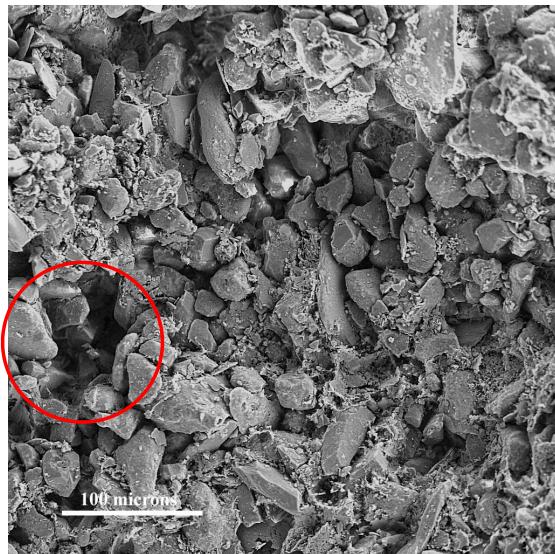




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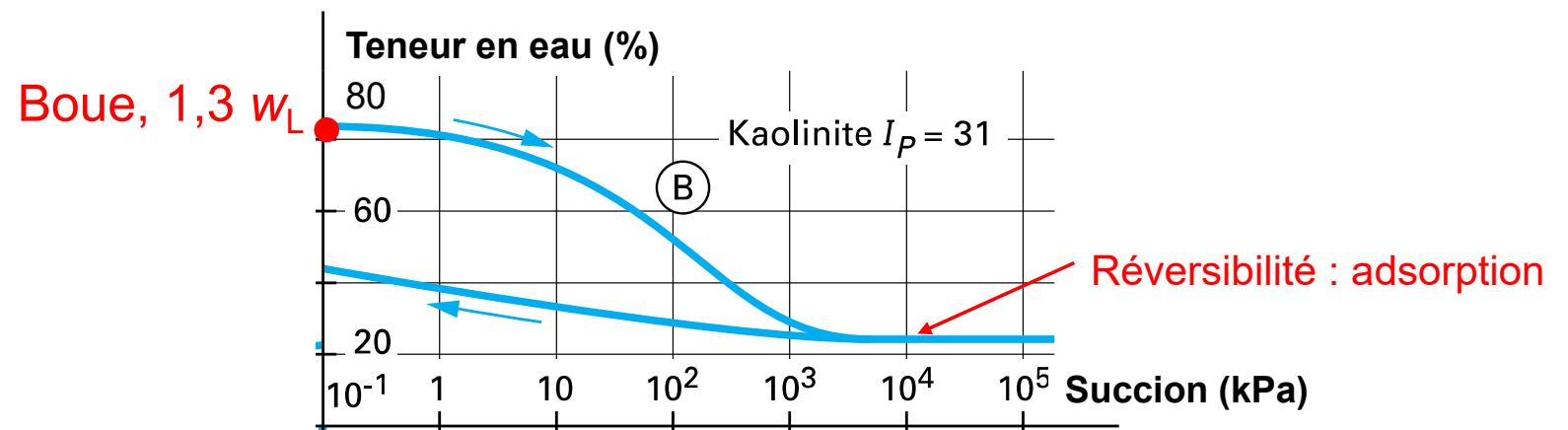


Courbe de rétention d'eau du loess ($I_p = 9$)

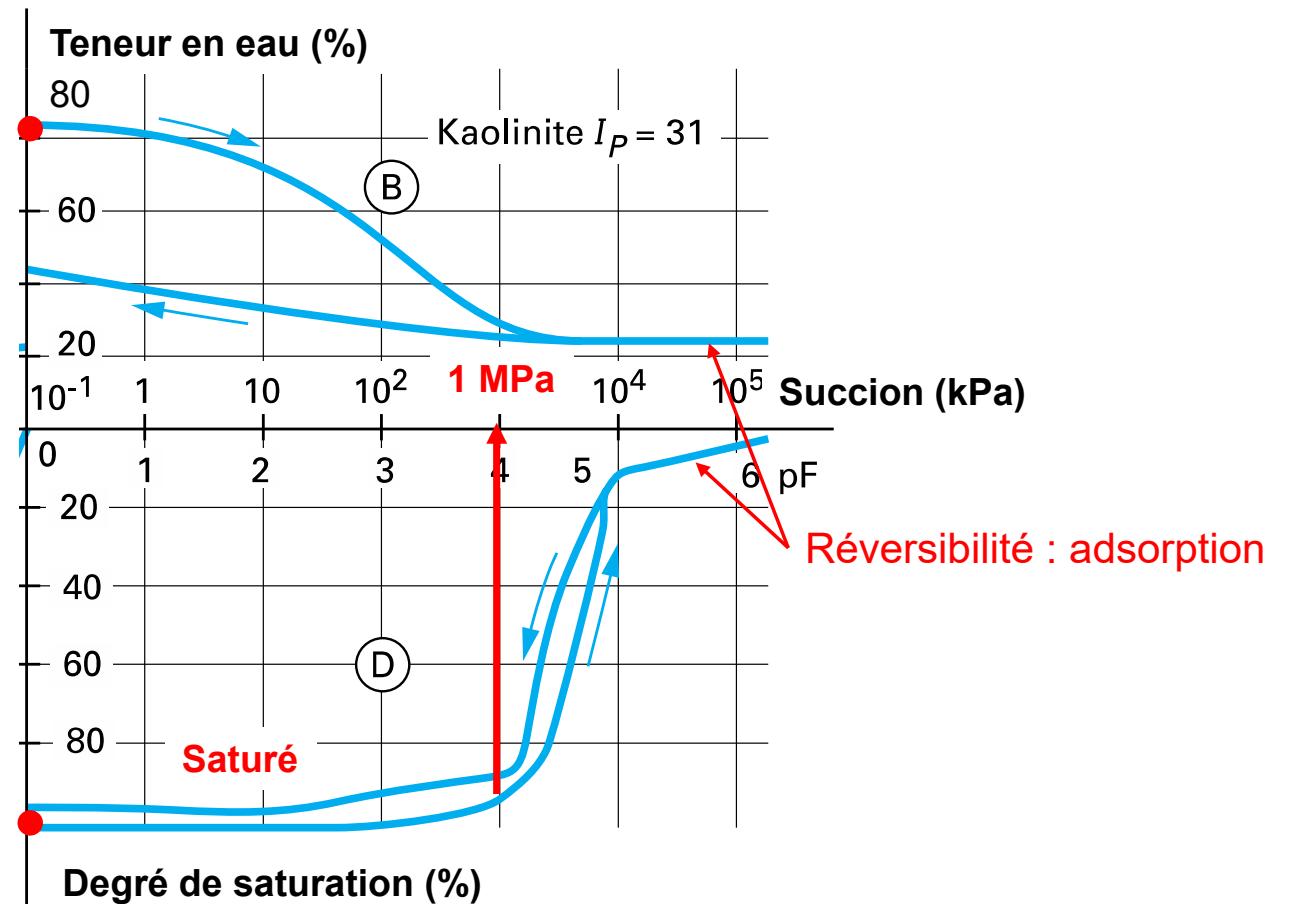


Munoz, Delage et al. 2012

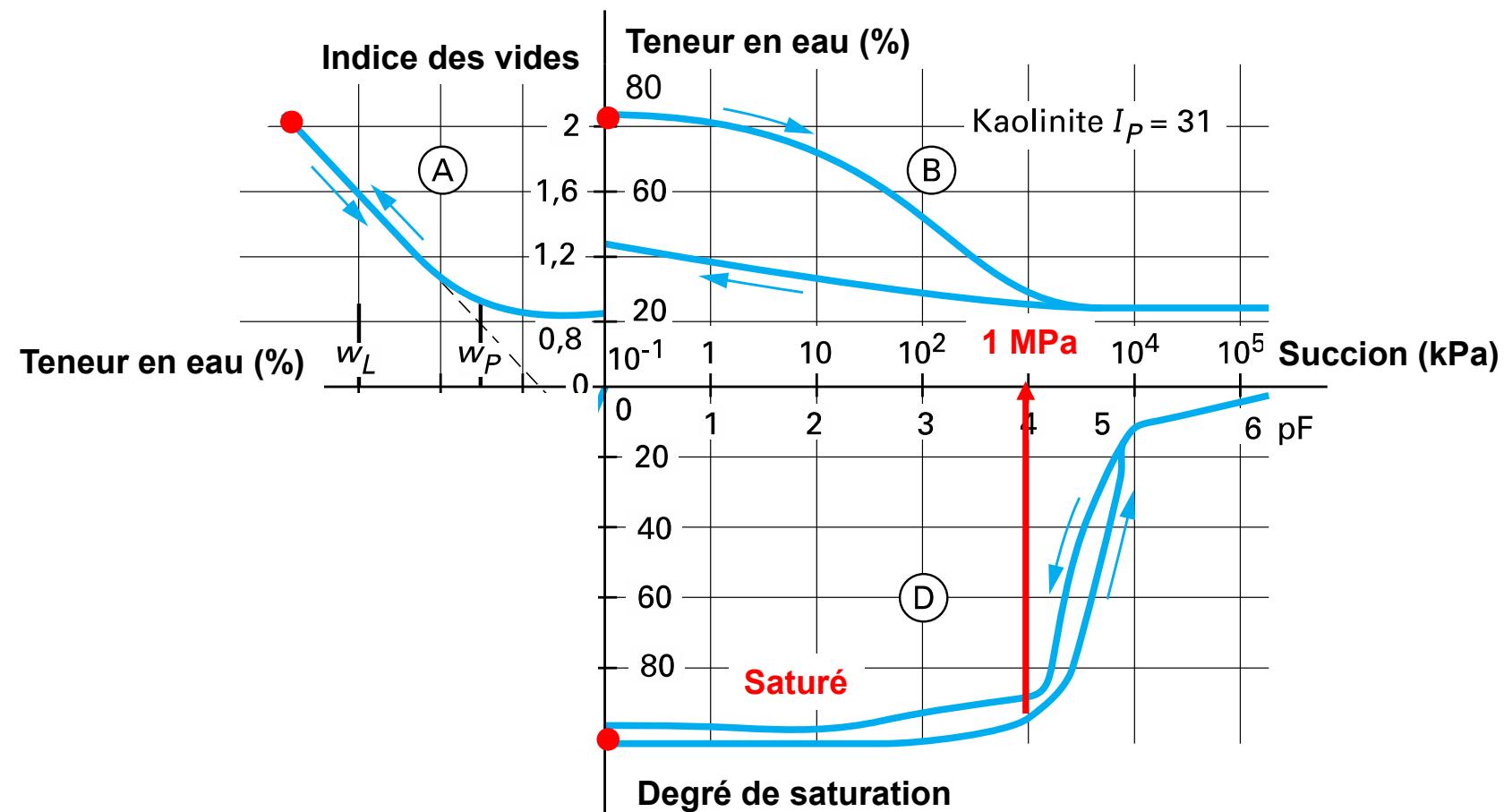
Courbe de rétention d'eau de la kaolinite ($I_p = 31$)



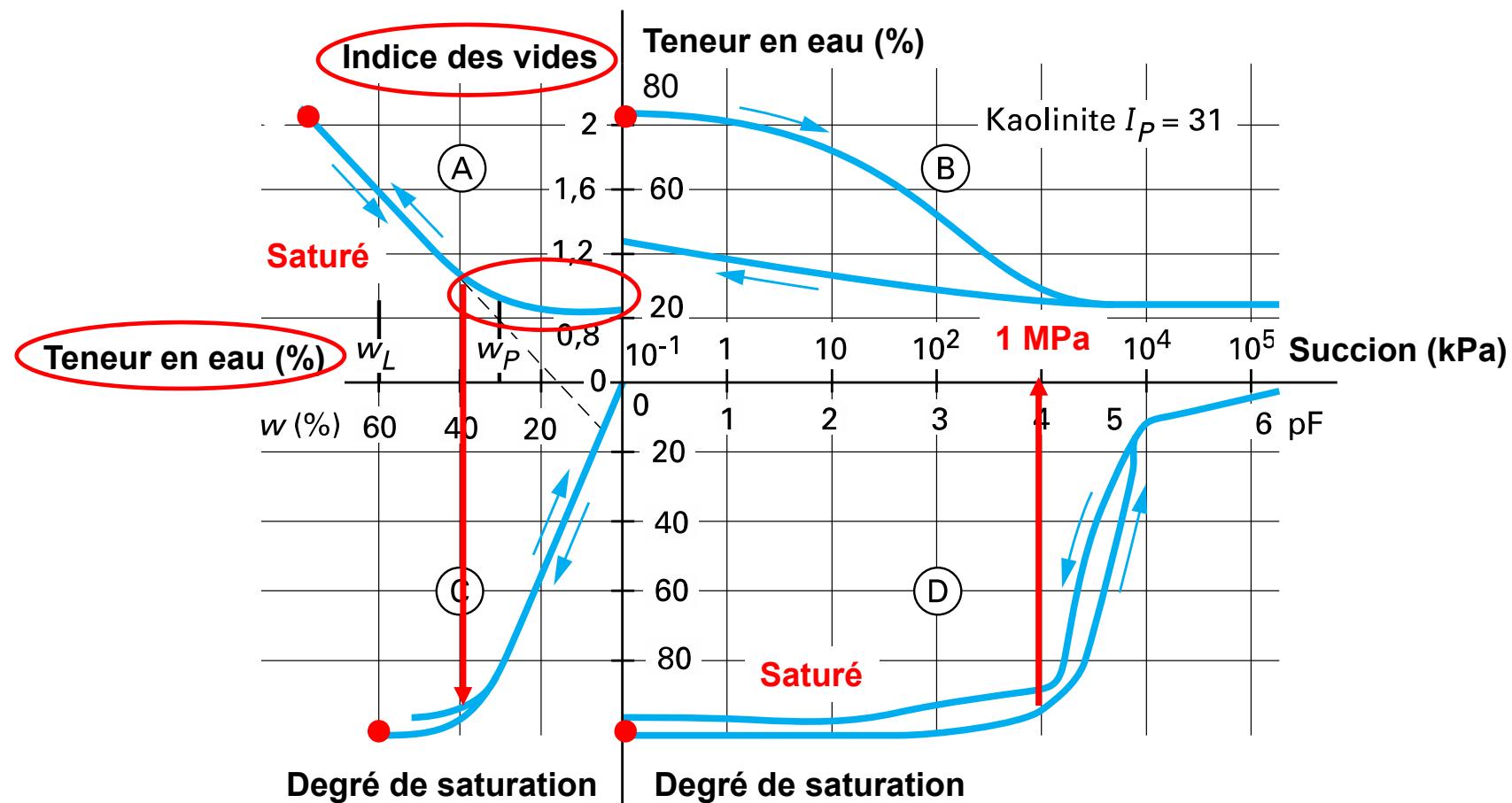
Courbe de rétention d'eau de la kaolinite ($I_p = 31$)



