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Faculty of Natural and Agricultural Sciences

Fakulteit Natuur- en Landbouwetenskappe
Lefapha la Disaense tša Tlhago le Temo

Contributions to the Characterisation of the Vadose Zone for Hydrogeological and Geotechnical Applications

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Introduction

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Perched wetland systems and shallow interflow

…aste and contaminant transport

Influences on i… …are development

COULD THESE HAVE BEEN PREVENTED?

Induced interflow and poor drainage

Ingress-scenario subsidence

Field Observations

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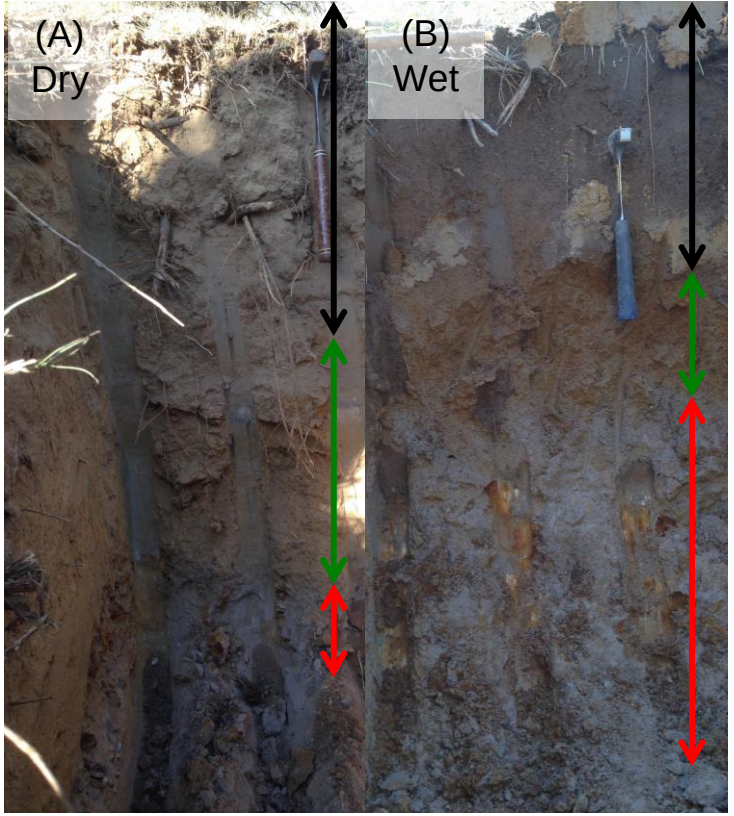
- In-situ descriptions may be misleading, notably due to in-situ moisture conditions
- Moisture does not affect purely mechanical properties such as grading
- Moisture conditions do, however, affect the behaviour of materials with similar mechanical properties
- Induced change will however alter moisture conditions, and this will change the behaviour of the earth materials

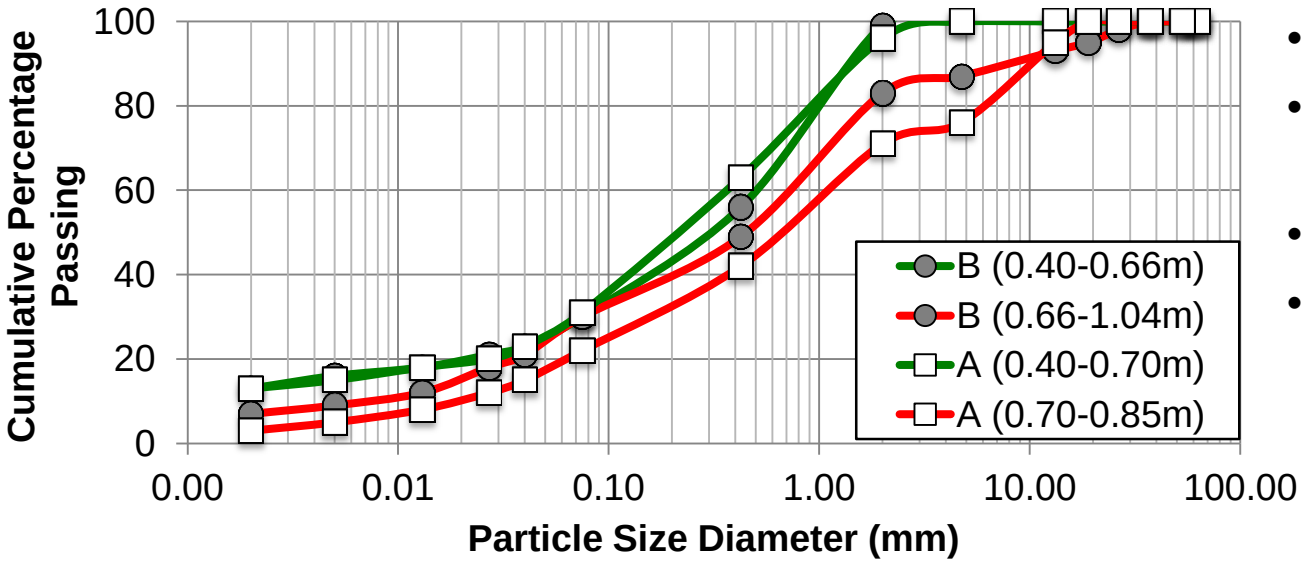
Field Observations

- Visually different profiles
- Similar mechanical properties

= Similar behaviour under similar moisture conditions

- Future moisture conditions depend on design; not in-situ conditions





- Lanseria Gneiss
- Johannesburg Dome Granite
- Johannesburg
- Archaean tonalite-migmatite gneiss

Field Observations

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- Similar mechanical properties

