



**Aquifères de socle : le point sur les concepts et les applications opérationnelles**  
**La Roche-sur-Yon, 11-13 juin 2015**

***Le modèle conceptuel hydrogéologique des aquifères de socle altéré et ses applications pratiques***

***The hydrogeological conceptual model of weathered Hard Rock Aquifers and its practical applications***

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**B. DEWANDEL, R. WYNS - BRGM**





***Le modèle conceptuel hydrogéologique des aquifères de socle altéré et ses applications pratiques***  
***The hydrogeological conceptual model of weathered Hard Rock Aquifers and its practical applications***

**1. Hard Rocks – Definition – Importance of HR aquifers**

**2. Structure of Hard Rock Aquifers**

**2.1. The classical concept of discontinuous aquifers**

**2.2. A new conceptual model demonstrated these last years**

**2.3. Mechanism of weathering-induced fracturation**

**3. Mapping Hard Rock Aquifers**

**4. Mapping Hard Rock Aquifers' hydrodynamic properties**

**5. Some hydrogeological applications**

**6. Questions / Discussion**

# 1. Hard Rocks (HR) – Definition

**Hard Rocks (or basement rocks):**

**All hard and compact rocks, not having a, or having lost their original hydrodynamic characteristics (effective porosity, hydraulic conductivity), from various origins:**

- plutonic rocks (granites, other intrusive rocks),
  - metamorphic rocks (gneiss, schists, paleo-sediments, paleo-volcanics, paleo-granites, etc.),
- from ancient massifs



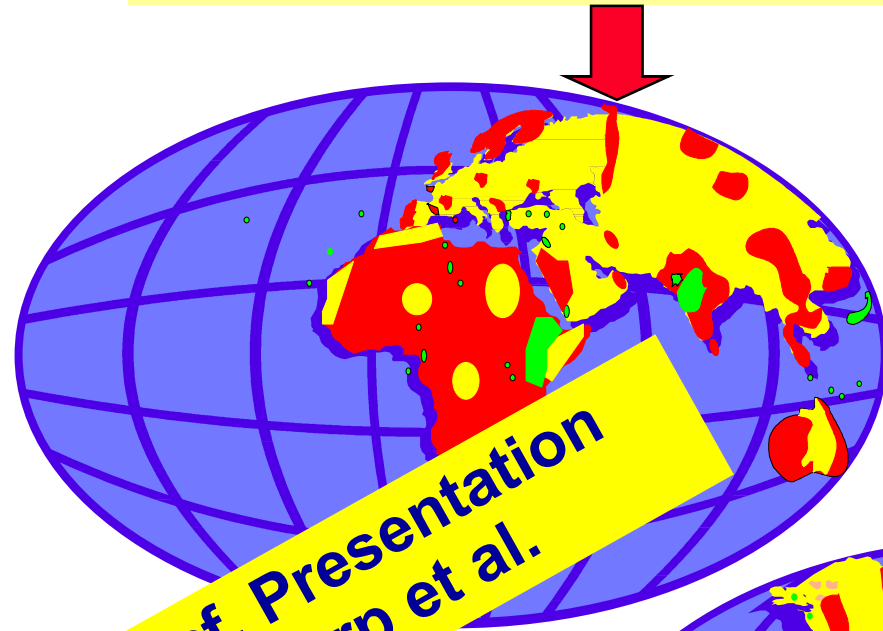
**→ Despite various origins:  
a similar hydrogeological behaviour**

~~Hard Rock:~~

- Marble (sl) (karstic), limestones
- recent volcanic rocks
- etc.

