5ème Ecole d'automne du GDR MBS

Eco-conception des matériaux biosourcés et géosourcés : de la ressource à la fin de vie

12 au 16 octobre 2025, Douai

La construction en terre crue

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RÉPUBLIQUE FRANÇAISE

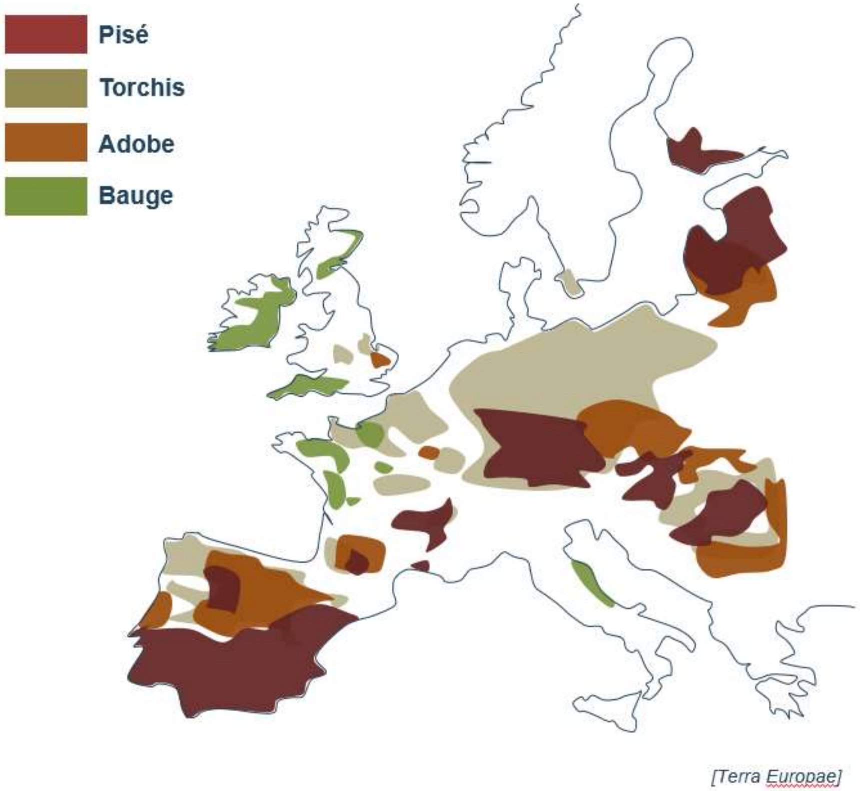
GdR MBS
MATÉRIAUX de CONSTRUCTION BIOSOURCÉS

cnrs

Sommaire

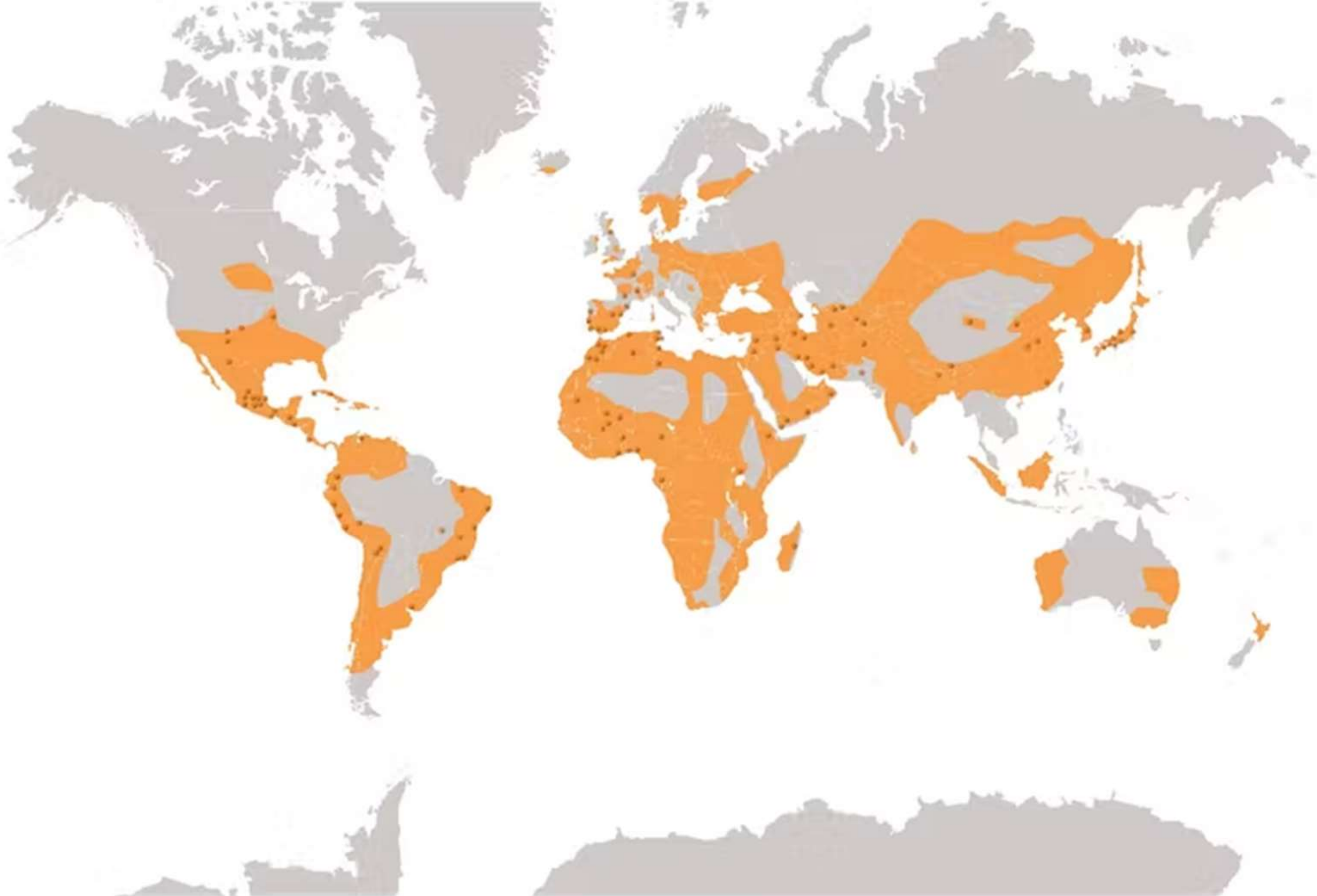
1. Patrimoine terre crue et systèmes constructifs
2. Nature du matériau
3. Spécificité du matériau terre : Enjeu de recherche

1. Patrimoine de la construction en terre



- 15% du patrimoine Français
- Entre 1/4 et 1/3 de la population mondiale

Répartition des constructions en terre crue[1]



[1] Craterre

Un riche patrimoine d’architectures en terre crue …

(a) la grande mosquée de Djenné, Mali

XIII^{e}

(b) La ville de Shibam, Yemen

XVI^{e} s

(e) Forteresse d’Alcazaba, Espagne

(f) Le “domaine de la terre”, France

(c) Jiayuguan la grande muraille, Chine

(d) La ville de Taos Pueblo, USA

(g) Une ferme en pisé, Lettonie

(h) Une maison réhabilitée, Pays-Bas

Ksar Aït-Ben Haddou, Maroc

Vestige archéologique en France

7. Le site du Bois d'Adrien à Maillé (Indre-et-Loire).

La construction en terre crue au Néolithique

Un état de la question en France

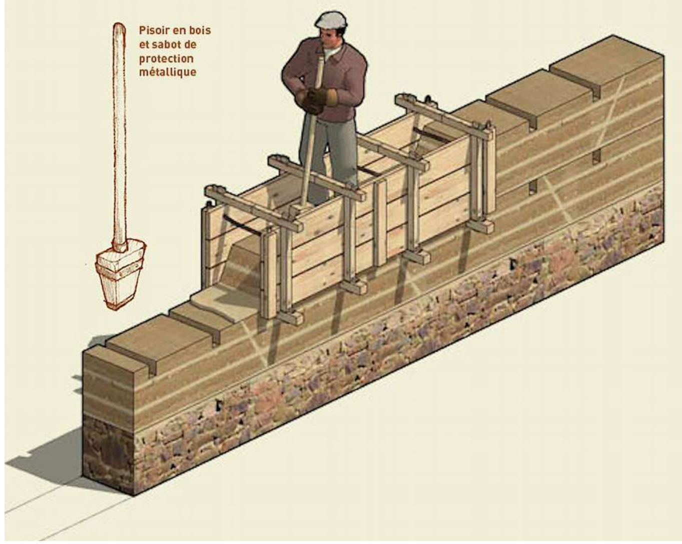
Building with earth in the Neolithic in France: an overview

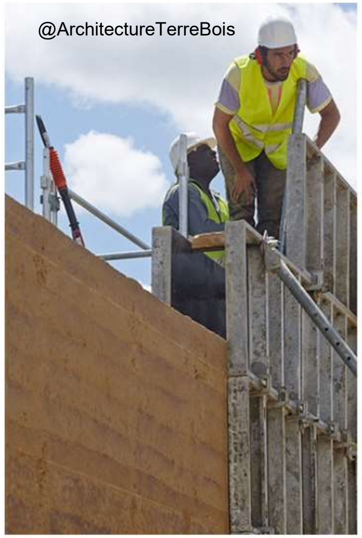
La construcción en barro durante el Neolítico: en Francia