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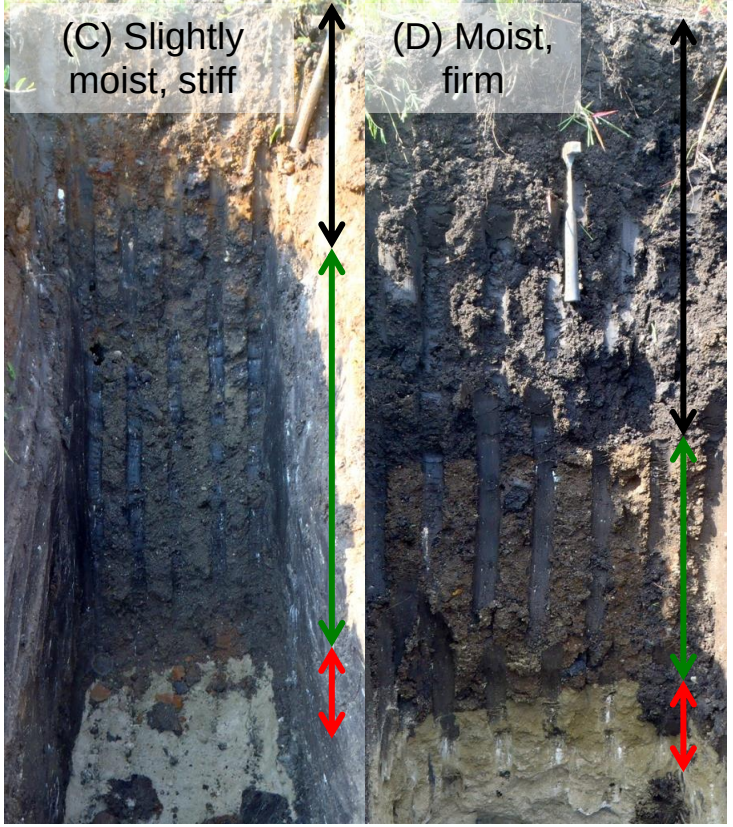

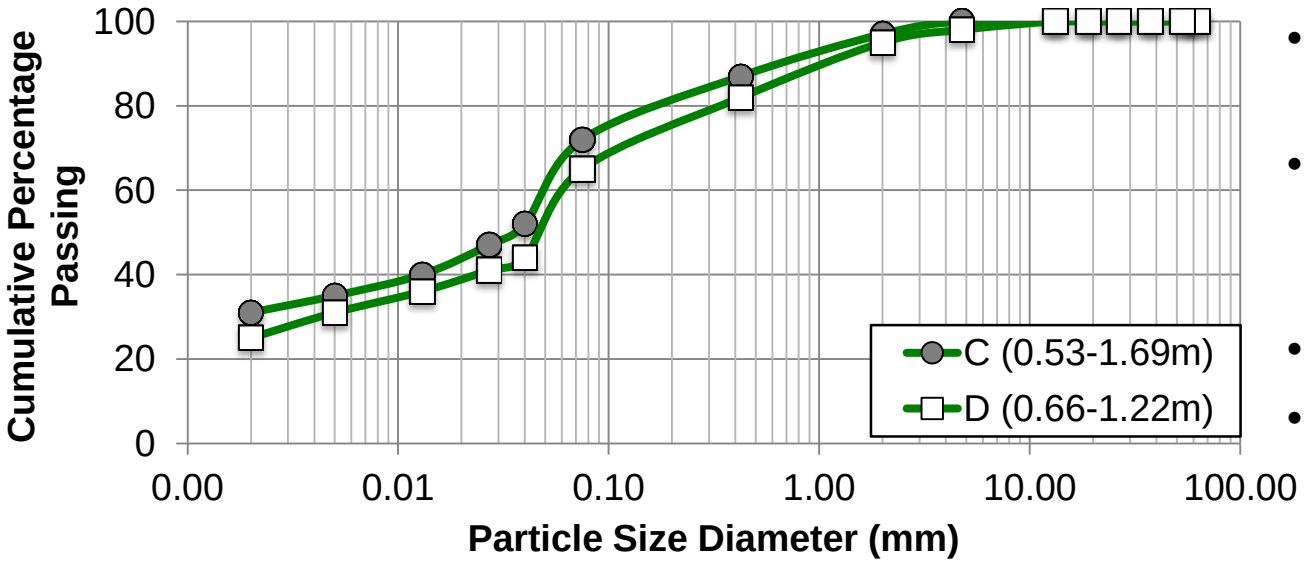

- Bierkraal Gabbronorite
- Upper Zone, Rustenburg Layered Suite
- Brits
- Proterozoic norite

Field Observations

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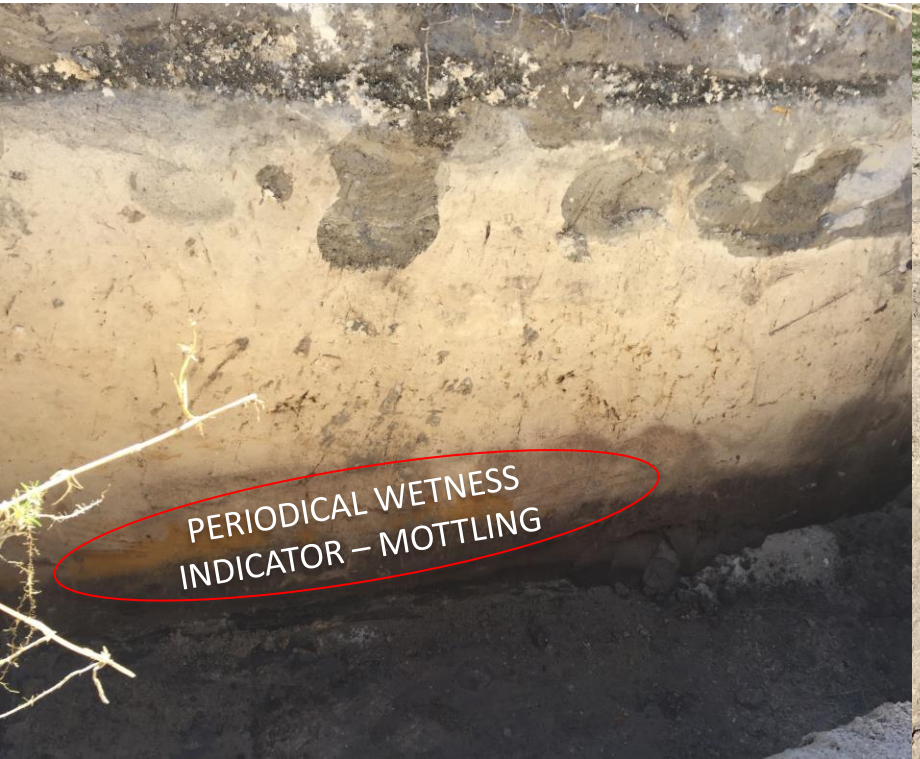
- Ferruginization in slightly more clayey sands
- Sidewall collapse above slightly indurated ferruginized horizon
- Periodical flooding of open excavations



