Aquifères de socle :
le point sur les concepts et les applications opérationnelles
Hard-Rock Aquifers:
up to date concepts and practical applications
du 11 au 14 juin 2015 / *June, 11-13 2015*

Comité Français d'hydrogéologie

Association internationale des hydrogéologues

Origine de la fracturation des aquifères de socle : quels sont les facteurs qui contrôlent les propriétés de l'horizon fissuré ?

Origin of fracturation in hard-rock aquifers: what are the factors that control the properties of the fissured horizon?

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PLAN

1. Weathering revisited: a classification of weathering profiles
2. Structure of a lateritic profile
3. Mechanisms of fissuration in the fissured layer
4. The fissured layer of lateritic profiles: a new concept of aquifer and hydrocarbon reservoir
5. Factors controlling the fissuration

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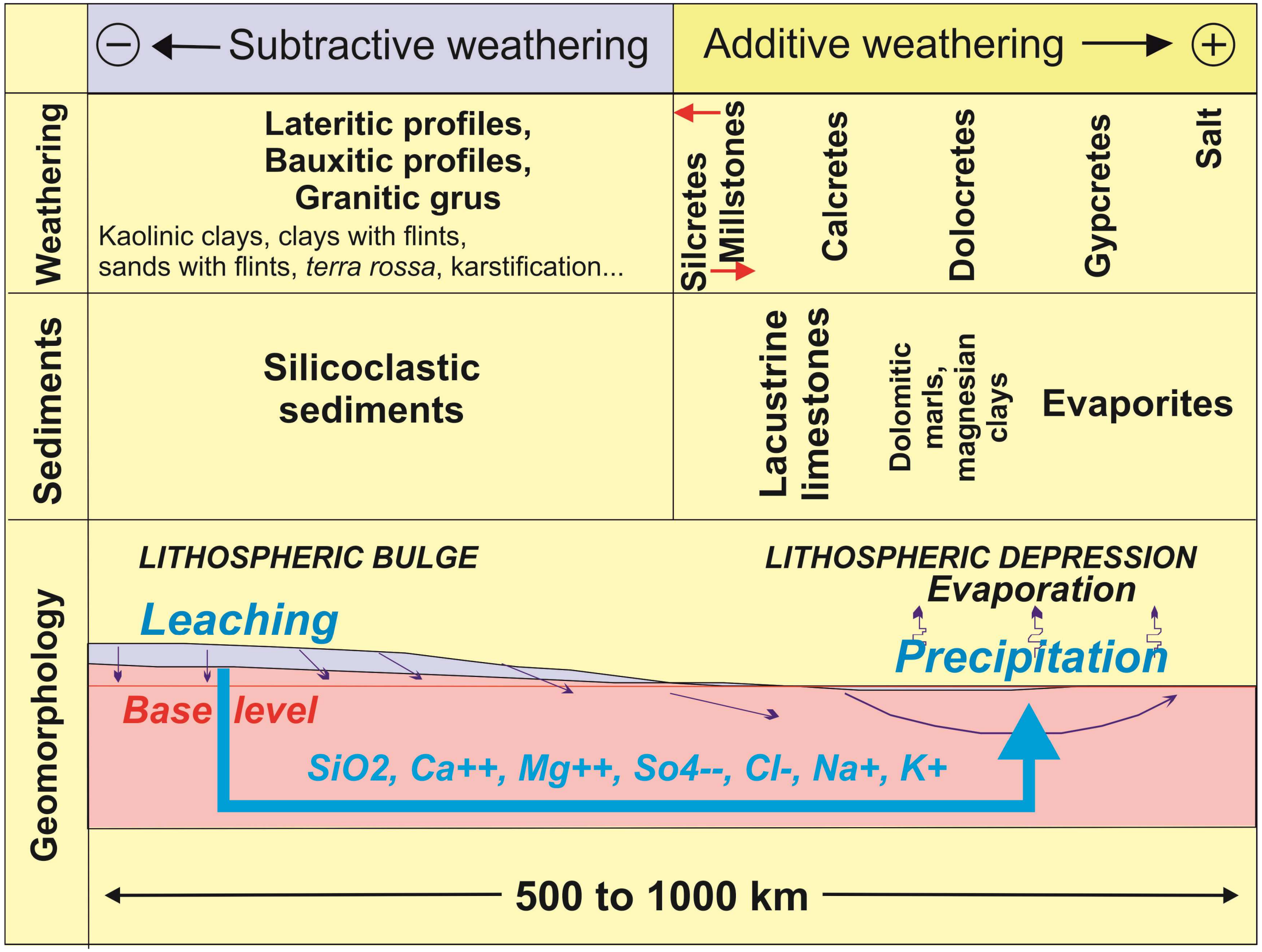
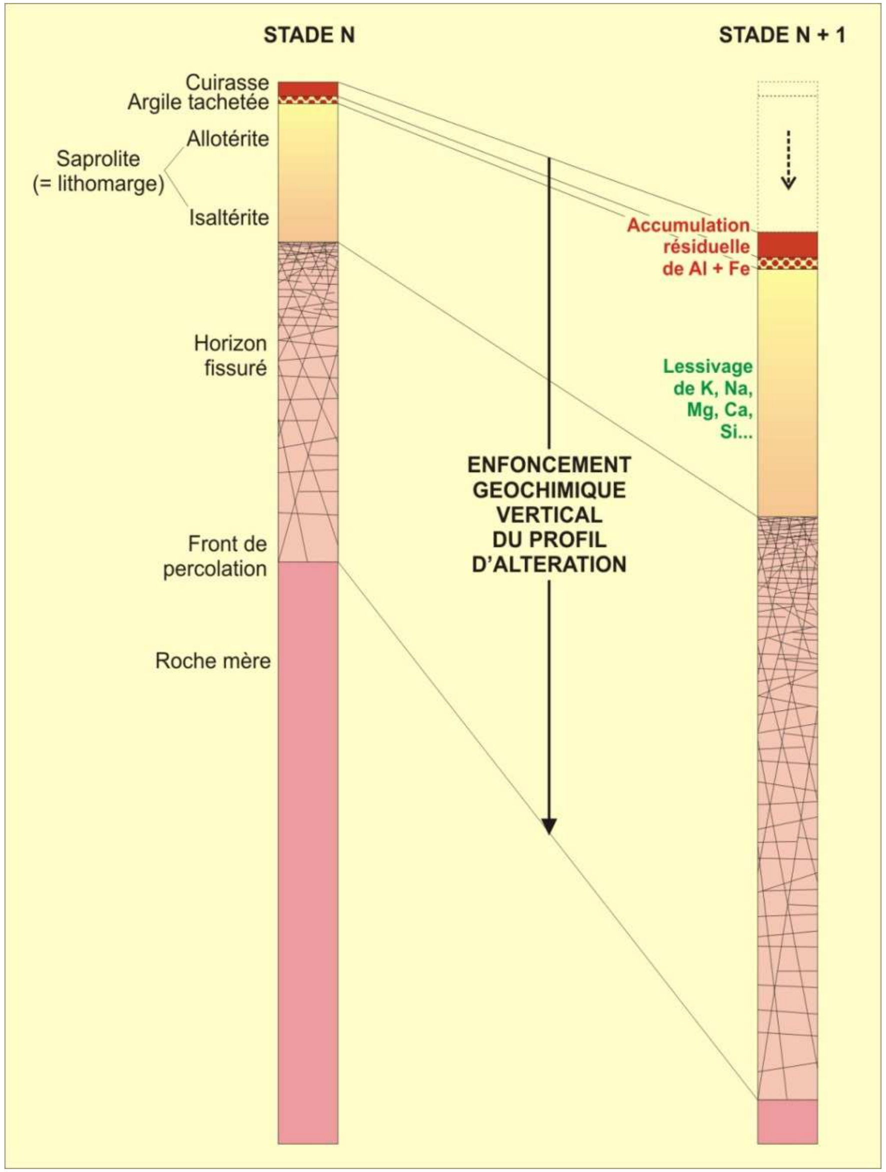
1. Weathering revisited