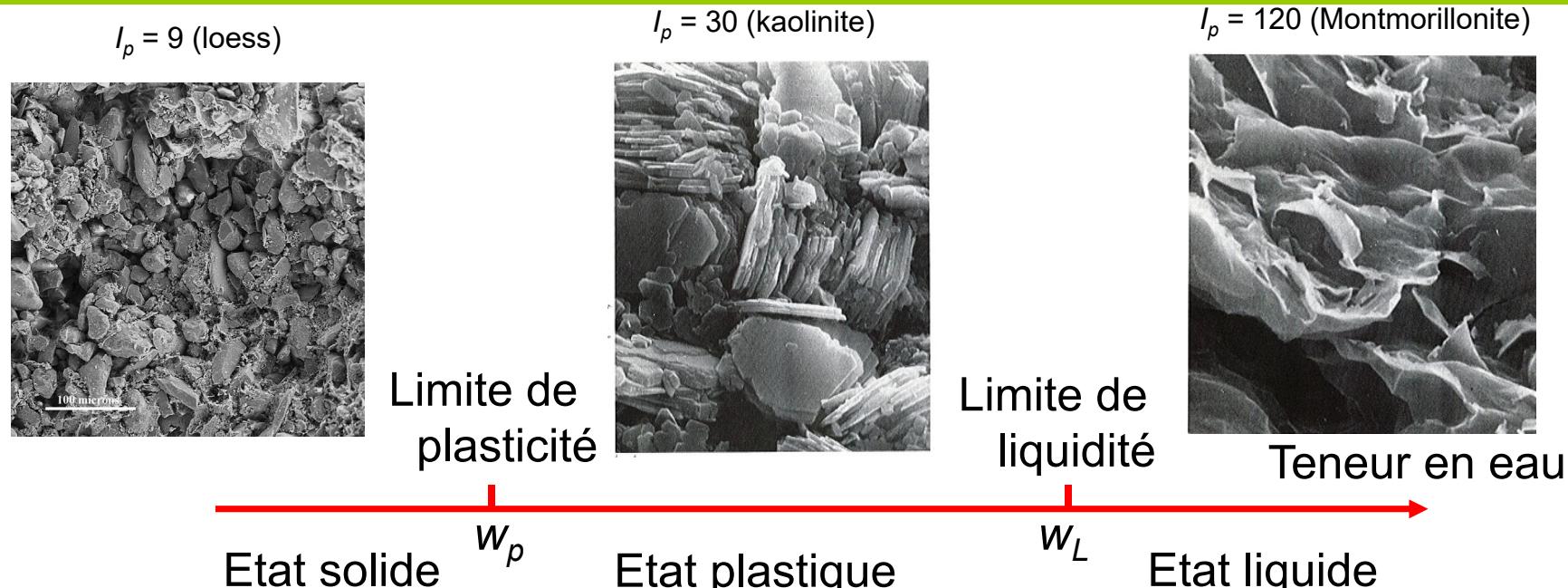
Courbe de rétention d'eau de la kaolinite ($I_p = 31$)



Courbe de rétention d'eau de la kaolinite ($I_p = 31$)



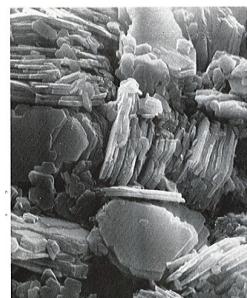
Limites d'Atterberg



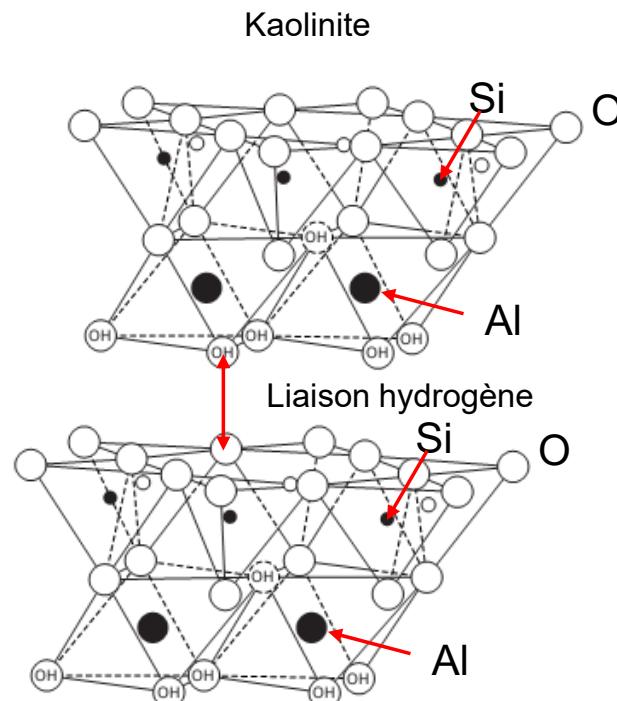
Quantité d' eau nécessaire pour faire passer
de l' état solide à l' état liquide

Interaction eau-argile

Minéralogie des argiles

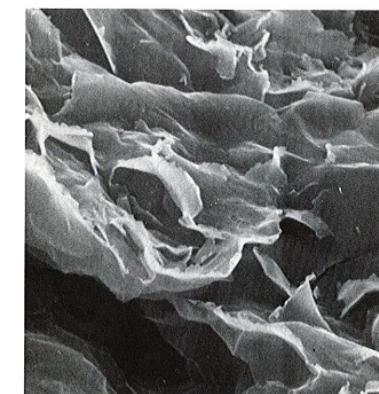
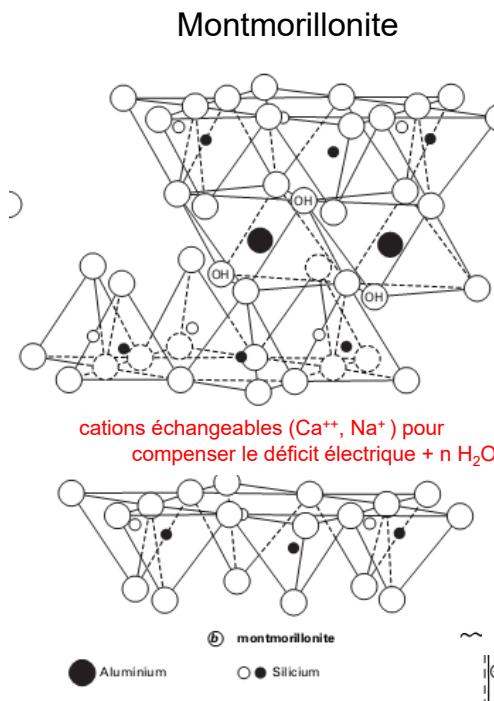


Particules stables



Surface spécifique accessible (seulement externe) : $70 \text{ m}^2/\text{g}$

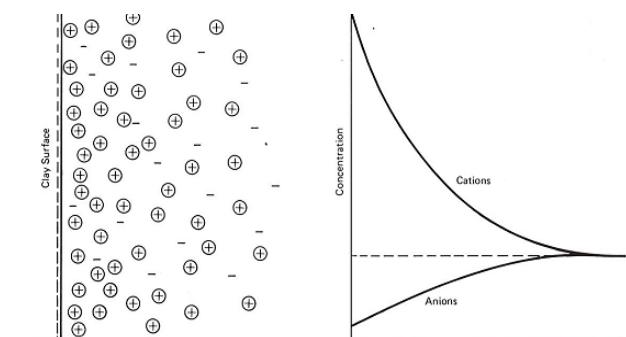
Bonne corrélation surface spécifique/ w_L



Particules instables

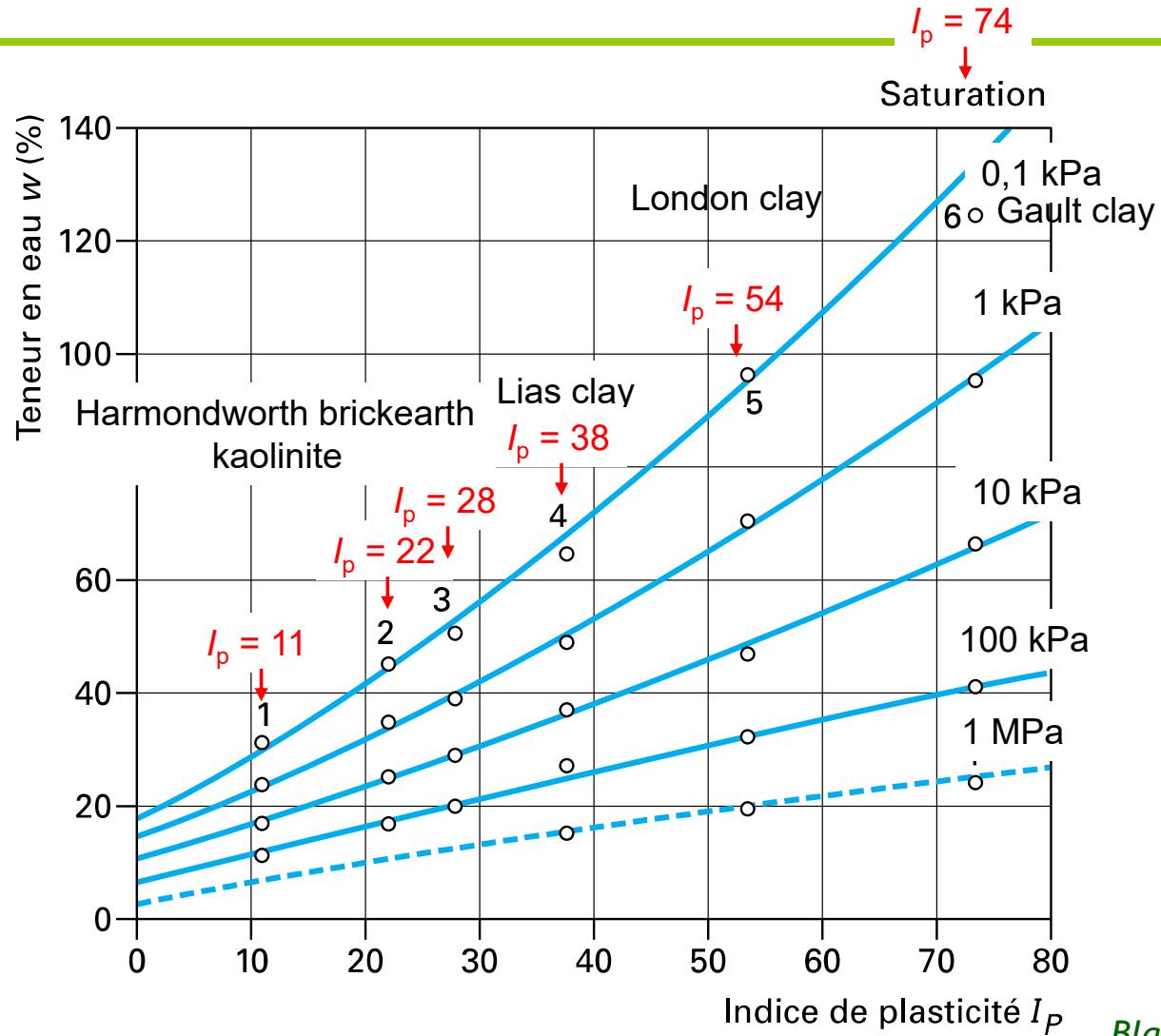
Surface spécifique accessible $700 \text{ m}^2/\text{g}$