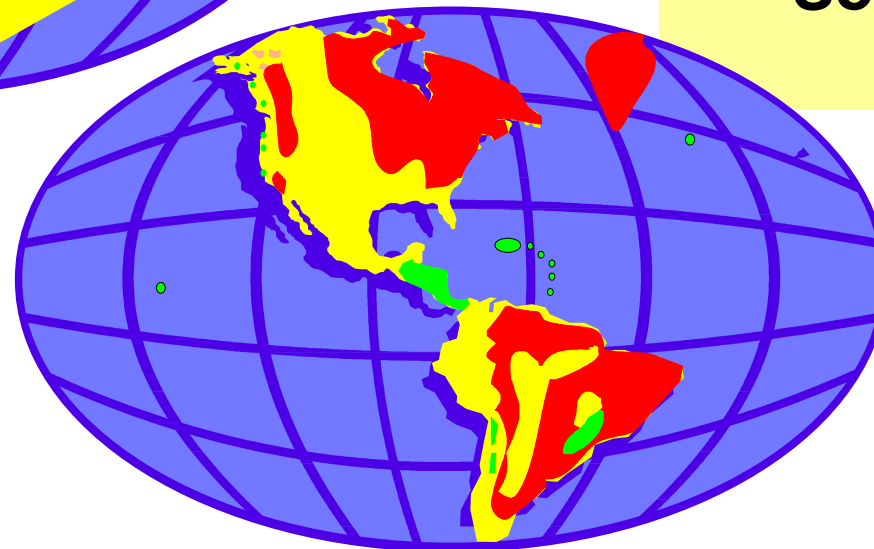
# 1. HR Aquifers (HRA) – an important issue

**Hard Rocks:  
Vast areas in the