Partially Saturated Seepage in Soil

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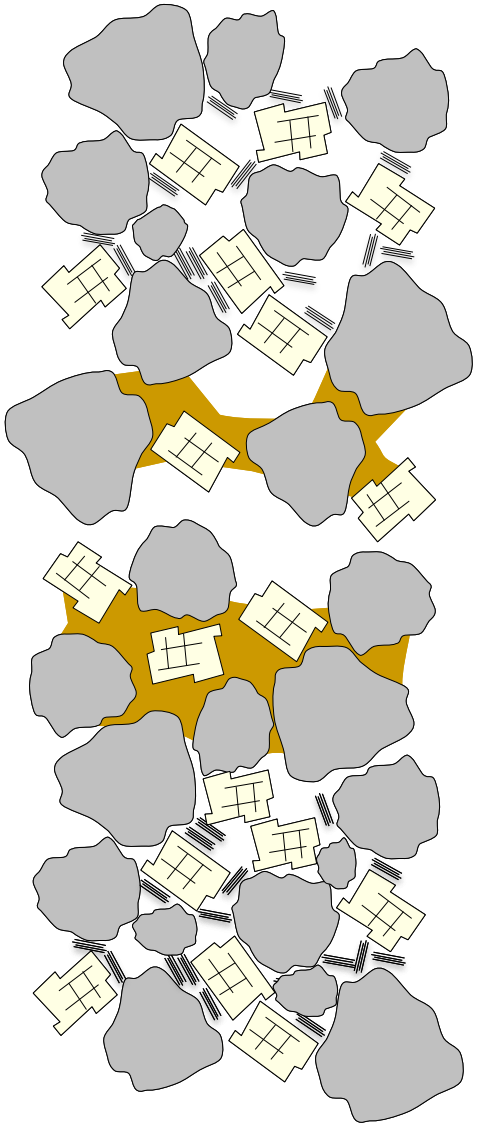
- Partial saturation
  - Flow is not necessarily gravity-driven
  - Water is not necessarily mobile
- Highly variable
  - Vertically (i.e. perched or “shallow aquifer” systems underlain by intermediate vadose zone)
  - Spatially (i.e. hillslope-scale flow processes)
  - Temporally (i.e. threshold-moisture breaching inducing seepage)
- Processes of
  - Capillarity vs gravity (adhesion vs cohesion)
  - Translocation (clay mobilisation and pedogenesis)



Colluvium

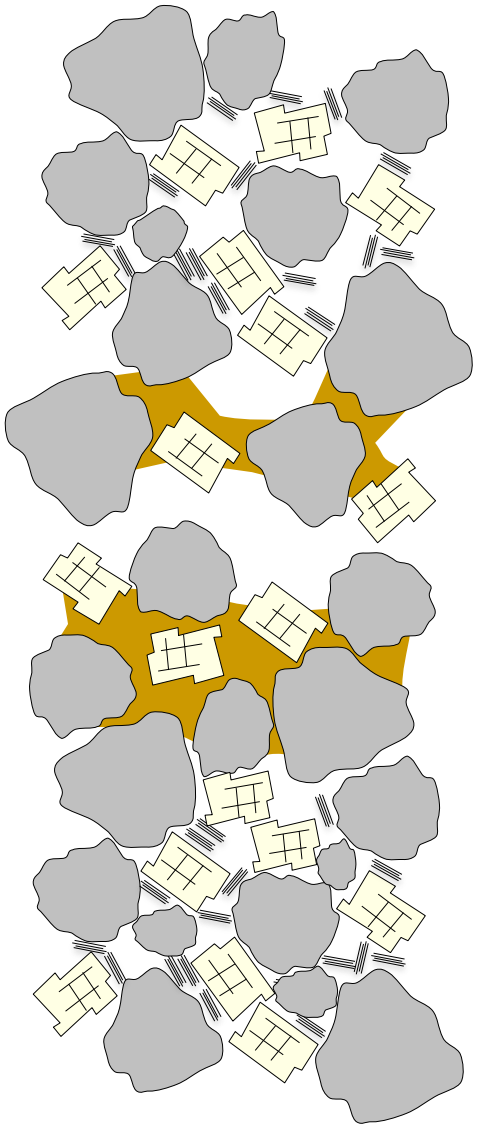
Porosity ca. 0.22
Pore size small
Connectivity poor
Adhesion dominates

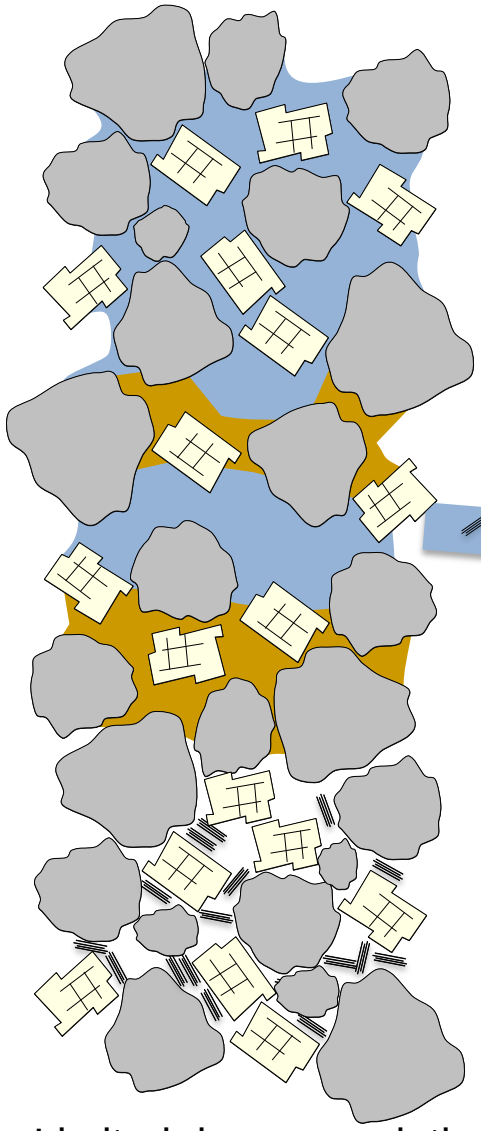
Ferruginized Horizon

Porosity ca. 0.15
Pore size large
Connectivity good
Cohesion dominates
Possibly periodically saturated

Granite Saprolite

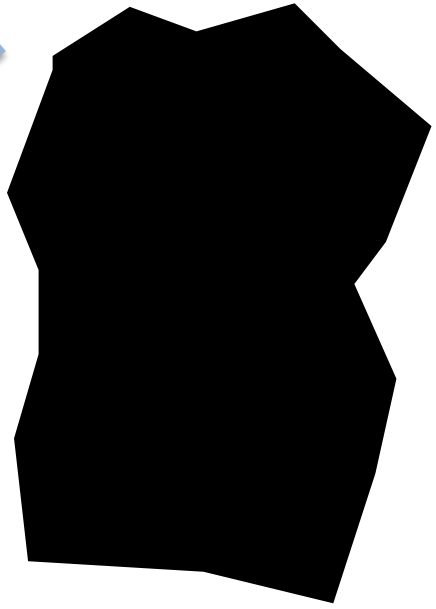
Limited deep percolation due to smaller pore sizes in saprolite





