Departamento de Ingeniería del Terreno, Cartográfica y Geofísica
UNIVERSITAT POLITÈCNICA DE CATALUNYA

Instituto de Investigaciones Antisísmicas "Ing Aldo Bruschi"
UNIVERSIDAD NACIONAL DE SAN JUAN

Laboratorio de Geotecnia
UNIVERSIDAD NACIONAL DE CÓRDOBA

Geotécnia e Ingeniería Sísmica aplicadas a la Minería

San Juan, Argentina, 16 de Octubre de 2007

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Departament d'Enginyeria
del Terreny, Cartogràfica i Geofísica
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Residuos mineros: Interacción con la atmósfera

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Universidad Nacional de San Juan

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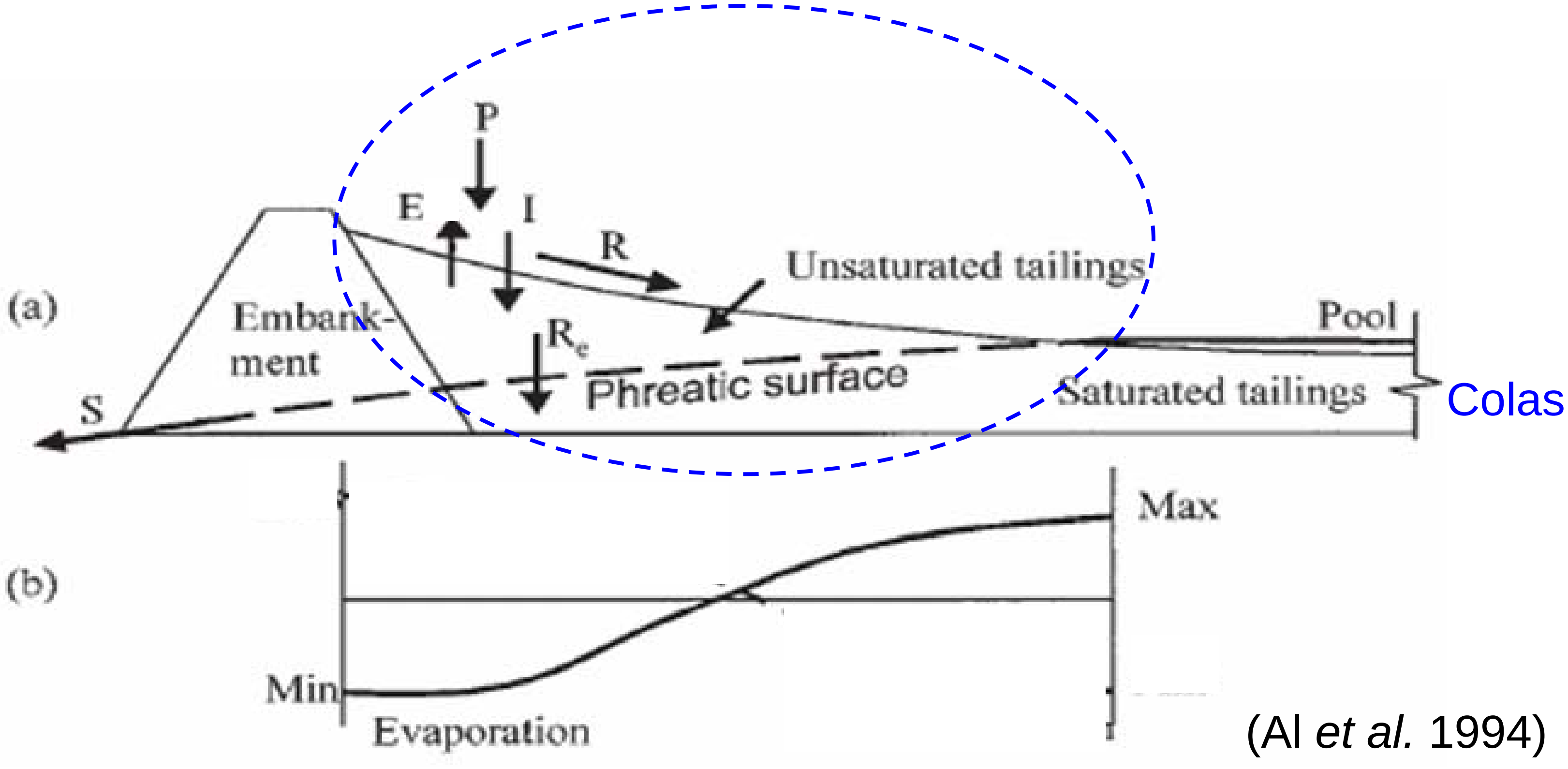
Índice de la presentación

- Consecuencias de la evaporación en las balsas de decantación (retracción y agrietamiento)
- Fenómenos de retracción (aspectos generales, irreversibilidad, acumulación con ciclo de secado / humedecimiento)
- Grietas de retracción (resistencia a la tracción, iniciación, efectos de tamaño, consecuencias sobre la permeabilidad al agua)
- Montajes experimentales en laboratorio e *in situ* para analizar la interacción con la atmósfera

Evaporación

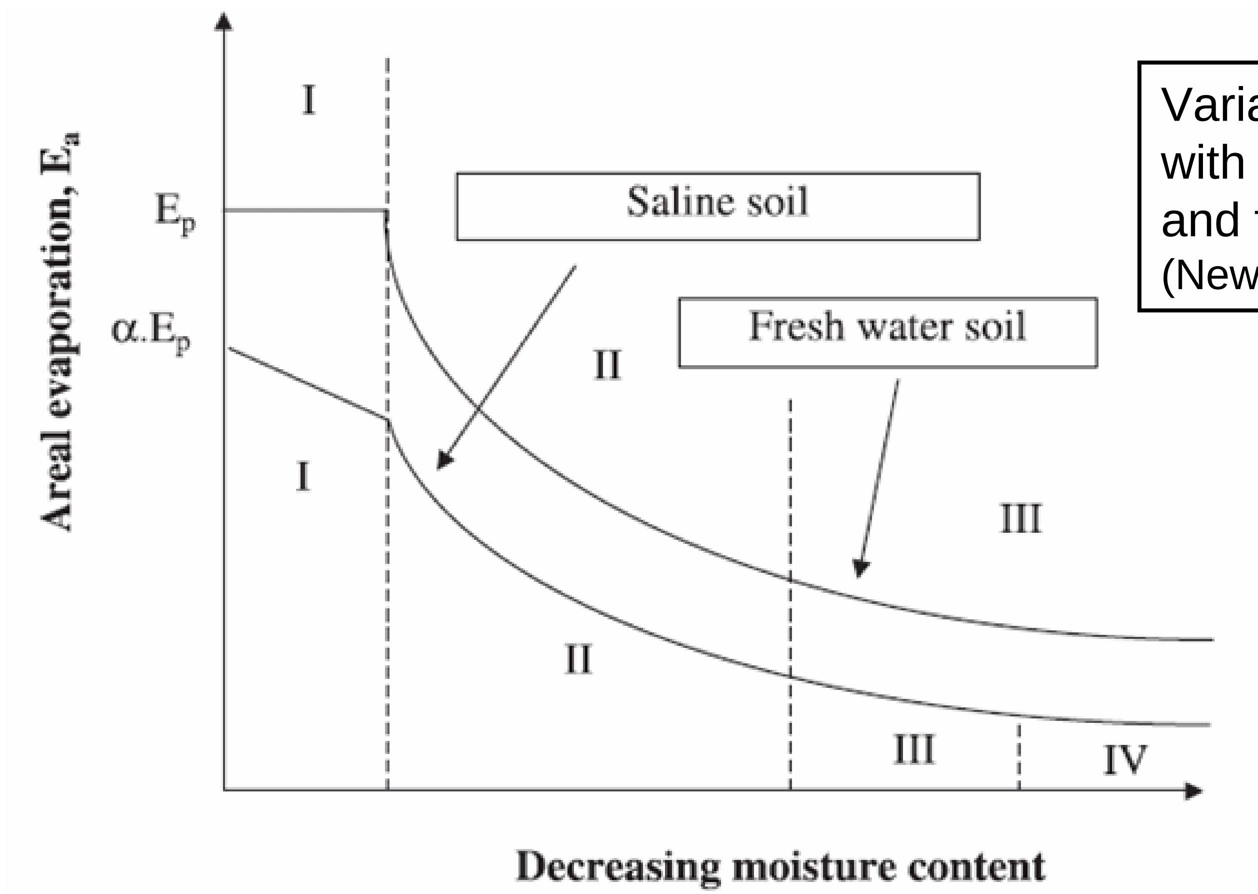


(Al *et al.* 1994)

a) Water mass balance:
Precipitation (P), infiltration (I), evaporation (E), runoff (R), effective recharge (R_e), seepage (S)

b) Spatial distribution of surface fluxes of infiltration and evaporation

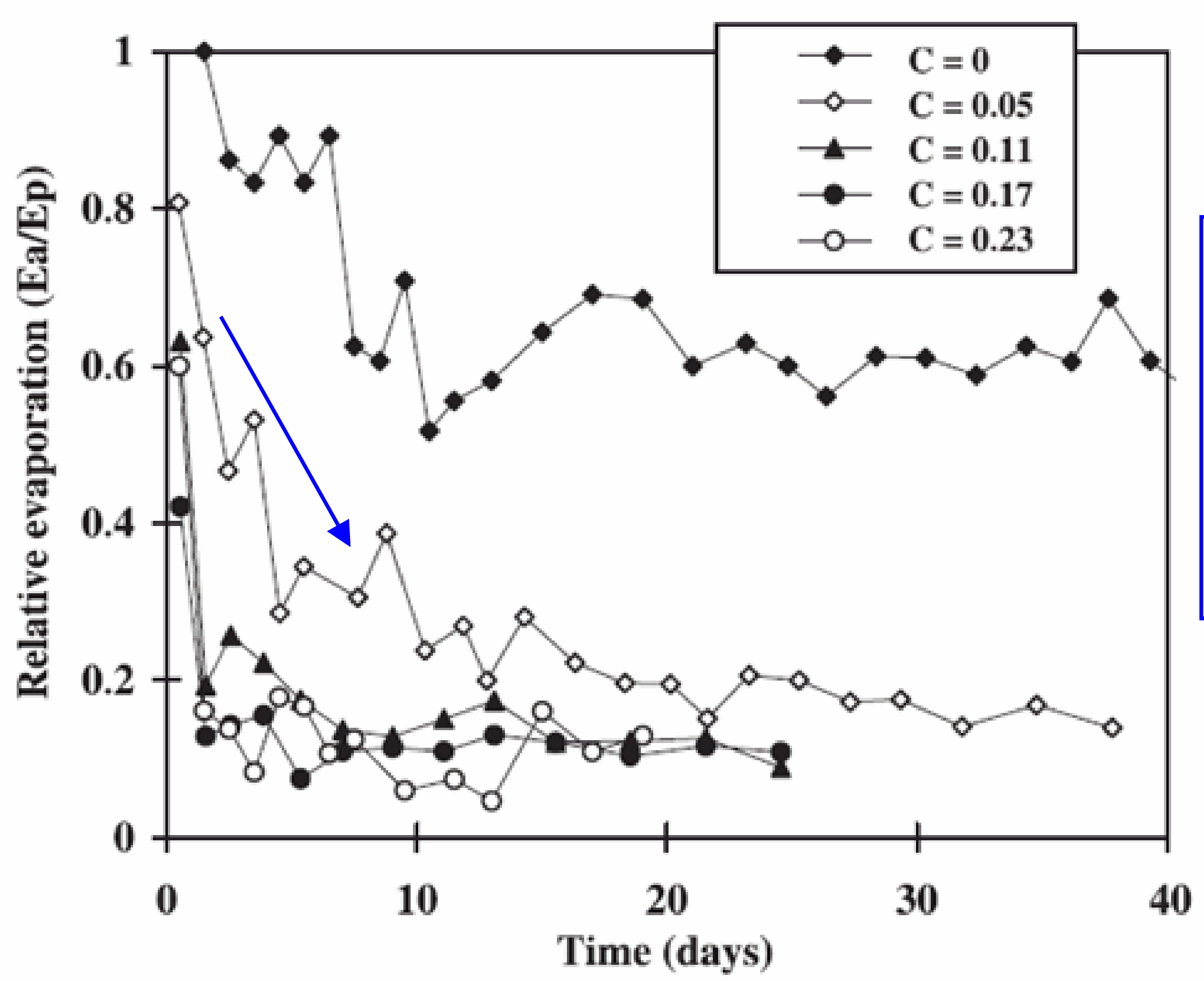
Contenido de humedad. Efecto de la salinidad y de las costras superficiales



Variations in relative evaporation with moisture content for saline and freshwater materials
(Newson & Fahey 2003)

I: Effect of increasing saline concentration (saline soil)
Reduction in vapour pressure as solutes increase their concentrations
II: Superficial crust formation (saturated material)
1) albedo, 2) moisture transfer resistance, 3) reduction in vapour pressure
III: Superficial crust (desaturation of crust)
IV: Water availability within the soil decreases. Residual moisture content (evaporation will tend to vanish)

Efecto de la salinidad



Evaporation from saline tailings surfaces. 'c' represents the initial water solute concentration –mass basis-

(Fahey & Fujiyasu 1994)

Efecto de la salinidad

Dalton-type surface boundary condition for evaporation:

E_v: evaporative volumetric flux
f_v: exchange function which depends on the mixing characteristics of the air above the evaporating surface
u_v: vapour pressure of the evaporating soil surface
u_v^a: vapour pressure in the air above the evaporating surface

For the same temperature for air and soil (u_{vo} is the common saturation vapour pressure):

$$E_v = f_v (u_v - u_v^a)\,; \quad E_v = f_v u_{vo} \left[\exp\left(-\frac{(s+\pi) v_w M_w}{RT} \right) - h_{ra} \right]$$

Psychrometric law:

$$\psi = s + \pi = -\frac{RT}{v_w M_w} \ln h_r = -\frac{RT}{v_w M_w} \ln \frac{u_v}{u_{vo}}$$

M_w: molecular mass of water
R: molar gas constant
T: absolute temperature
v_w: specific water volume ($=1/\rho_w$)

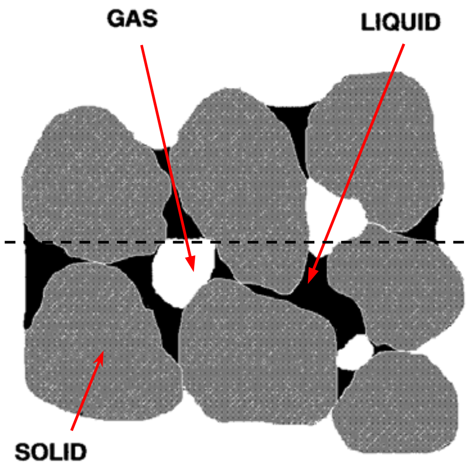
ψ: total suction
s: matric suction, $s = (u_a - u_w)$
π: osmotic suction

u_{da}=const. ; T = const.

$s = u_a - u_w$

Pure water	Soil water	Soil + soil water
u_{da}	u_{da}	u_{da} ; $u_v(T, \chi_{w1}, s)$
$u_{v0}(T, \chi_{w0} = 1, s = 0)$	$u_{v1}(T, \chi_{w1}, s = 0)$	$u_w = u_a - s = u_{da} + u_v - s$
$u_{w0} = u_{a0} = u_{da} + u_{v0}$	$u_{w1} = u_{a1} = u_{da} + u_{v1}$	
$\chi_{w0} = 1$	χ_{w1}	

$z = 0$



REFERENCE (0) STATE

OSMOTIC (A)

$$h_\pi = \frac{u_{v1}}{u_{v0}}$$

MATRIC (B)

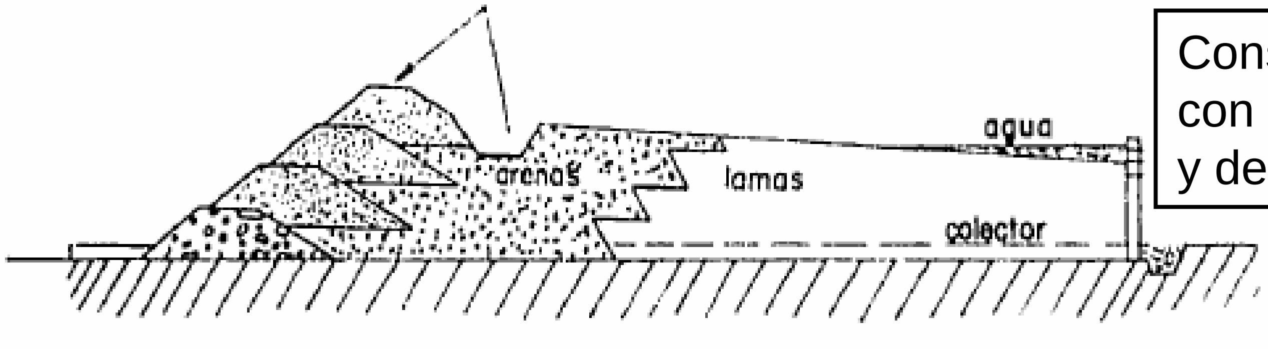
capillary menisci + surface adsorption

$$h_m = \frac{u_v}{u_{v1}}$$

$$\psi = s + \pi = -\frac{RT}{v_w M_w} \ln h_r = -\frac{RT}{v_w M_w} \ln \frac{u_v}{u_{vo}}$$

Consecuencias asociadas con la evaporación

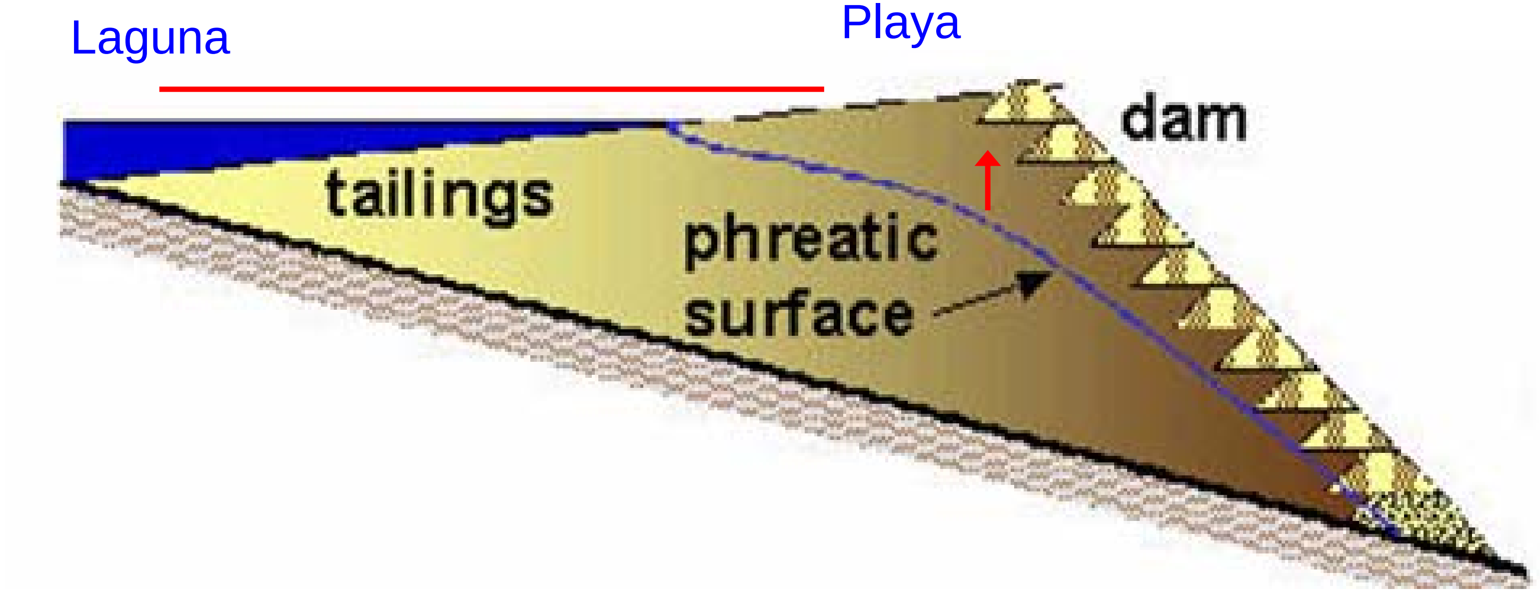
- Disminución del nivel del embalse
- Cambios en la superficie freática, que se aleja de la cara del talud
- Aumento de la estabilidad frente a deslizamiento de los taludes
- Retracción
  a) disminución volumen, endurecimiento, influencia sobre la capilaridad
  b) acumulación en ciclos sucesivos de humedecimiento / secado
- Grietas de retracción
  a) afectan el flujo y el transporte de solutos (flujos preferentes, afectación de acuíferos)
  b) afectan la erosión interna (tubificación)
  c) afectan la resistencia del material
  d) incrementan la accesibilidad de oxígeno (oxidación, perturbaciones químicas)
- Estratificación (costras desecadas sobreconsolidadas, 'pancakes')
- Aumento de la concentración de especies químicas por pérdida de solvente (desarrollo de costras salinas, 'salt crusts')
- Impacto ambiental sobre la atmósfera
- …



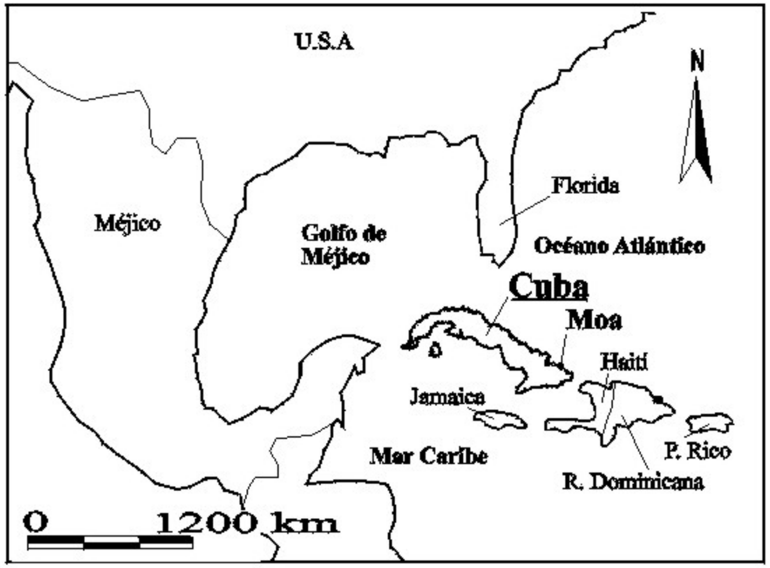
Construcción aguas arriba con material escarificado y desecado

Consecuencias asociadas con la infiltración

- Aumento del nivel del embalse
- Aumento del grado de saturación
  a) agua almacenada en la zona parcialmente saturada
  b) aumento de la permeabilidad al agua
  c) disminución de la resistencia al corte
- Cambios (ascensos) en la superficie freática, que se acerca a la cara del talud
- Disminución de la estabilidad frente a deslizamiento de los taludes
- Dilución de especies químicas (aporte de solventes)
- Reblandecimiento de costras
- Impacto ambiental sobre suelos y acuíferos
- …



Desecación de los residuos mineros (grietas y costras superficiales)



Depósito de la industria cubana del níquel
(Rodríguez 2002)

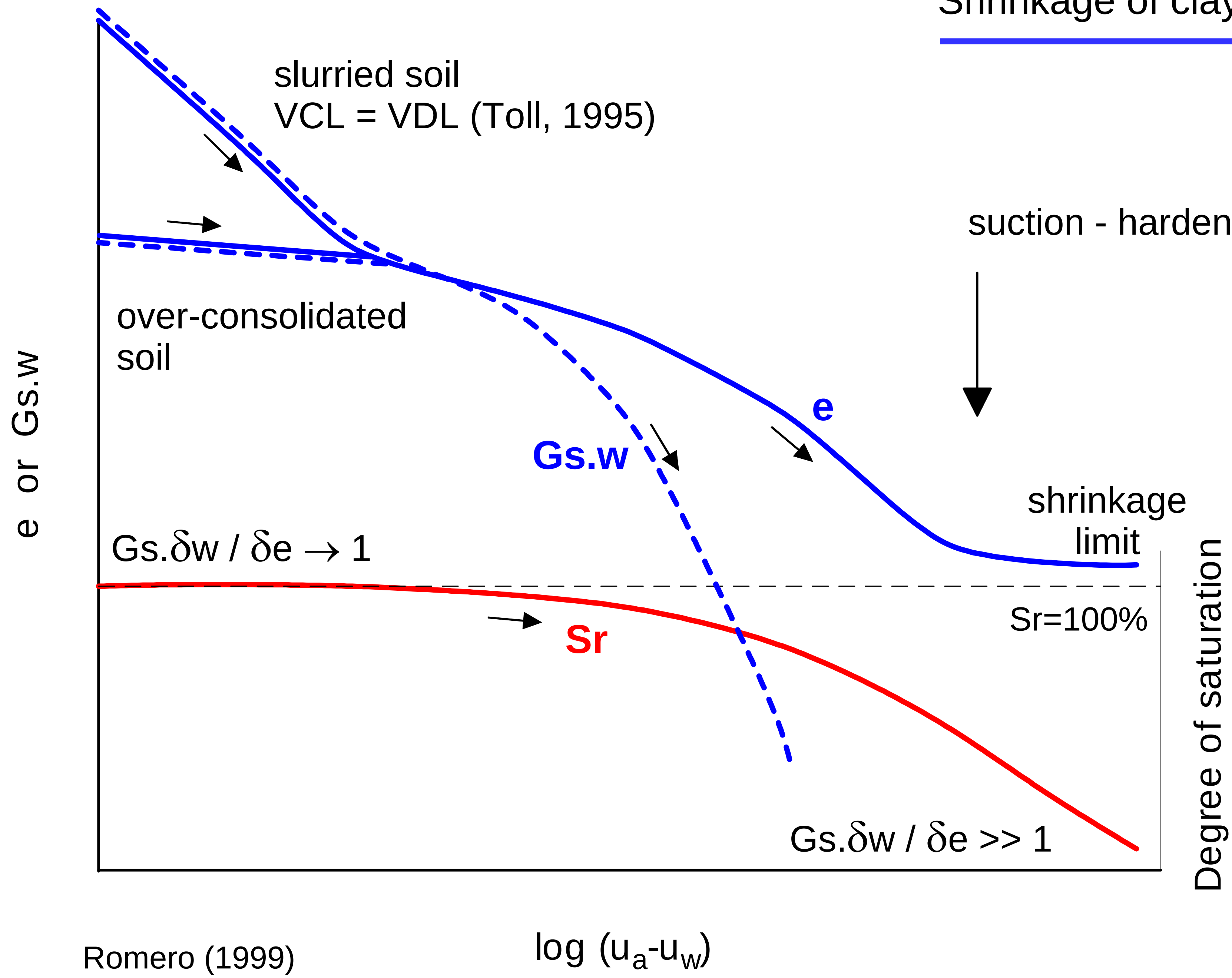
Punto de vertido de colas

Desecación y estratificación de los residuos mineros

Depósito de la industria cubana del níquel

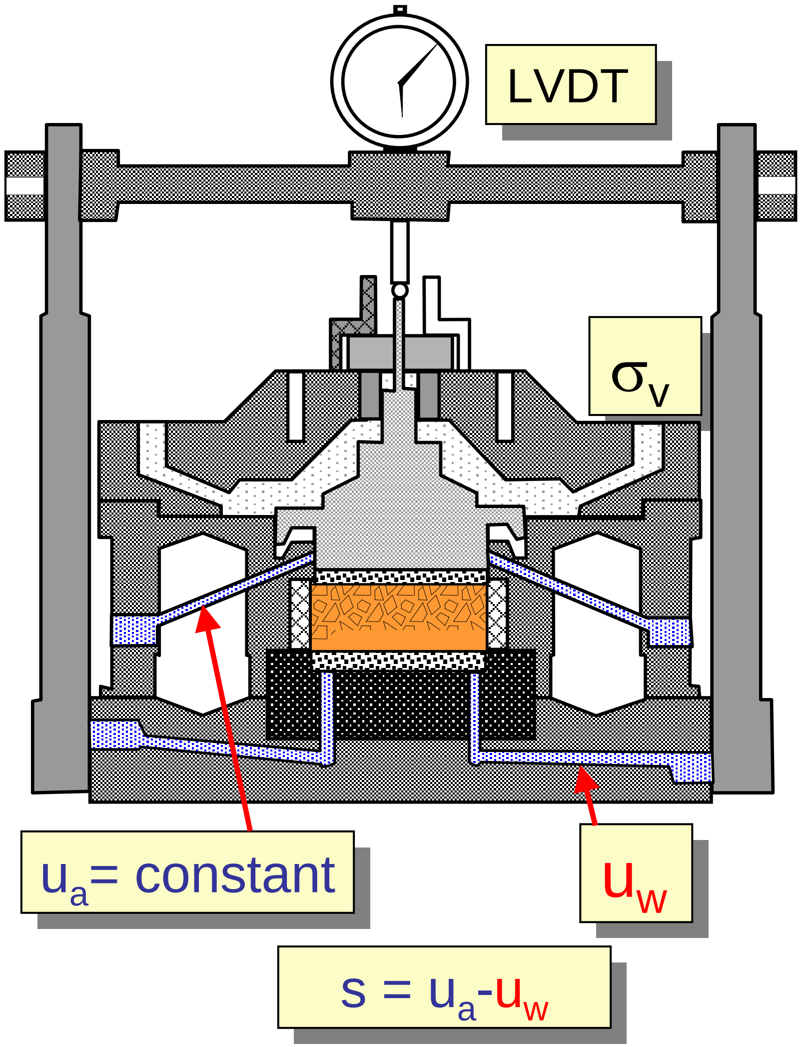
(Rodríguez 2002)