2. Structure of a lateritic profile



- → The thickness of the fissured layer is about twice that of the saprolite
- → The thickness of the fissured layer varies commonly between 70 and 200 m and can reach 300 to 400 m depending of the weathering conditions,
- → The length of functioning of a profile is several tens of Ma

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Iron duricrust/cuirasse ferrugineuse, Deccan (Inde)

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Saprolite on schists (Saint Cyr des Gâts, Vendée)

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Isaltérite, (base of saprolite) Chemillé (Maine et Loire):

The fissured layer in Mortagne granite, Vendée) :

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3. Mechanisms of fissuration in the fissured layer

<u>History</u>

The existence of a high fractured hard-rock zone below saprolite was known for a long time by hydrogeologists: the first water inlets are at the top of the bed-rock, and their frequency and yield decrease downward

Furthermore, geologists and geomorphologists have for a long time noticed the sheeting in granites

This sheeting has been interpreted in various ways: thermal contraction during magmatic cooling, insolation…

The most common explanation is: decompression by erosion (off-loading)

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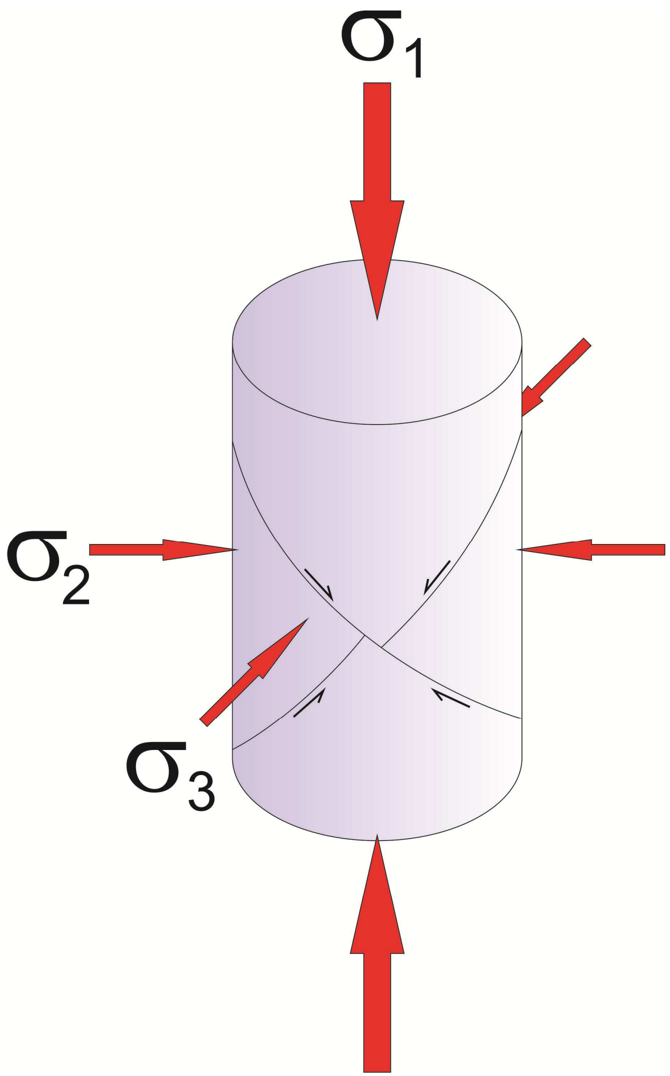
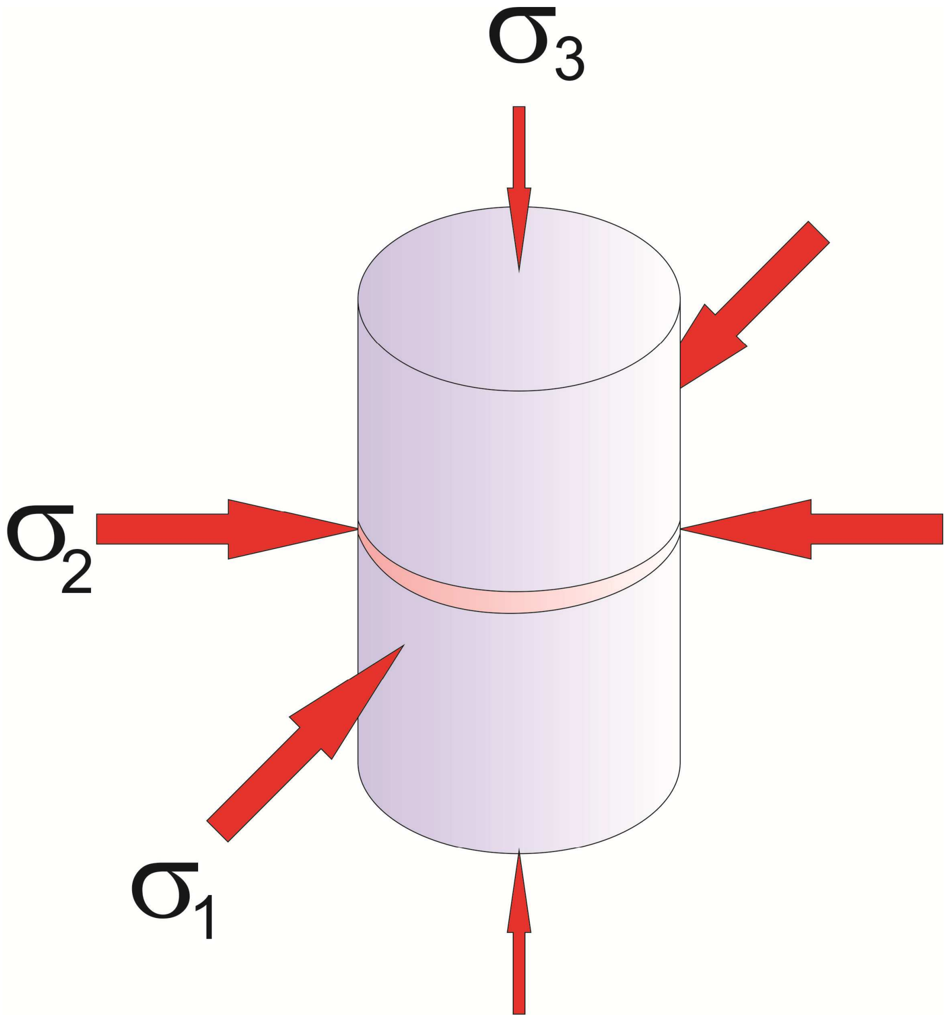
Review of the « decompression » concept

