

# LE NUOVE FRONTIERE DELLA STABILIZZAZIONE A CALCE

## DA RIFIUTO A RISORSA

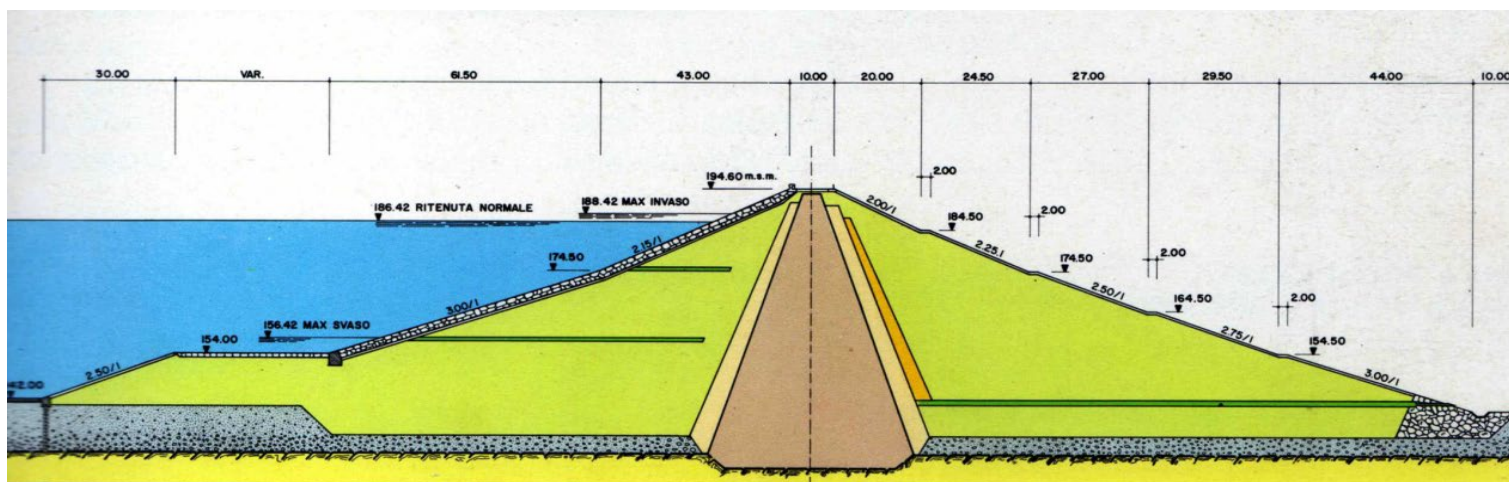
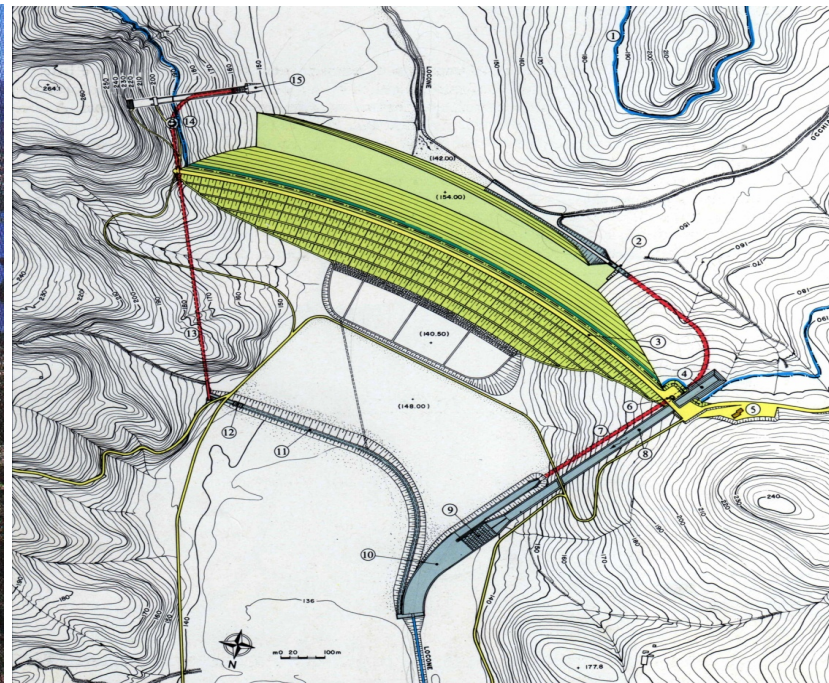
Catania, 31 Maggio 2024

### La stabilizzazione a calce

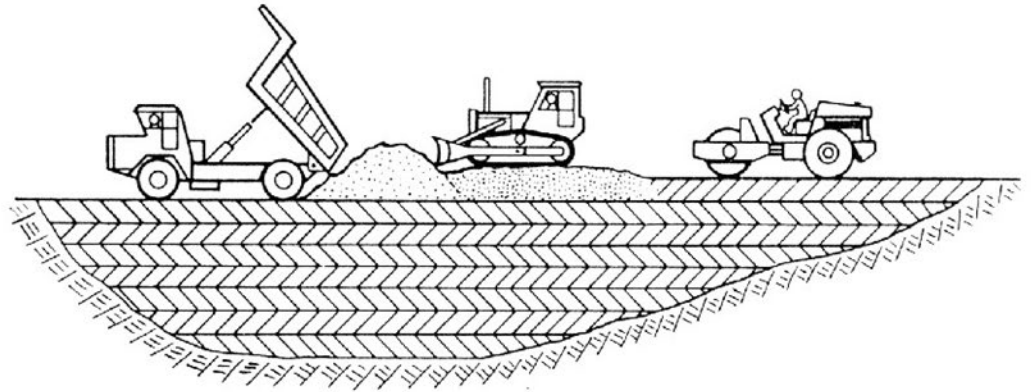
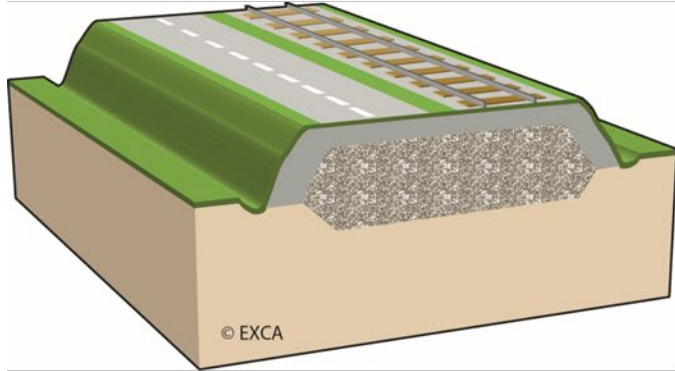


GIACOMO RUSSO  
UNIVERSITA' DI NAPOLI FEDERICO II

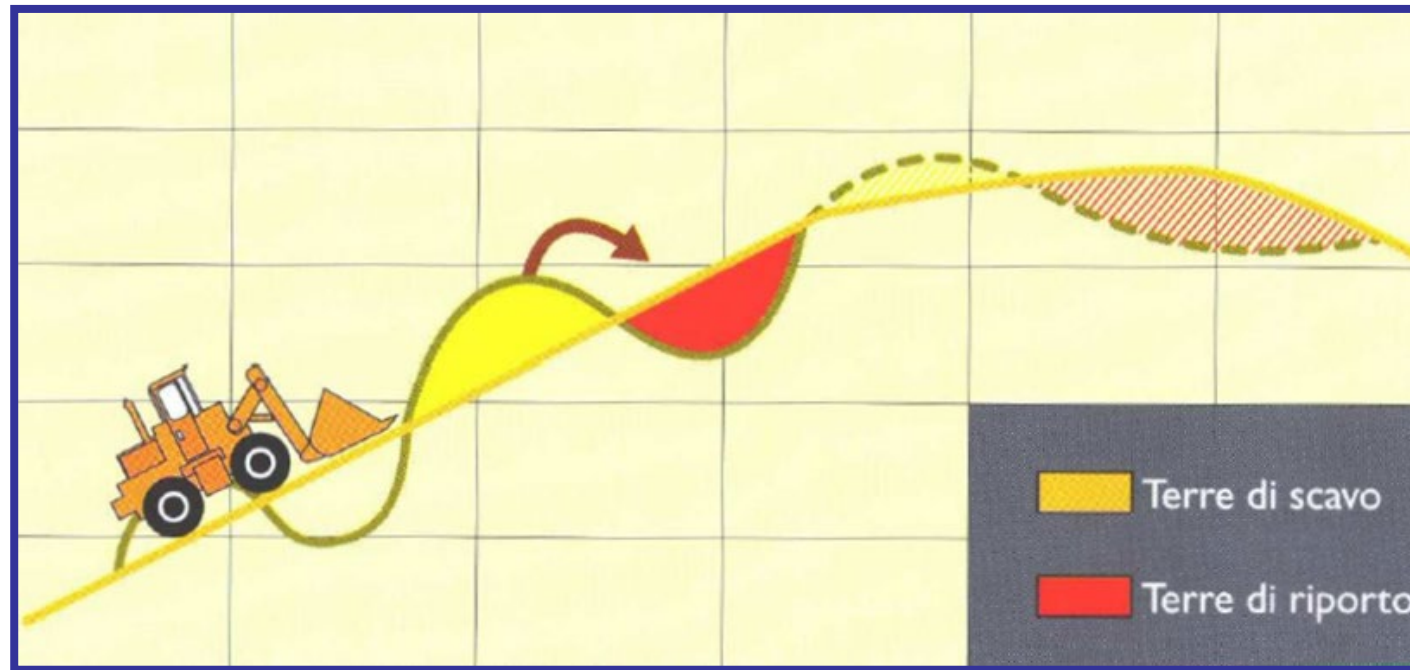
# TERRENO COME MATERIALE DA COSTRUZIONE



# TERRENO COME MATERIALE DA COSTRUZIONE



# BILANCIO DELLE TERRE – RIUSO DELLE TERRE DI SCAVO



I terreni di scavo sono idonei come materiale da costruzione?

**si**

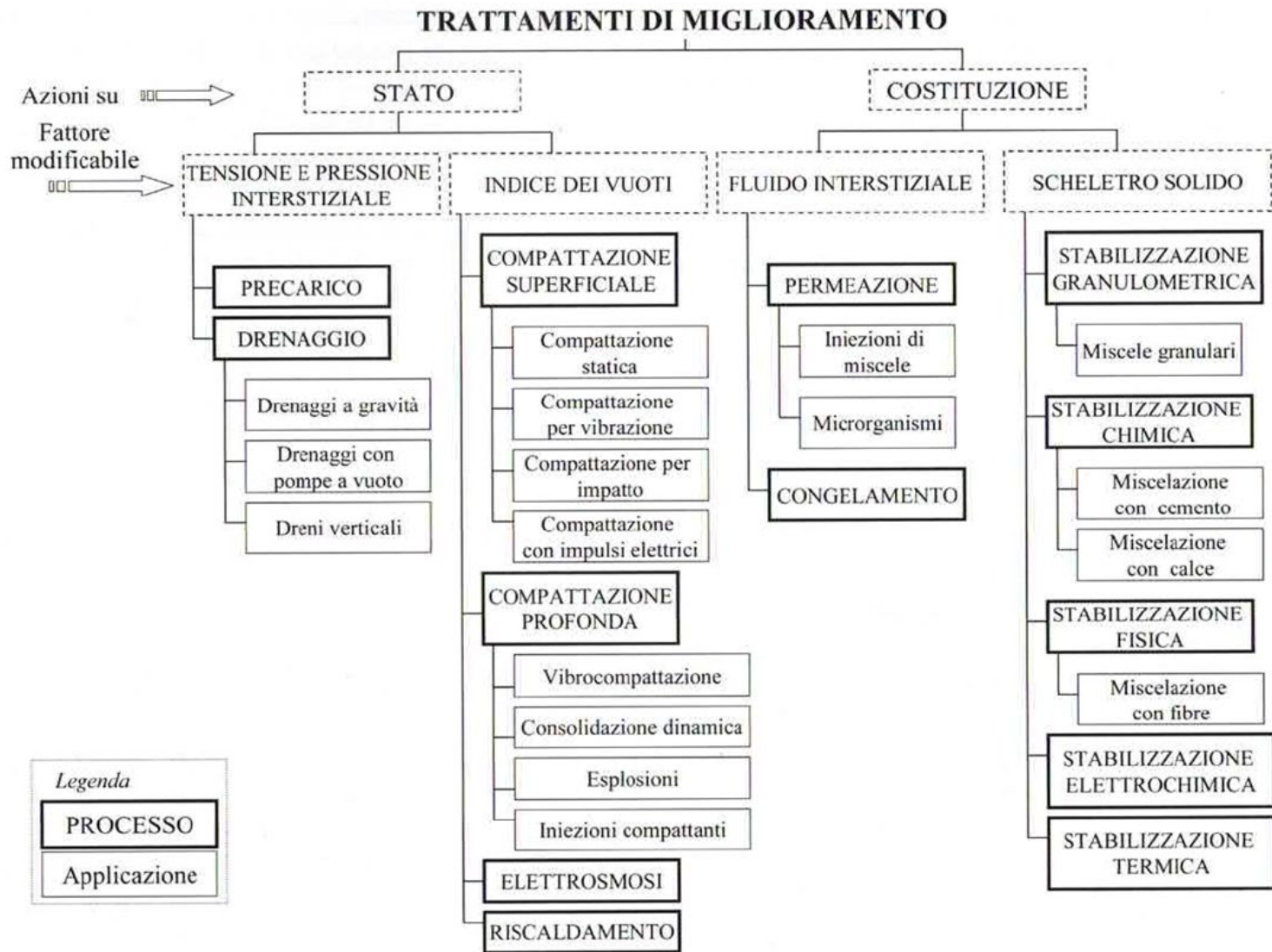
*riuso*

**no**

*sito di deposito o....*

**trattamenti di miglioramento**

# TRATTAMENTI DI MIGLIORAMENTO

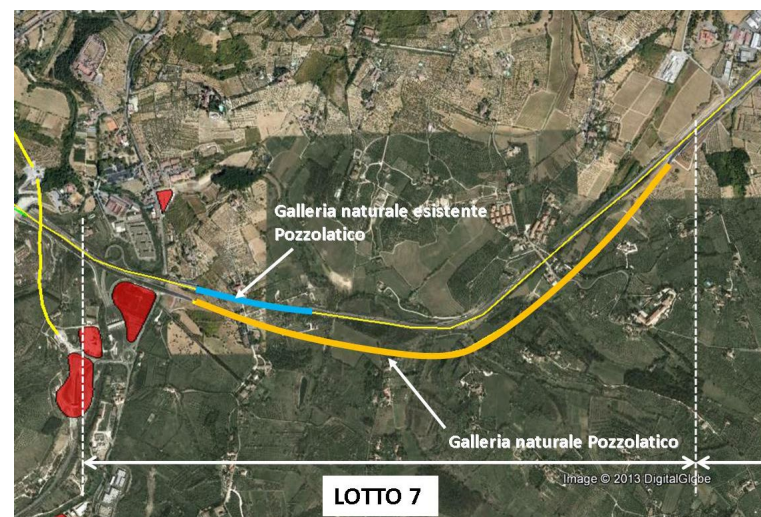
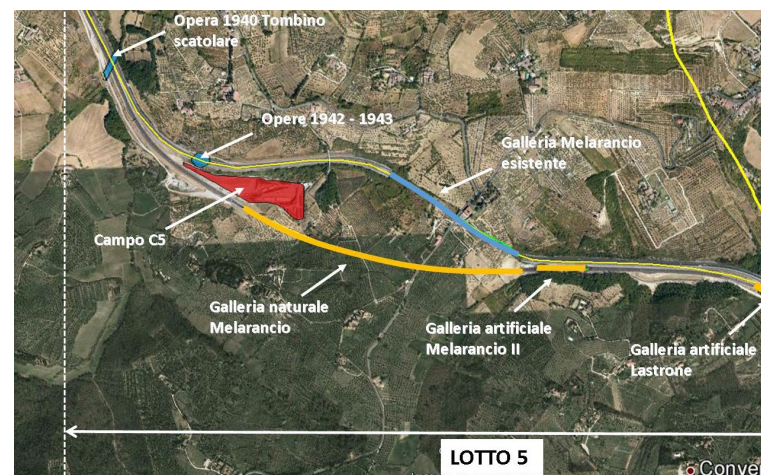


(Flora e Lirer, 2011)

# RIUSO DELLE TERRE E ROCCE DA SCAVO

## Autostrada A1 Milano – Napoli

Riuso dei terreni di scavo di due gallerie di nuova costruzione (2000 - 2002)



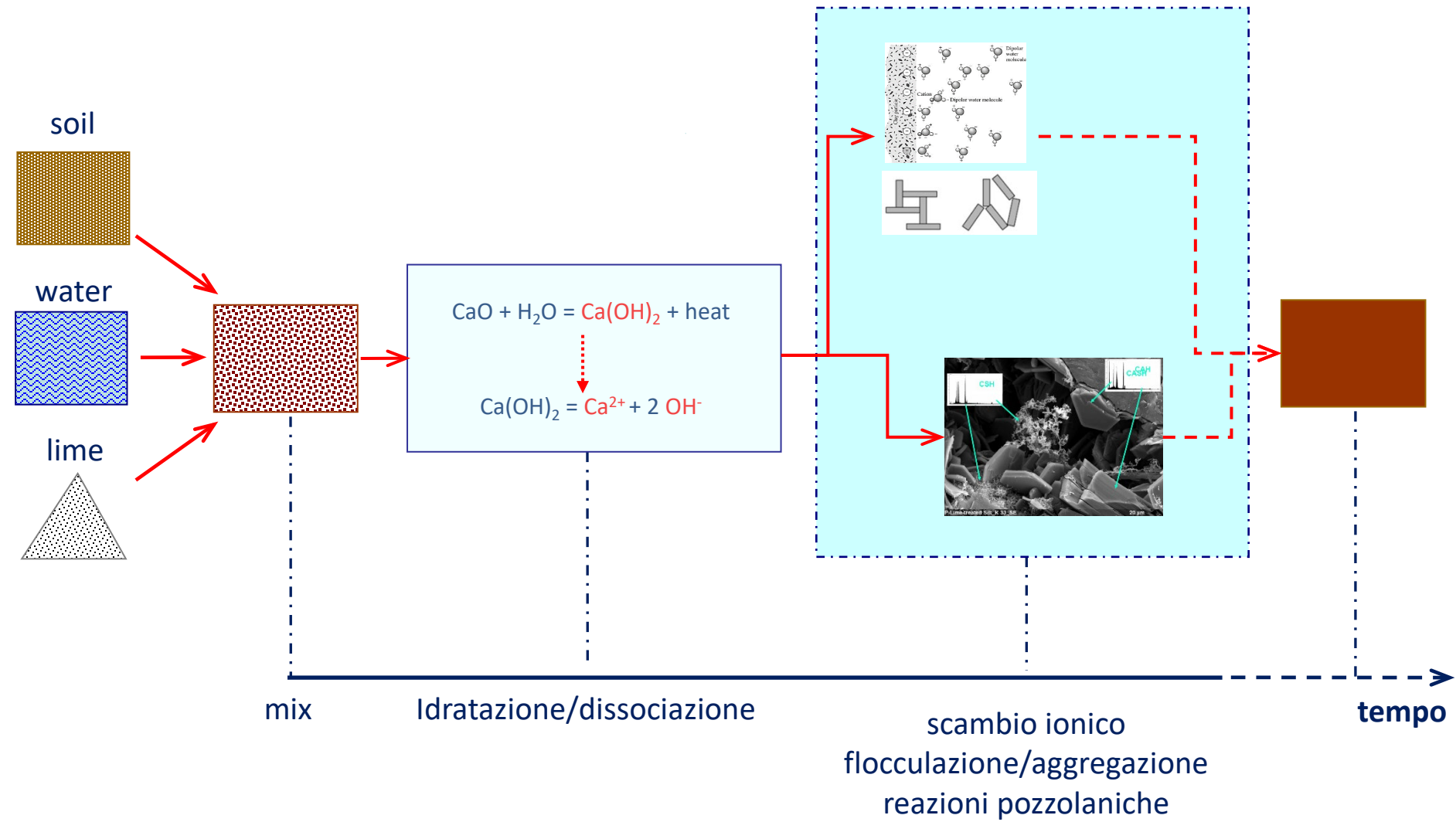
# RIUSO DELLE TERRE E ROCCE DA SCAVO



53% del terreno di scavo ( $\approx 401.000 \text{ m}^3$ ) è stato riutilizzato mediante trattamento a calce



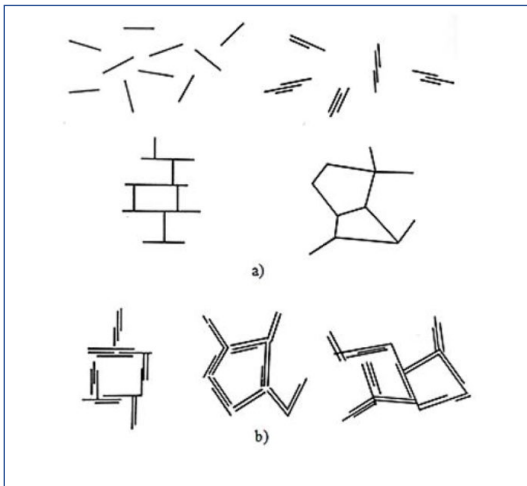
# TRATTAMENTO A CALCE



## Analisi multi-scala

**Reattività del sistema  
terreno-calce-acqua**

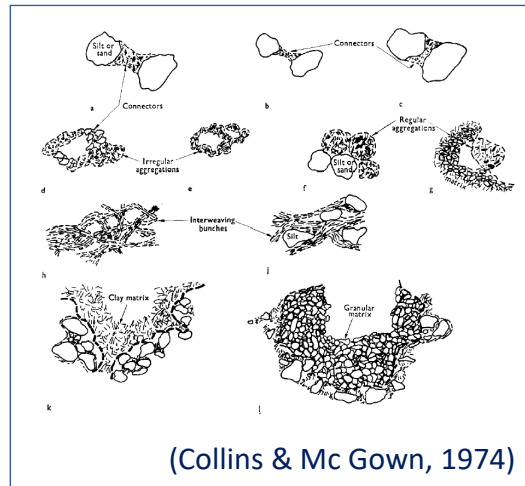
particelle



(Van Olphen, 1977)

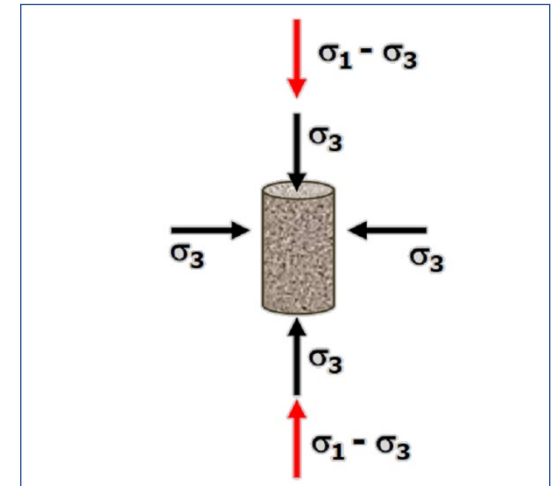
**Aggregazione delle  
particelle**

Microstruttura

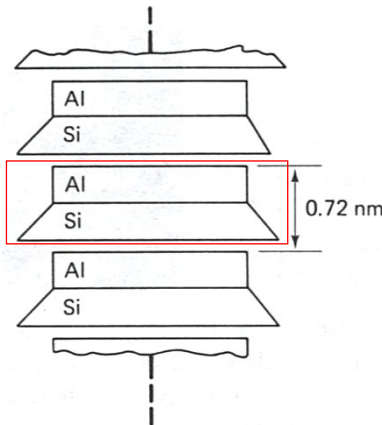
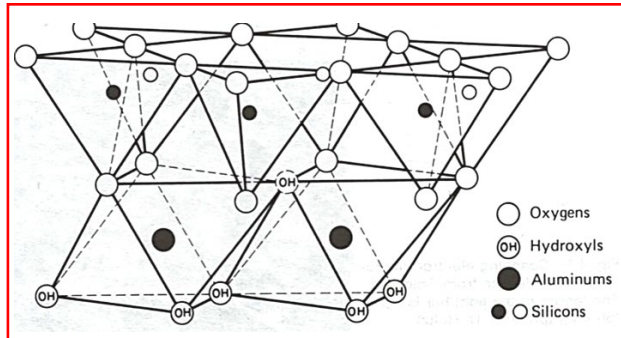
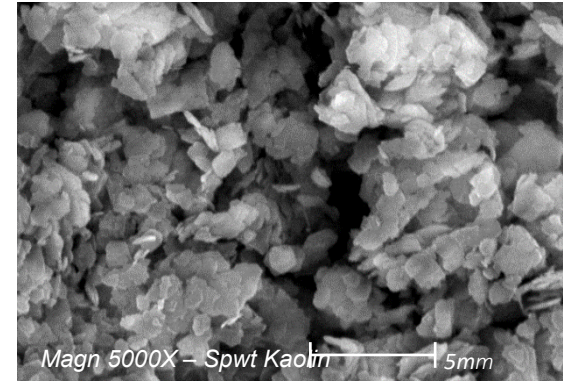
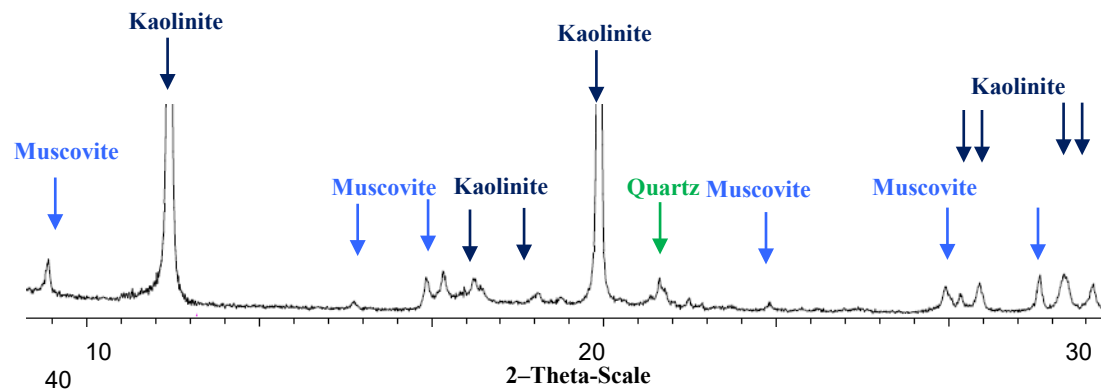