Théorie de la double couche

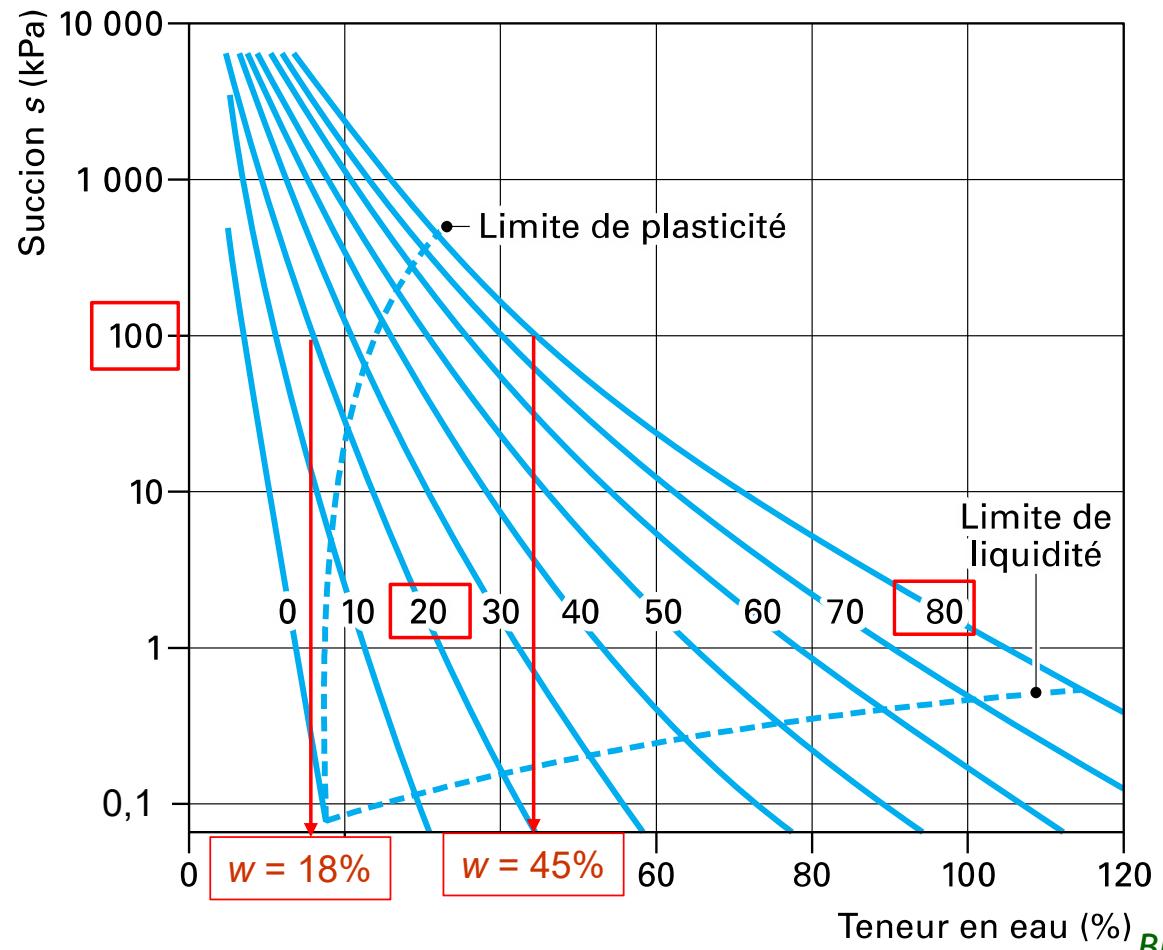


Mitchell & Soga 2005

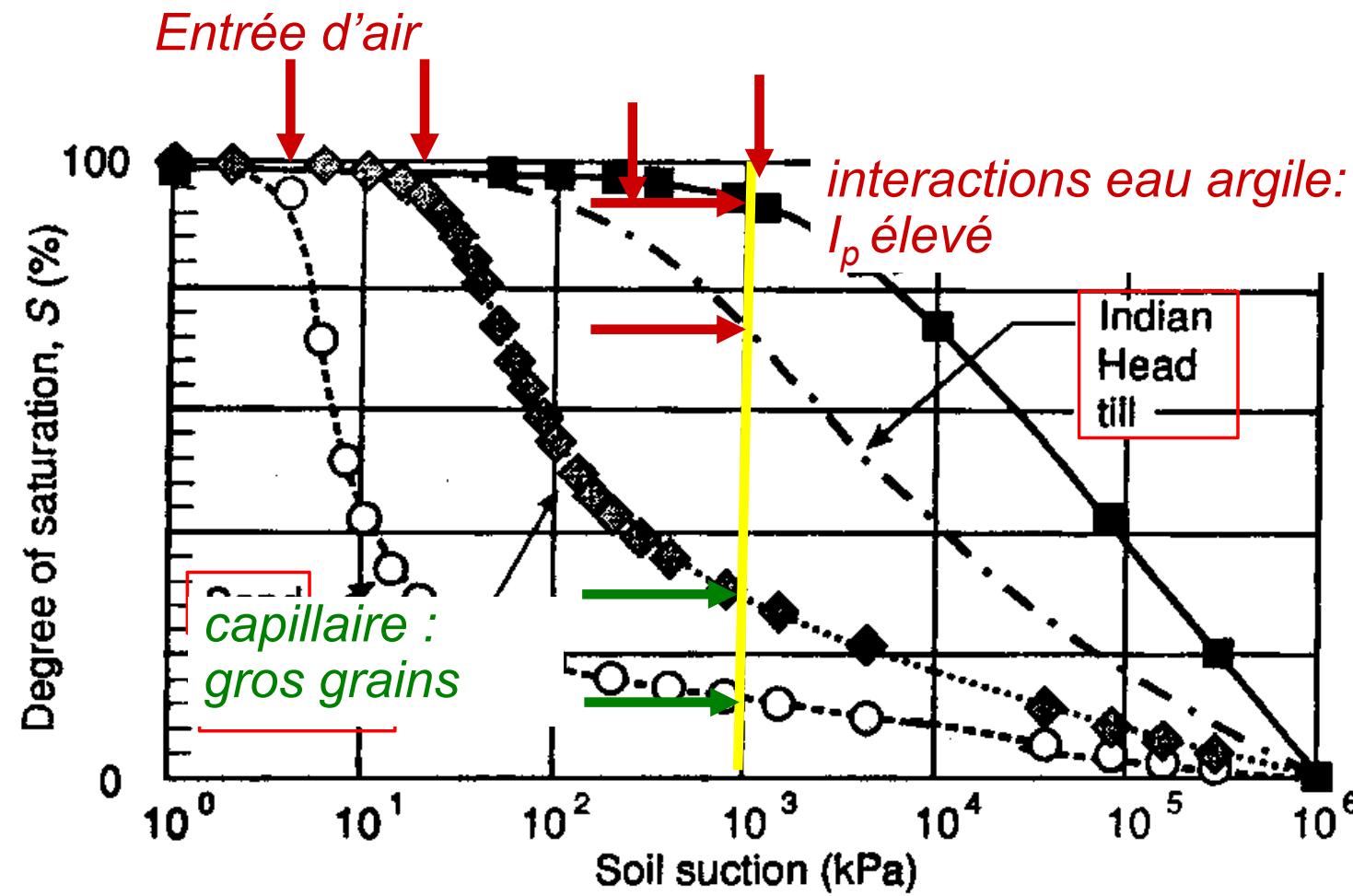
Effet de la plasticité (adsorption eau-argile)



Courbes de rétention / I_p

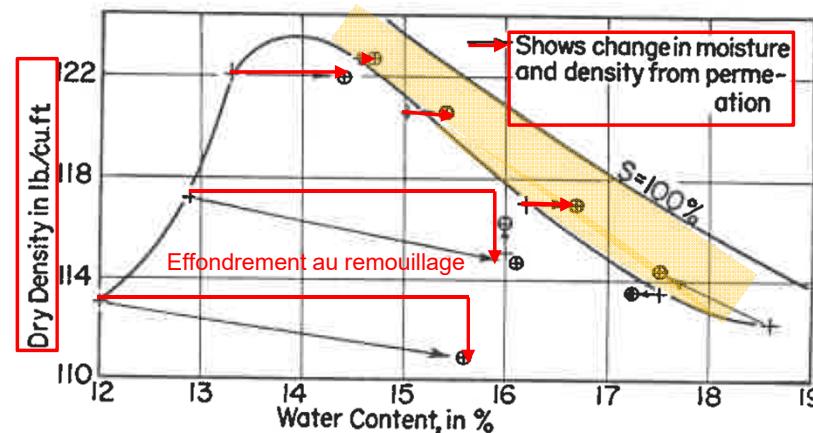
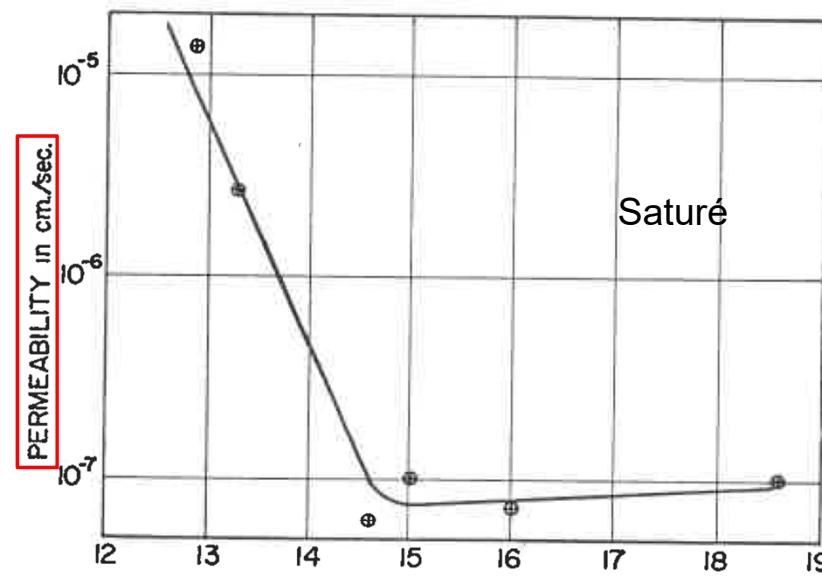


Courbes de rétention / I_p



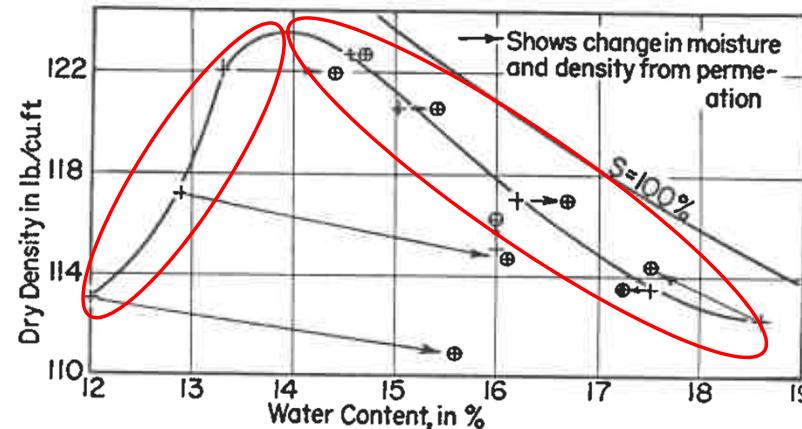
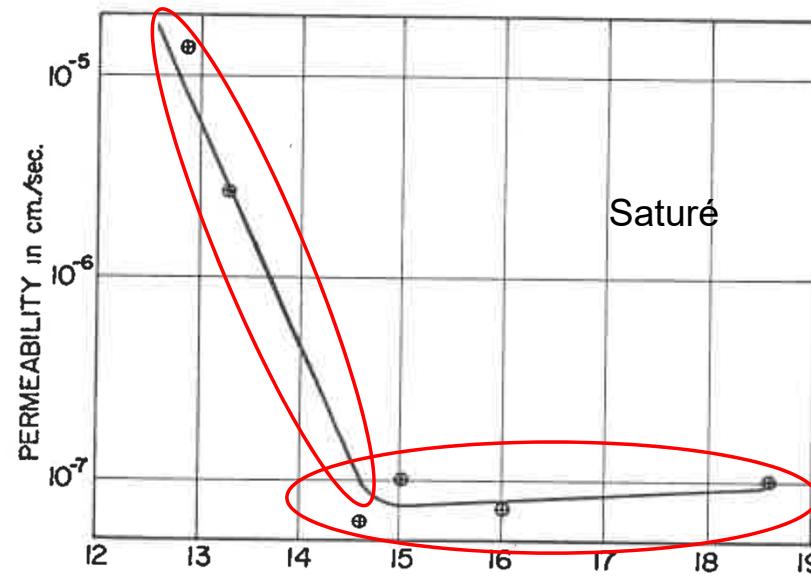
Barbour 1998

Sols compactés (Lambe 1958)



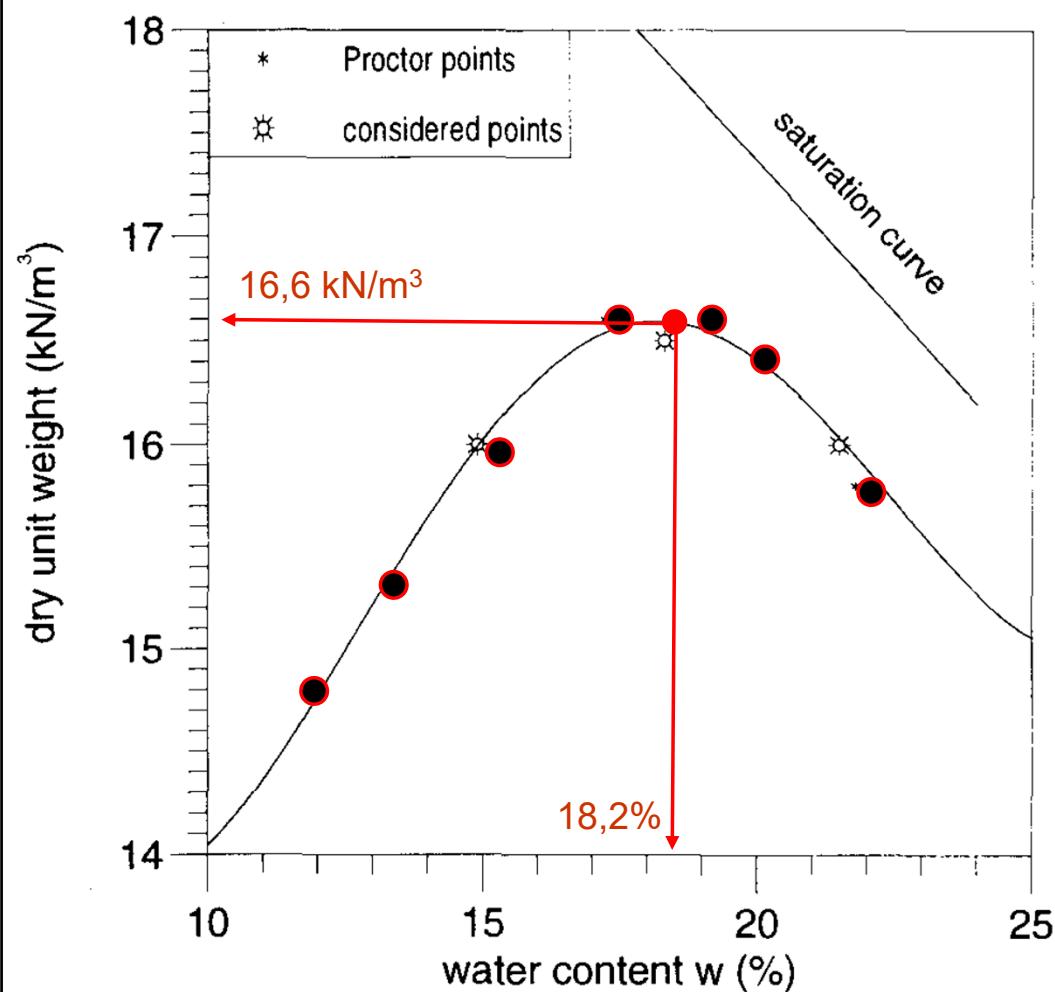
Lambe 1958

Sols compactés (Lambe 1958)