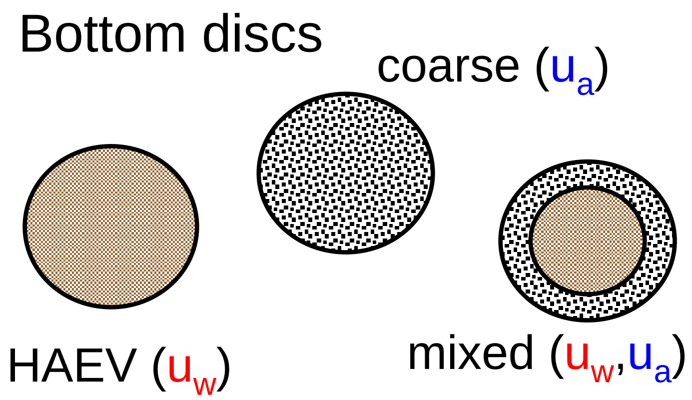
Shrinkage of clayey soils

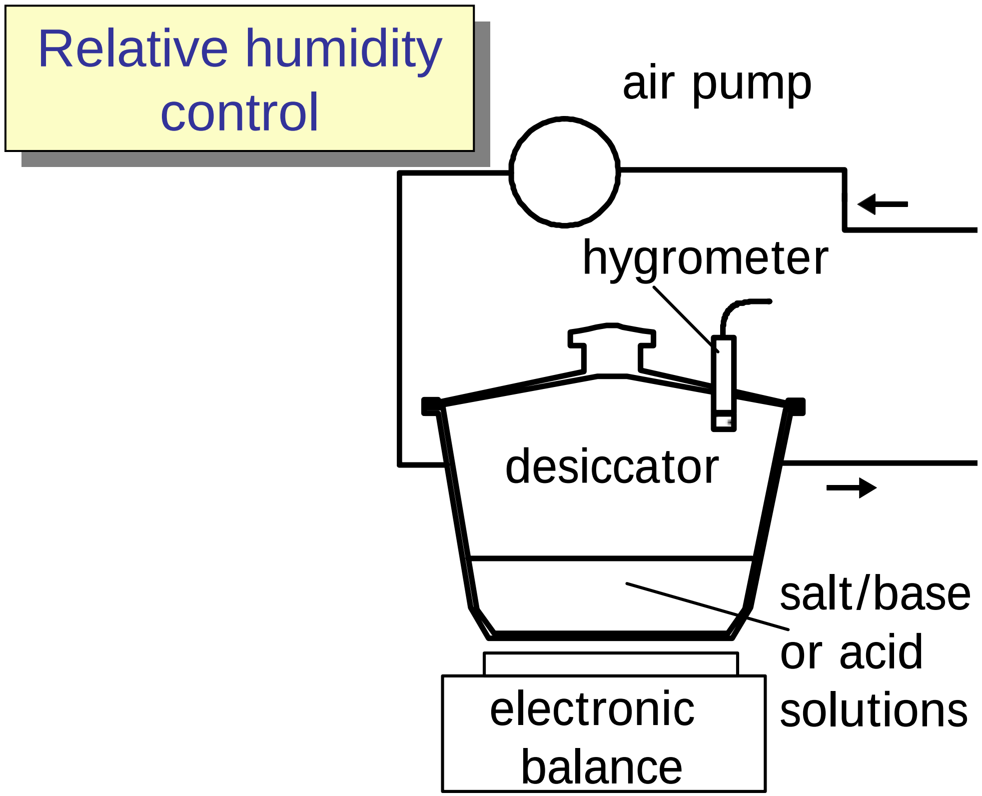


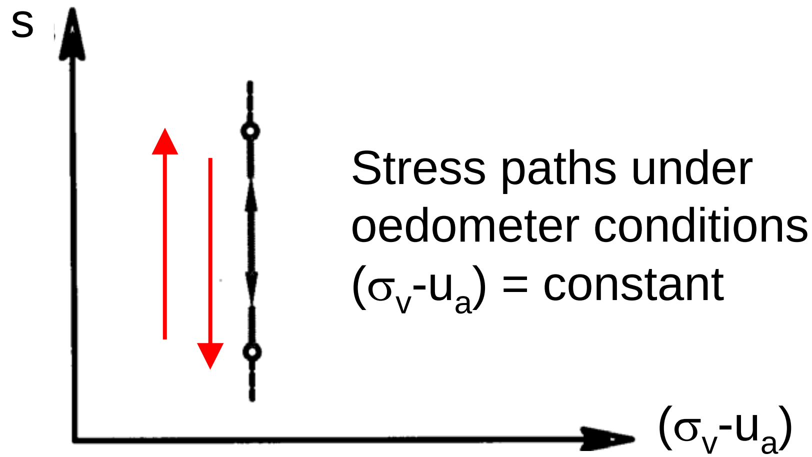
Romero (1999)

UPC controlled-suction oedometer cell

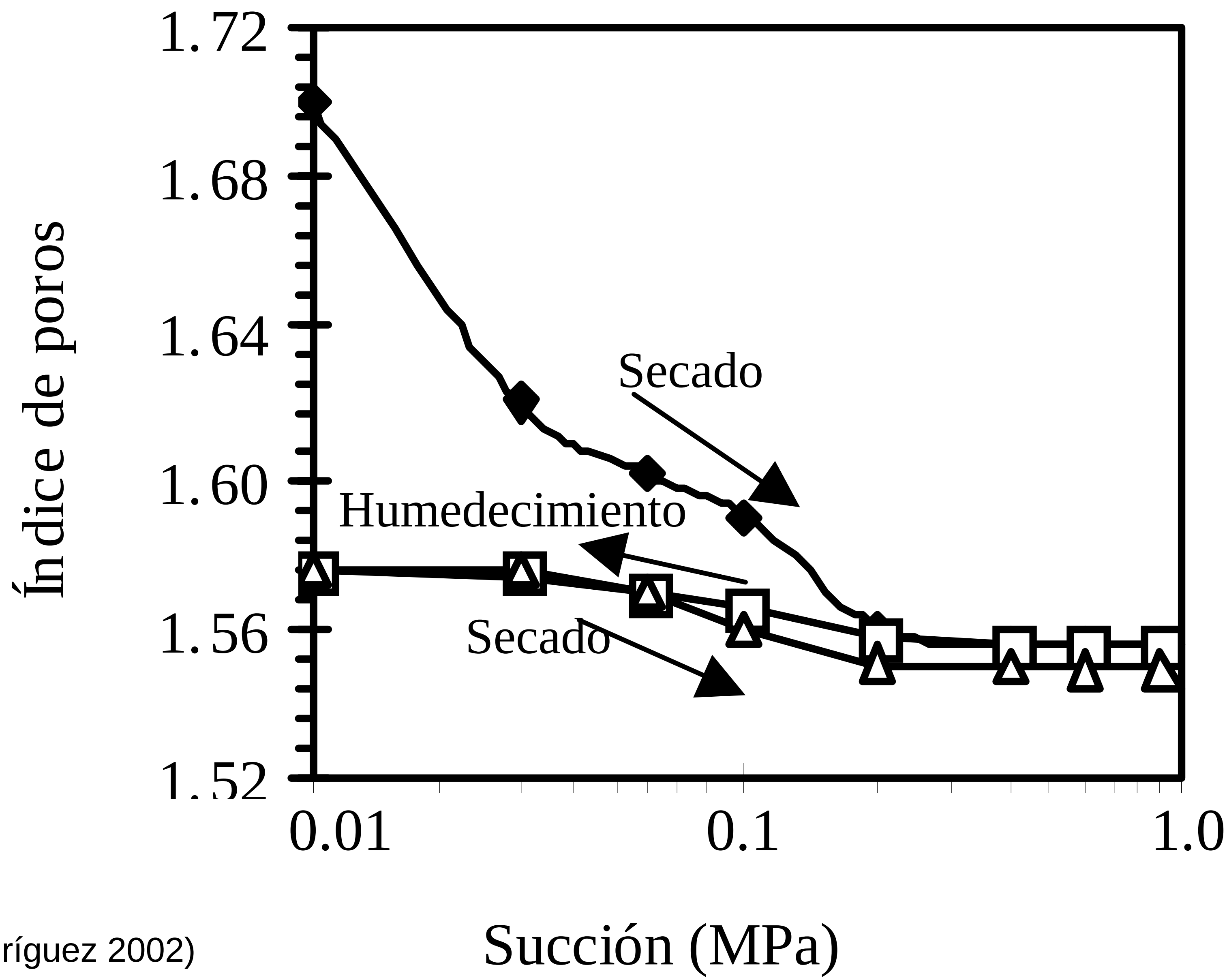






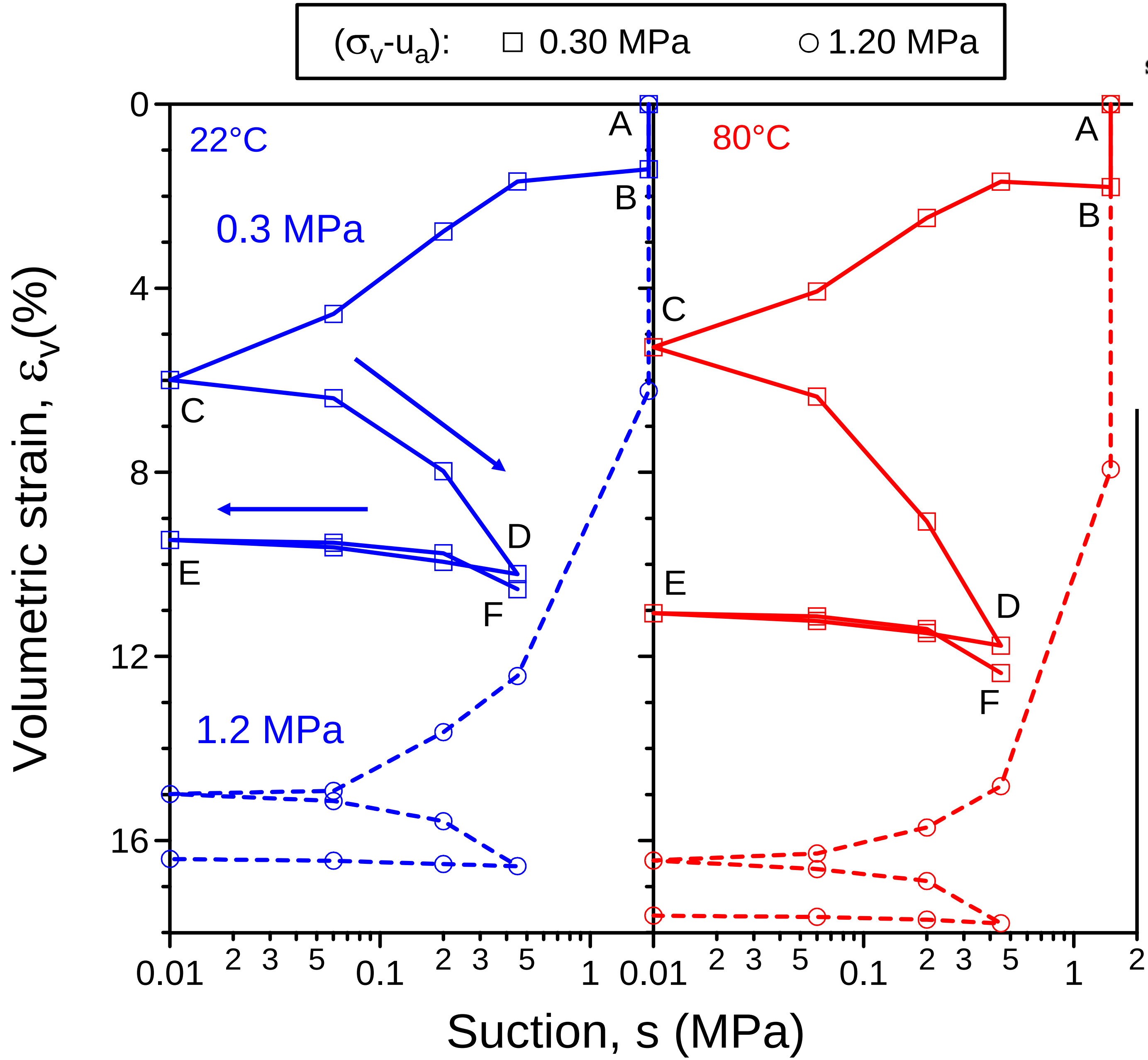


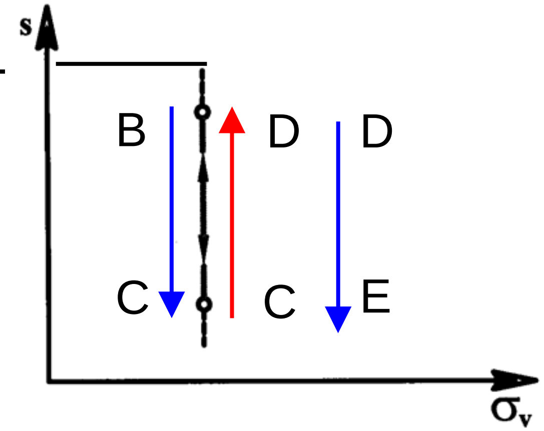
Retracción de residuos mineros (industria del níquel)



(Rodríguez 2002)

Shrinkage





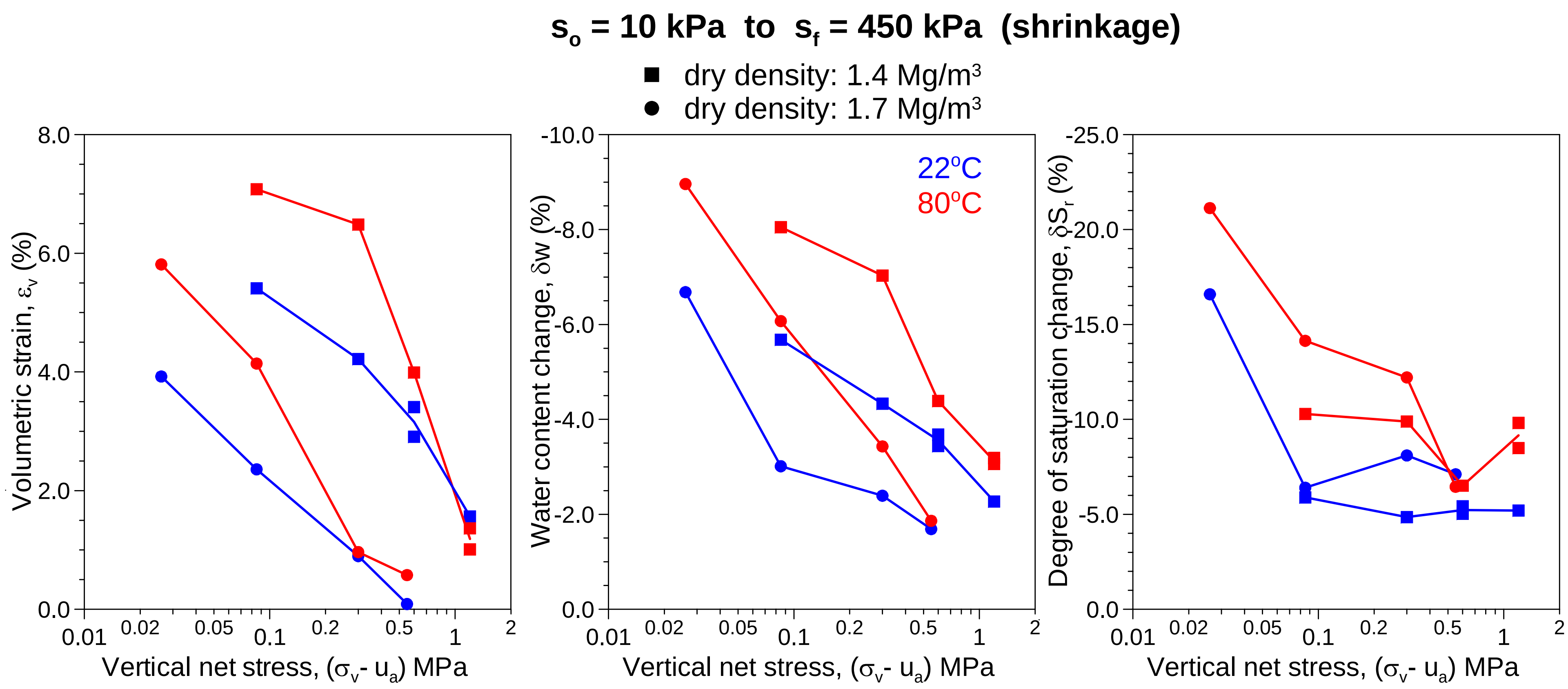
Stress paths under oedometer conditions (σ_v-u_a) = constant

Kaolinitic-illitic clay at ρ_{do} = 1.4 Mg/m³
w_o = 15%

Romero (1999)

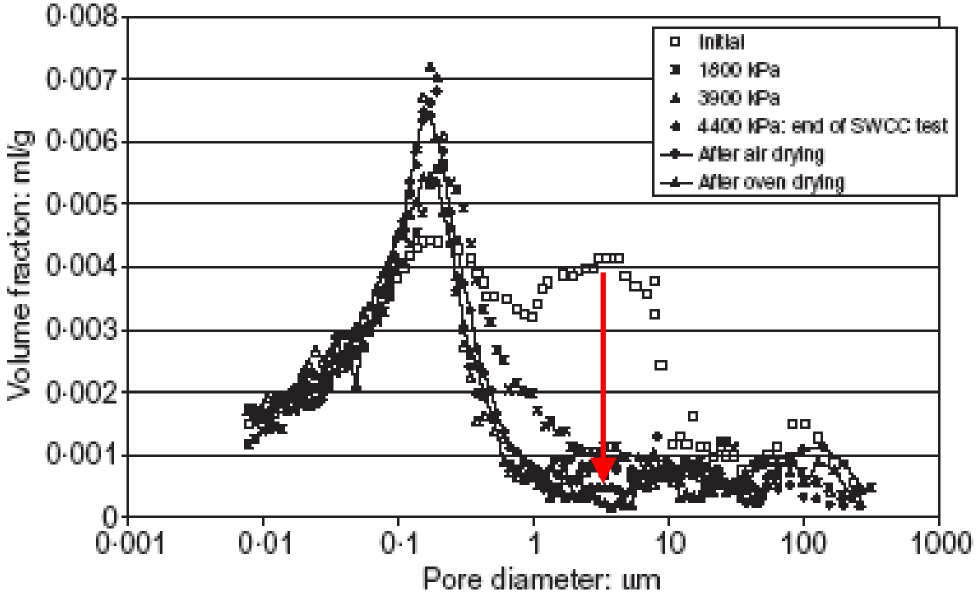
Shrinkage (dry density and temperature effects)

Kaolinitic-illitic clay
at ρ_{do} = 1.4 Mg/m^3
w_o = 15%



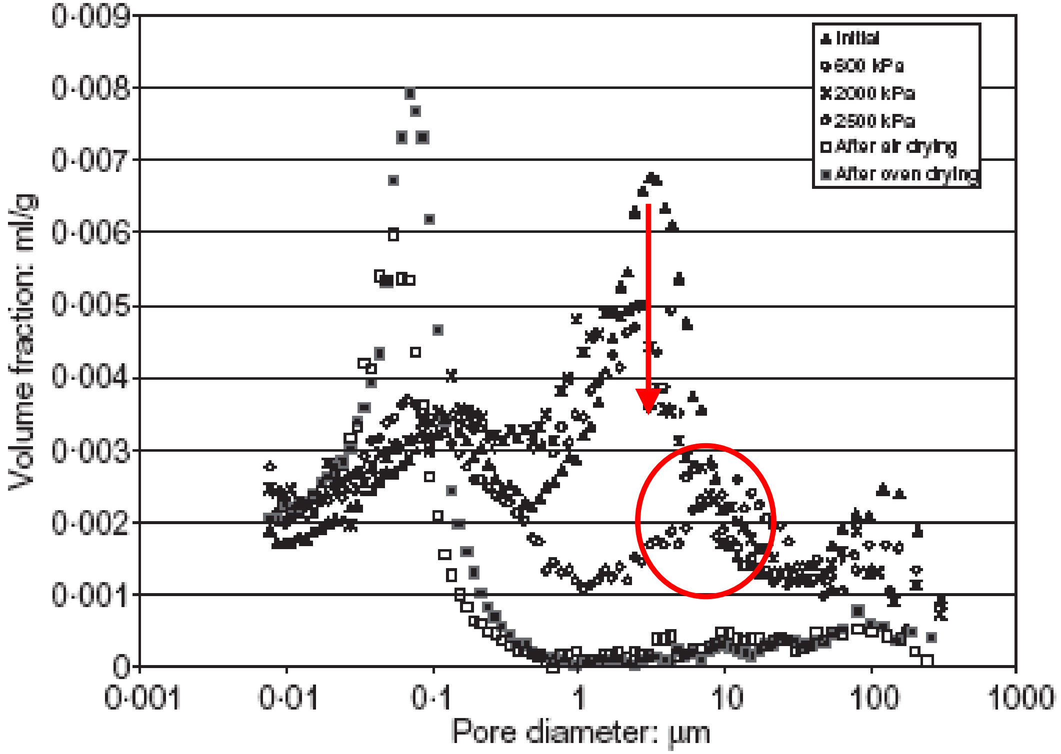
Romero (1999)

Evolution of PSDs during drying (Simms & Yanful 2002)



Halton Till at w_o=19%

suction increase leads to total destruction of macroporosity



Regina Clay at w_o=29%

certain class of pores of the macroporosity are not affected by shrinkage during suction increase

Modification of sample microstructure when suction is increased

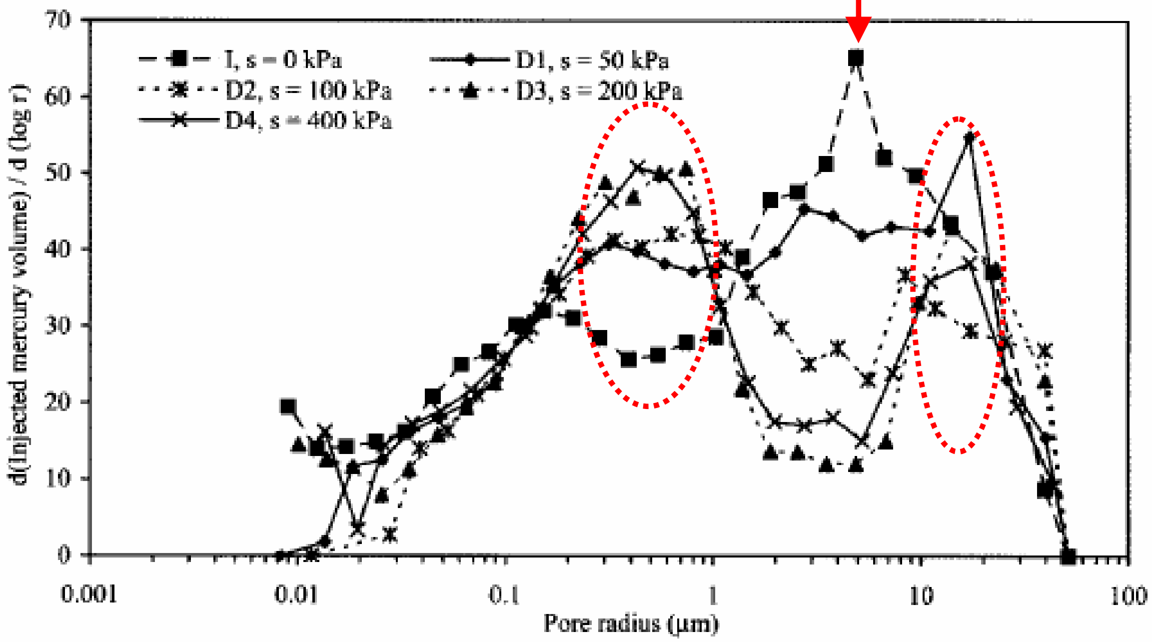
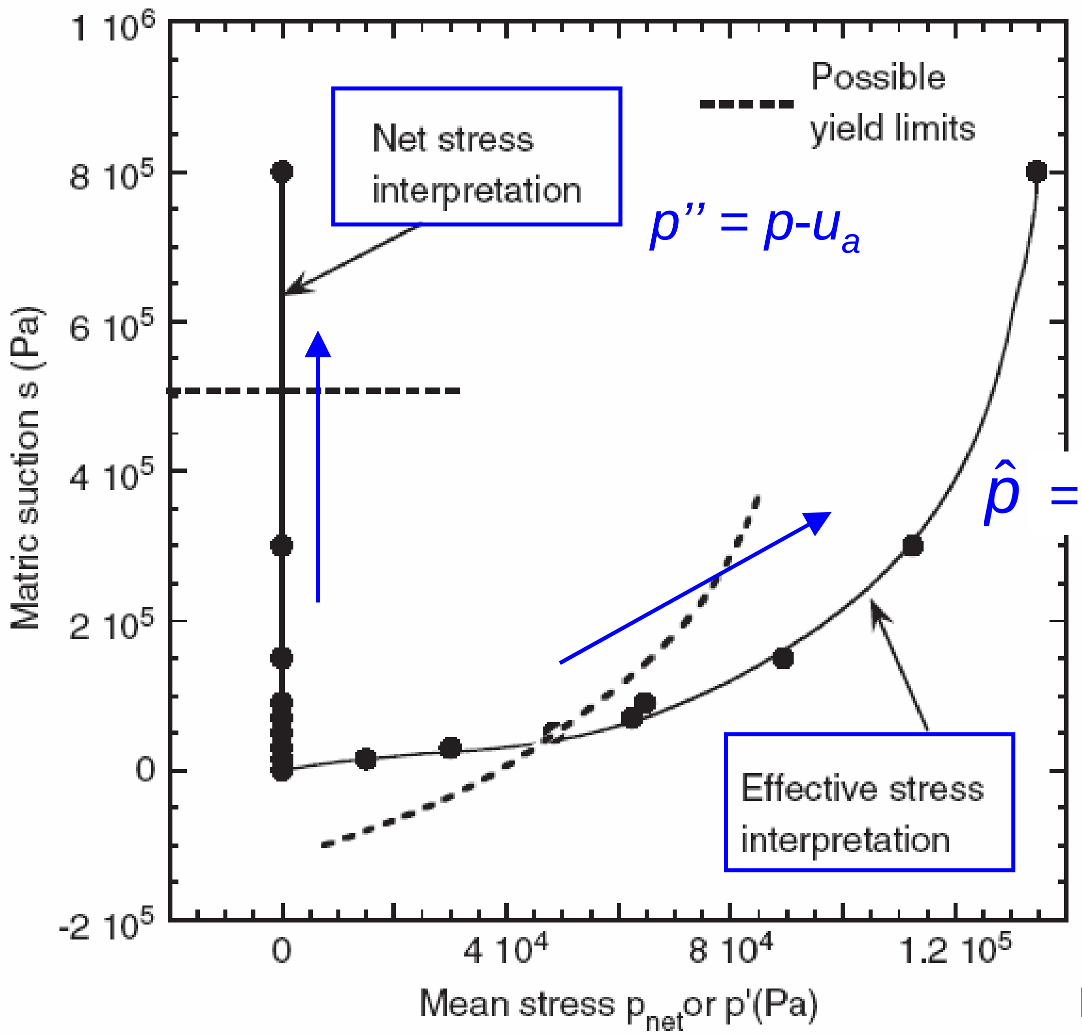


Figure 7. Modification of samples fabric when suction is increased from 0 up to 400 kPa (tests I and Dl to D4).

Sandy loam (morainic soil, PI=12%, LL=30%)
(Cuisinier & Laloui 2004)

Shrinkage (irreversible aspects)

Hydraulic ‘loading’ associated with:
- shrinkage of soil aggregations
- increase with mean stress acting on soil skeleton



$p'' = p - u_a$

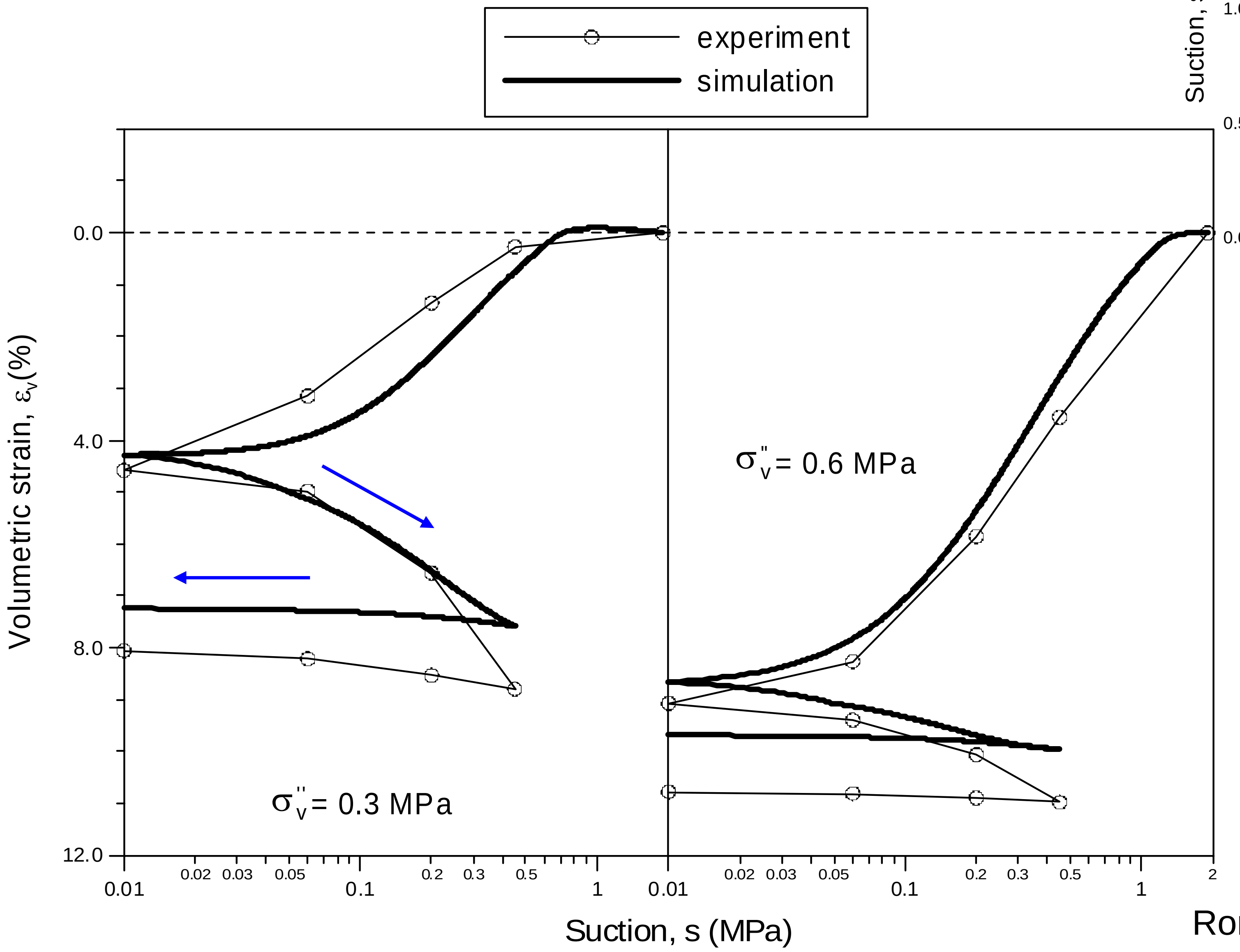
$\hat{p} = [(p - u_a) + S_r\, s] = p'' + S_r\, s$

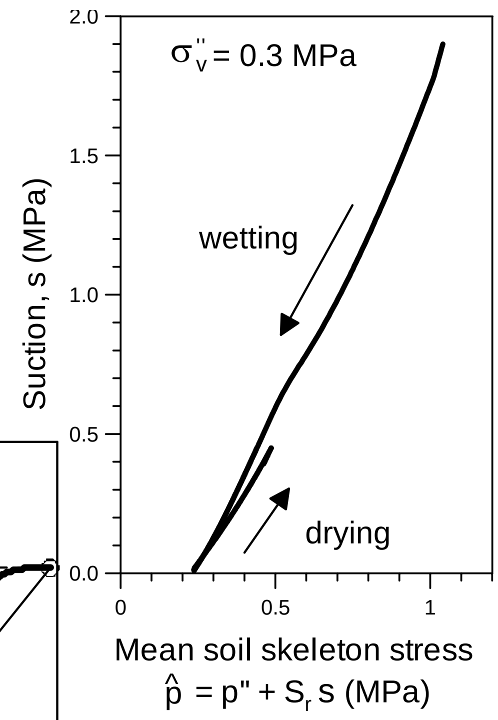
Hysteresis effects are can be included in the stress variable

Nuth & Laloui (2007)

