College on Soil Physics
3 March – 21 March 2003

FAUBA

SOIL SHRINKAGE CHARACTERISTICS IN SWELLING SOILS

Miguel A. Taboada

Department of Agricultural Engeenering and Land Use,
College of Agriculture, University of Buenos Aires

E-mail: mtaboada@agro.uba.ar

OBJECTIVES OF THE LECTURE

- to distinguish between soils having different magnitude of swelling, as well as the consequences on soil structural behaviour,

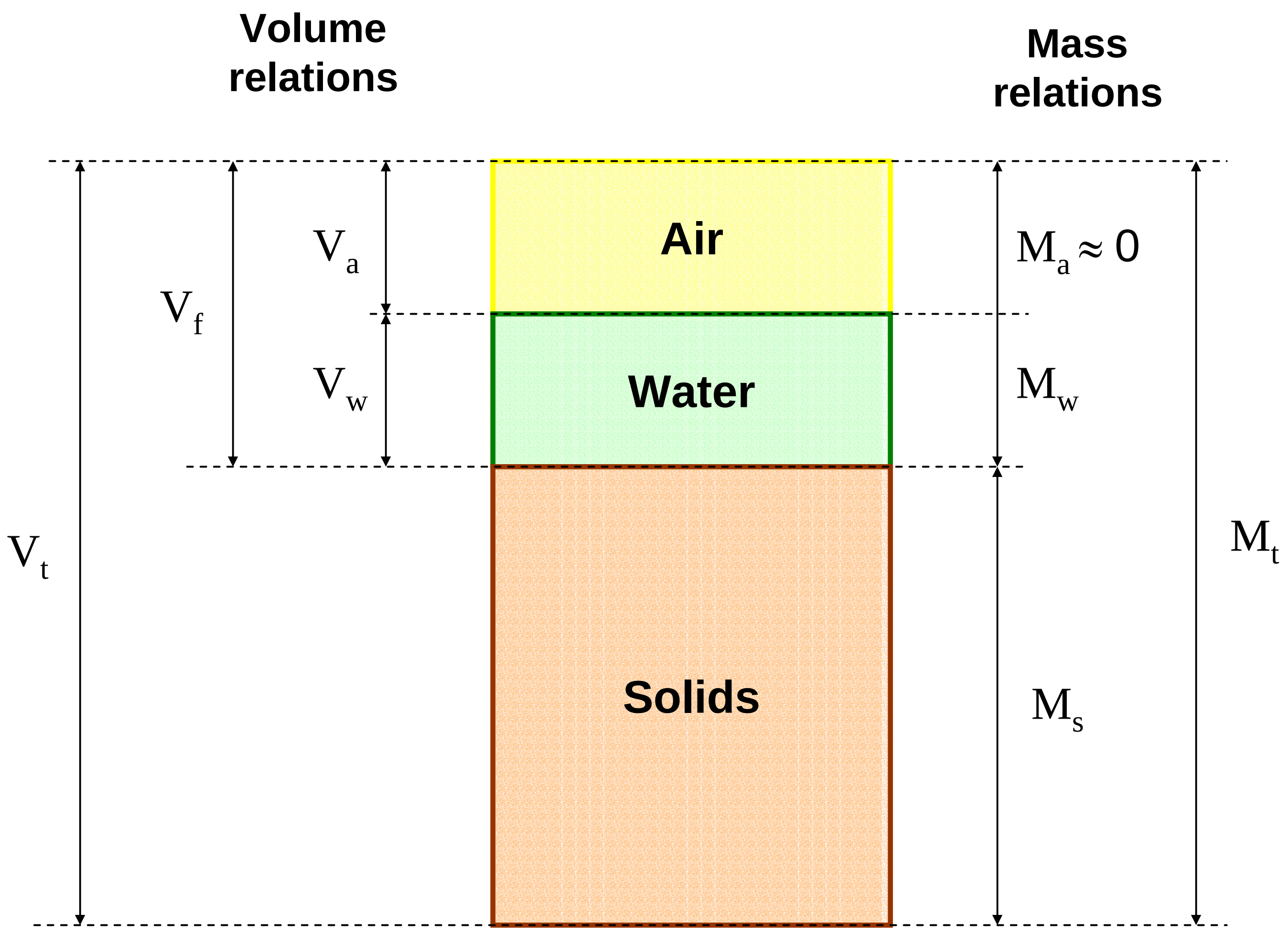
- to understand soil swelling and shrinkage mechanisms, and the development of desiccation cracks;

- to know methods to characterise soil swell/shrink potential;

- to construct soil shrinkage curves, and derive shrinkage indices, as well to apply them to assess soil management effects.

The “physics” of soil physics traditionally assumes that soils have rigid behaviour; that is relatively stable relations between their solid and pore volume**.**

In the well - known schematic diagram of the three phase system, the solid phase remains stable while the volumes of water and air vary conversely within pore space.



Schematic diagram of the soil as a three phase system

When a rigid soil dries, a given volume of air enters to the pore space in replacement of an equivalent volume of water.

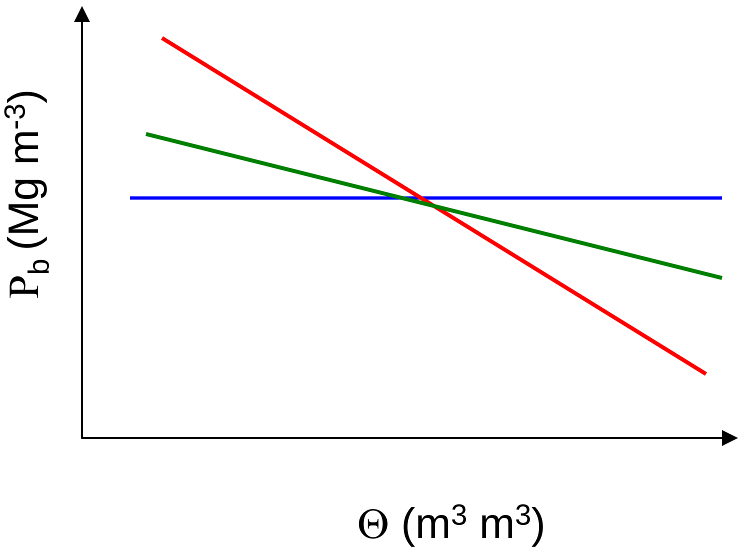
$$d\,V_w = d\,V_a$$

Therefore, air-filled porosity increases as a rigid soil dries.

Based on this theoretical approach several methodologies have been developed. For instance, the determination of pore size distribution by the water desorption method.

Rigid or non swelling soils do not change their specific volume, ν, and hence, their their bulk density, ρ_b,during their water content, θ, variation range.

In contrast, extensively swelling soils undergo significant bulk density, ρ_b, variations during their water content, θ, variation range.



Between those extreme situations, there is a great number of soils that develop only moderate swelling.
It has important consequences on the dynamics of soil structure.