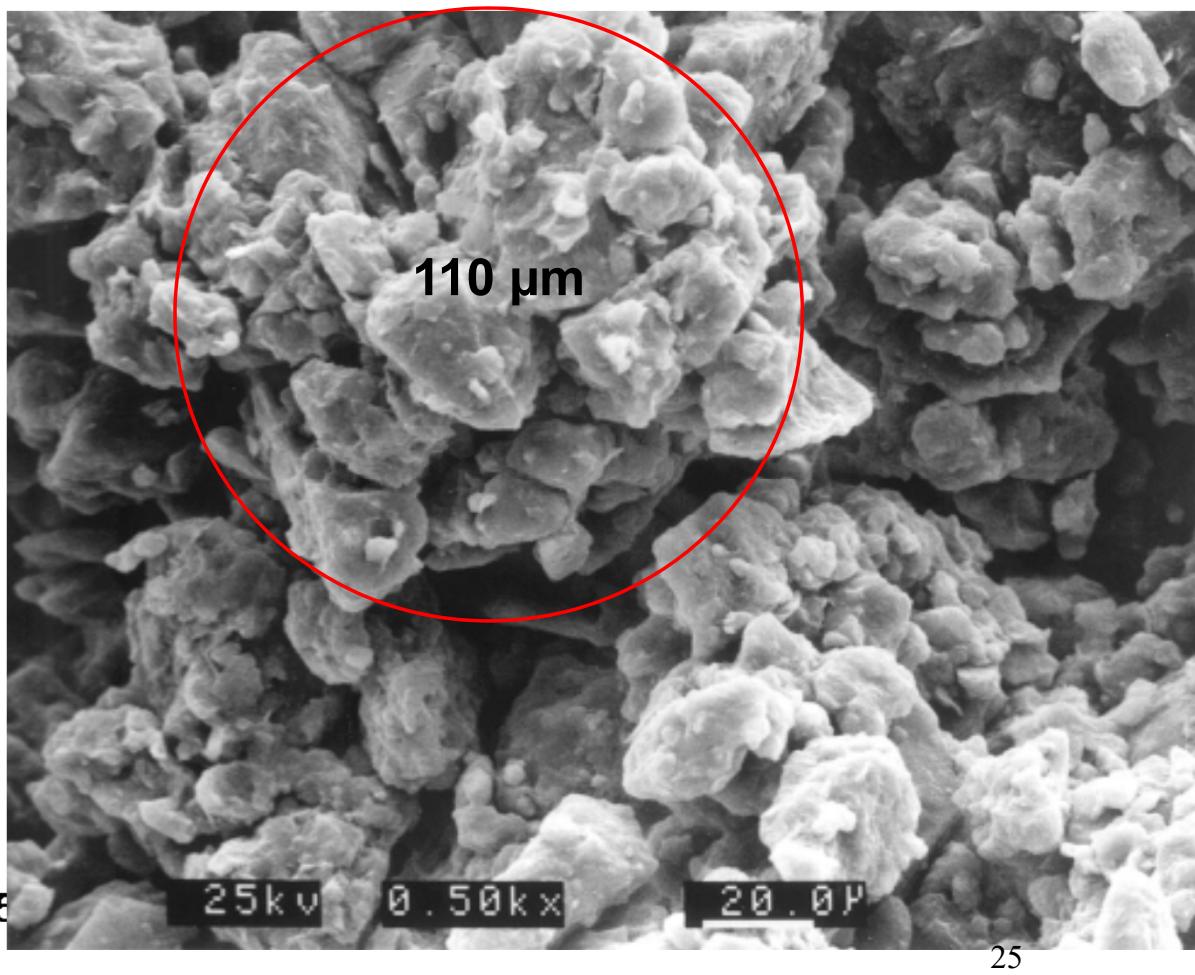
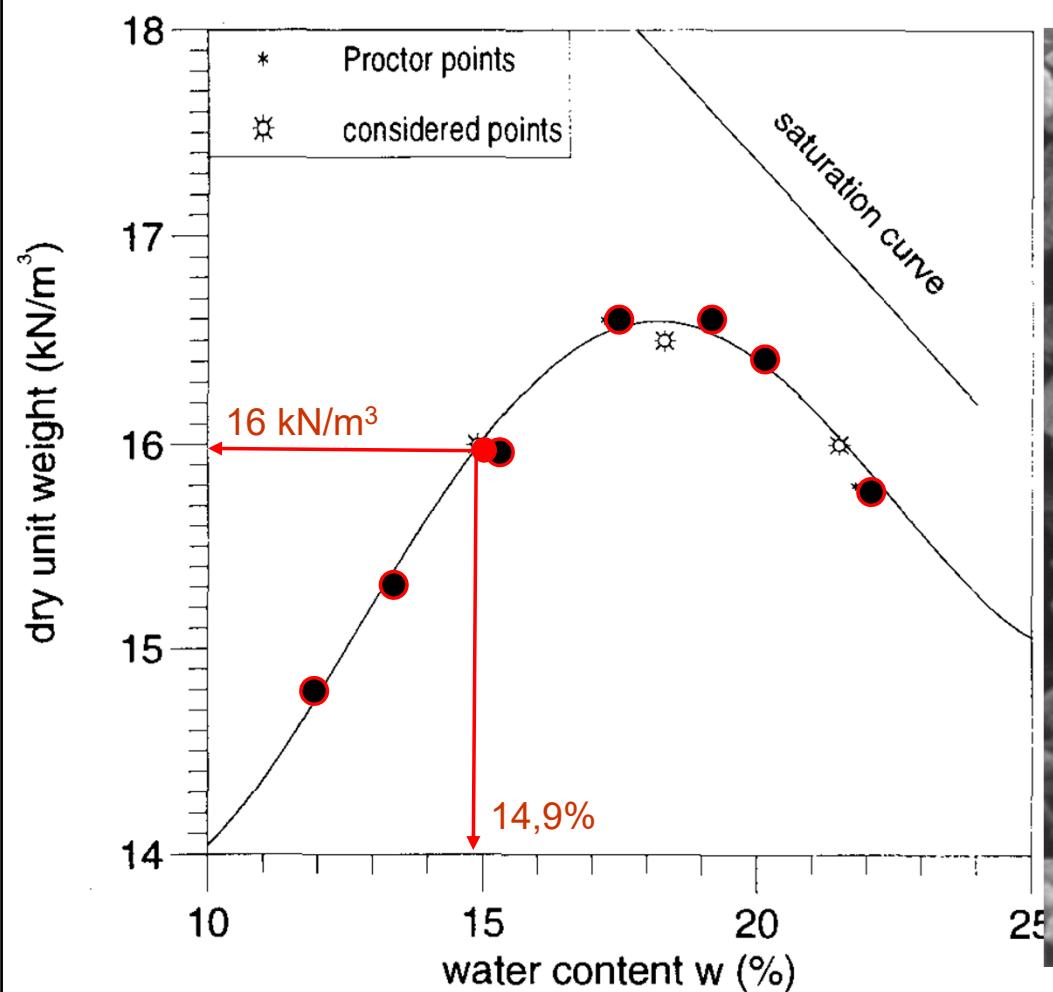


Lambe 1958

Limon de Jossigny compacté ($I_p = 18\%$, $34\% < 2 \mu\text{m}$)

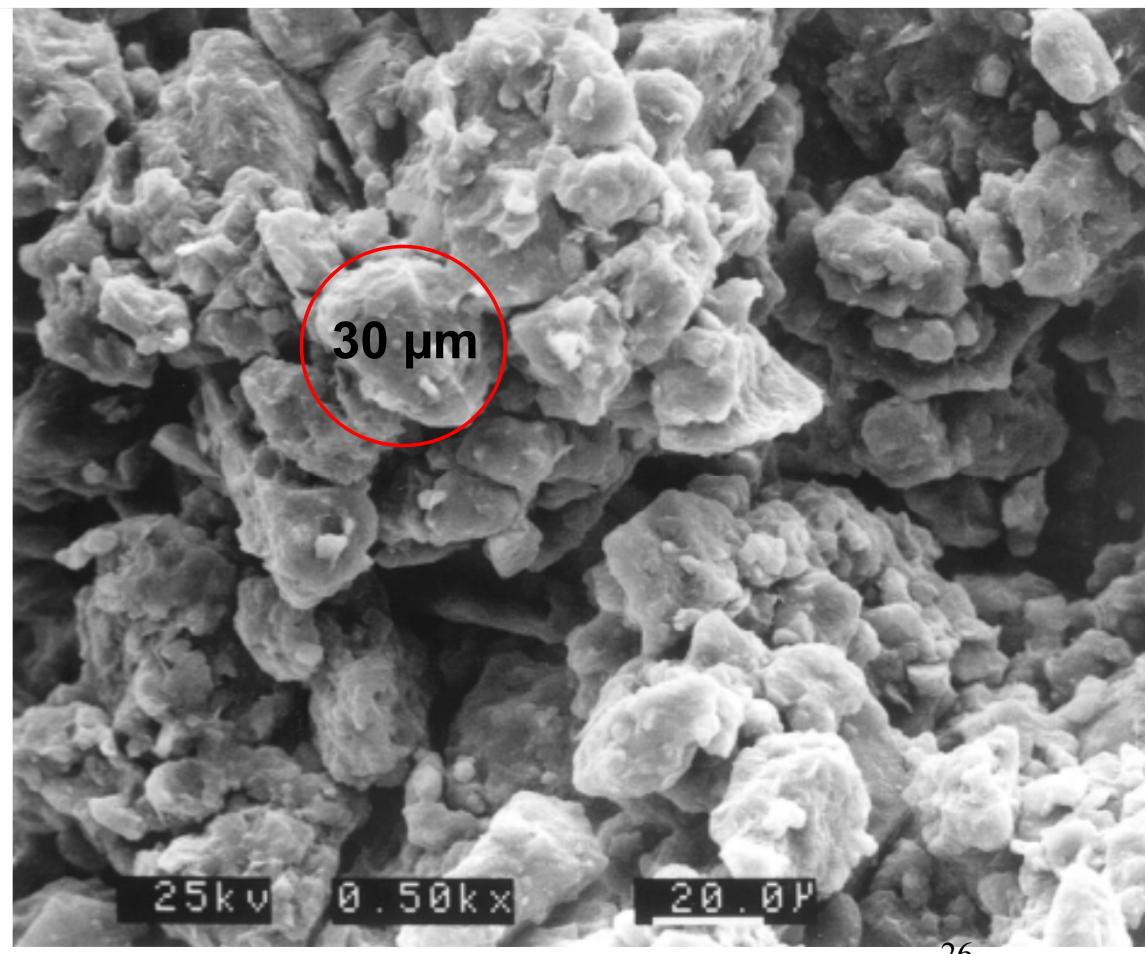
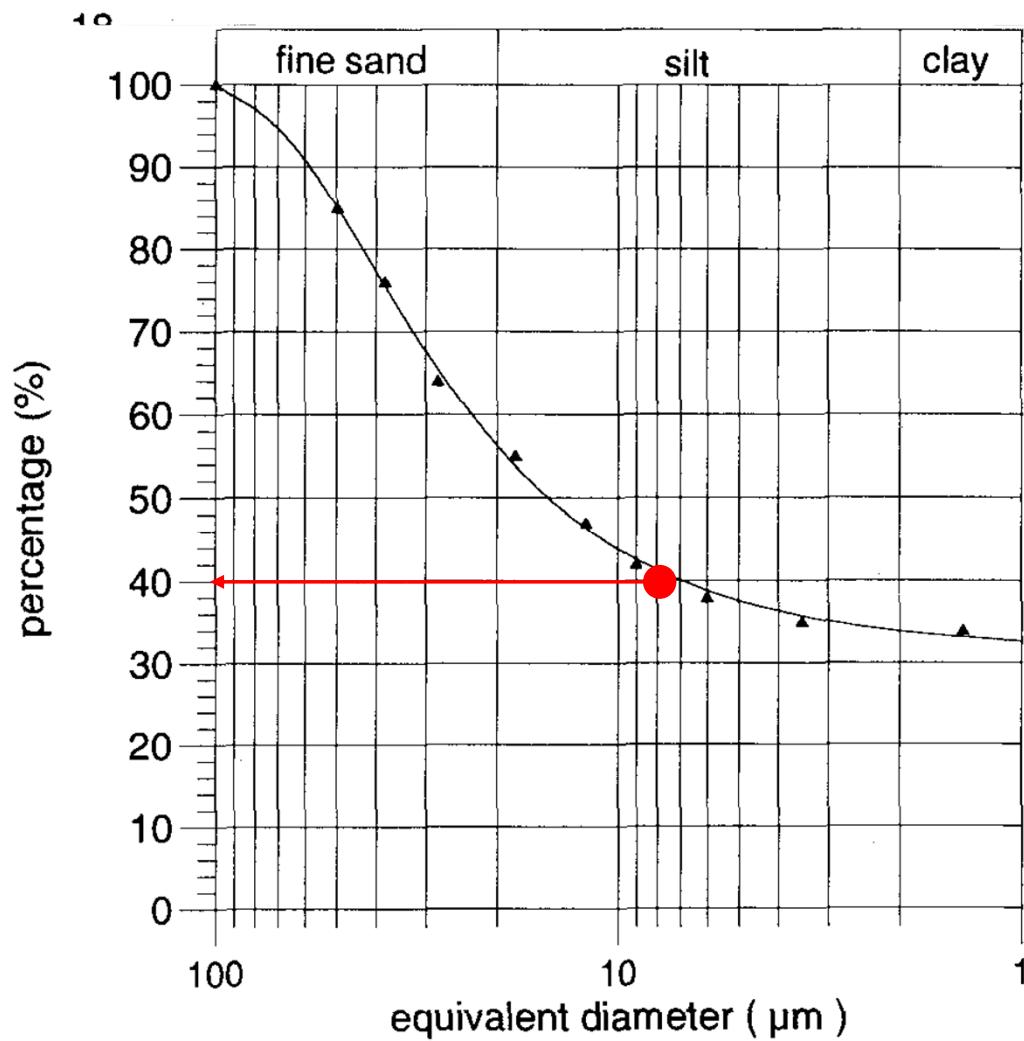


Microstructure limon de Jossigny côté sec



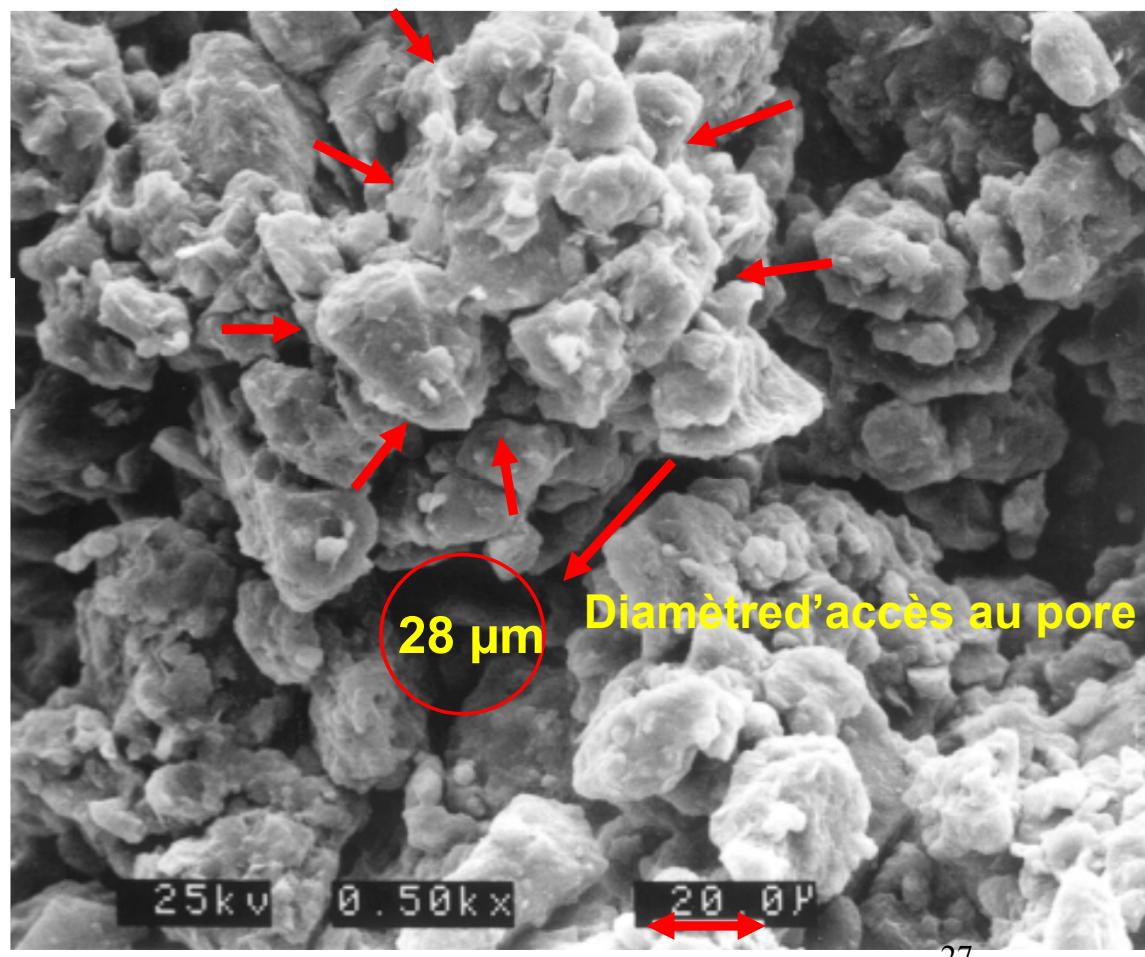
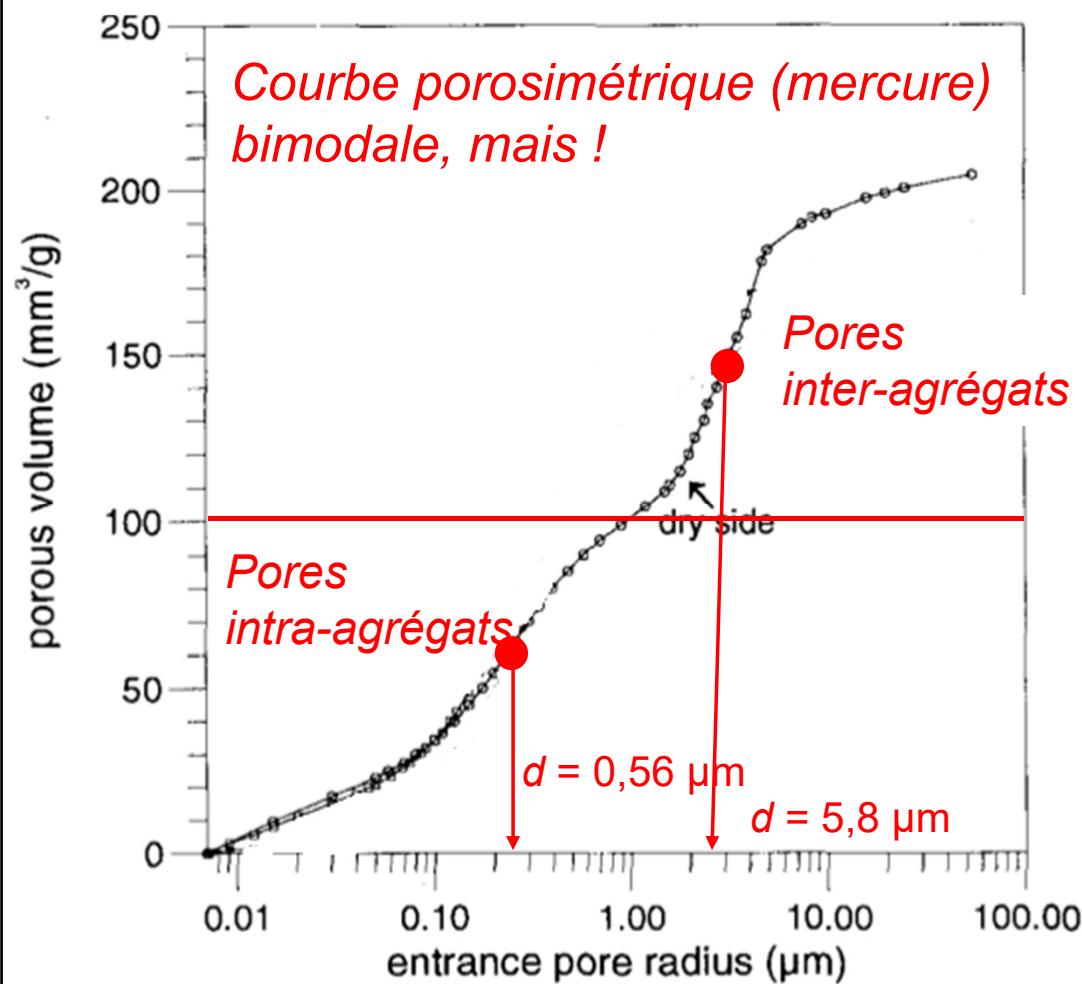
Delage et al. 1996