Limited deep percolation due to smaller pore sizes in saprolite

INTERFLOW



Translocated downslope with interflow
Weathers further into expansive clays
Deposited at footslope as duplex soil
Often waterlogged at surface

Quartz
Feldspar
Clay/ Mica
Goethite
Water
2:1 Clays

Partially Saturated Flow in Rock

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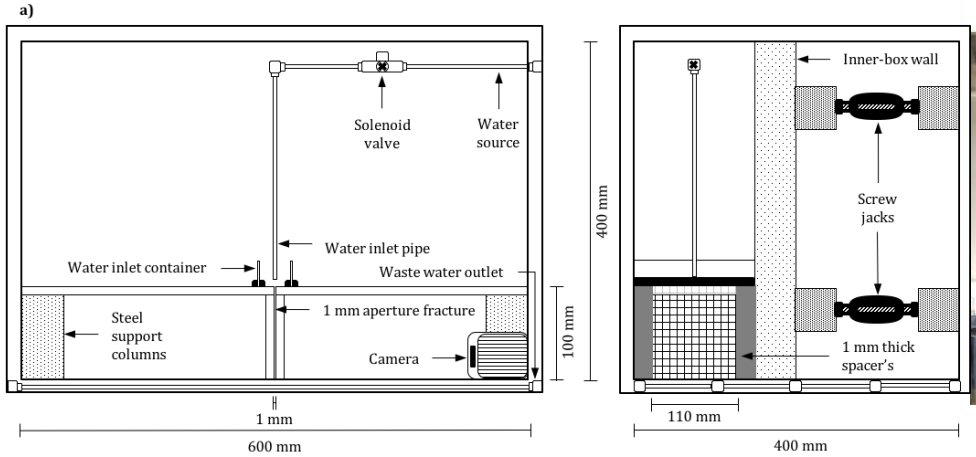
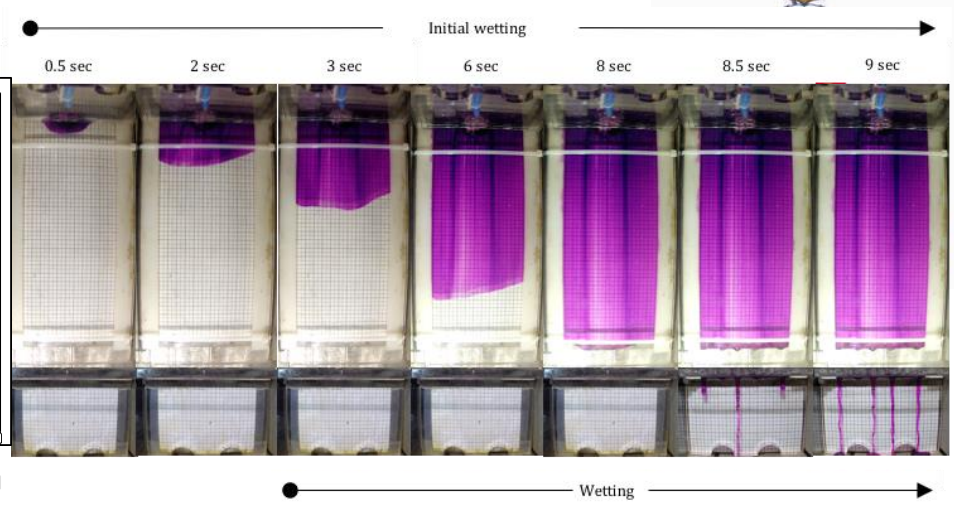
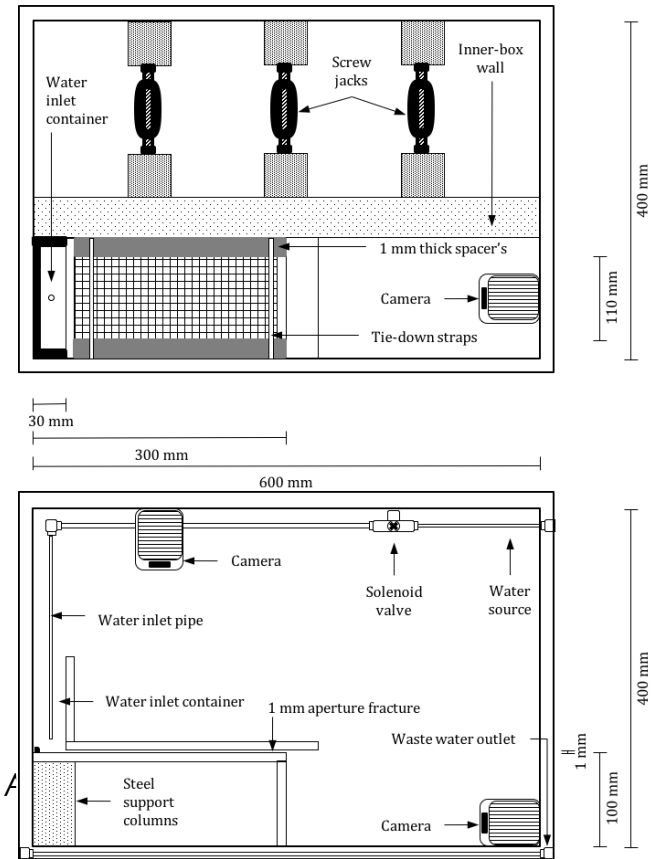
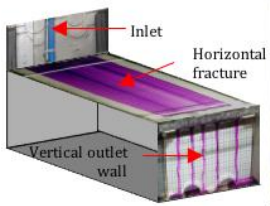
- Partial saturation predominantly on non-horizontal joints
- Recent findings:
  - Horizontal $K_{S<1}$ depends on large aperture
  - Vertical $K_{S<1}$ depends on small aperture and obstacles
  - Crossing intersections depends on adhesion (i.e. flow tends to change orientation at intersections)
  - Horizontal fractures more saturated than vertical fractures