**Proprietà fisiche e  
meccaniche**

Elemento di volume



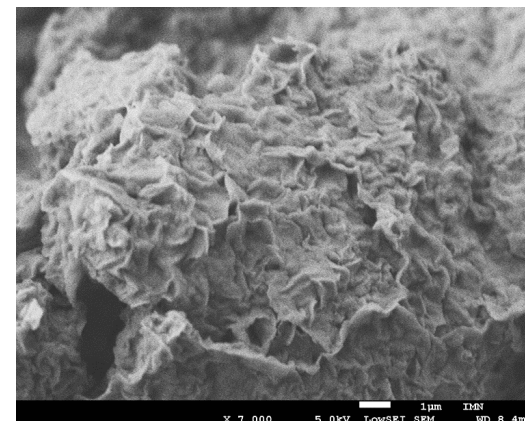
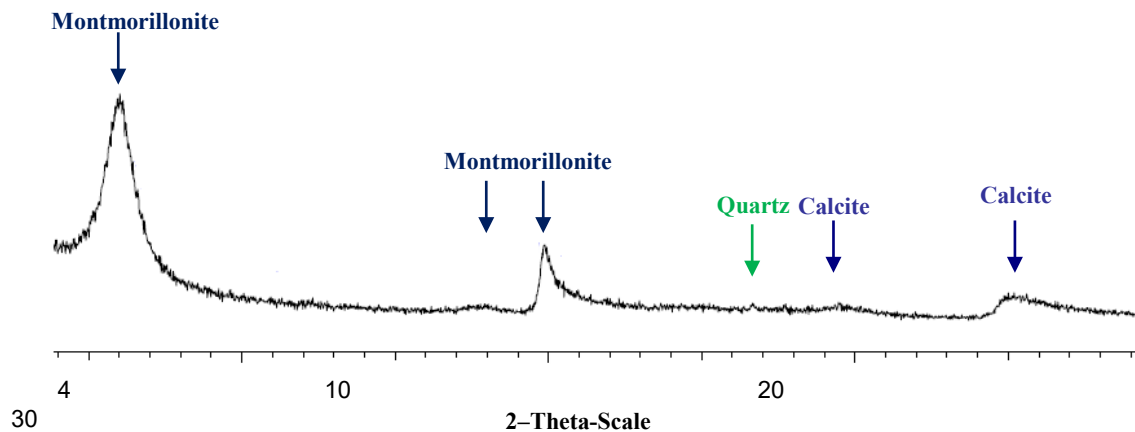
# CAOLINO SPESWHITE



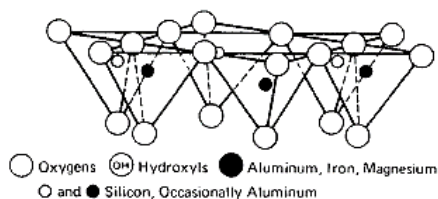
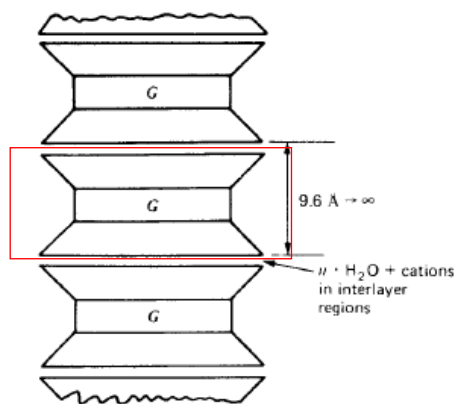
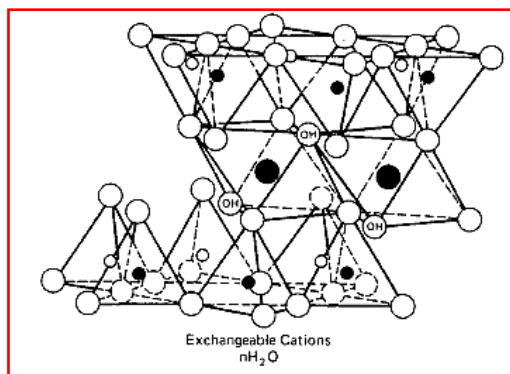
Surface Area (BET) 14,13 m<sup>2</sup>/g

Component	Percentage (%)
SiO <sub>2</sub>	53.80
Al <sub>2</sub> O <sub>3</sub>	43.75
Na <sub>2</sub> O	0.92
CaO	0.02
K <sub>2</sub> O	1.45
TiO <sub>2</sub>	0.05

# BENTONITE

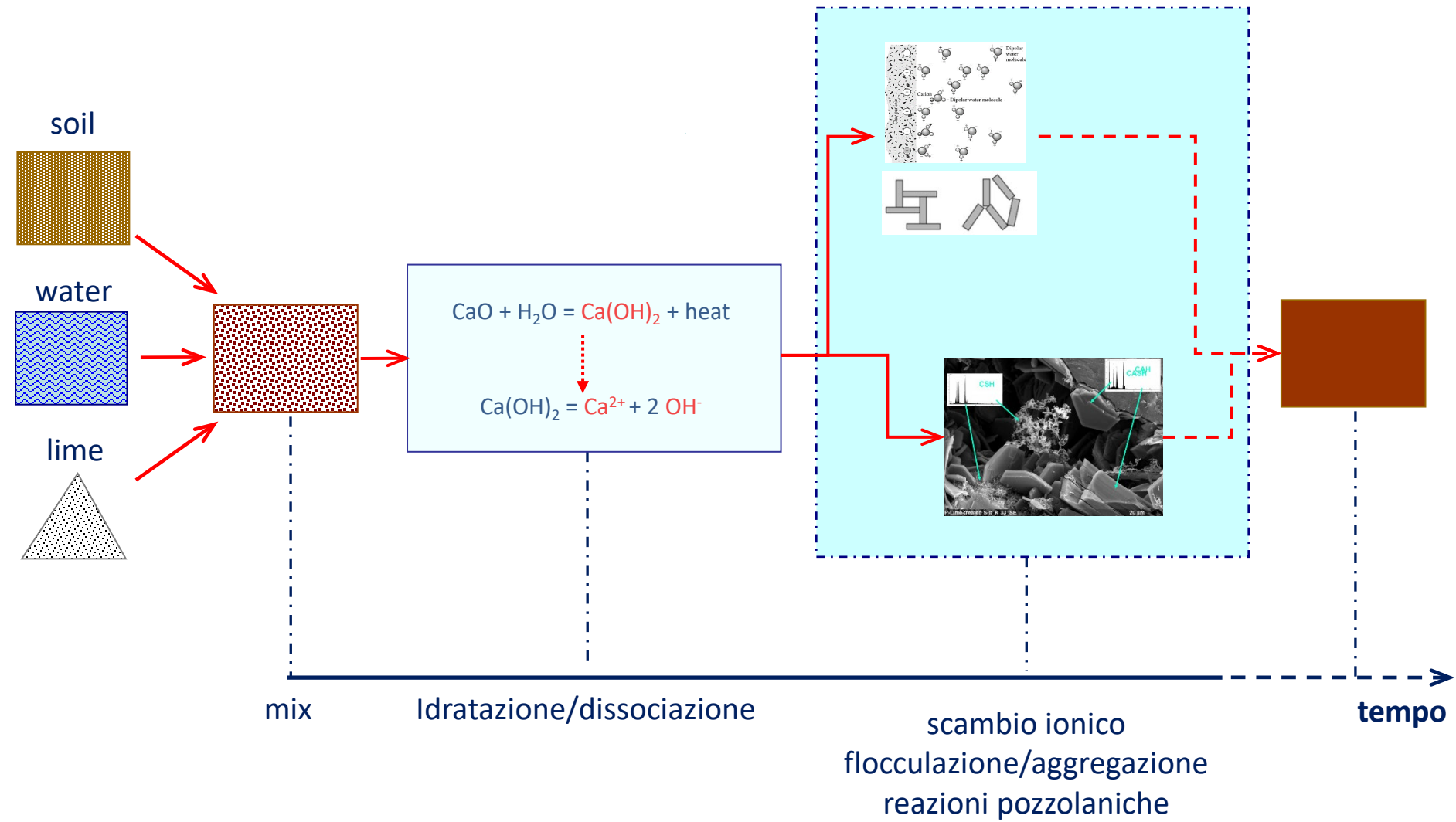


Surface Area (BET) 99,38 m<sup>2</sup>/g



Component	Percentage (%)
SiO <sub>2</sub>	64.85
Al <sub>2</sub> O <sub>3</sub>	24.33
Na <sub>2</sub> O	0.47
CaO	2.14
K <sub>2</sub> O	0.21
MgO	3.18
FeO	4.21

# TRATTAMENTO A CALCE



# IDRATAZIONE DELLA CALCE

Idratazione dell'ossido di calcio (calce viva)



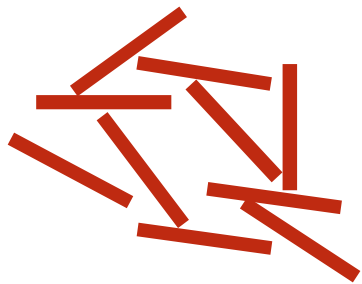
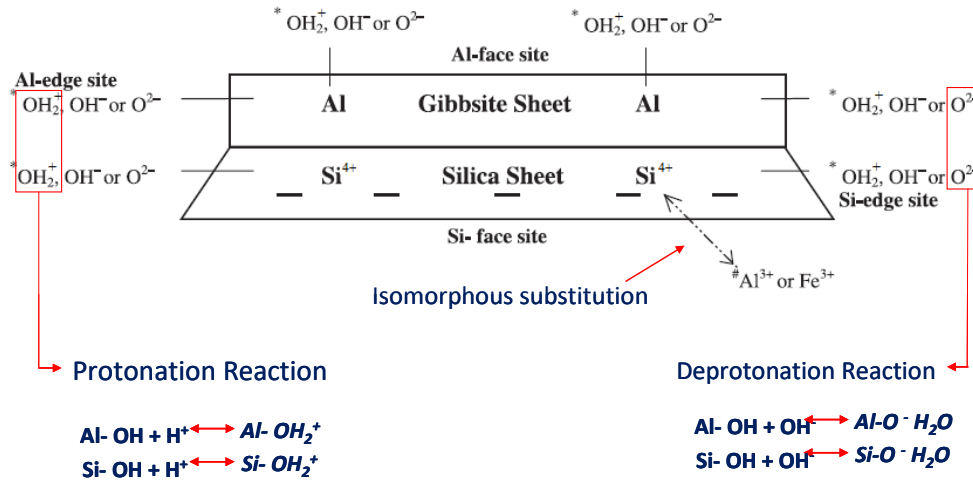
Dissociazione ionica



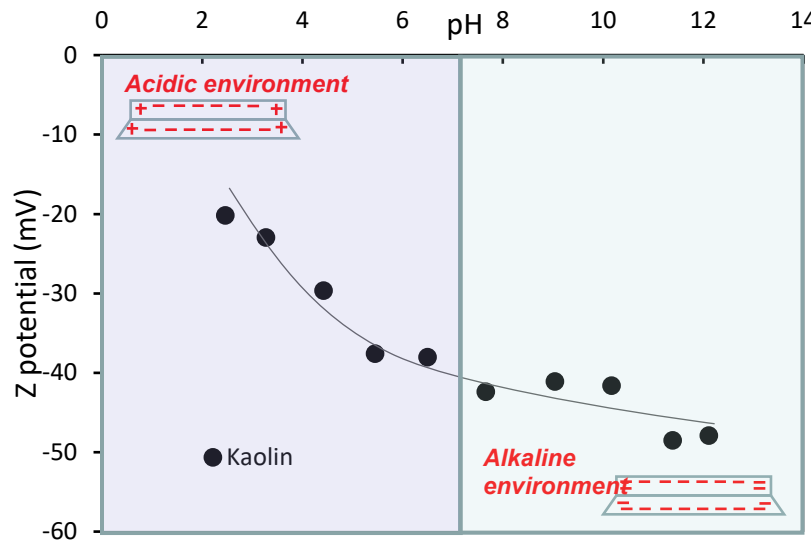
# FLOCCULAZIONE/AGGLOMERAZIONE DELLE PARTICELLE

Attrazioni di van der Waals, repulsioni del doppio strato diffuso, forze elettrostatiche coulombiane

- effetto del pH

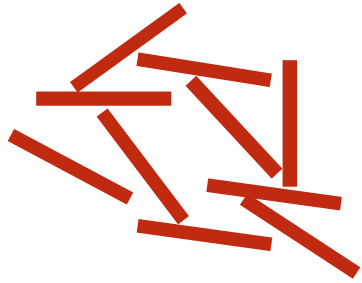


edge-to-face (EF)  
edge-to-edge (EE)

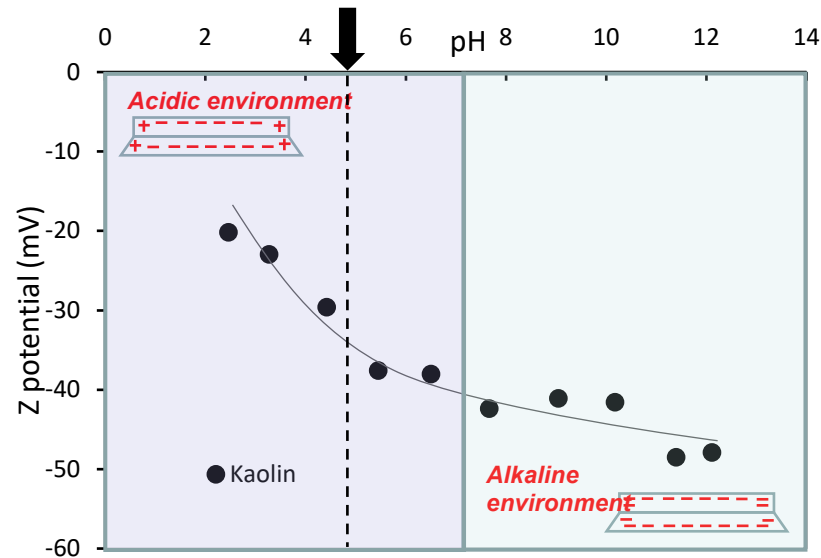


face-to-face (FF)

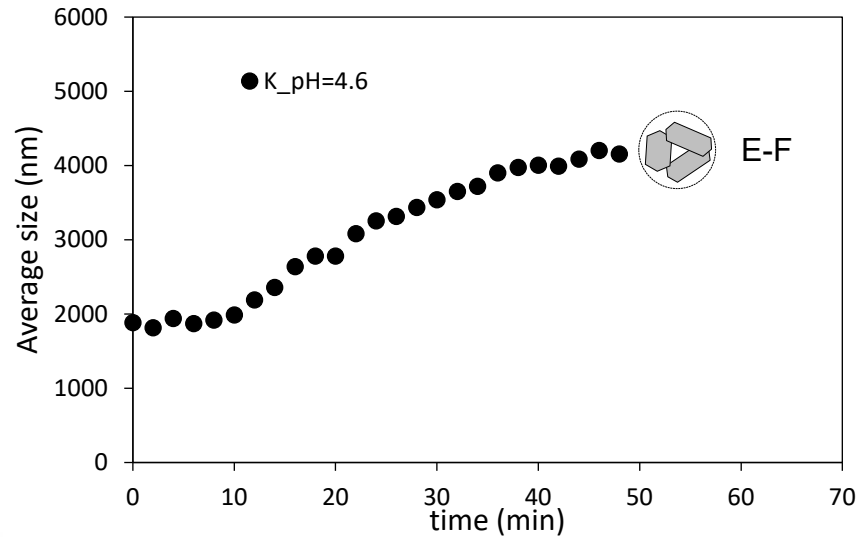
# FLOCCULAZIONE/AGGLOMERAZIONE DELLE PARTICELLE



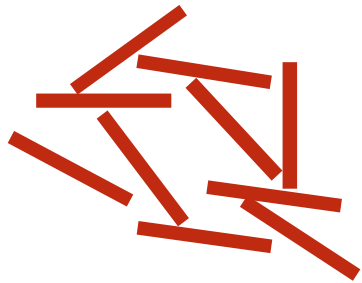
*edge-to-face (EF)*  
*edge-to-edge (EE)*



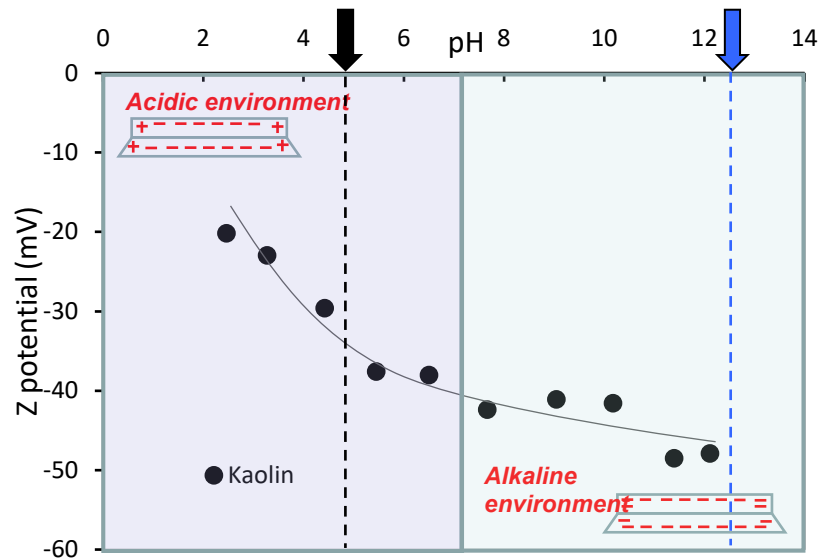
*face-to-face (FF)*



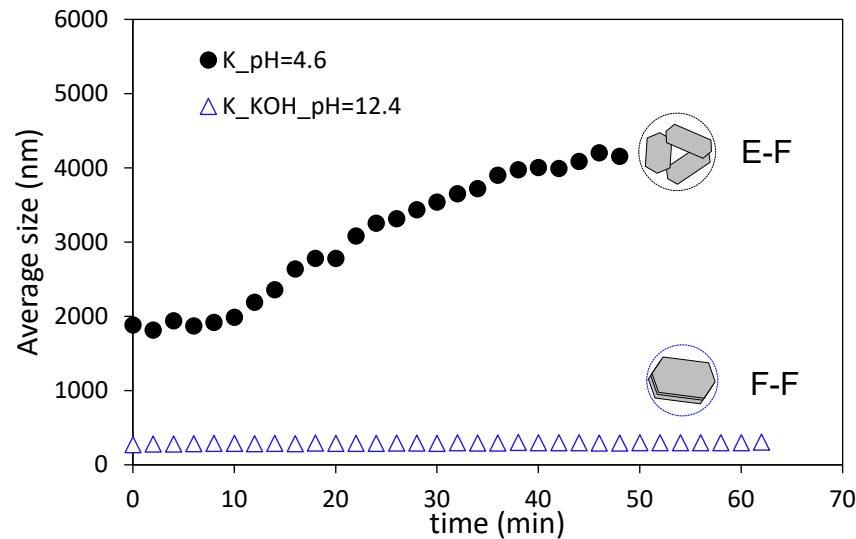
# FLOCCULAZIONE/AGGLOMERAZIONE DELLE PARTICELLE



*edge-to-face (EF)*  
*edge-to-edge (EE)*



*face-to-face (FF)*

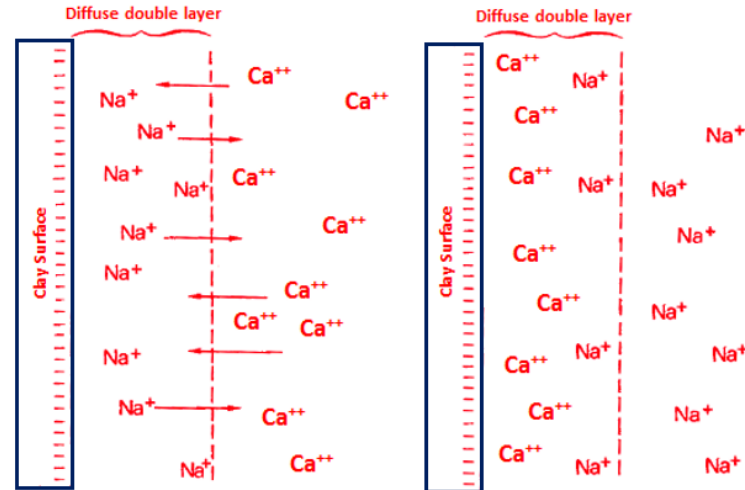


# FLOCCULAZIONE/AGGLOMERAZIONE DELLE PARTICELLE

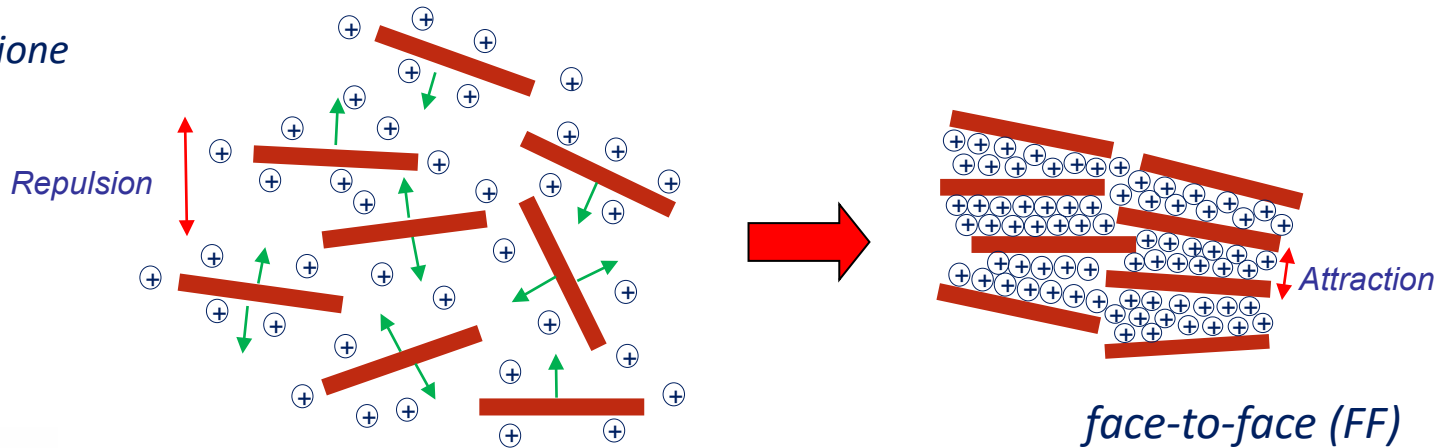
*Attrazioni di van der Waals, repulsioni del doppio strato diffuso, forze elettrostatiche coulombiane*