Microstructure limon de Jossigny côté sec



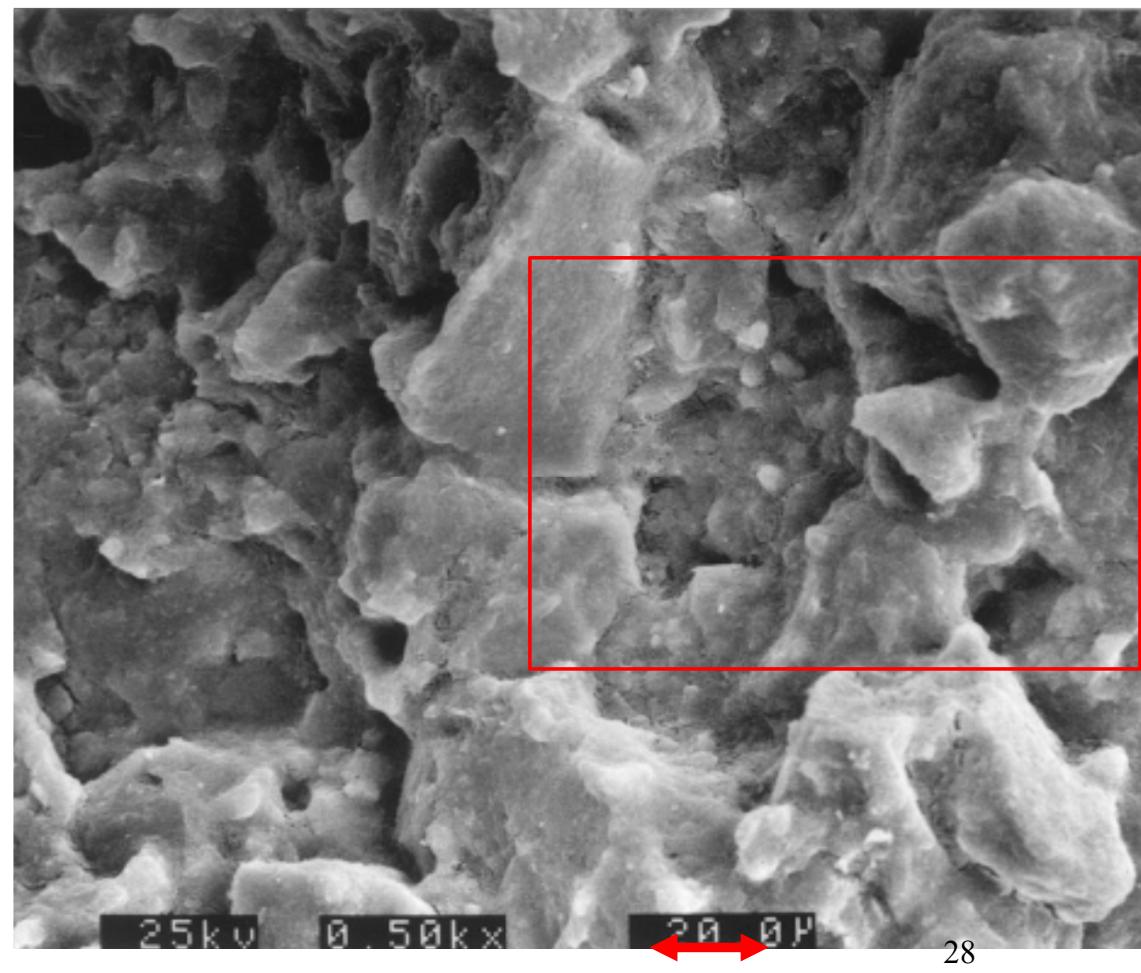
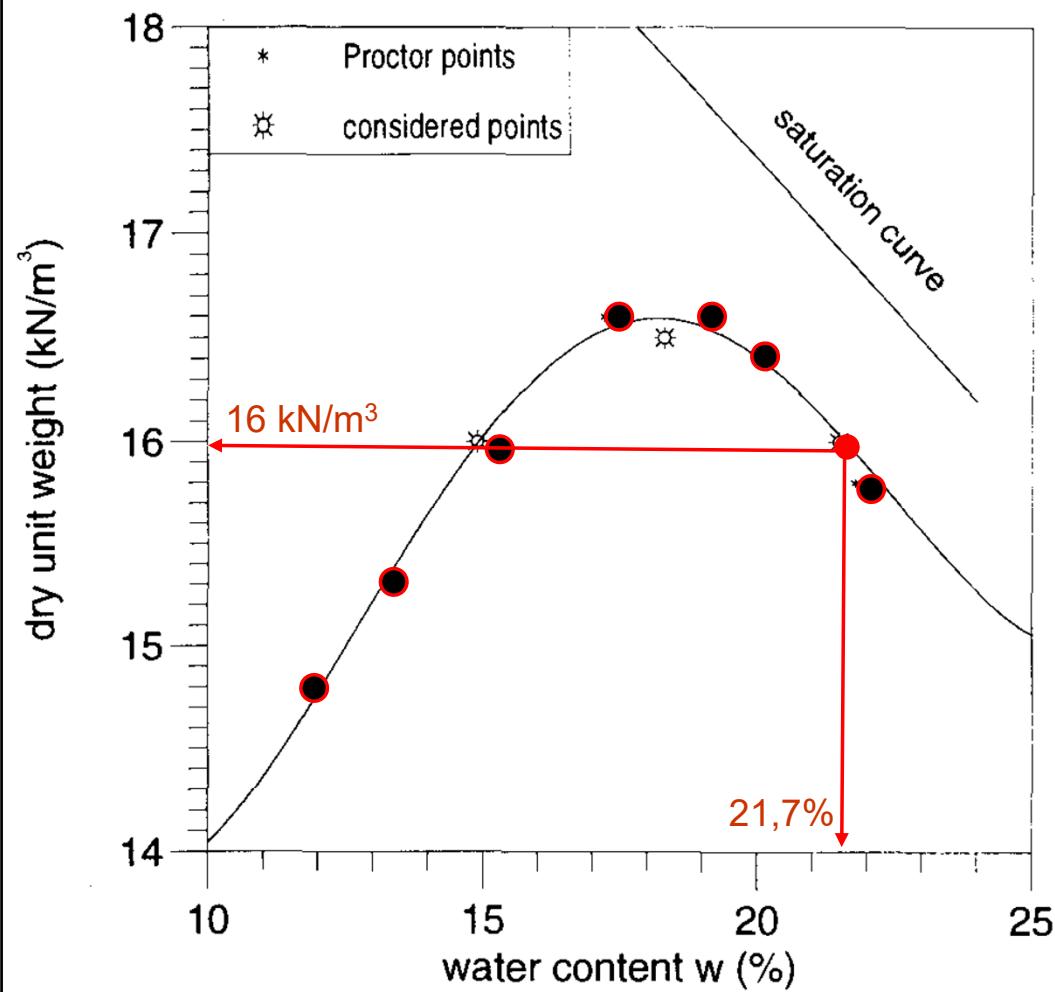
Delage et al. 1996

Microstructure limon de Jossigny côté sec



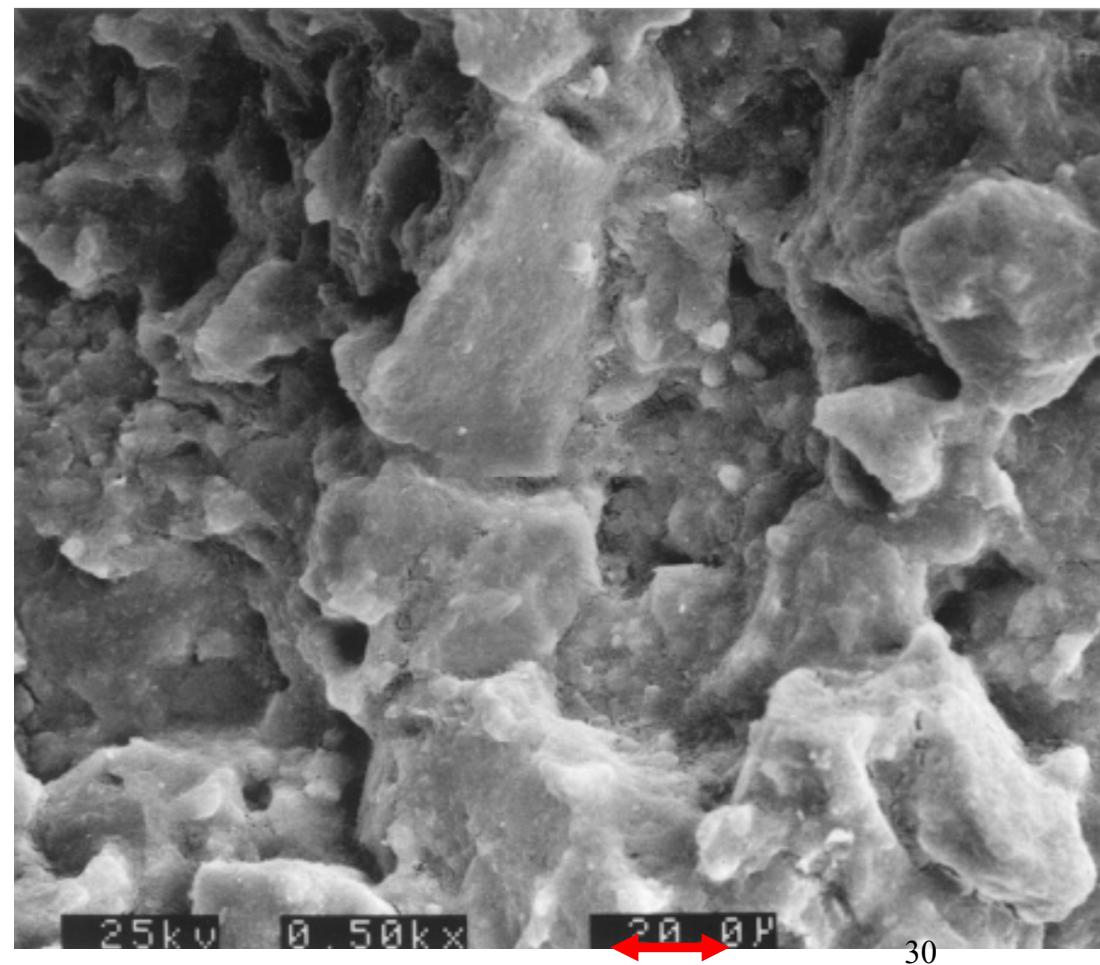
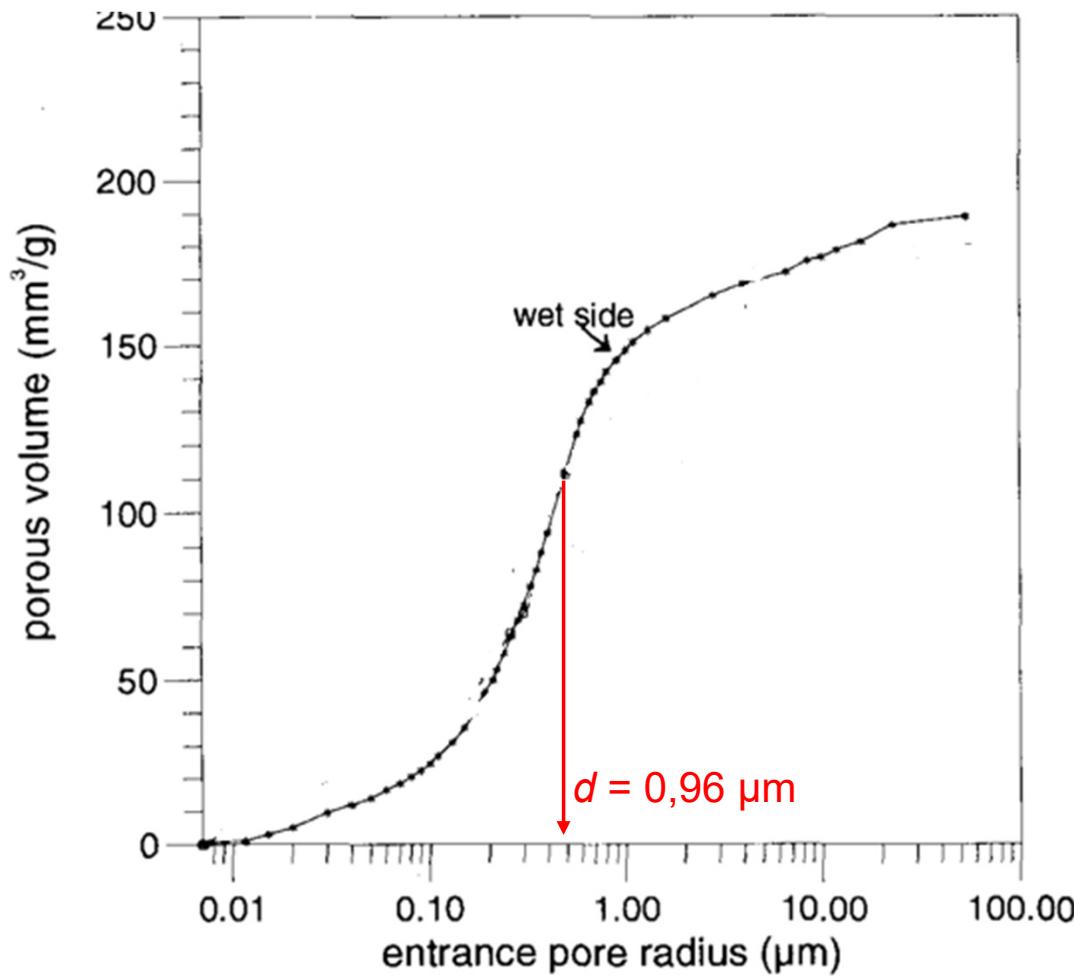
Delage et al. 1996