Shrinkage (irreversible aspects)

$$\hat{p} = [(p - u_a) + S_r\, s] = p'' + S_r\, s$$

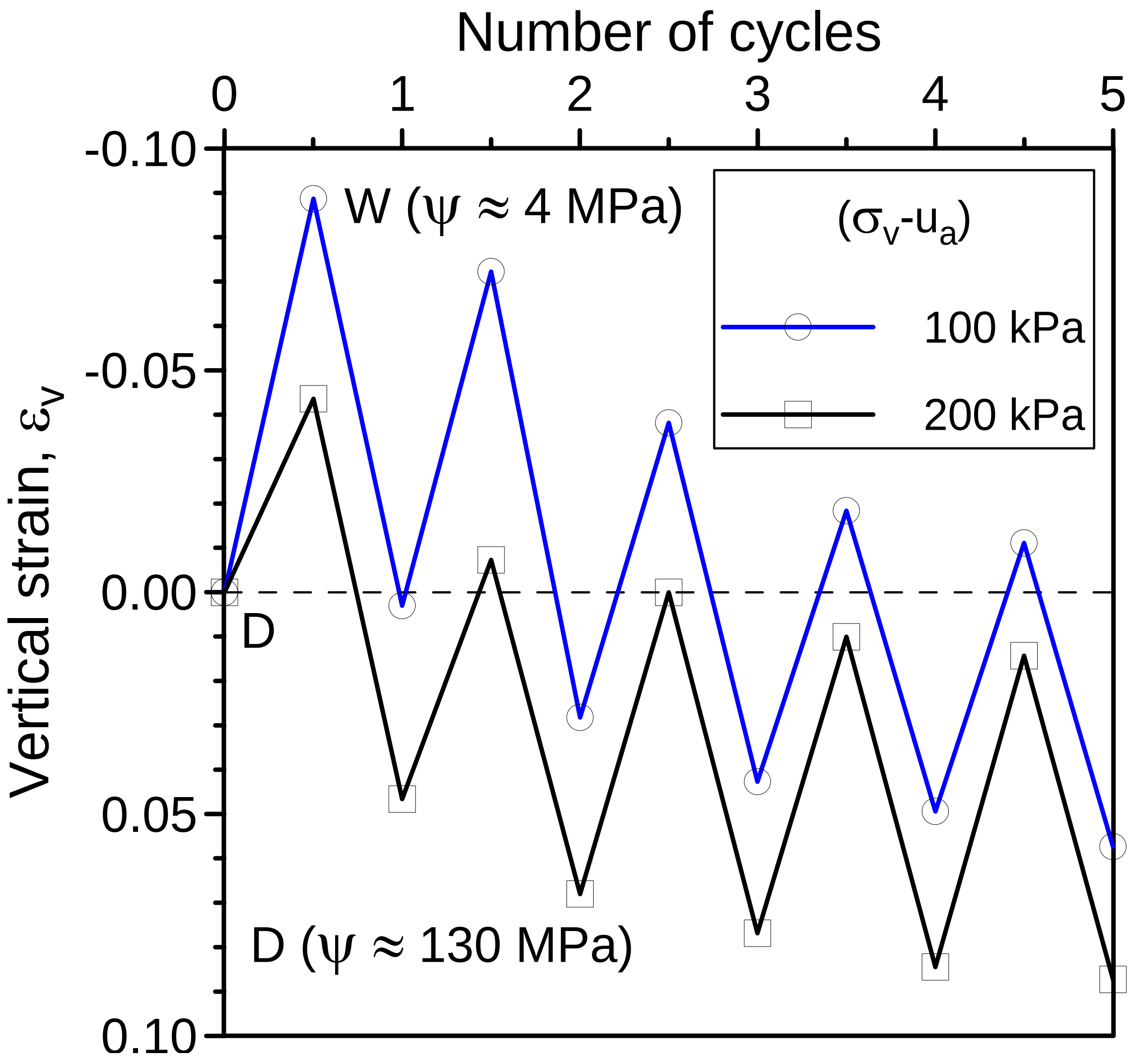


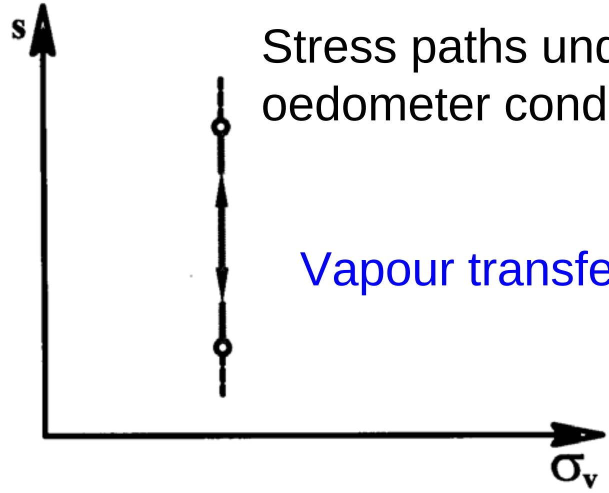


Romero & Jommi (2007)

Shrinkage accumulation (suction cycling)

Bentonite/sand 80/20, e_o = 0.80, w_o = 13%





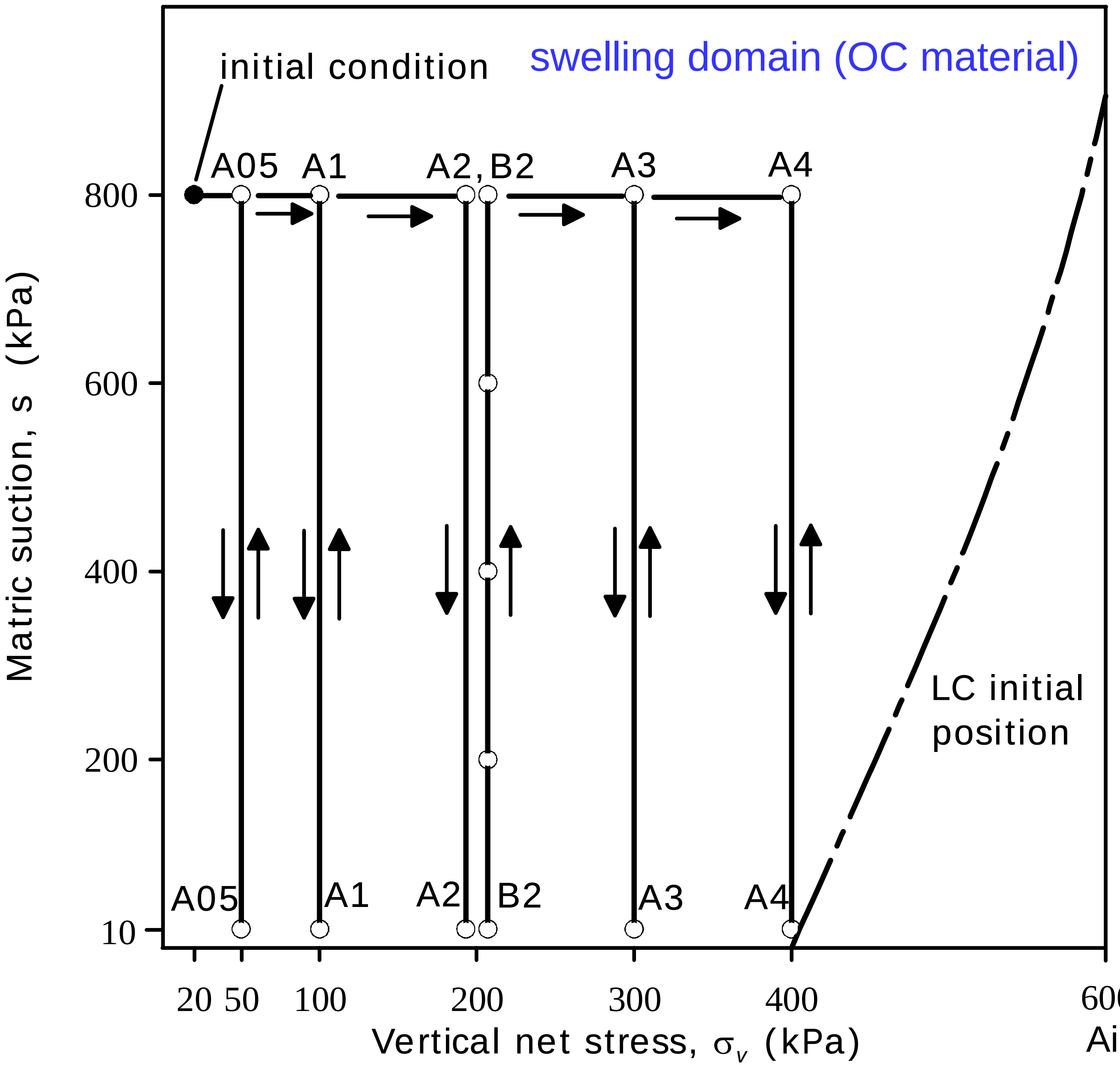
Stress paths under oedometer conditions

Vapour transfer

Shrinkage accumulation ('fatigue' of swelling) that increases at higher vertical stresses

Alonso et al. (2005)
Romero et al. (2006)

Stress paths followed (oedometer conditions)

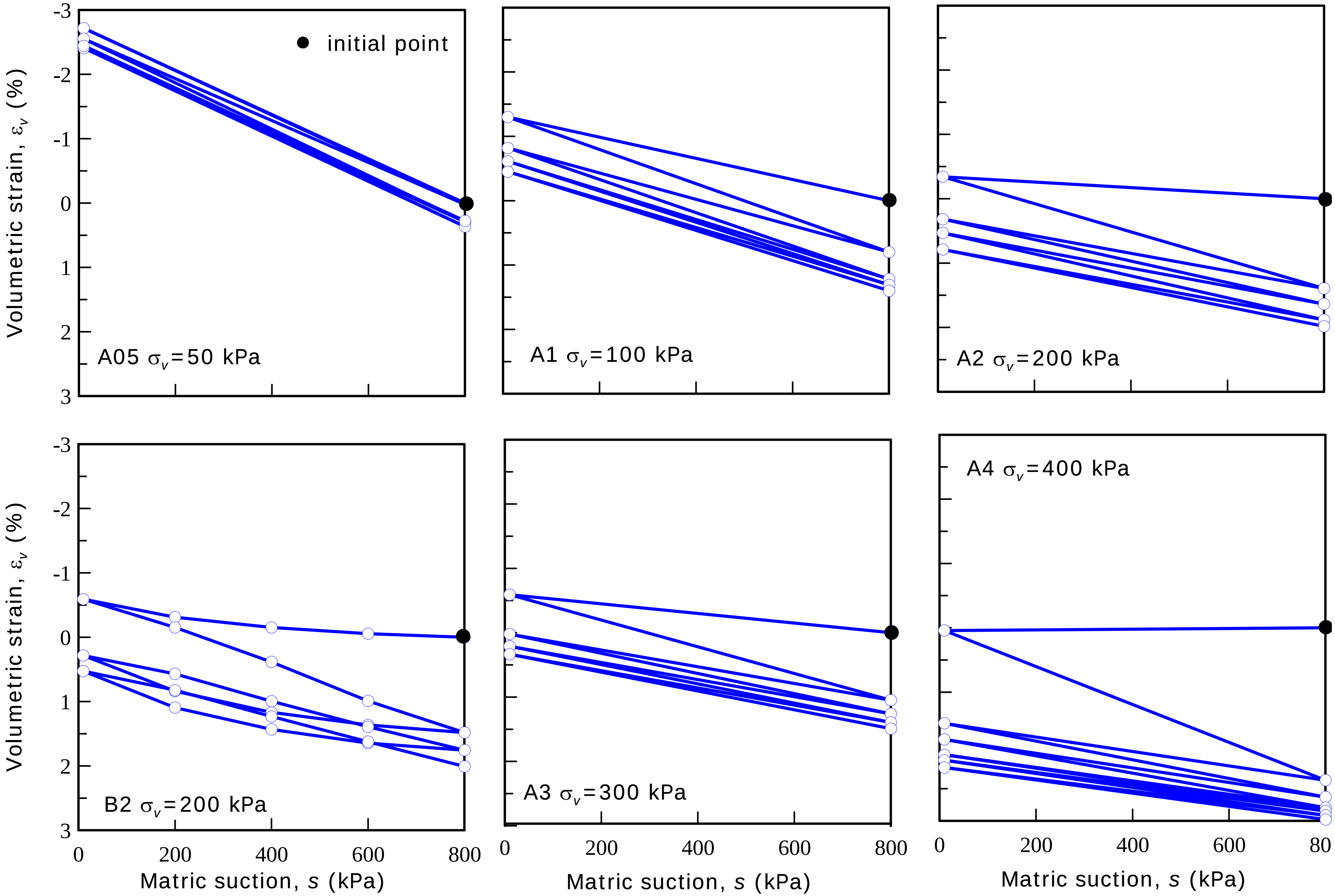


Kaolinitic-illitic clay:
w_o = 15.2%,
γ_d = 17.8 kN/m^3

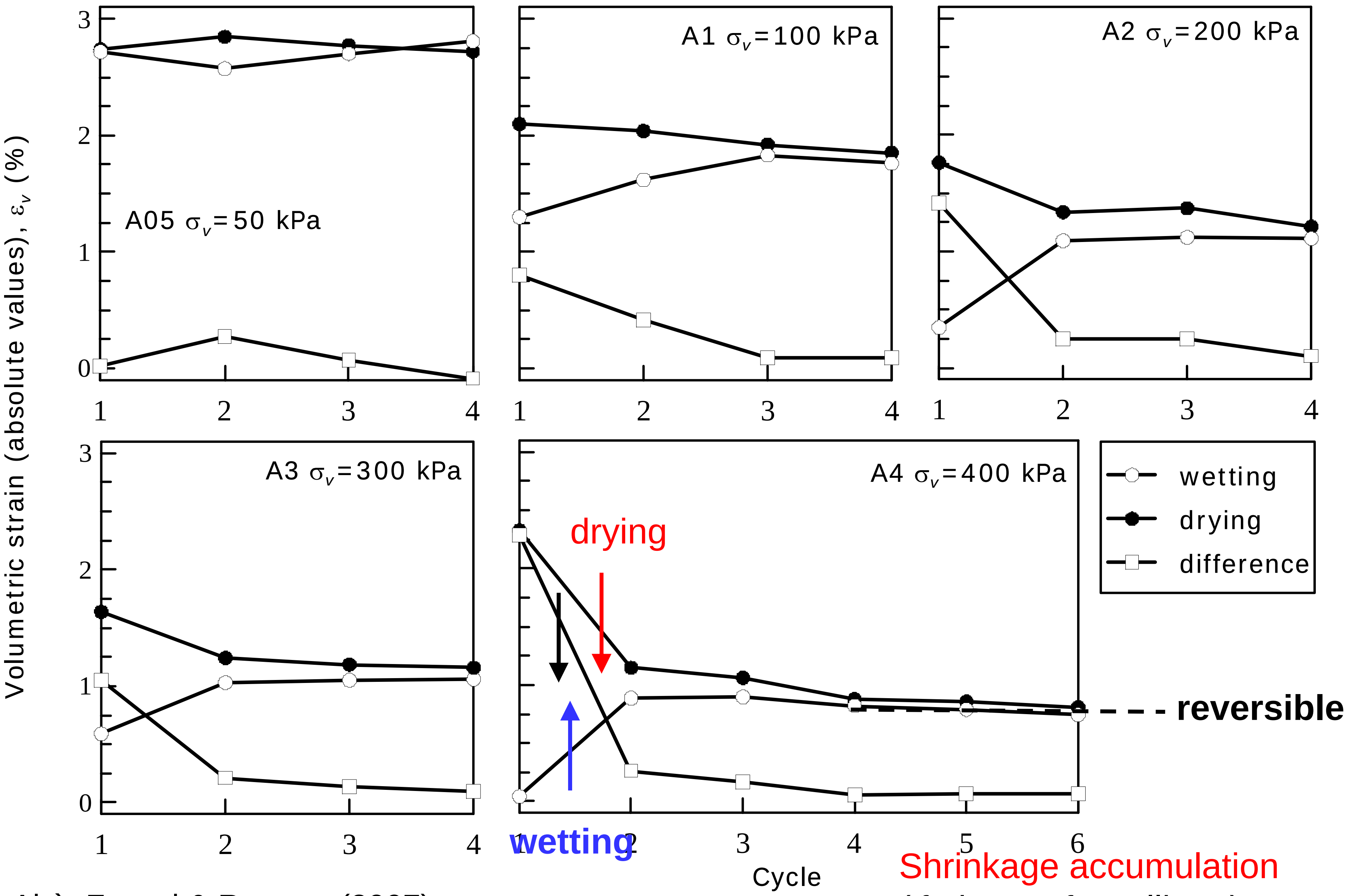
4 to 6 W/D cycles

Airò, Ferrari & Romero (2007)

Volumetric strain evolution with suction cycling (10-800 kPa)

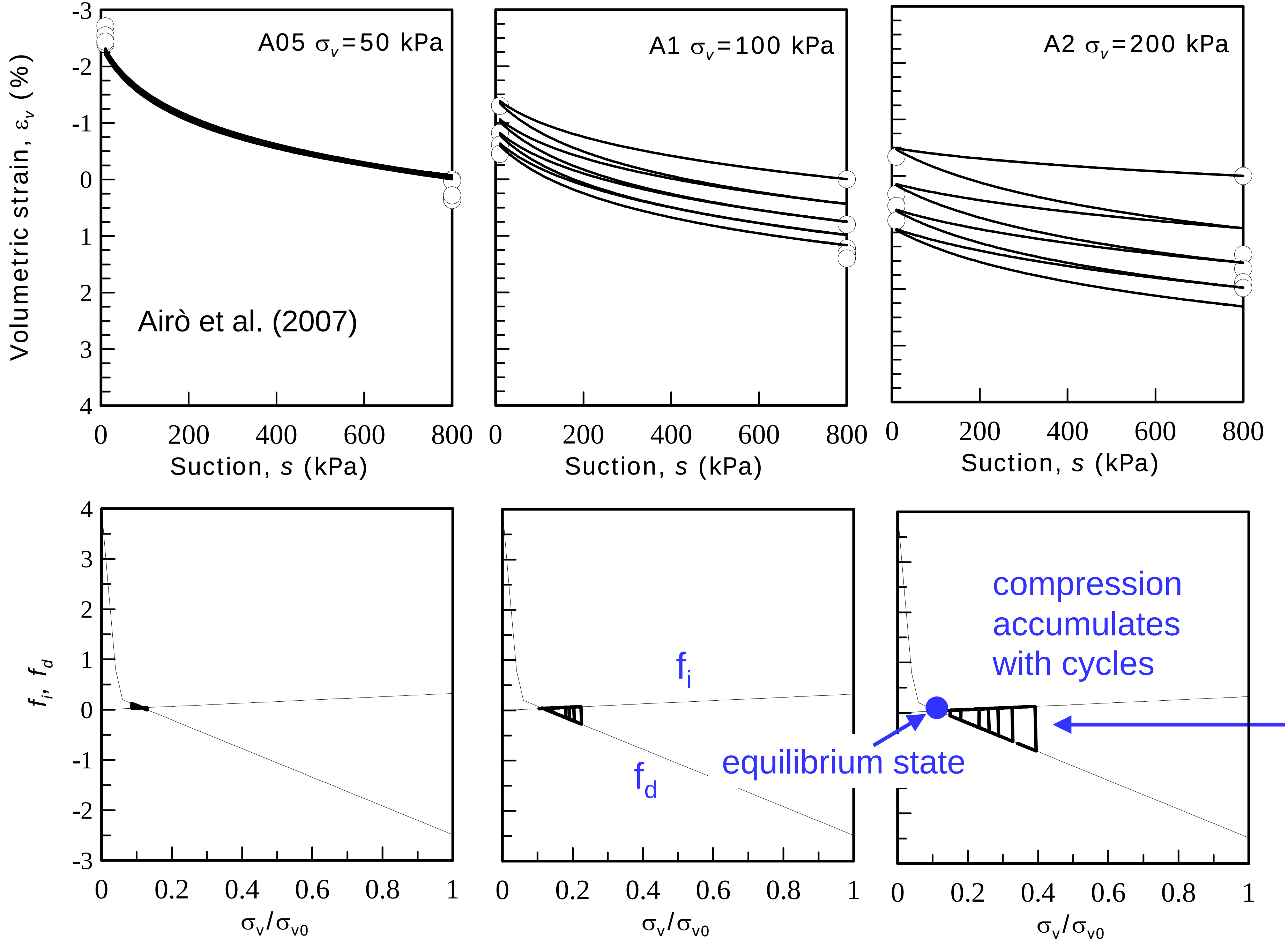


Evolution of volume change response on suction cycling

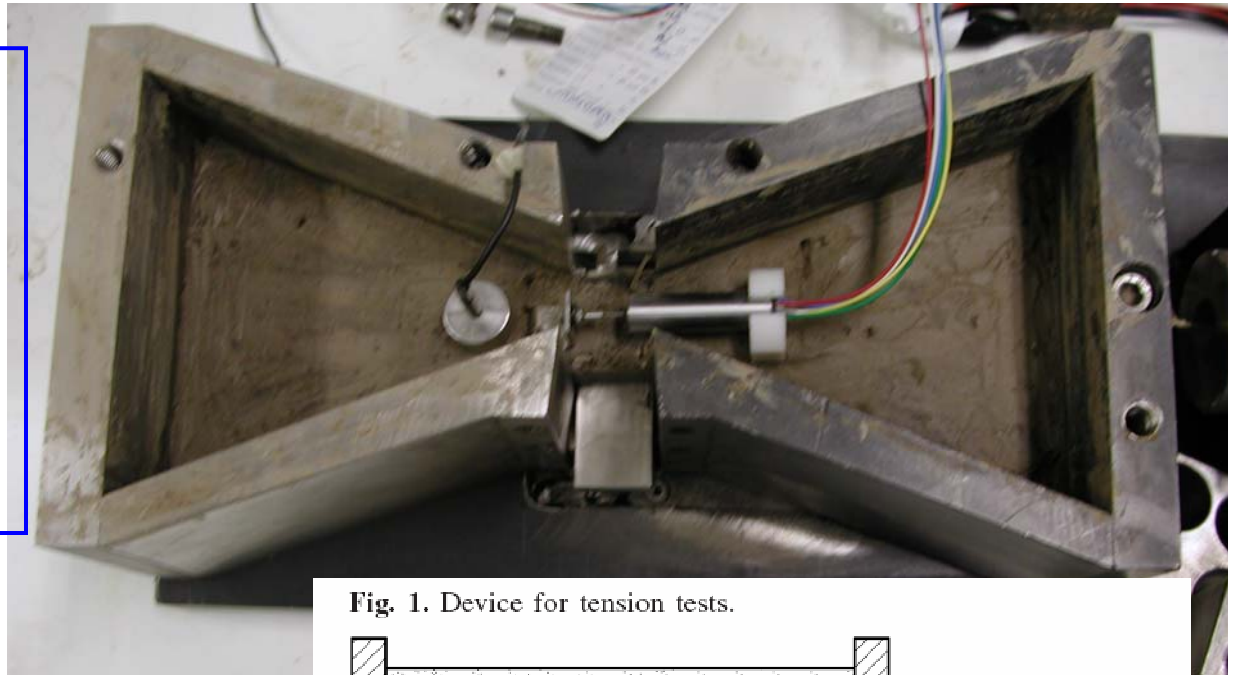


Airò, Ferrari & Romero (2007)

Simulation of experimental results and evolution of coupling functions



Objetivo:
Estimar el tiempo en el que aparecen las primeras grietas de retracción (se alcanza durante el secado una tensión horizontal equivalente a la resistencia de tracción)



Imperial College high-range tensiometer

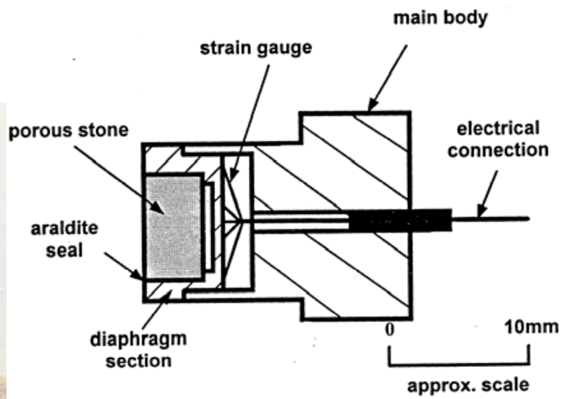
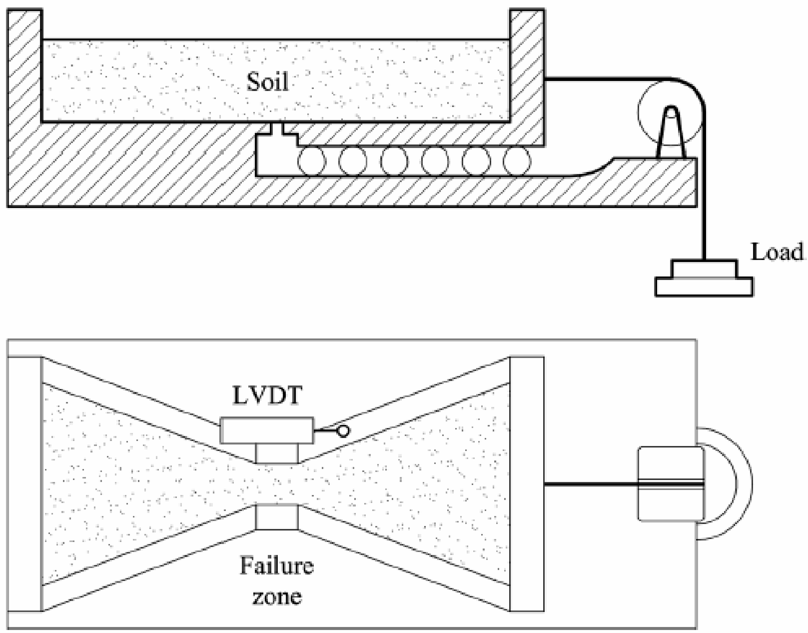


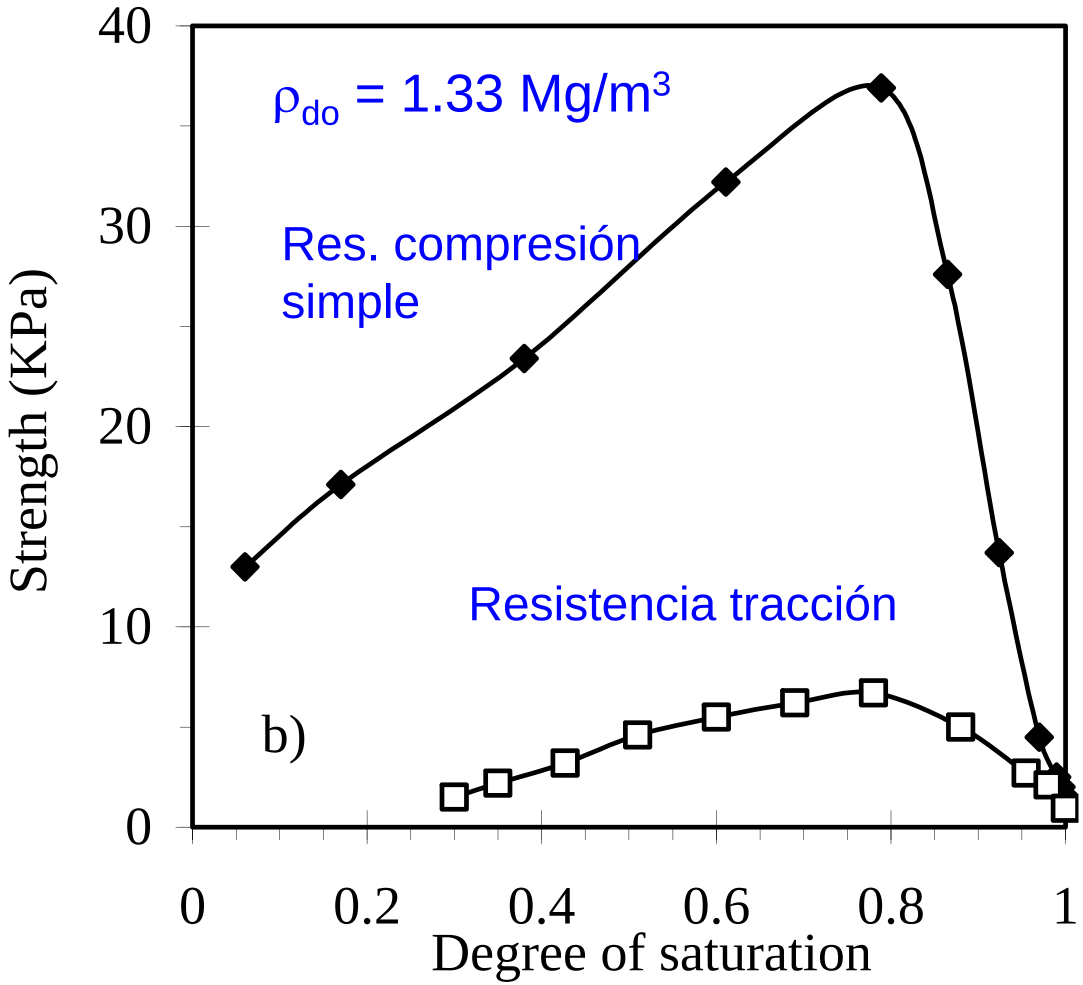
Fig. 1. Device for tension tests.