- Effetto del  $\text{Ca}^{2+}$

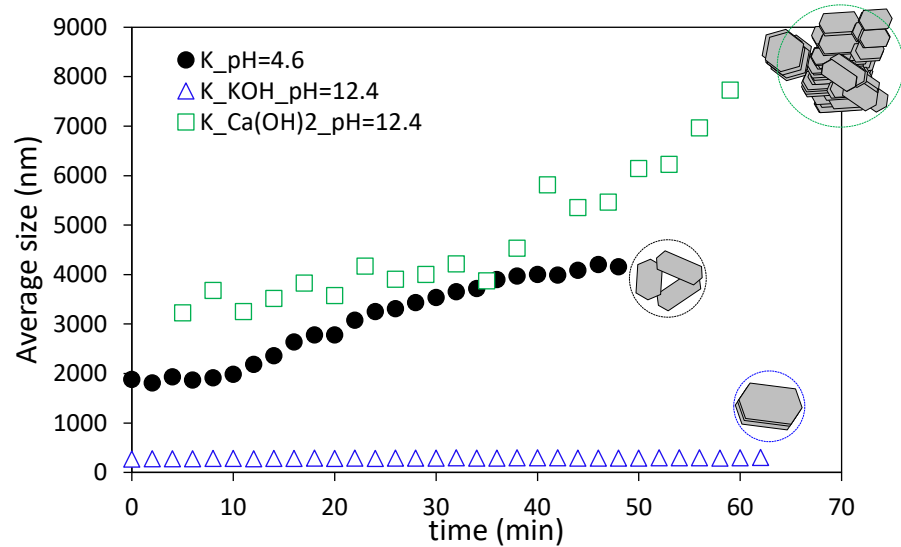
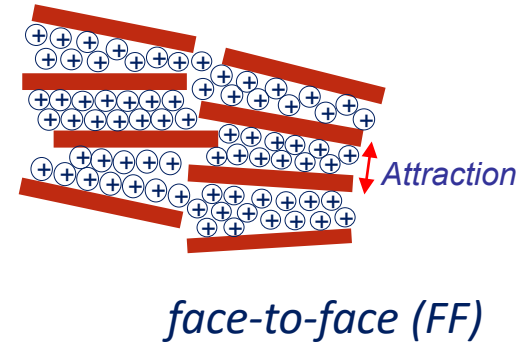
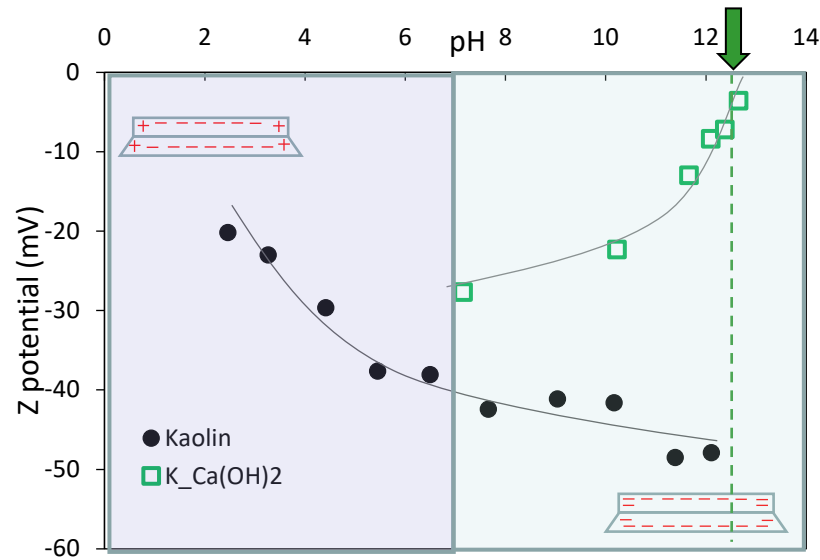
*scambio ionico*



*agglomerazione*

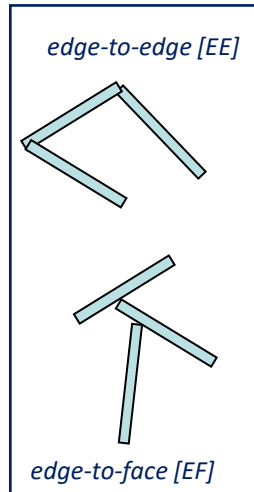


# FLOCCULAZIONE/AGGLOMERAZIONE DELLE PARTICELLE

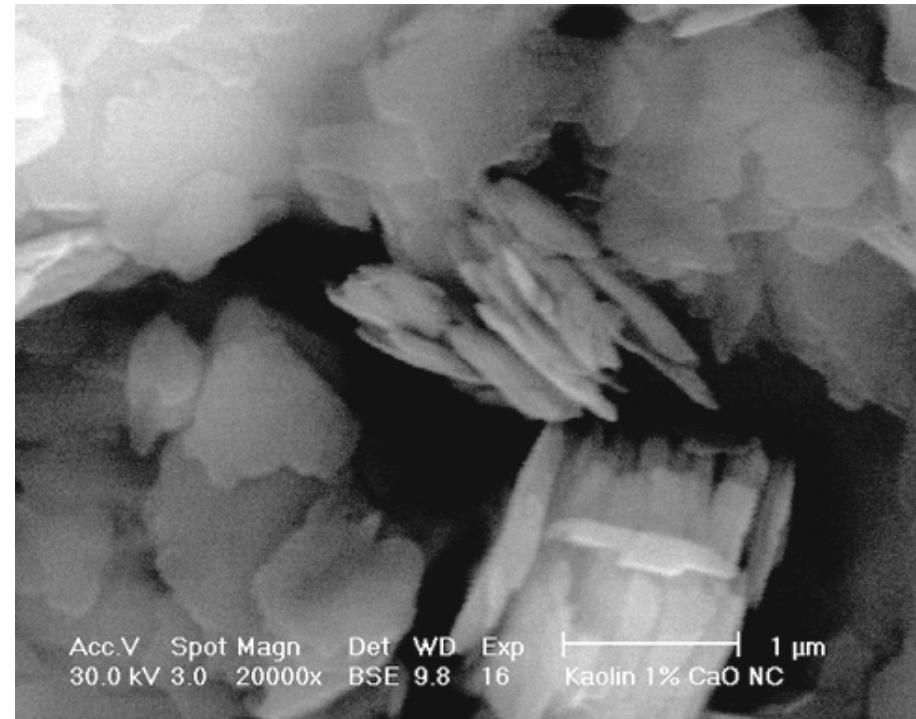
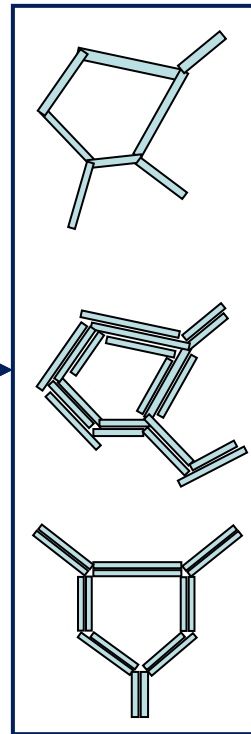
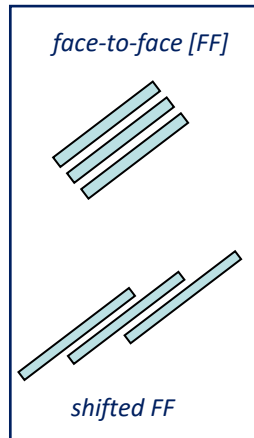


# FLOCCULAZIONE/AGGLOMERAZIONE DELLE PARTICELLE

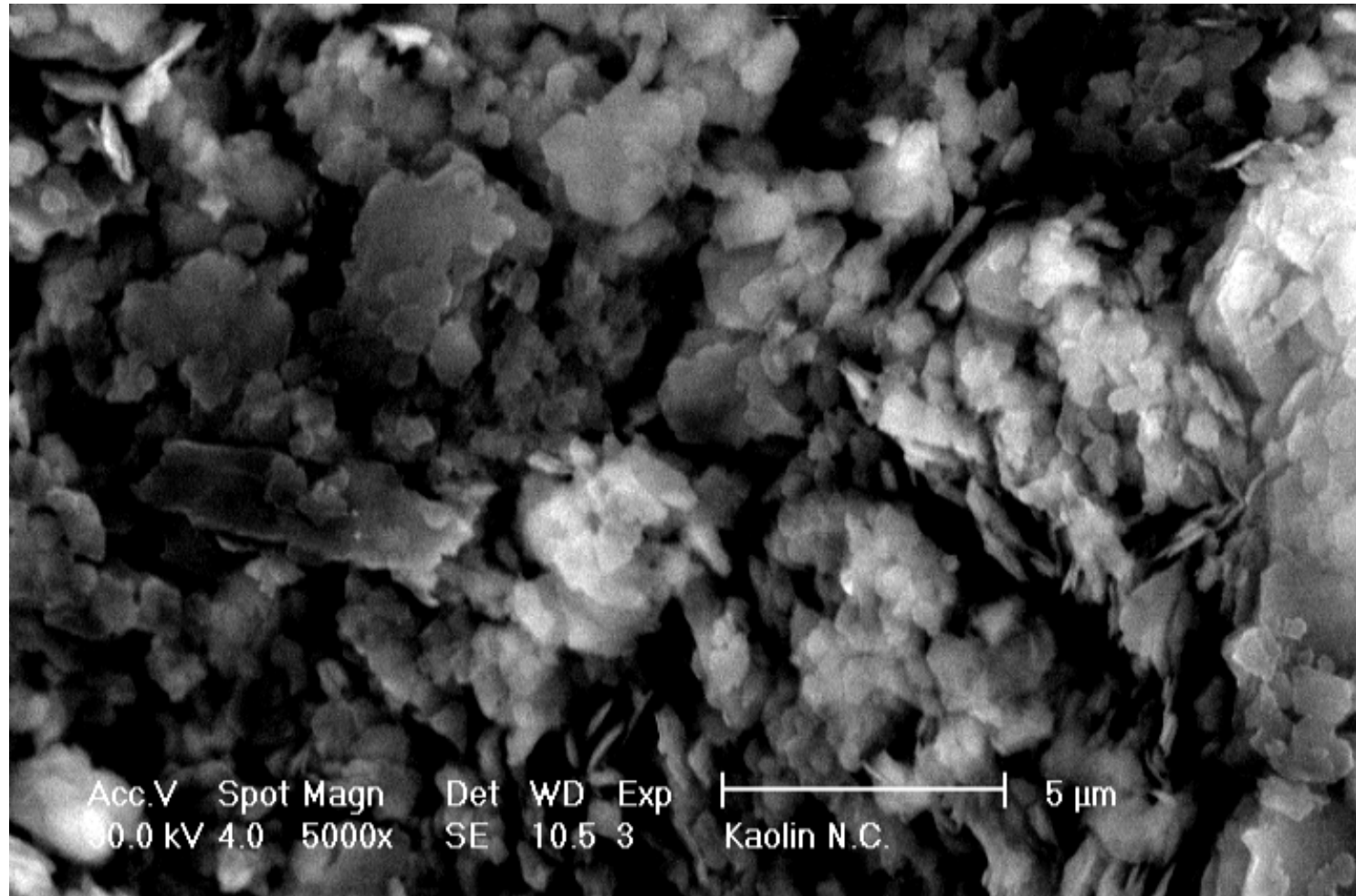
- effetto del pH



- effetto del  $\text{Ca}^{2+}$

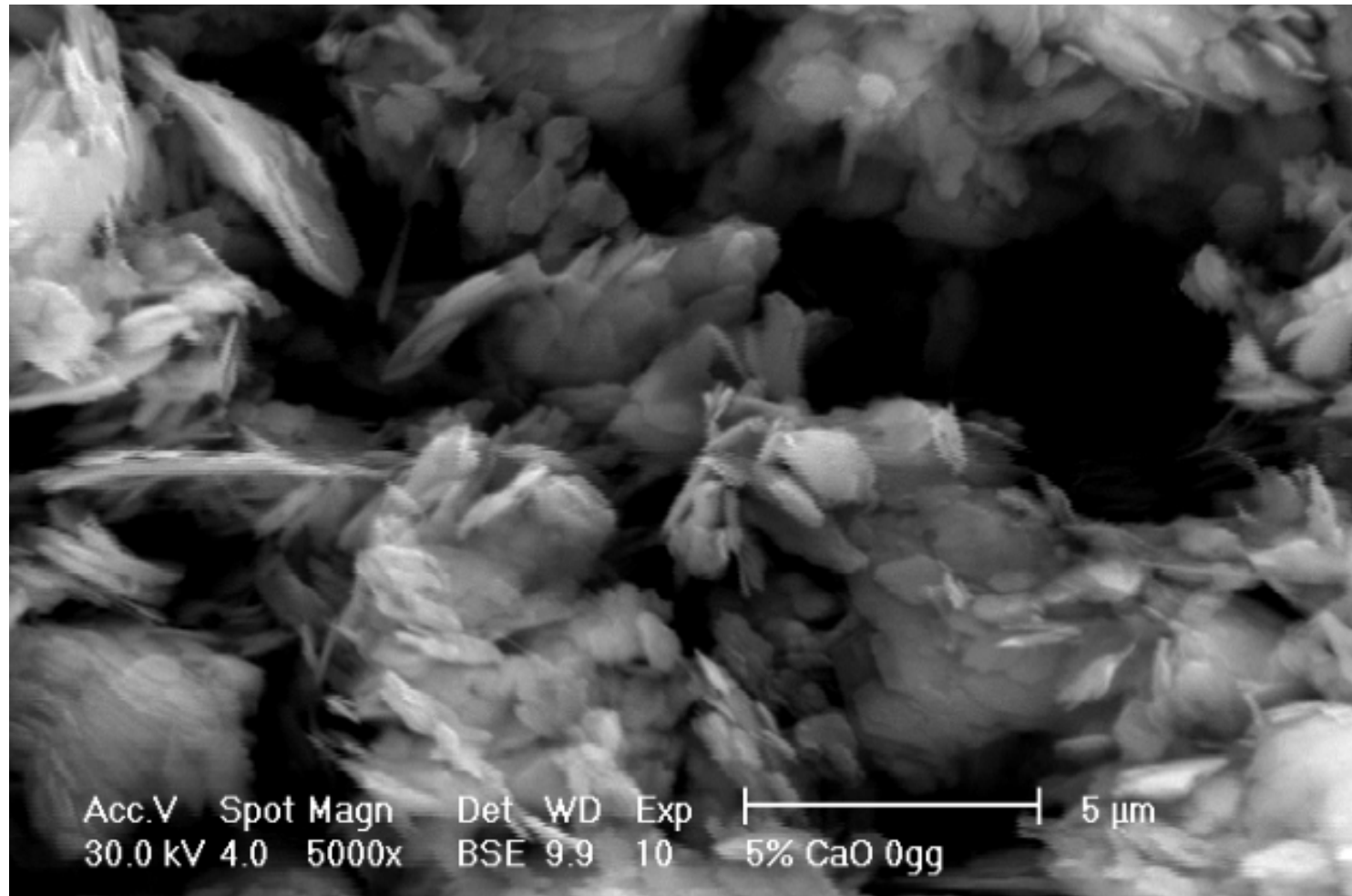


# FLOCCULAZIONE/AGGLOMERAZIONE DELLE PARTICELLE



**Kaolinite @ pH = 4.6 – Magn. 5000x**

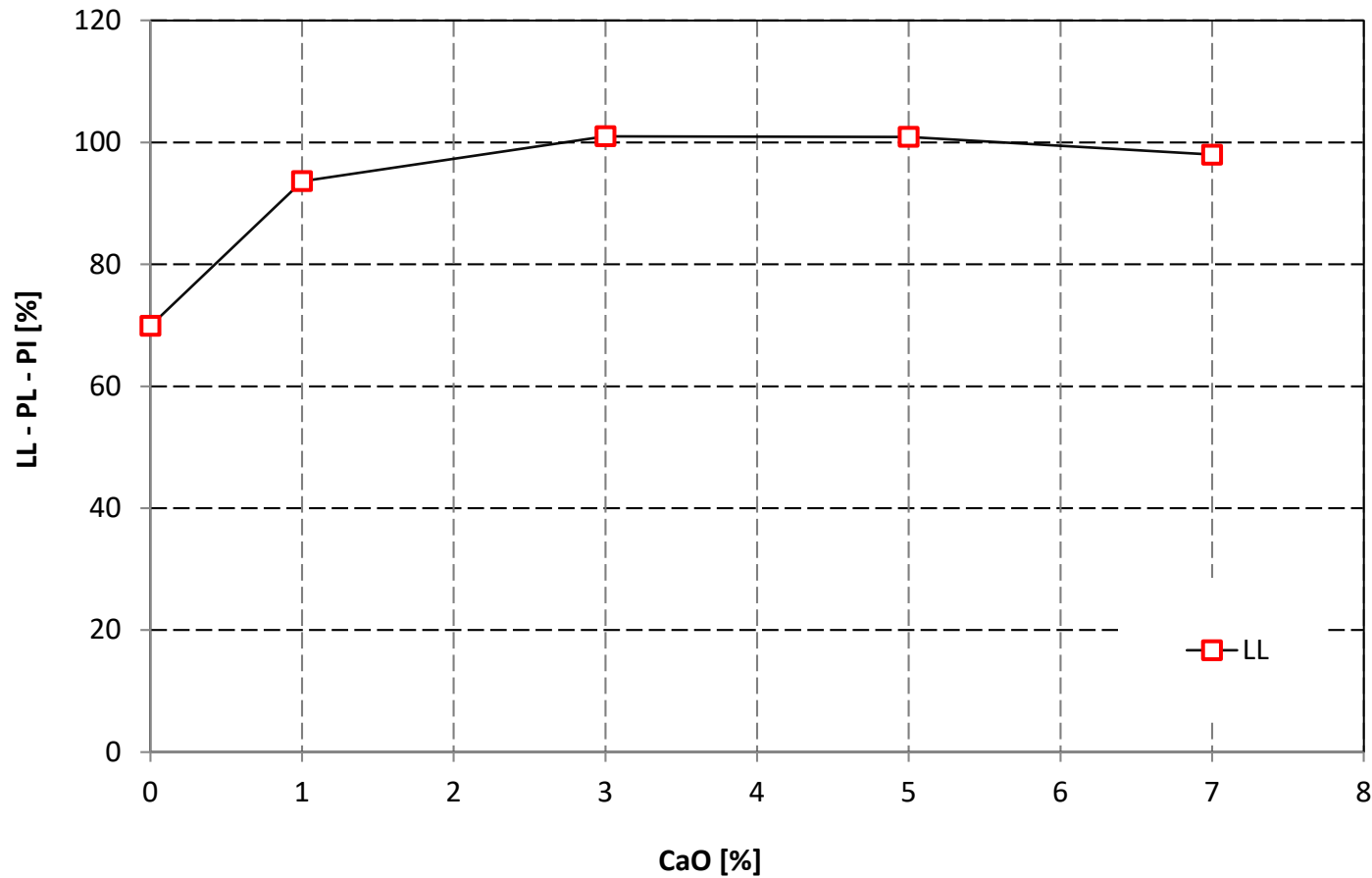
# FLOCCULAZIONE/AGGLOMERAZIONE DELLE PARTICELLE



5%CaO treated kaolin - pH = 12.4 – Magn. 5000x

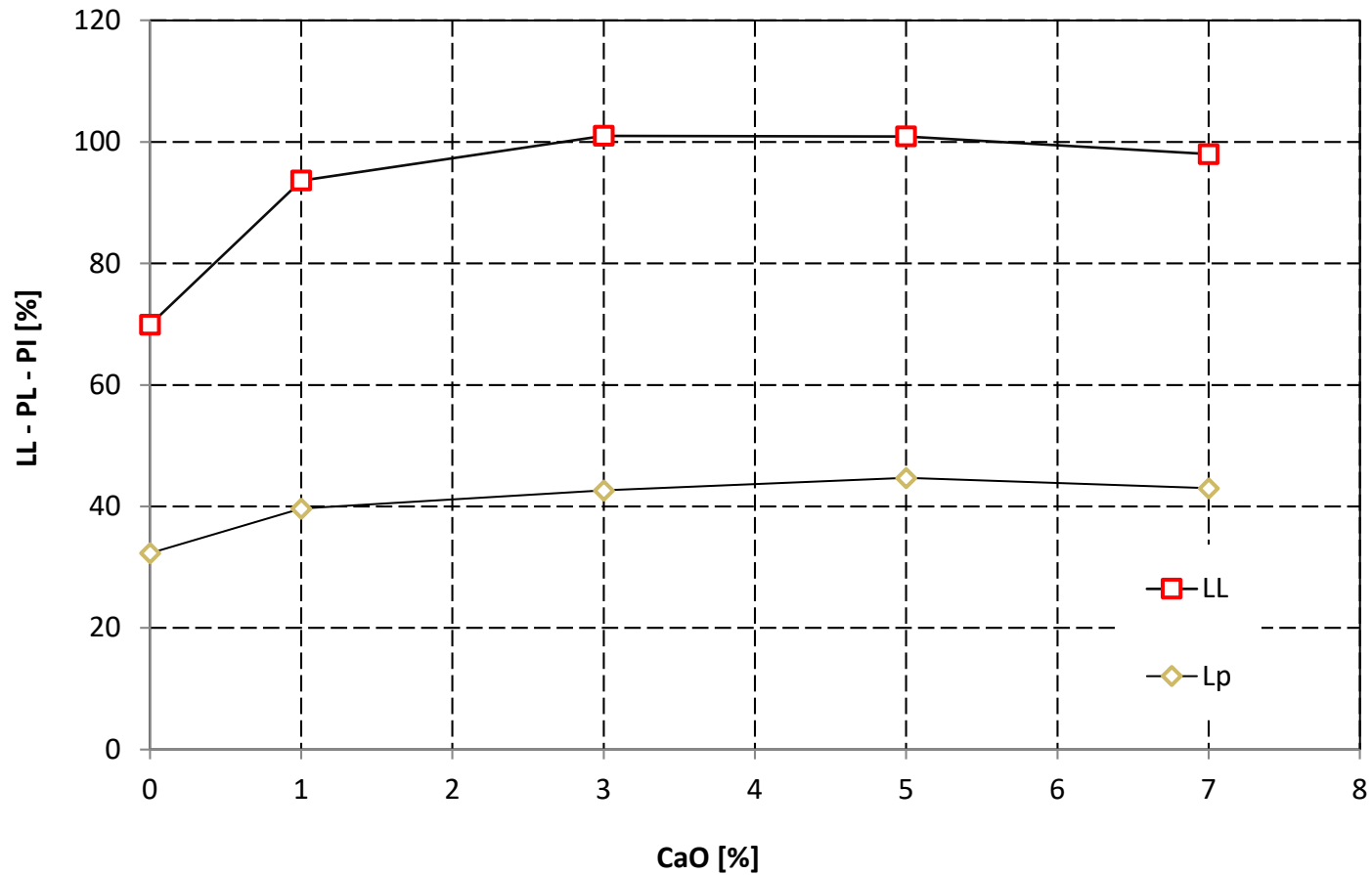
# EFFETTO DELLA CALCE SUI LIMITI DI ATTERBERG

Caolino



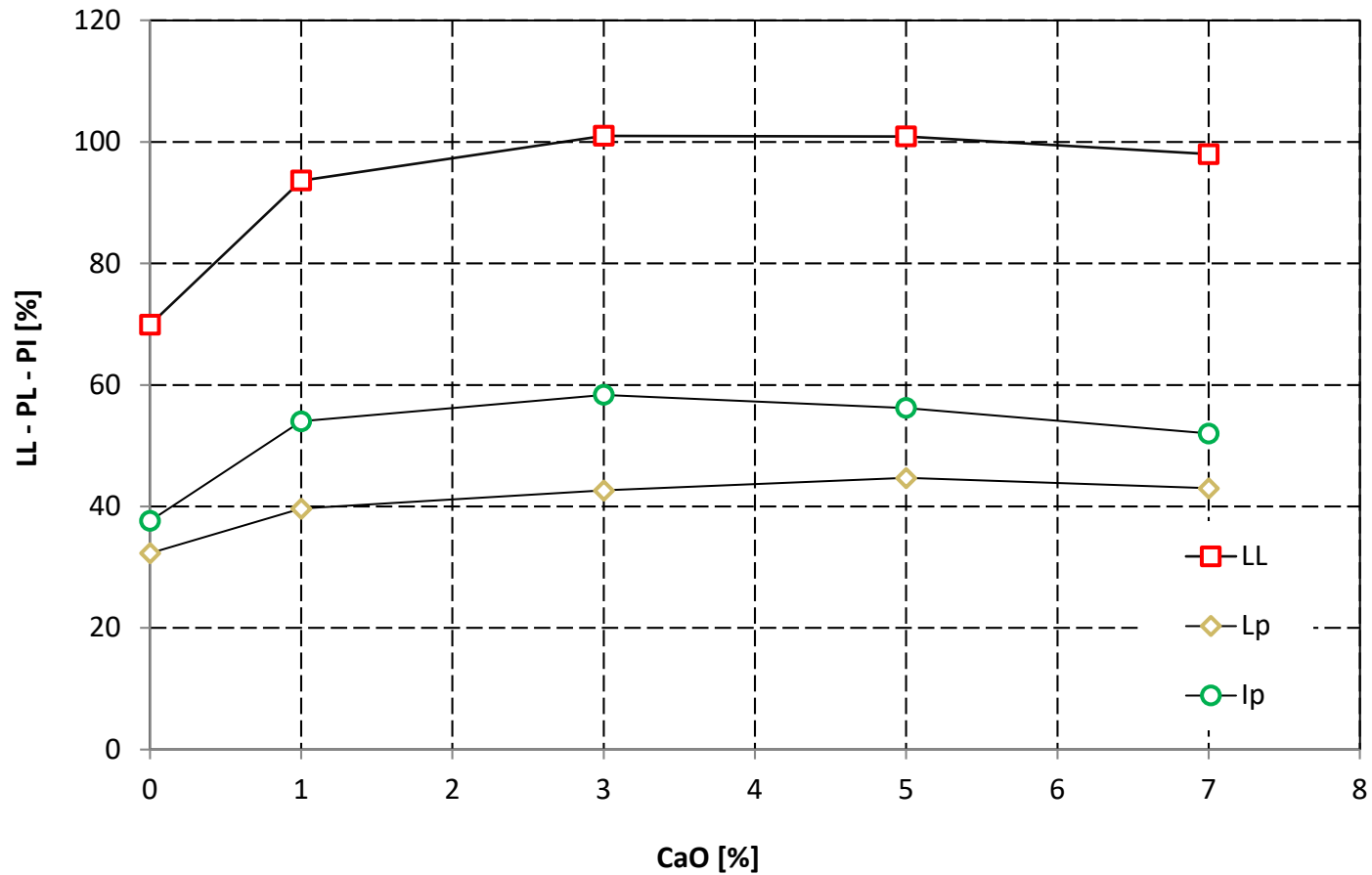
# EFFETTO DELLA CALCE SUI LIMITI DI ATTERBERG