Ingrid Sénépart, Julia Wattez, Luc Jallot, Tony Hamon and Marylise Onfray

Entre 5800 et 2500 avant notre ère

1. Patrimoine de la construction en terre : le cas du pisé





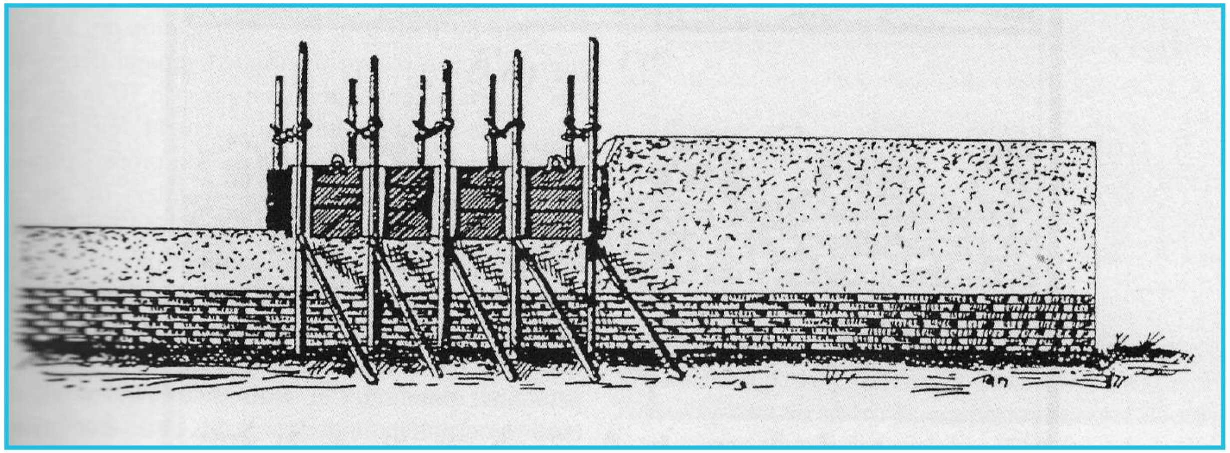
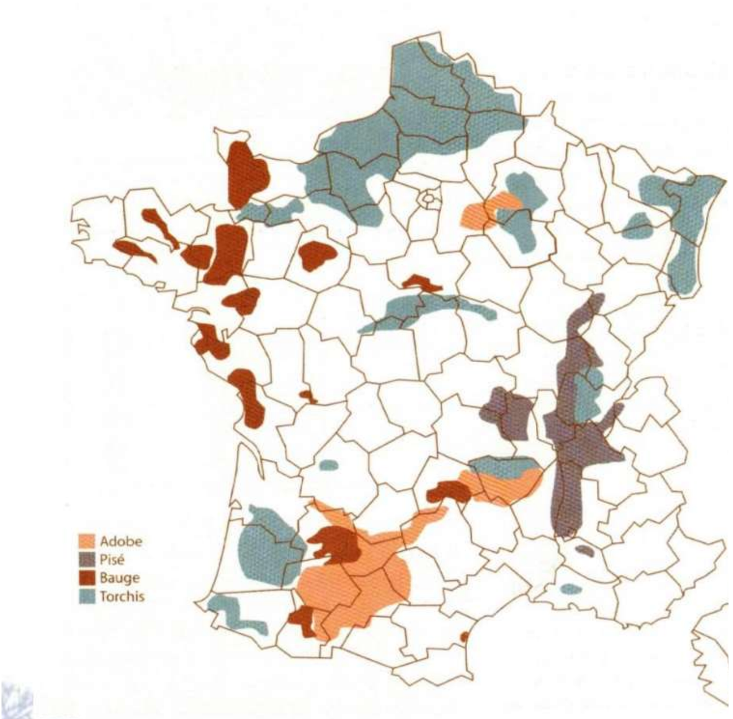
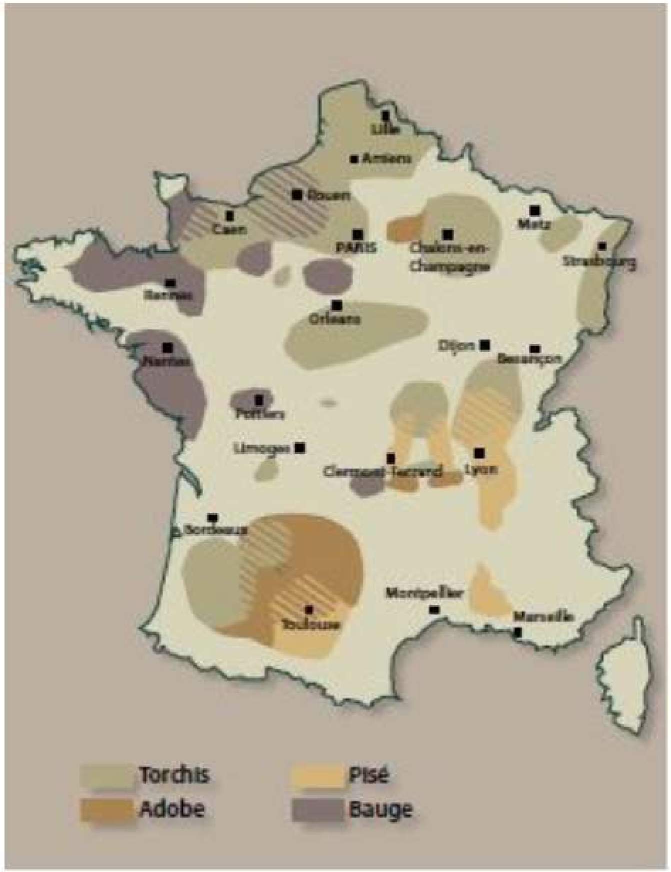


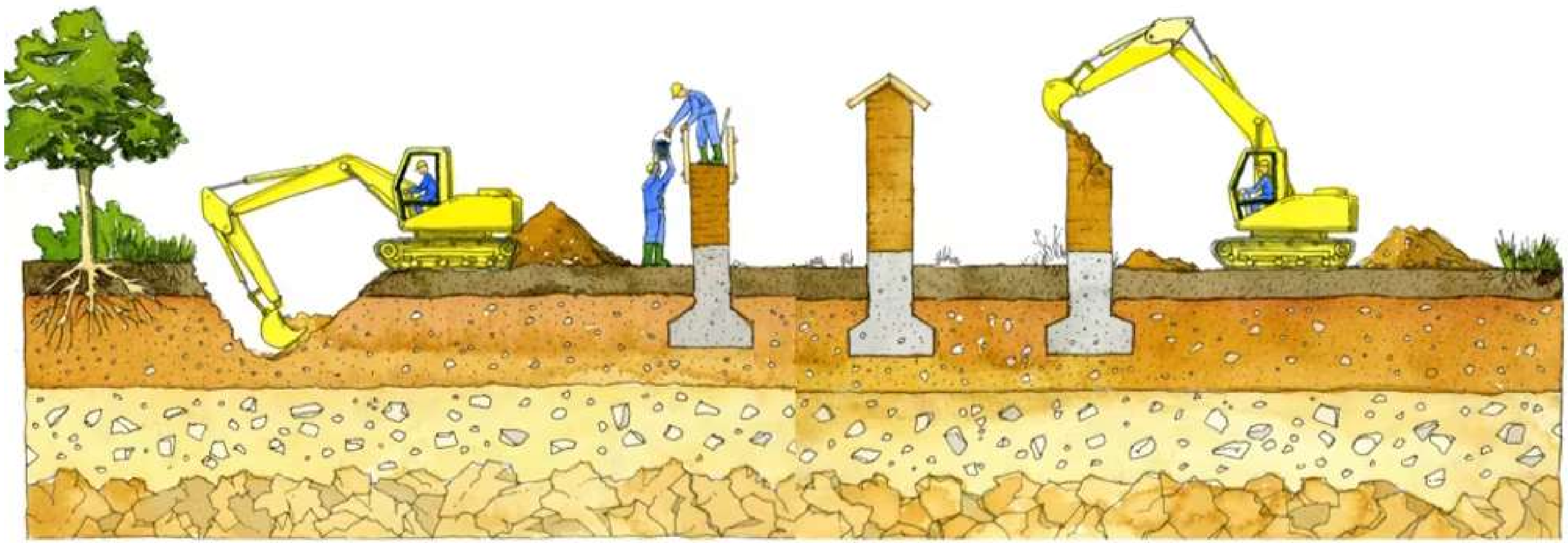
Fig. 32 Méthode du Bugey décrite par l'architecte François Cointereaux en 1790 (Cointereaux 1790, planche X)





Carte d'après Terra Europea. « Earthen Architecture in the European Union »

Un matériau naturel local et circulaire



@ Arnaud Misse

https://culture.isere.fr/page/la-construction-en-pise-en-isere

https://www.st-michel-de-st-geoirs.fr/maisons-en-pise-et-galets-roules/

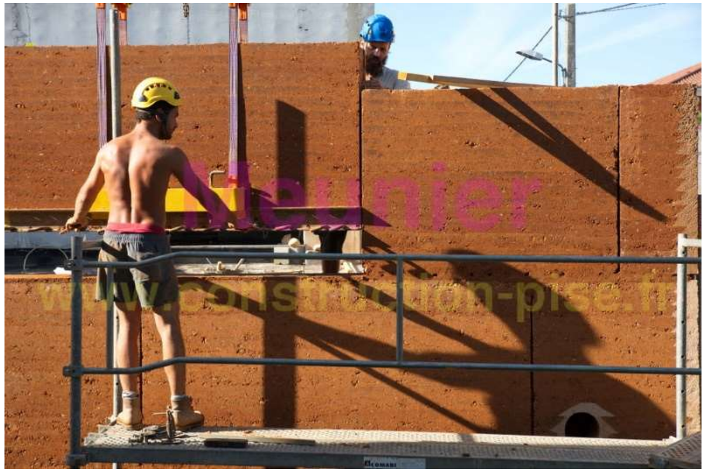
https://culture.isere.fr/page/la-construction-en-pise-en-isere

Château La bastie d'Urfé (42)
XVème

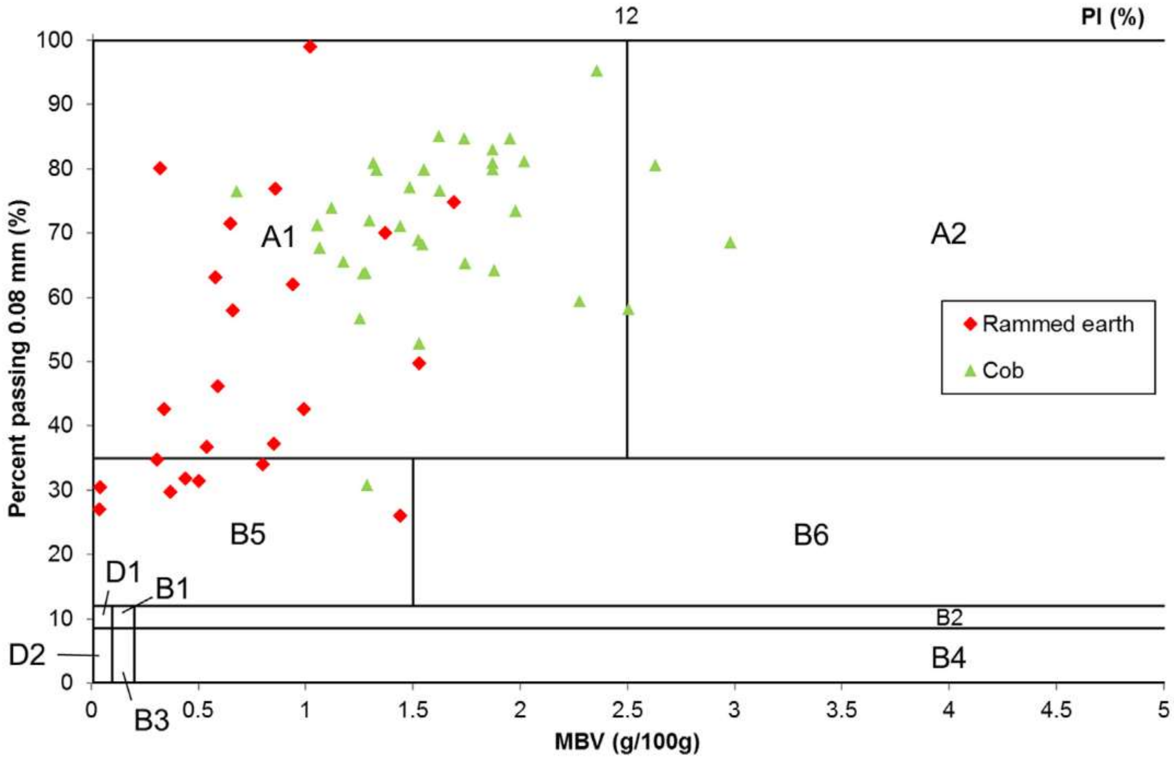
Salle héraldique la Diana
Montbrison (42) XIIIème