world and ... in Vendée (France, Europe)**



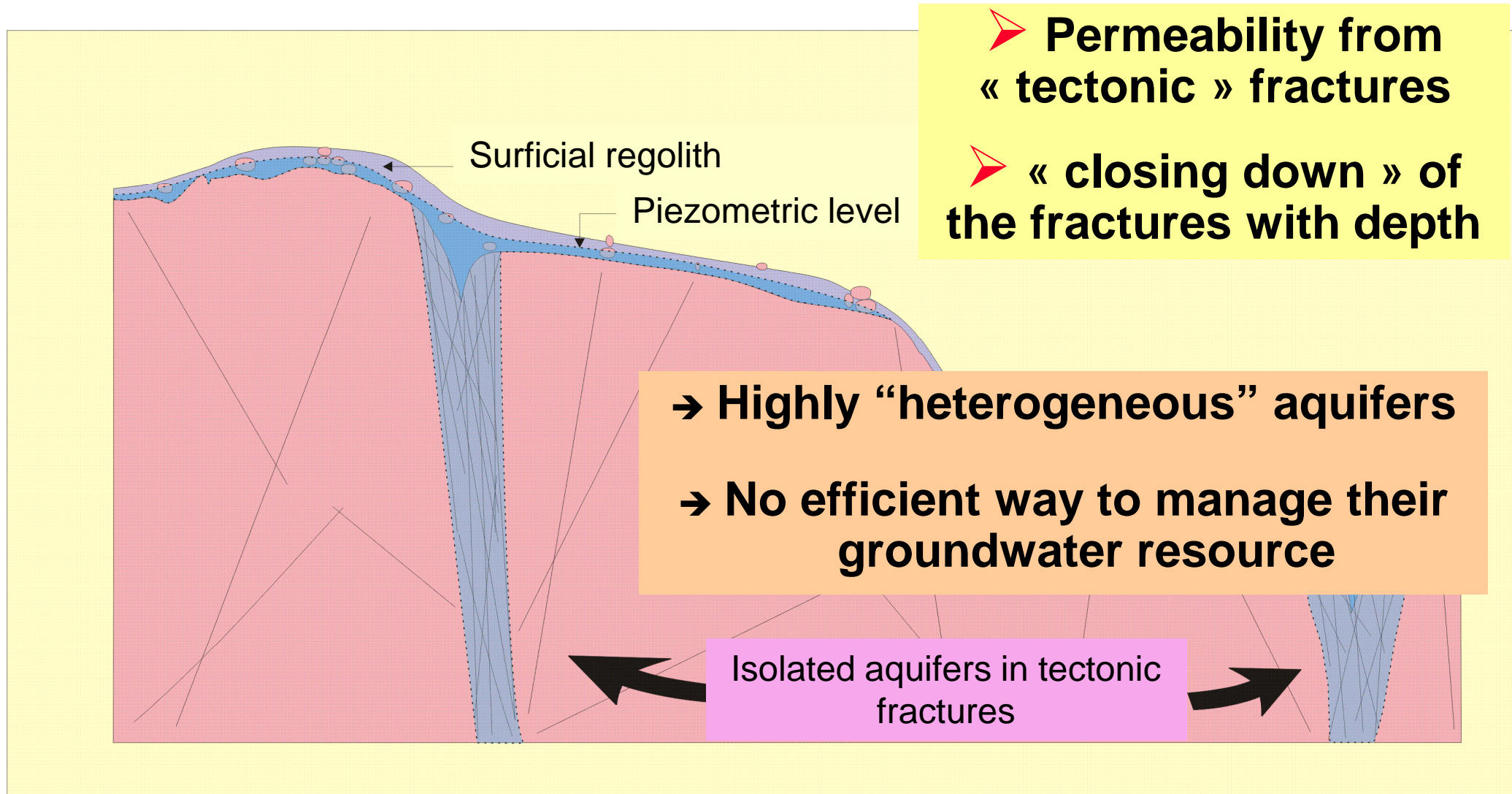
→ cf. Presentation  
Sharp et al.