Caolino



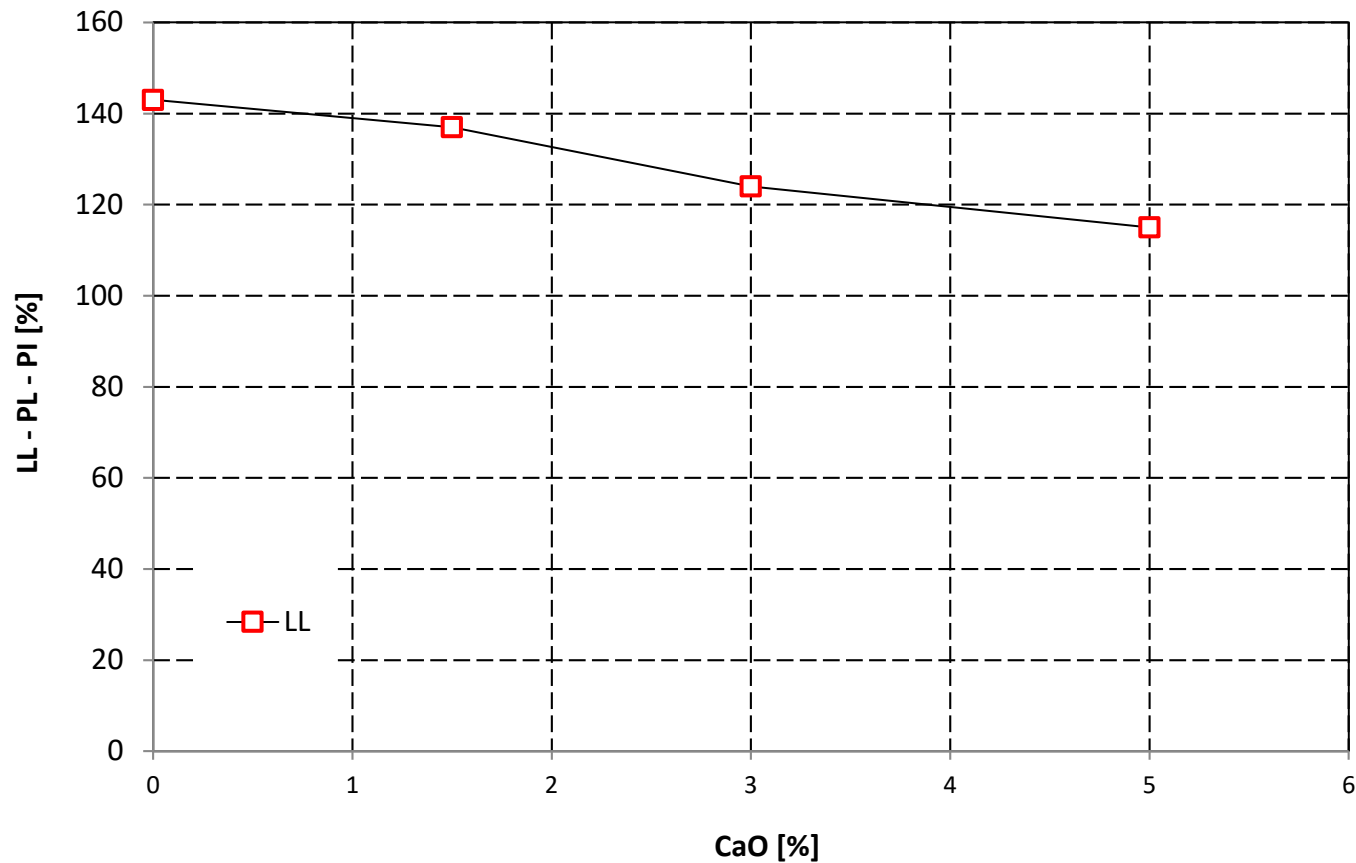
# EFFETTO DELLA CALCE SUI LIMITI DI ATTERBERG

Caolino



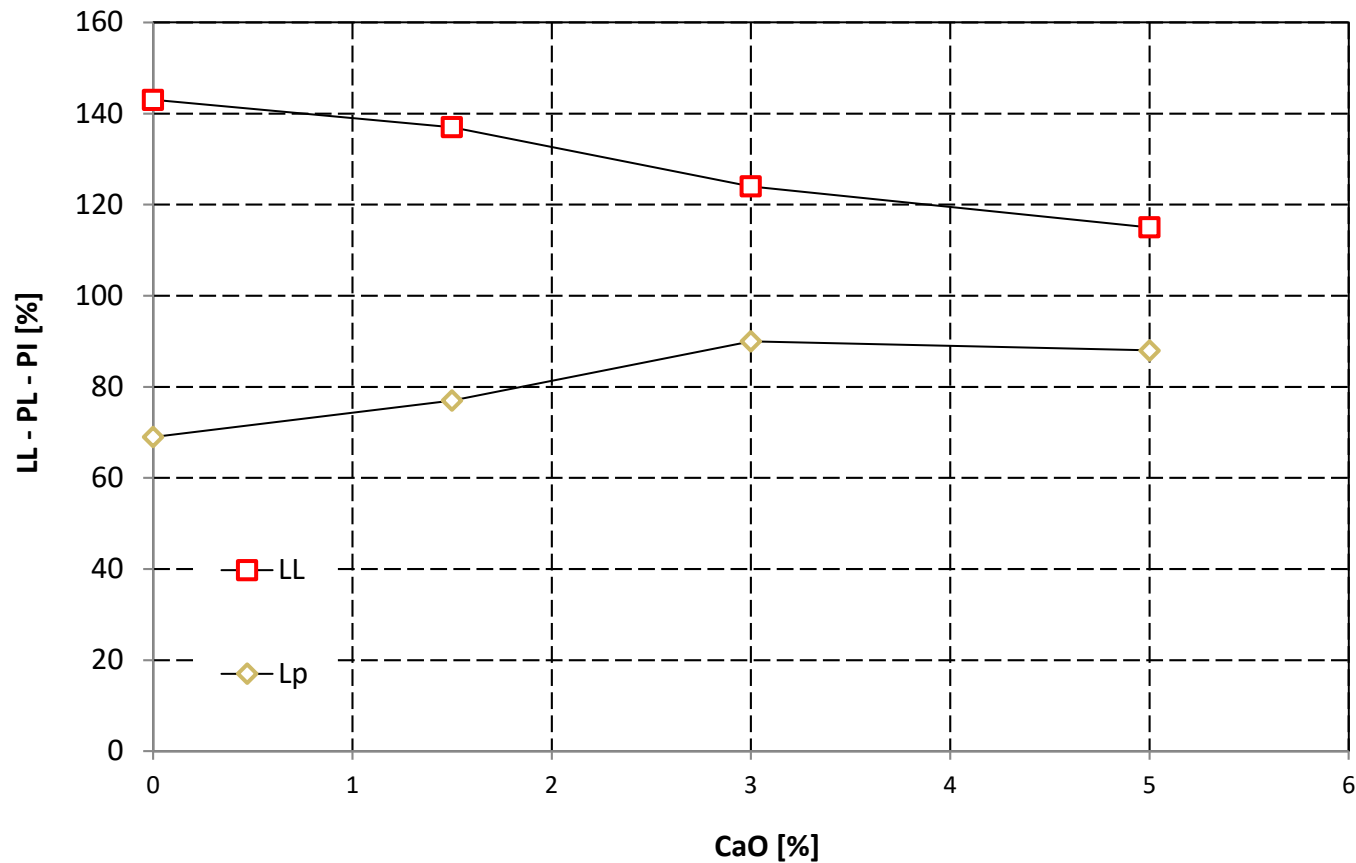
# EFFETTO DELLA CALCE SUI LIMITI DI ATTERBERG

Bentonite



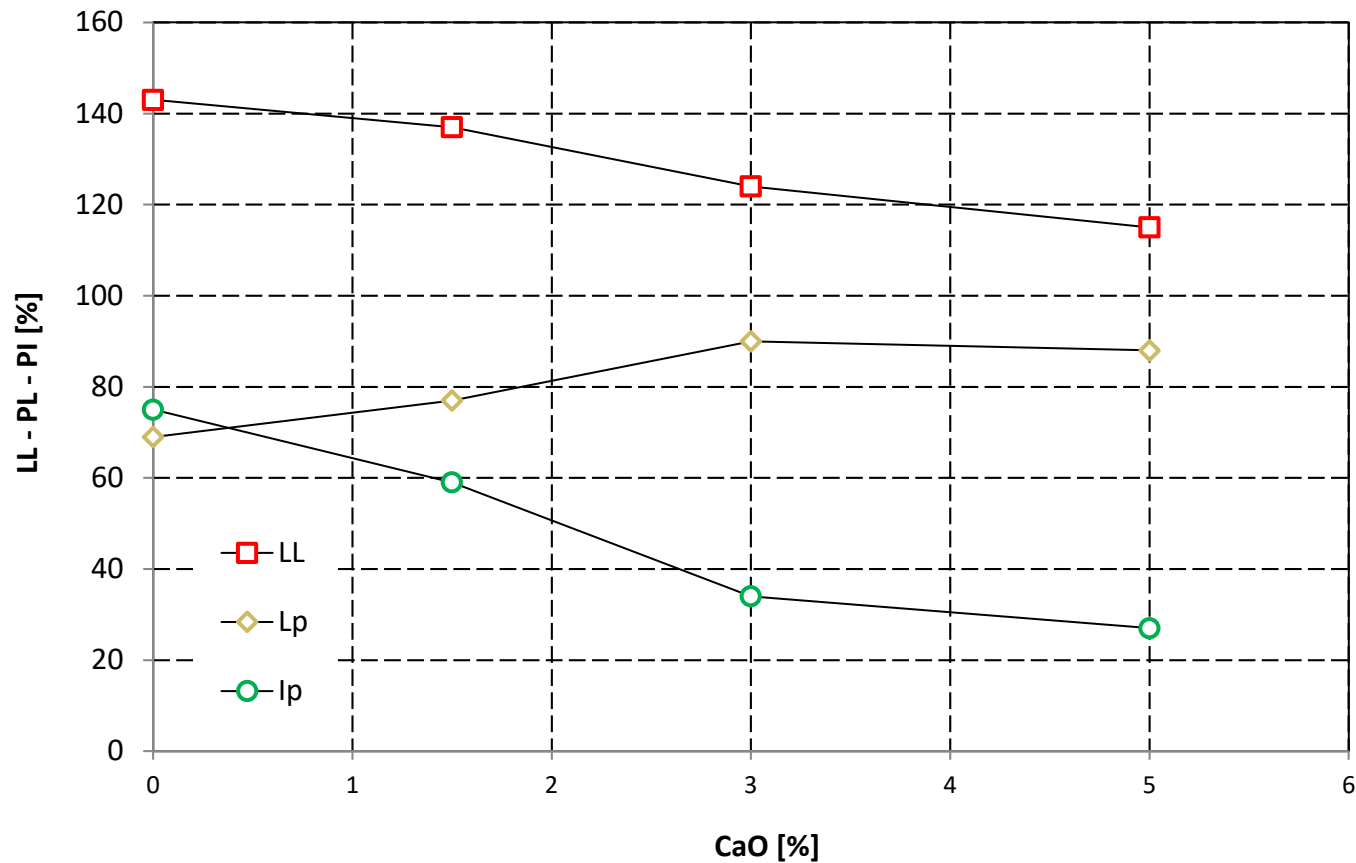
# EFFETTO DELLA CALCE SUI LIMITI DI ATTERBERG

Bentonite



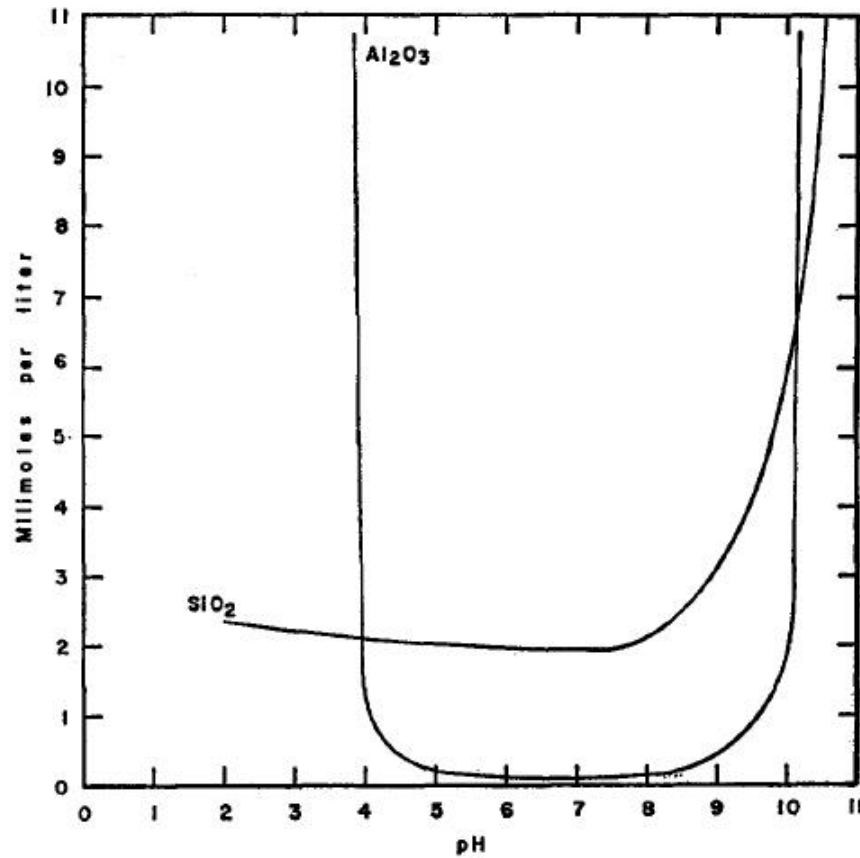
# EFFETTO DELLA CALCE SUI LIMITI DI ATTERBERG

Bentonite



# REAZIONI POZZOLANICHE

## Dissoluzione di Silicio ed Alluminio



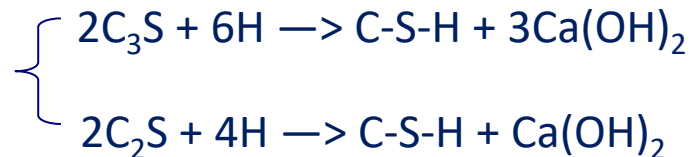
$\text{Al}_2\text{O}_3$  data from Correns  
 $\text{SiO}_2$  data from Krauskopf

(Keller, 1964)

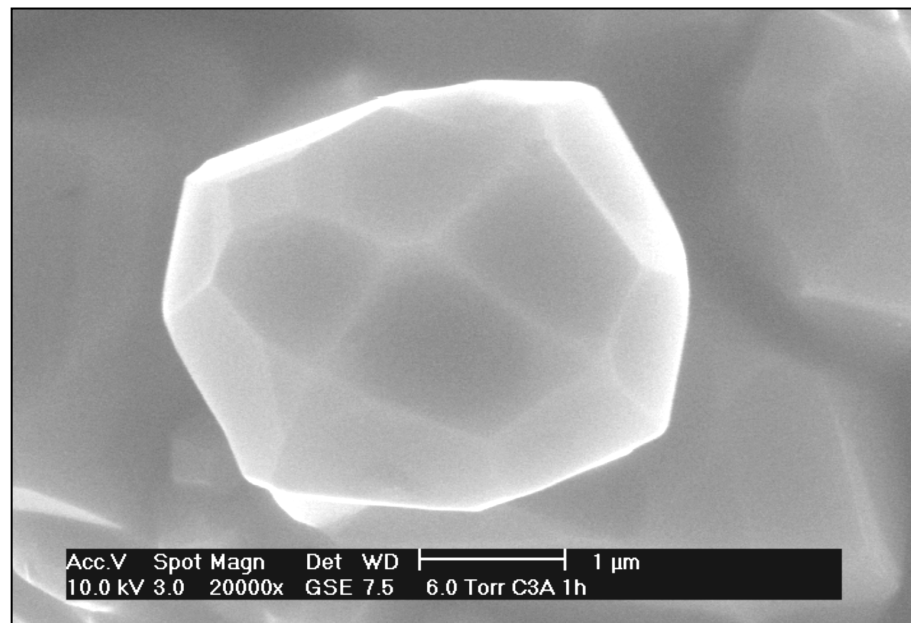
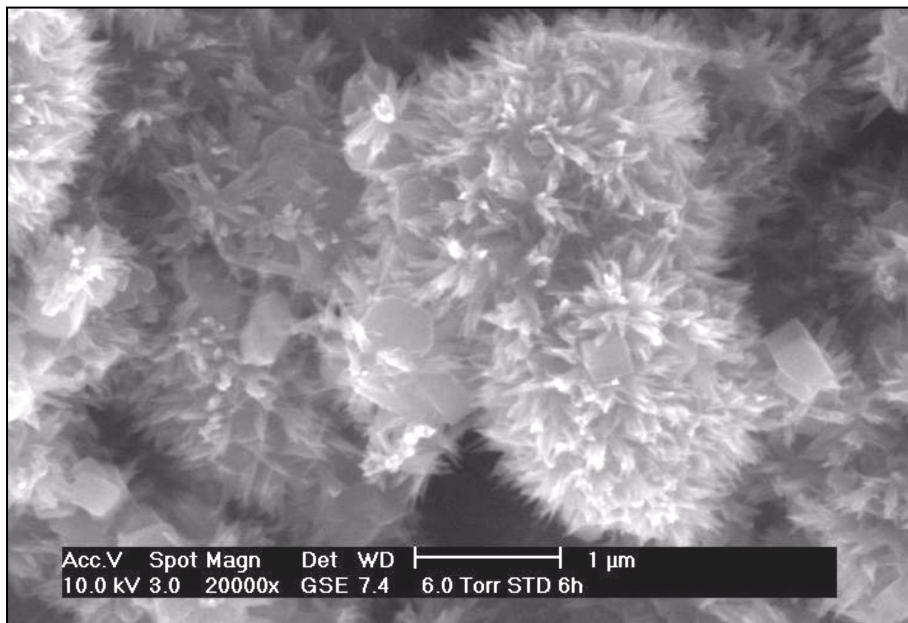
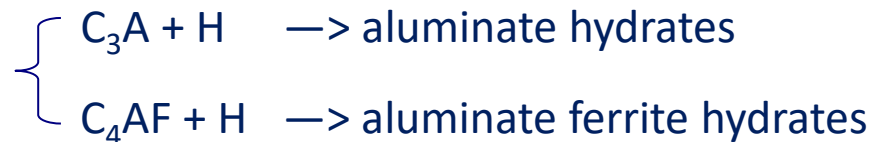


# REAZIONI POZZOLANICHE

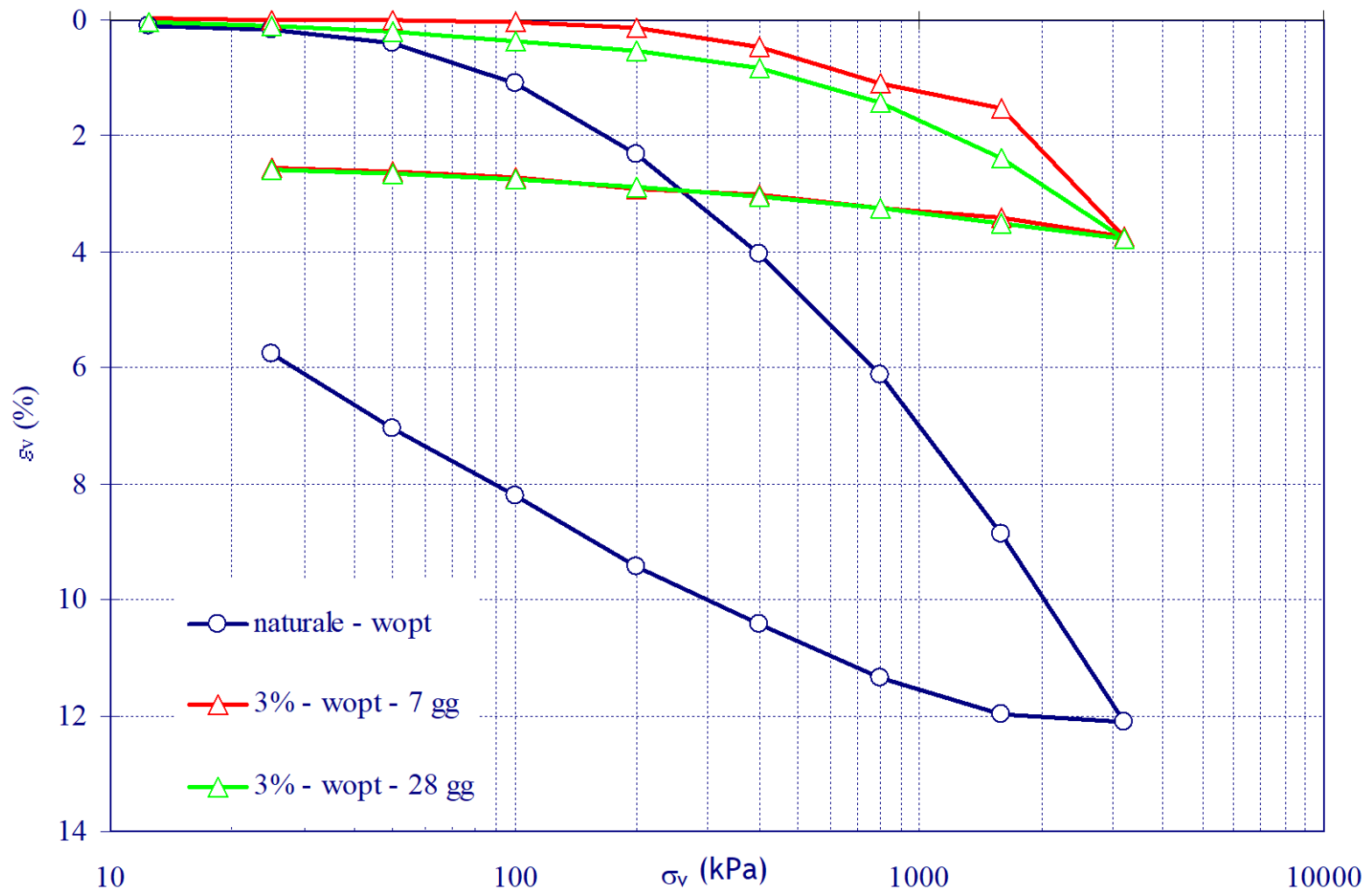
Calcium Silicate Hydrates (CSH)



Calcium Alluminate Hydrates (CAH)