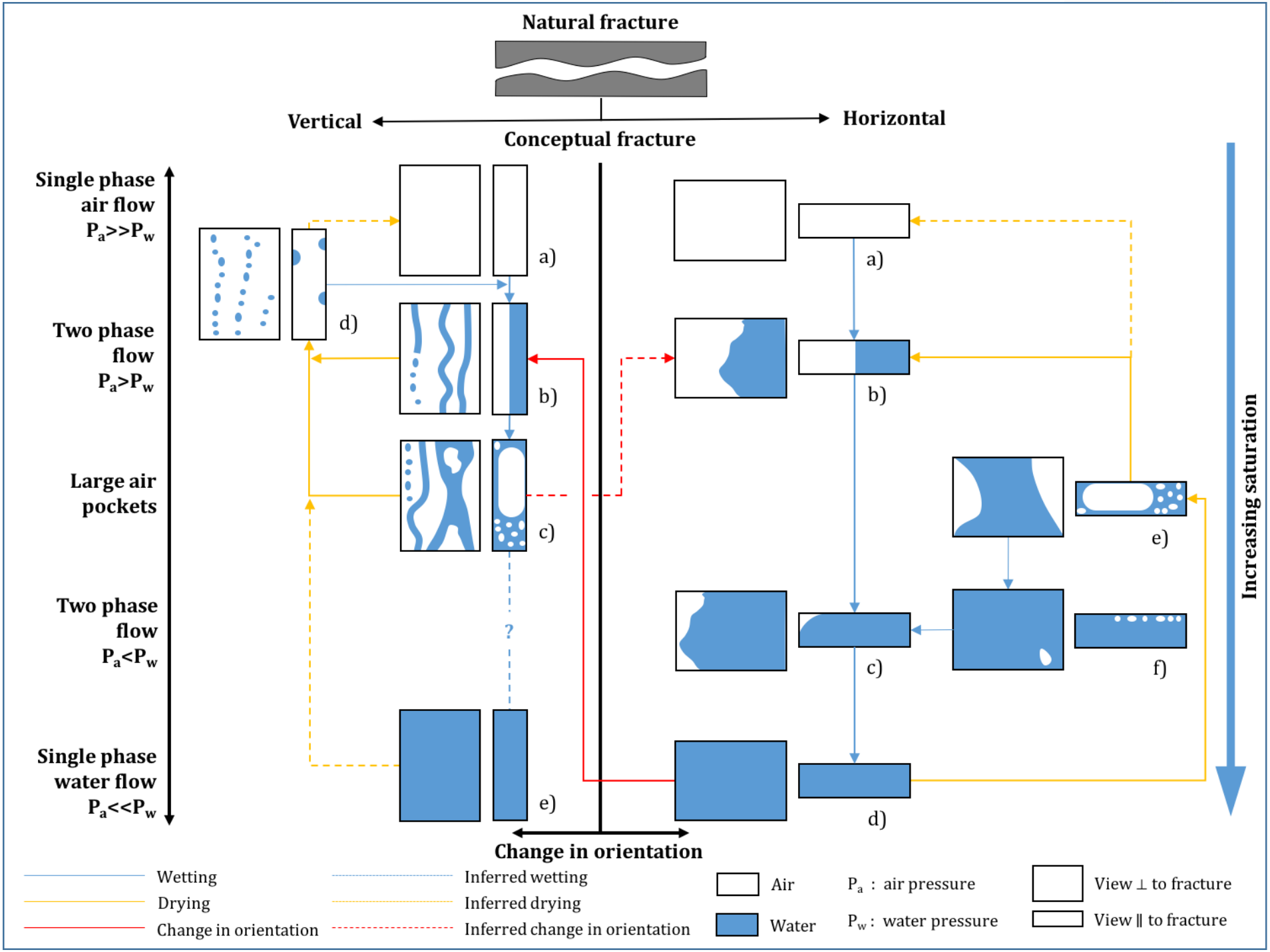

a)
Solenoid valve
Water source
Water inlet pipe
Water inlet container
Waste water outlet
1 mm aperture fracture
Steel support columns
Camera
100 mm
400 mm
1 mm
600 mm
Inner-box wall
Screw jacks
1 mm thick spacer's
110 mm
400 mm


Initial wetting
0.5 sec
2 sec
3 sec
6 sec
8 sec
8.5 sec
9 sec


b)
Water inlet container
Screw jacks
Inner-box wall
1 mm thick spacer's
Camera
Tie-down straps
400 mm
110 mm
30 mm
300 mm
600 mm
Camera
Solenoid valve
Water source
Water inlet pipe
Water inlet container
1 mm aperture fracture
Waste water outlet
Steel support columns
Camera
H 1 mm
100 mm
400 mm


Inlet
Horizontal fracture
Vertical outlet wall

Wetting
20 l/hr
40 l/hr
60 l/hr
80 l/hr
100 l/hr
Drying
Rewetting
0 l/hr
0 l/hr
20 l/hr
40 l/hr
60 l/hr
80 l/hr
100 l/hr


Natural fracture
Vertical
Horizontal
Conceptual fracture
Single phase air flow $P_a >> P_w$
Two phase flow $P_a > P_w$
Large air pockets
Two phase flow $P_a < P_w$
Single phase water flow $P_a << P_w$
Increasing saturation
Change in orientation
a)
b)
c)
d)
e)
f)
?
Wetting
Drying
Change in orientation
Inferred wetting
Inferred drying
Inferred change in orientation
Air
Water
P_a : air pressure
P_w : water pressure
View ⊥ to fracture
View ∥ to fracture