Breaking of a solid needs than the difference of module between minimal and maximal stress components exceeds the *elastic boundary* of the solid.

During a triaxial test on a rock sample, if we increase one of the stress components (σ_1) while maintaining constant the two others ($\sigma_2 = \sigma_3$ = confining stress), we get a breaking by shearing, the shear plane orientation being intermediate between σ_1 and σ_2 / σ_3.



At the opposite, if we increase the confining stress ($\sigma_1 = \sigma_2$) while maintaining constant the third component (σ_3), then we get a breaking by tension cracks, the cracks being parallel to σ_1 and σ_2.



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Natural decompression by offloading: does it exists ?

On in situ rock, if we decrease suddenly one of the stress components, we can create tension cracks: that occurs for example in a *mine gallery*.

But in natural conditions, the decreasing of the vertical stress due to erosion is too slow to cause cracking: the stress has enough time to reorganise at the scale of grain joints.

Decompression due to erosion is not able to generate horizontal joints in bed-rock.

Numerous field observations show than planar jointing does exist only in rocks containing swelling minerals (biotite, pyroxene, olivine).

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Example : absence of planar jointing in Thouars microgranite…

…50 km away of Thouars, on the same paleosurface, the 2-micas Mortagne granite shows characteristic planar jointing:

Mechanism of cracking: case of coarse-grained plutonic rocks (granitoids)

During weathering, biotite crystals transform in chlorite or vermiculite with a volume increasing of 40 %: layer thickness passes from 10 Å to 14 Å.

That change occurs in a hard rock, whose hardness does not permit dilatation. Therefore, in horizontal dimension, stress will increase. In vertical dimension, stress will increase until lithostatic stress will be offset, and after, vertical dilatation will be possible.

→ The resulting stress tensor will have a vertical minimal component (σ_3), and maximal horizontal components (σ_1 and σ_2).

→ *When the module difference between* σ_3 and σ_1 /σ_2 reaches the elastic limit of the rock, tension cracks will appear.