Mikulitsch & Gudehus (1995), Rodríguez (2002)

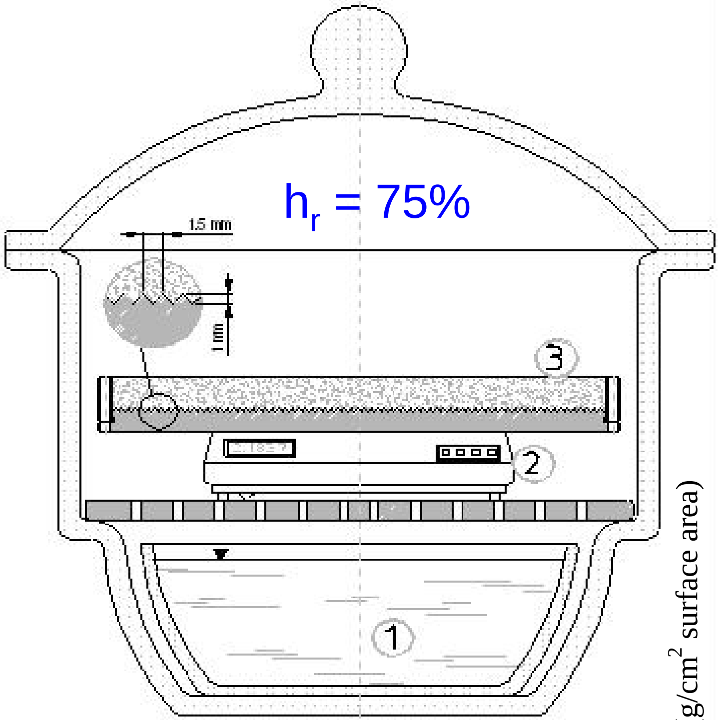
Resistencia a la tracción de residuos de la industria del níquel. Influencia de la saturación

Percent < 80 μm	Percent < 2 μm	C_U	w_L	w_P	PI	ρ_s (Mg/m^3)
92	10	11	43.9	39.9	4	3.97

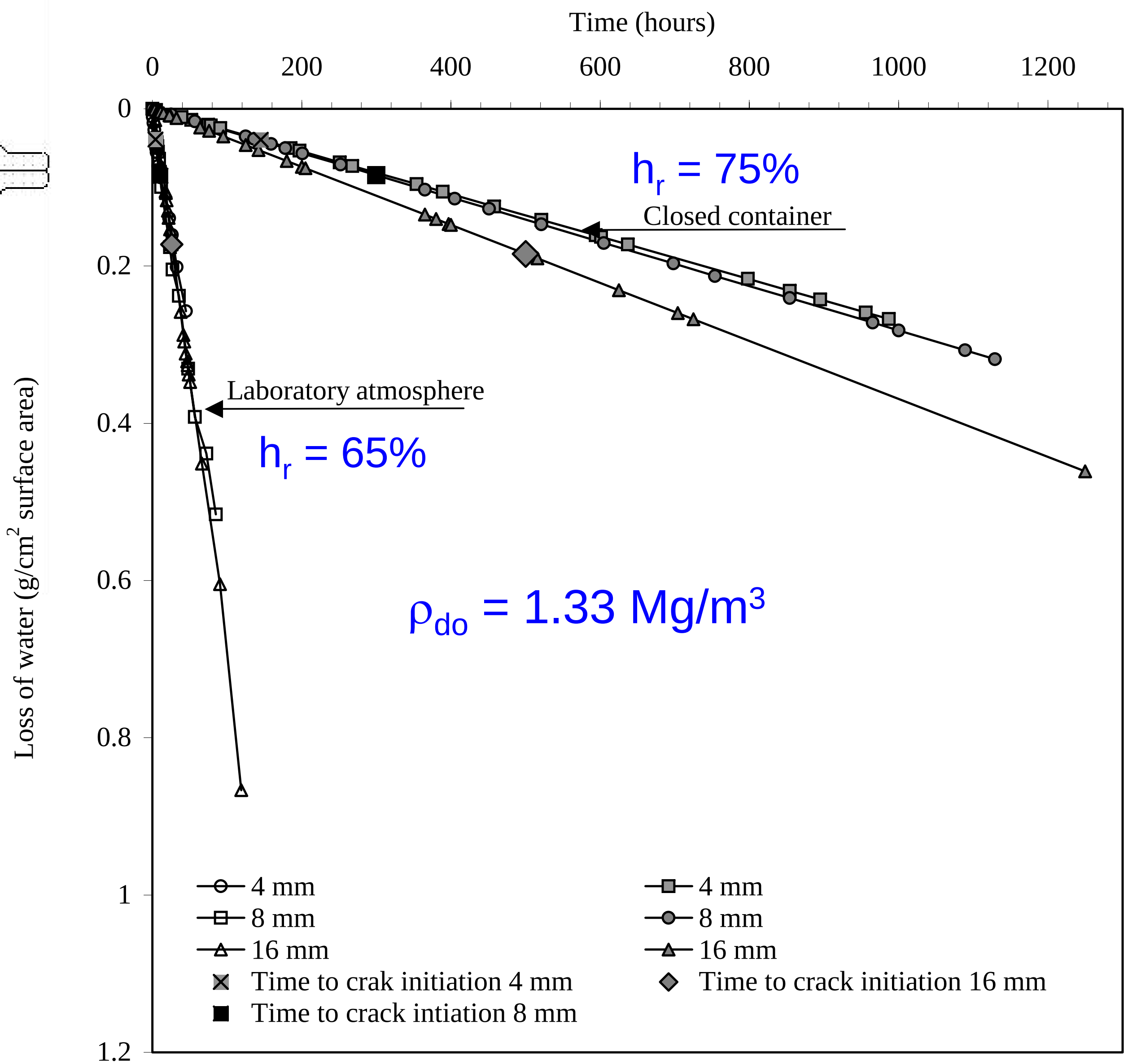


Rodríguez (2002)

Evaporación con control de humedad relativa (residuo de la industria del níquel)



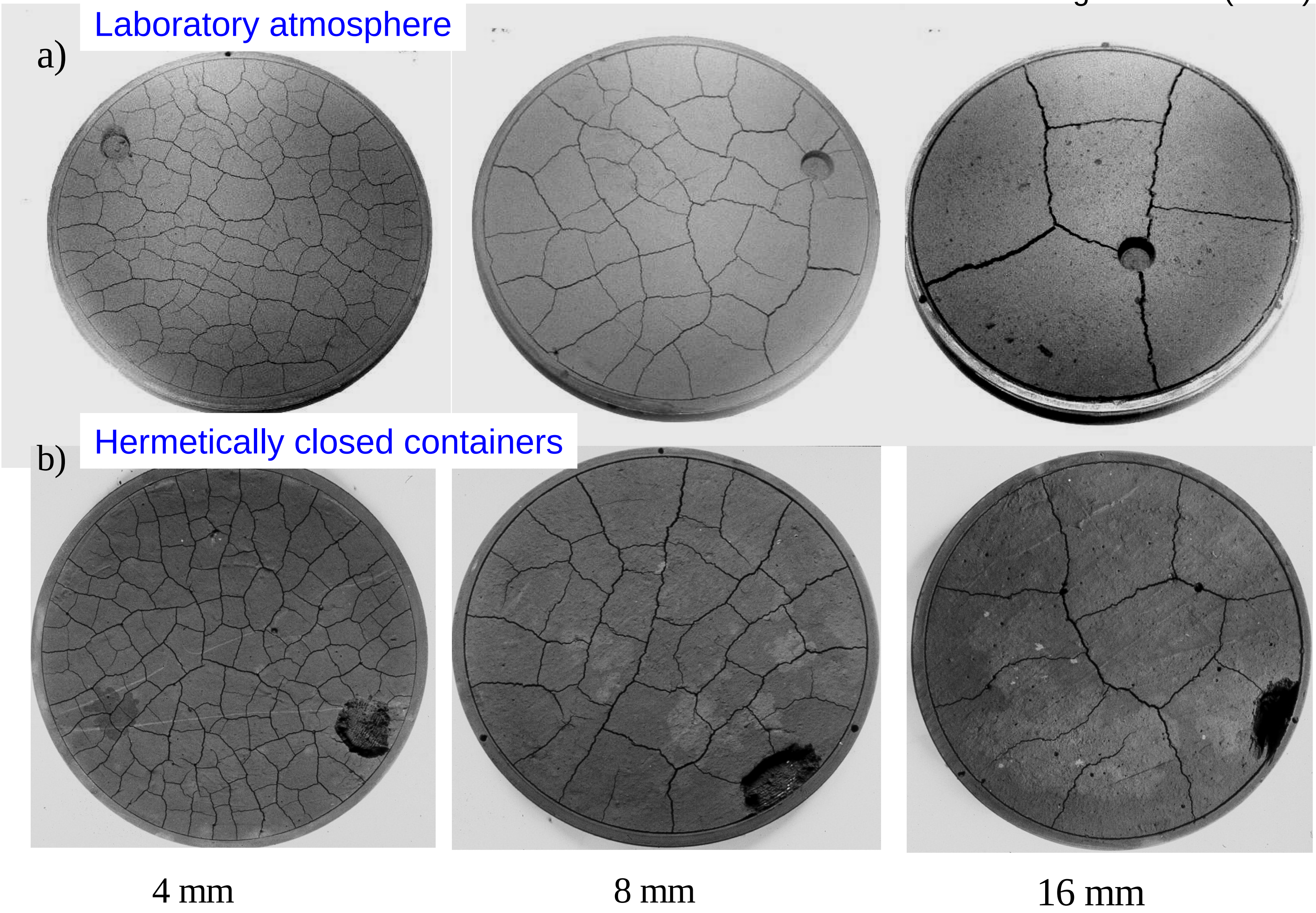
Closed container:
1) saline solution
2) precision balance
3) waste plate



Rodríguez et al. (2007)

Pictures of crack patterns for different waste thicknesses

Rodríguez et al. (2007)

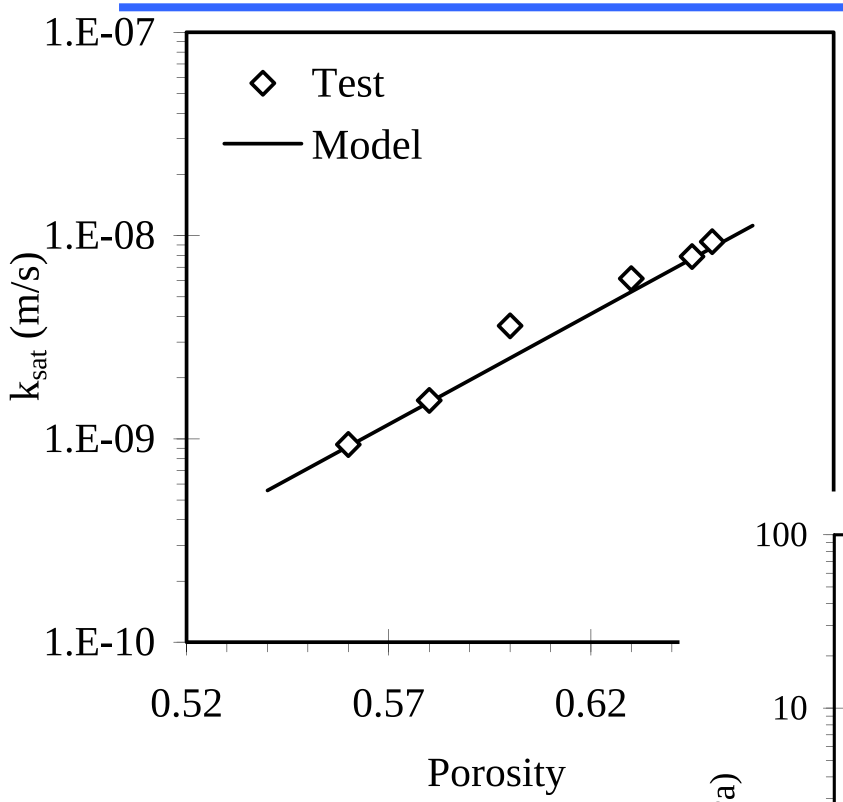


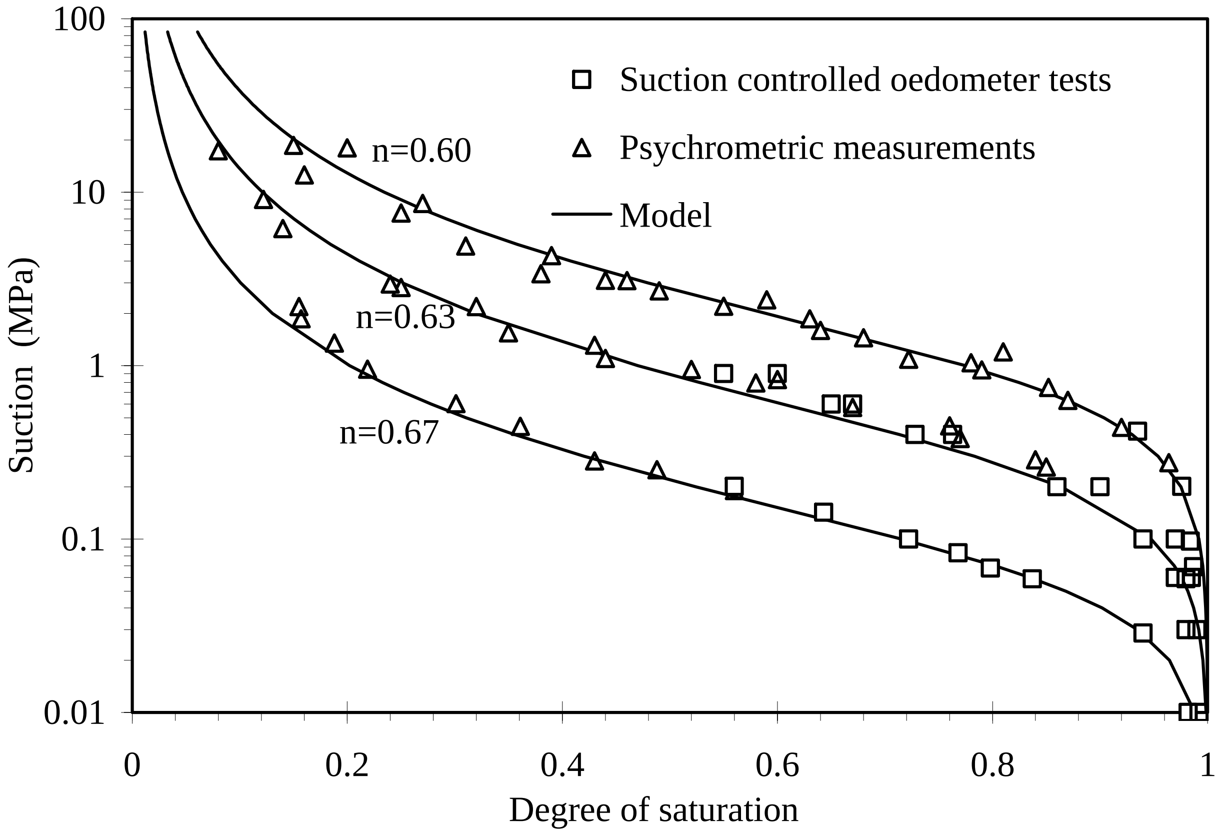
Main equations and unknowns adopted in the HM formulation

Balance equations	**Main variables (unknowns)**
Mass balance of solid	Porosity, n
Mass balance of water	Liquid pressure, P_l
Momentum balance	Displacements, $\mathbf{u}$
Constitutive equations	**Dependent variables**
Mechanical model	Stress tensor, σ
Darcy's law	Liquid and gas advective flux, $\mathbf{q}_l$, $\mathbf{q}_g$
Retention curve	Liquid degree of saturation, S_l
Fick's law	Vapour and air nonadvective fluxes, $\mathbf{i}_g^w$, $\mathbf{i}_l^a$
Phase density*	Liquid density, ρ_l
Phase viscosity*	Liquid viscosity, ν
Gases law	Gas density, ρ_g
Equilibrium restriction	
Psychrometric law	Vapour concentration in the gas phase, ω_g^w

*Not included in this work.

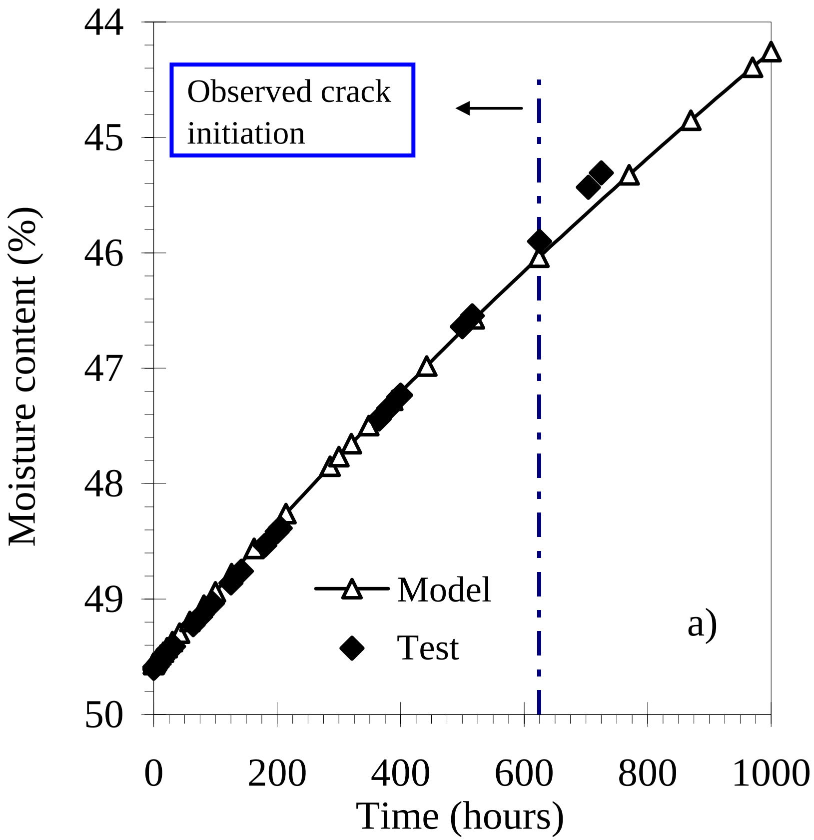
Water permeability and water retention properties (metallurgical Ni waste)





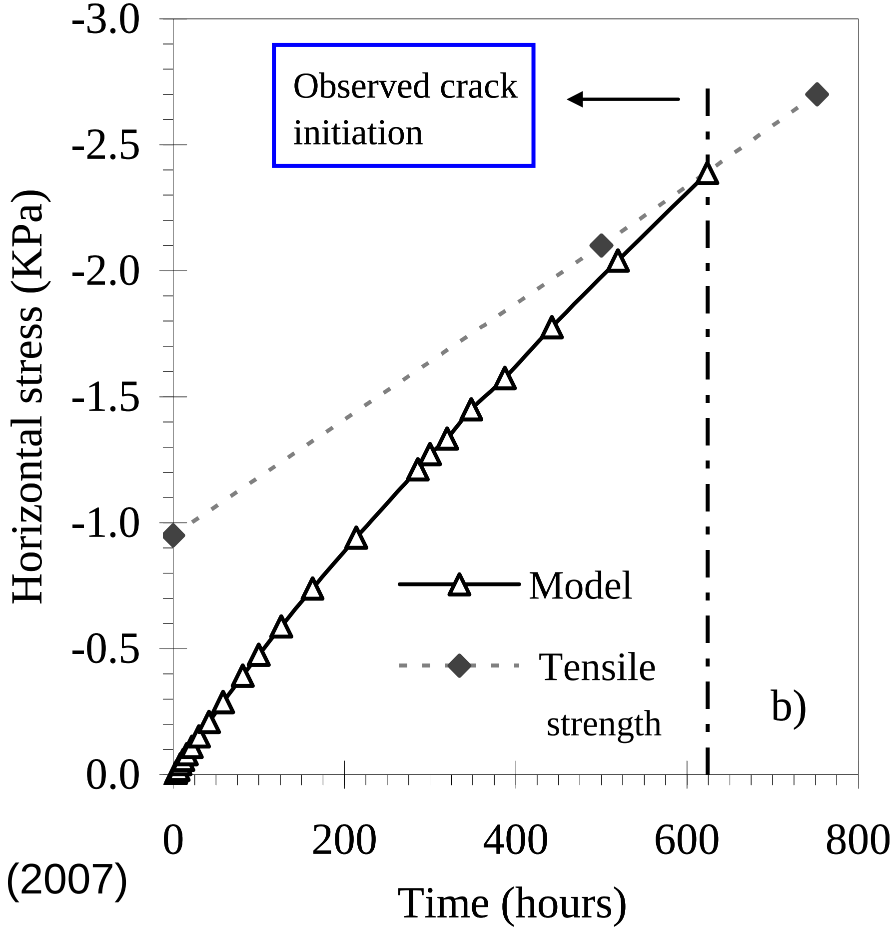
Rodríguez (2002)

Drying in closed container (h_r = 75%)



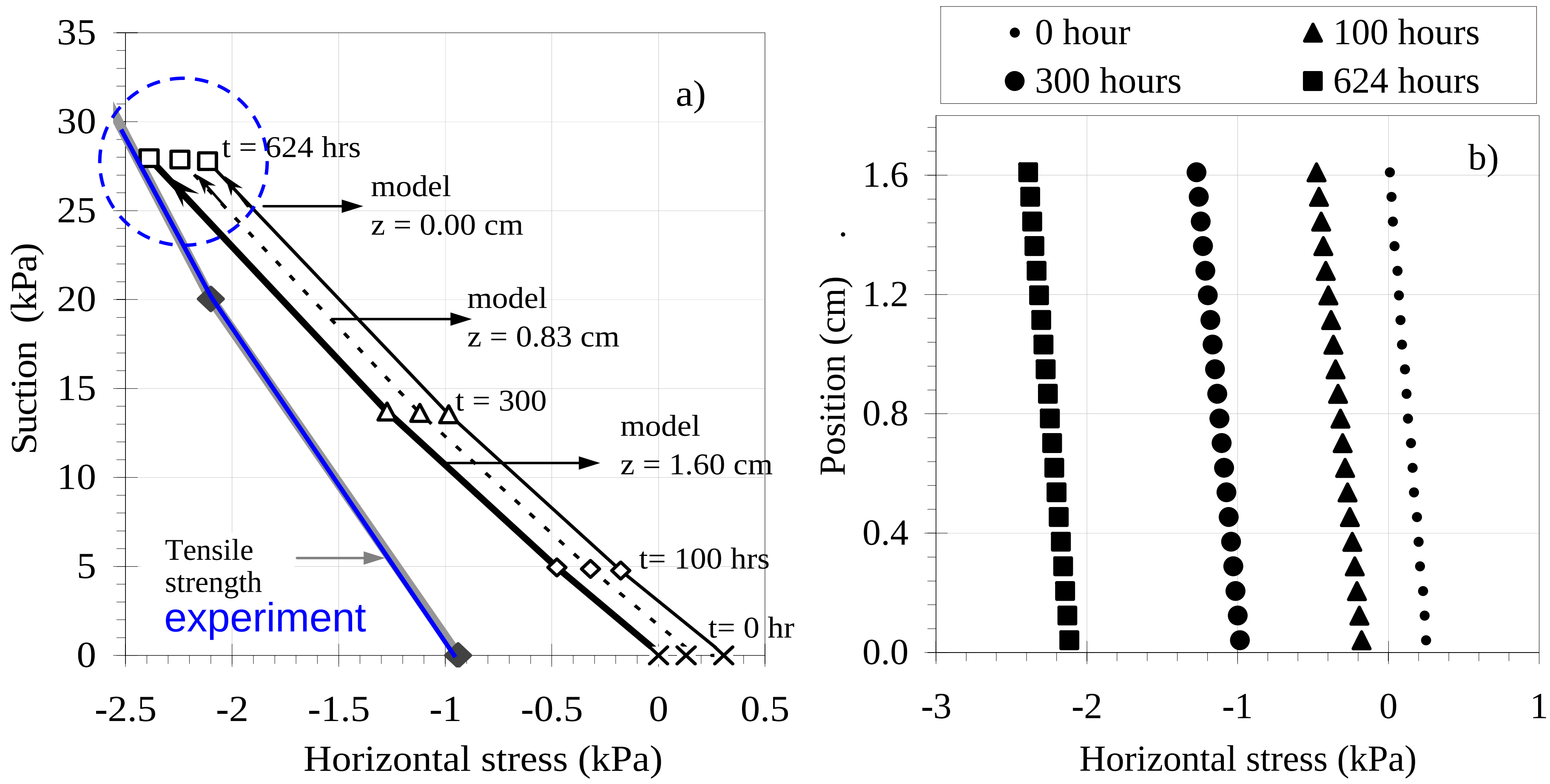
Computed and measured evolution of water content (crack initiation)

Evolution of computed horizontal stress and tensile strength



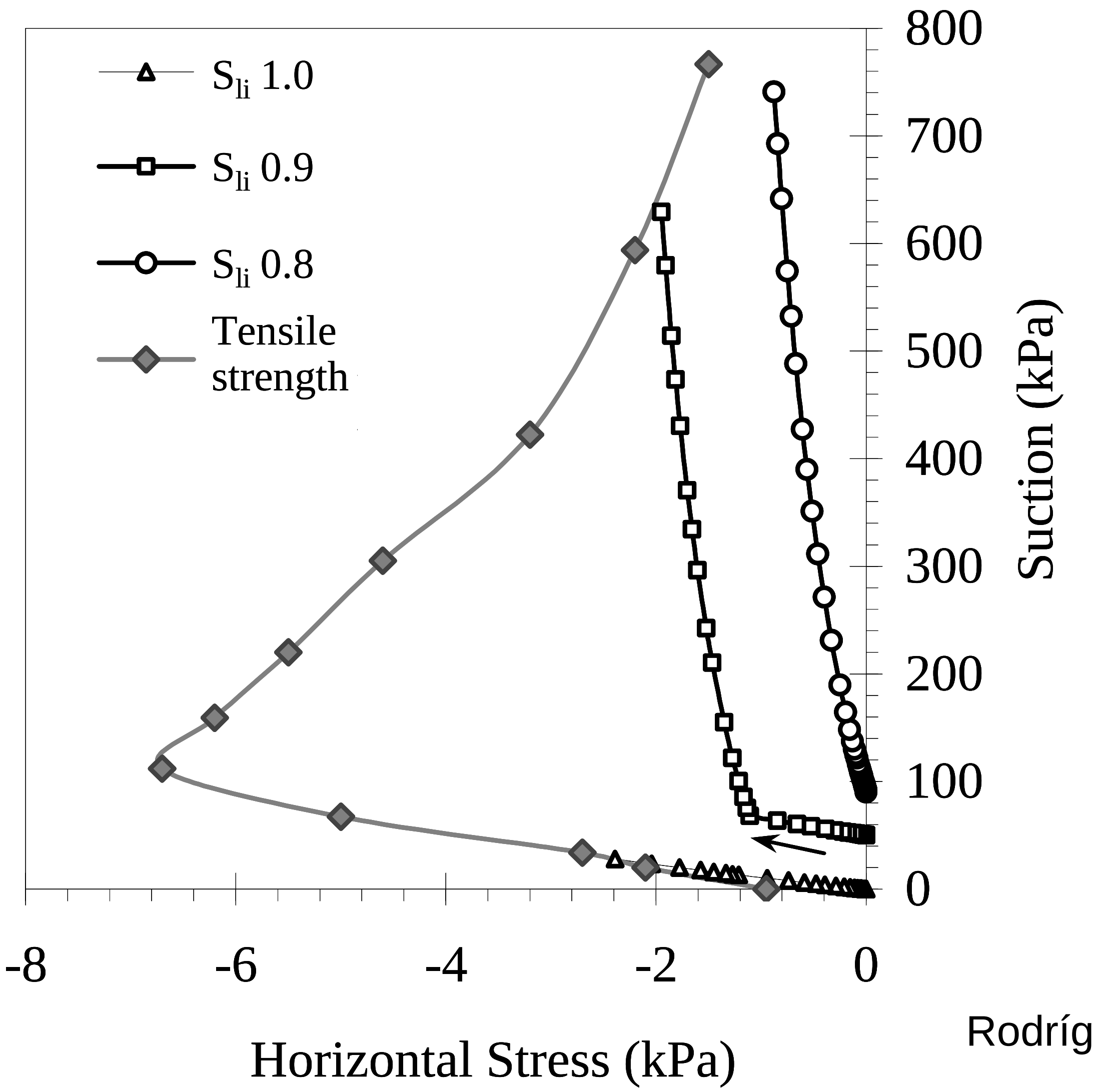
Rodríguez et al. (2007)

Evolution of horizontal stress at different depths and times (drying at h_r = 75%)



Rodríguez et al. (2007)

Tensile strength and drying process for samples with different initial degrees of saturation



Rodríguez et al. (2007)

La formación de las grietas ocurre a un grado de saturación muy alto (usualmente mayor del 80%) → Retracción importante

Size effect in the cracking of drying (crack development and propagation)

Clayey silt: 60% passing No.200 sieve, w_L = 32%, PI = 16%, w_o = 24.5%

Trays with different surfaces:
A: smooth, B: circular grooves, C: grid

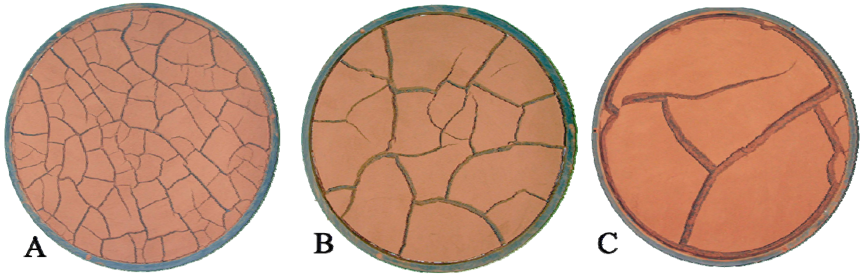


Figure 1. Cracking pattern for different sample thickness (circular groove) A: 4 mm; B: 8 mm; C: 16 mm

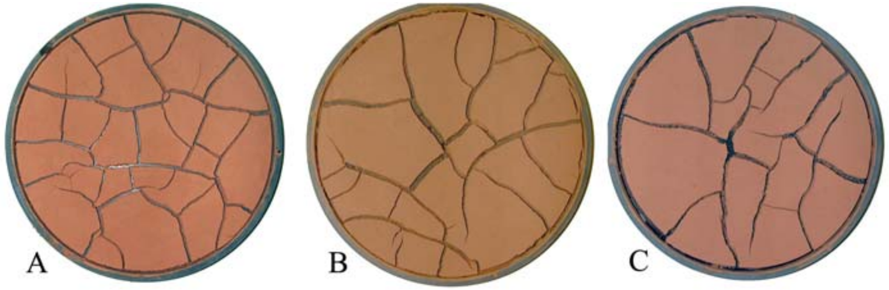


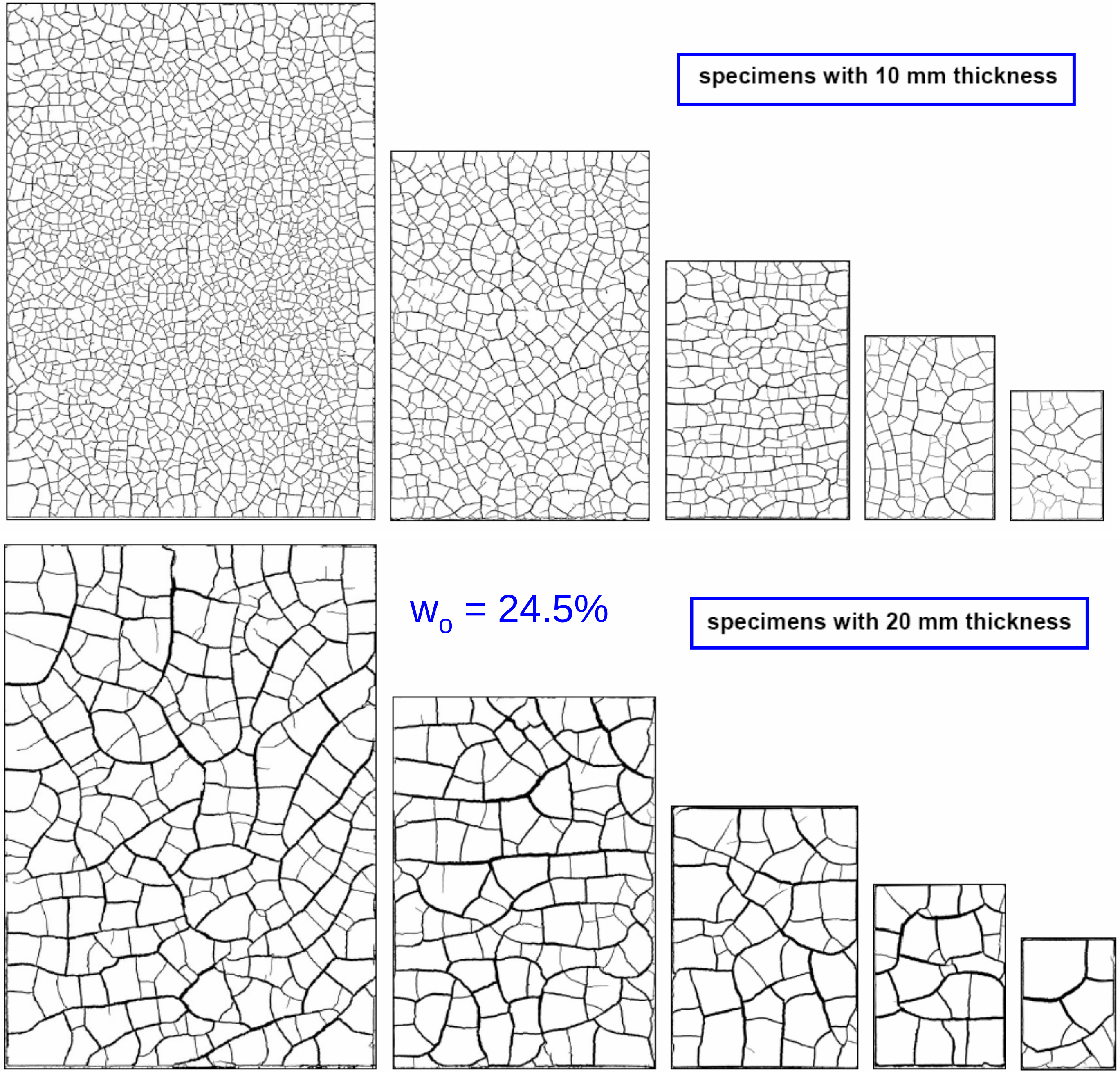
Figure 2. Cracking pattern for different contact surfaces (8 mm thick sample) A: Smooth; B: Circular grooves; C: Square grid