Pisé préfabriqué : L'Orangerie à Lyon

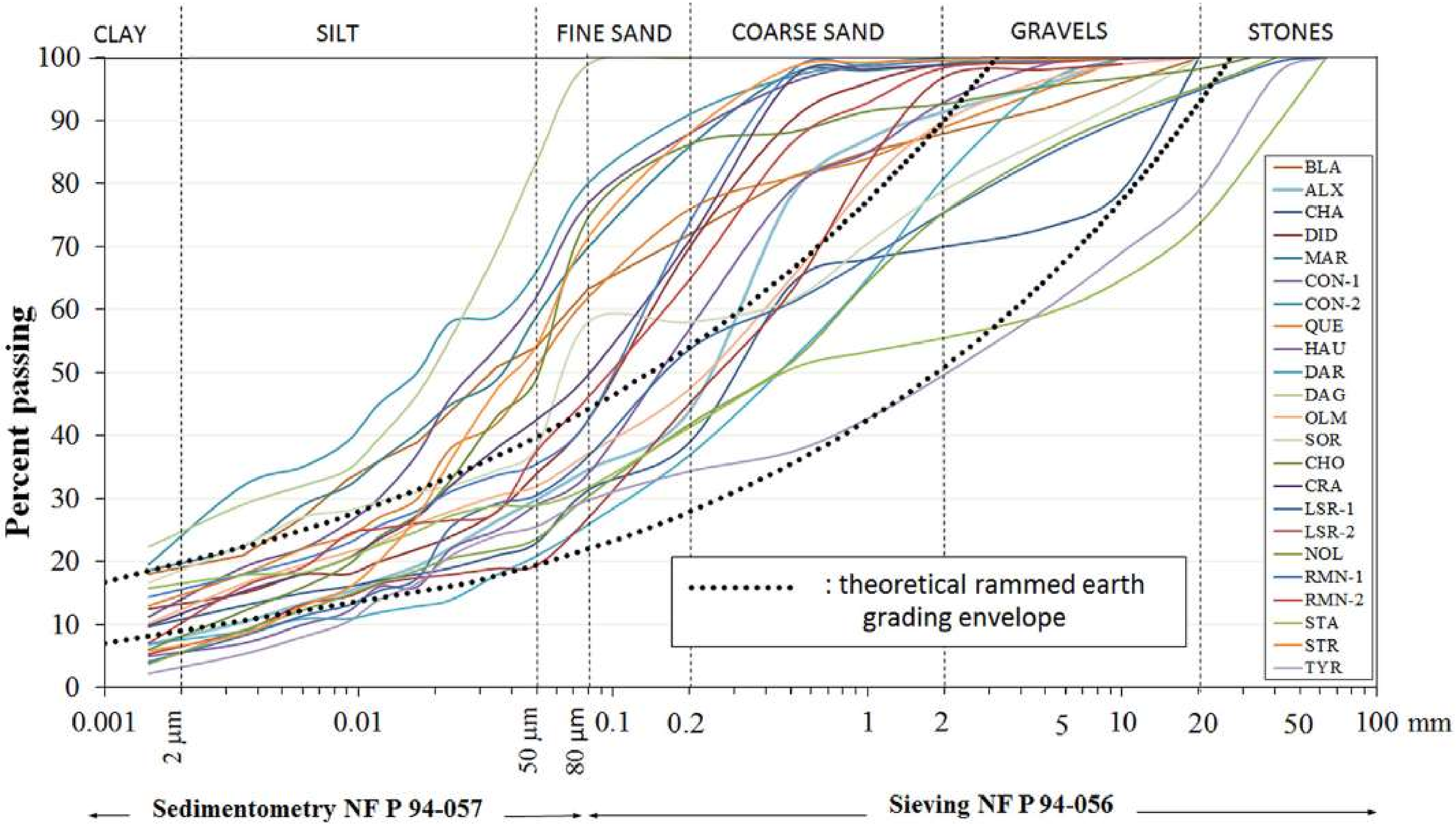
Source : Thibault Vialleton, Batiserf



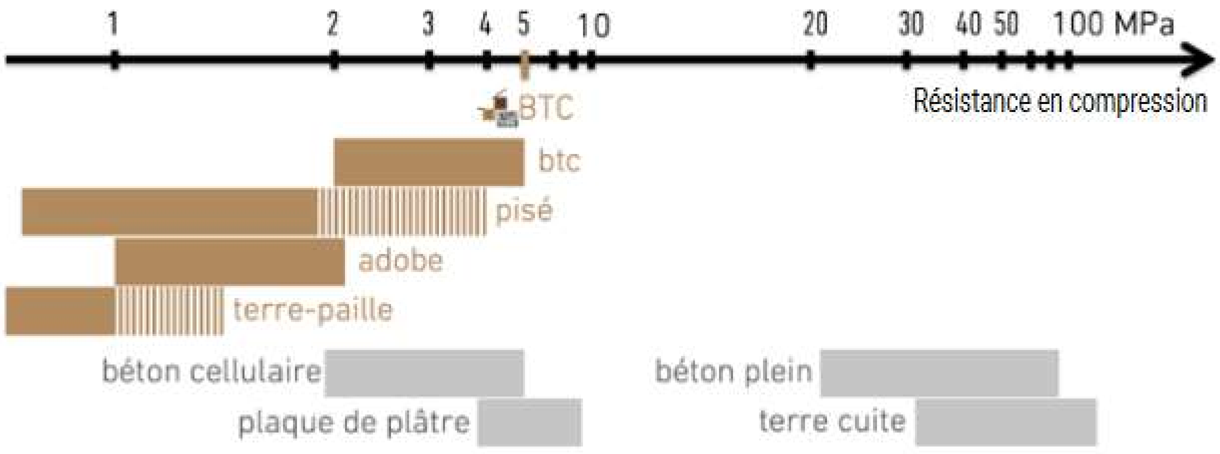
(Ph: E. Mille, CRAterre-ENSAG)



Rojat et al., 2020, Towards an easy decision tool to assess soil suitability for earth building, Construction and Building Materials



Rojat et al., 2020, Towards an easy decision tool to assess soil suitability for earth building, Construction and Building Materials



GUIDE DE CONCEPTION ET DE CONSTRUCTION, Cycle Terre

1. Patrimoine de la construction en terre : le cas de la brique (ou adobe)

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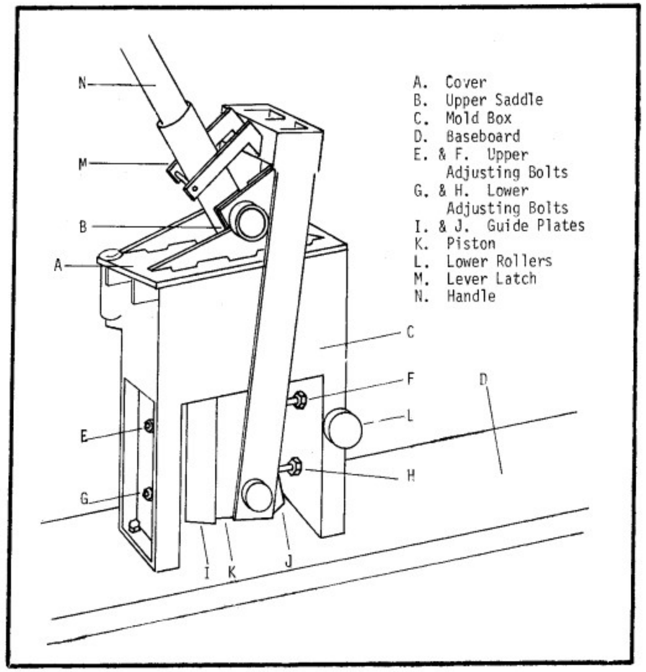


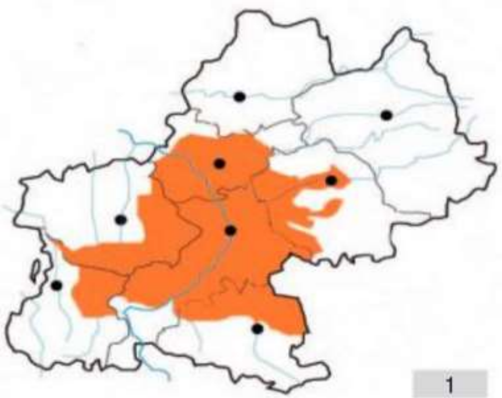
Fig. 1 - The CINVA-Ram Block Press and Its Parts

Revue passerelle éco

1. Patrimoine de la construction en terre : le cas de la brique (ou adobe)

Le Parisien chez BTC

MIDI-PYRÉNÉES



1

2

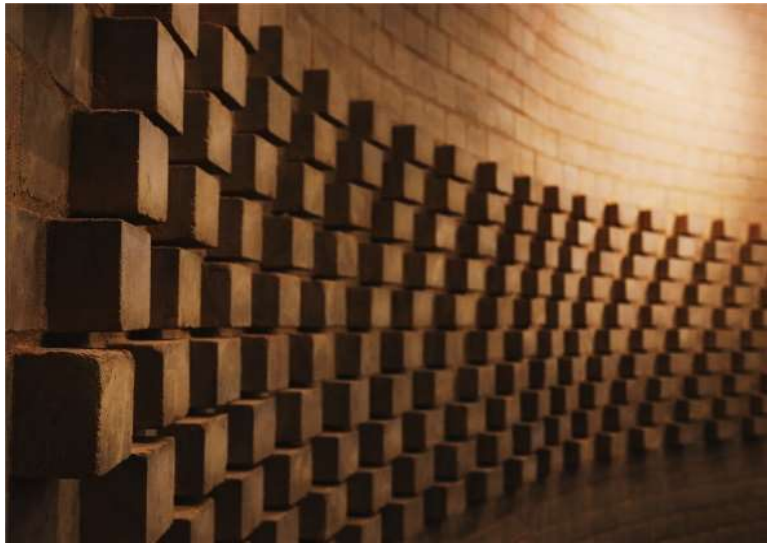
[PRÉSENTATION]