Rigid soils ≠ **Swelling soils**

Rigid soils

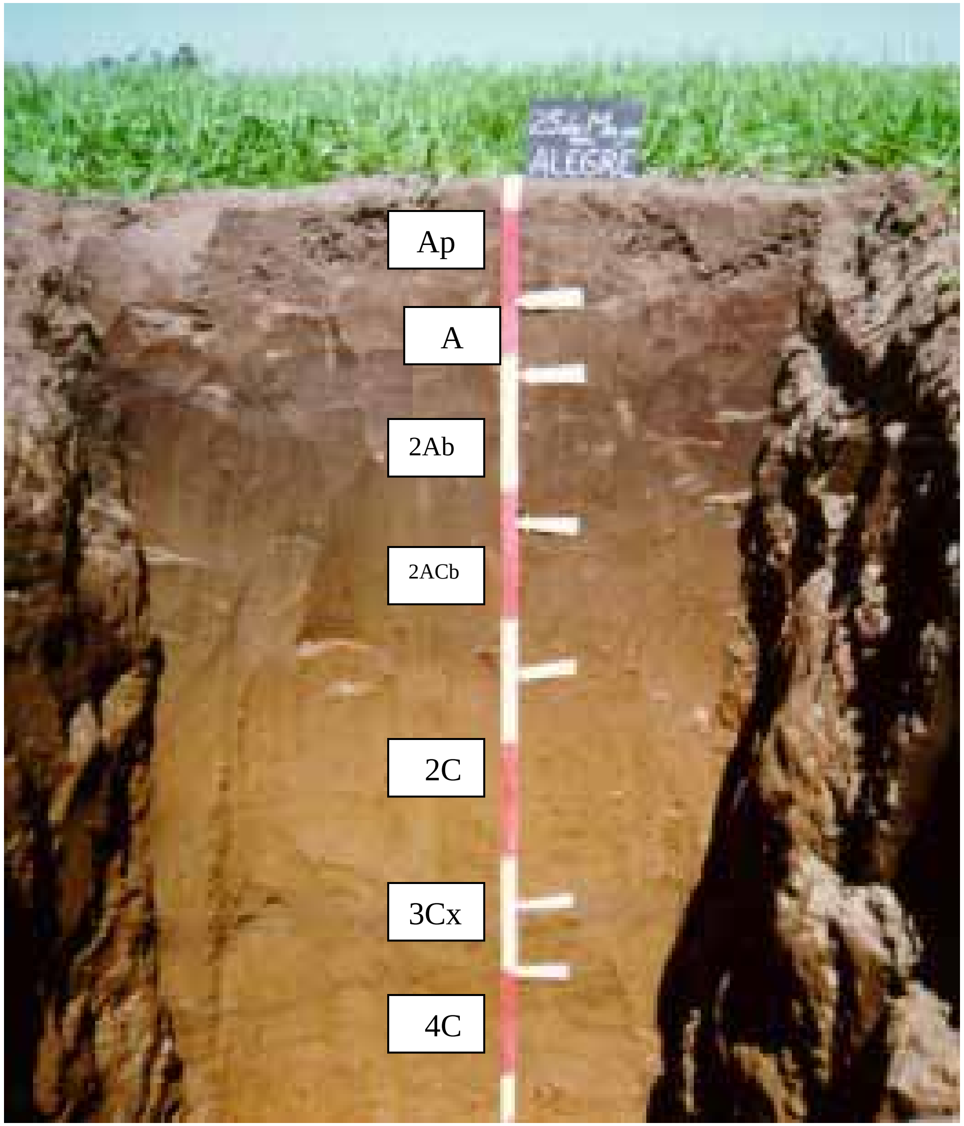
- coarse – textured;
- organic matter – poor
- low aggregate stability
- high module of rupture
- hard to till
- low resilience

Hard – set behaviour

Swelling soils

- fine – textured
- smectitic type of clays
- development of dessication craks
- high resilience
- do not require tillage

Self – mulch behaviour



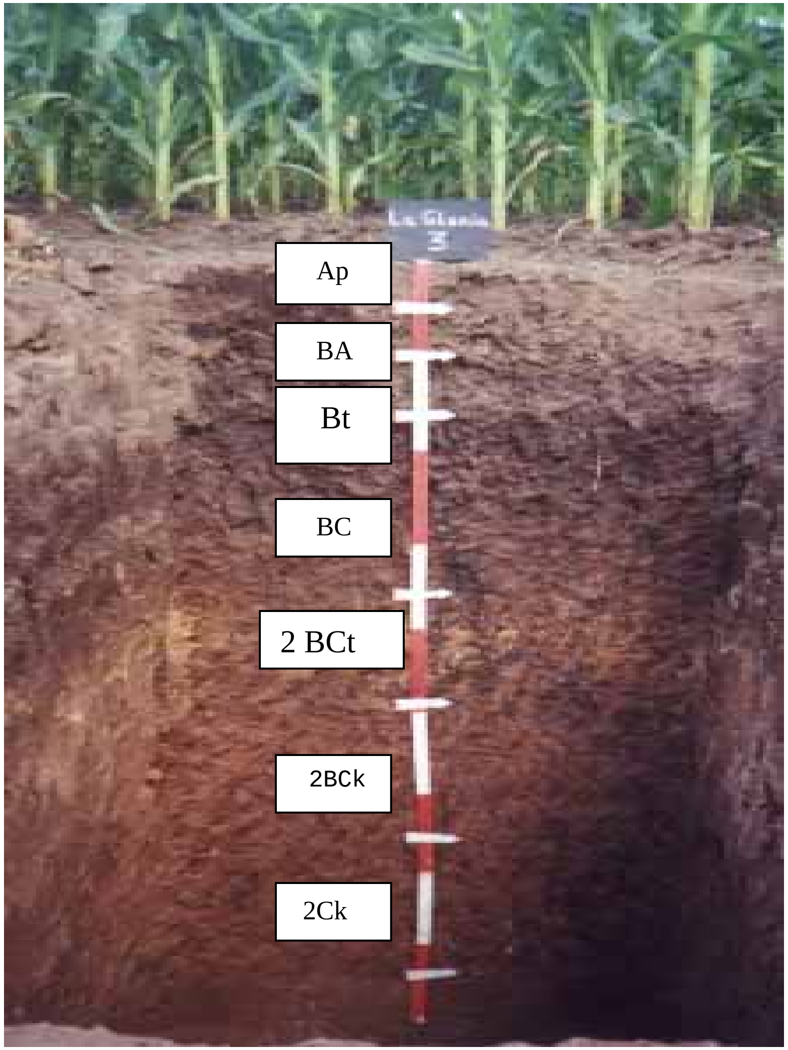
Pampean soils

Southern Rolling Pampa:

Loamy sand, Haplic Phaeozem

Non swelling soil cropped to wheat

A loamy sand, Haplic Phaeozem, having an induced plow pan. The soil was cropped to wheat



Pampean soils

Center of the Rolling Pampa:

Silty clay loam, Abruptic Phaeozem

Moderately swelling soil cropped to maize

Mesopotamia (Entre Ríos Province):

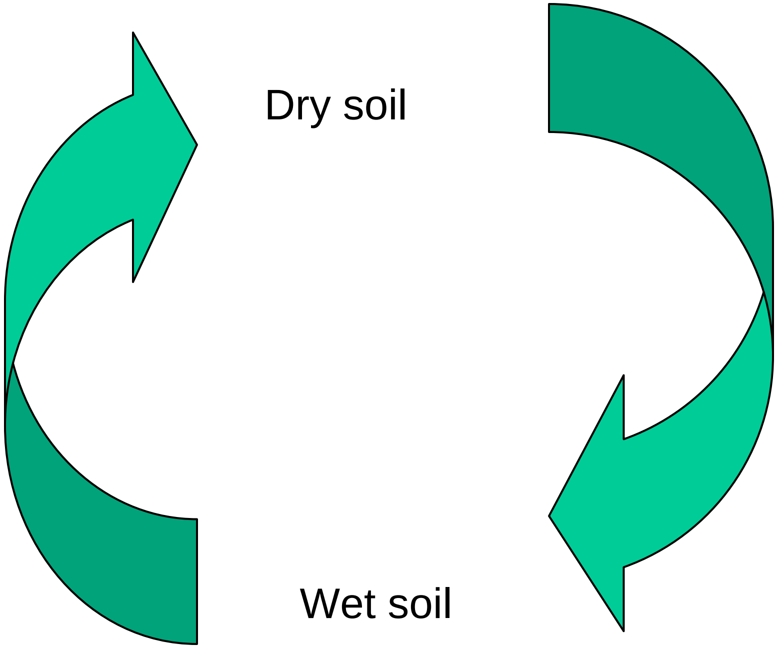
A silty clay loam, Vertisol.

Extensively swelling soil cropped to soybean using zero tillage.

Processes taking place in swelling soils during drying and wetting

Drying:

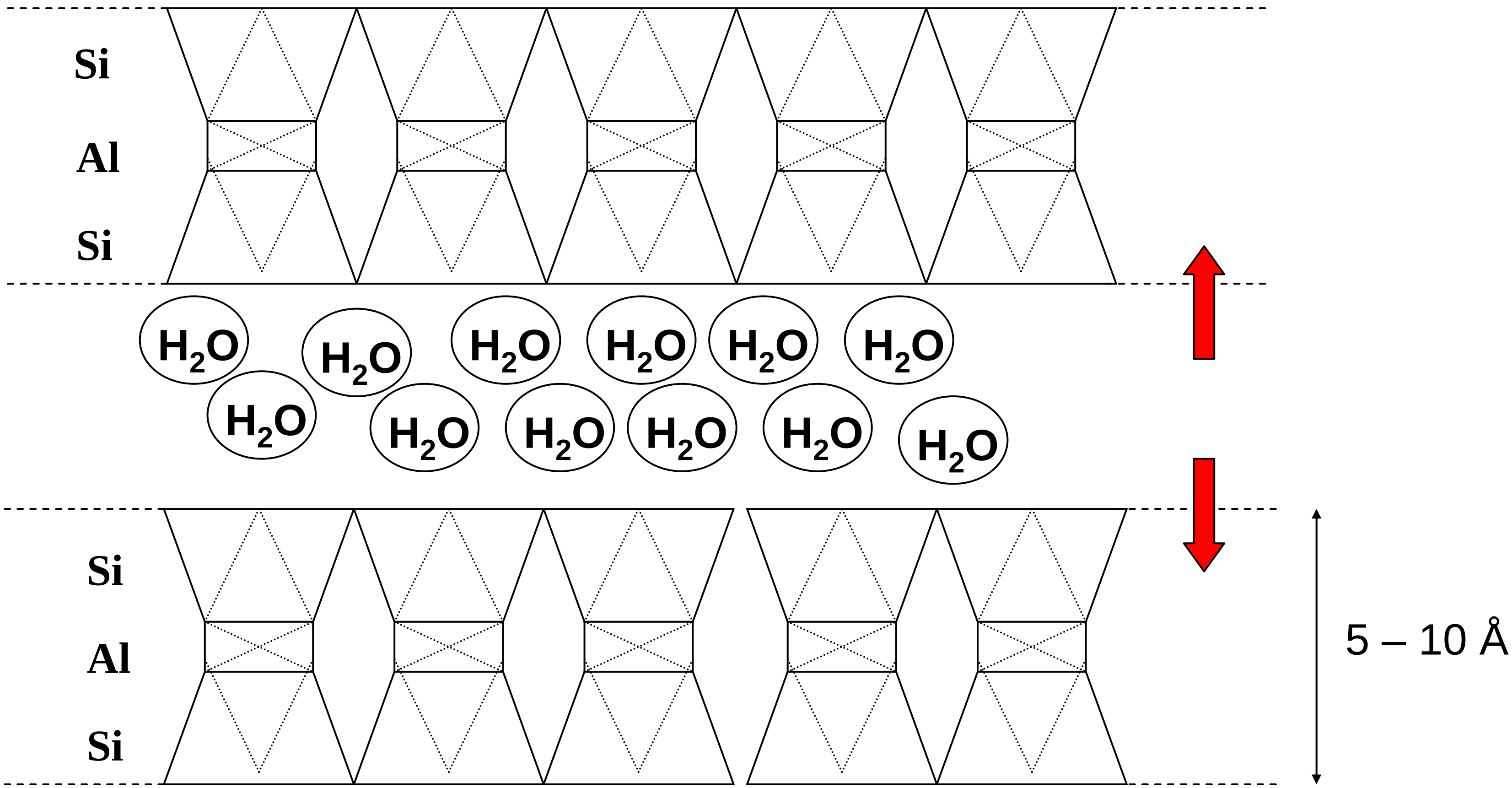
- shrinkage
- cracking
- subsidence



Wetting:

- swelling
- cracks closening
- soil raising

Soil swelling is mainly caused by the intercalation of water molecules entering to the interplane space of smectitic clay minerals.

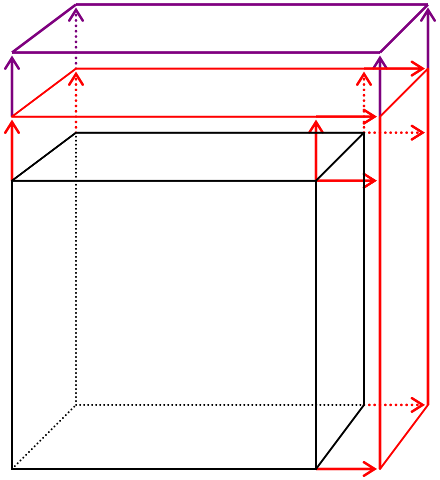


Types of soil swelling

Dry soil

Soil wetting

3-D
While dessication cracks are still opened



1-D
After dessication cracks were closed

Wet soil

Consequences of soil swelling

Unfavourable

Uncroped soils:

- destruction of buildings, roads and pipelines.

Cropped soils:

- by – pass flow phenomena;

- breaking of capillarity when there are horizontal cracks.

Favourable

Uncroped soils:

- sealing of landfills with swelling clays:

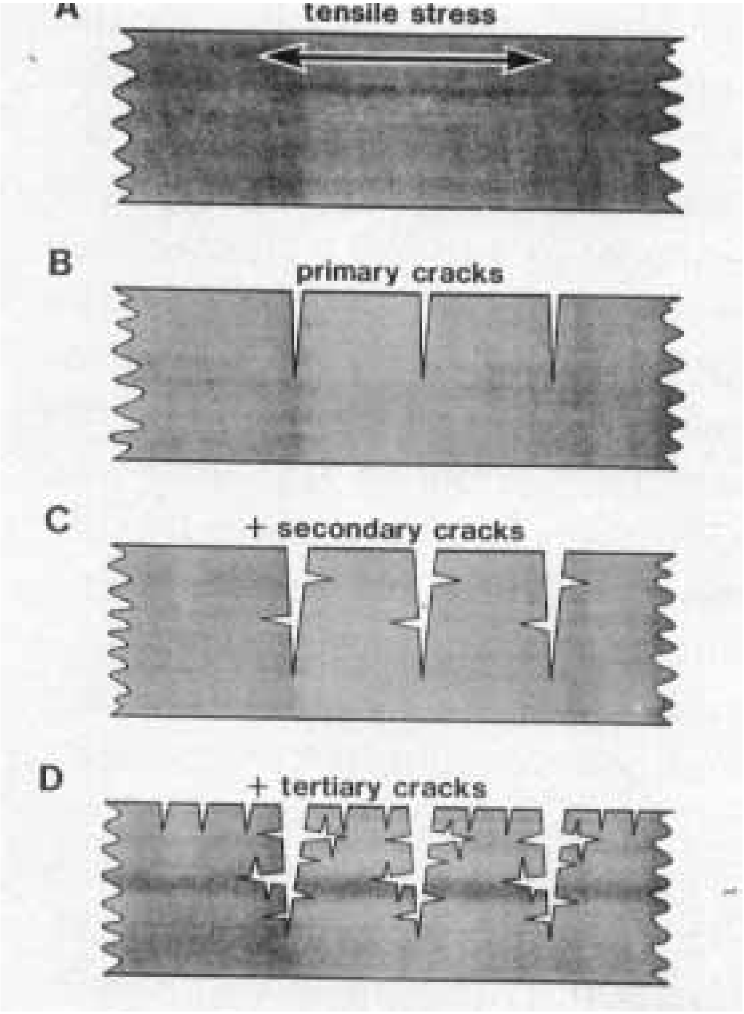
Cropped soils:

- improvement of drainage and aeration through cracks;

- decreasing of runoff

- recovery of compaction by self – mulching.

Development of dessication cracks (after Dexter 1988)



Planes of weakness

Microcrack pattern

Cracks = future void spaces and
Walls of future aggregates

Soil structural recovery after compaction

Soil swell – shrink potential

Coefficient of linear extensibility (COLE) = $(\nu_{1/3\ atm} - \nu_{dry})^{1/3} - 1$

$\nu_{1/3\ atm}$ = soil volume at 1/3 atm water retention;
ν_{dry} = soil volume at oven dry conditions

Soil swell – shrink potential ....:.....	**COLE**
Low	< 0.03
Moderate	0.03 – 0.06
High	0.06 – 0.09
Very high	> 0.09

Relationship between COLE and some edaphic variables

Independent variables	R^2
Clay < 2 µm	0,87***
Clay 2 - 0.2 µm	0,41**
Clay < 0.2 µm	0,43**
Smectites < 0.2 µm	0,61***
Interstratified swelling clay < 0.2 µm	0,2
Swelling clay < 0.2 µm	0,91***
Porosity	0,33*
organic C	0,08
Sodium Adsorption Ratio	0,01