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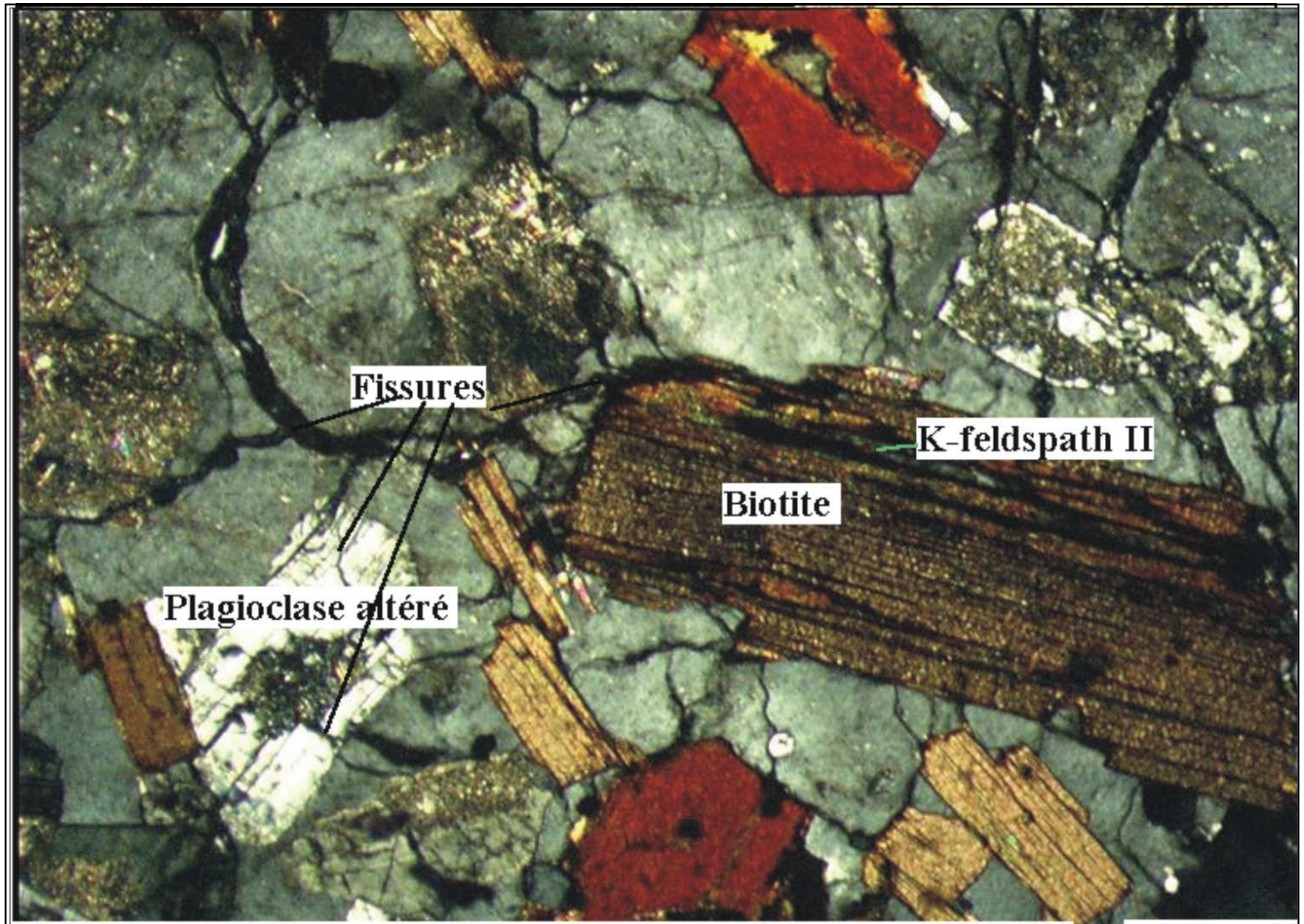
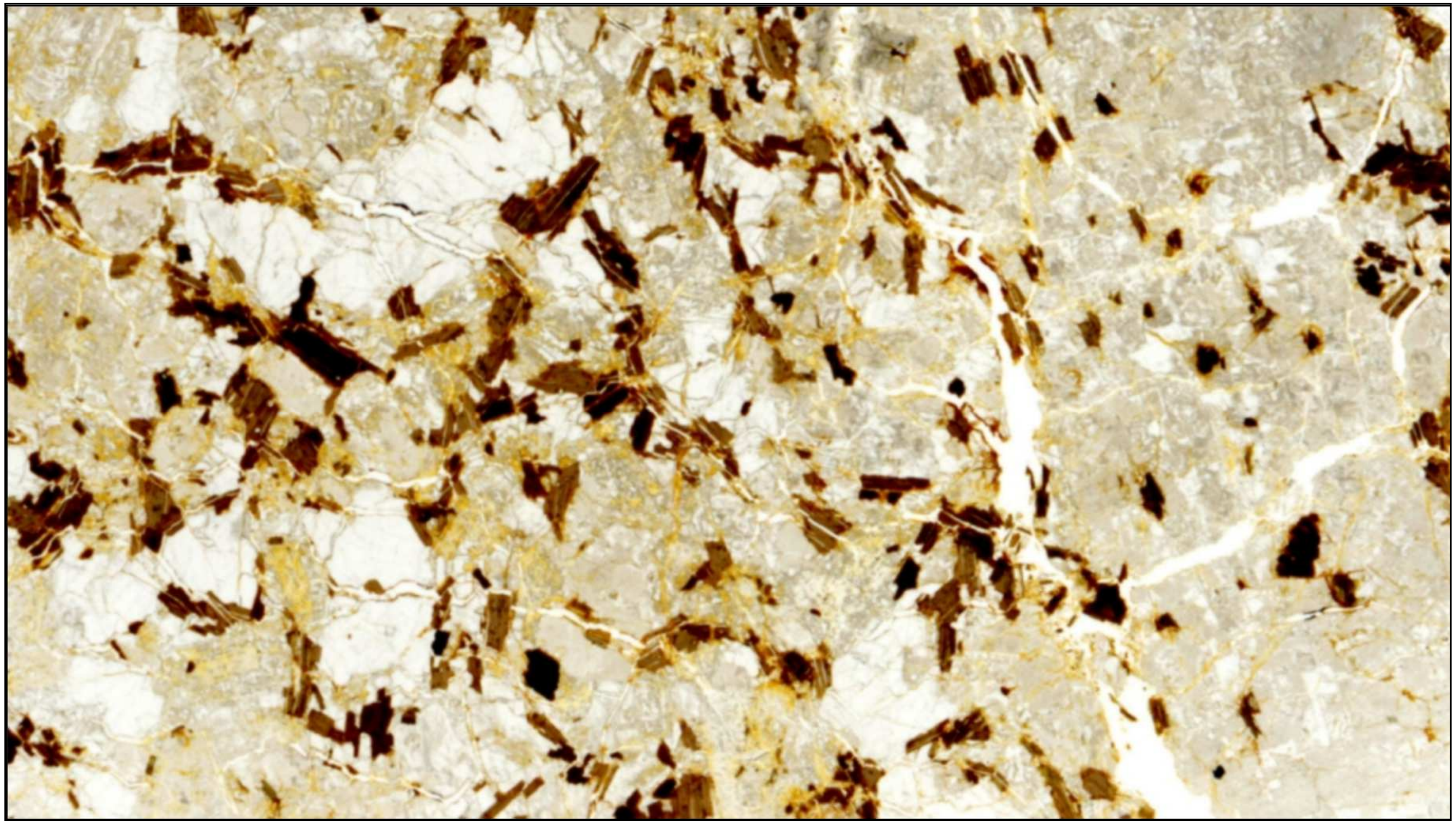
Weathering of a biotite-bearing granite:



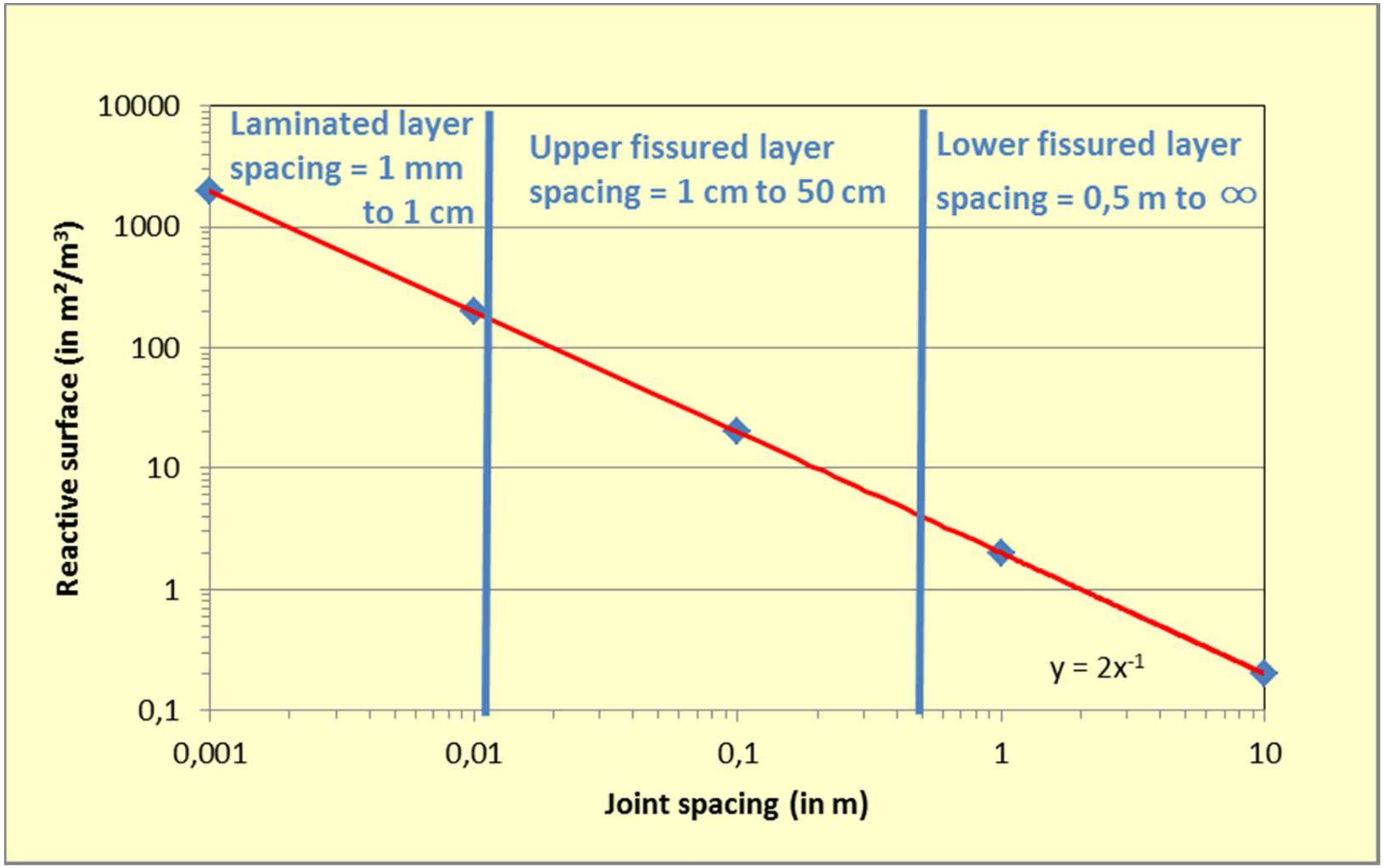
B1 - 16,20 m. Microfissuration et altération du granite L.P. x 20

At the base of the saprolite (laminated layer), all biotites have been weathered: there is a dense network of microcracks:



The laminated layer in a biotite granite (India)

The reactive surfaces (available for water-rock interaction) increase like twice the inverse of joint spacing.