Lakshmikantha et al. (2006)

Size effect in the cracking of drying soil

Aspect ratio: $2^{1/2}$

Area:
1, 0.5, 0.25, 0.125 and 0.0625 m^2



Appear to be energy-driven phenomena (depend on the size)

Prat, Ledesma & Lakshmikantha (2007)

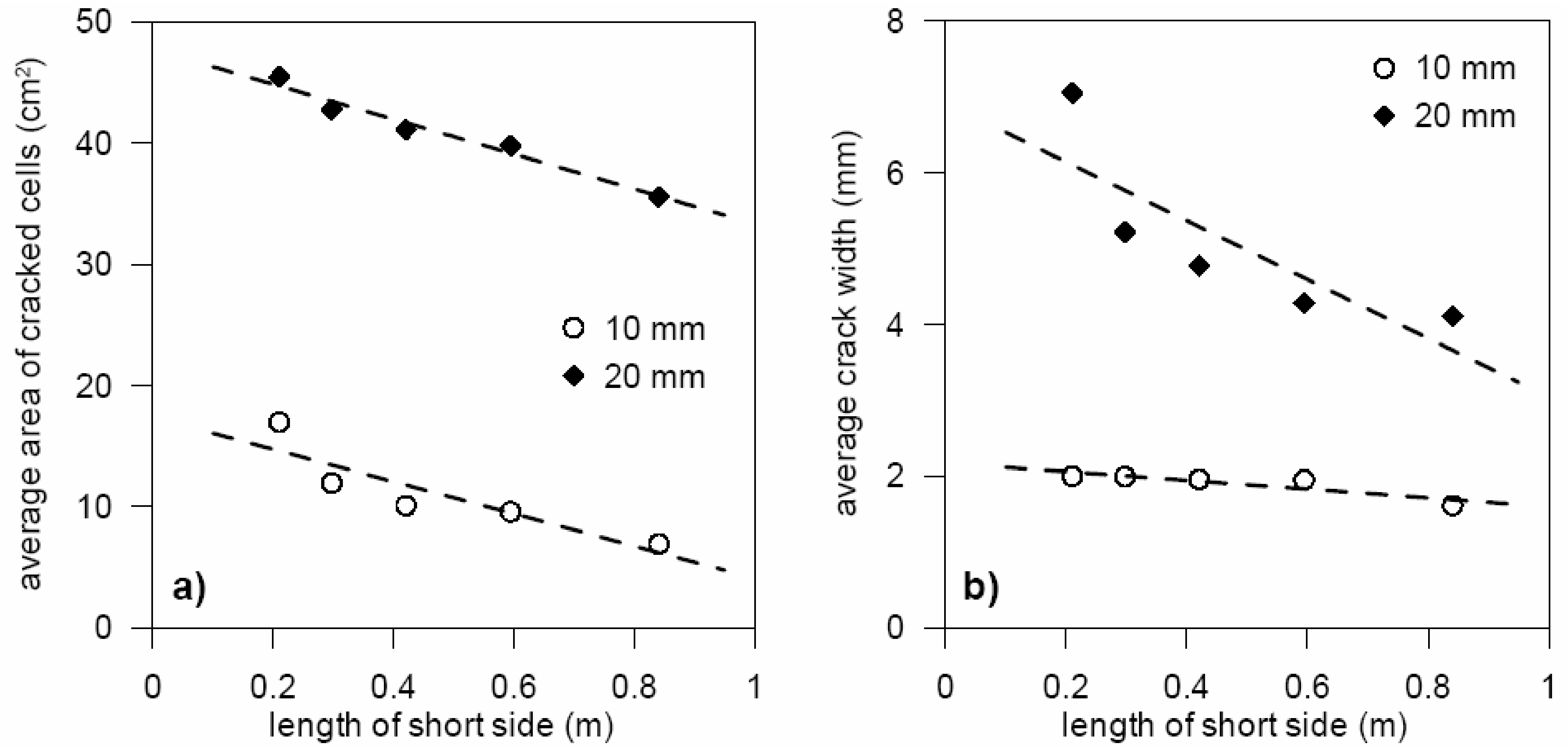
Specimen geometry and results from image analysis

Test #	nominal area of specimen (m^2)	thick-ness (mm)	area of uncracked material (cm^2)	surface shrinkage (CDF) (%)	total crack area (cm^2)	average area of cells (cm^2)	total length of cracks (cm)	average width of cracks (mm)	length of cracks per unit area (cm^{-1})
A0-10	1.0000	10	8828.69	11.71	1171.31	6.94	7280.76	1.61	0.73
A1-10	0.5000	10	4460.48	10.79	539.52	9.57	2746.49	1.95	0.55
A2-10	0.2500	10	2208.29	11.67	291.71	10.08	1460.33	1.96	0.58
A3-10	0.1250	10	1135.96	9.12	114.04	11.96	560.26	1.99	0.45
A4-10	0.0625	10	577.22	7.64	47.78	16.98	232.92	2.00	0.37
A0-20	1.0000	20	8850.88	11.49	1149.12	35.55	2793.85	4.11	0.28
A1-20	0.5000	20	4333.98	13.32	666.02	39.76	1545.88	4.28	0.31
A2-20	0.2500	20	2176.31	12.95	323.69	41.06	668.24	4.77	0.27
A3-20	0.1250	20	1068.88	14.49	181.12	42.76	342.08	5.22	0.27
A4-20	0.0625	20	545.50	12.72	79.50	45.46	110.91	7.05	0.18

Crack network pattern was studied using an image processing software (ImageJ)

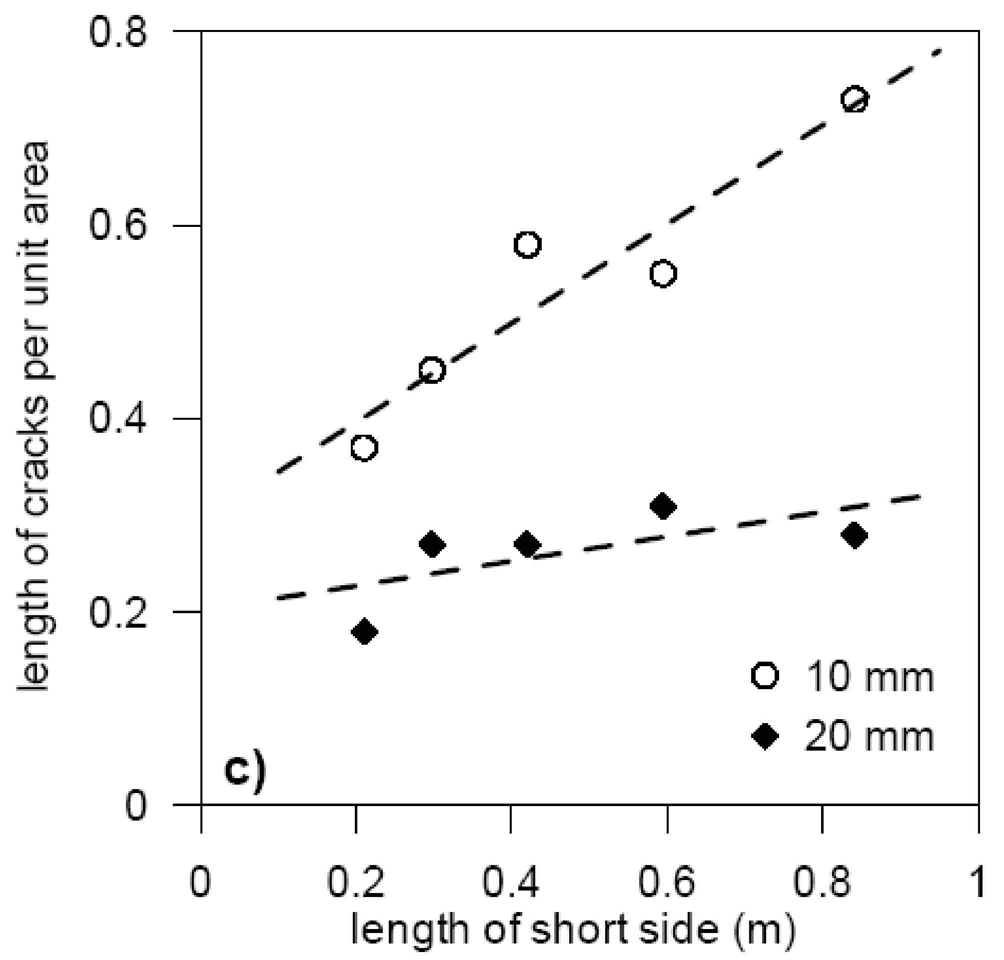
Prat, Ledesma & Lakshmikantha (2007)

Effect of specimen size on several measurements



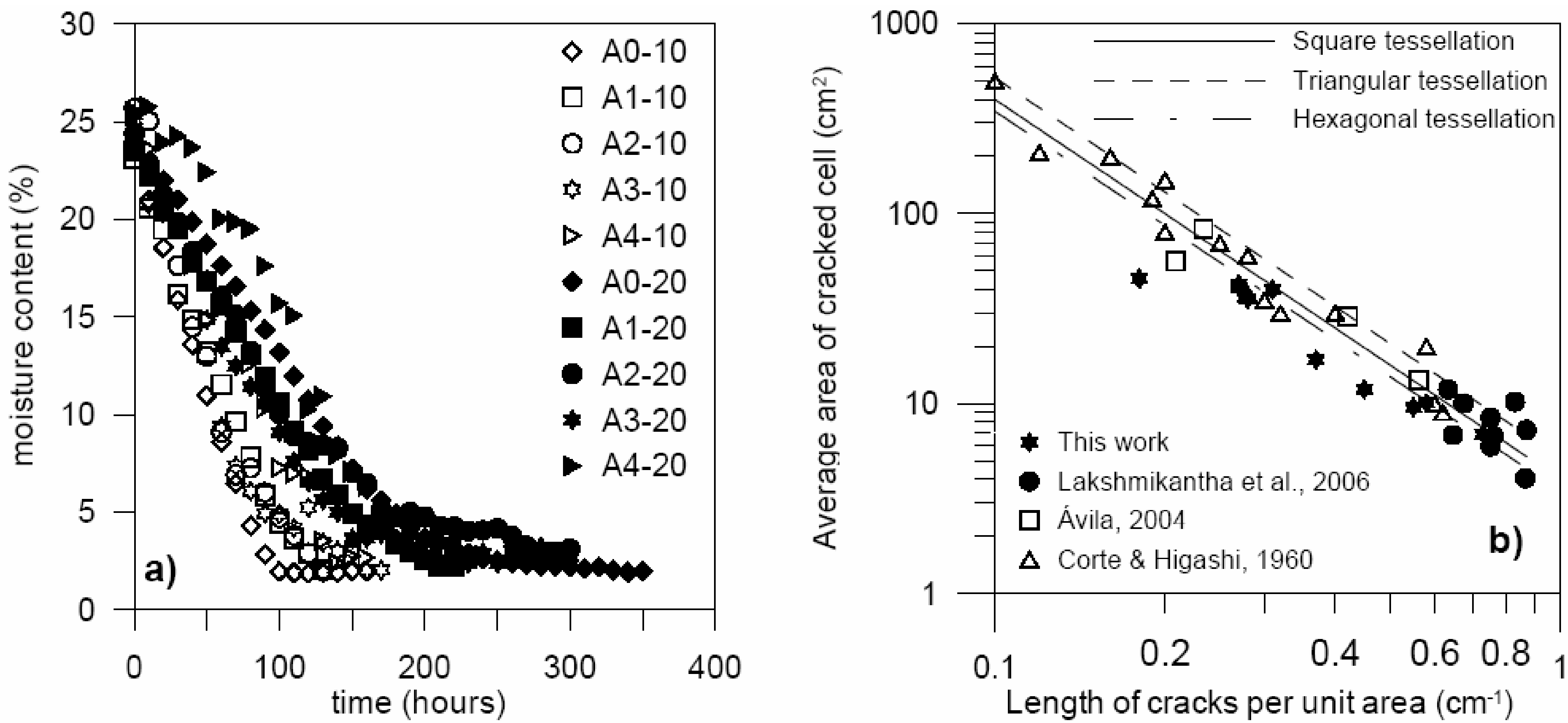
Prat, Ledesma & Lakshmikantha (2007)

Effect of specimen size on several measurements



Prat, Ledesma & Lakshmikantha (2007)

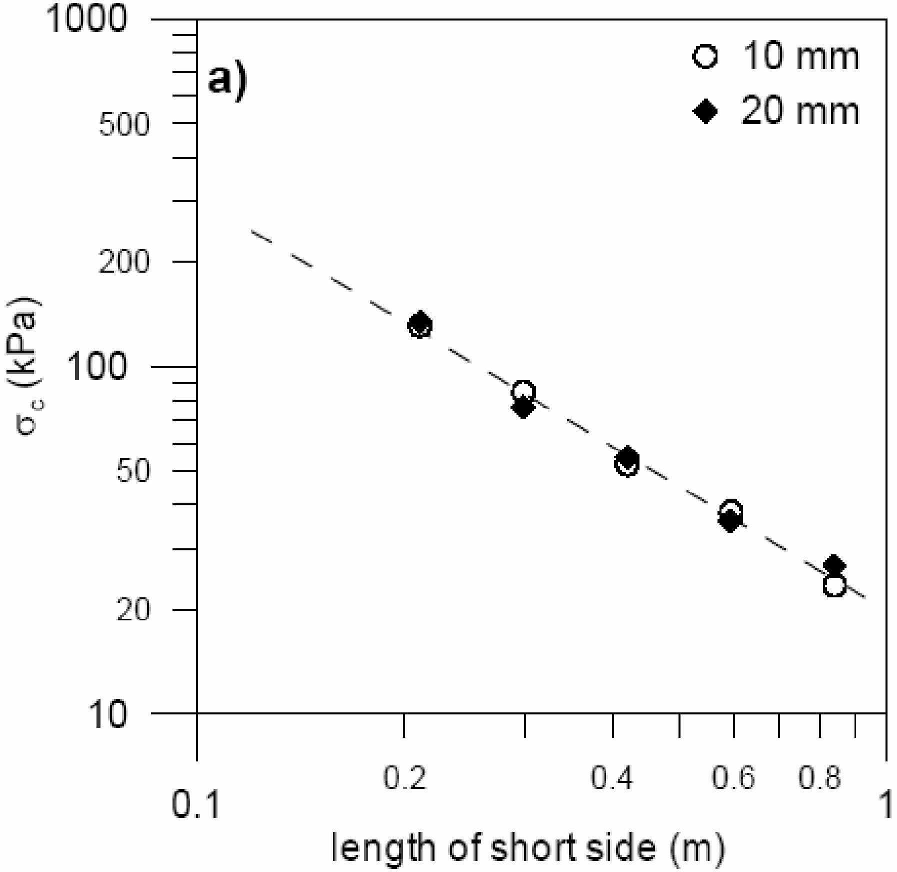
Effect of specimen size on several measurements



Prat, Ledesma & Lakshmikantha (2007)

Fracture mechanics (size effects of 'cracking stress')

Prat, Ledesma & Lakshmikantha (2007)

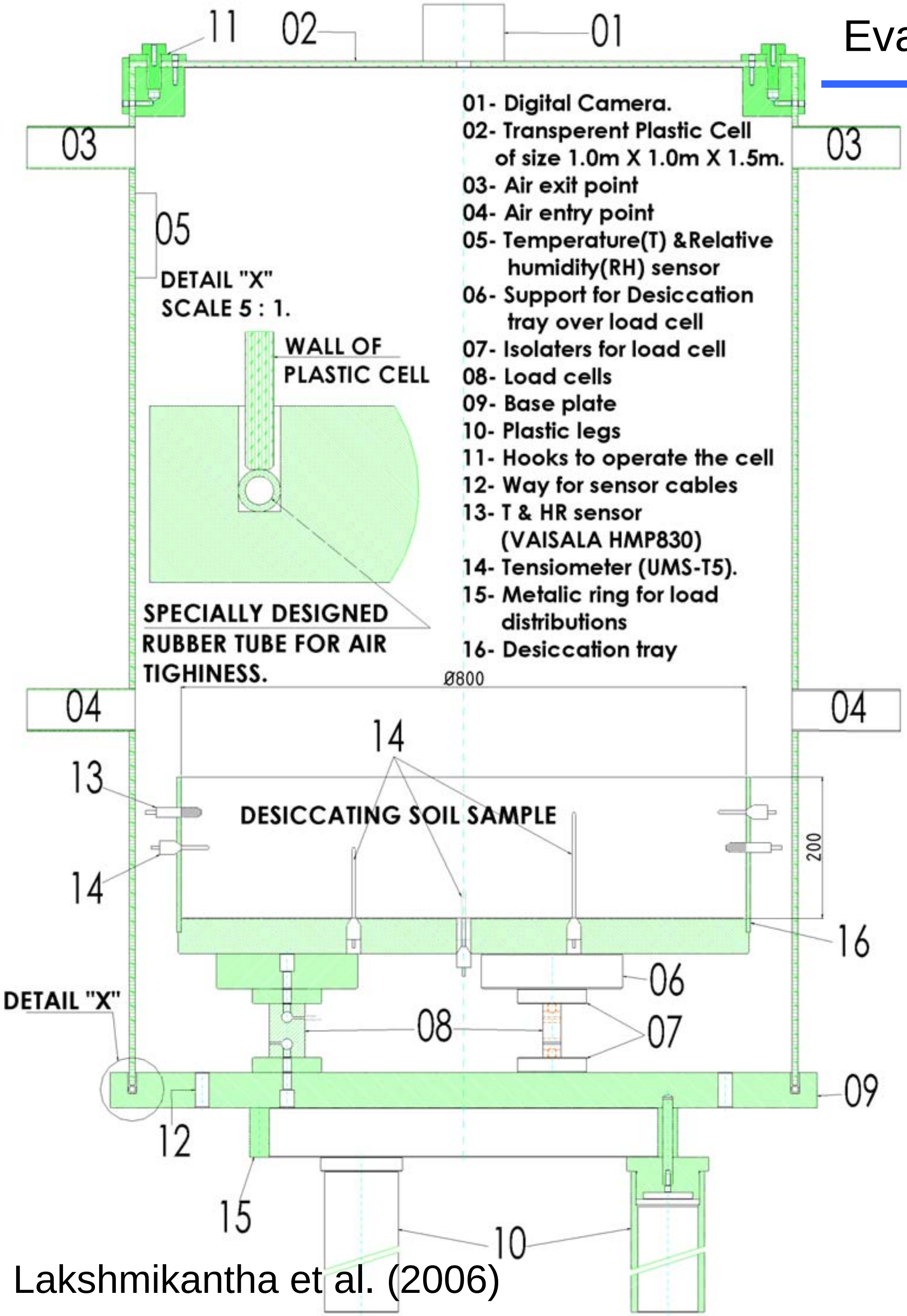


Average 'cracking stress' can be estimated using LEFM relation: $\sigma_c = \sqrt{\frac{G_{IC}E}{\pi a}}$

G_{IC}: fracture energy (5 N/m), assumed a material property
E: Young's modulus (250 MPa)
a: total length of cracks

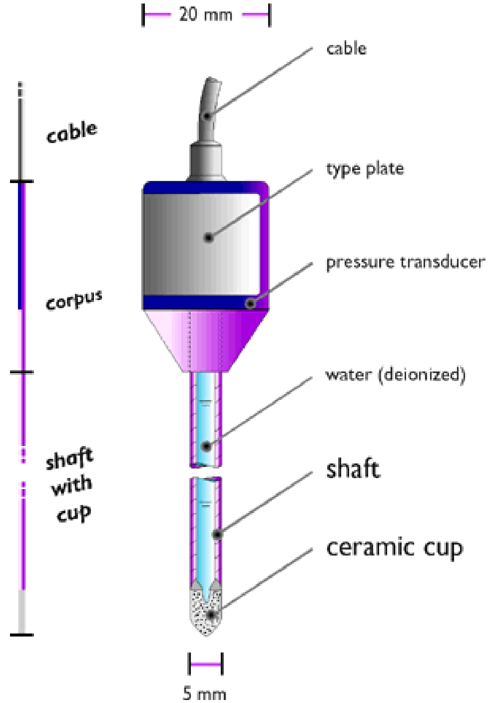
$$\sigma_c = \sqrt{\frac{5\frac{N}{m}\cdot 250\times 10^6\frac{N}{m^2}}{\pi\cdot a}} \simeq \frac{20000\,N\times m^{-3/2}}{\sqrt{a}\,m^{1/2}} = \frac{20}{\sqrt{a}}\,kPa$$

Evaporative column for dessication monitoring

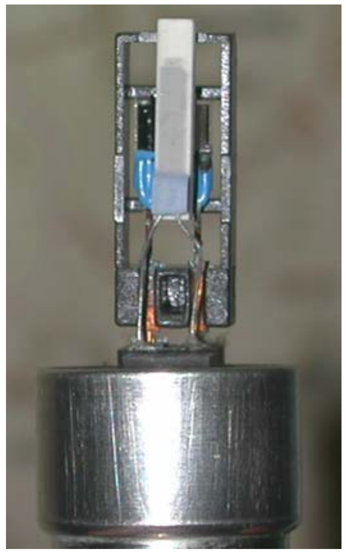


Lakshmikantha et al. (2006)

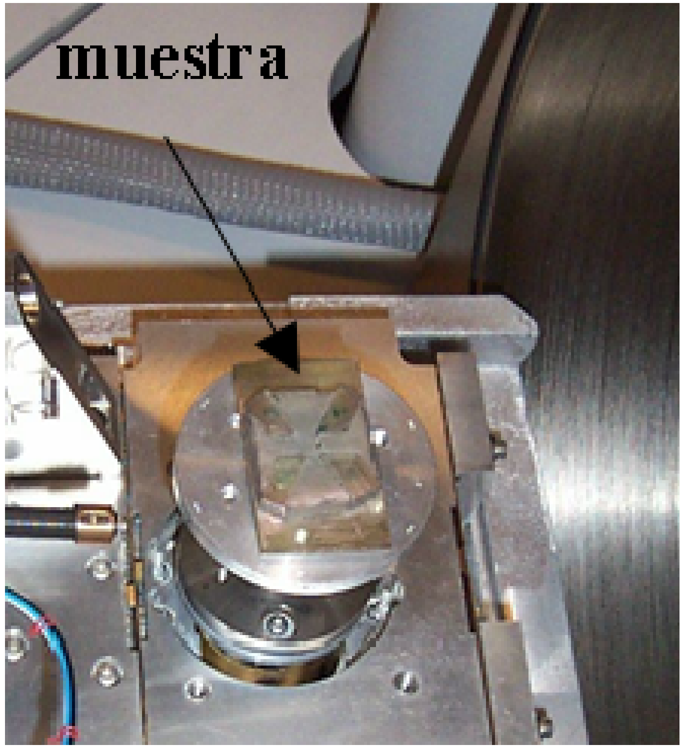
Low-range tensiometers



Capacitive hygrometer (relative humidity)

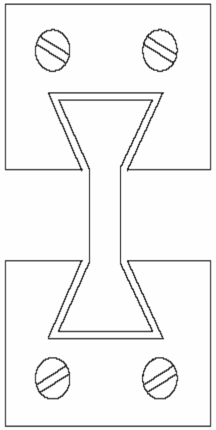


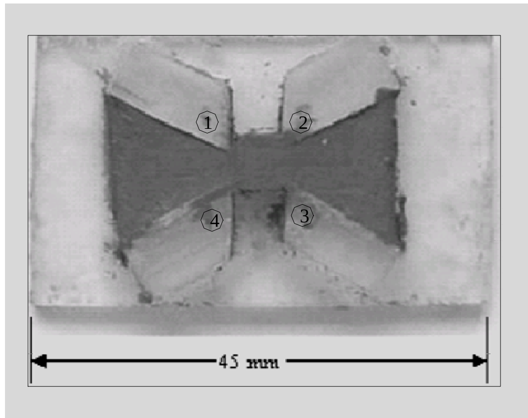
Evolution of μ-cracking of clay induced by desiccation using ESEM (Ávila 2005)



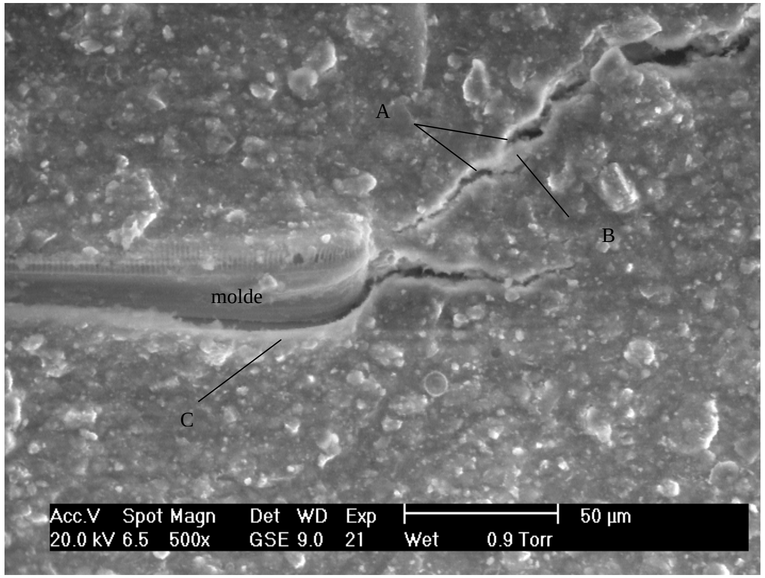
Shrinkage/tensile
test geometry

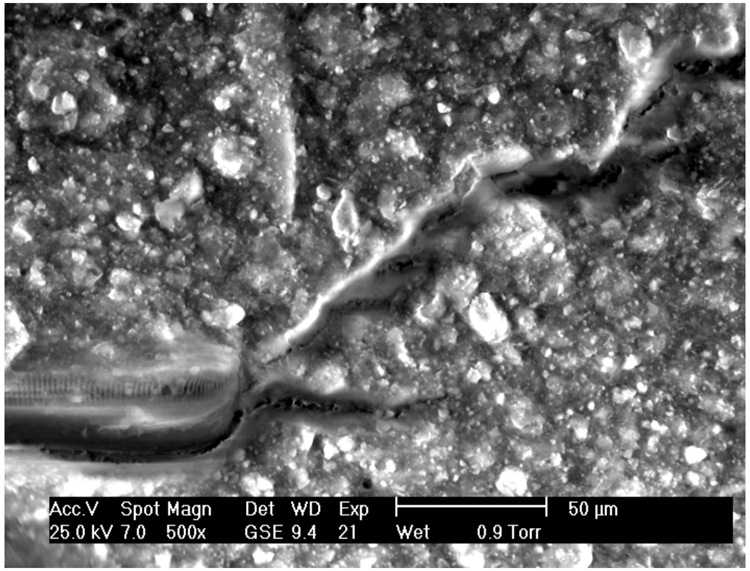
Ends of specimen wedge
into fixed grips

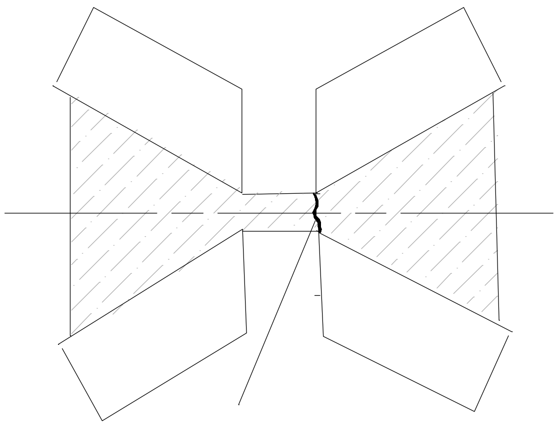




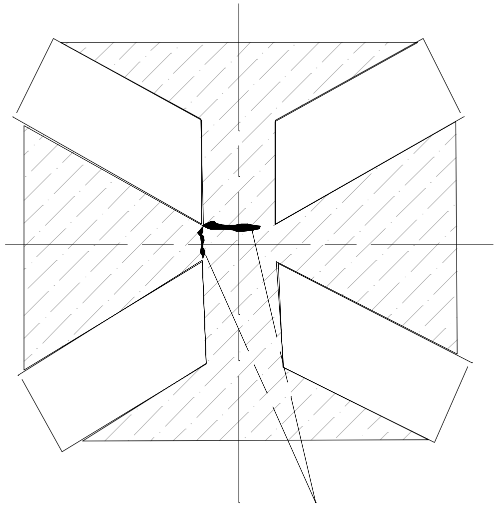
Constrain effects on shrinkage



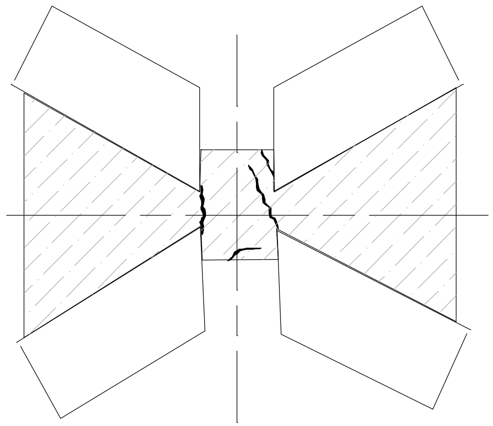




Una grieta principal perpendicular al eje de tracción



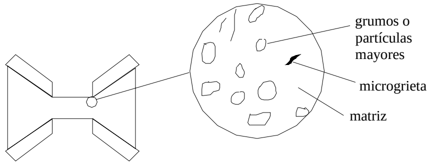
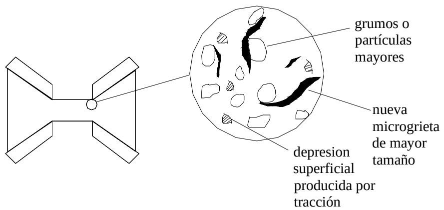
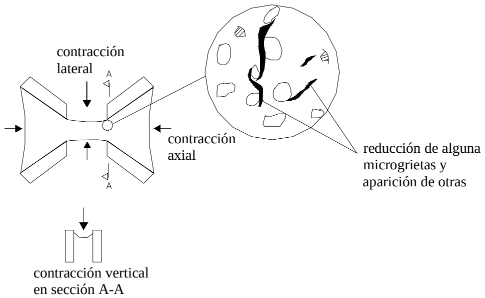
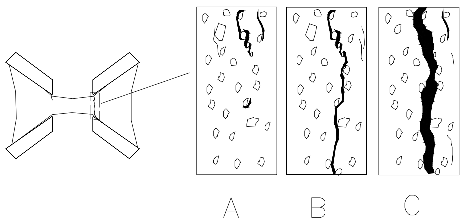
Dos grietas perpendiculares