Partially Saturated Seepage from Soil into Rock

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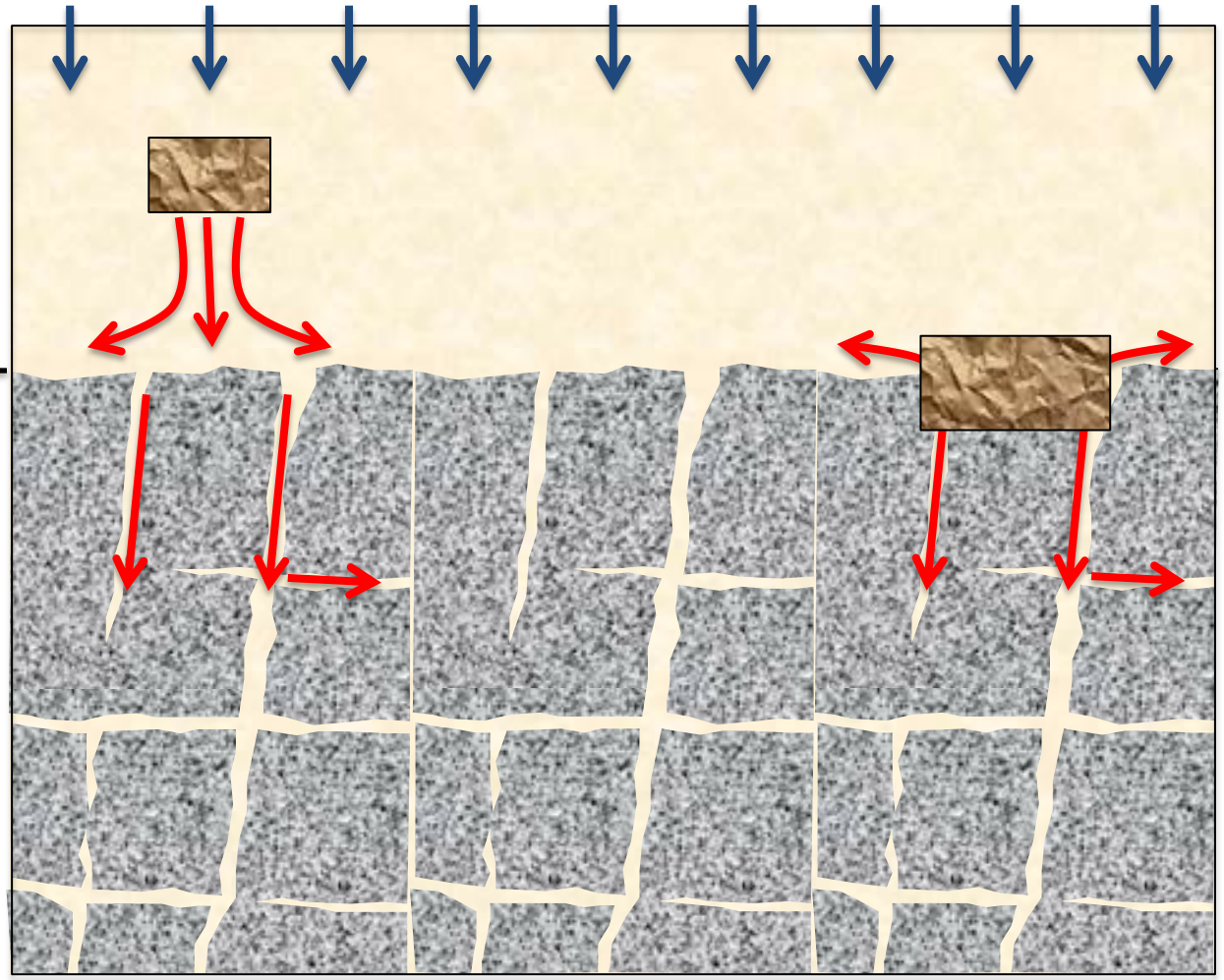
Infiltrating water (blue arrows)