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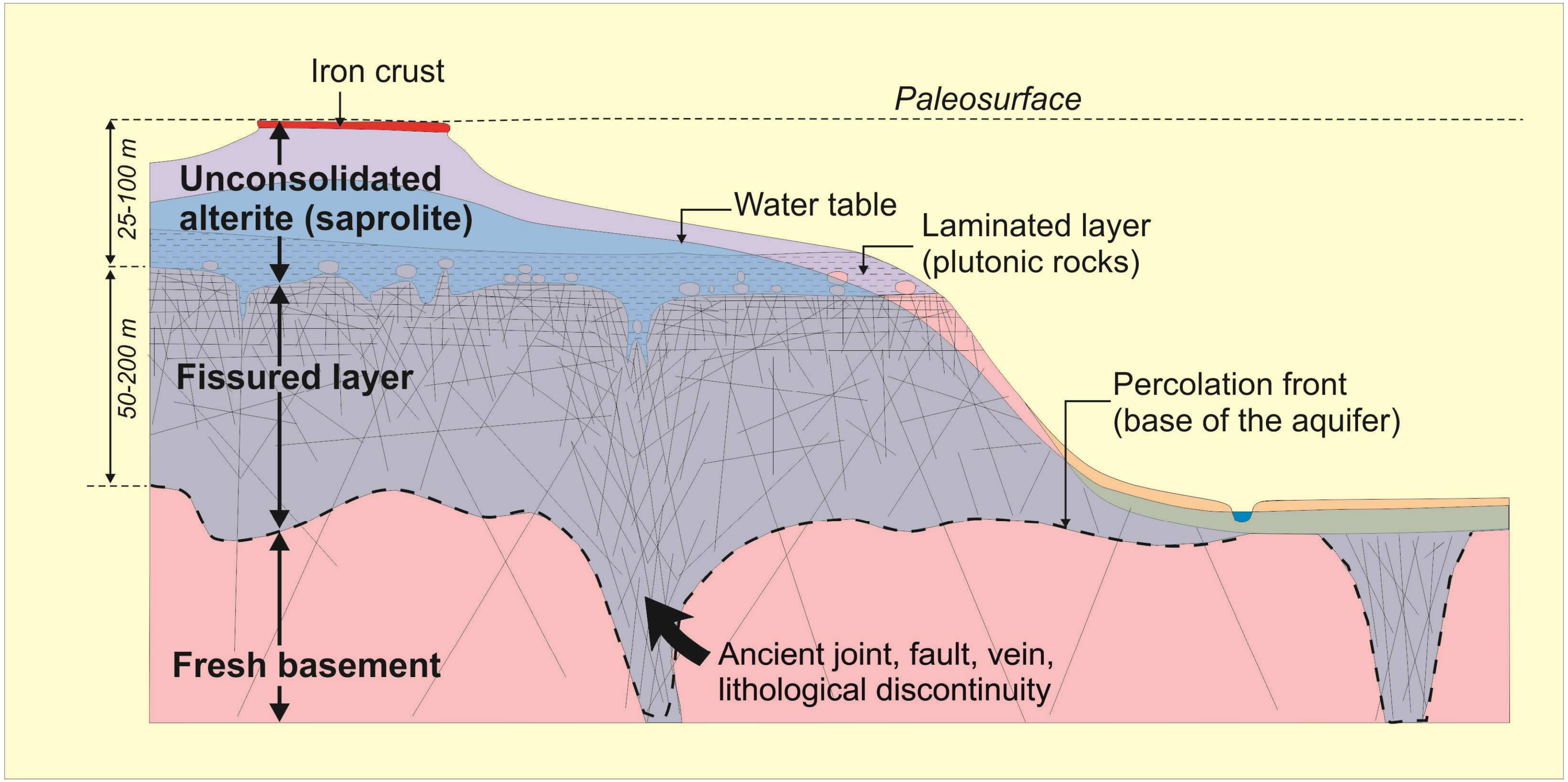
4. The fissured layer of lateritic profiles: a new concept of aquifer and hydrocarbon reservoir



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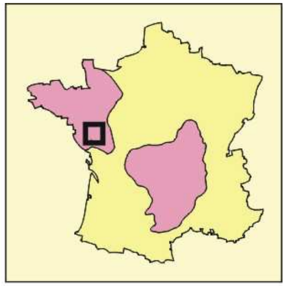
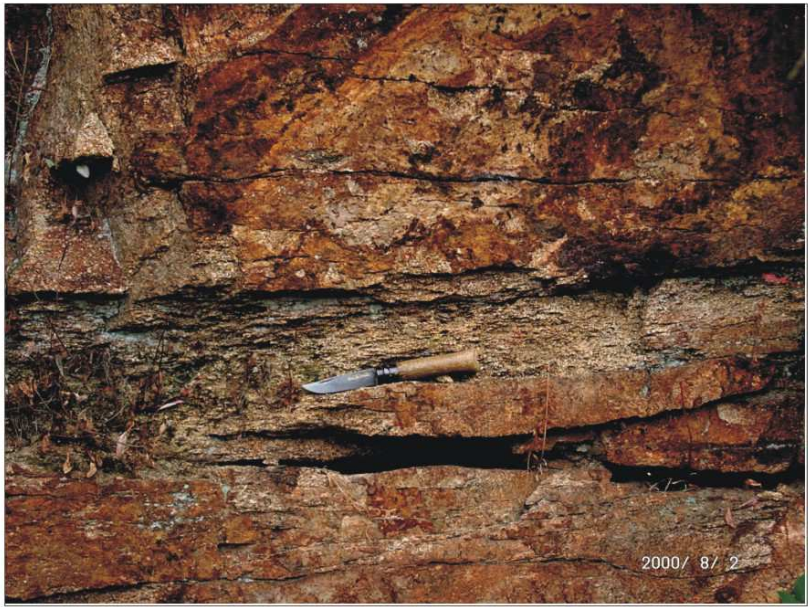
Examples of macroscopic tension joints:

Granite de Mortagne (Vendée)