Microstructure limon de Jossigny côté humide



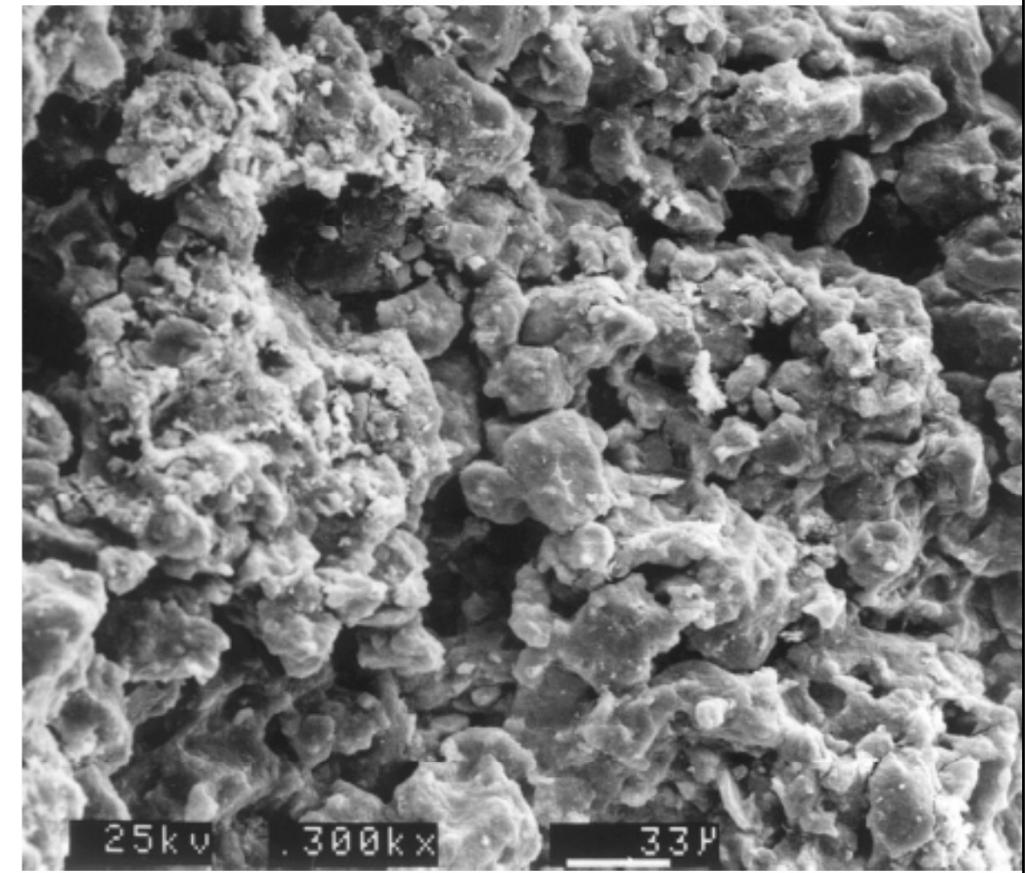
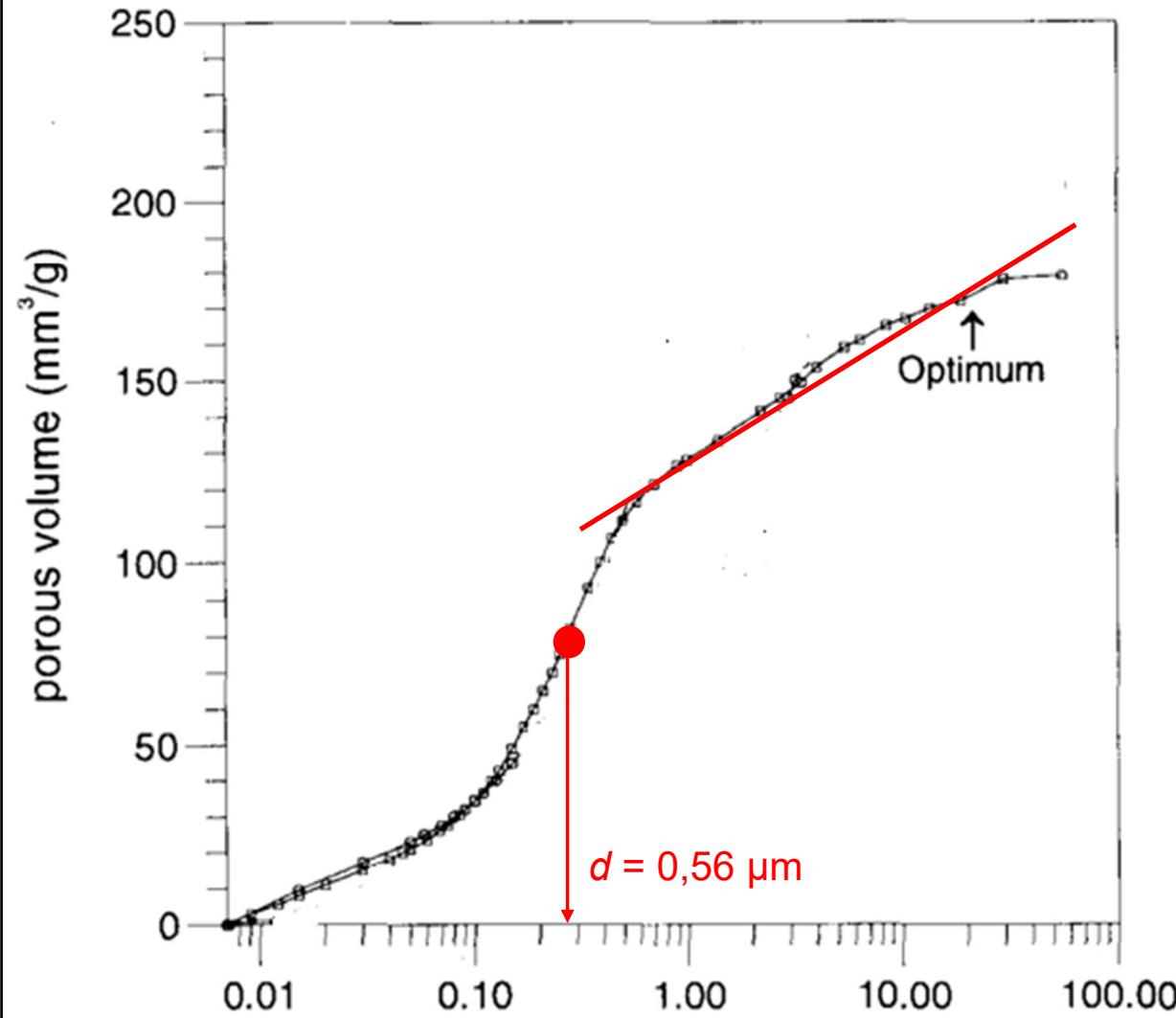
Delage et al. 1996

Microstructure limon de Jossigny côté humide



Delage et al. 1996

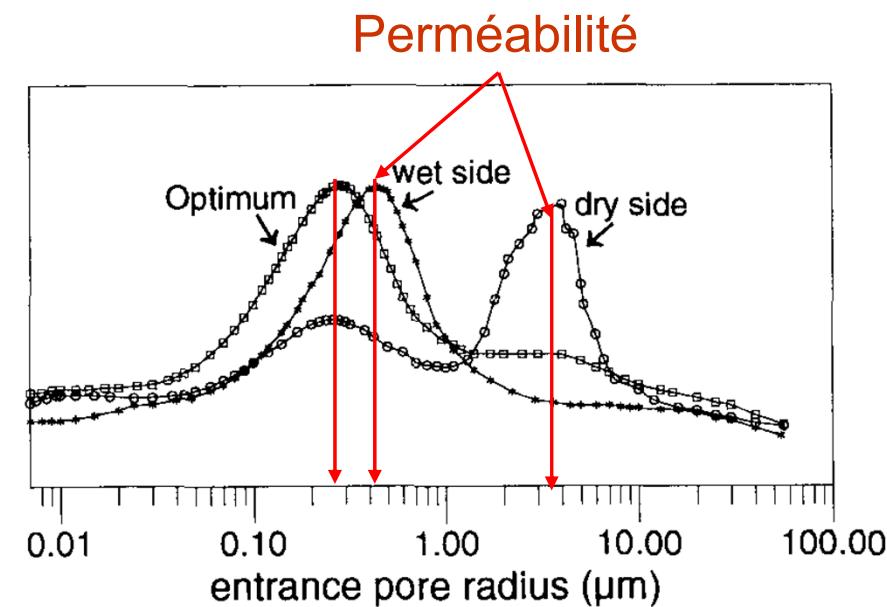
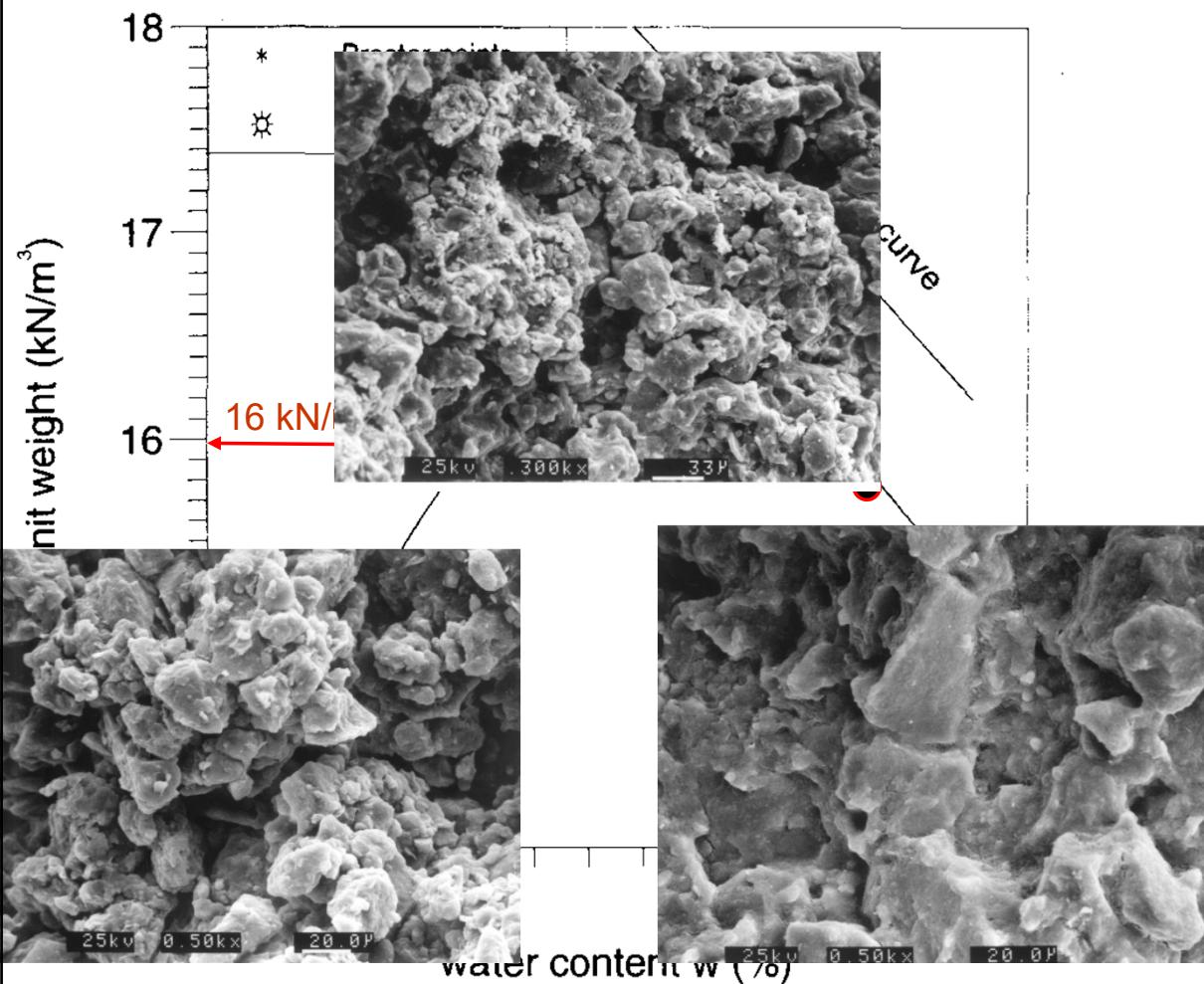
Microstructure limon de Jossigny à l'optimum