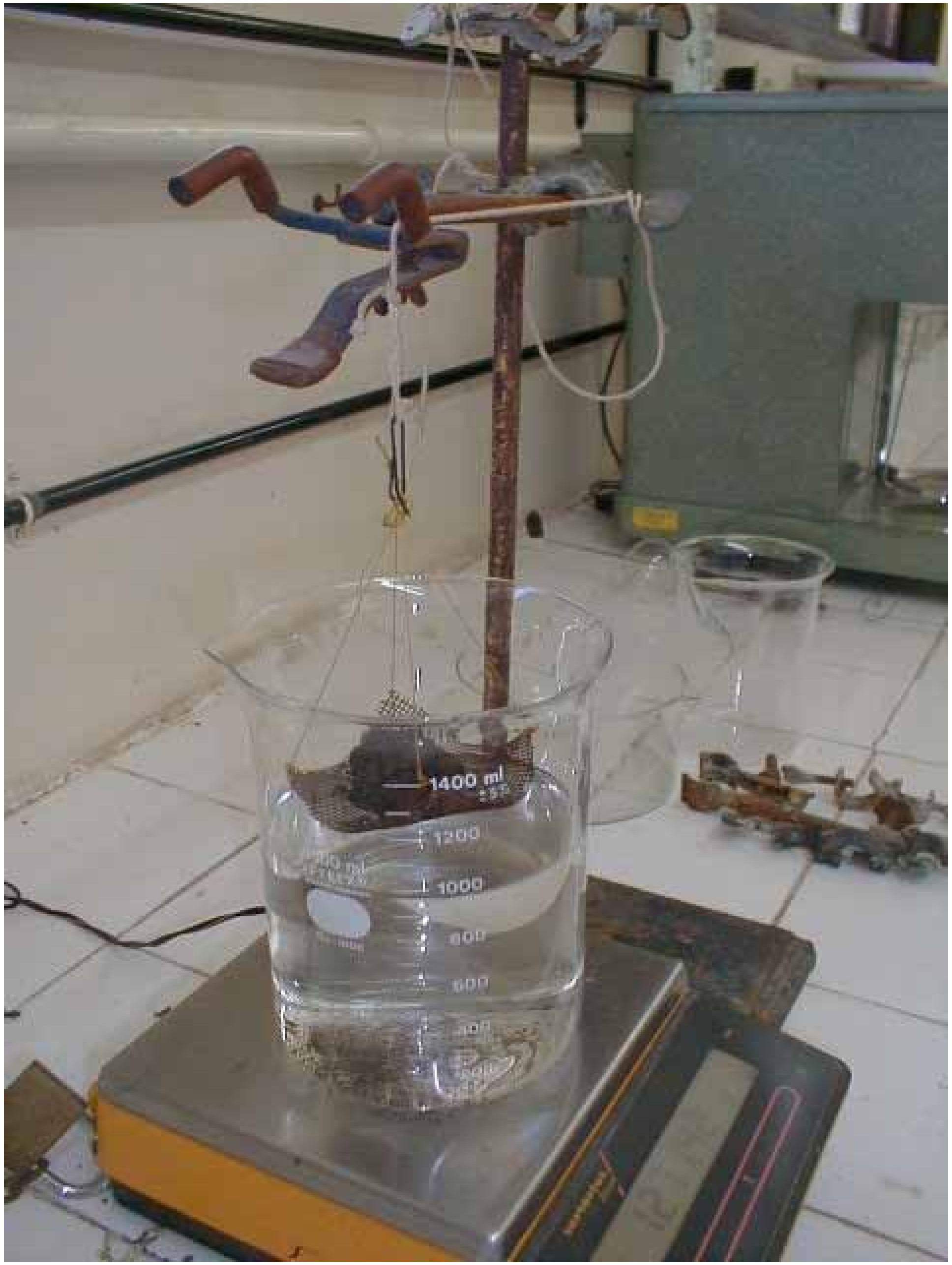
After Parker et al. (1982)

The shrinkage characteristic or shrinkage curve

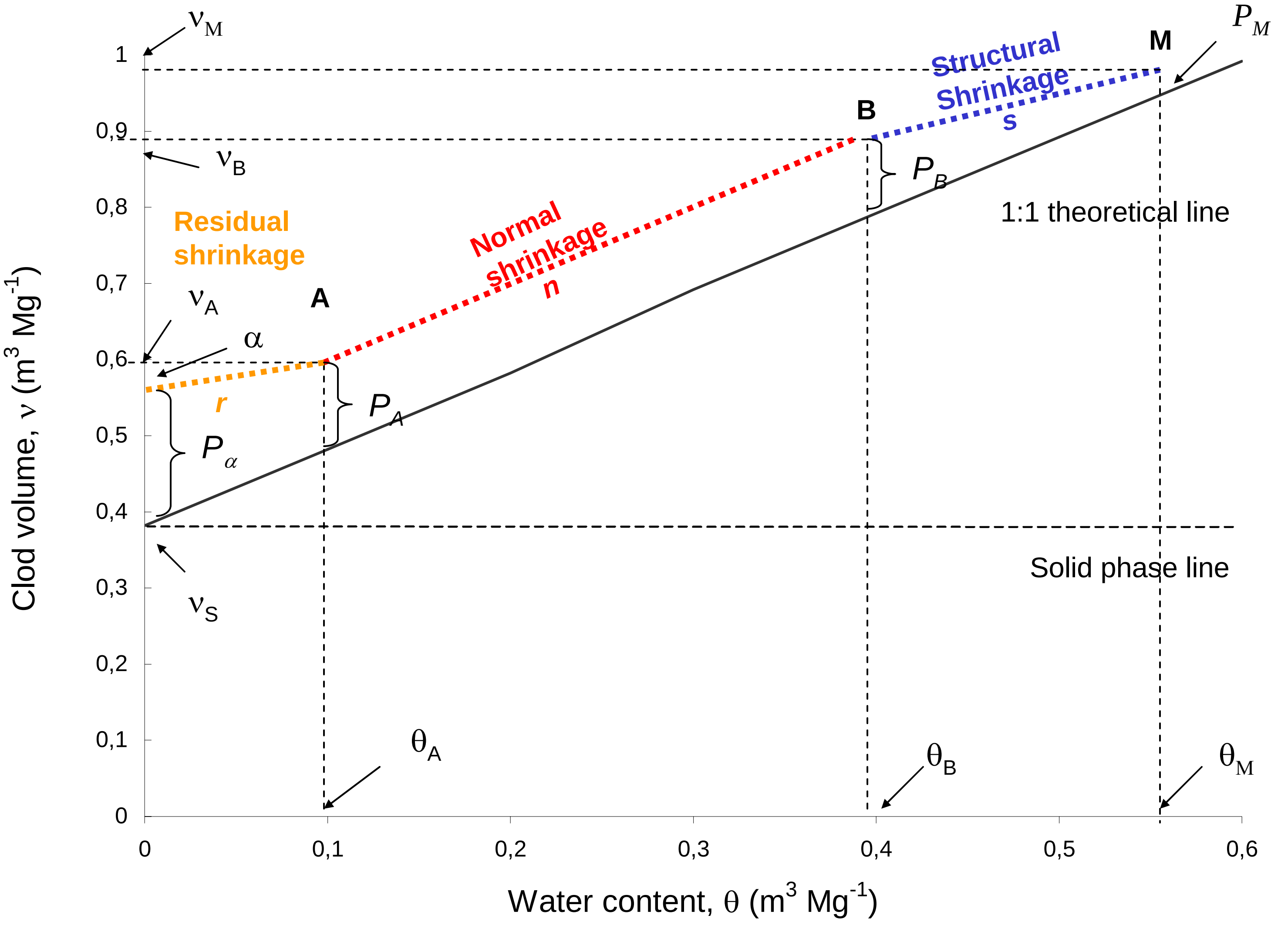
(Mc Garry and Daniells 1987)

Each soil has a characteristic water retention curve (water content *vs* matric potential). Likewise, swelling soils also have a **characteristic shrinkage curve**.

It shows the variation of soil specific volume, ν, with water content, θ, during the air – drying of water saturated natural clods.



The volume of aggregates is measured by hydrostatic up thrust in a non polar liquid (kerosene) during air drying. The corresponding water content is also measured at different times of drying.



Structural
Shrinkage
s
M
P_M
ν_M
B
P_B
ν_B
Residual
shrinkage
Normal
shrinkage
n
1:1 theoretical line
ν_A
A
α
r
P_A
P_α
Solid phase line
ν_S
θ_A
θ_B
θ_M
Clod volume, ν (m3 Mg-1)
Water content, θ (m3 Mg-1)
1
0,9
0,8
0,7
0,6
0,5
0,4
0,3
0,2
0,1
0
0,1
0,2
0,3
0,4
0,5
0,6

Indices and related variables from the shrink data of natural soil clods (Mc Garry and Daniells 1987).

ν_B specific volume at the limit of normal swelling

ν_A specific volume at the air entry point

n slope of the line B $\rightarrow$ A (normal shrinkage)

θ_B θ at the limit of normal swelling

θ_A θ at the air entry point, i.e. the end of residual shrinkage

r slope of the line A $\rightarrow$ α (residual shrinkage)

P_B specific volume of air filled pores at B

P_A specific volume of air filled pores at A

P_α specific volume of air filled pores at α

θ_B-θ_A difference between θ at the limit of normal swelling and θ at the air entry point, i.e. range of θ in the normal shrinkage zone.