Múltiples grietas

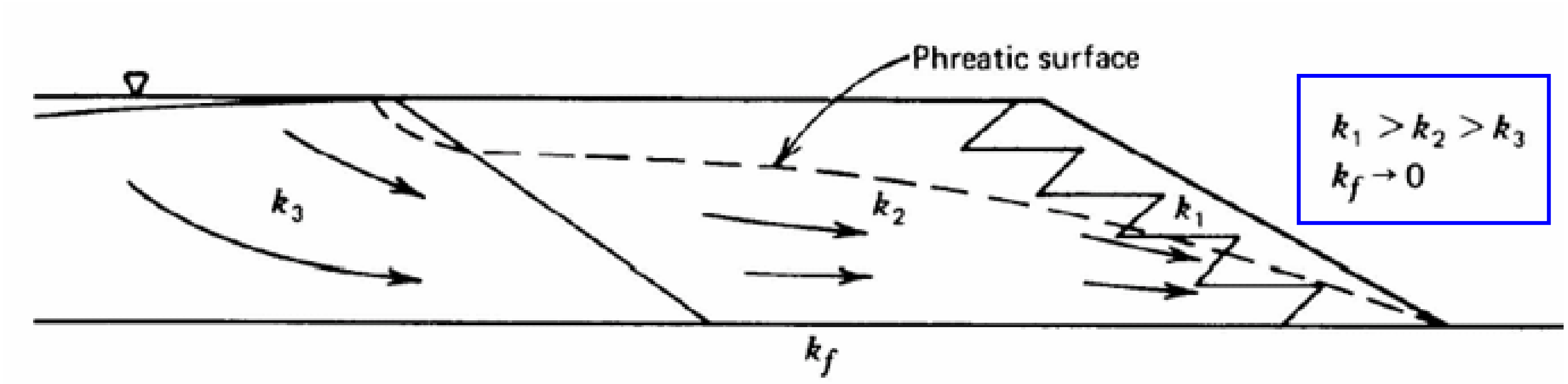
(Ávila 2005)

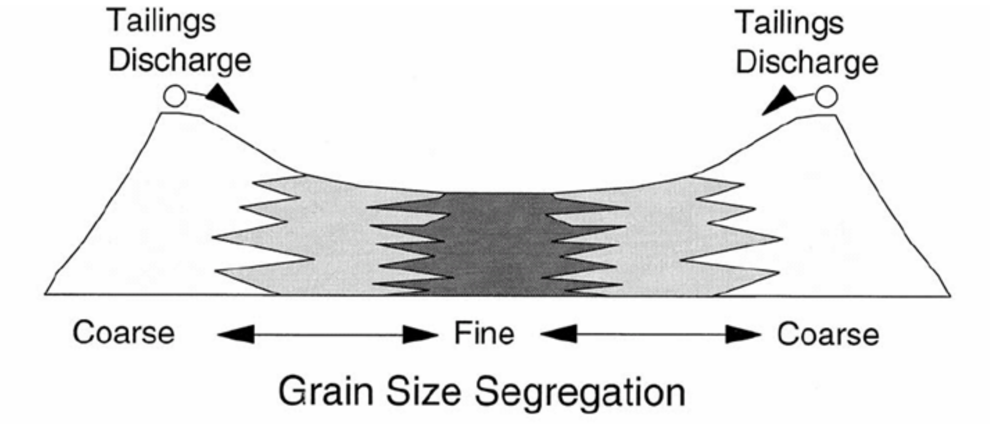
Evolution of μ-cracking induced by desiccation

Etapa	Intervalo de Humedad (%)	Intervalo de Succión (kPa)	**Esquema**	**Descripción Macroscópica**	**Descripción Microscópica**
1 Muestra húmeda	50 40	90 200		Muestra húmeda, recién instalada en el molde. No se observan grietas, material uniforme, textura lisa y color brillante	Rugosidad superficial por presencia de algunos grumos y por moldeado de la muestra. Micrigrietas ocasionales muy superficiales y pequeñas, de 1 a 5 micras de abertura y de 10 a 20 micras de longitud.
2 Inicio desecación	40 35	200 500		La arcilla pierde brillo superficial y la textura se aprecia menos uniforme. Ligera contracción longitudinal de la muestra	Se notan más resaltados los granos mayores respecto a la matriz (mayor rugosidad). Aparecen nuevas microgrietas con diferentes orientaciones bordeando a las partículas mayores. Las microgrietas predominantes son de 5 a 20 micras de abertura y de 20 a 100 micras de longitud. Se notan depresiones superficiales en la dirección de la tracción.
3 Propagación estable	35 30	500 1100		El color se hace opaco, la textura es similar a la etapa anterior, evidente contracción volumétrica aunque restringida por el molde y separación en algunos sitios de la muestra respecto a las paredes del molde.	Microgrietas en las esquinas internas de la muestra, incremento de tamaño y coalescencia de algunas de ellas y reducción de otras. Clara separación entre la muestra y el molde en algunos tramos. Abertura de microgrietas entre 20 y 30 micras y longitud entre 300 y 500 micras.
4 Propagación inestable	30 27	1100 2000		Propagación rápida del agrietamiento en sentido transversal de la muestra. en general sólo se presenta una grieta principal. La muestra se nota relativamente seca.	Se distinguen tres etapas: A. Se inicia prolongación y coalescencia de microgrietas. B. La grieta principal se prolonga totalmente en sentido transversal en un tiempo muy corto (10 a 20 segundos). Las grietas adyacentes tienden a cerrarse. C. Aumenta la apertura de grieta, después de unos minutos aparecen grietas secundarias y luego se estabiliza el proceso.

(Ávila 2005)

Permeabilidad al agua. Influencia de las grietas de retracción

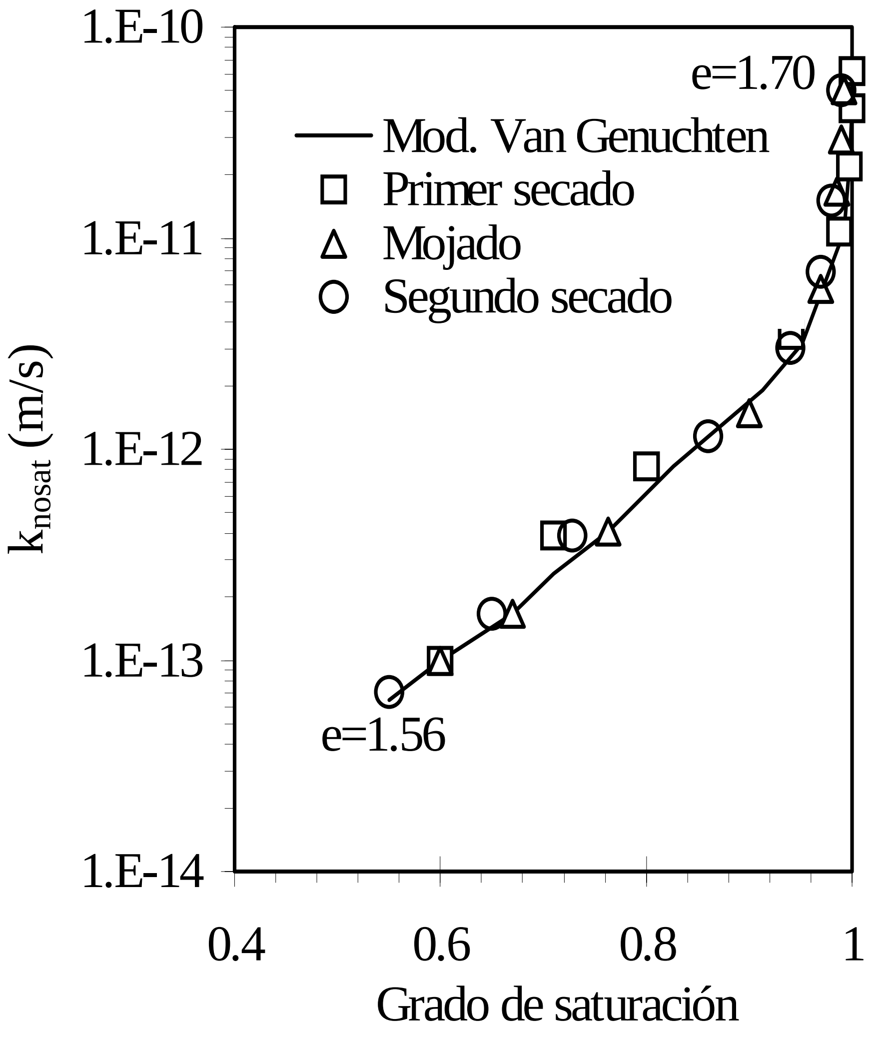


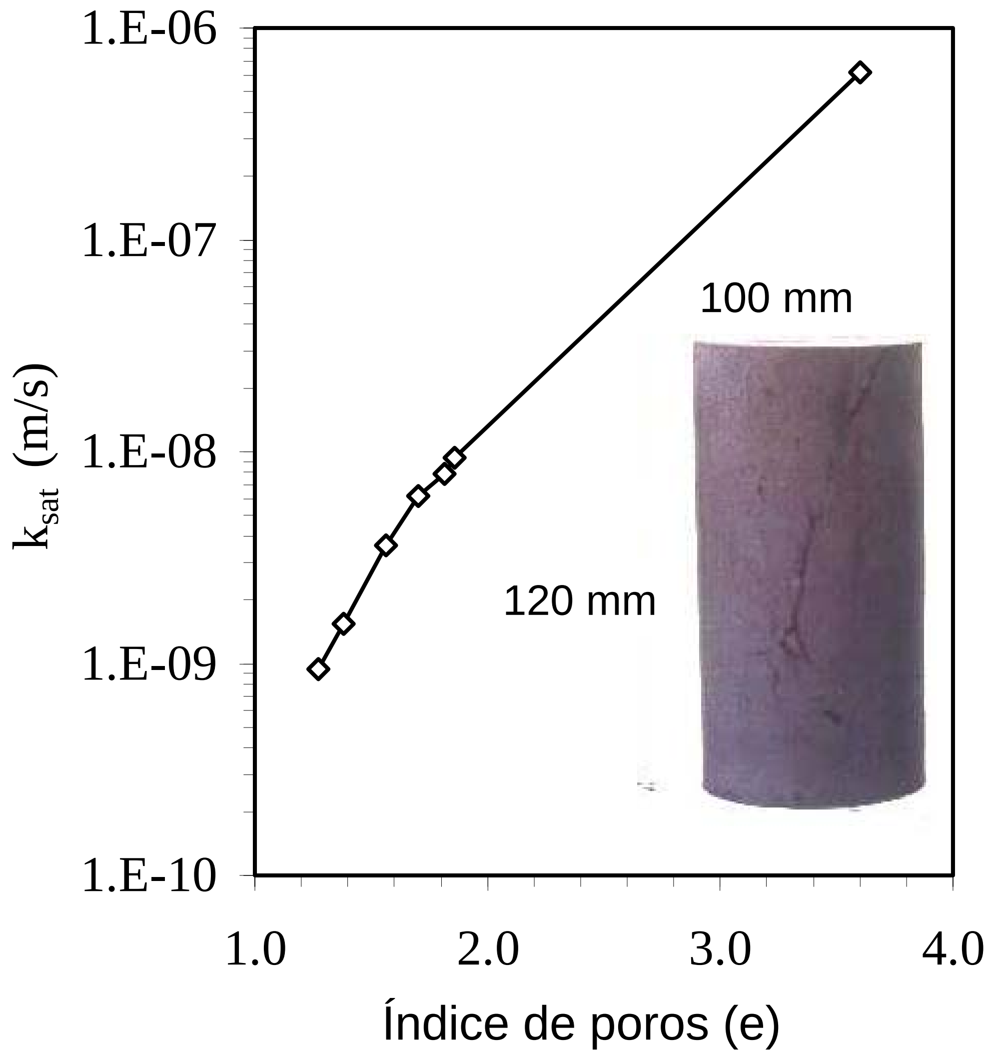


Al *et al.* (1994)

Grain size sorting effect resultant from discharge of low density tailing slurries (10-20 wt% solids) from perimeter dam

Permeabilidad al agua. Residuos de la industria del níquel





Rodríguez (2002)

Preparación de muestras simulando vertido y secado *in situ*

1- Se preparó una mezcla sólido-líquido en proporción similar a la del vertido

2- Se depositó en un recipiente y se dejó secar hasta que se formó la primera grieta. Se estabilizó el peso

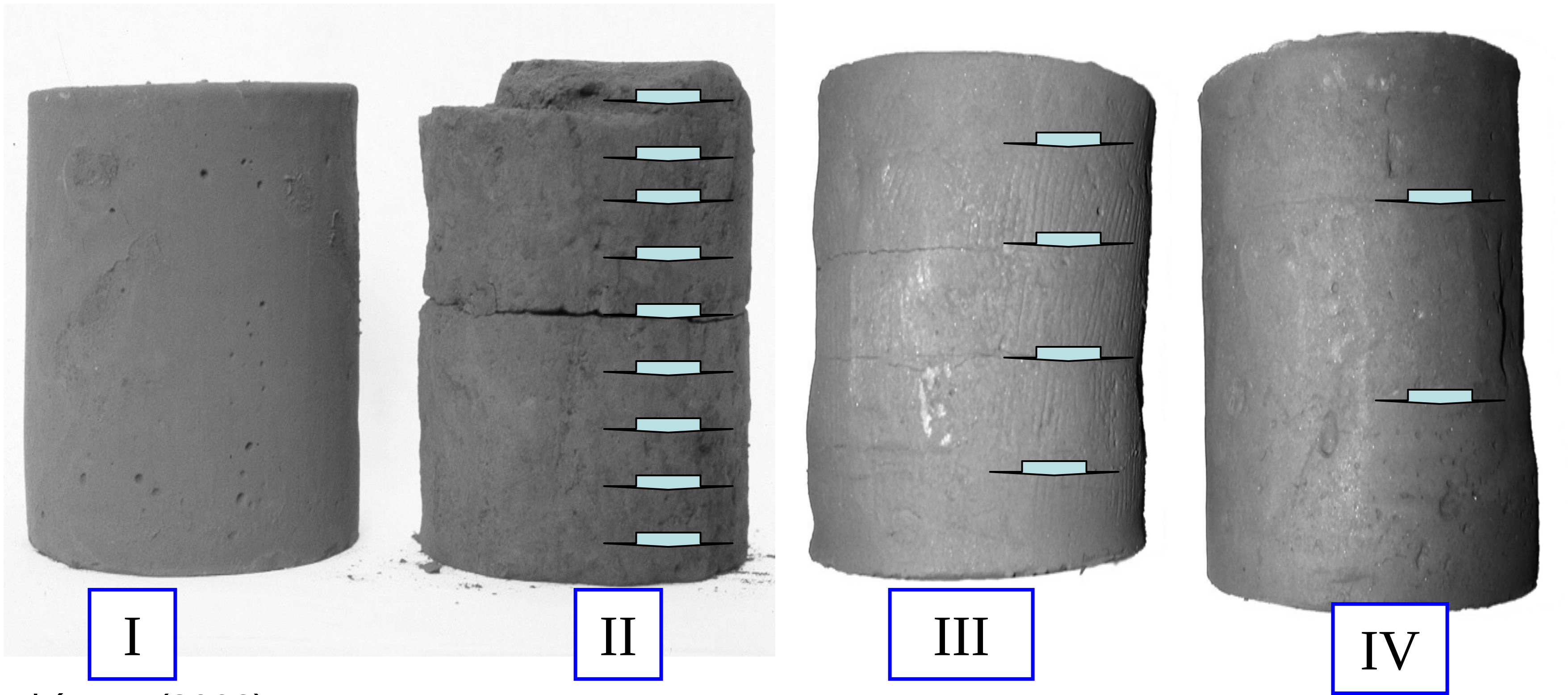
3- Se depositó una nueva capa y se siguió el mismo proceso

4- Se tallaron las muestras para realizar los ensayos de permeabilidad al agua

Preparación de probetas

I Muestra continua
II Muestra en capas de h=10 mm

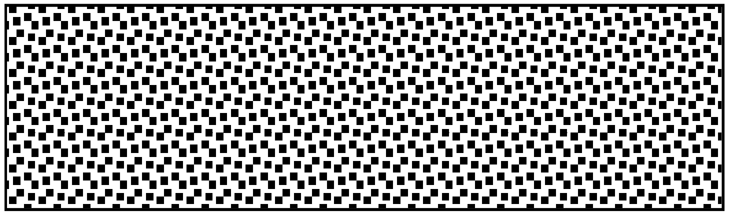
III Muestra en capas de h=20 mm
IV Muestra en capas de h=40 mm



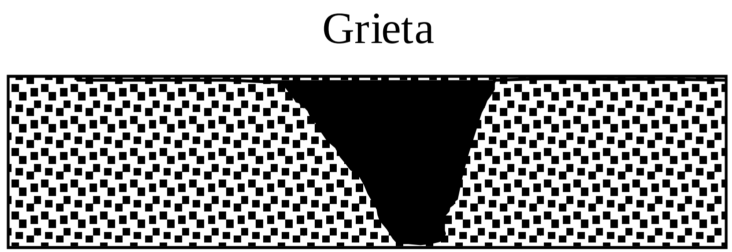
Rodríguez (2002)

Hipótesis del mecanismo de formación de caminos de flujo preferencial

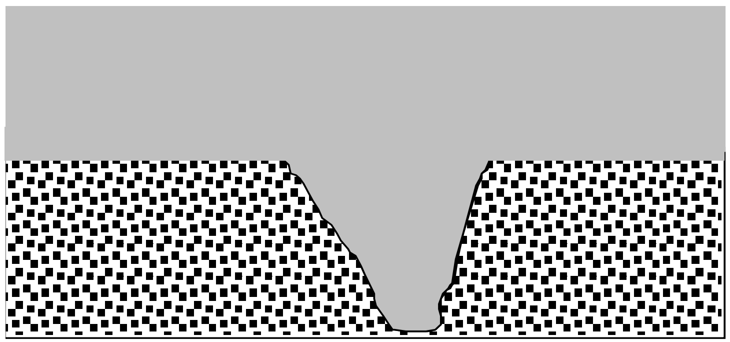
Vertido inicia primera capa
Muestra saturada



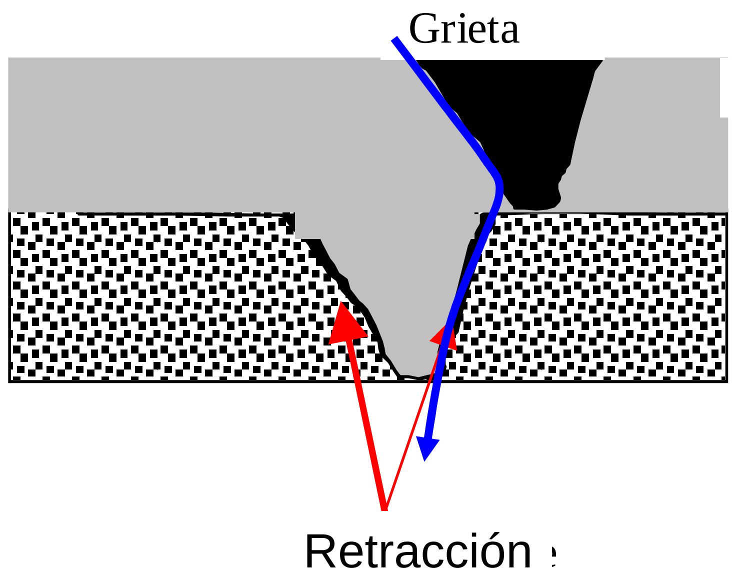
Primer secado capa
Evaporación, retracción y agrietamiento



Vertido de la segunda capa
Sellado de la grieta

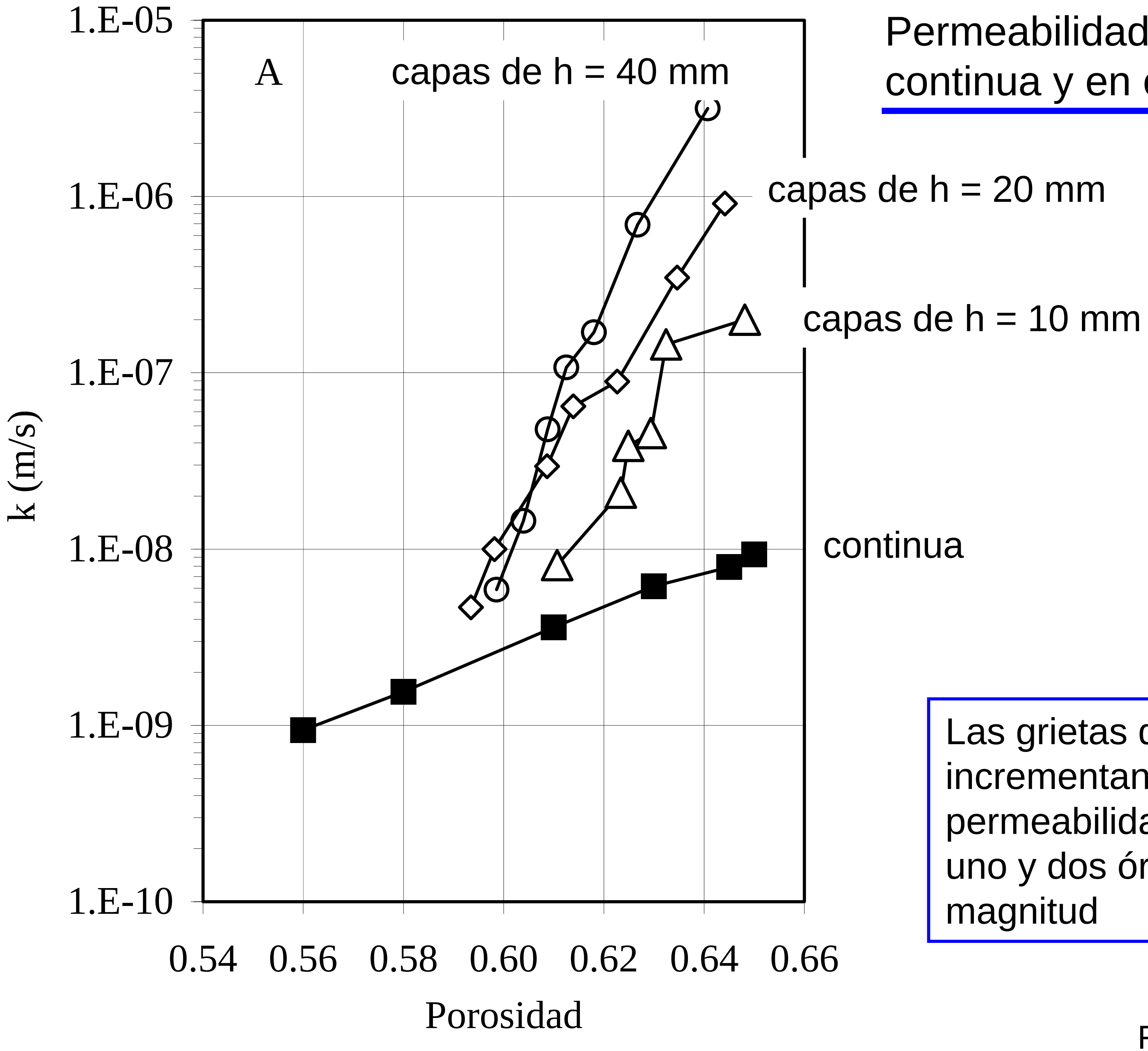


Primer secado capa
Evaporación, retracción y agrietamiento



Rodríguez (2002)

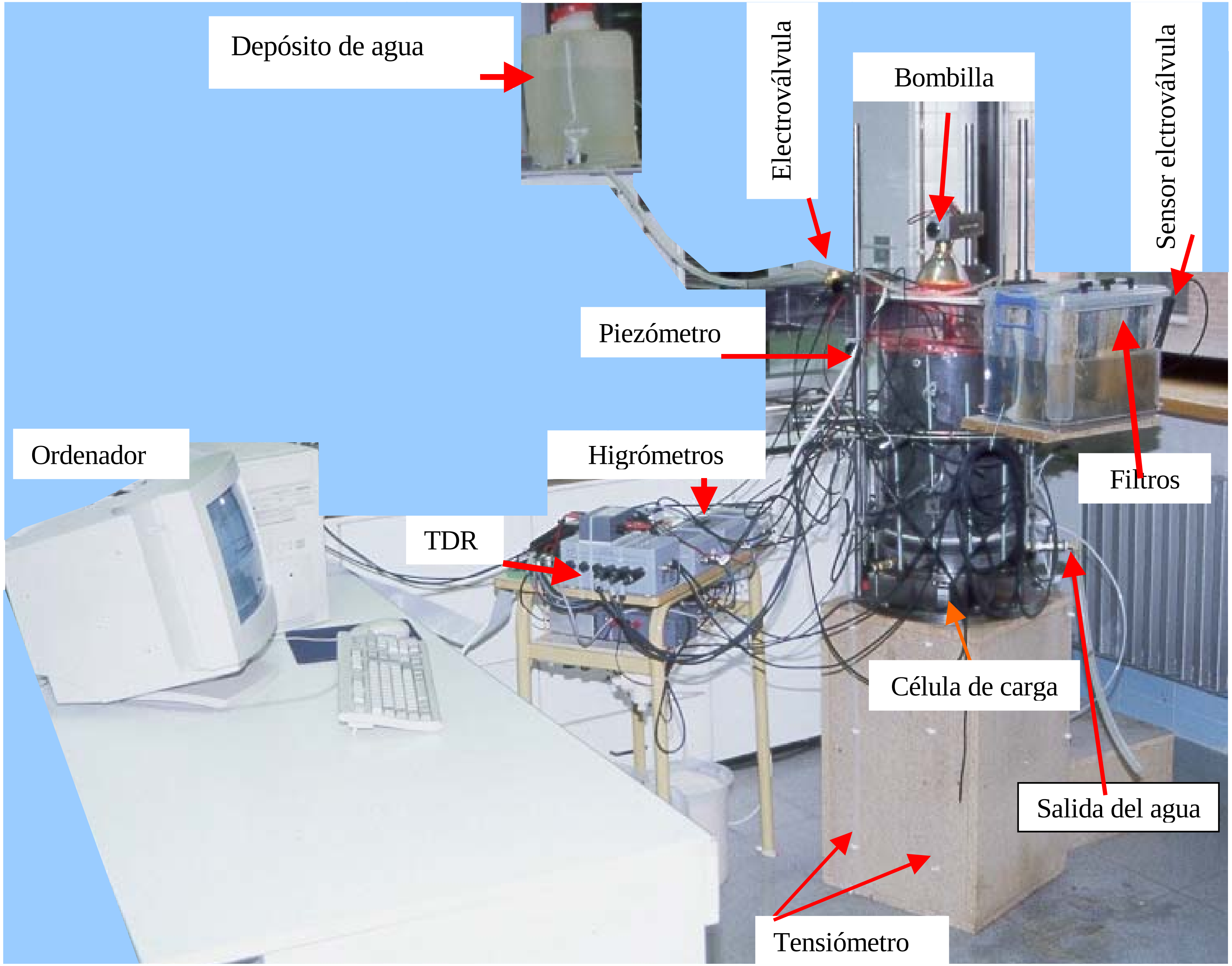
Permeabilidad de muestras continua y en capas



Las grietas de retracción incrementan el valor de la permeabilidad al agua entre uno y dos órdenes de magnitud

Rodríguez (2002)

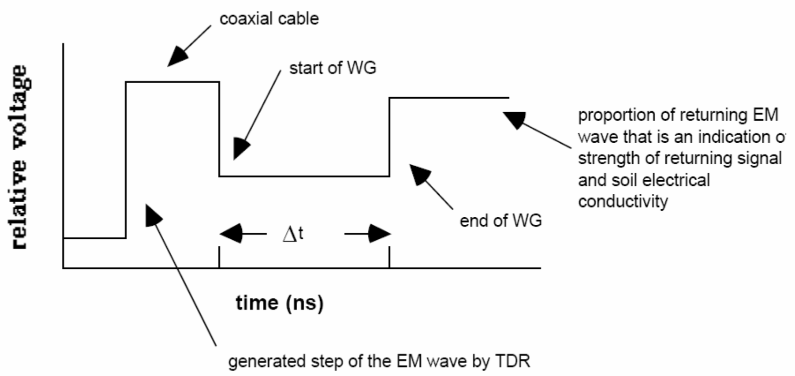
Columna de evaporación / infiltración (Rodríguez 2002)