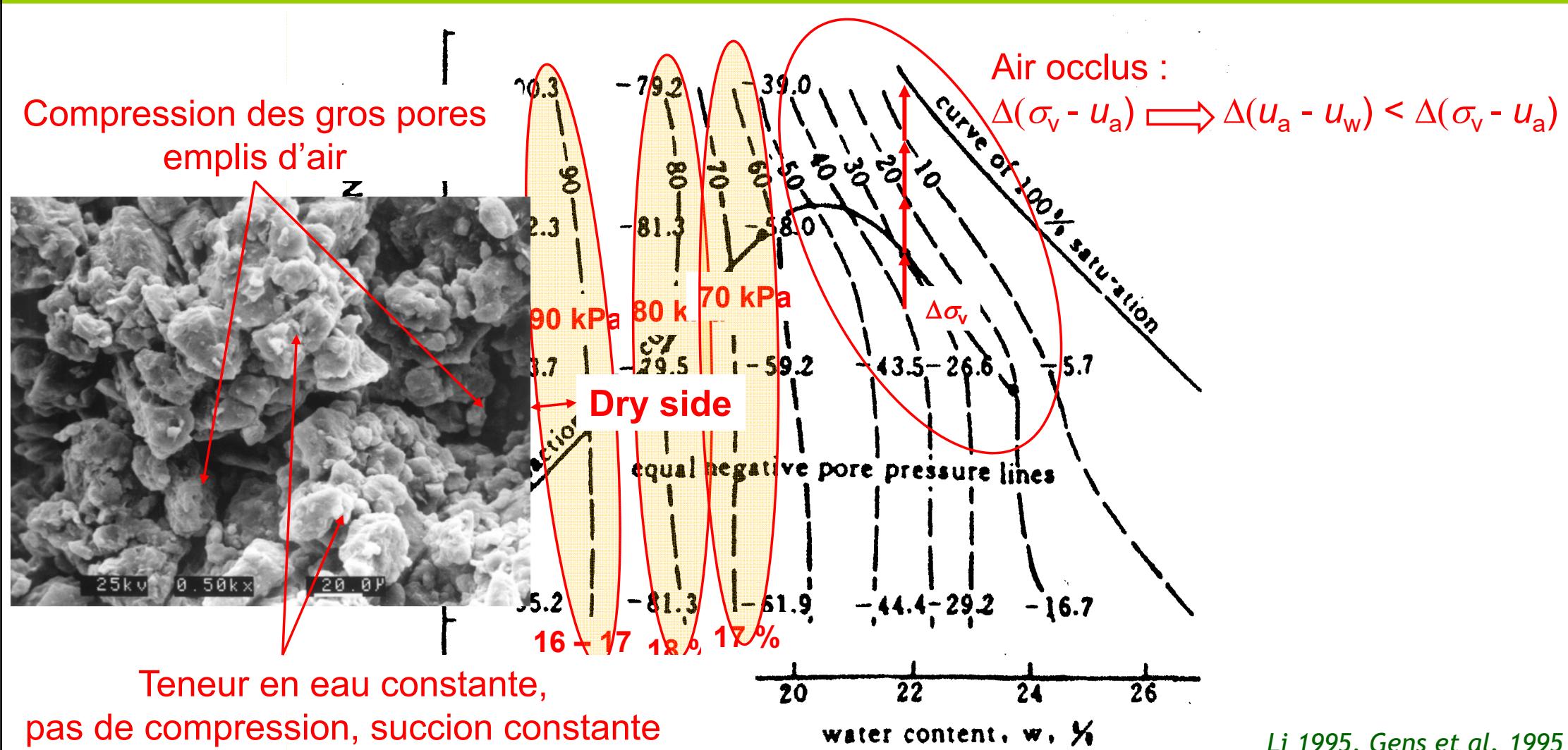
31

Delage et al. 1996

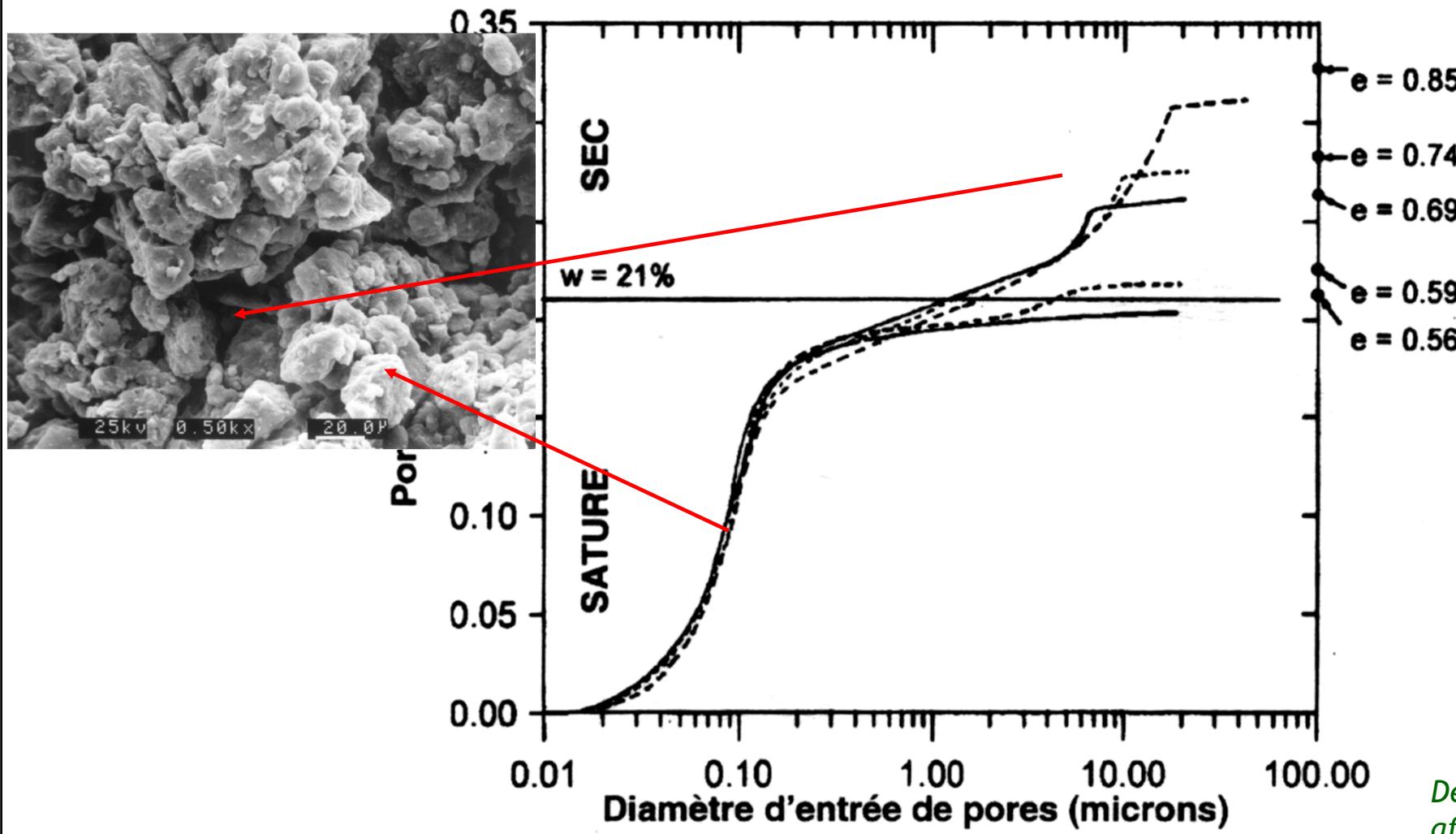
Microstructure limon de Jossigny compacté



Isovaleurs de succion, loess compacté ($I_p = 10$)

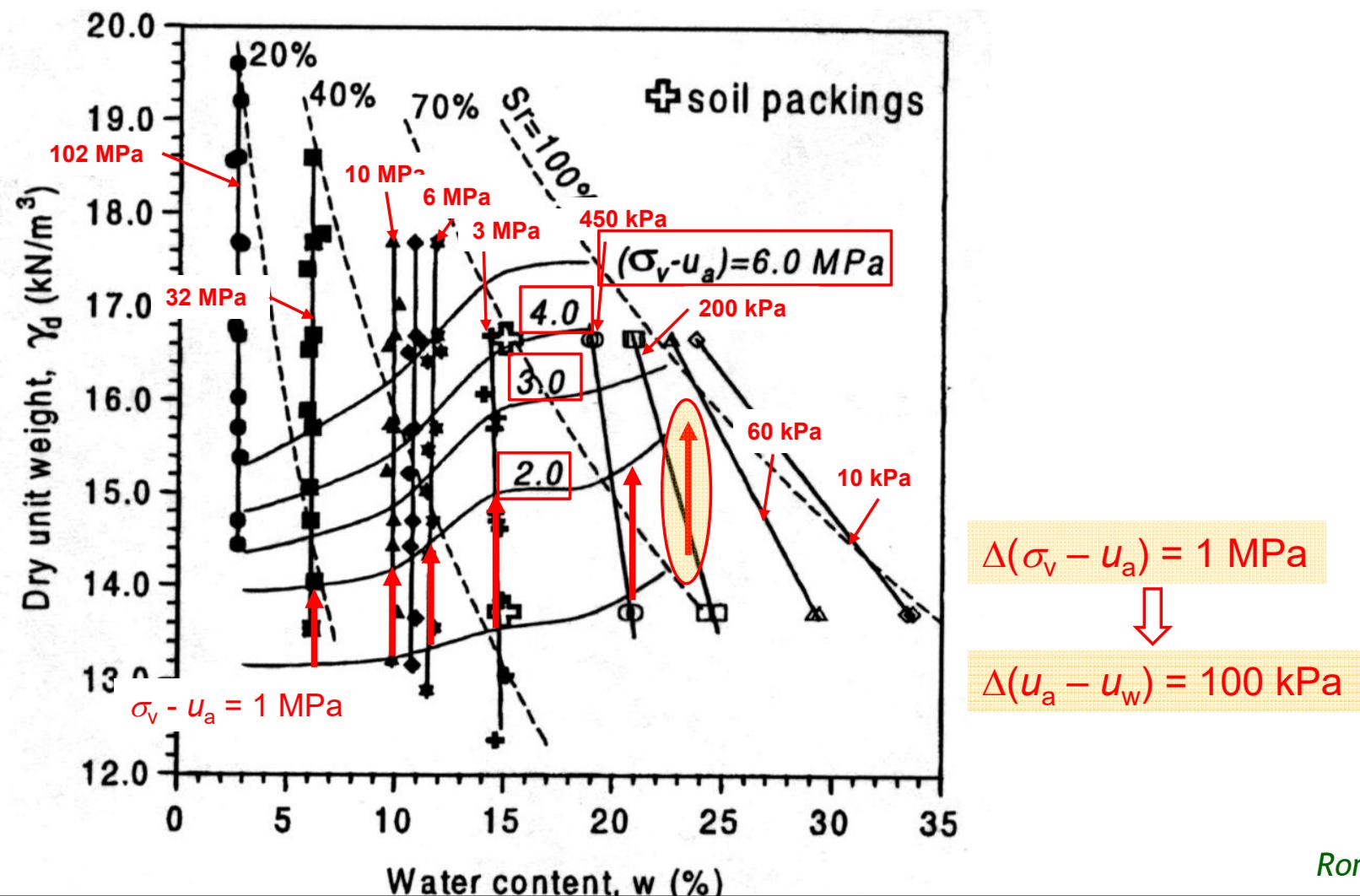


Compression du côté sec

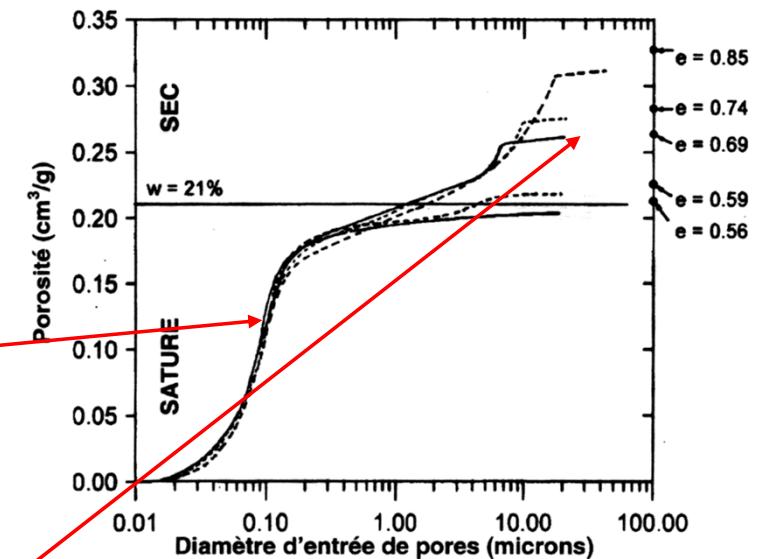
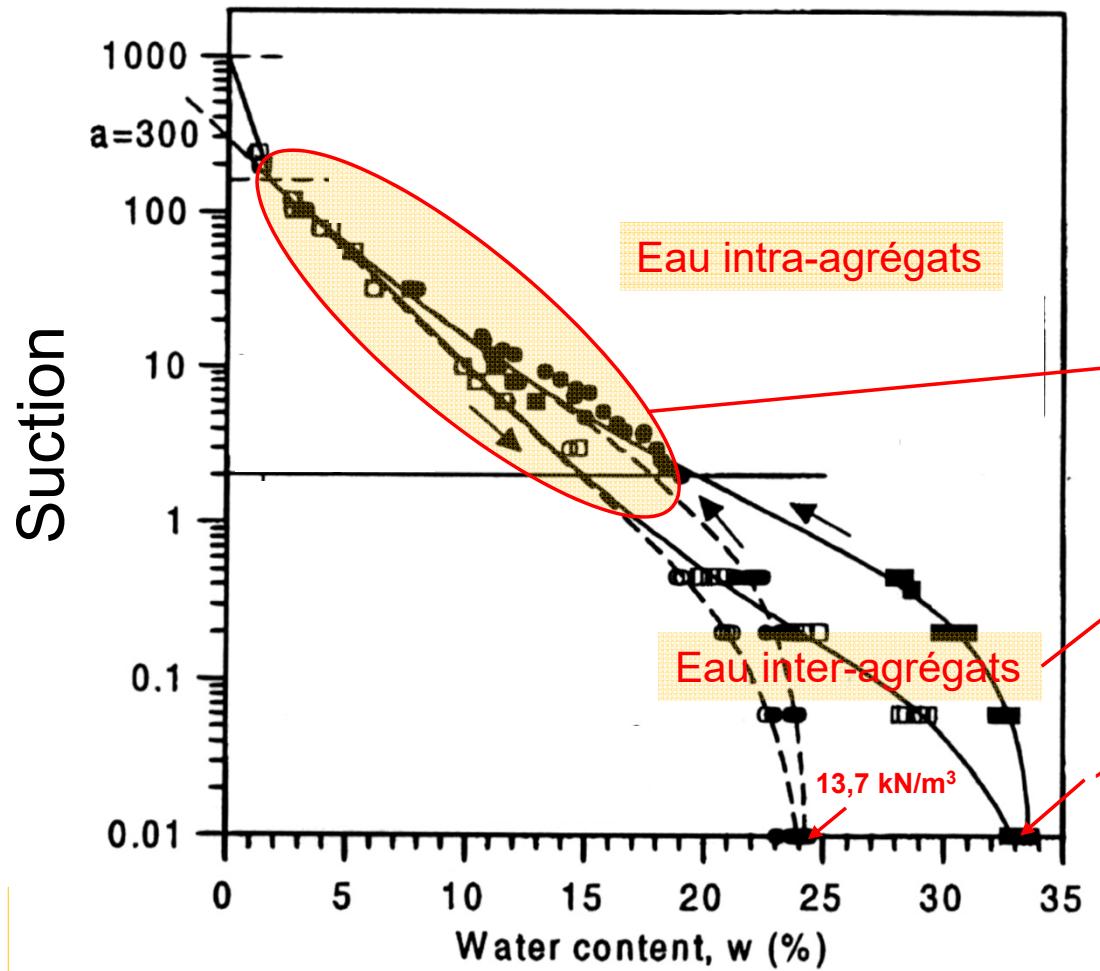