# REAZIONI POZZOLANICHE



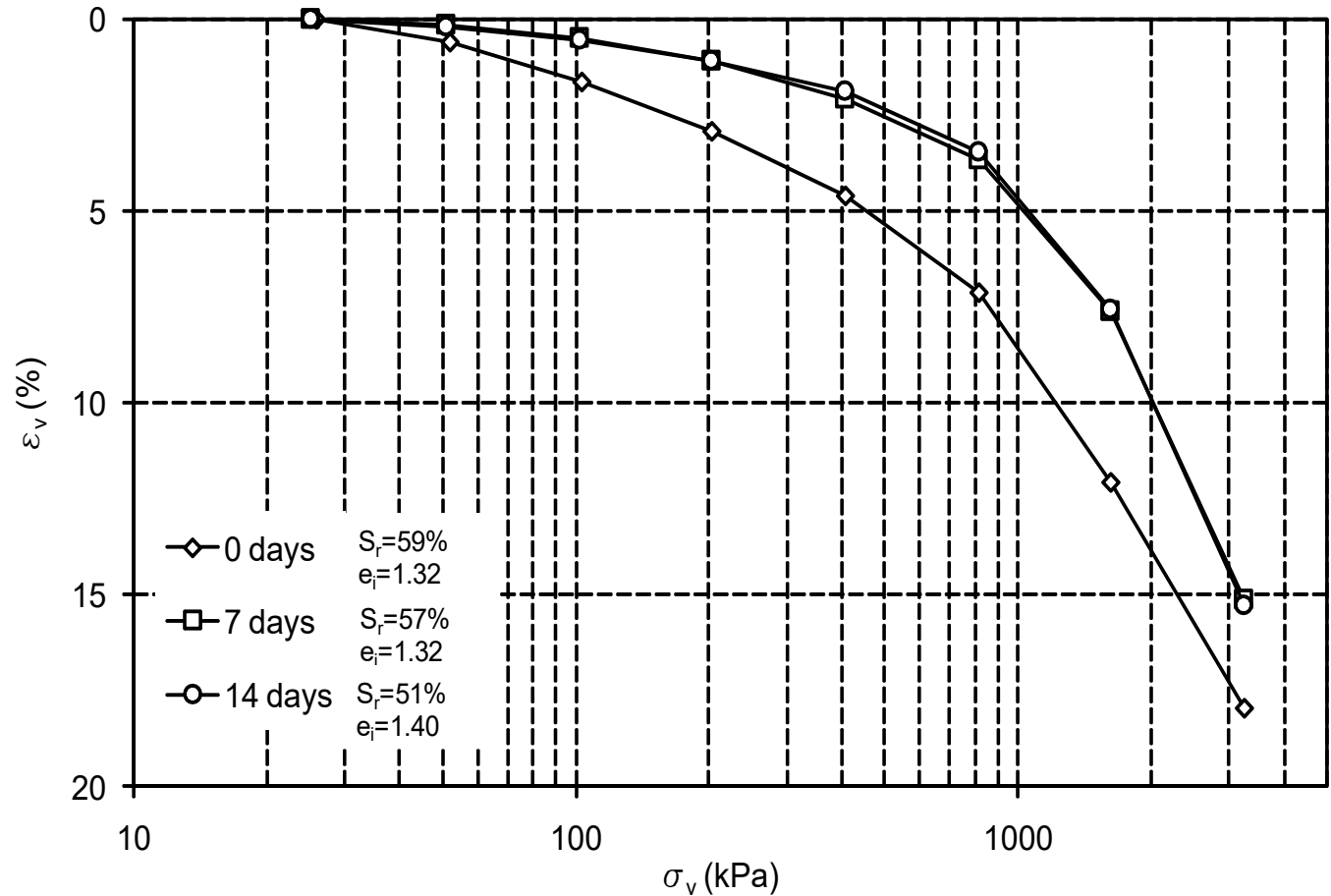
Poggiolino – 3% CaO

# REAZIONI POZZOLANICHE

1D Compressibility  
(Oedometer tests)

Monteforte  
(7% CaO)

(Cecconi et al., 2010)



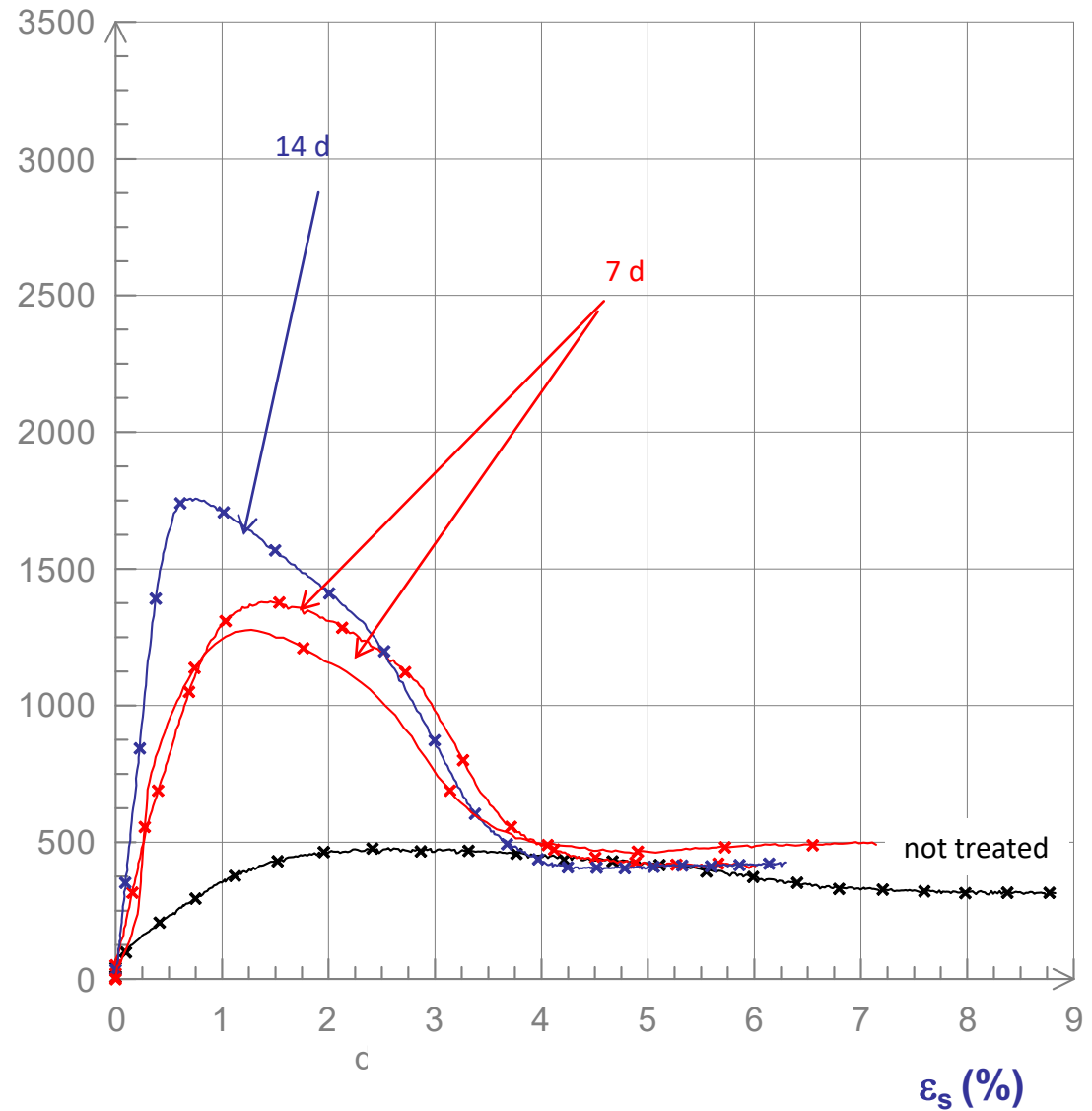
# REAKZIONI POZZOLANICHE

Shear strength  
(*Triaxial tests*)

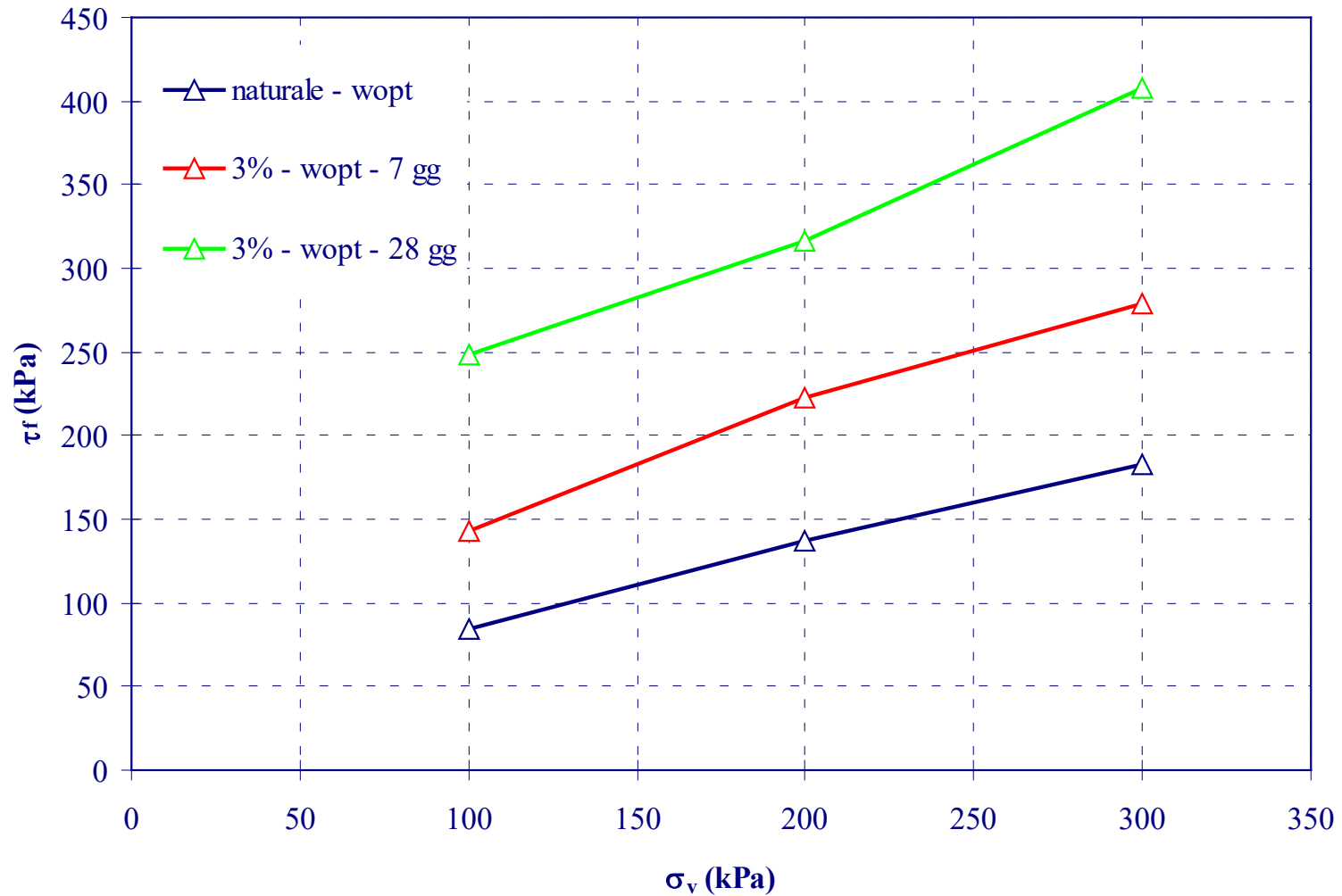
Roma (PN)  
(not treated, 10% CaO)  
(Cecconi et al., 2010)