**Particularly present in  
semi-arid regions  
where groundwater is  
quite the unique  
resource (Africa,  
South America,  
India...)**



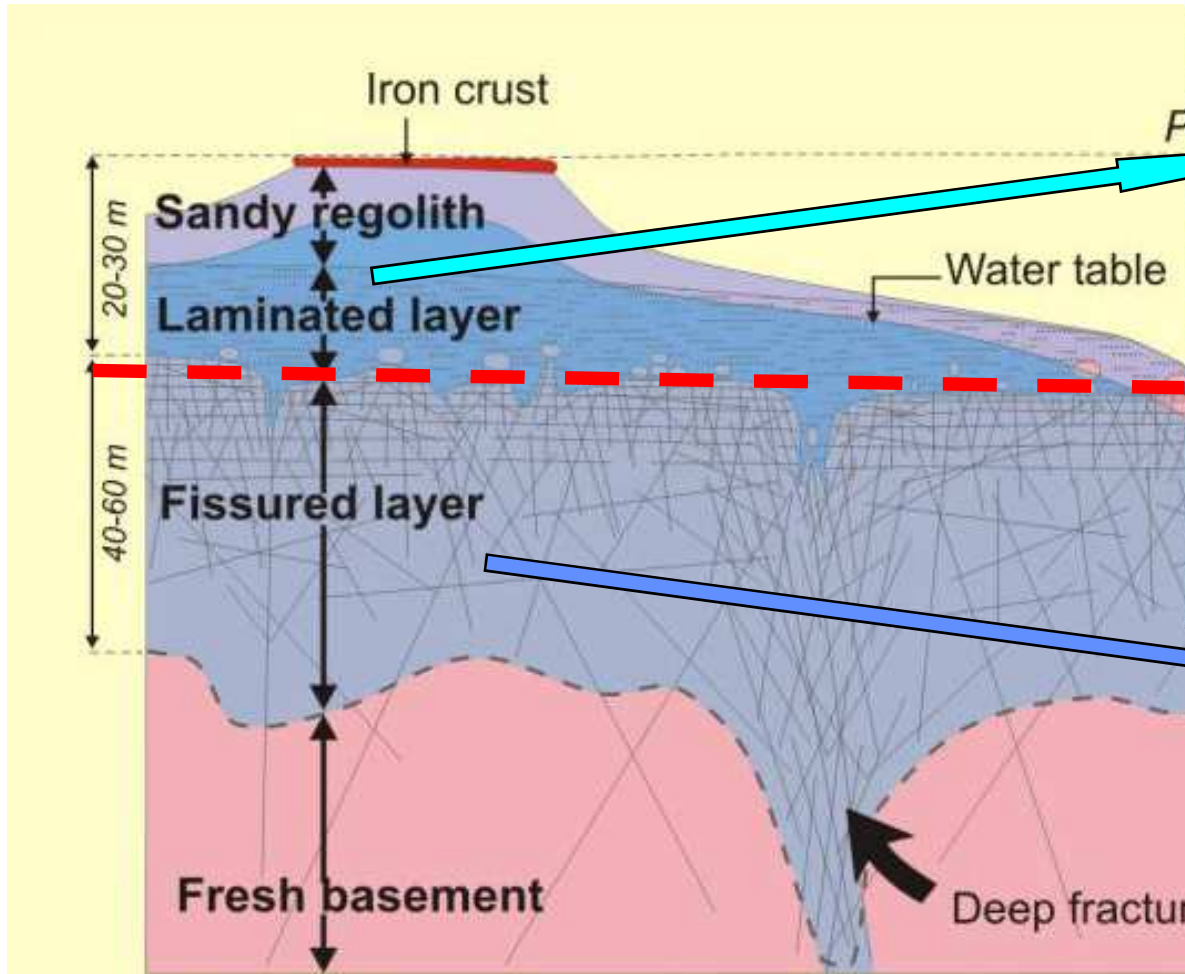
## 2. Structure of Hard Rock Aquifers (HRA)