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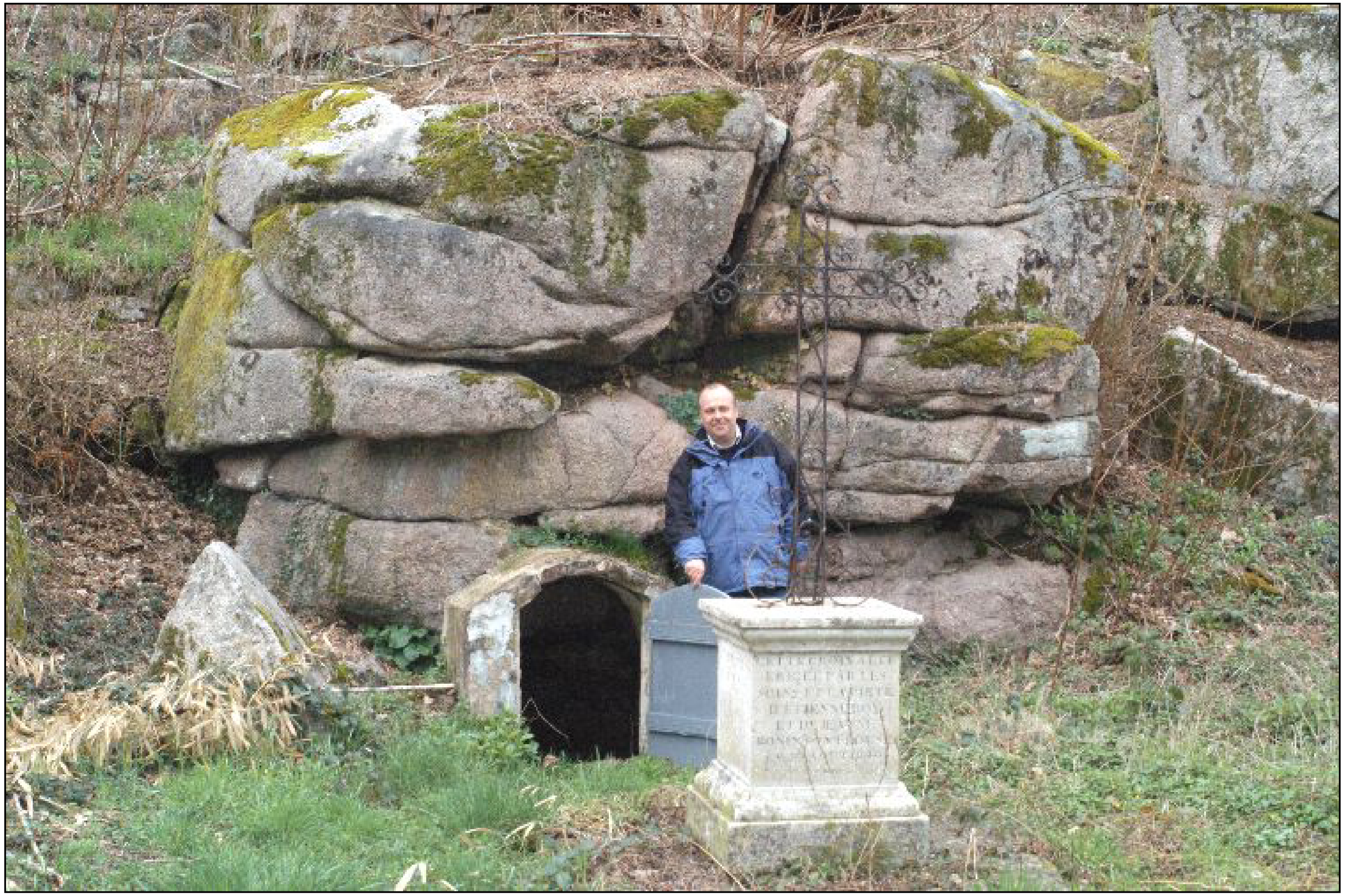
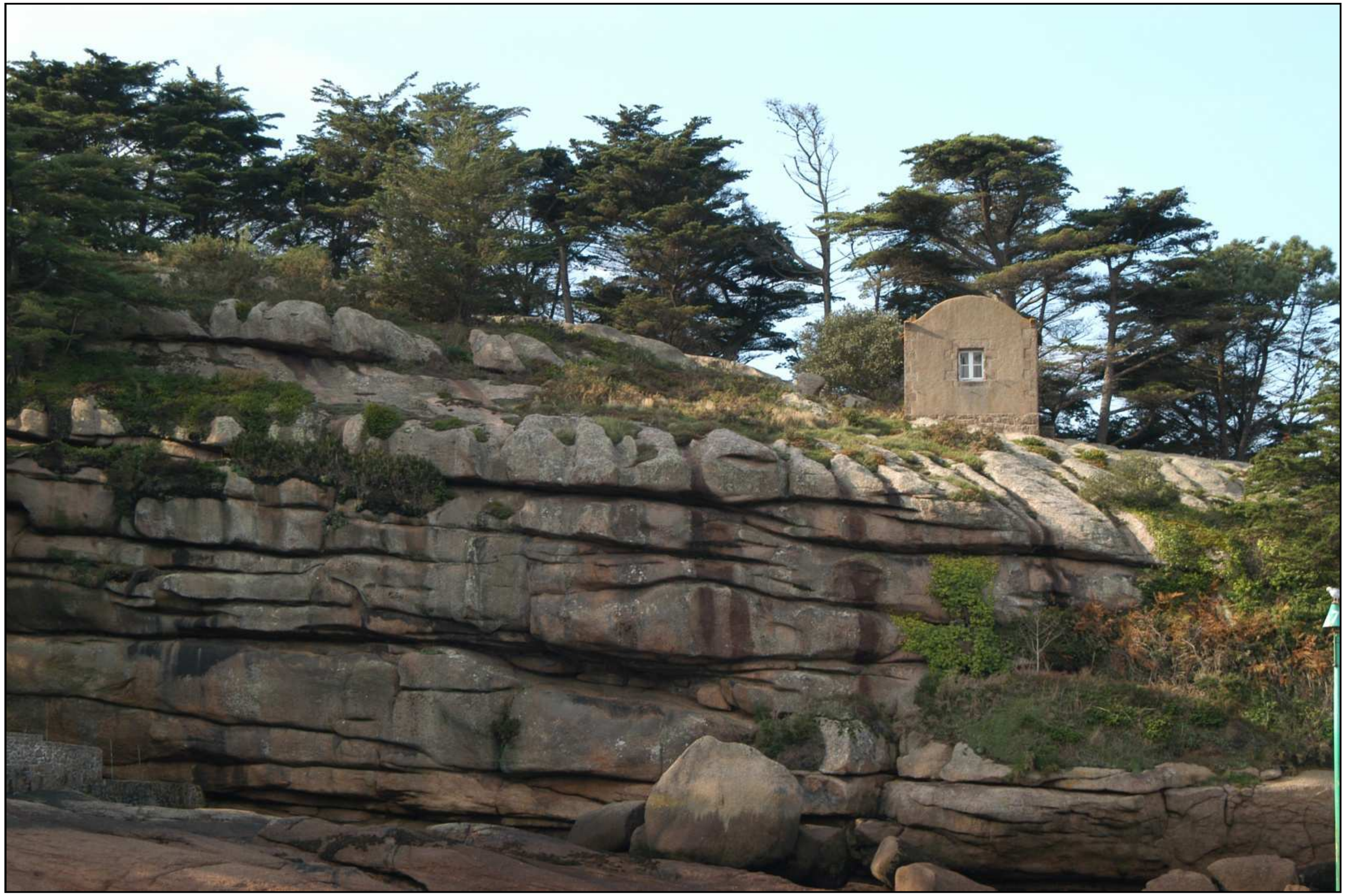
Cousin valley (Morvan)