$p'_0 = 100 \text{ kPa}$

$q \text{ (kPa)}$



# REAZIONI POZZOLANICHE



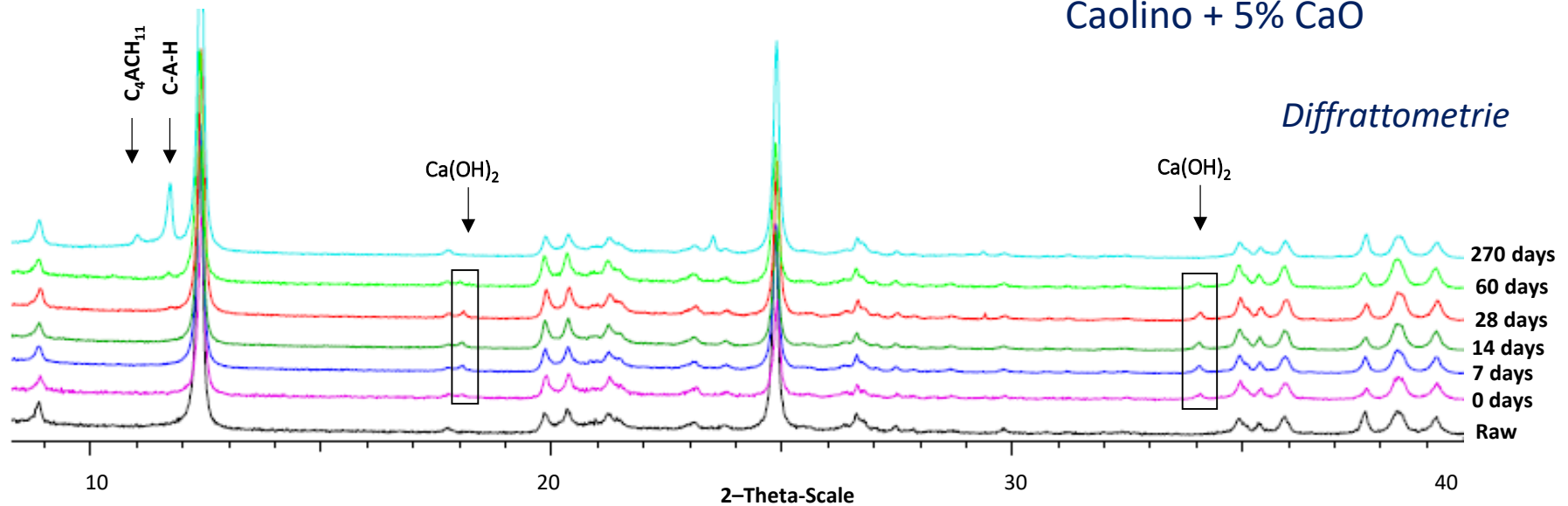
Poggiolino – 3% CaO



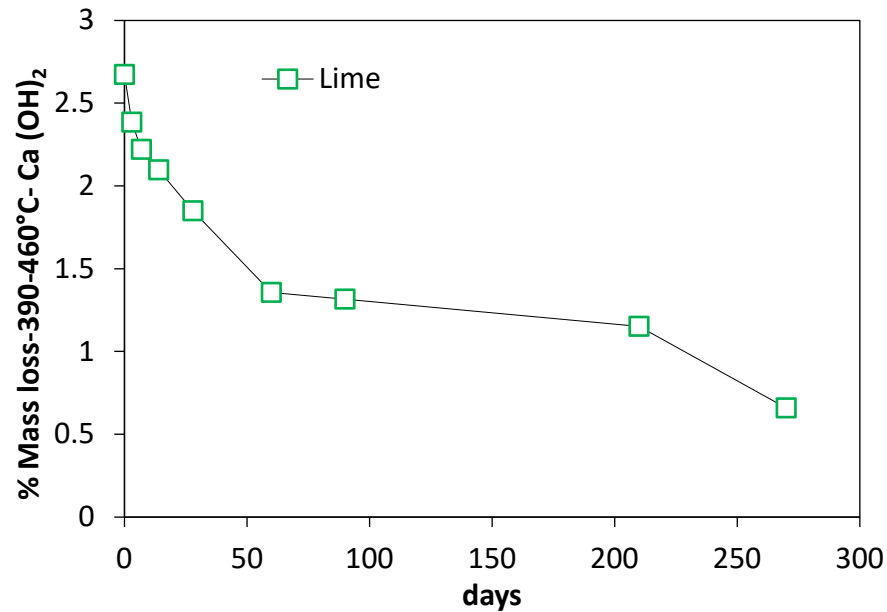
# REAZIONI POZZOLANICHE

Caolino + 5% CaO

*Diffrazione*



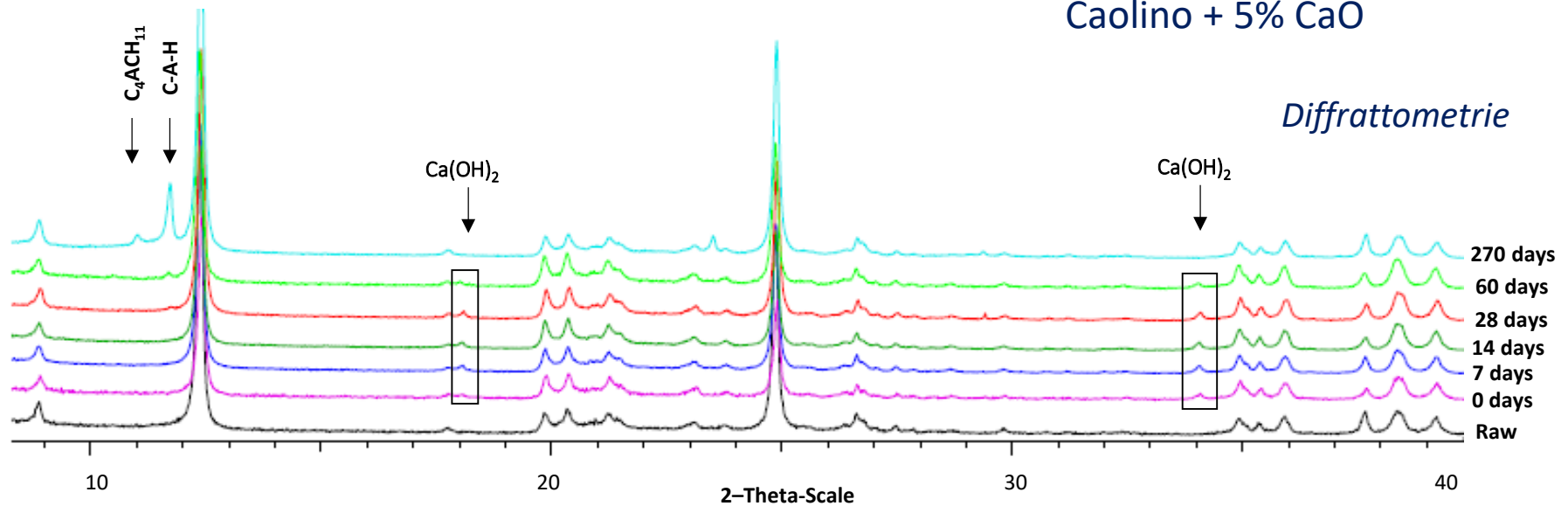
*Termogravimetrie*



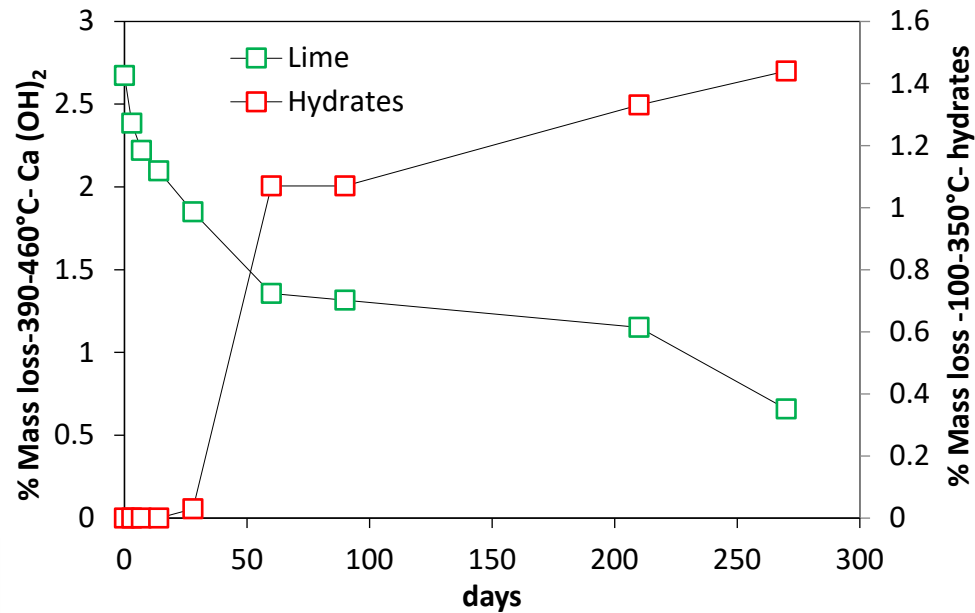
# REAZIONI POZZOLANICHE

Caolino + 5% CaO

*Diffrazione*

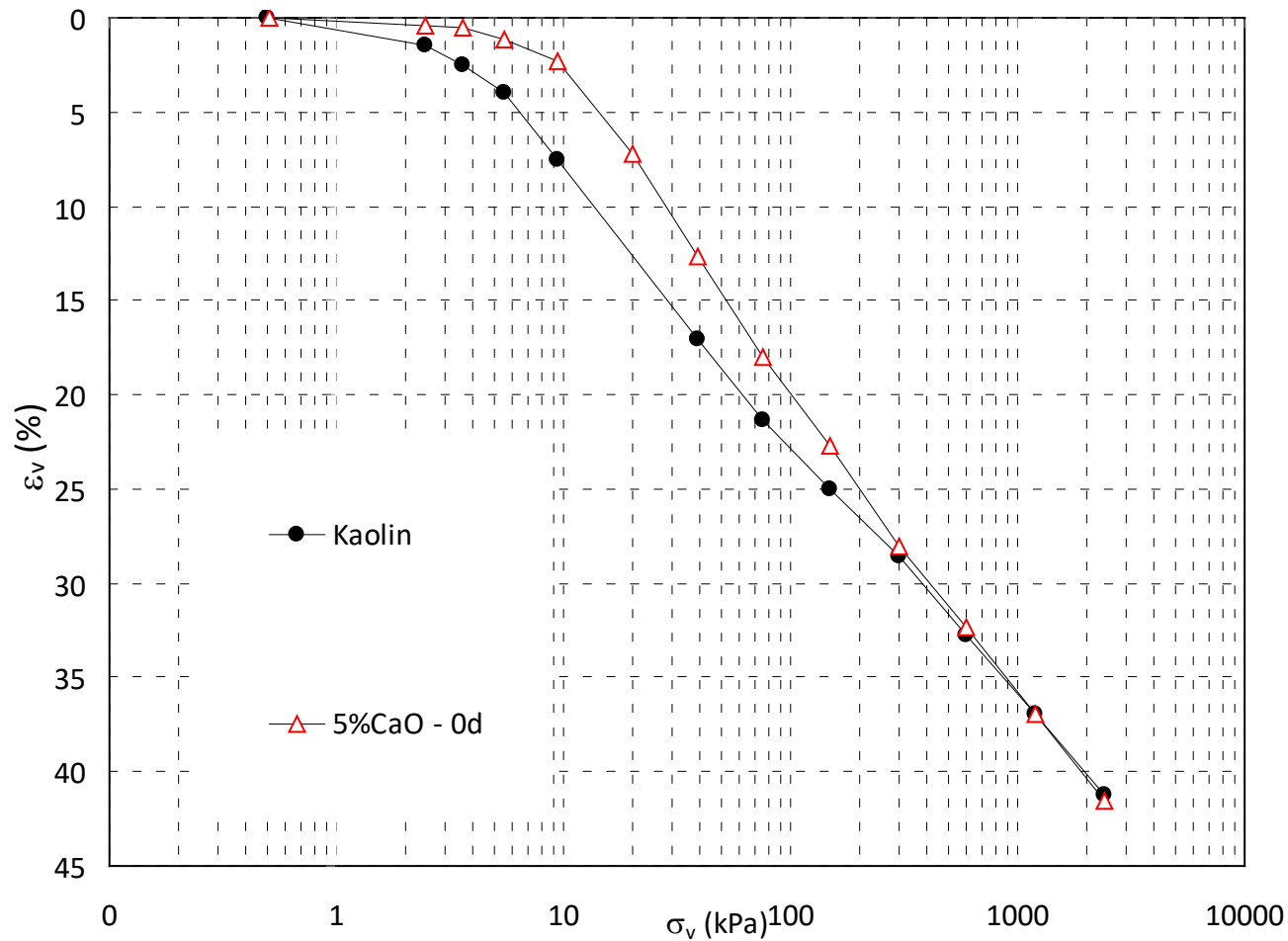


*Termogravimetrie*



# REAZIONI POZZOLANICHE

Caolino + 5% CaO

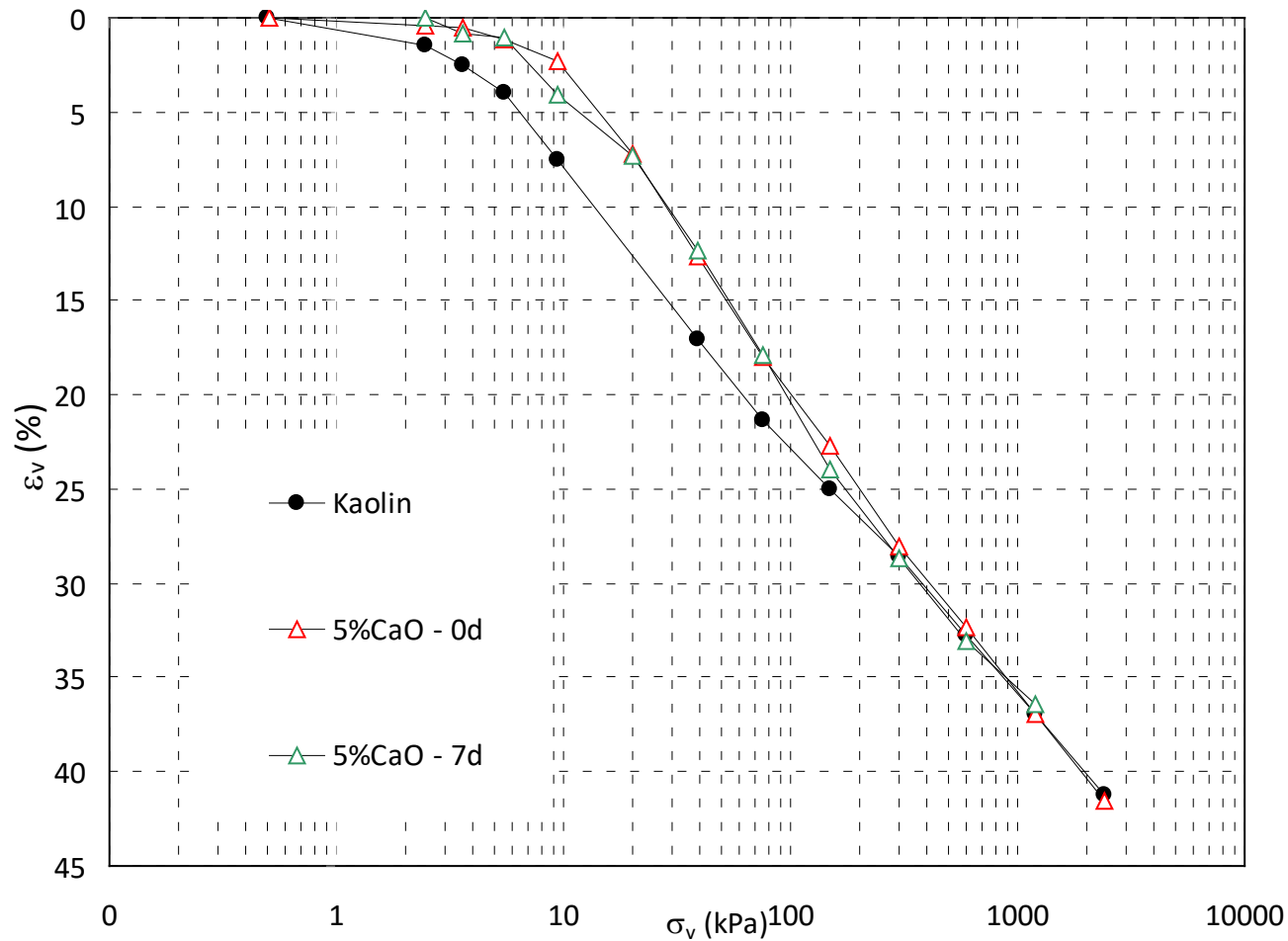


*Prove di compressione 1D (edomteriche)*



# REAZIONI POZZOLANICHE

Caolino + 5% CaO

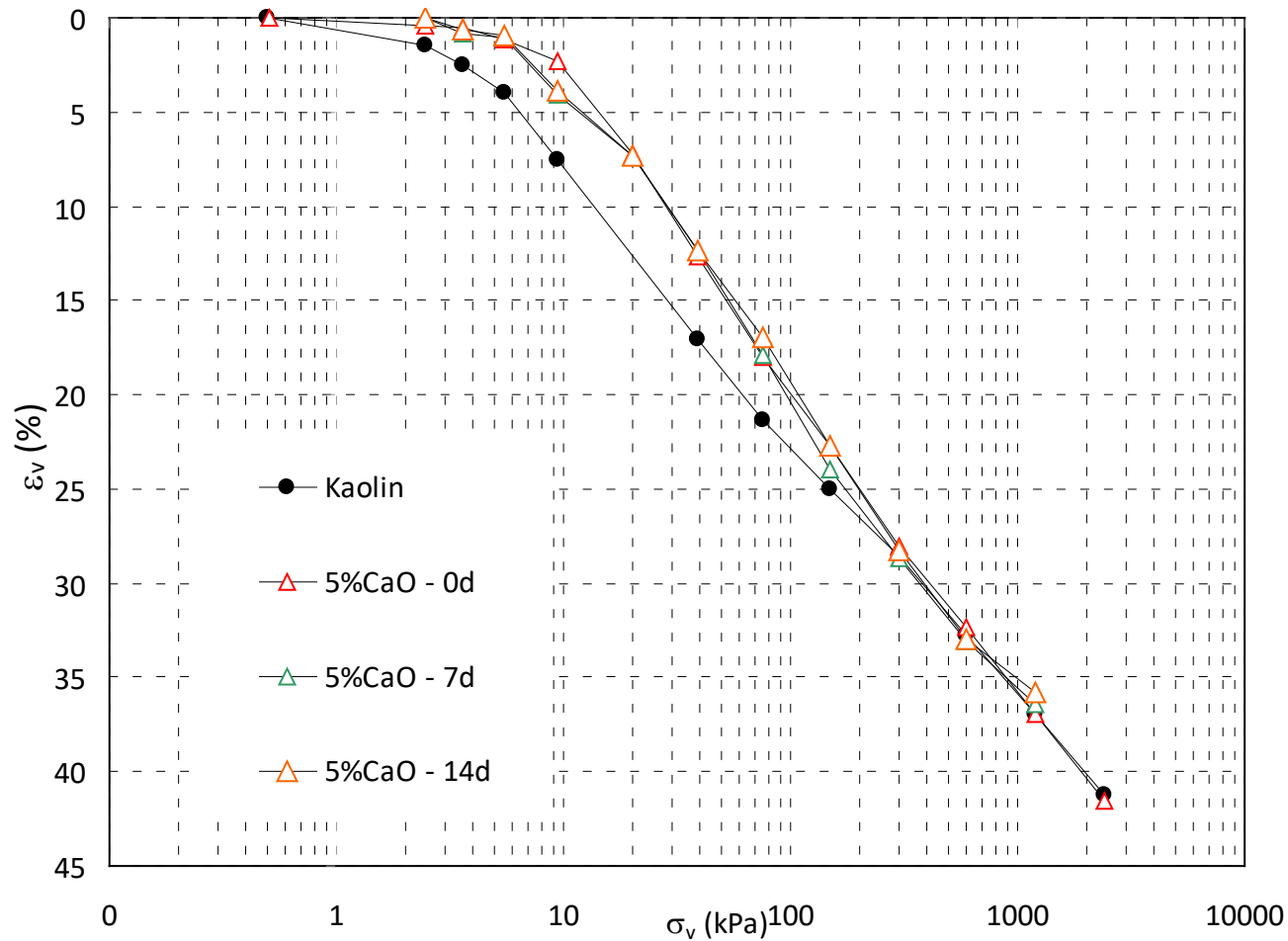


*Prove di compressione 1D (edomteriche)*



# REAZIONI POZZOLANICHE

Caolino + 5% CaO

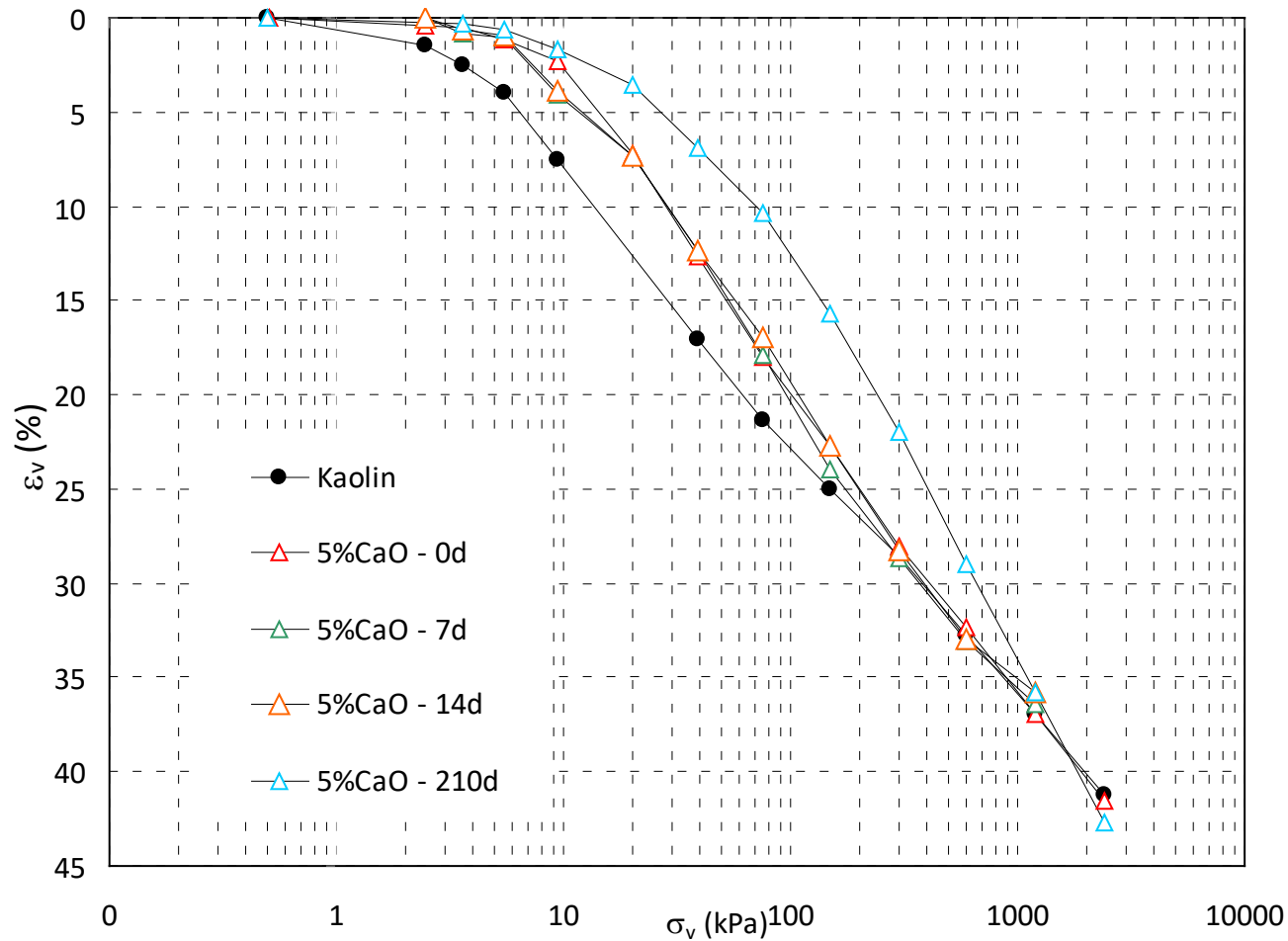


*Prove di compressione 1D (edomteriche)*



# REAZIONI POZZOLANICHE

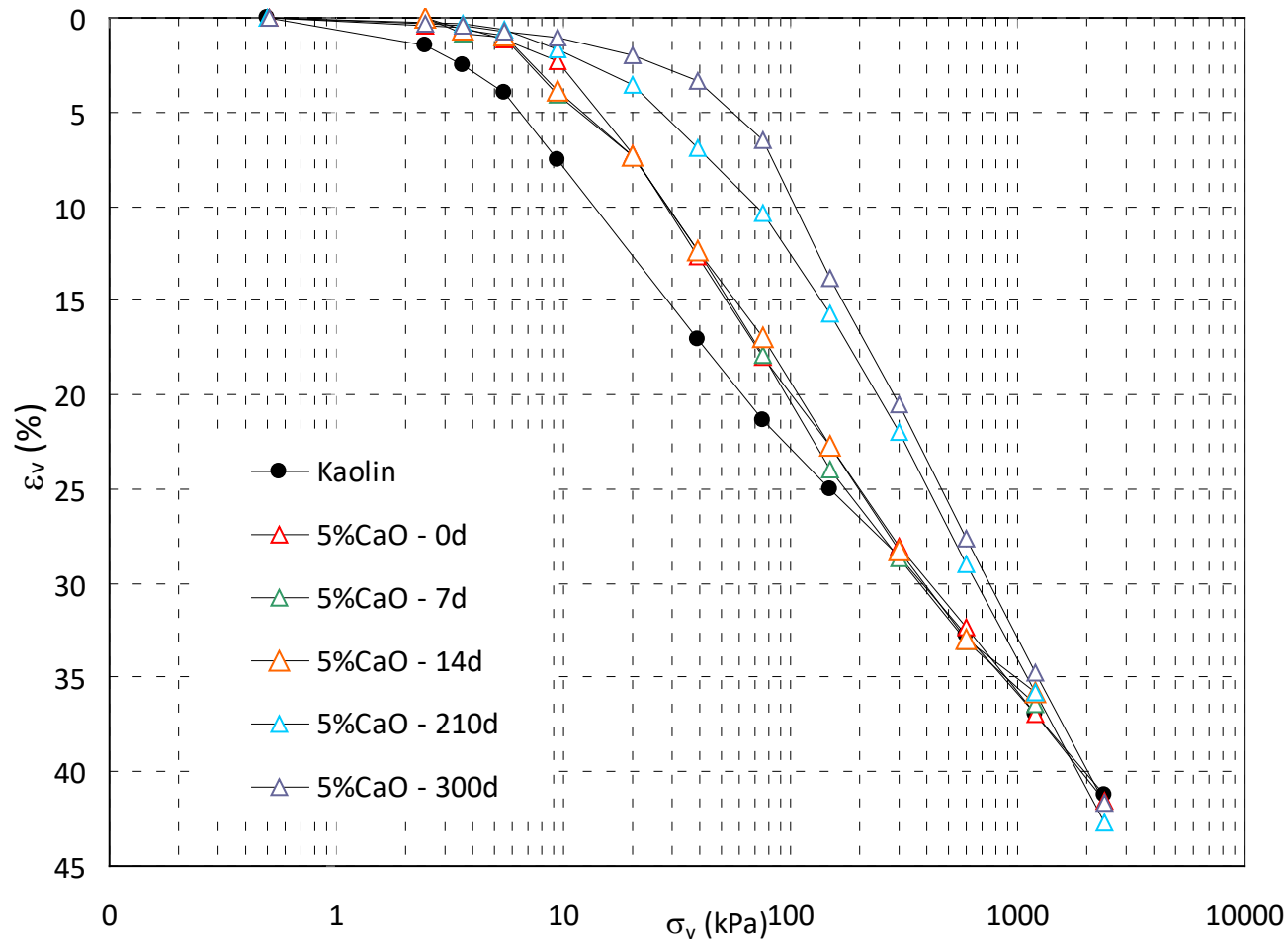
Caolino + 5% CaO



*Prove di compressione 1D (edomteriche)*

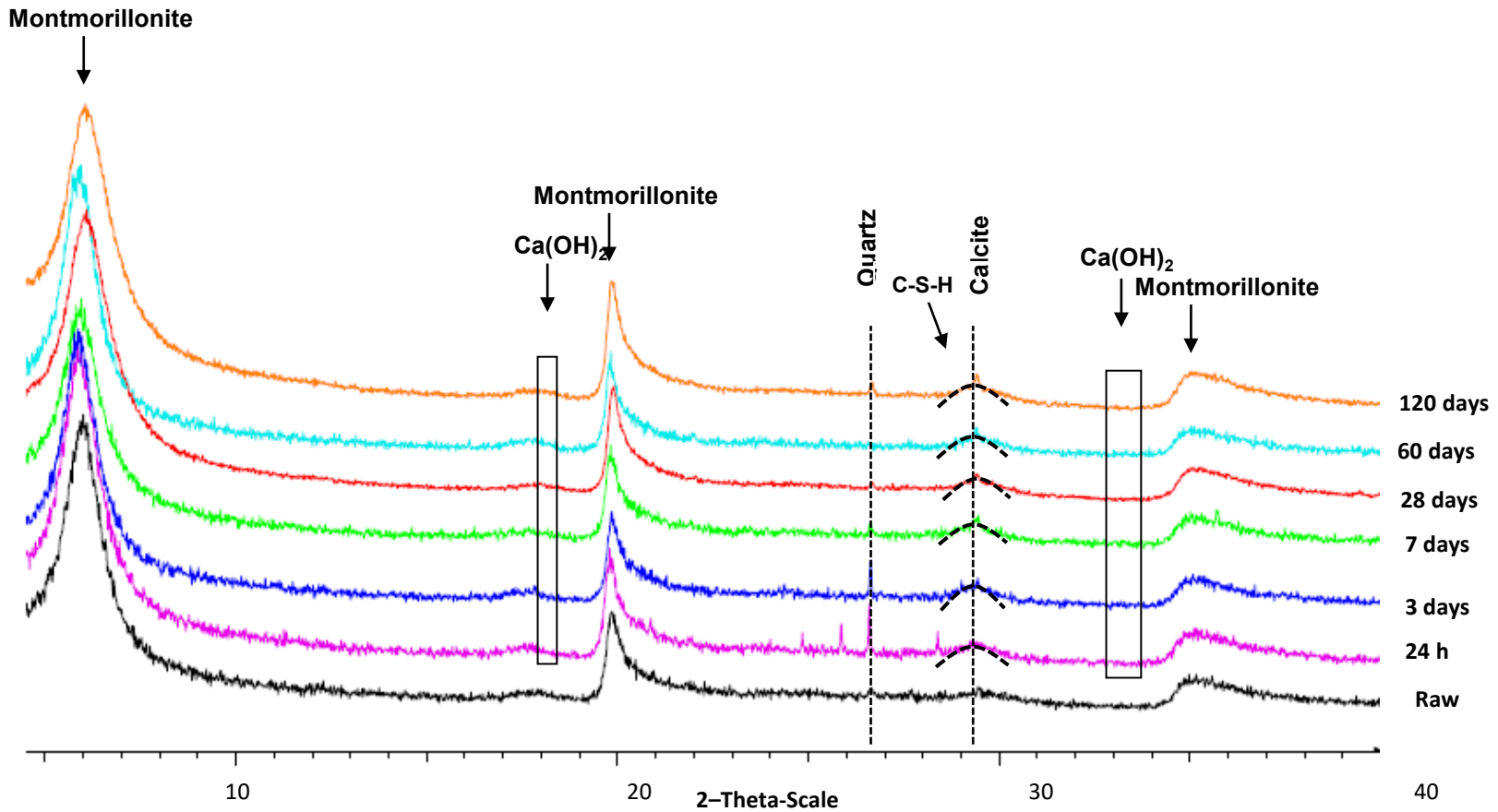
# REAZIONI POZZOLANICHE

Caolino + 5% CaO