CAUE du Gers

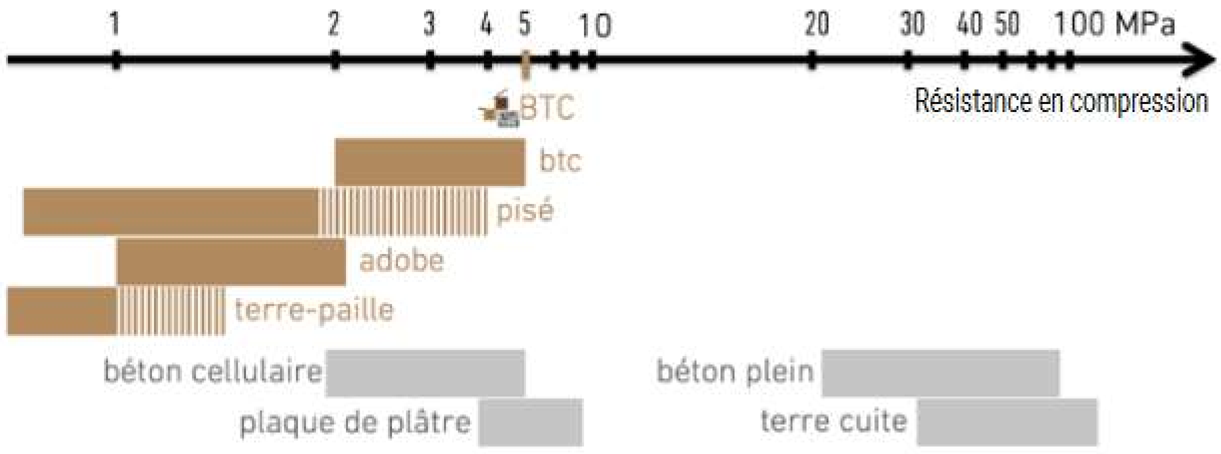
CAUE du Gers

https://www.ladepeche.fr/article/2018/09/26/2876283-terre-crue-locale-invitee-ecole-architecture-toulouse.html

Pôle Culturel Aria, Cornebarrieu



Source : Etienne Gay, Briques Technics Concept



GUIDE DE CONCEPTION ET DE CONSTRUCTION, Cycle Terre

1. Patrimoine de la construction en terre : le cas de la bauge

Photo Dominique Le Villain © Maisons Paysannes de l'Eure.

1. Patrimoine de la construction en terre : le cas de la bauge

Photo Dominique Le Villain © Maisons Paysannes de l'Eure.

1. Patrimoine de la construction en terre : le cas de la bauge

Photo François Streiff, Parc Naturel Régional du Marais du Cotentin et du Bessin

2. Nature du matériau

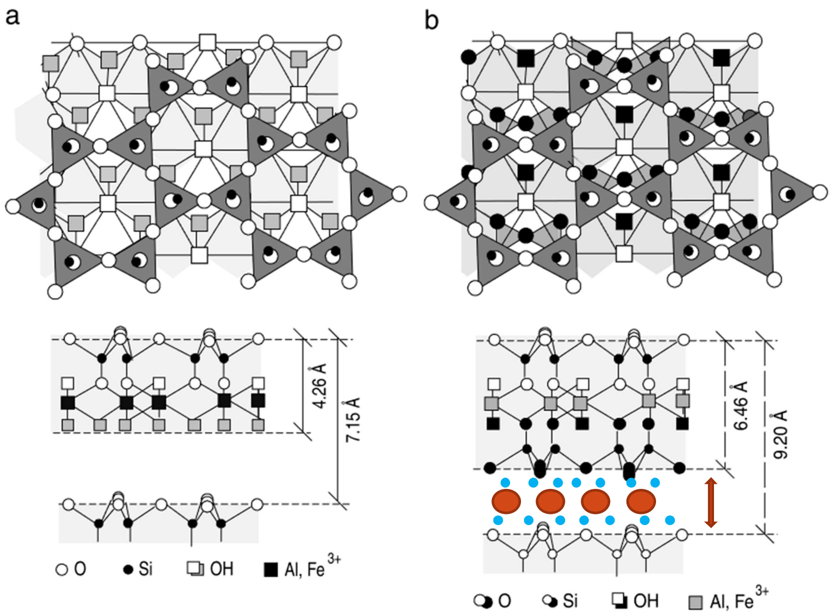
Argiles et minéraux argileux

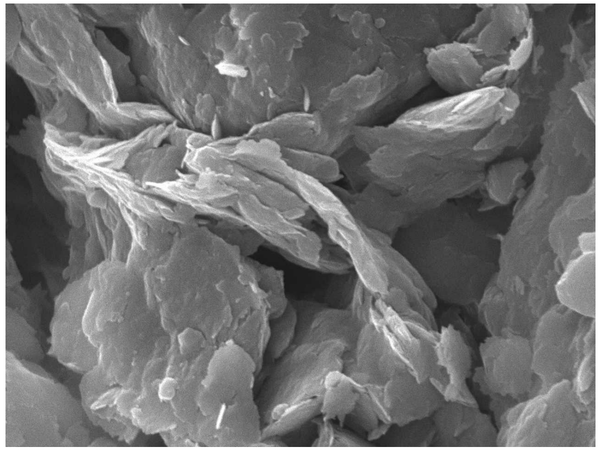
Clay : « …a naturally occuring material composed primarily of fine-grained minerals, which is generaly plastic at appropriate water contents and will harden when dried or fired » Joint Nomenclature Committee (JNC) of AIPEA and The Clay Minerals Society

Clay size fraction : Soil particles with a size below 2 µm

Clay minerals : Sheet like minerals from the phyllosilicate group, most often small

Minéraux argileux (phyllosilicates)





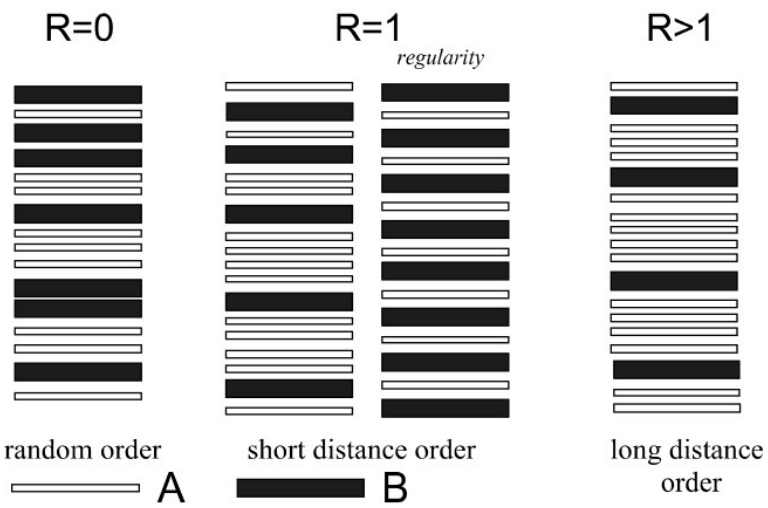
X6000, SE 15KV

Type 1:1 (Ex:Kaolinite) Type 2:1 (Ex:Smectites)

From Meunier, 2005

Empilement de couches

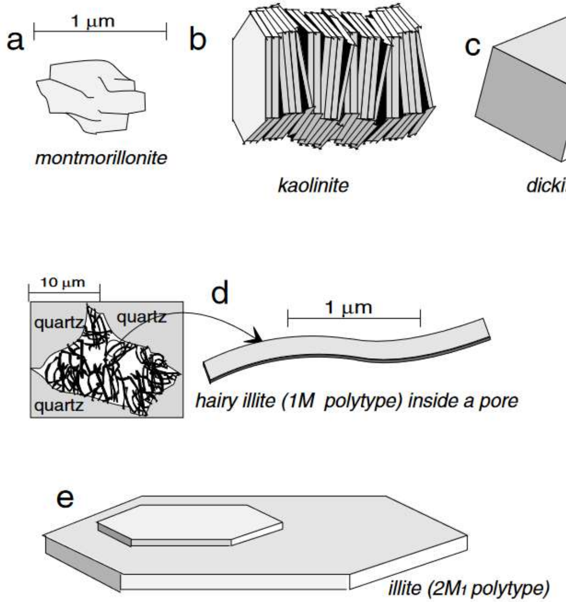
Interstratified: Illite/smectite, kaolinite/smectite,…