Ploumanac'h Granite (Brittany)



Vertically foliated migmatites (Guinée)

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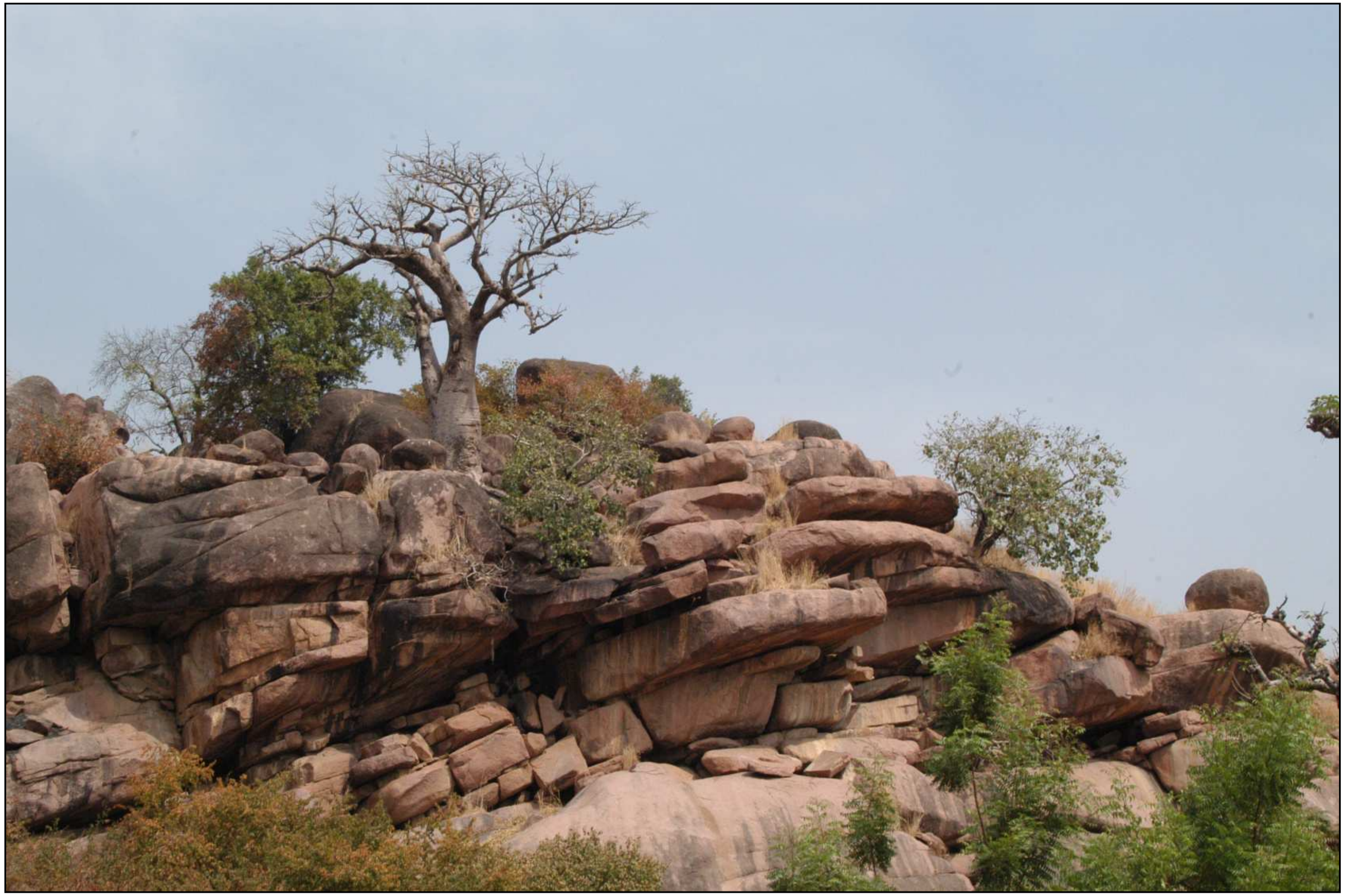
Granite, Burkina-Faso



Granite, India (Hyderabad, Andhra Pradesh) :

Granite, Saudi Arabia

Case of folded and foliated rocks (schists, micaschists, gneiss)

→ Phyllites orientation depends of rock deformation
→ The layered texture induces preferential weakness planes
→ Cracks geometry is generally irregular:

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Unweatherable rocks in weatherable environment:

Typically, quartz veins intruding biotite granite have been subjected to stress induce by granite weathering, and show a dense network of open cracks (India)

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India

5. Factors controlling the fissuration

Different factors control the possibility to get a well developed lateritic profile, so the possibility to get a well developed fissured layer:

- ***Geomorphology at a continental scale***
  - → subtractive weathering only develops on large uplifted areas of continental lithospheres: water needs to flow laterally to stay unsaturated regarding rock minerals, necessary condition for hydrolysis
  - → The topographic surface needs to be statistically as plane as possible to let time for water to percolate
- ***Mineralogy of the rock***
  - → To develop a fissured layer, the rock needs to contain minerals able to swell during weathering: **biotite**, **pyroxene** or **olivine** (other weatherable minerals like plagioclase or amphibole do not swell, and are unable to induce a fissured layer.

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- ***Texture of the rock***
  - → The ability of a rock to develop fissuring during weathering depends of the size of swelling minerals: for a same mineralogical composition, corse-grained rocks develop fissuring more easily than fine-grained rocks

- ***Structure of the rock***
  - → The presence or not of a foliation (orientation of swelling minerals) and its orientation will control the aperture and the geometry of fissures and the tensor of permeability

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- **A last condition for good aquifer properties…**

→ The fissures network should have stay open after its creation

→ If the fissured layer has been buried below a thick sedimentary cover, fissures could have been sealed by diagenesis minerals (dolomite, baryte, calcite, quartz…)

→ Old weathering profiles are often partially or totally sealed by new minerals

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Thank's !