θ_A-θ_α difference between θ at the air-entry point and θ = 0, i.e. the range of θ over the residual shrinkage zone (i.e.the value of θ_A).

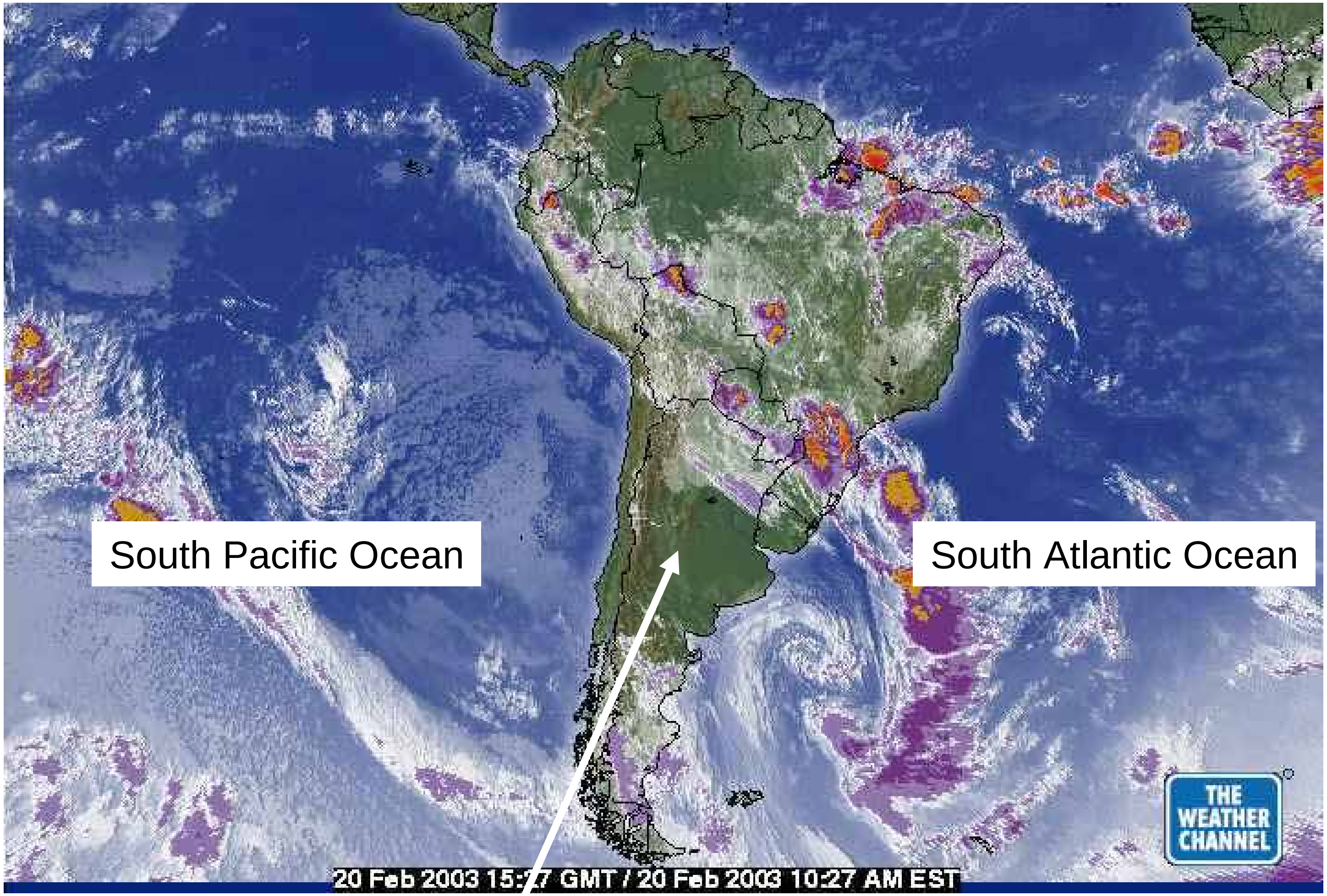
Shrinkage characteristic of pampean silty clay loams affected by water erosion (Barbosa et al. 1999)

Pampean silty loams have low structural regeneration capacity.

We hypothesized whether this could be improved, or not, by the enrichment of topsoil with swelling clays.

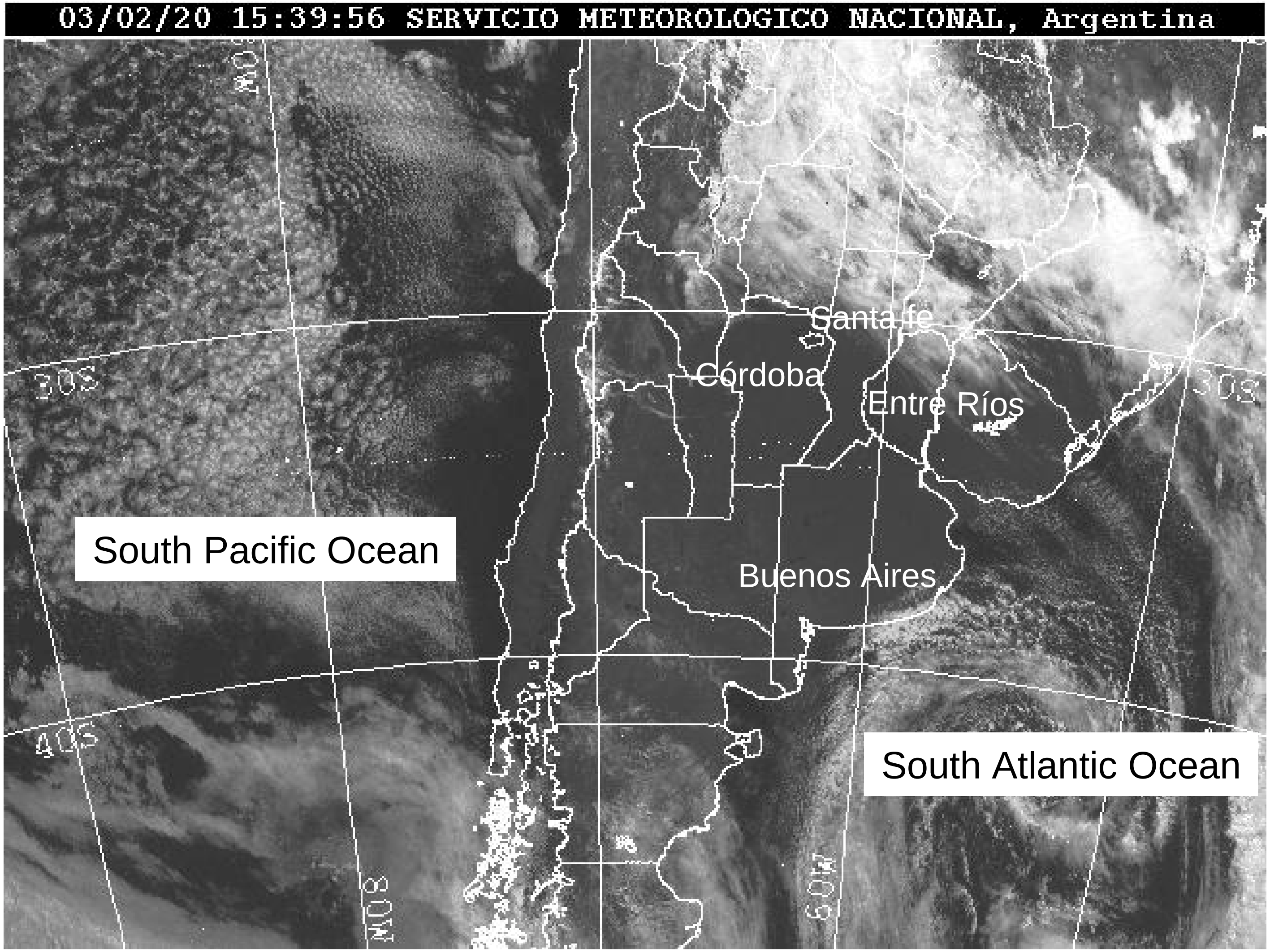
This situation can be found in severely degraded soils, in which the shallow A horizon was previously mixed with the below lying B horizon.