*Delage & Graham³⁴ 1995,
after Sridharan et al. 1971*

Argile de Boom compactée ($I_p = 40$)



Courbe de rétention de l'argile de Boom ($I_p = 40$)



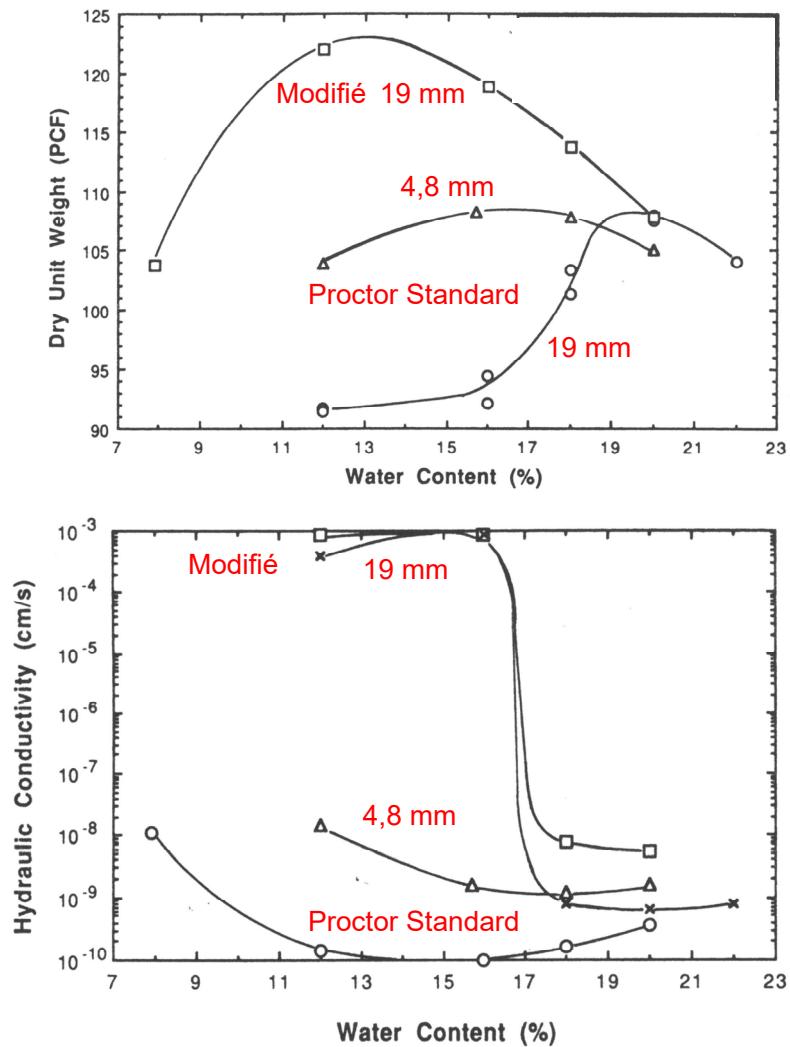
Du laboratoire au chantier (!)



P. Londe, ENPC

- **Changement d'échelle**
- **Mêmes principes**
- **Agrégat : motte, déformabilité variable**
- **Variabilité**
 - **Composition**
 - **Teneur en eau**
 - **Densité**

Des agrégats aux mottes



Du laboratoire au chantier

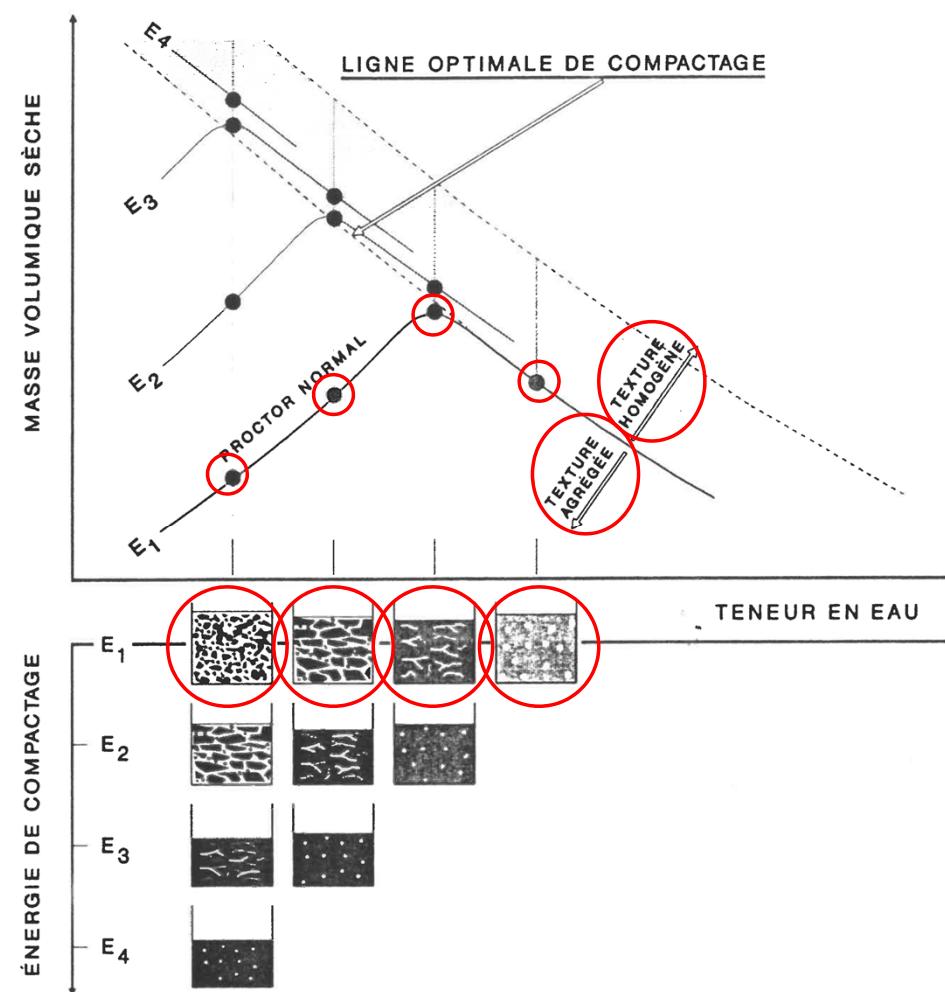


FIG. 1. Évolution de la texture de l'argile en cours de compactage.

Du laboratoire au chantier

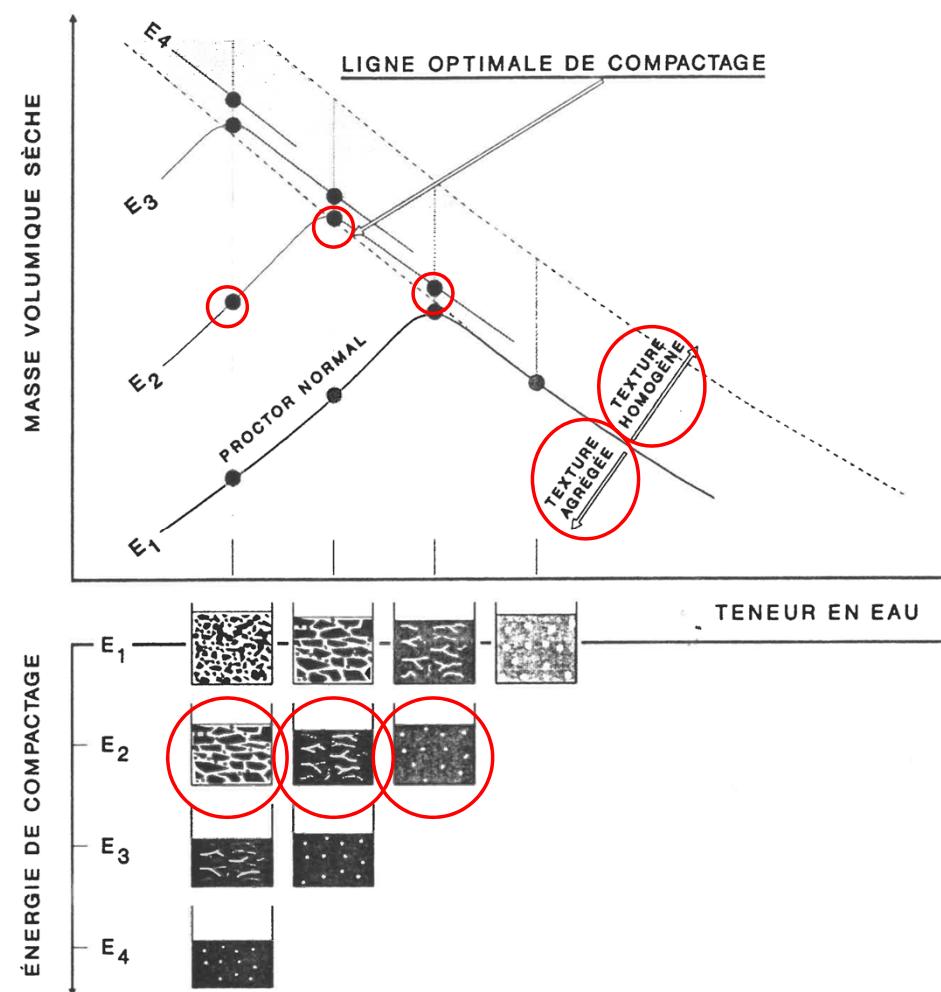


FIG. 1. Évolution de la texture de l'argile en cours de compactage.

Du laboratoire au chantier (Cabot & Le Bihan)

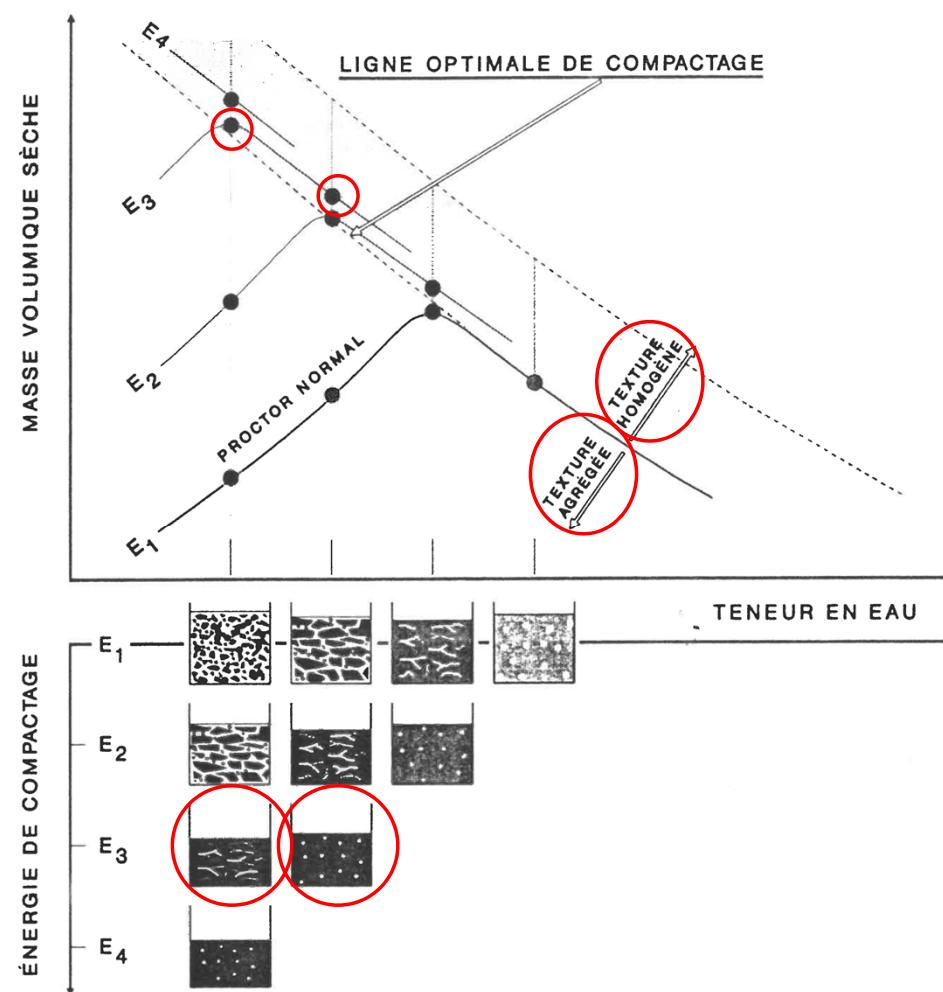
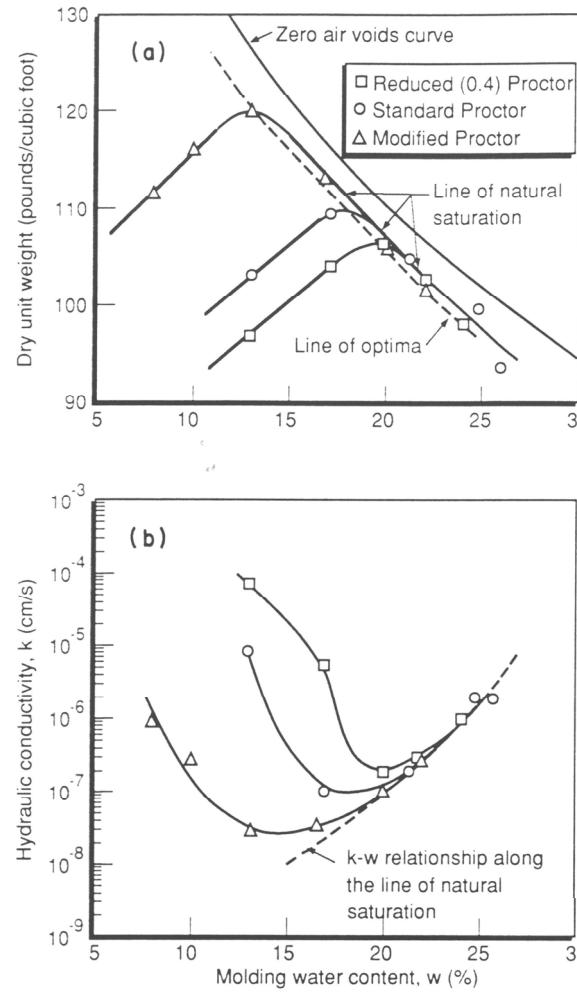


FIG. 1. Évolution de la texture de l'argile en cours de compactage.

Du laboratoire au chantier (Cabot & Le Bihan)



Conclusions

Sols compactés : sols non saturés

Succion, pression d'entrée d'air, rétention d'eau (transferts eau/air)

Interactions sol / eau : capillarité, adsorption

Forte sensibilité à la teneur en eau

3 types de microstructure (agrégats/mottes de diverses rigidités) / teneur en eau

Fort effet sur la perméabilité et les transferts

Phase air continue/discontinue

References

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CONCEPTION ET CONSTRUCTION des ouvrages en sols fins

Merci de votre attention...