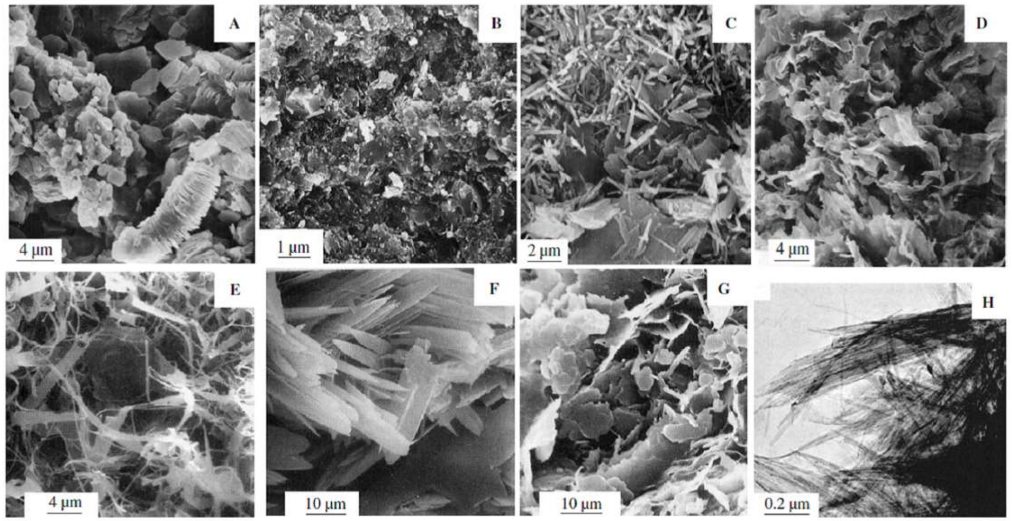


From Meunier, 2005

2:1 phyllosilicates ("10 Å phases")		
Muscovite	$[Si_3Al]O_{10}Al_2(OH)_2K$	$x=-1; y=0; IC=+1$
Biotite	$[Si_3Al]O_{10}(Fe^{2+},Mg)_3(OH)_2K$	$x=0; y=0; IC=+1$
Celadonite	$Si_4O_{10}[(Al,Fe^{3+})(Fe^{2+},Mg)](OH)_2K$	$x+y=-1.0; IC=+1.0$
Phengites	$[Si_{4-x}Al_x]O_{10}[Al_{2-y}(Fe^{2+},Mg)_y](OH)_2K_{x+y}$	$x+y=-1.0; IC=+1.0$
Glauconite	$[Si_{4-x}Al_x]O_{10}[(Al,Fe^{3+})_{2-y}(Fe^{2+},Mg)_y](OH)_2K_{x+y}$	$x<-0.3; y<-0.6; IC\cong+0.9$
Illite	$[Si_{4-x}Al_x]O_{10}[Al_{2-y}(Fe^{2+},Mg)_y](OH)_2K_{x+y}$	$-0.3<x<-0.7; -0.2<y<-0.6;$ $IC\cong+0.9$
Vermiculite (Dioctahedral)	$[Si_{4-x}Al_x]O_{10}[(Al,Fe^{3+}{}_{2-y})Mg_y](OH)_2K_{x+y}$	$-0.3<x<-0.7; -0.2<y<-0.6;$ $+0.6<IC<+0.8$
Beidellite	$[Si_{4-x}Al_x]O_{10}(Al,Fe^{3+})_2(OH)_2K_x$	$-0.3<x<-0.6; y=0; +0.3<IC<+0.6$
Montmorillonite	$Si_4O_{10}[(Al,Fe^{3+}{}_{2-y})Mg_y](OH)_2K_y$	$x=0; -0.3<y<-0.6; +0.3<IC<+0.6$
Vermiculite (Trioctahedral)	$[Si_{4-x}Al_x]O_{10}[(Fe^{2+},Mg)_{3-y-z},(Al,Fe^{3+})_y,<>_z](OH)_2K_{x+y-2z}$	$-0.3<x<-0.7; -0.2<y<-0.6;$ $+0.6<IC<+0.8$
Saponite	$[Si_{4-x}Al_x]O_{10}[(Fe^{2+},Mg)_{3-y-z},(Al,Fe^{3+})_y,<>_z](OH)_2K_{x+y-2z}$	$-0.3<x<-0.6; y+2z=0;$ $+0.3<IC<+0.6$

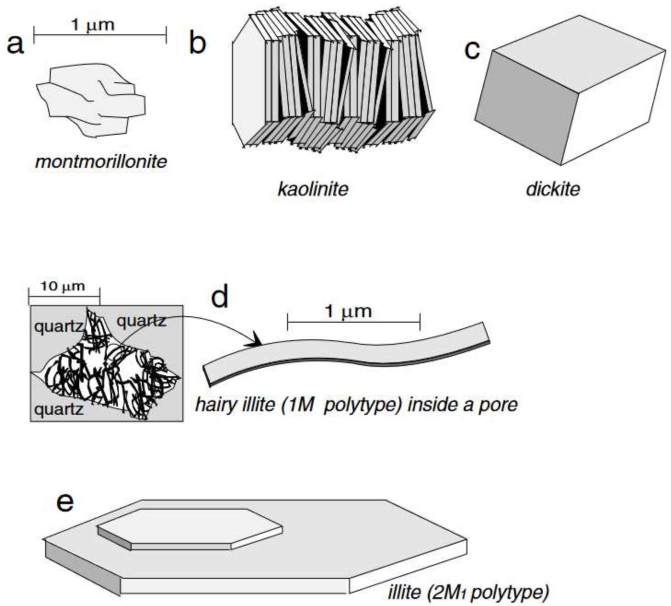
Tailles et formes



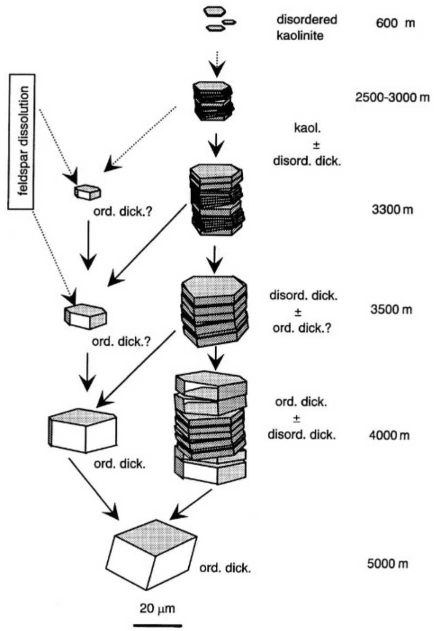


From Meunier, 2005

Tailles et formes

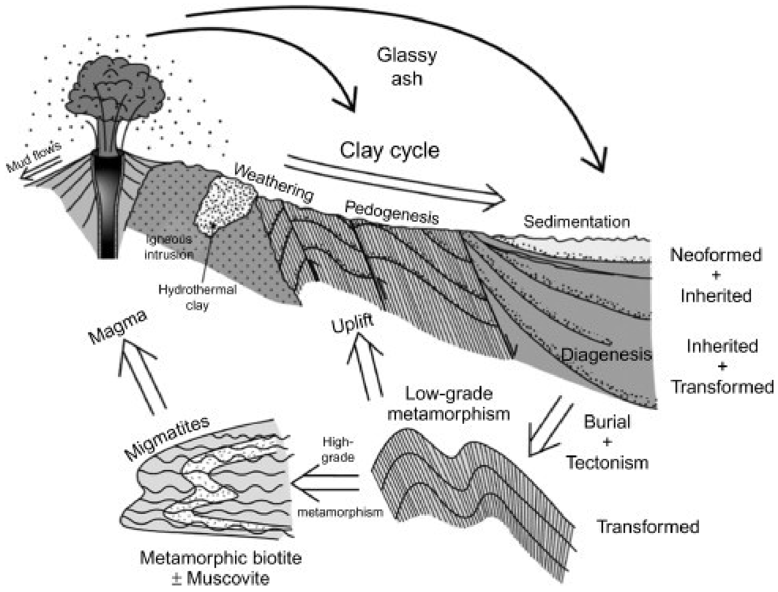


From Meunier, 2005



From Galan, 2006

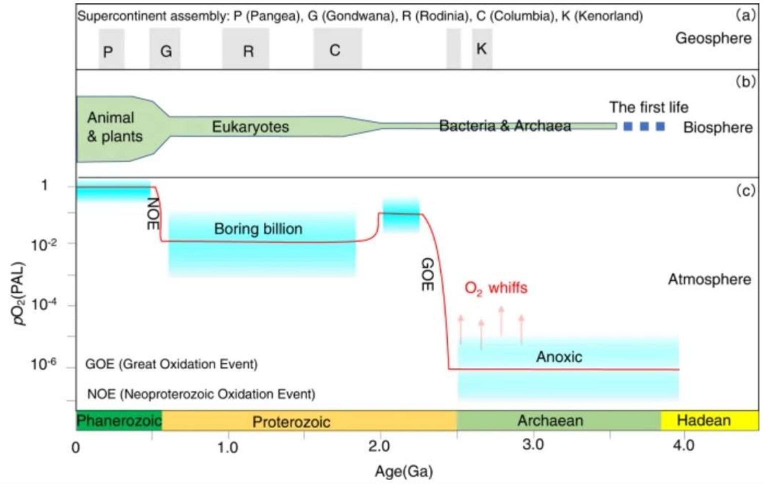
Origine des minéraux argileux



E. Galán, R.E. Ferrell, Chapter 3 - Genesis of Clay Minerals, Editor(s): Faïza Bergaya, Gerhard Lagaly, Developments in Clay Science, Elsevier, Volume 5, 2013

Origine des minéraux argileux The "clay mineral factory"

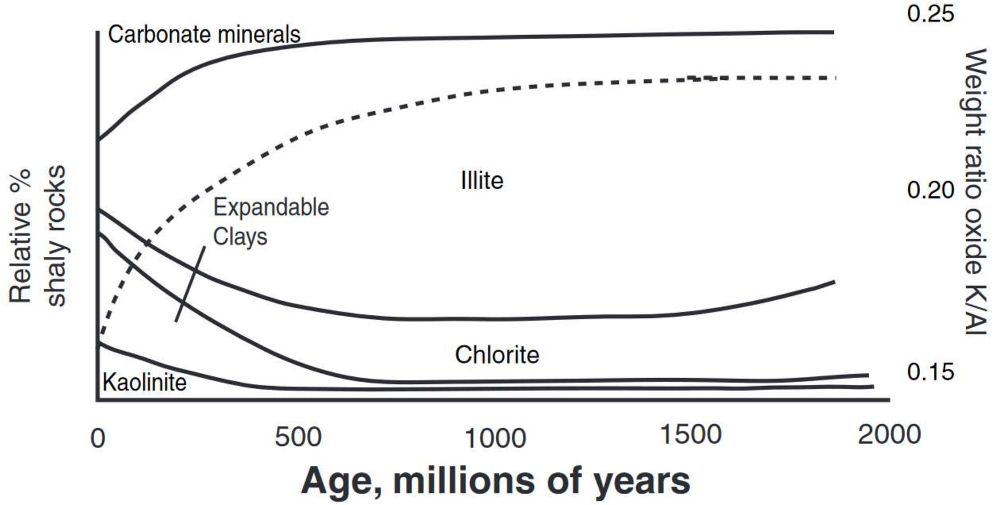
Fig. 1: Co-evolution of the Earth system (geosphere, atmosphere, and biosphere) through time.



Neoproterozoic Oxidation event : Strong increase in the biological activity and land biota

G. Chen, Q. Cheng, T. W. Lyons, J. Shen, F. Agterberg, N. Huang, M. Zhao, Reconstructing Earth's atmospheric oxygenation history using machine learning, Nature Communications, 13, 2022

Origine des minéraux argileux The “clay mineral factory”



Increase of Pedogenic Clay minerals (PCM) : kaolinite and expandable clays

M. Kennedy, M. Droser, L. M. Mayer, D. Pevear, D. Mrofka, Late Precambrian Oxygenation; Inception of the Clay Mineral Factory, (2006), Science, 311

D'où provient la terre utilisée?