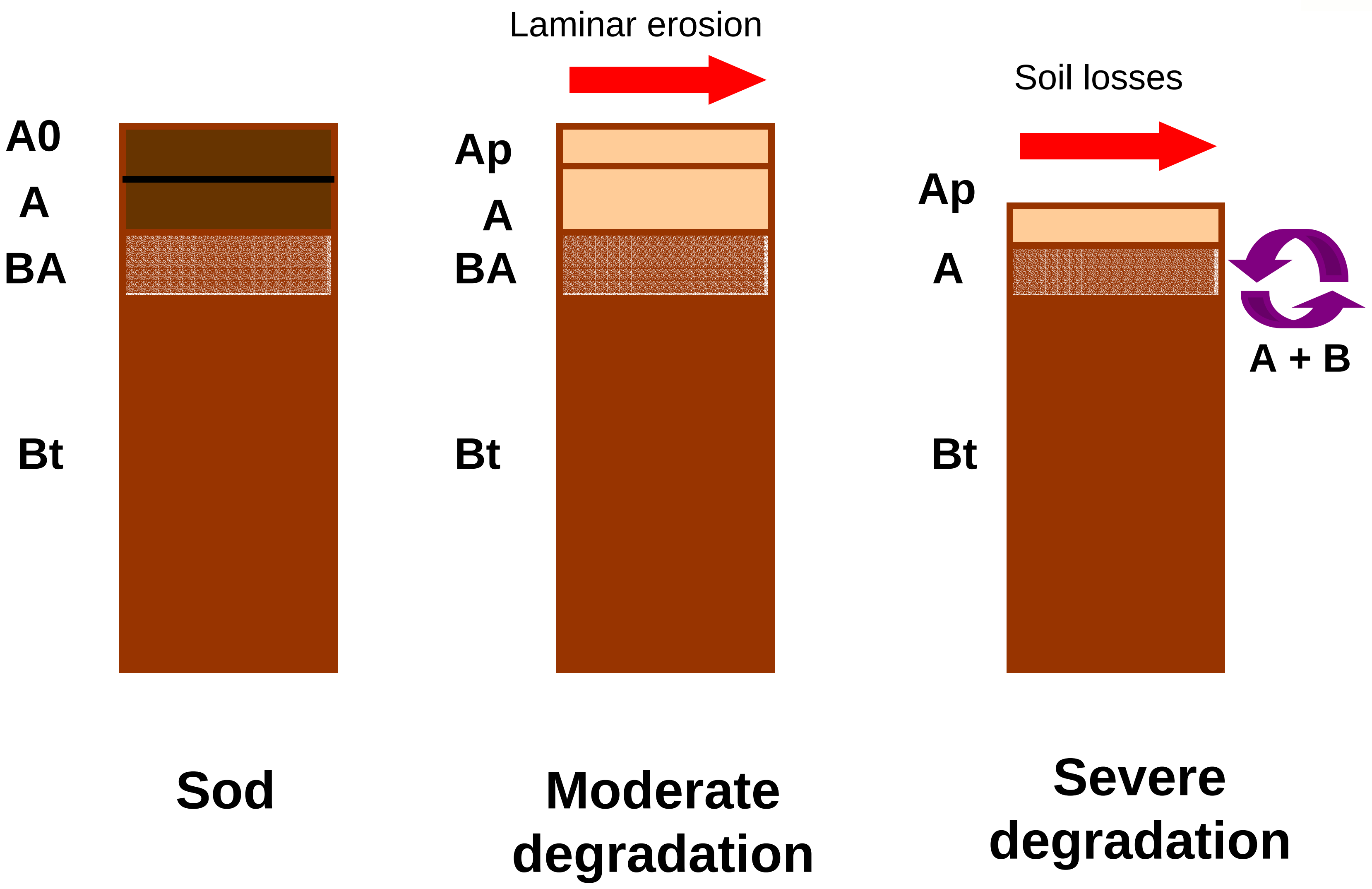
Satellite Image of South America, showing the location of Argentina



Argentina

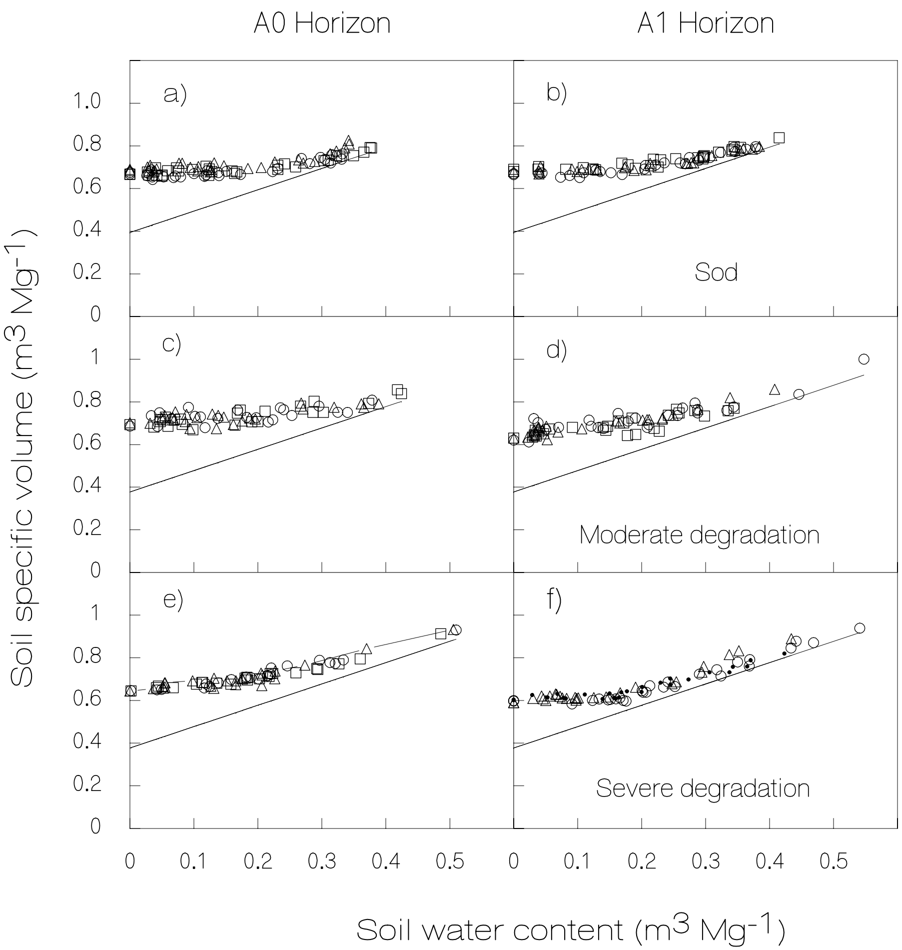
Satellite Image of Argentina showing its main cropland area (Pampean and Mesopotamian regions)





Laminar erosion
Soil losses
A0
A
BA
Bt
Ap
A
BA
Bt
Ap
A
Bt
A + B
Sod
Moderate degradation
Severe degradation

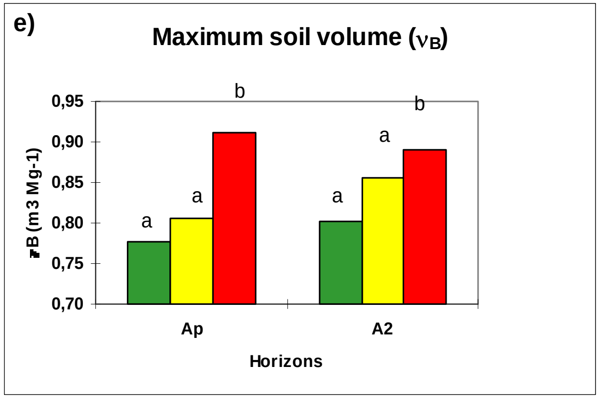
Soil shrinkage curves in top horizons of a Peyrano silty clay Loam (Argillic Phaeozem), under different degradation levels (Barbosa et al. 1999)