Soil

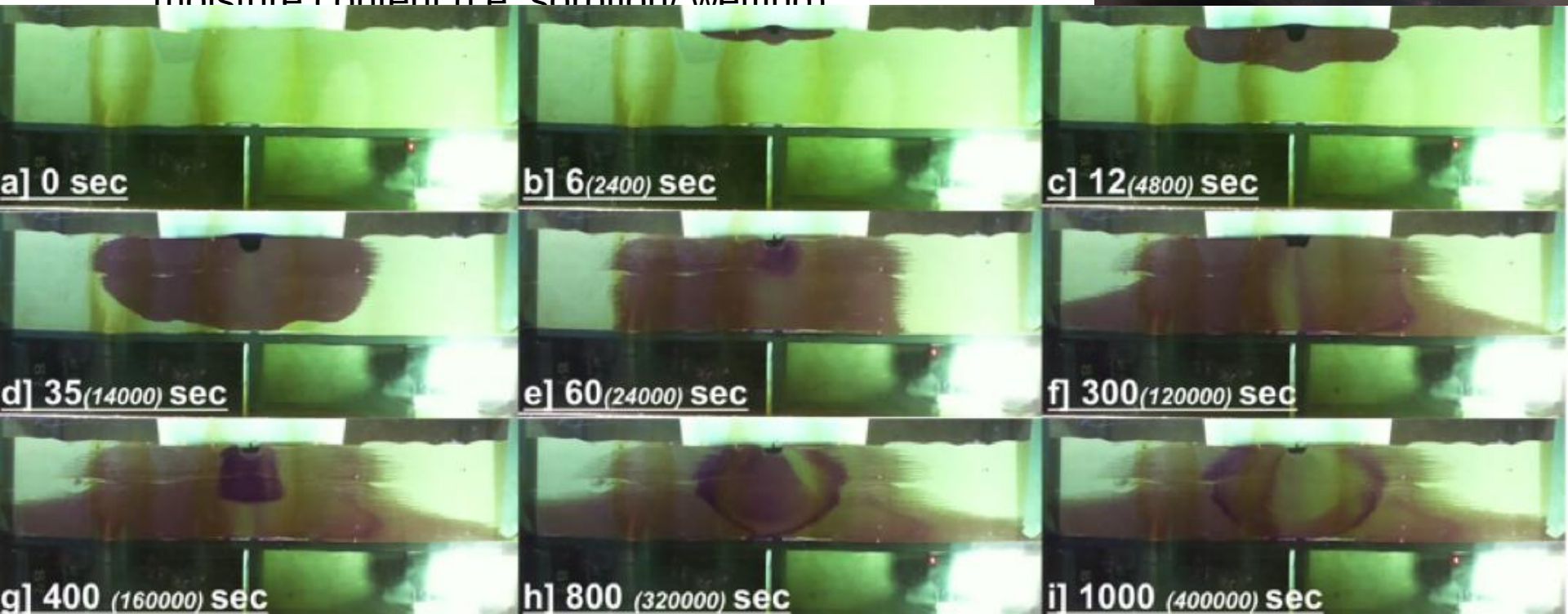
Fractured Rock

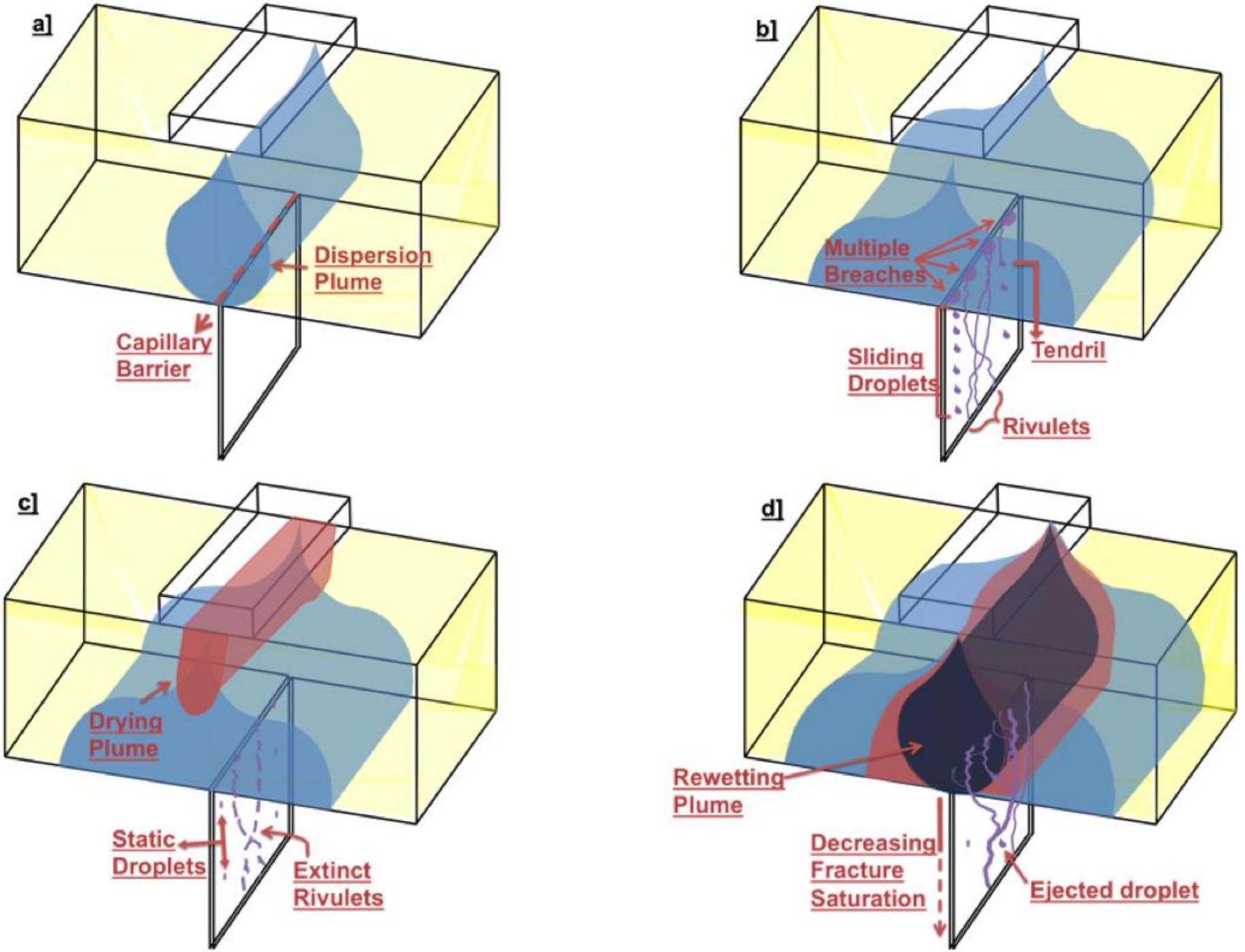
Possible paths of water movement (red arrows)



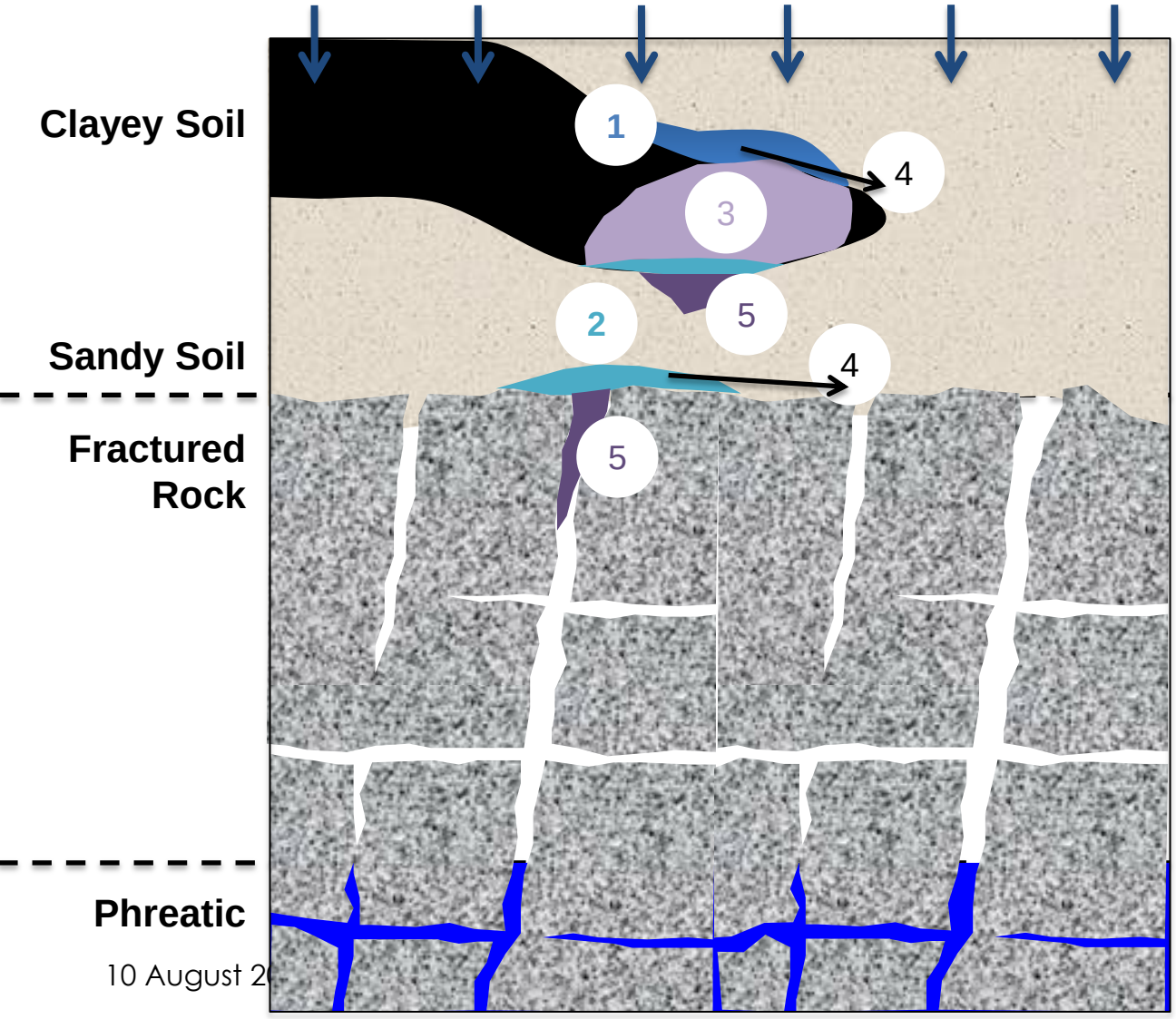
Partially Saturated Seepage from Soil into Rock

- Dispersion in soil overlying single vertical fracture
- Initial dispersion plume formed above capillary barrier
- Breach into fracture beyond some threshold moisture content (i.e. sorption/ wetting)