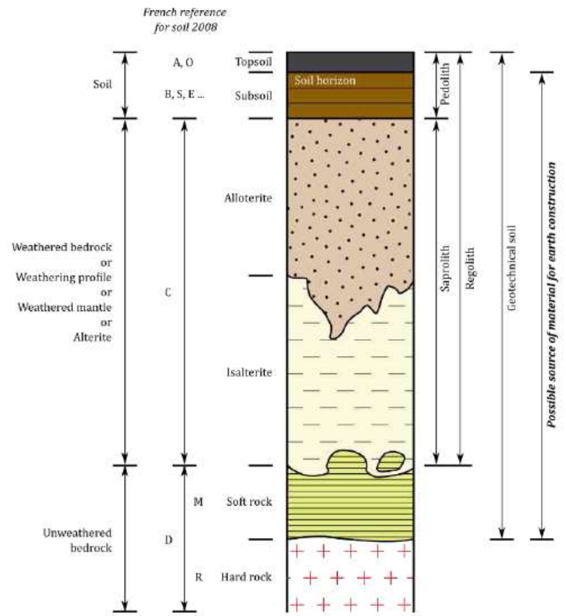
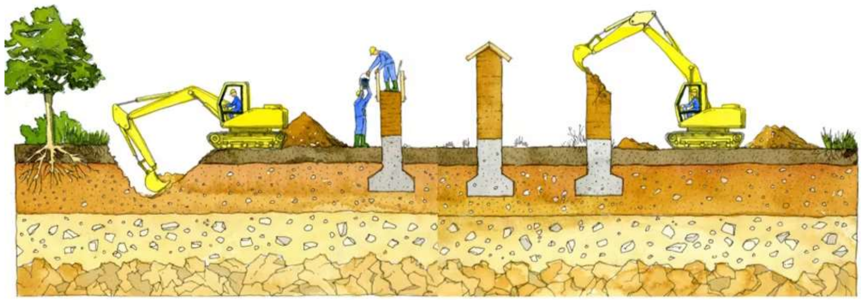


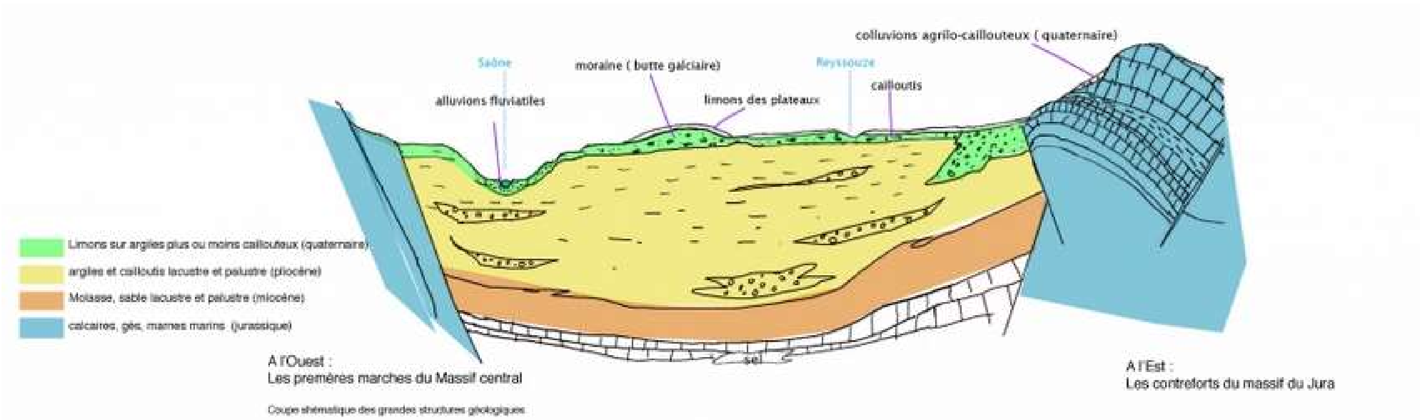
Figure 1. Vertical cross-section of weathered materials from ground surface to unweathered bedrock, according to several disciplines definitions (Hamard, 2017).

- The subsoil, potentially from the saprolith (neoformed and inherited clay minerals)



Source : Arnaud Misse

D’où provient la terre utilisée?



- Clay sedimentary deposits, the case of the “Limon des plateaux” in east of France, in the Dombes region, used for rammed earth buildings, mainly inherited and transformed clay minerals

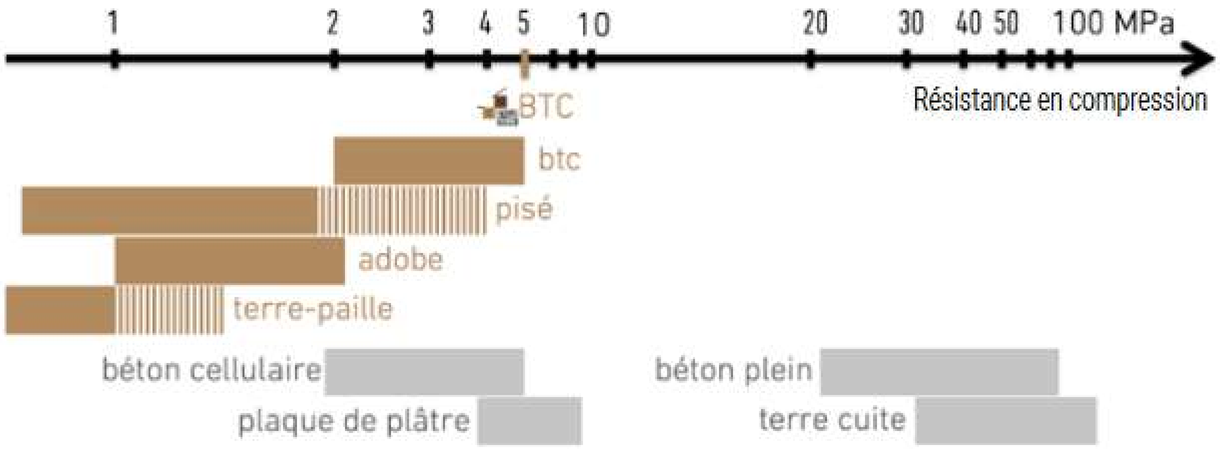
Minéralogie typique?

Table 3.3: Mineralogical data

Sample	Main clay minerals	Secondry clay mineral	Other main minerals
Gr	Illite/Smectite	-	-
Ib	-	-	-
Al	Kaolinite	Illite/Mica	Quartz, Hematite
Bi	Kaolinite	Illite/Mica	Quartz, Chlorite
Ch	Kaolinite	Illite/Mica	Quartz, Illite/smectite
Le	Illite/Mica	Chlorite	Quartz, K-Feldspar
Th	Kaolinite	Illite/Mica	Quartz, Chlorite
CFL	Illite/smectite	-	-
DAG	Smectite	Kaolinite	Quartz, Plagioclase, Mica/illite
STA	Kaolinite	Illite/Mica	Quartz, Smectite
NAG	Smectite	Illite/Mica	Quartz, Kaolinite, Calcite, Dolomite
BUI	Kaolinite	Illite/Smectite, Illite/Mica	Quartz, Dolomite, Fe Oxides
STR	-	-	-
ALX	-	-	-
Pamplona	Illite/Smectite (R=1)	Illite/Mica	Quartz, Calcite, Kaolinite
Tudela	-	-	-
Bidart	Illite/smectite (R=0)	Illite/Mica	Quartz, Calcite, Kaolinite

- Subsoil : higher presence of complex minerals, smaller crystals, more actif (smectite type)
- Sedimentary clay deposits used in the brick manufacturing industries are potentially less active (mainly kaolinite and illite)

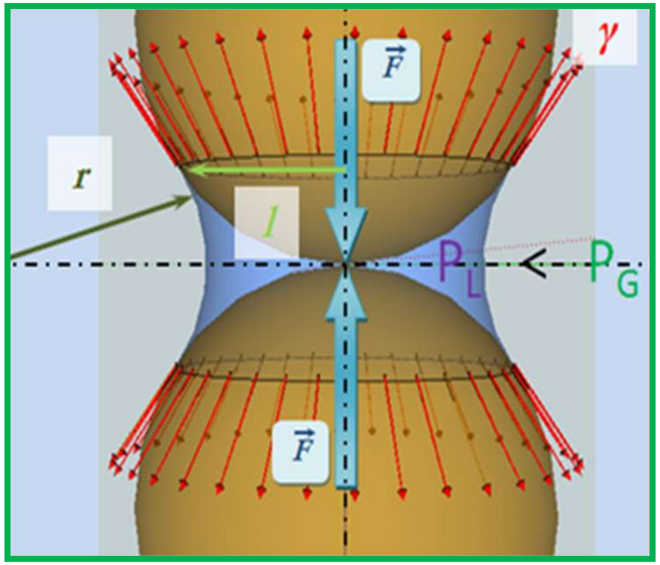
3. Spécificité du matériau terre : Enjeu de recherche