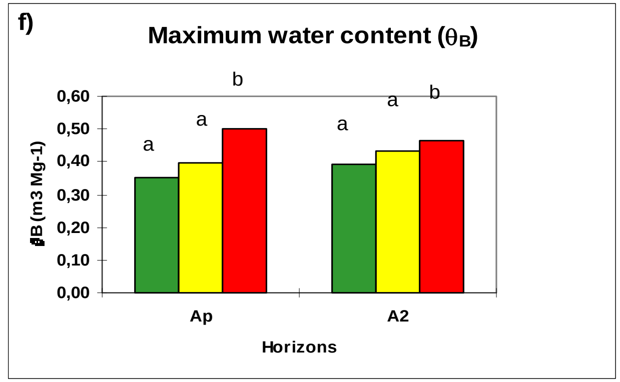


Perennial pasture

Conventionally ploughed soil, affected by laminar erosion

Shallow top horizon, mixed with the belowlying Bt by ploughing

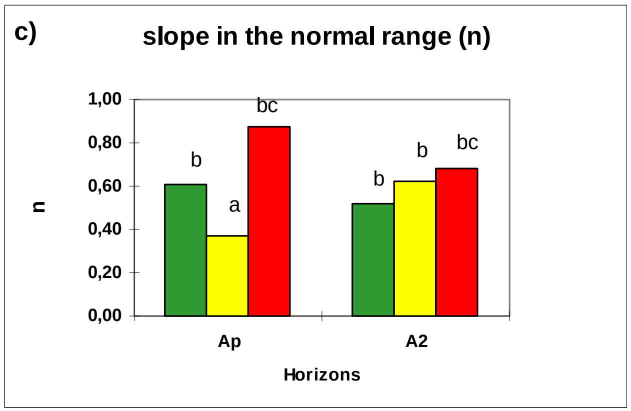


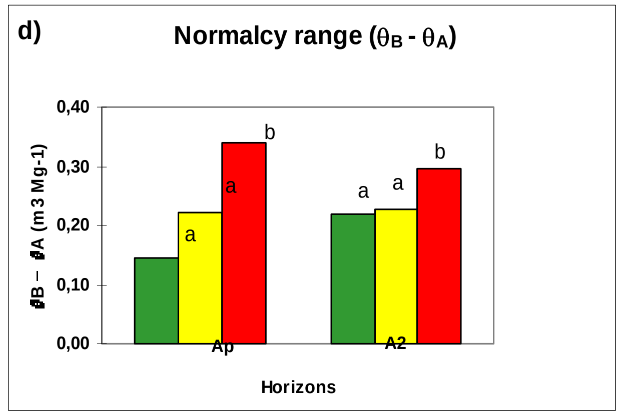


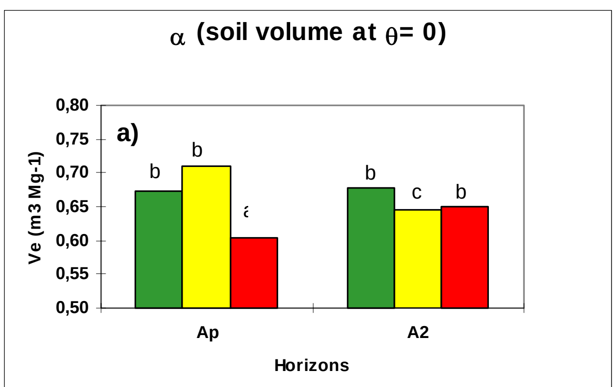
Sod

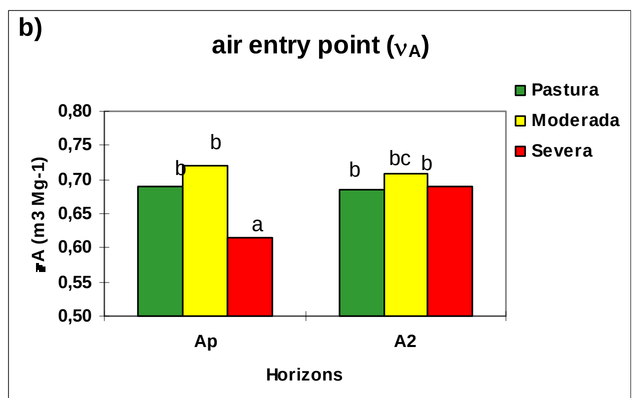
Moderate

Severe









Conclusions

Clay enrichment (severe degradation) accentuated soil swelling (> ν_B and θ_B and normalcy range), but did not improve air filled porosity.

Soil horizons mixture can not be recommended to the farmers, as a practice suitable to improve topsoil structure in Pampean silty loams.

Shrinkage characteristic of natric soils in the Flooding Pampa (Taboada et al. 2001)

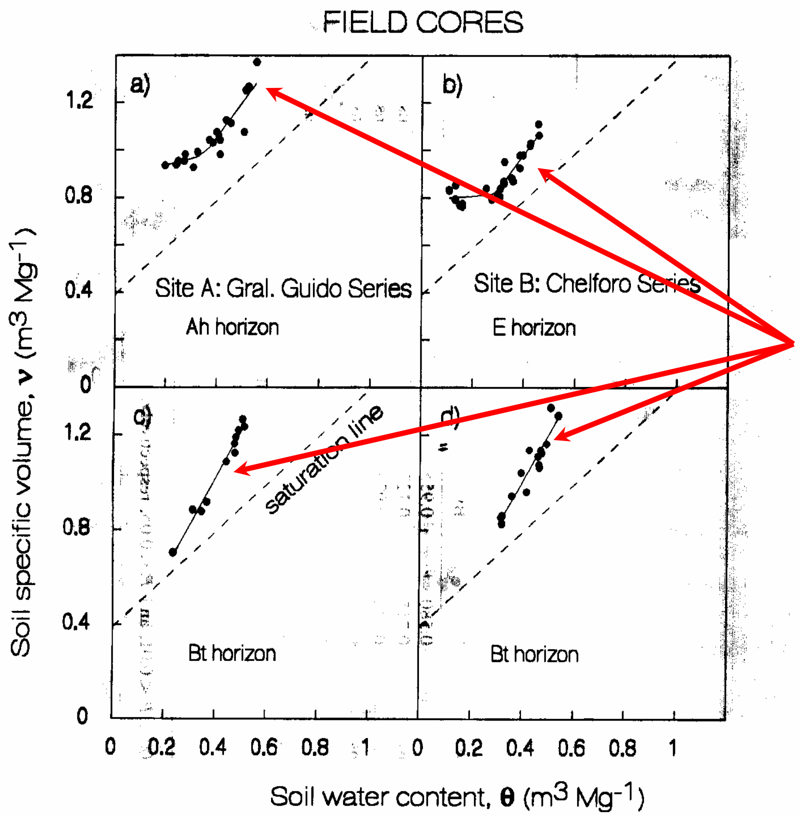


Fig. 4. Soil specific volume—water content relationships from repeated core sampling in the field of surface (a and b) and Bt horizons (c and d) of soils in sites A (Typic Natraquoll) and B (Mollic Natraqualf).

Air – filled porosity increases as soil wets (after Taboada et al. 2001)

Abnormal soil swelling caused by air entrapment.

Soils are periodically flooded. Water table rises and surface ponding promote the build up of trapped air pressures in top horizons.

Air entrapment causes **abnormal soil swelling**, despite the lack of a definite expansible clay mineralogy.

Trapped air was usually found to be responible for < 25 % of swelling.

In the environmental conditions of the flooding Pampa of Argentina, Trapped air is responsible for most of the swelling of soils having little expansible mineralogy of clays