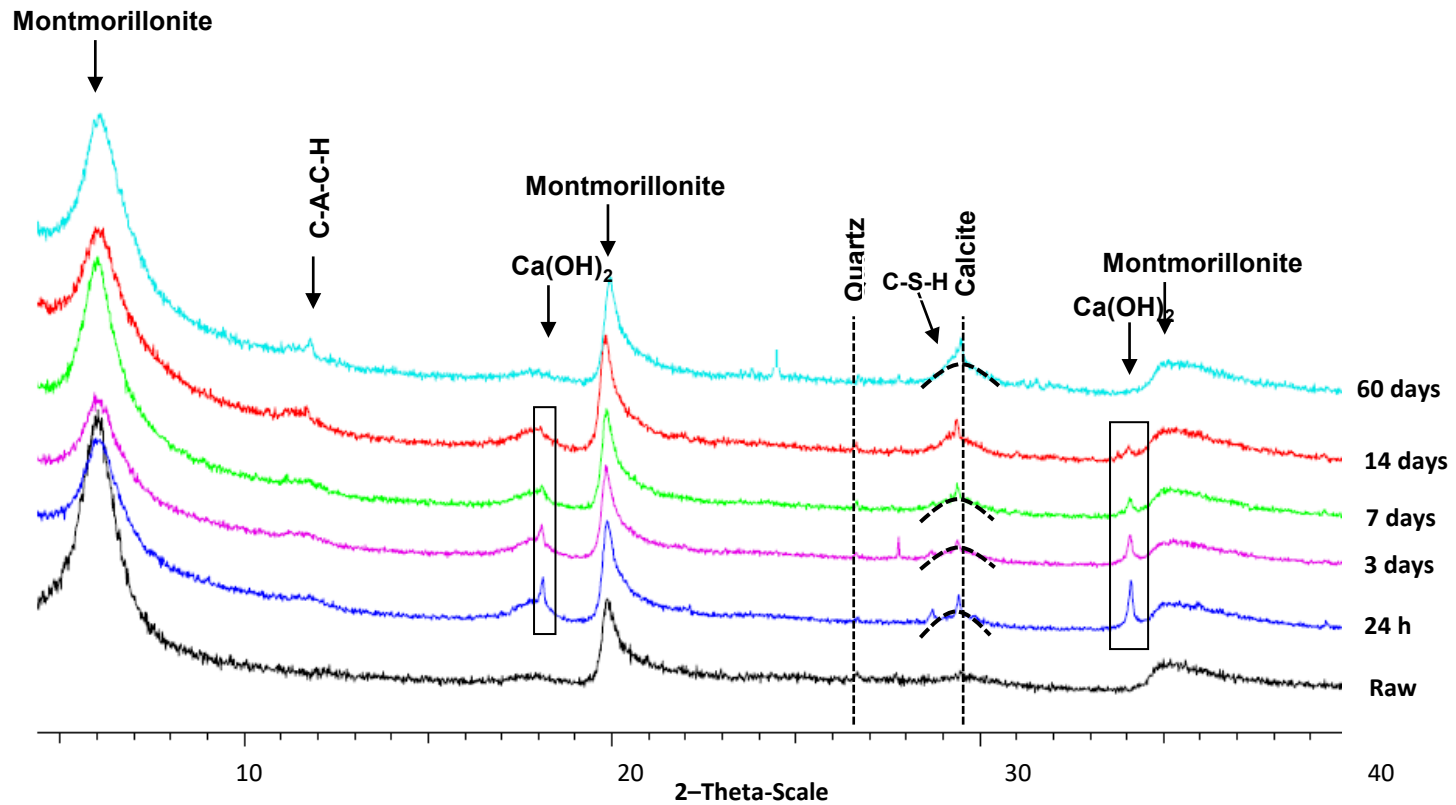


*Prove di compressione 1D (edomteriche)*

Bentonite + 5% CaO



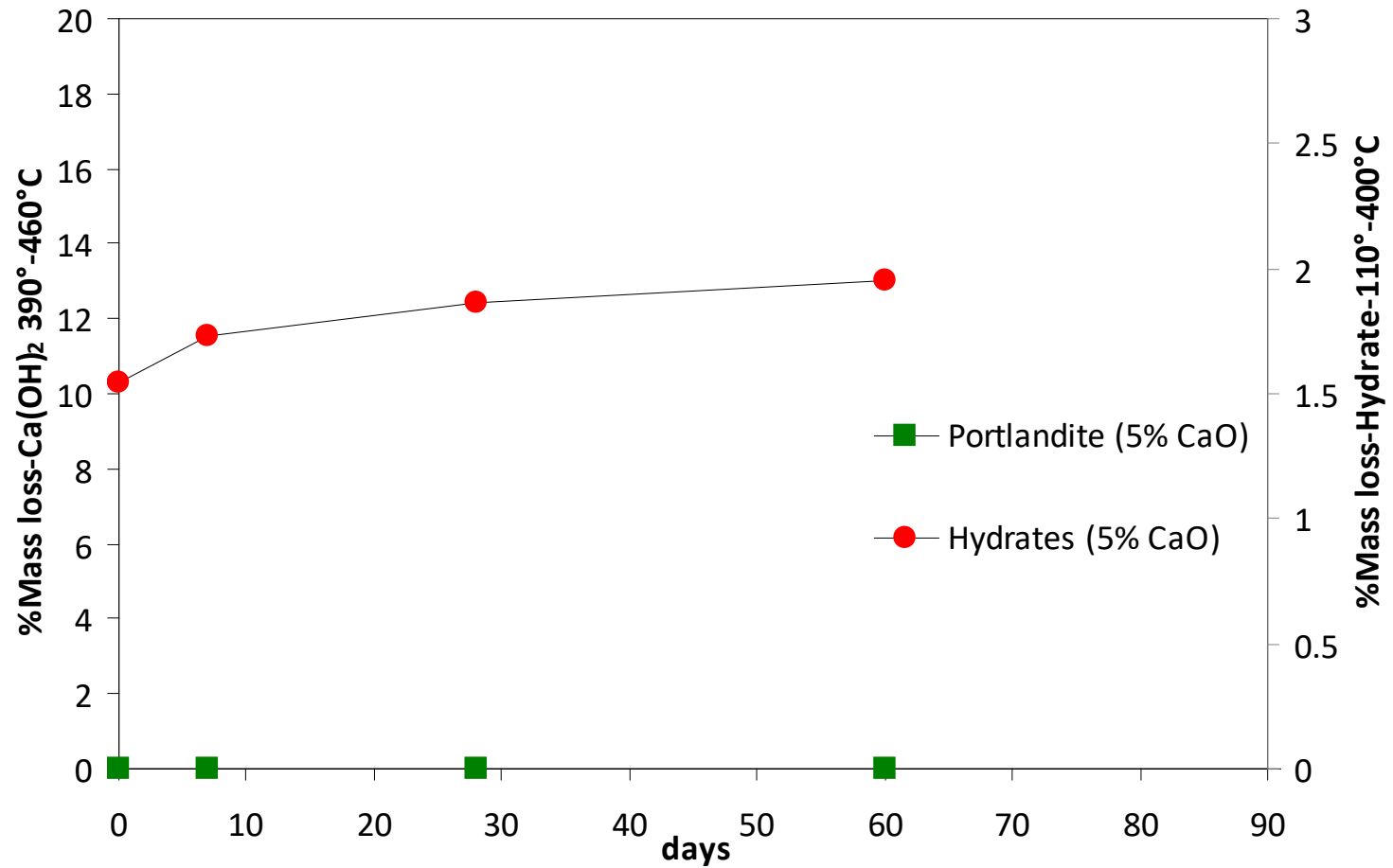
*Diffraattometrie a raggi X*



*Diffrazione a raggi X*

# REAZIONI POZZOLANICHE

Bentonite + X% CaO

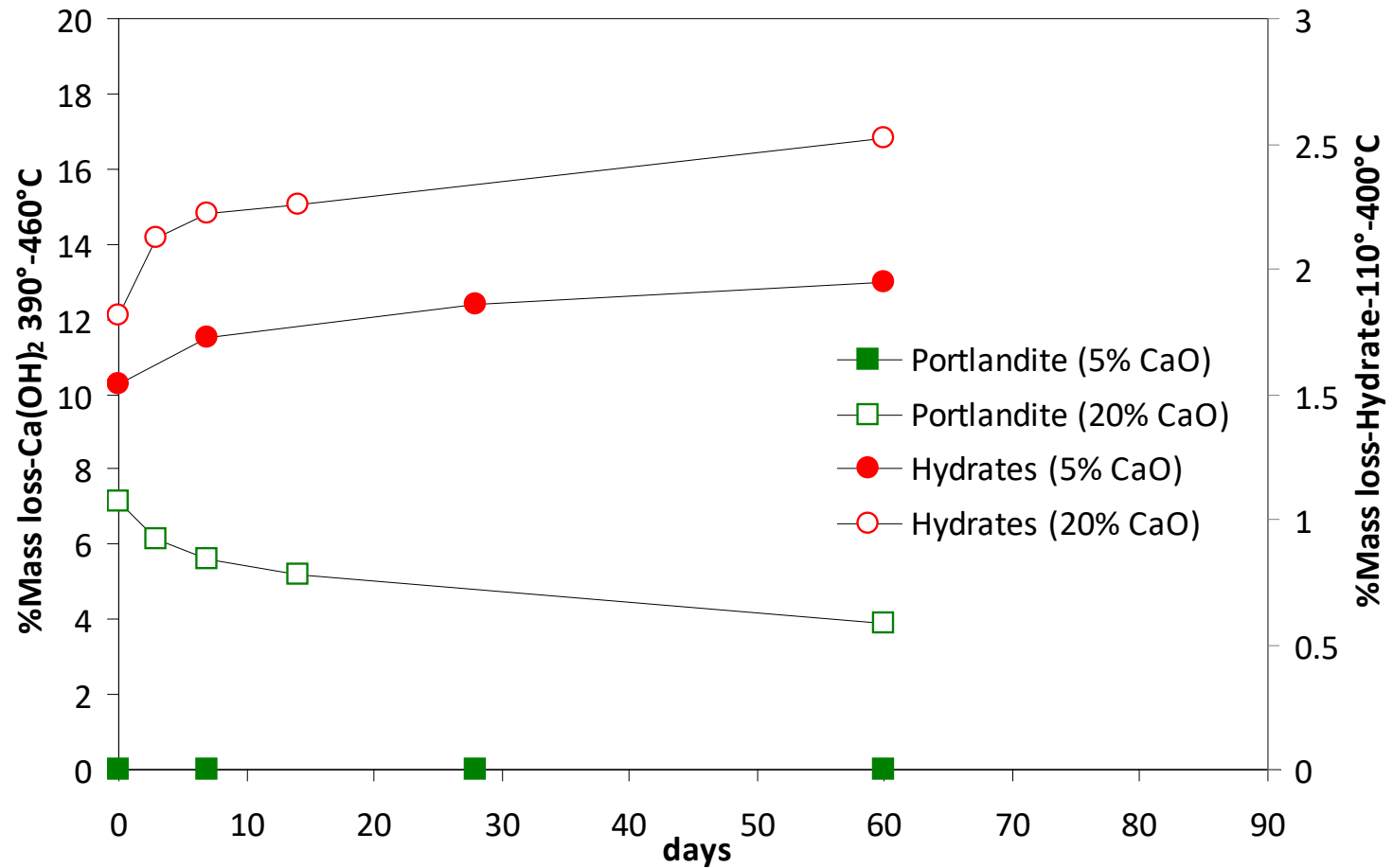


*Termogravimetrie*



# REAZIONI POZZOLANICHE

Bentonite + X% CaO

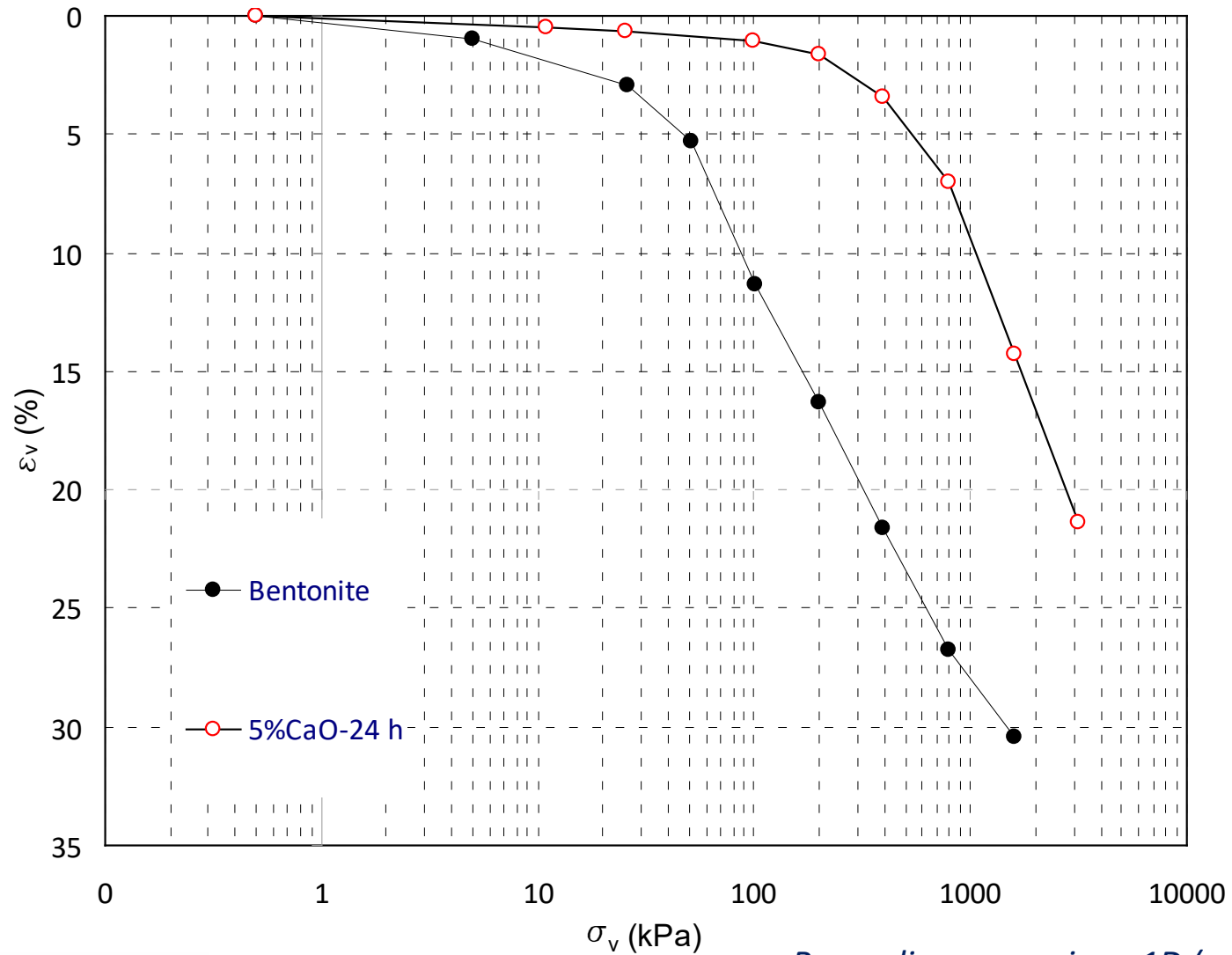


*Termogravimetrie*



# REAZIONI POZZOLANICHE

Bentonite + 5% CaO

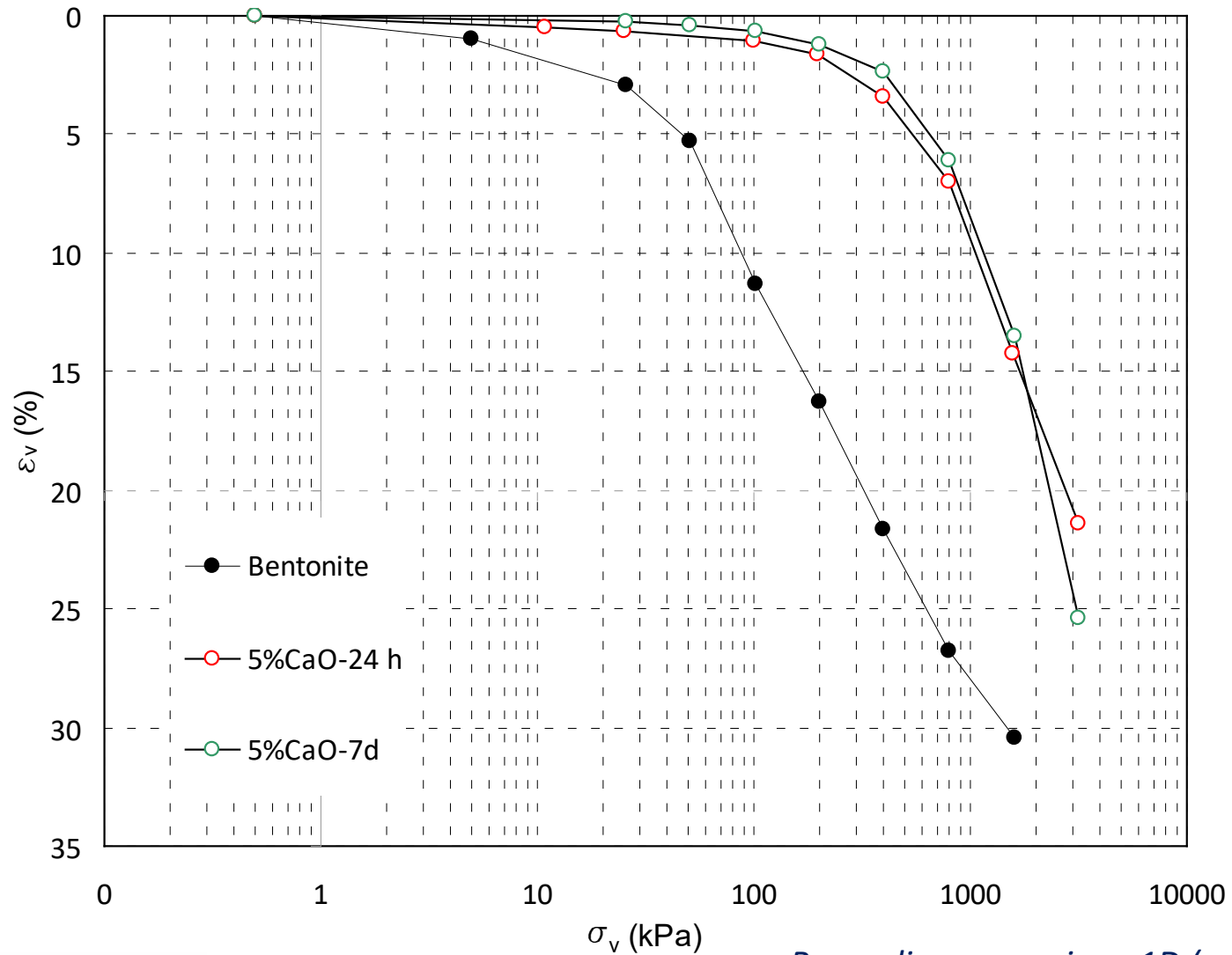


*Prove di compressione 1D (edomteriche)*



# REAZIONI POZZOLANICHE

Bentonite + 5% CaO

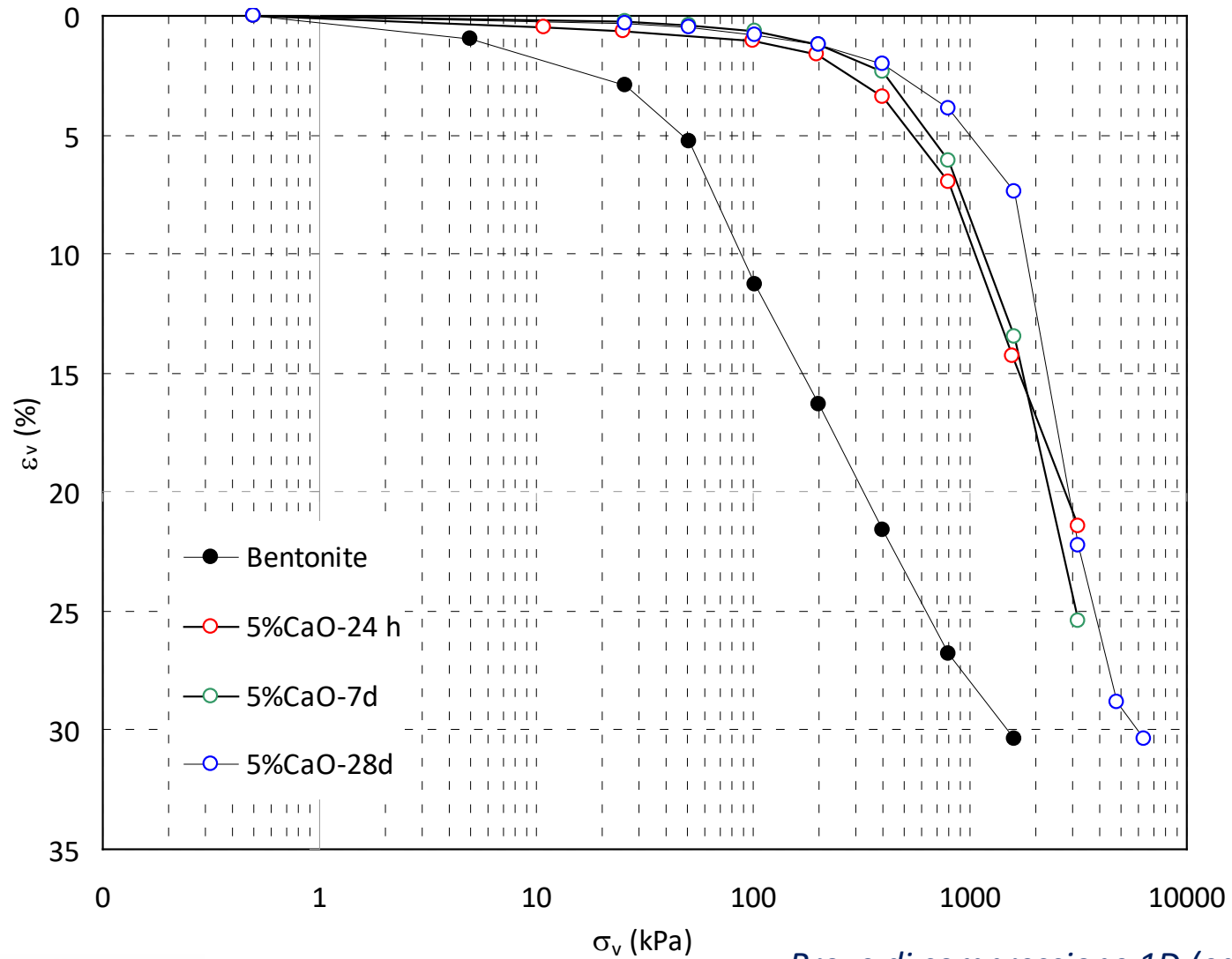


*Prove di compressione 1D (edomteriche)*



# REAZIONI POZZOLANICHE

Bentonite + 5% CaO

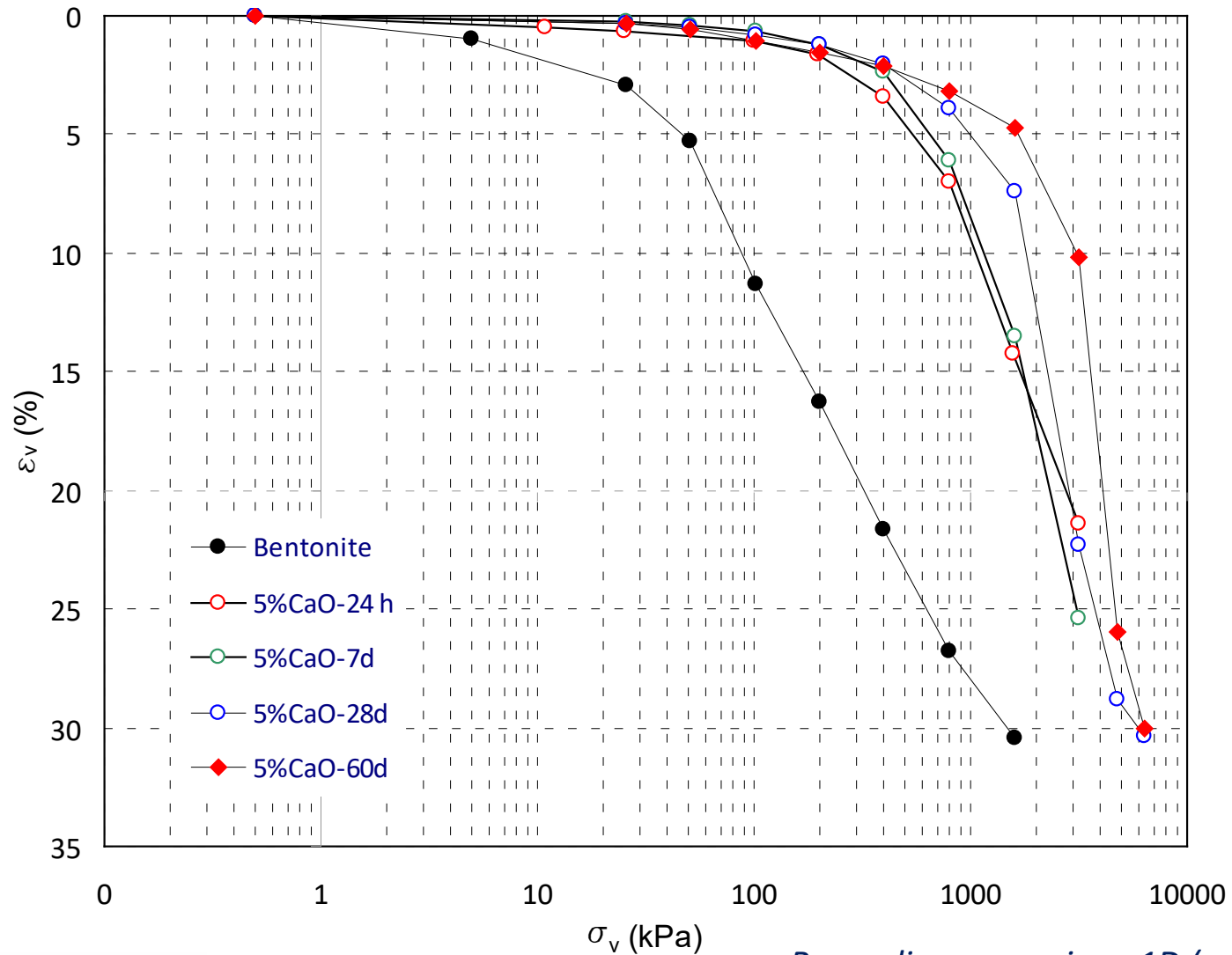


*Prove di compressione 1D (edomteriche)*



# REAZIONI POZZOLANICHE

Bentonite + 5% CaO

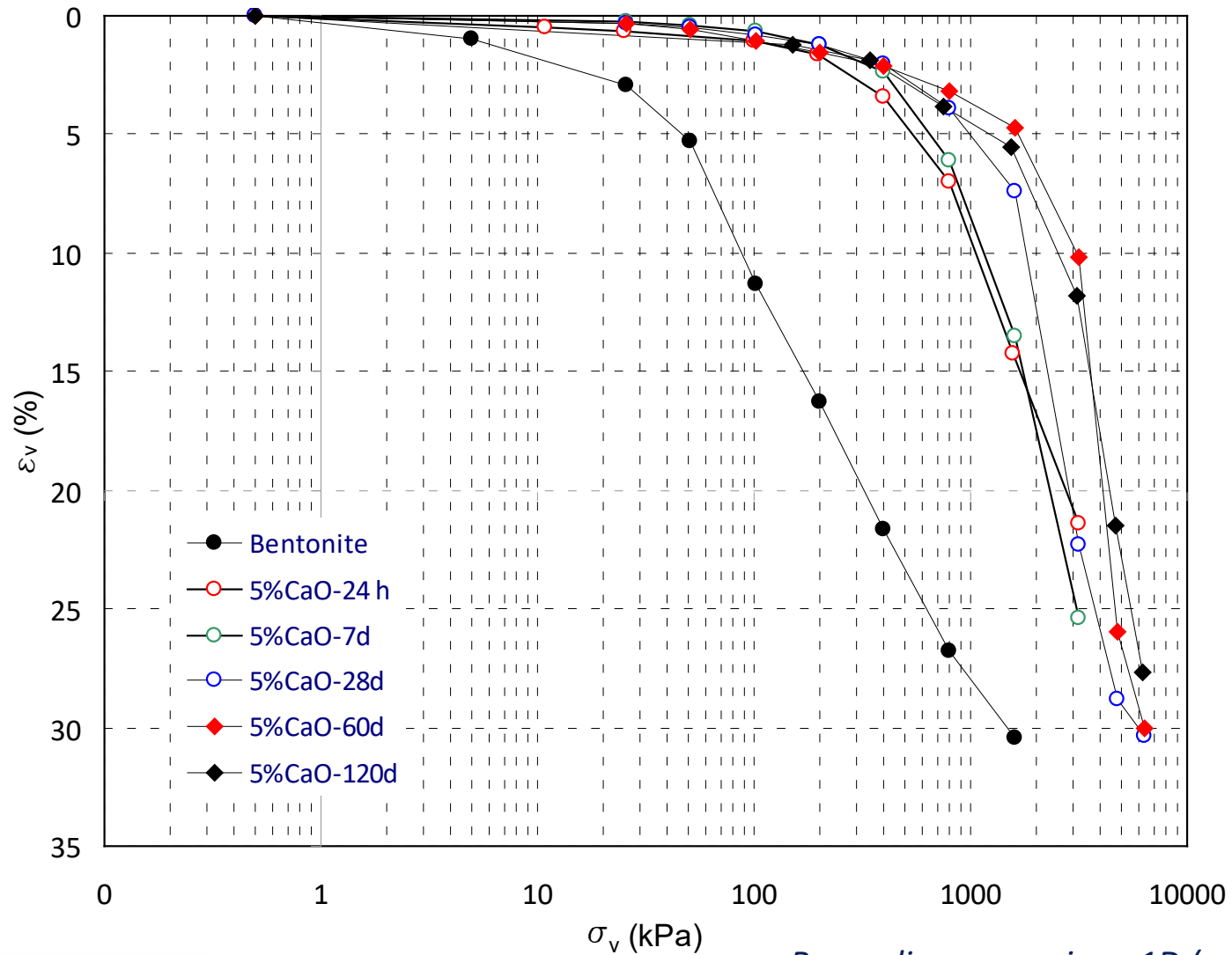


*Prove di compressione 1D (edomteriche)*



# REAZIONI POZZOLANICHE

Bentonite + 5% CaO



Prove di compressione 1D (edomteriche)