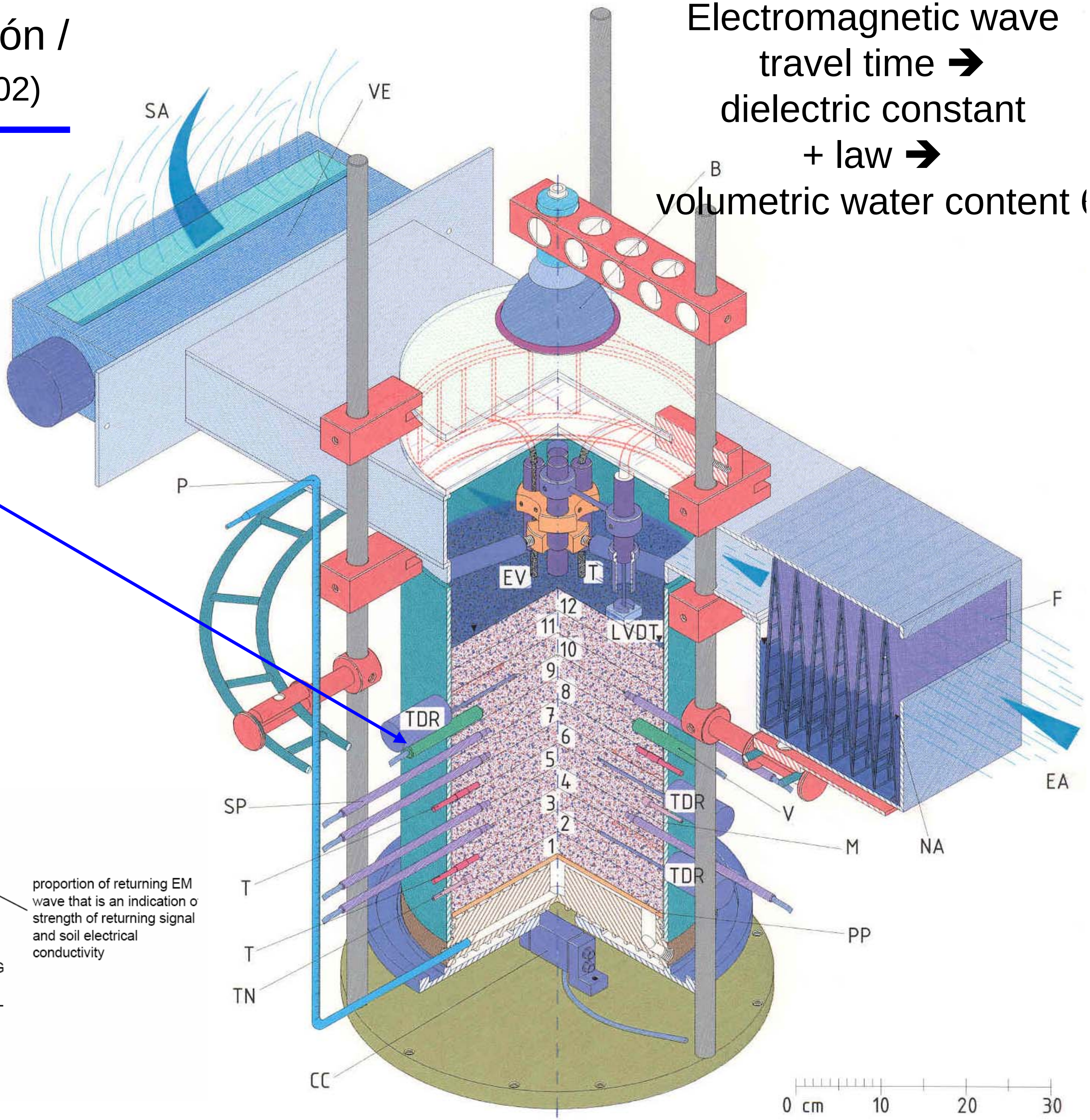


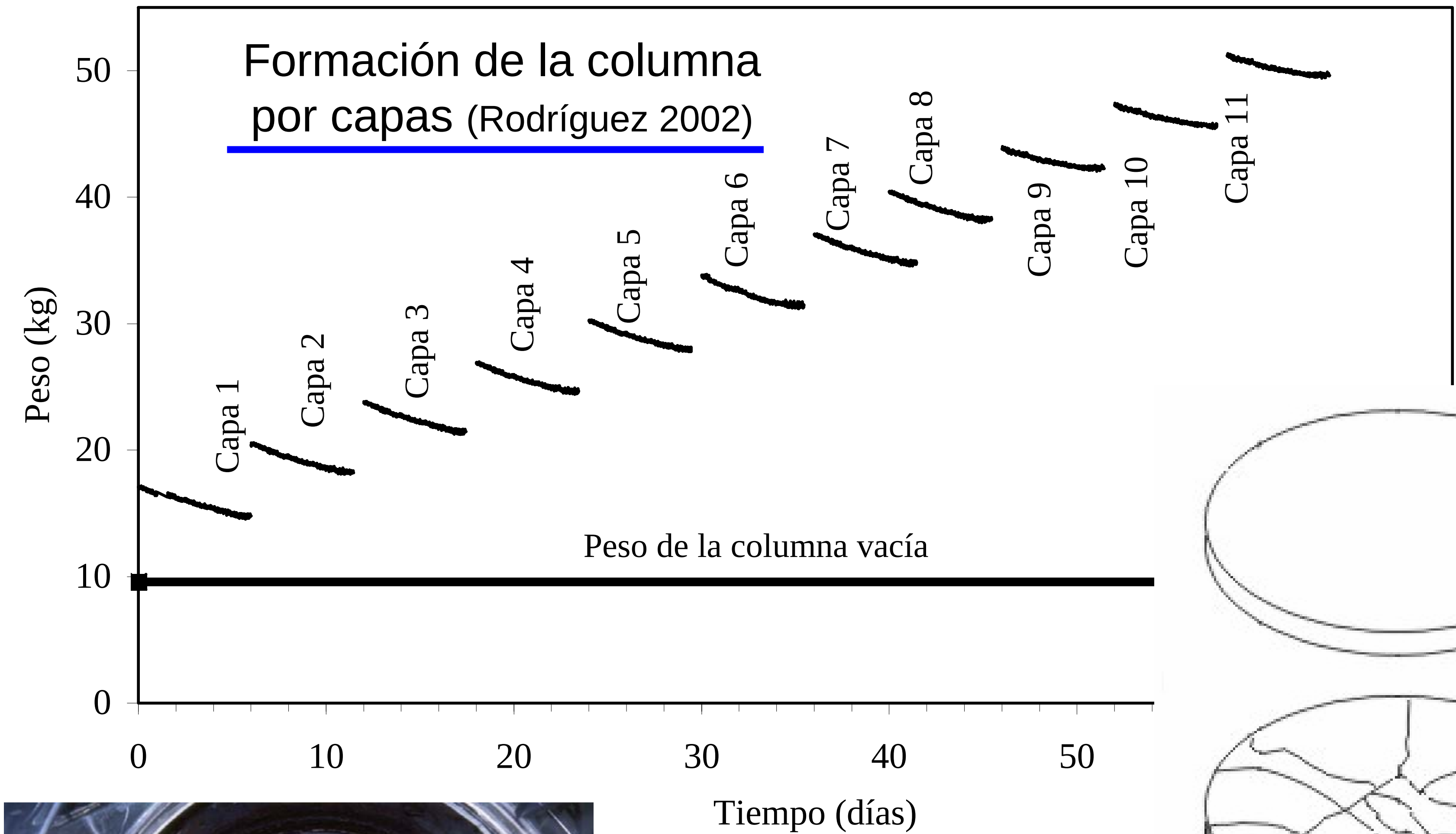
Columna de evaporación / infiltración (Rodríguez 2002)

Electromagnetic wave travel time ➔ dielectric constant + law ➔ volumetric water content (

TDR probes

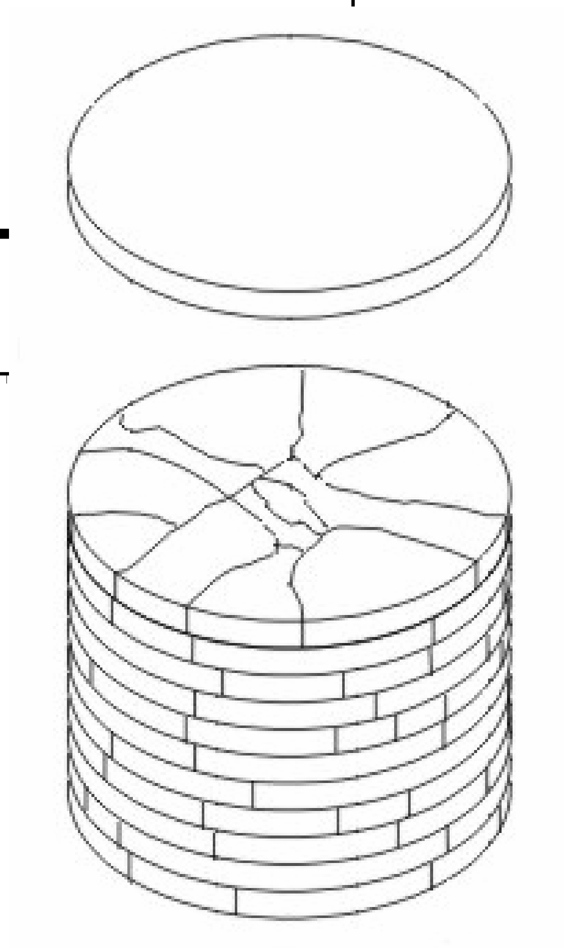






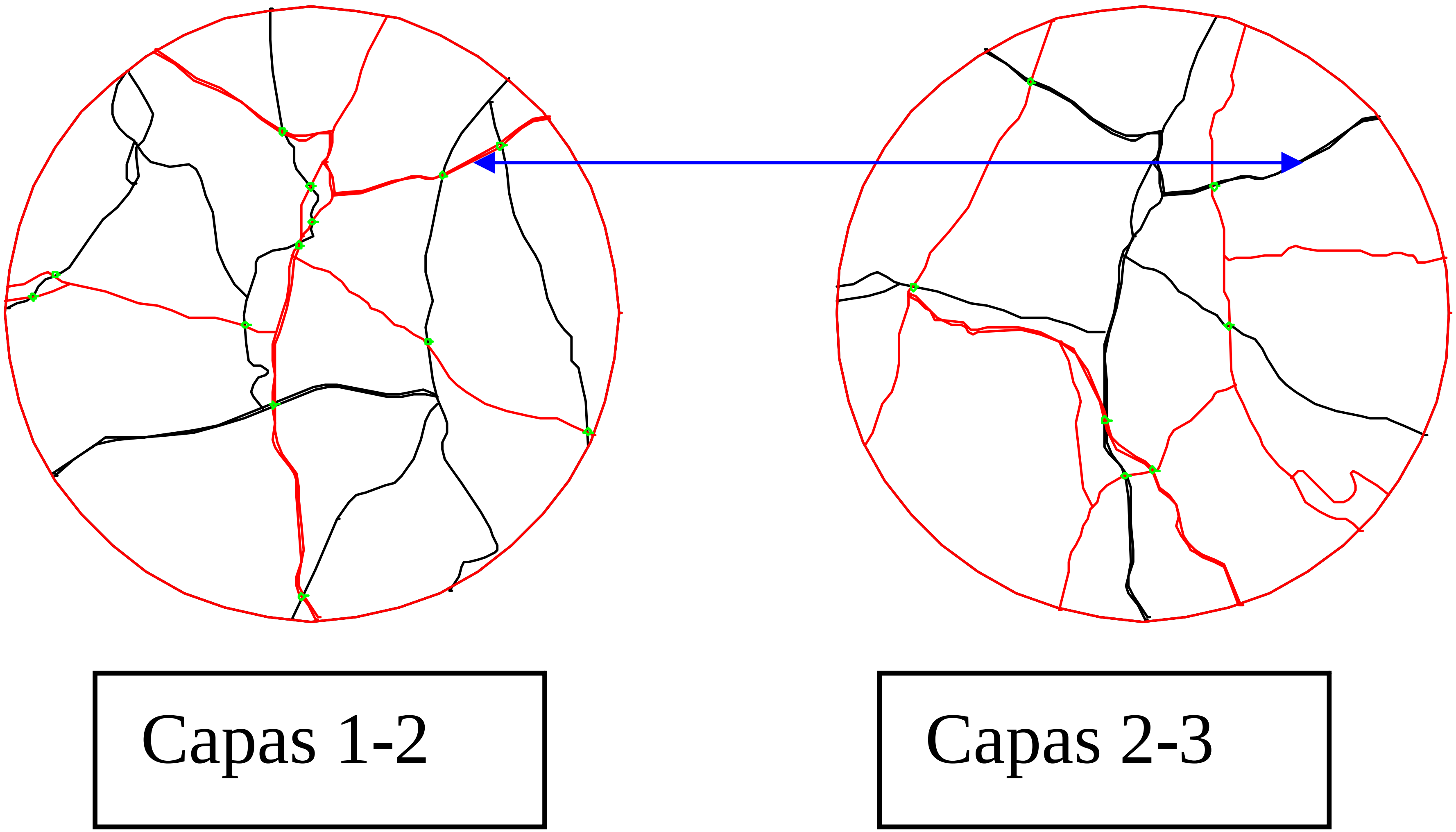
$A = 638\ cm^2$

25 mm por capa

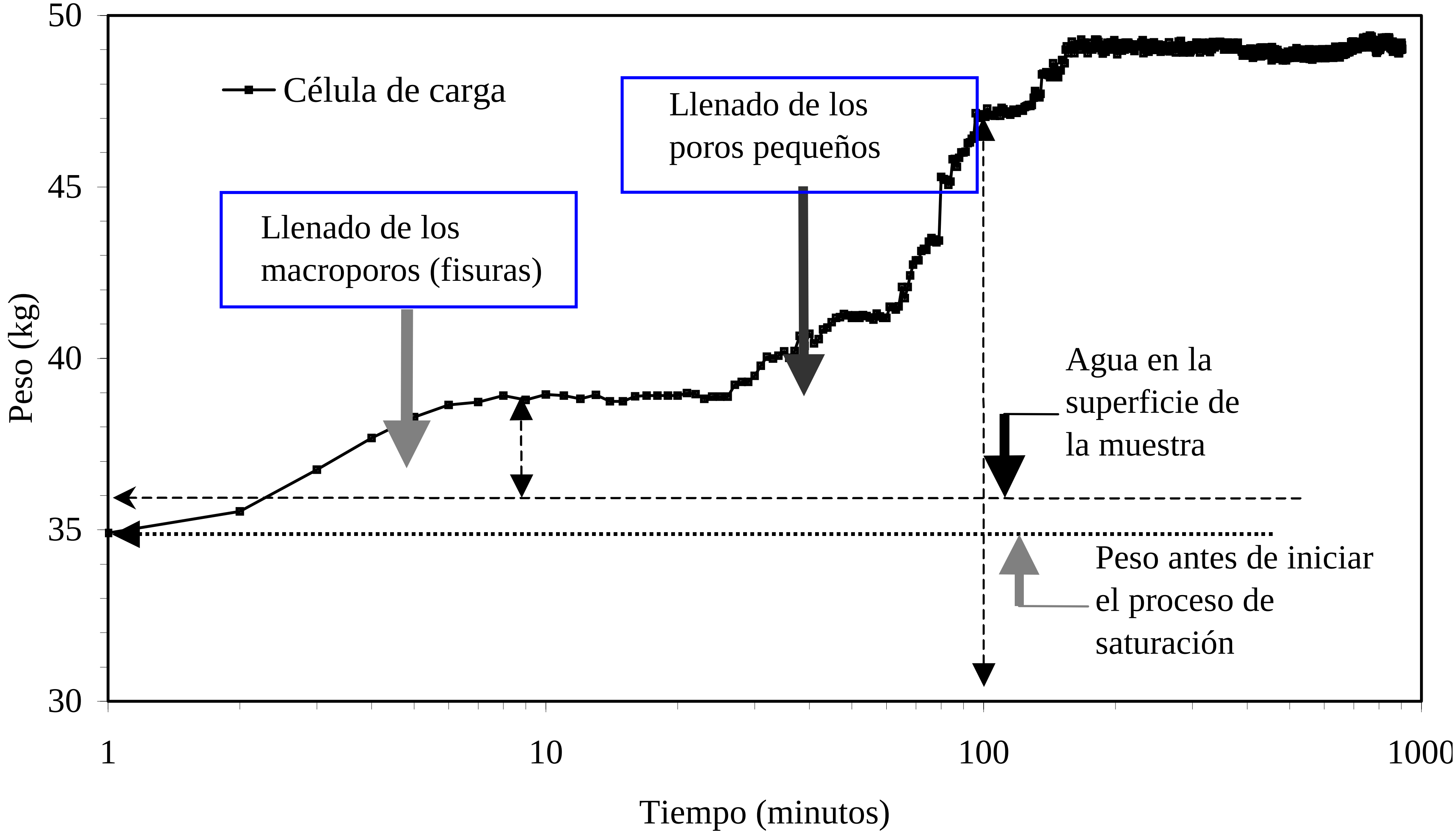


Agrietamiento (capas de residuos)

Rodríguez (2002)

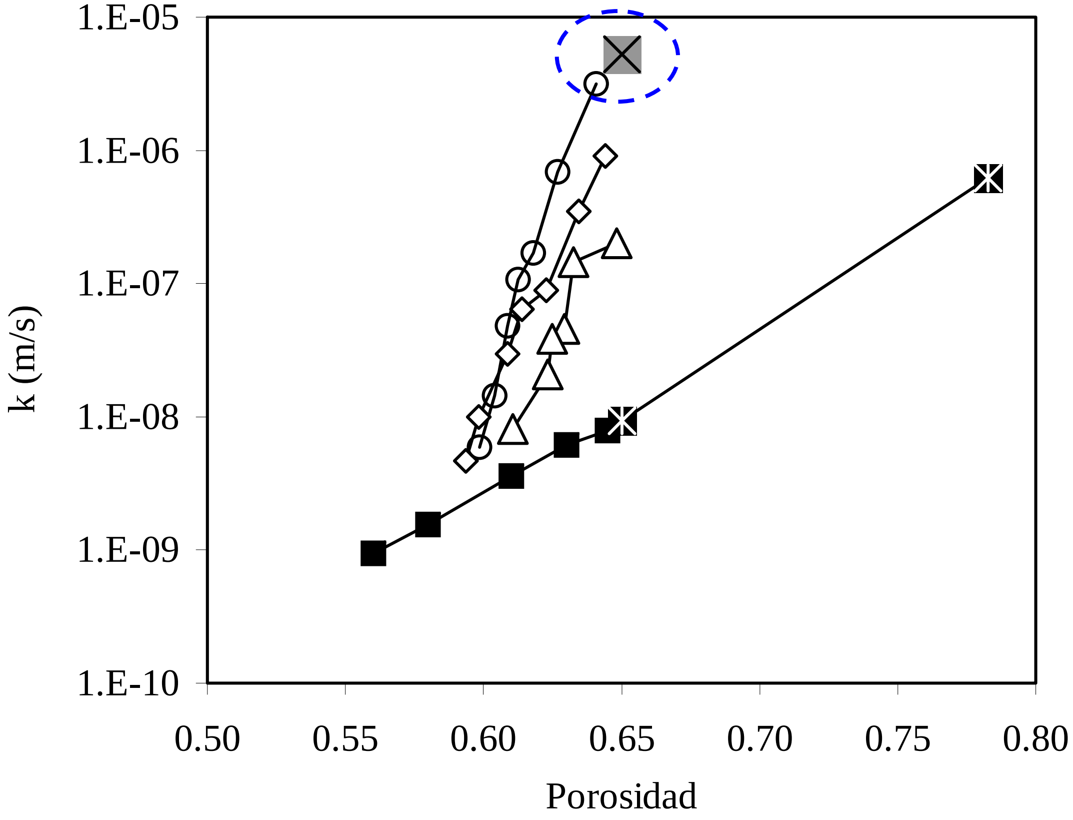


Saturación de la columna



Rodríguez (2002)

Permeabilidad al agua



Rodríguez (2002)

- Muestra continua ensayo cámara triaxial: altura total 120 mm y diámetro 100 mm
- Muestra continua ensayo a carga constante: altura total 50 mm y diámetro 50 mm
- Muestra en capas agrietadas h=10 mm ensayada en cámara triaxial: altura total 120 mm y díámetro 100 mm
- Muestras en capas agrietadas h=20 mm ensayo cámara triaxial: altura total 120 mm y diámetro 100 mm
- Muestra en capas agrietadas h=40 mm ensayada en cámara triaxial: altura total =120 mm y diámetro 100 mm
- Columna gran diámetro en capas agrietadas altura media por capa 25 mm: altura total 315 mm y diámetro 285 mm

Ensayo de flujo y transporte con fluoresceína sódica columna agrietada

Rodríguez (2002)

Salty crust formation. Hard layers found in tailing waste (Cueva de la Mora, Huelva, SW Spain)

Evaporation of water from saline tailings induces the accumulation of salts at the surface (thin salt crusts < 5 mm)

Sulphated upper crust in pyritic tailings

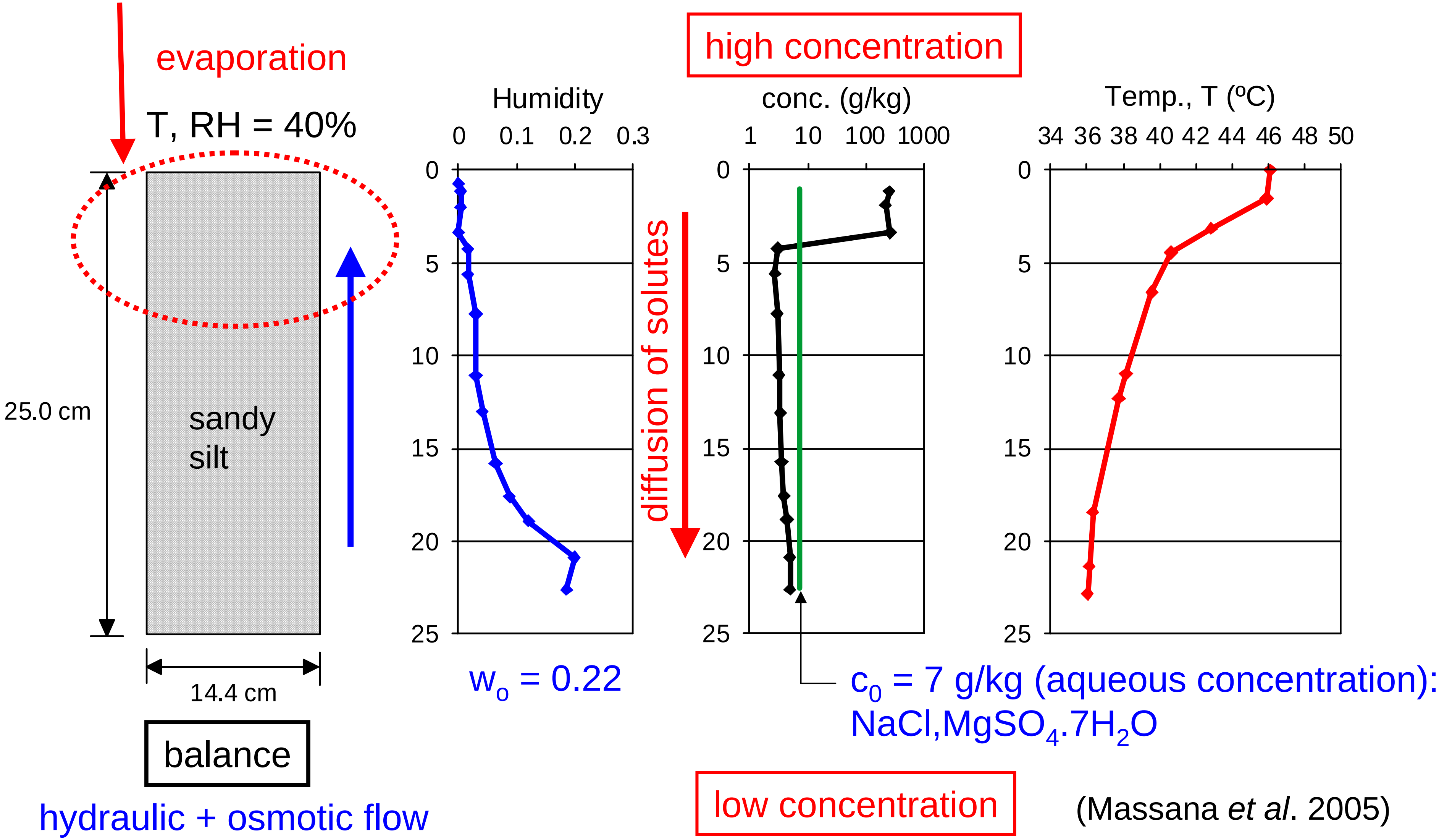
Piece of hardpan extracted from oxidized upper tailings

Blanco (2007)

Mock-up test (Evaporation columns). Ground-atmosphere interactions

Changes of geochemical variables due to solvent evaporation

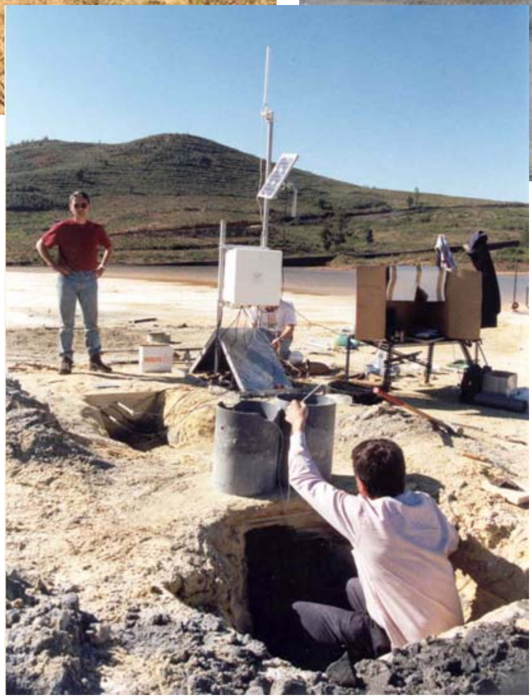
Chemo-mechanical interaction:
Shrinkage and cracking due to water loss and increase in aqueous concentration



(Massana *et al*. 2005)

Instrumentation layout of a pyritic tailing (Monte Romero tailing-dams, SW Spain)

In situ instrumentation for the study of atmospheric – tailing waste interactions



Blanco (2007)

Sensors for monitoring w/c related variables. 'La Mora' Autonomous Station

Variable measured	Units	Brand	Model	Characteristics
Relative Humidity	2	VAISALA	HMP230	Capacitive hygrometer
	2	CAMPBELL	MP100A	Capacitive hygrometer
Volumetric water content	2	CAMPBELL	CS615	EM. TD Transmision Line Oscillator.
	4	DECAGON	ECH2O	EM. FD
Matric suction	3	SDEC	SMS2500S	Tensiometer with pressure transductor
Water pressure	3	DRUCK	PDCR1830	Pressure transductor
Temperature	2	VAISALA	HMP230	Thermistor PT100
	4	CAMPBELL	108	Thermistor PT100

EM: electromagnetic sensor

TD: time domain

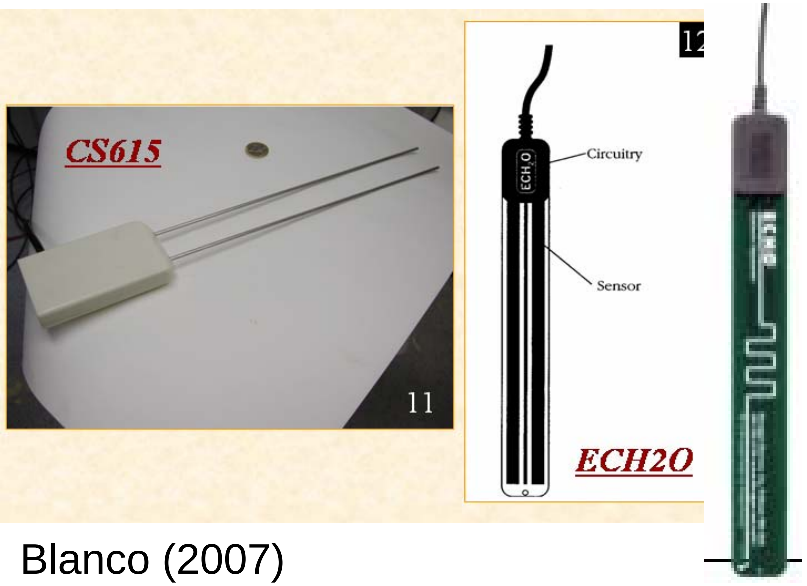
FD: frequency domain

Blanco (2007)

Sensors for monitoring w/c related variables. ‘La Mora’ Autonomous Station

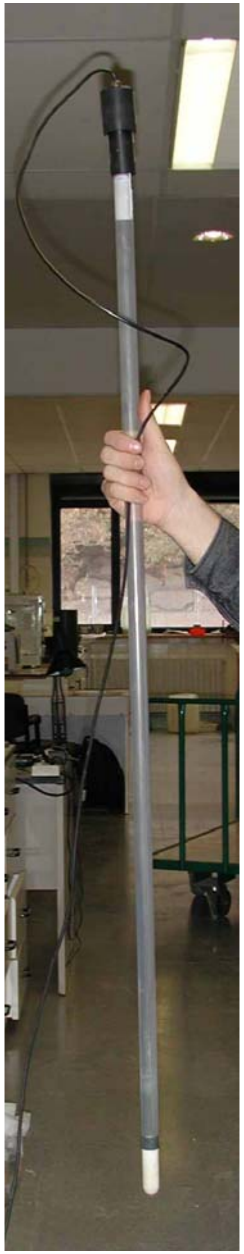
Relative humidity capacitive hygrometer

TDR and FD (capacitance) volumetric w/c sensors

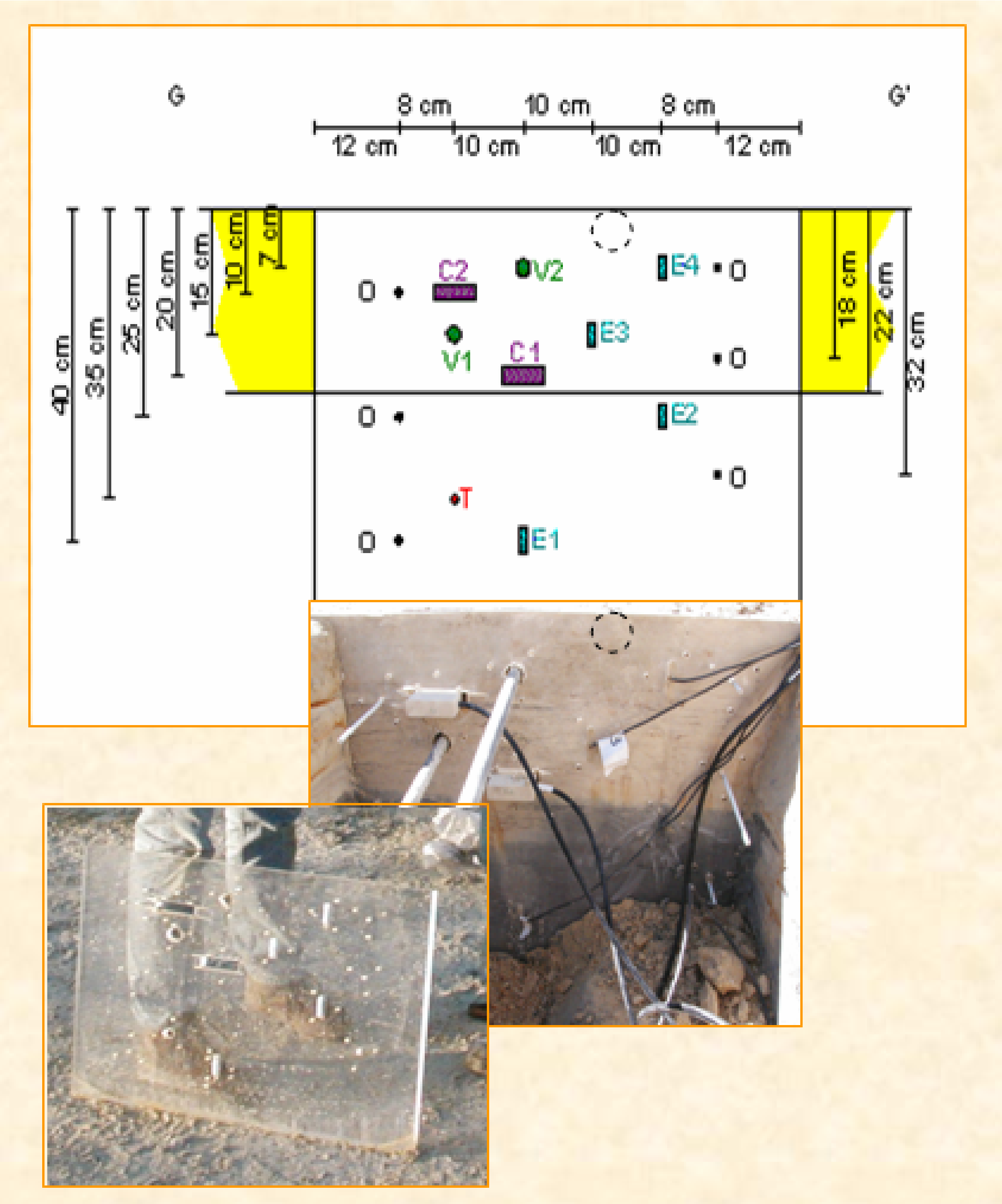


Blanco (2007)