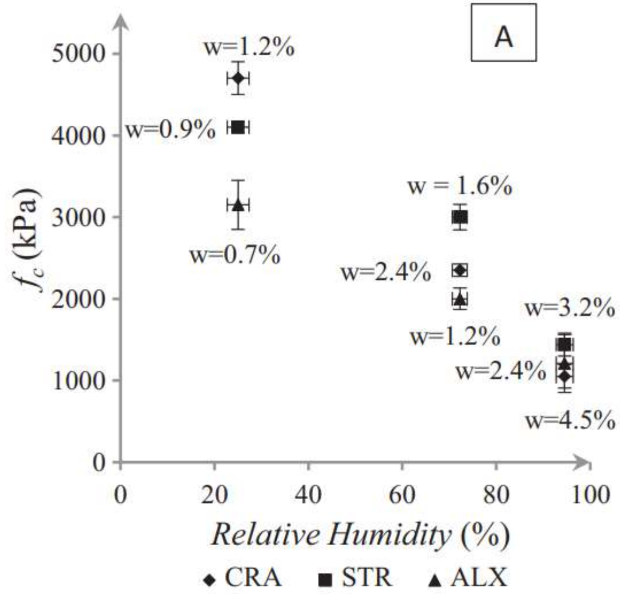


GUIDE DE CONCEPTION ET DE CONSTRUCTION, Cycle Terre

3. Spécificité du matériau terre : Enjeu de recherche

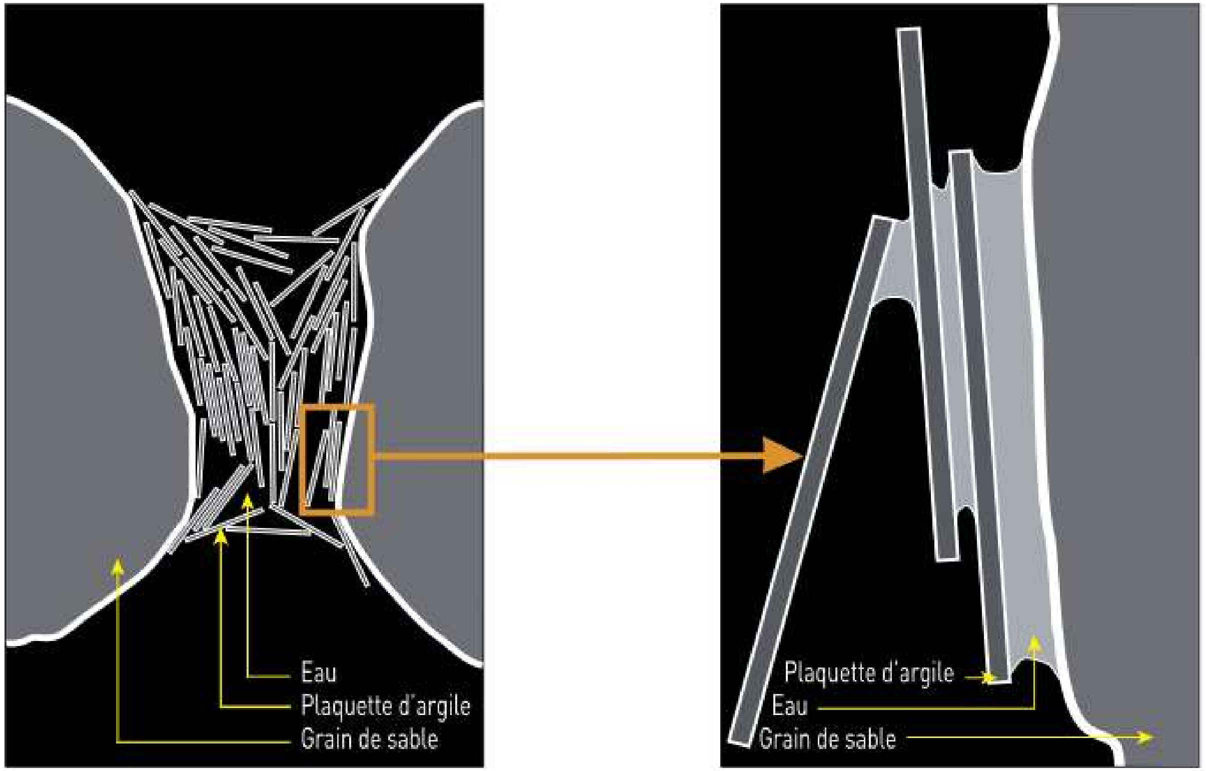
Influence de la teneur en eau sur le comportement mécanique





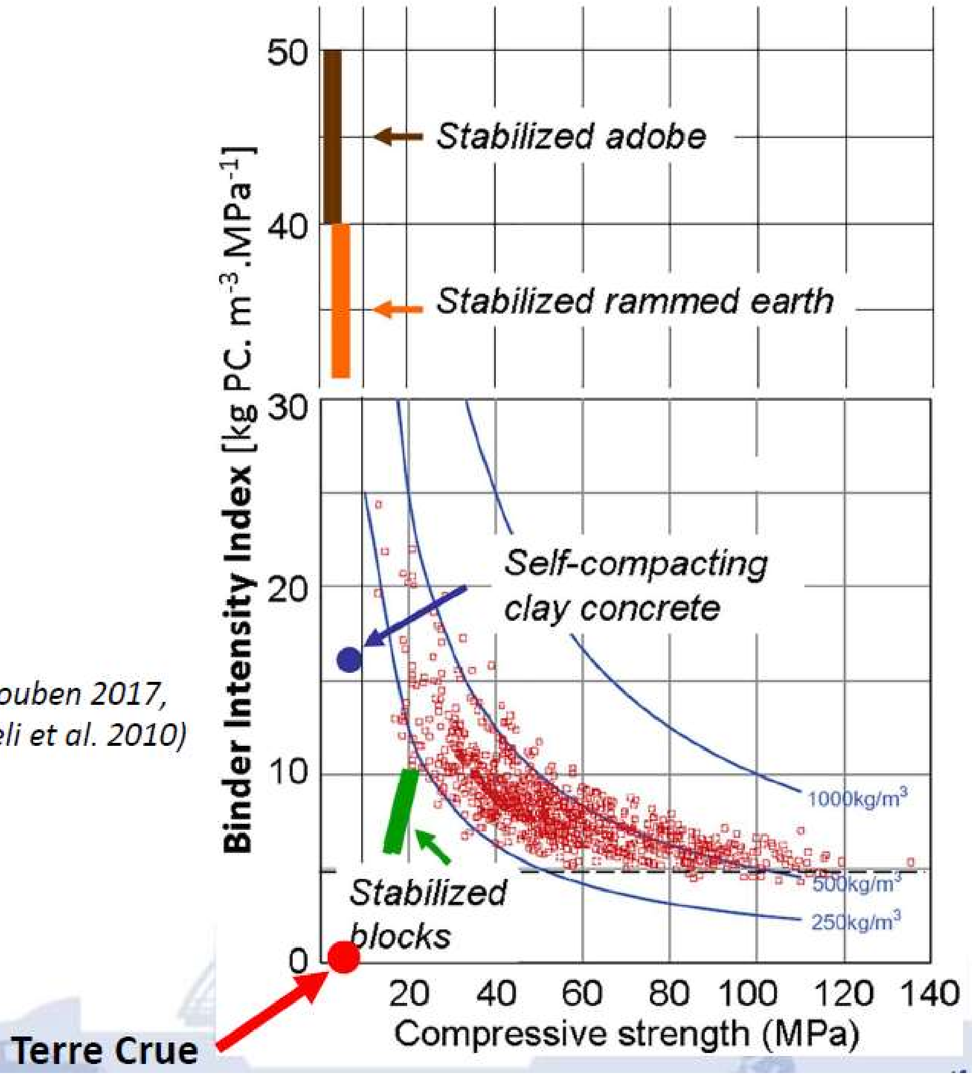
Champiré, F., Fabbri, A., Morel, J.-C., Wong, H., McGregor, F. Impact of relative humidity on the mechanical behavior of compacted earth as a building material (2016) *Construction and Building Materials*, 110, pp. 70-78

Le liant : l'argile

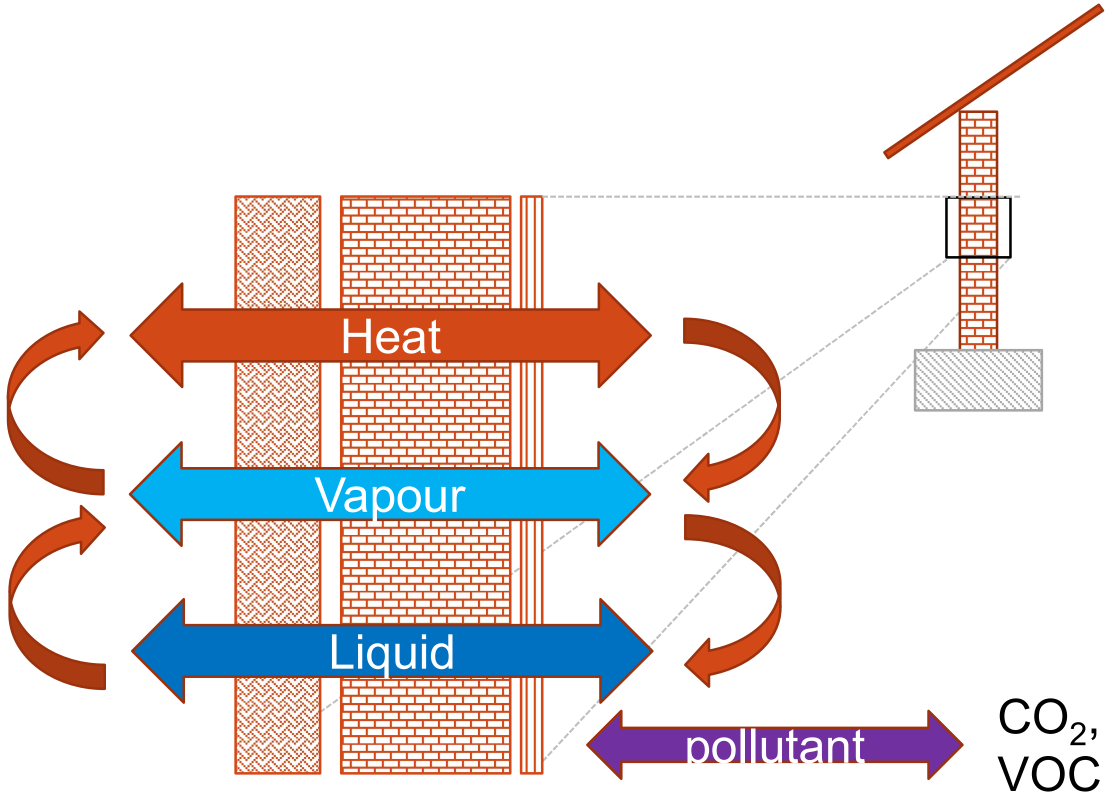


Source : Bâtir en terre de Laetitia Fontaine et Romain Anger (Éditions Belin)

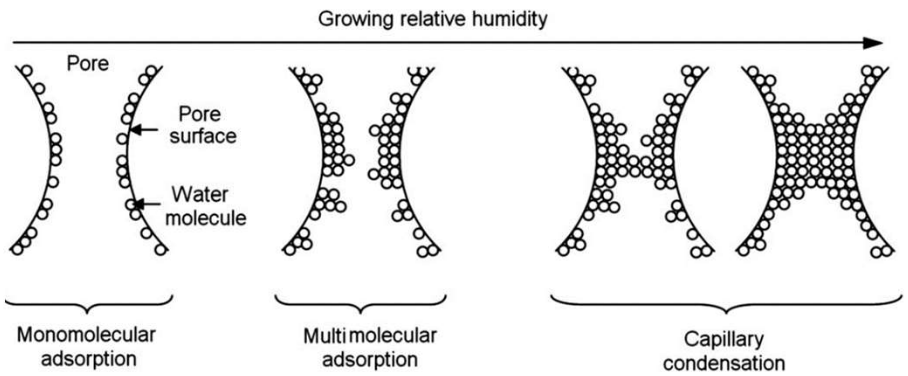
(Van Damme et Houben 2017, adapté de Damineli et al. 2010)



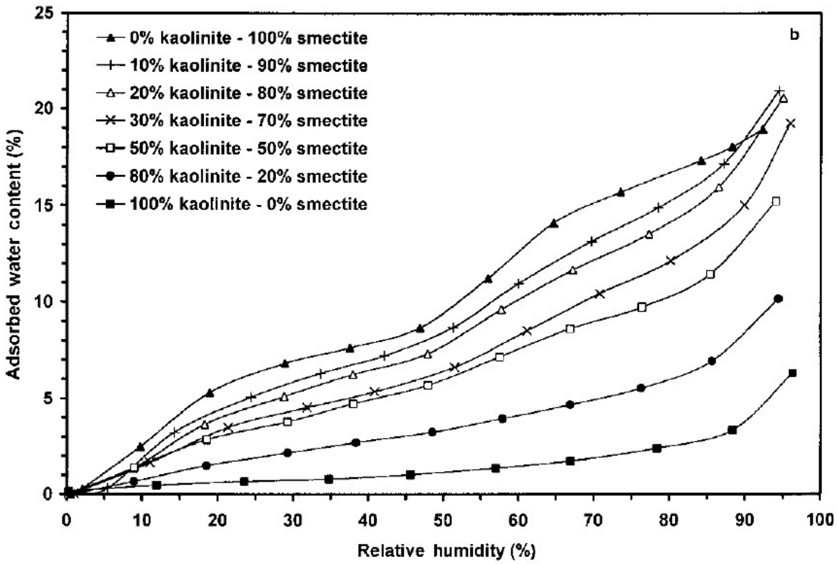
3. Spécificité du matériau terre : Enjeu de recherche