# IDONEITA' DEI TERRENI AL TRATTAMENTO A CALCE

Tabella 18.6.3.1.1-1

LIMITI DI ACCETTAZIONE DEL TERRENO NATURALE			
Test di Laboratorio	Norma di riferimento	Requisito	Limiti di accettabilità
Analisi granulometrica	CNR B.U n. 36 UNI EN 933-1 UNI CEN ISO/TS 17892-4	Granulometria	par. 2.1 della norma CNR B.U. n.36 <sup>(1)</sup>
Limiti di Atterberg (LL-LP)	UNI CEN ISO/TS 17892-12	Indice di plasticità IP	>10 <sup>(1)</sup>
Contenuto in sostanze organiche	ASTM D 2974 - C	Sostanze organiche	< 2% <sup>(2)</sup>
Contenuto in solfati	UNI EN 1744-1	Solfati totali	< 0,25% <sup>(3)</sup>

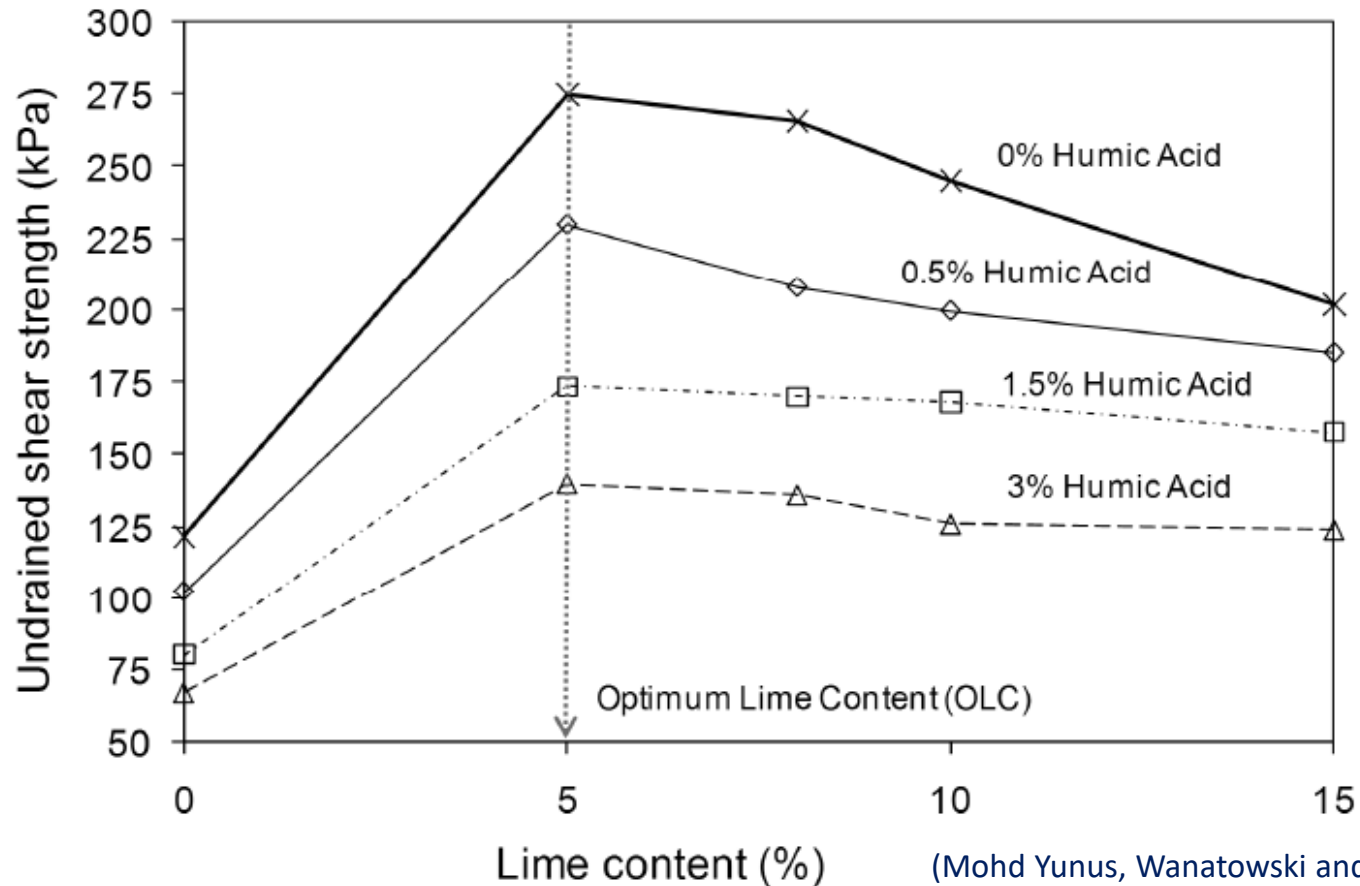
<sup>(1)</sup> Saranno ammesse granulometrie diverse da quelle interamente comprese nel fuso (es. piroclastiti e argilliti) e un valore minore della plasticità a condizione che si dimostri l'idoneità della terra ad essere trattata, attraverso lo studio delle miscele di laboratorio e un campo prova preventivamente approvato da Ferrovie. In ogni caso il diametro massimo degli elementi non dovrà essere maggiore di un quarto (1/4) dello spessore finito di ciascuno degli strati di terra trattata per la realizzazione dei rilevati e l'indice di plasticità dovrà essere  $IP > 5$

<sup>(2)</sup> Questo limite potrà essere superato, a condizione che siano soddisfatti i valori delle prove sul prodotto finale riportati al capitolo II.5 e che l'intervento venga giudicato economicamente conveniente da Ferrovie.

<sup>(3)</sup> Questo valore può essere aumentato fino a raggiungere l'1%, qualora lo studio di laboratorio della miscela sia stato ritenuto idoneo da Ferrovie e che il materiale venga utilizzato unicamente per la formazione del piano di posa del rilevato.

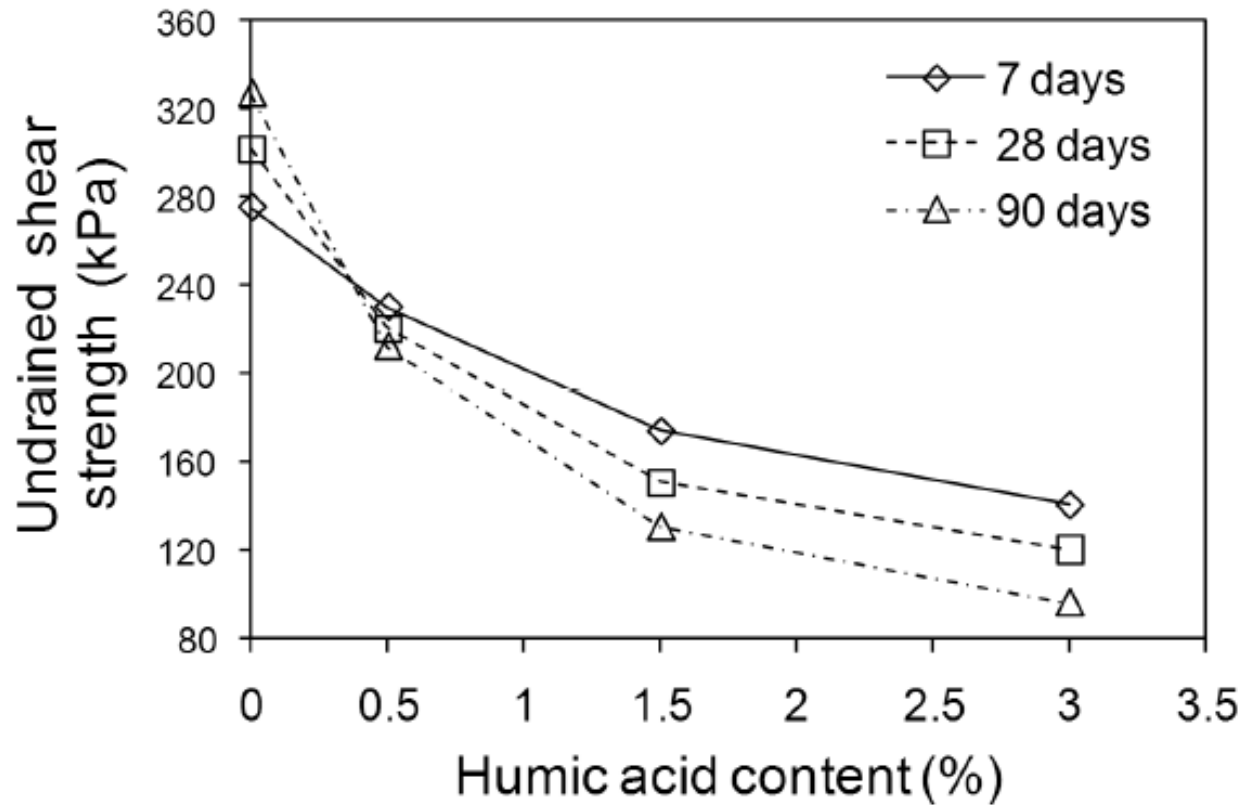
(da ITALFERR, 2024)

# EFFETTO DELLA SOSTANZA ORGANICA



Prove di compressione ELL su provini di caolino stabilizzati  
in presenza di acido umico (  $t = 7$  gg)

# EFFETTO DELLA SOSTANZA ORGANICA



(Mohd Yunus, Wanatowski and Stace, 2011)

Effetto del tempo di maturazione sulla resistenza al taglio  
di provini stabilizzati (5% calce idrata) in presenza di acido umico

# EFFETTO DEI SOLFATI



(Harris, 2006)



# EFFETTO DEI SOLFATI

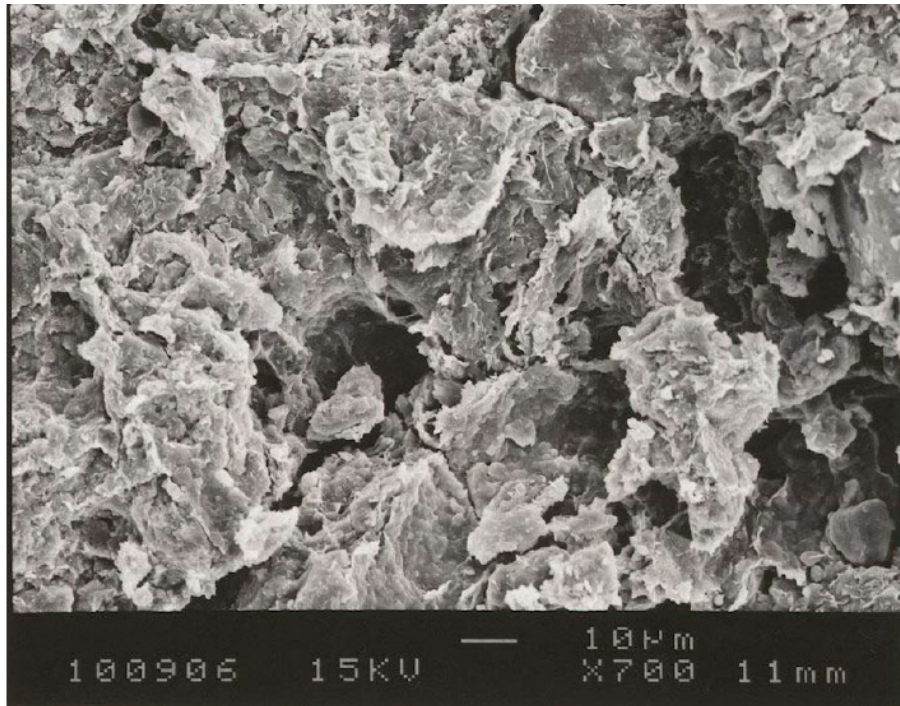


(Harris, 2006)

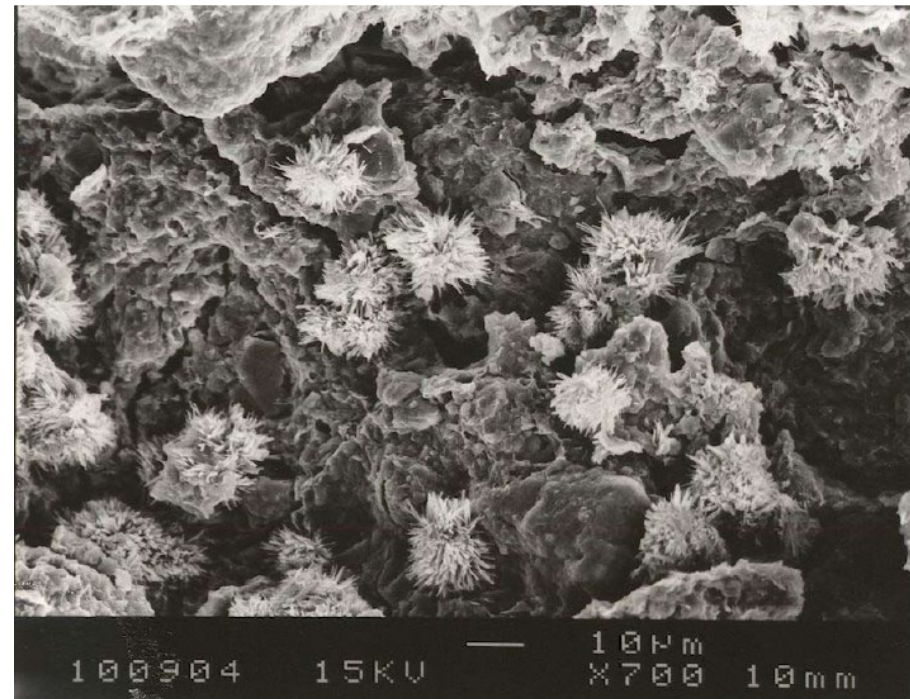


# EFFETTO DEI SOLFATI

In presenza di solfati, l'aggiunta di calce favorisce la formazione di composti espandenti  
(**taumasite, ettringite**)



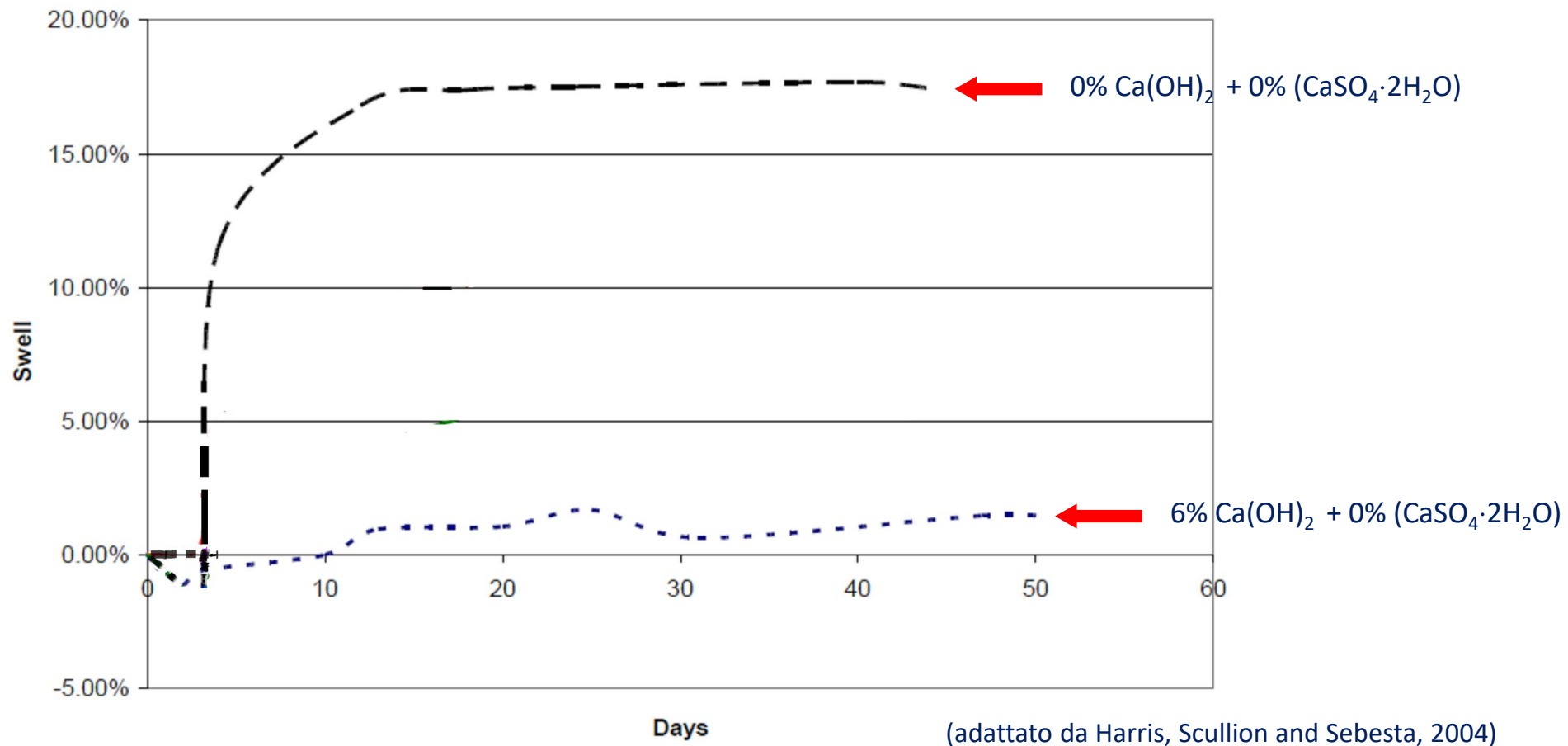
terreno non trattato



terreno stabilizzato

(Harris, 2006)

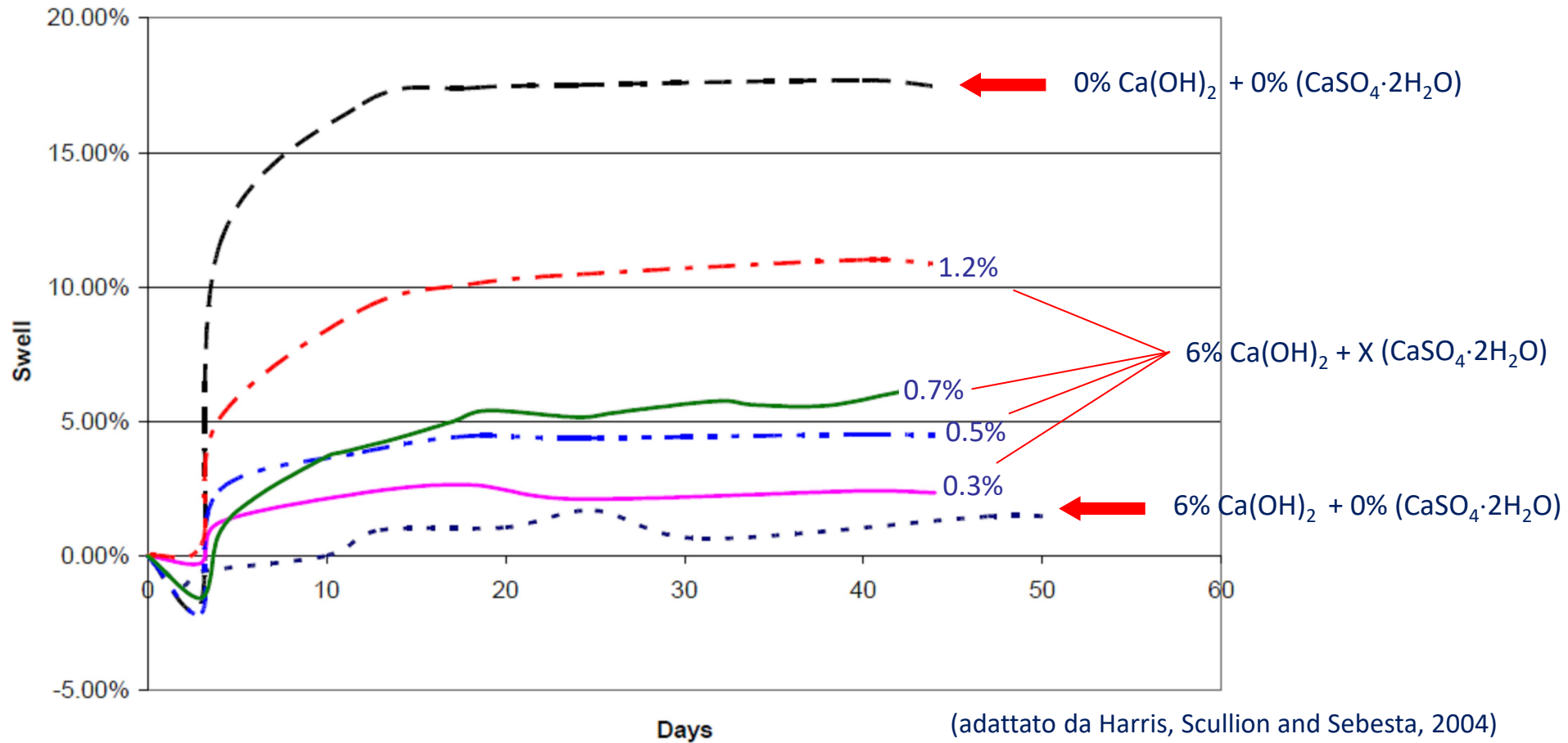
# EFFETTO DEI SOLFATI



Provini non trattati e stabilizzati con 6% di calce idrata

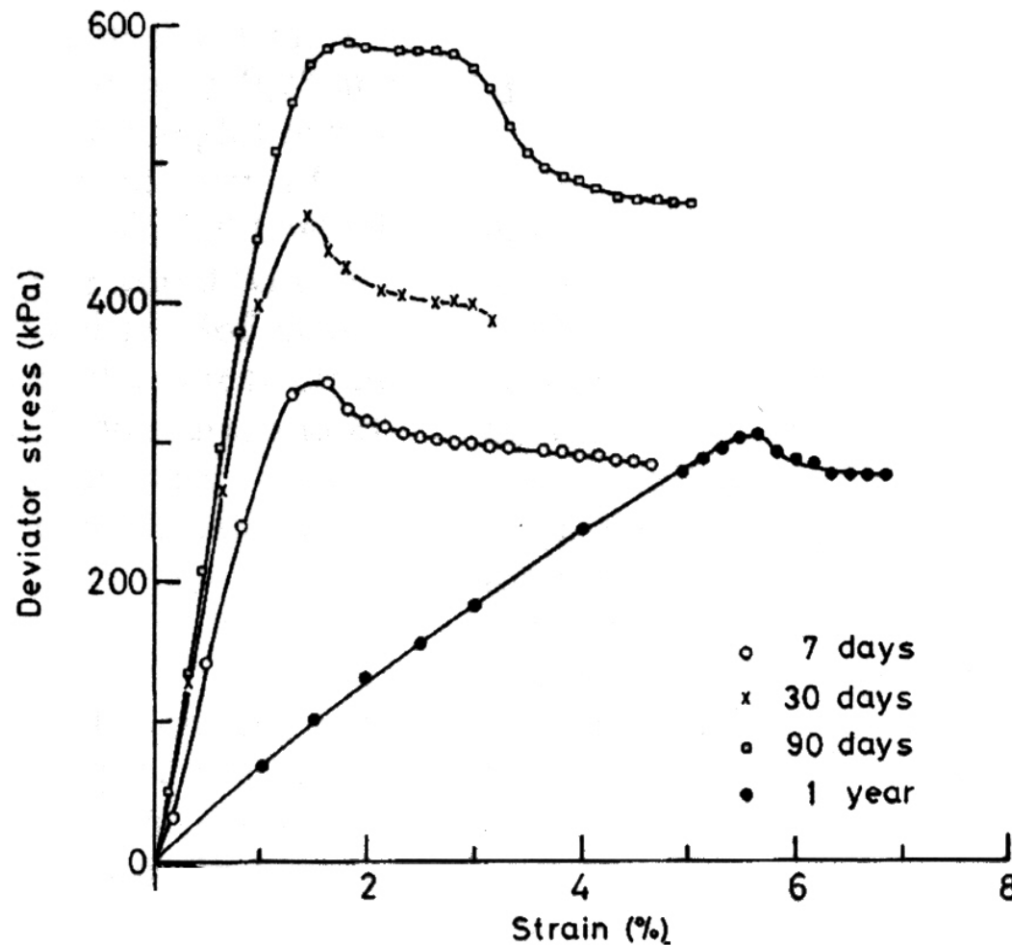


# EFFETTO DEI SOLFATI



Provini stabilizzati (6% calce idrata) in presenza di varie percentuali di solfati

# EFFETTO DEI SOLFATI



(Sivapullaiah *et al.*, 2000)

Resistenza al taglio di provini stabilizzati (6% calce idrata) in presenza del 3.0%  $\text{Na}_2\text{SO}_4$

# LE NUOVE FRONTIERE DELLA STABILIZZAZIONE A CALCE DA RIFIUTO A RISORSA

Catania, 31 Maggio 2024

## La stabilizzazione a calce



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