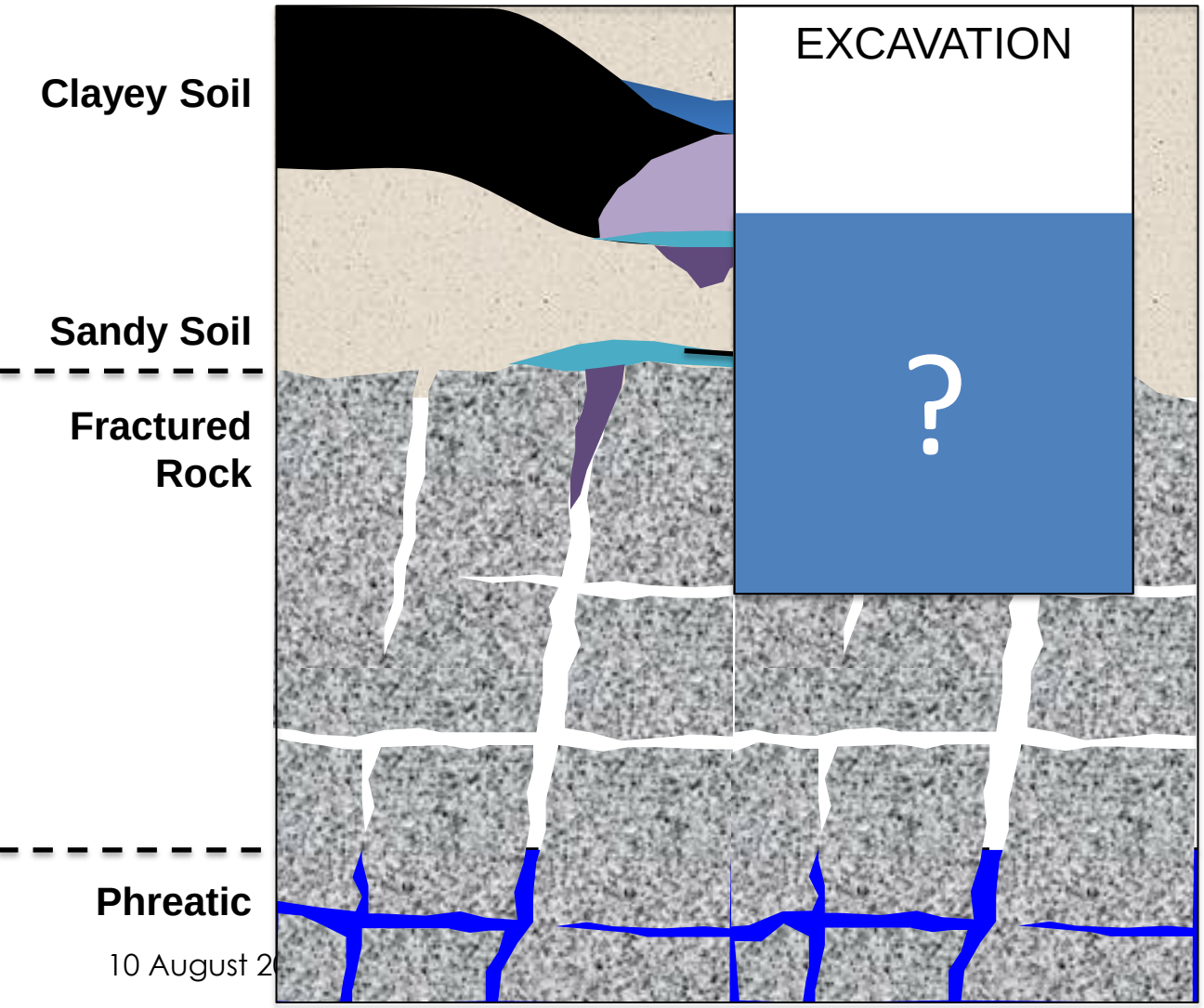

a]
Dispersion Plume
Capillary Barrier
b]
Multiple Breaches
Tendril
Sliding Droplets
Rivulets
c]
Drying Plume
Static Droplets
Extinct Rivulets
d]
Rewetting Plume
Decreasing Fracture Saturation
Ejected droplet

With Progressive Wetting…



1. Perch on or in lower permeability materials (ponding) OR
2. Perch above higher permeability material (capillary barrier)
3. Imbibe into lower permeability material (tension/ suction)
4. Seep laterally on a lower permeabililty material (interflow) OR
5. Drain into higher permeability material (gravity flow/ percolation)

Change Induced…



Disrupting the ground profile affects this very complex combination of flow paths

Partial and variable saturation is complex even before altering the ground profile

How will these flow systems impact on the development, and how will the flow systems be altered?

Final Thoughts

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- Traditionally we neglect the different flow mechanisms and consider water a singular parameter during site investigation
- Wet conditions during investigation do not necessarily imply a single saturated system, and hysteresis cannot be discounted
- A conceptual earth system model interpreting soil profile hydrology can inform about flow mechanisms and more appropriate mitigation measures
- This affects groundwater recharge, interflow, attenuation of contaminants and engineering development
- Better understanding
- = better conceptual models
- = safer and more feasible development

Thank you!

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- Contributions of Brendon Jones, Luke Brouwers et al. duly acknowledged
- Project publications to date:
  - Jones, B. R., Brouwers, L. B., van Tonder, W. D. and Dippenaar, M. A. (2017). Assessing geotechnical centrifuge modelling in addressing variably saturated flow in soil and fractured rock. Environ. Sci. Poll. Res. 24:13203-13223.
  - Dippenaar, M. A. and Van Rooy, J. L. (2016). On the cubic law and variably saturated flow through discrete open rough-walled discontinuities. Int. J. Rock Mech. Min. Sci. 89:200-211.
  - Dippenaar, M. A. and Van Rooy, J. L. (2014). Review of engineering, hydrogeological and vadose zone hydrological aspects of the Lanseria Gneiss, Goudplaats-Hout River Gneiss and Nelspruit Suite Granite (South Africa). J. Afr. Earth Sci. 91:12-31.
  - Dippenaar, M. A. (2014). Towards hydrological and geochemical understanding of an ephemeral palustrine perched water table “wetland” (Lanseria Gneiss, Midrand, South Africa). Environ. Earth Sci. 72(7):2447-2456.
  - Dippenaar, M. A. (2014). Towards a multi-faceted Vadose Zone Assessment Protocol: cemetery guidelines and application to a burial site located near a seasonal wetland (Pretoria, South Africa). Bull. Eng. Geol. Environ. 73(4):1105-1115.