The build up of trapped air pressures is the “other” soil swelling factor

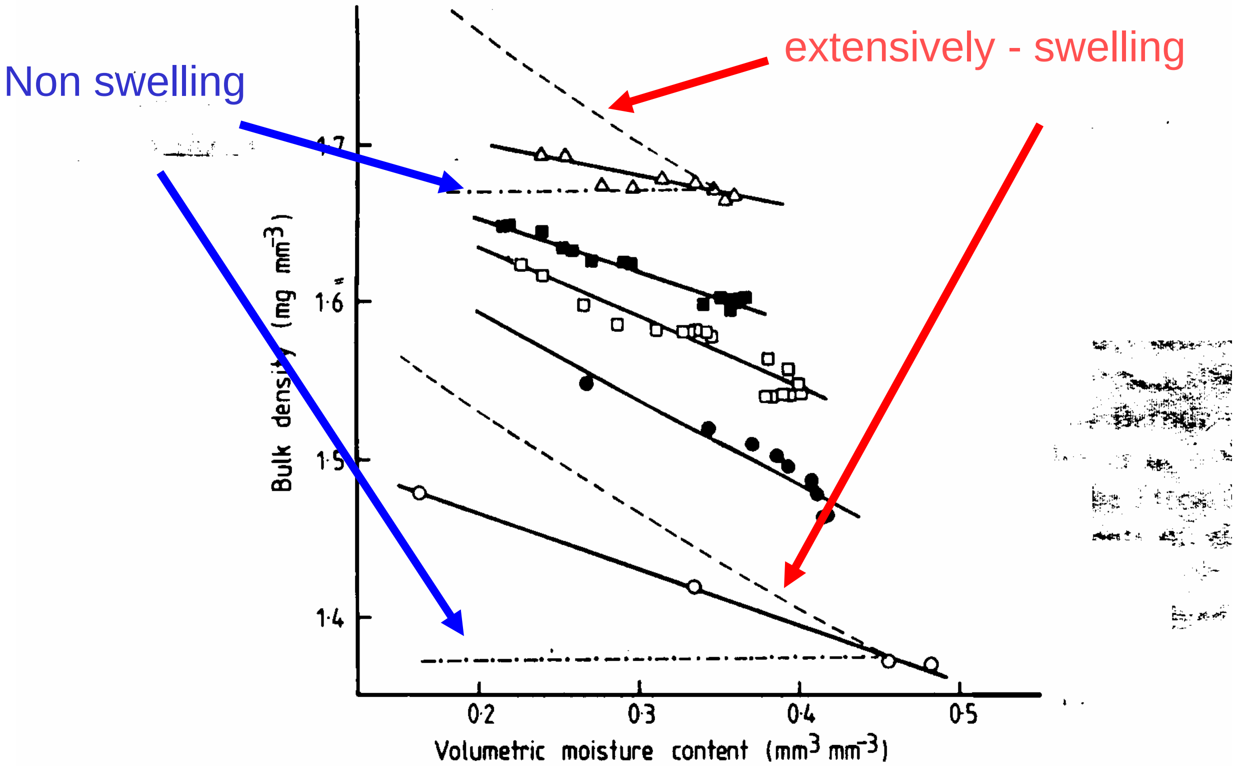


Fig. 1. Bulk density–volumetric moisture content relationship of a transitional red-brown earth soil for layers 0·10–0·25 m (○), 0·25–0·55 m (●), 0·55–0·85 m (□), 0·85–1·50 m (■) and 1·50–2·10 m (△). Theoretical swelling curves are shown for extensively-swelling (3-D normal) soils (– – –) (Fox 1964), and for non-swelling soils (–·–·–).

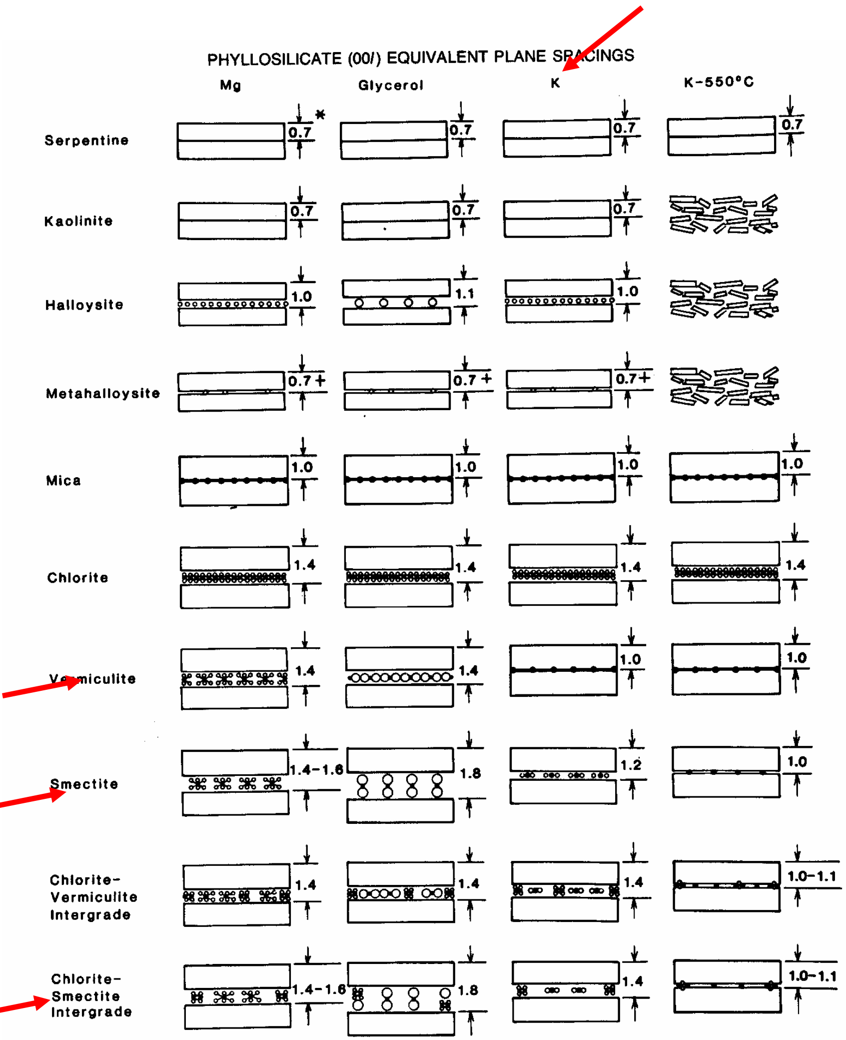


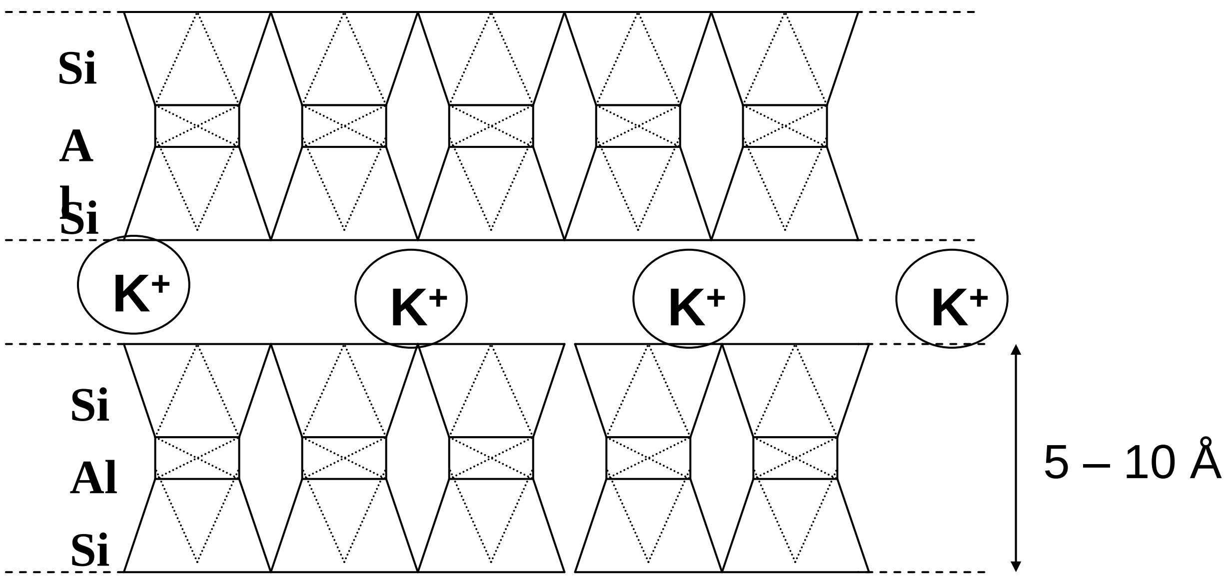
Fig. 12–5. Pictorial representation of response of phyllosilicates to differentiating treatments.
*Approximate spacings (nm).

The expansive characteristics of smectites are affected by the nature of adsorbed ions and molecules.

Smectite increases its plane spacing as a results of the loss of adsorbed cations.

K+ causes the narrowing of plane spacing

In mica and illite the saturation by K^+ in the interlayer space counteracts the repulsion by negative forces of nearby oxygen atoms. This prevents the occurrence of swelling.



Extensively – swelling soils develop *normal* volumetric changes during most of their moisture variation range. The variations in specific volume (i.e. the converse of bulk density), ν, are equivalent to those in volumetric water content, θ:

$$d\nu / d\theta \approx 1 \qquad \text{(1 – D soil swelling)}$$

$$d\nu / d\theta \approx 0.33 \qquad \text{(3 – D soil swelling)}$$

As a result, during *normal shrinkage* there is no air entrance to soil pore space. In Vertisols aggregates remain always water – saturated, and aeration processes mainly take place through dessication cracks.

In contrast, moderately – swelling soils mainly develop *residual* or *irreversible* volumetric changes.

In them, soil specific volume, ν, variations are lower than volumetric water content, θ. variations:

$$d\nu \,/\, d\theta < 1$$

During the drying phase there is air entrance to soil pores, which determines increases in air – filled porosity.

Residual or *irreversible* shrinkage is one of the mechanisms responsible for the creation of pores > 100 μm. These macropores may be free spaces for the growth of primary roots of cereals,