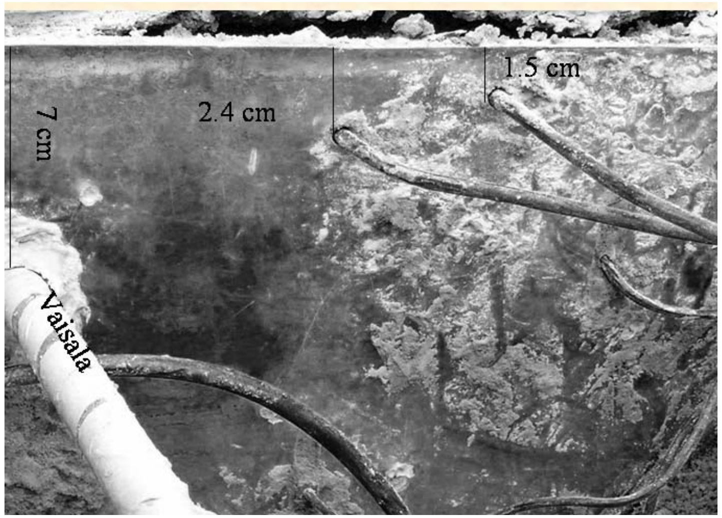
Low-range tensiometers



Sensors for monitoring w/c related variables. 'La Mora' Autonomous Station

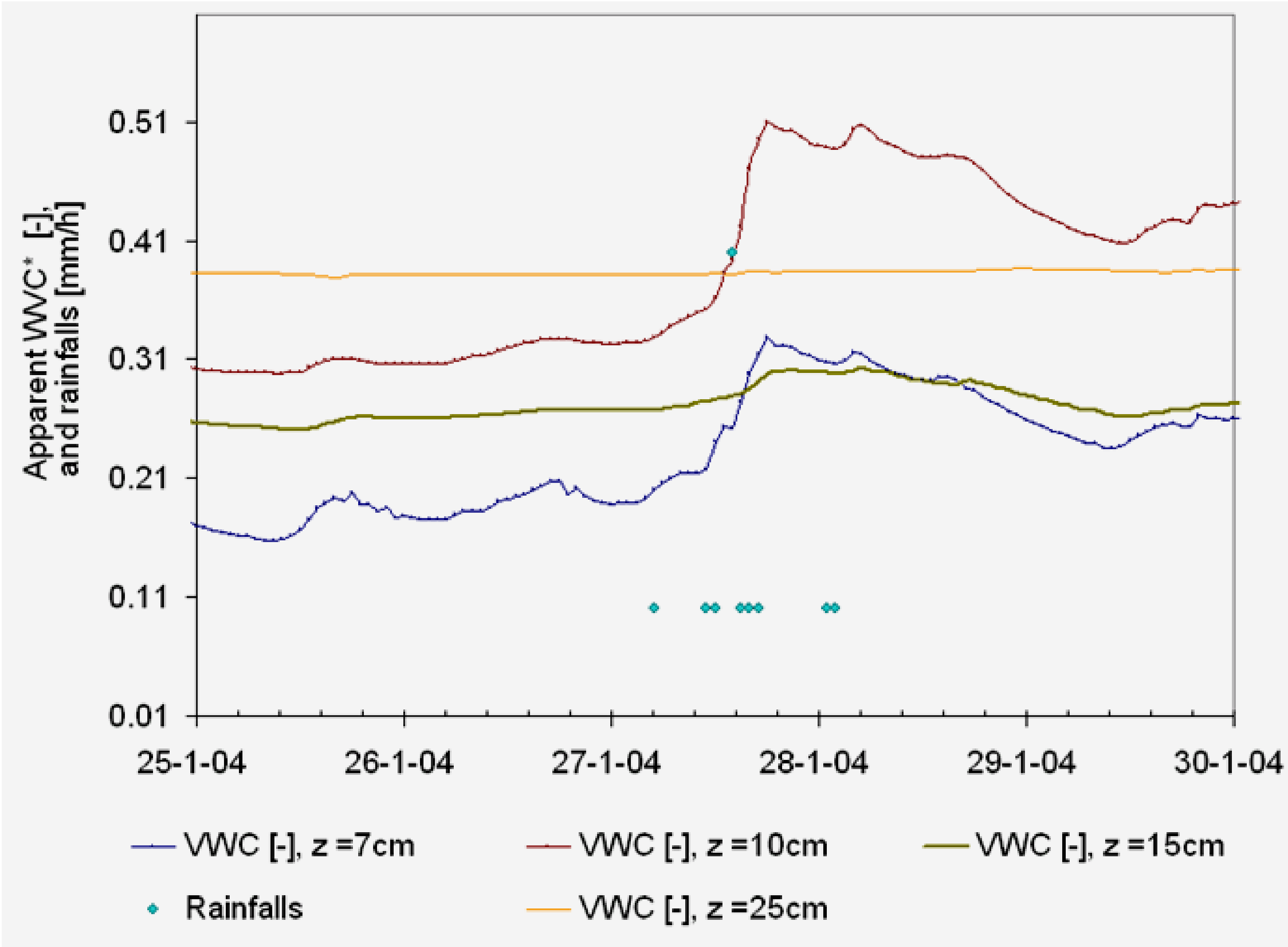


C: TDR sensor
V: relative humidity sensor
E: FDR sensor
T: thermistor



Blanco (2007)

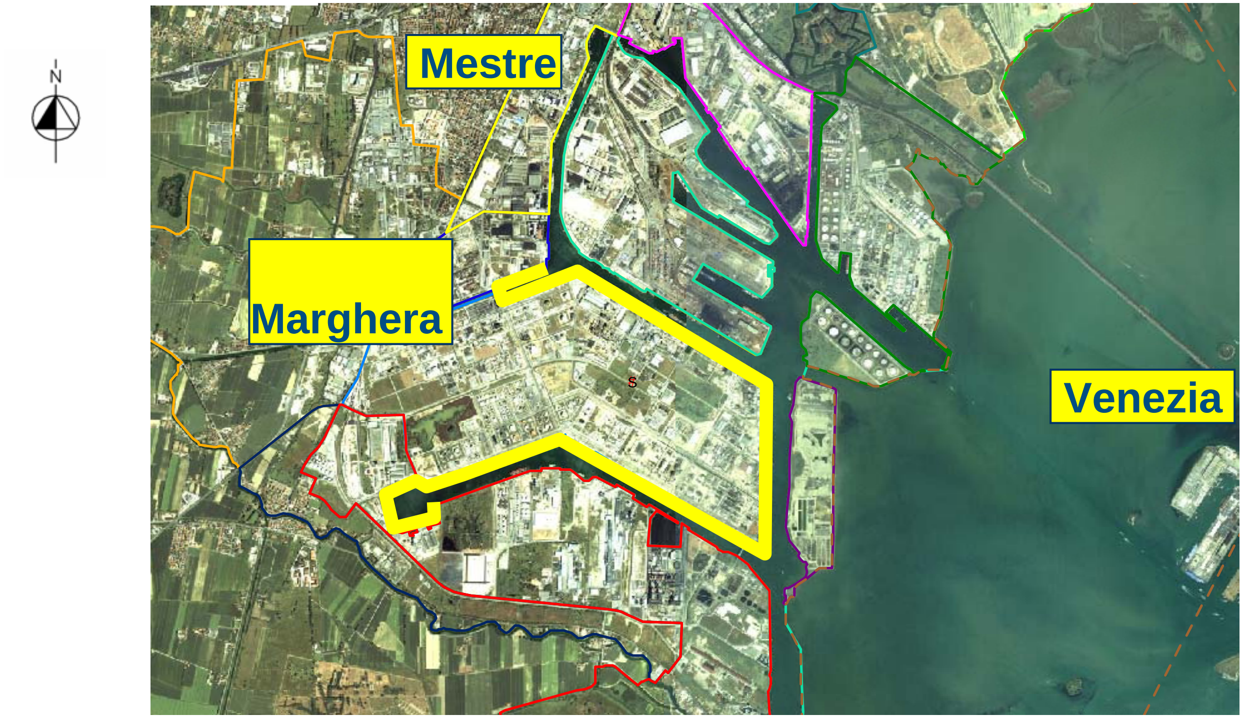
Sensors for monitoring w/c related variables. 'La Mora' Autonomous Station



Event of water infiltration during rainfalls at January 27th-28th 2004
Apparent soil water volumetric content VWC* were deduced applying standard low electrical conductivity calibrations

Blanco (2007)

Monitoring the hydrologic balance of unsaturated soils in the area of Mestre and Marghera (VE, Italy)



Caruso, Jommi & Venturini (2007)

Sheet piling over a wide area in Marghera and Mestre, presently hydraulically connected to the lagoon, is under construction

In order not to change dramatically the subsurface hydraulic circulation (from NW to SE), pumping wells are being designed to compensate the natural discharge into the lagoon

The local recharge in the superficial unsaturated soils must be evaluated

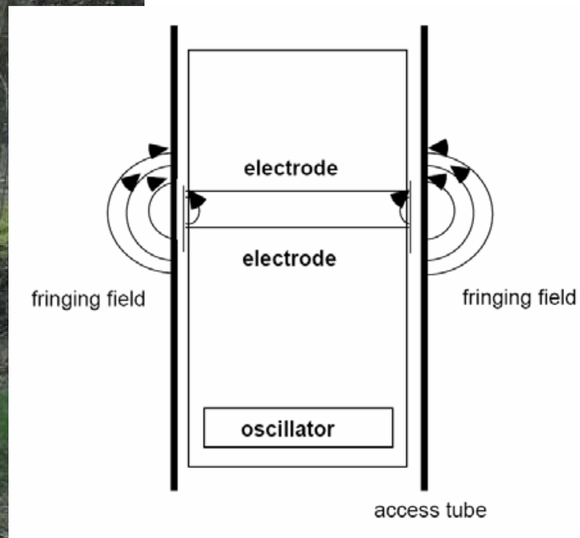
Frequency domain sensor installation

Problems with classical TDR sensors:
- Limited installation depth (-1.5 m)
- High sensitivity of the reading to the chemical composition of water

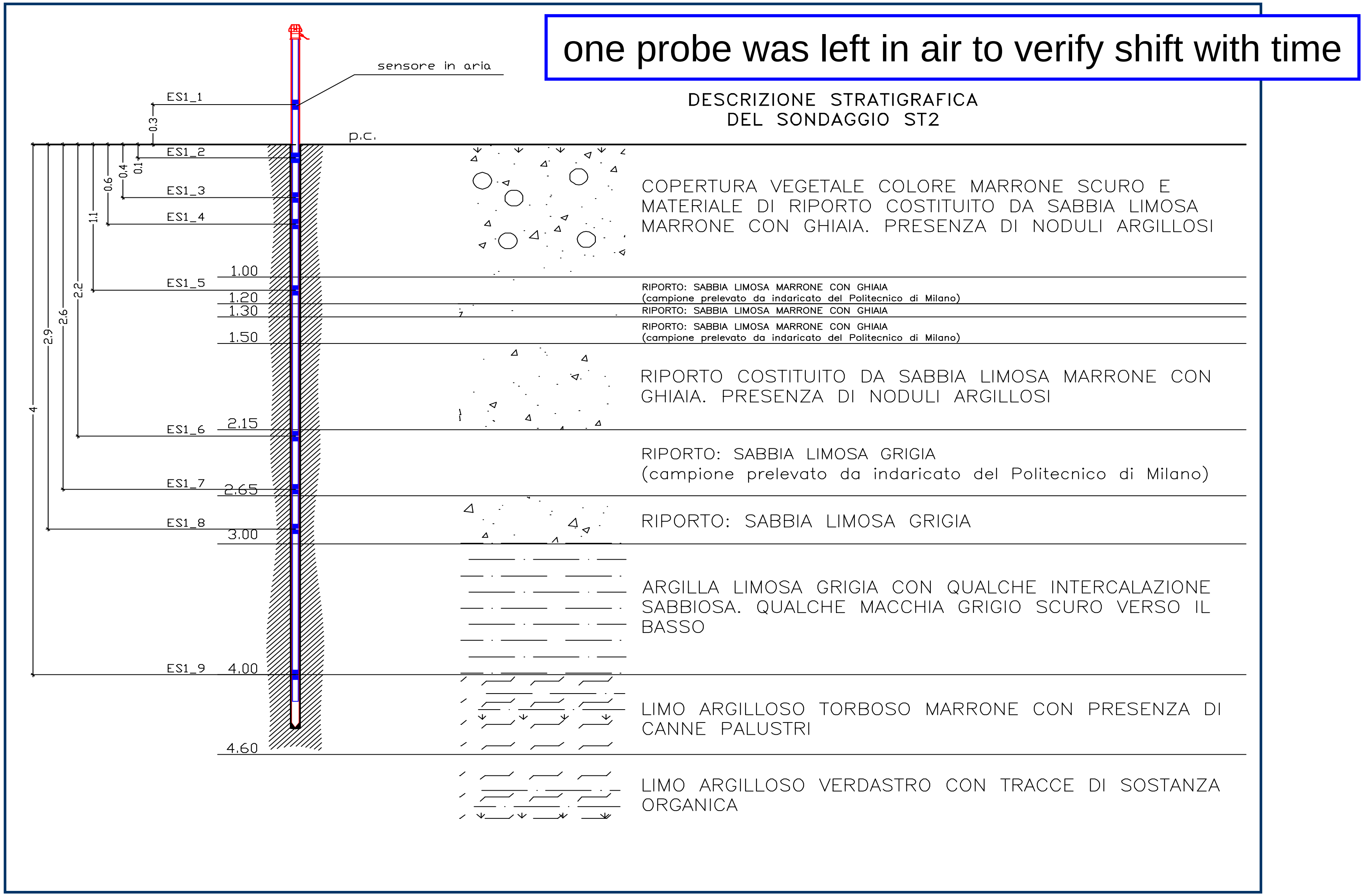
- Maximum depth: z = – 4.5 m
- Calibration of the instrument for salinity

Fixed installation: data logger with remote data transmission via GPRS

Caruso, Jommi & Venturini (2007)

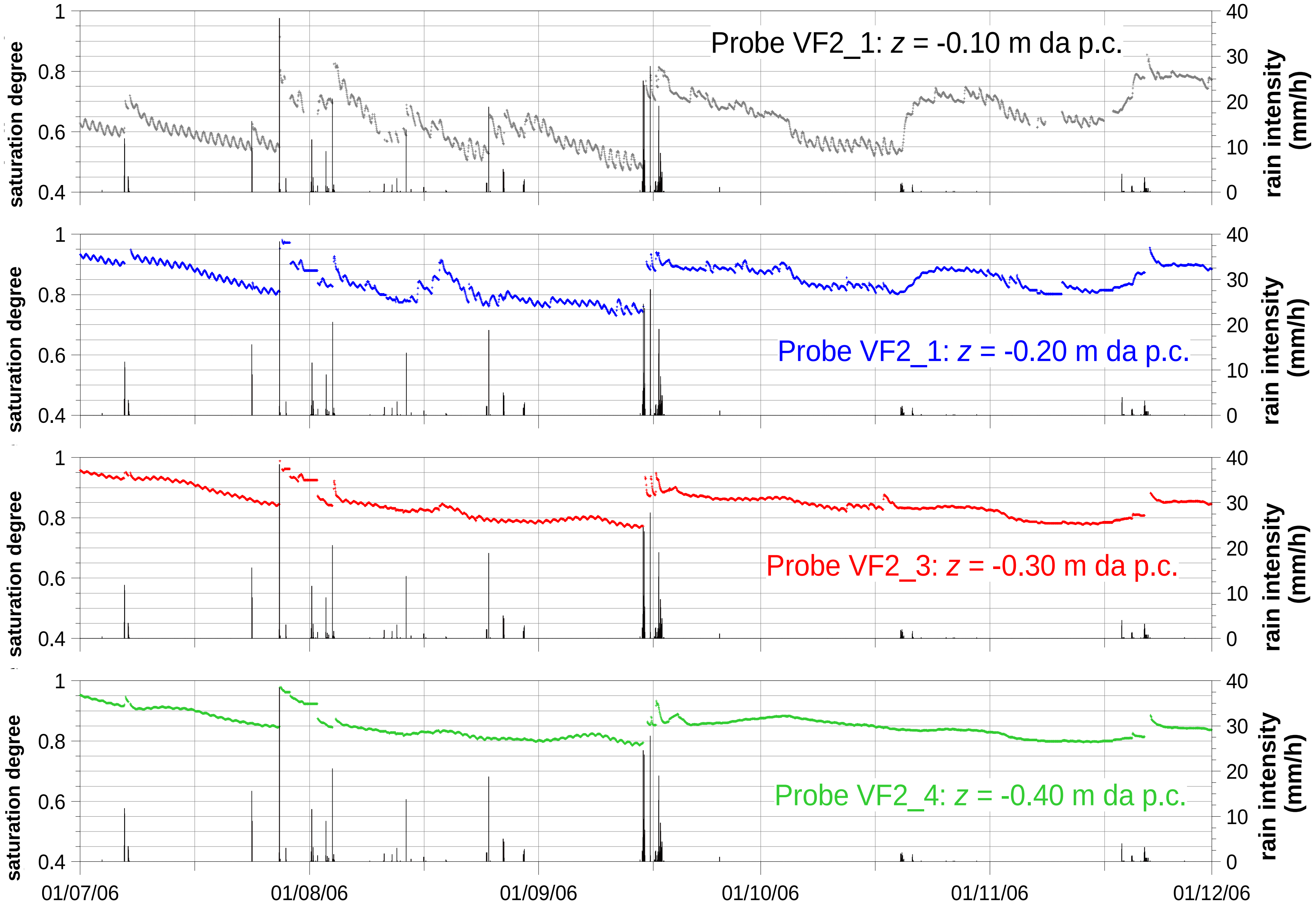


Frequency domain sensor installation



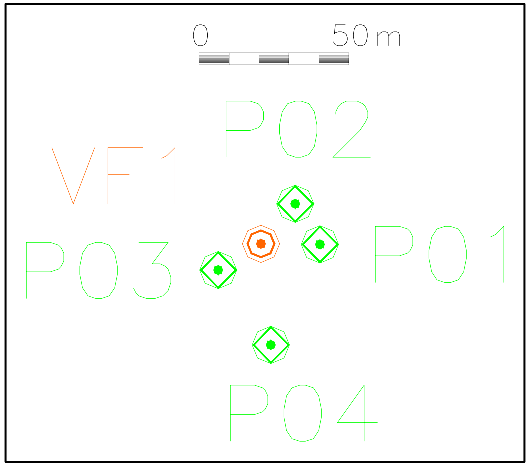
Caruso, Jommi & Venturini (2007)

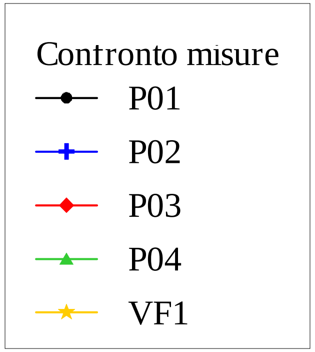
Variation of the degree of saturation with time at fixed depths

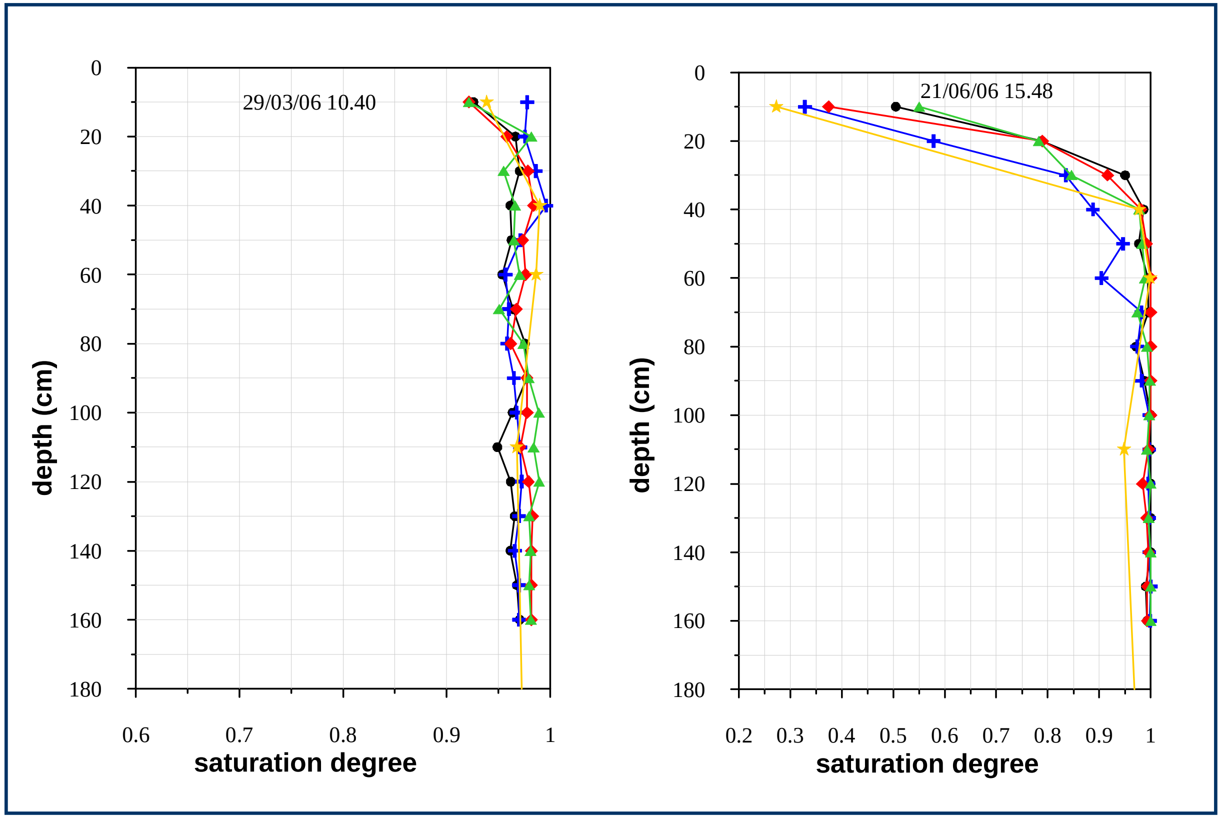


Caruso, Jommi & Venturini (2007)

Repeatability of the experimental data





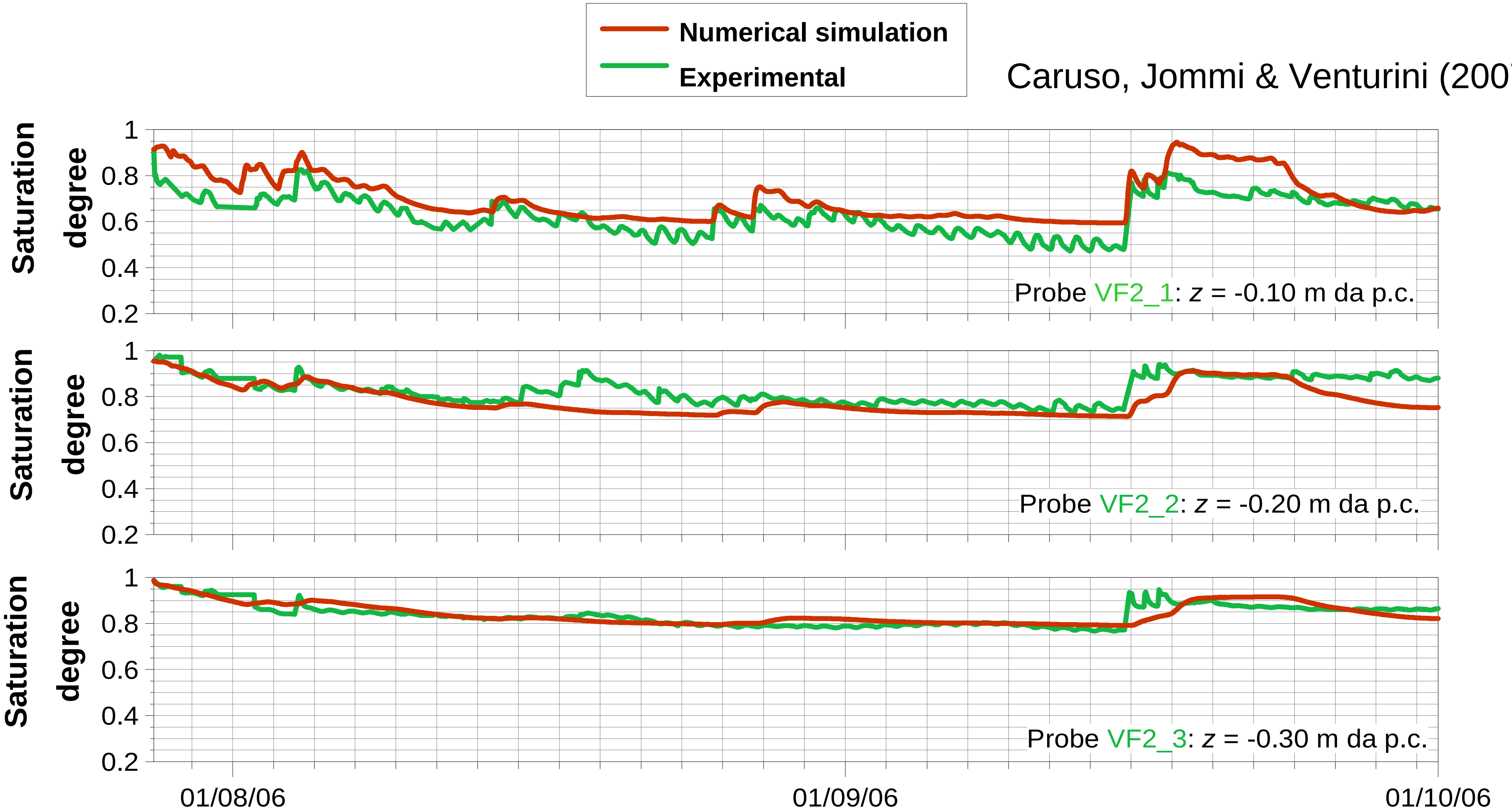


Caruso, Jommi & Venturini (2007)

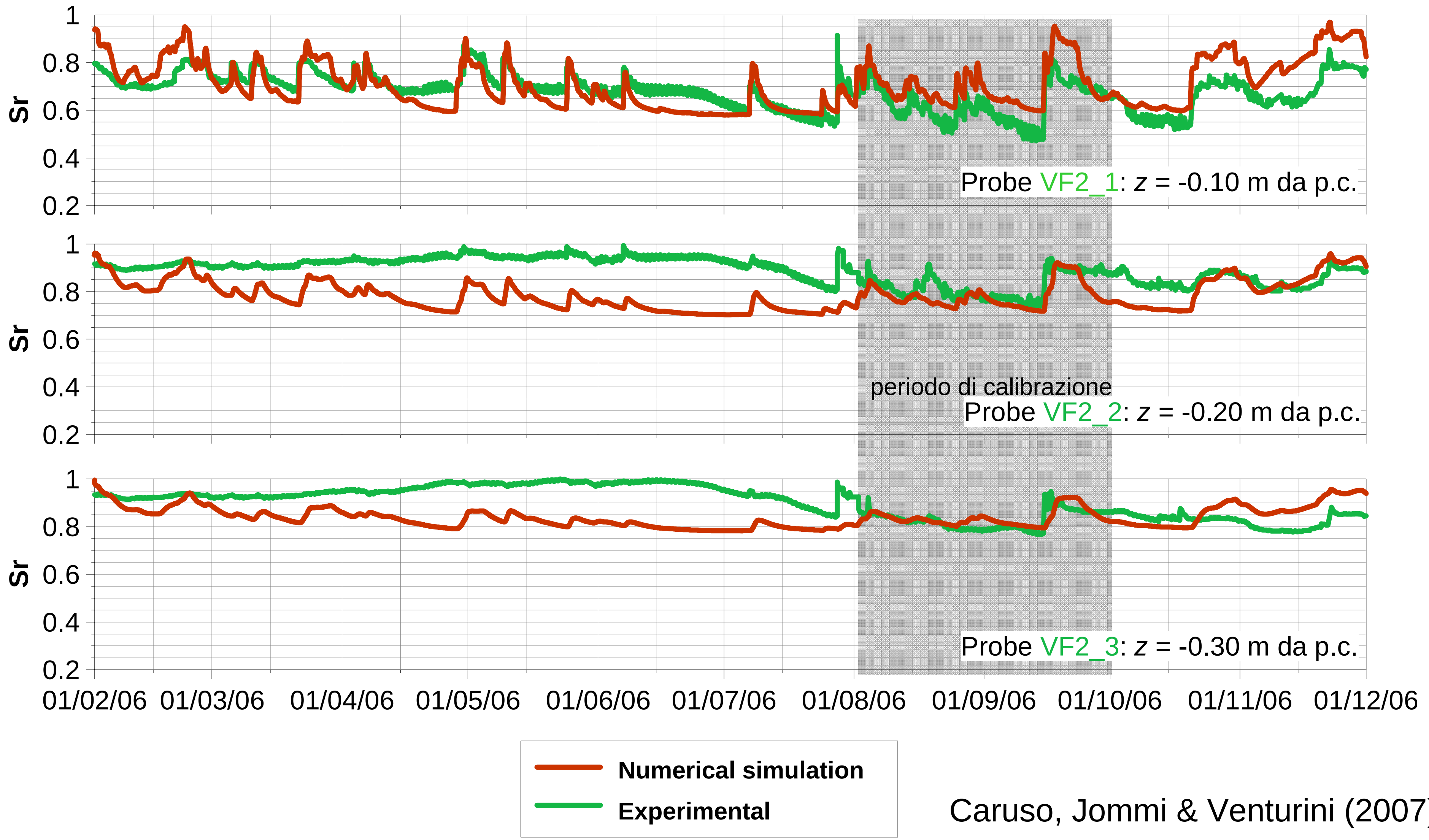
Calibration of the 1-D numerical model: August-September 2006
(most significant rainfall events and highest evaporation rate)

CODE_BRIGHT (Olivella et al., 1995) was used to consider liquid / vapour transfer taking into account relative humidity and temperature variations

Caruso, Jommi & Venturini (2007)



Capability of the numerical model



Caruso, Jommi & Venturini (2007)

Resumen

- Se han presentado algunas consecuencias de la evaporación (retracción, agrietamiento)
- Fenómenos de retracción (aspectos generales, irreversibilidad, acumulación con ciclo de secado / humedecimiento)
- Grietas de retracción (resistencia a la tracción, iniciación, efectos de tamaño, consecuencias sobre la permeabilidad al agua)
- Montajes experimentales en laboratorio e *in situ* para estudiar el efecto de la interacción con la atmósfera