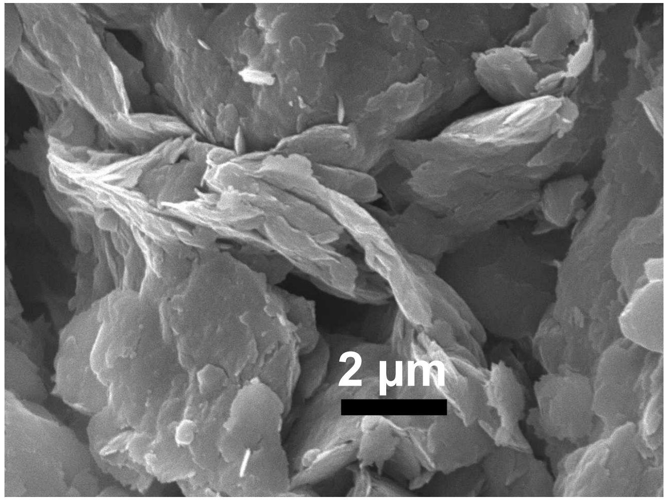


Echange de vapeur d'eau



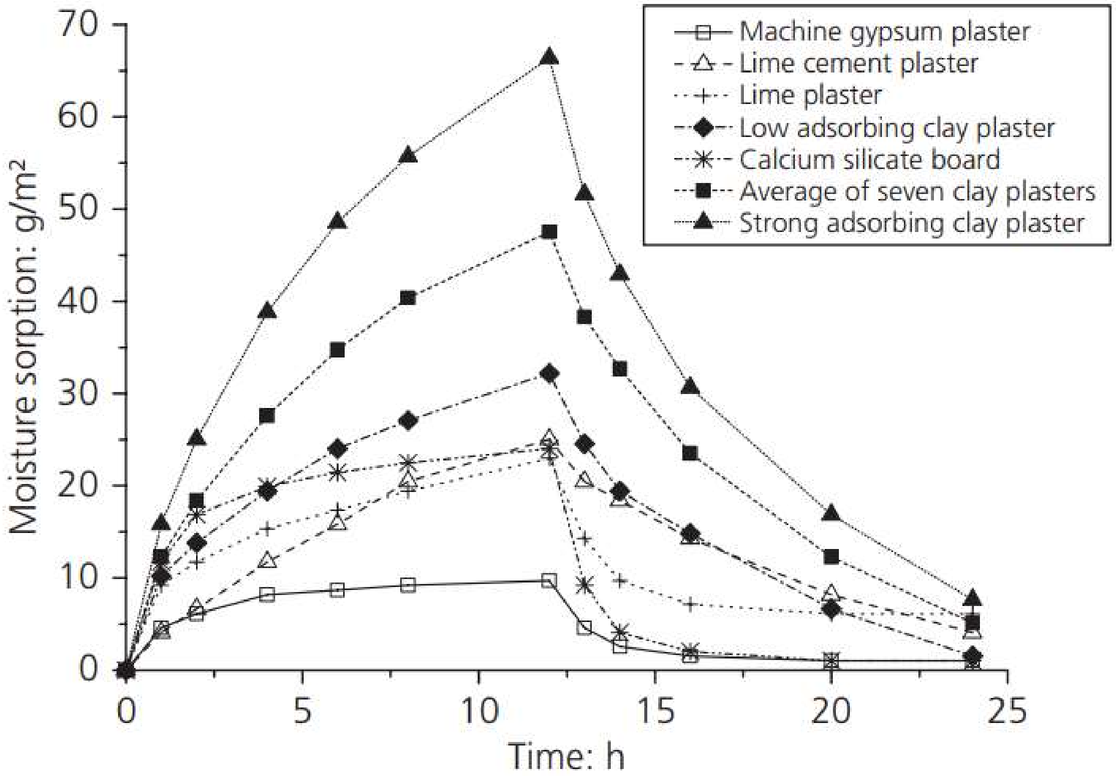
From Collet et al., 2011





From, Likos and Lu 2002

Effet tampon



McGregor, F., Heath, A., Maskell, D., Fabbri, A., Morel, J.-C. A review on the buffering capacity of earth building materials (2016) Proceedings of Institution of Civil Engineers: Construction Materials, 169 (5), pp. 241-251

3. Enjeux de recherche

-Comprendre l'impact de la variabilité du matériau sur son comportement thermo-hygro-mécanique

-La durabilité :

-quels paramètres?

-quelles mesures?

-comment garantir une durabilité optimale dans les constructions?

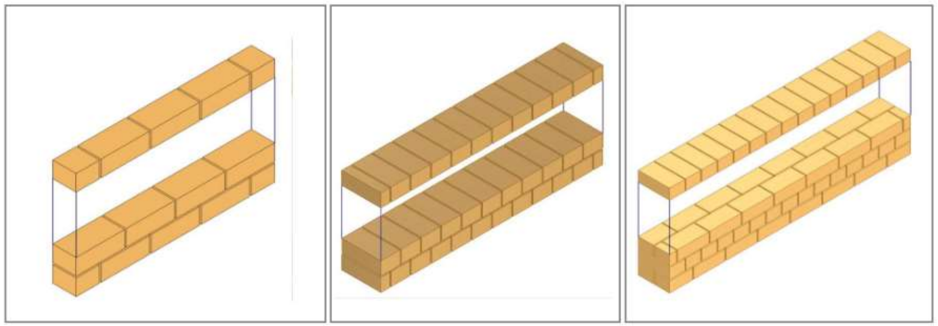
3 TC de la RILEM :

- Characterisation of the mechanical performance and durability of earthen materials and structures
- Resilience and durability of bio-stabilised earth-based construction: testing methods based on performances approach
- Processing of earth-based materials

Réglementation

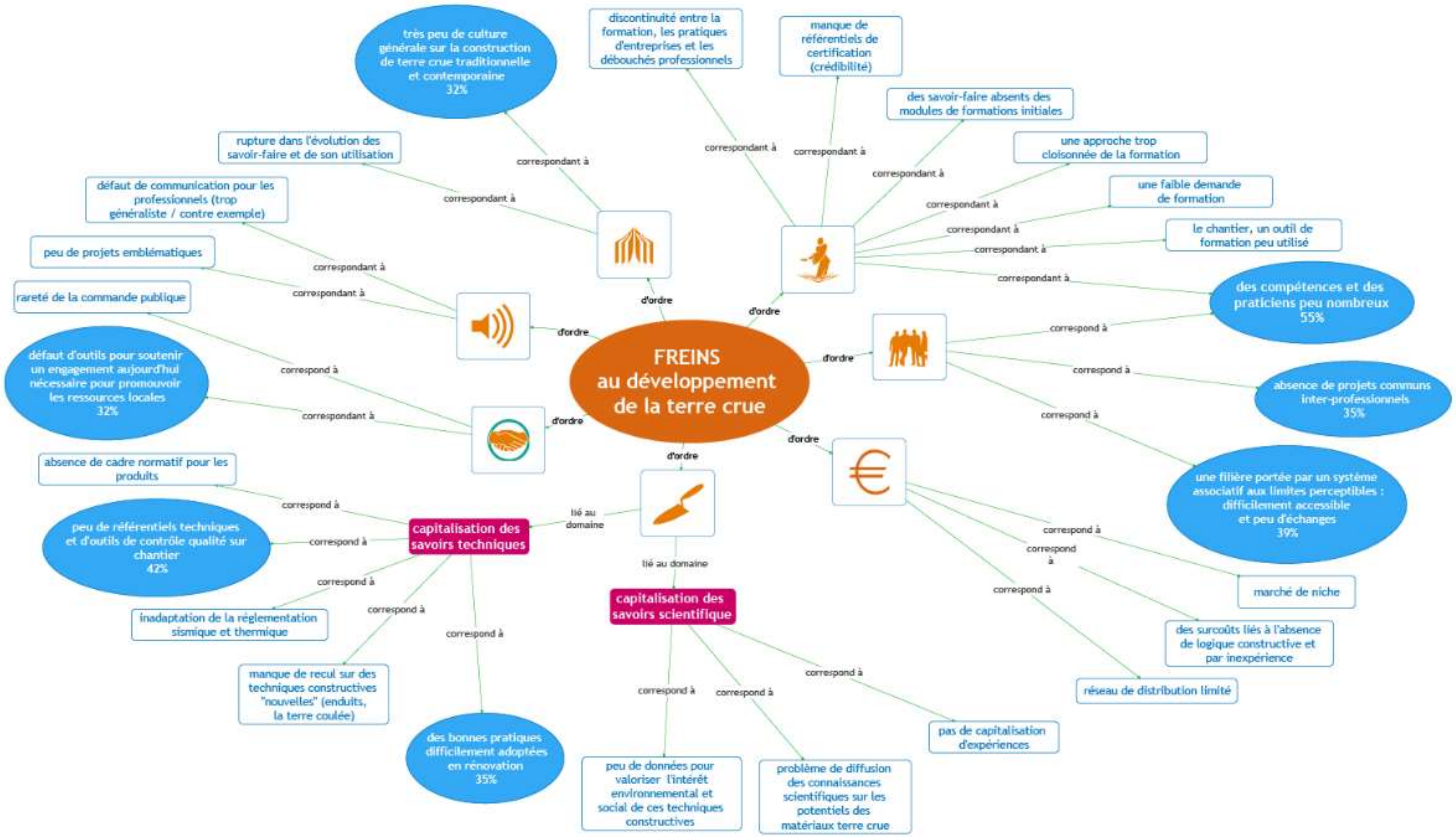
- Norme XP-P13 901
- Guides des bonnes pratiques (Enduit, Pisé, Terre allegée, Torchis, Bauge)
- Règles professionnels pour les enduits sur support en terre crue
- ATEx Validé par le CSTB (L'Appréciation Technique d'expérimentation (ATEx) est une simple opinion technique à dire d'experts, formulée en l'état des connaissances, sur la base d'un dossier technique produit par le demandeur.)

Les BTC sont posées selon un des trois appareillages ci-dessous :



« Panneresse » « Boutisse » « Boutisse- Panneresse »

Autre enjeux



Carte des freins au développement de la construction en terre crue

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