### 2.1. The “classical” concept of “discontinuous aquifers”



## 2. Structure of Hard Rock Aquifers (HRA)

### 2.2. A new conceptual model demonstrated these last years



➤ Weathering profile:

The **weathered-fractured** horizon is belonging to the weathering profile



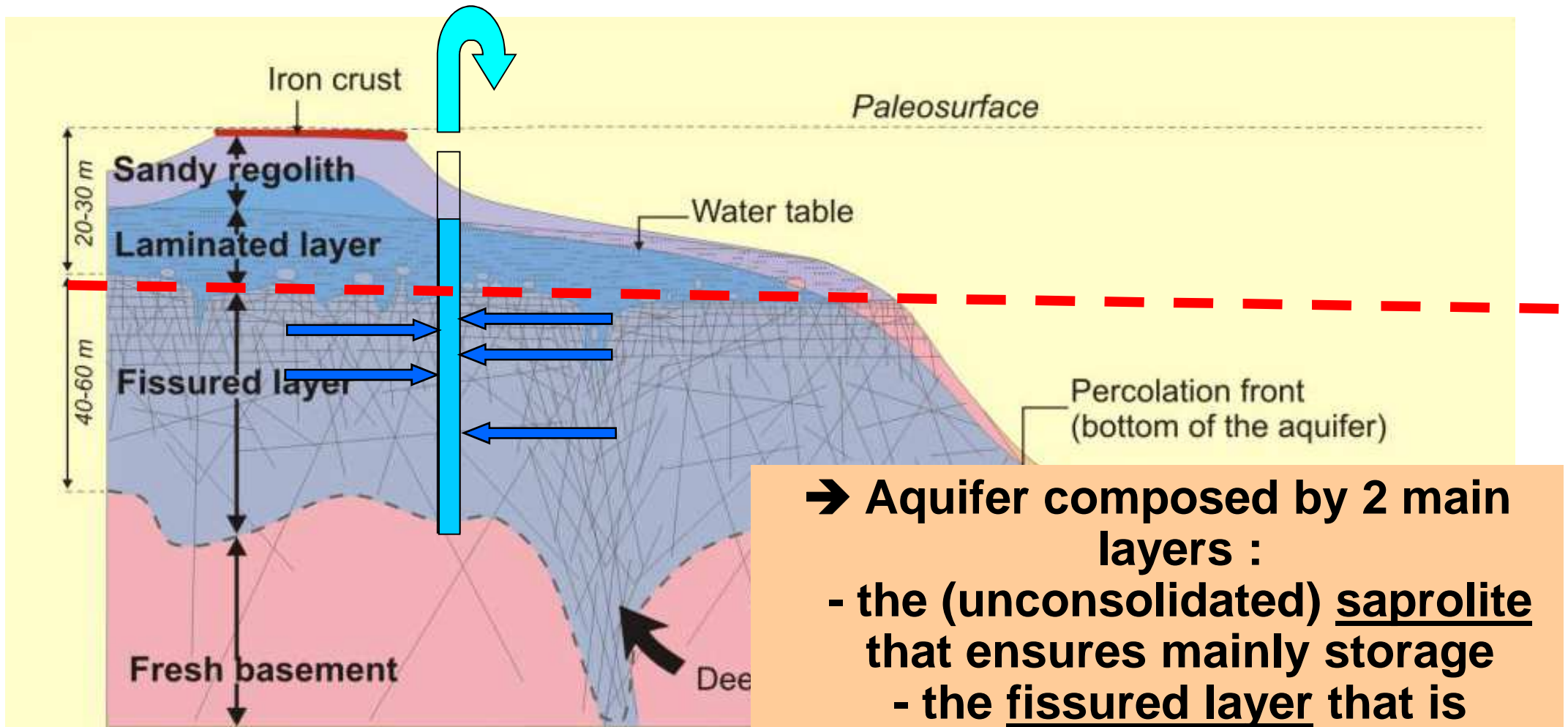
**Weathered-Fractured horizon**

See for instance: Lachassagne, Wyns , Dewandel, 2011 (Terra No

Aquifères de socle. La Roche, 11 jui

## 2. Structure of Hard Rock Aquifers (HRA)

2.2. A new conceptual model demonstrated these last years  
→ Hydrogeological consequences



See for instance: Lachassagne, Wyns , Dewandel, 2011

Aquifères de socle. La Rochelle

→ Aquifer composed by 2 main layers :

- the (unconsolidated) saprolite that ensures mainly storage
- the fissured layer that is permeable enough for water well sitting and also ensures storage

# 2. Structure of Hard Rock Aquifers (HRA)

Cho et al., 2003 – Proceedings Prag IAH Conference

Jeonju-Wanju area

## 2.3. How was it demonstrated?

Evidence with a data set from borewells in Korea (several hundred shallow to deep wells) gathered by KIGAM:

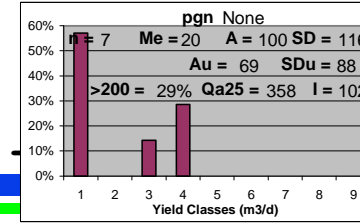
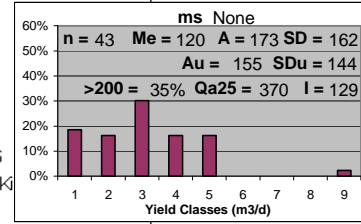
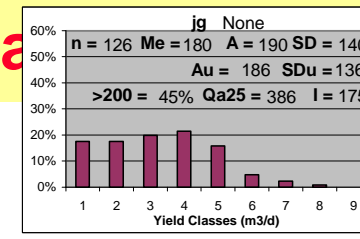
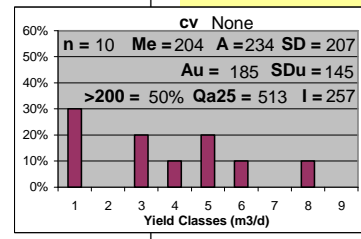
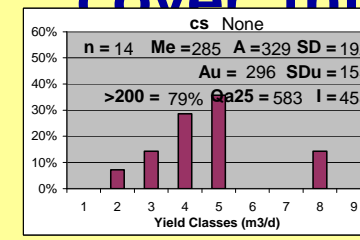
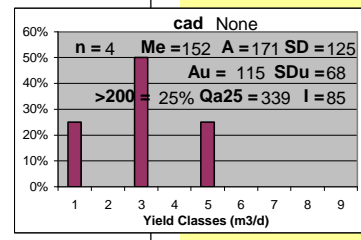
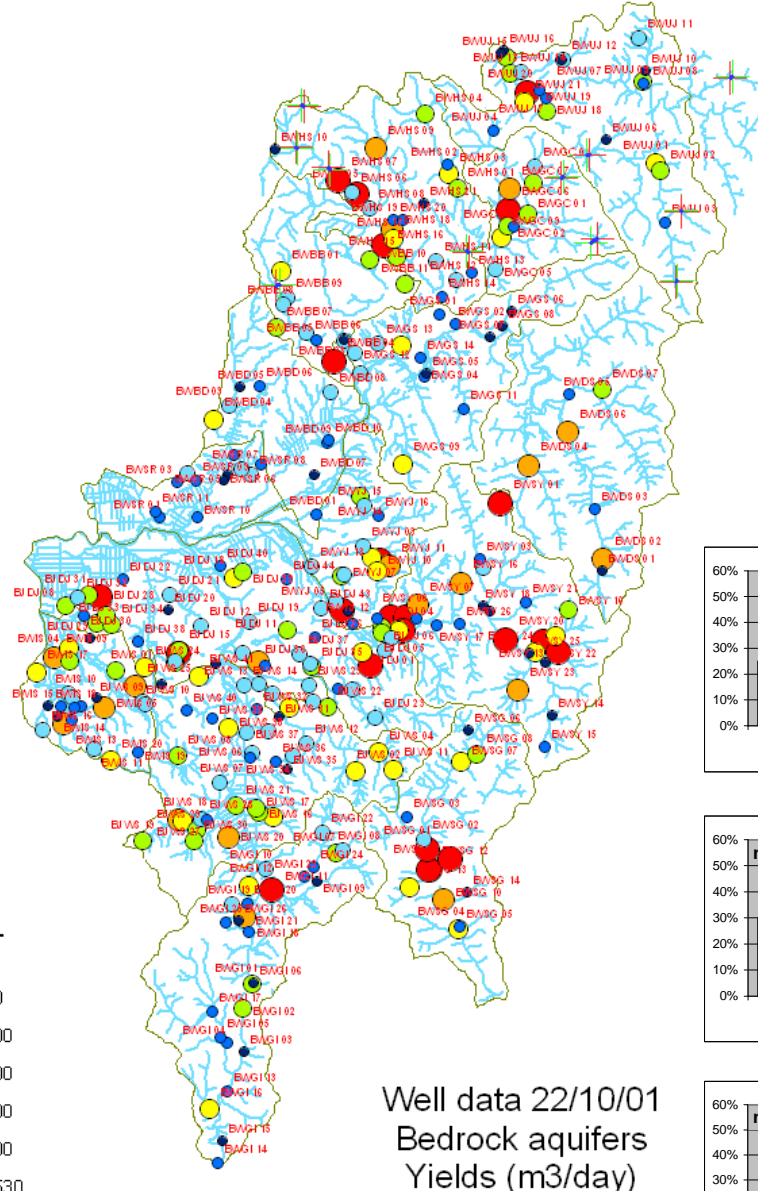
- lithology

- presence or not of a weathering

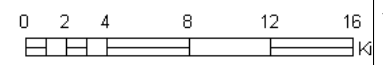
cover thickness,

well, d, etc.

chemical treatment



- Legend**
- YIELD\_M3\_
- 0 - 50
  - 51 - 100
  - 101 - 200
  - 201 - 300
  - 301 - 400
  - 401 - 500
  - 501 - 1530
  - wj\_drain
  - wj\_myen



chassagne

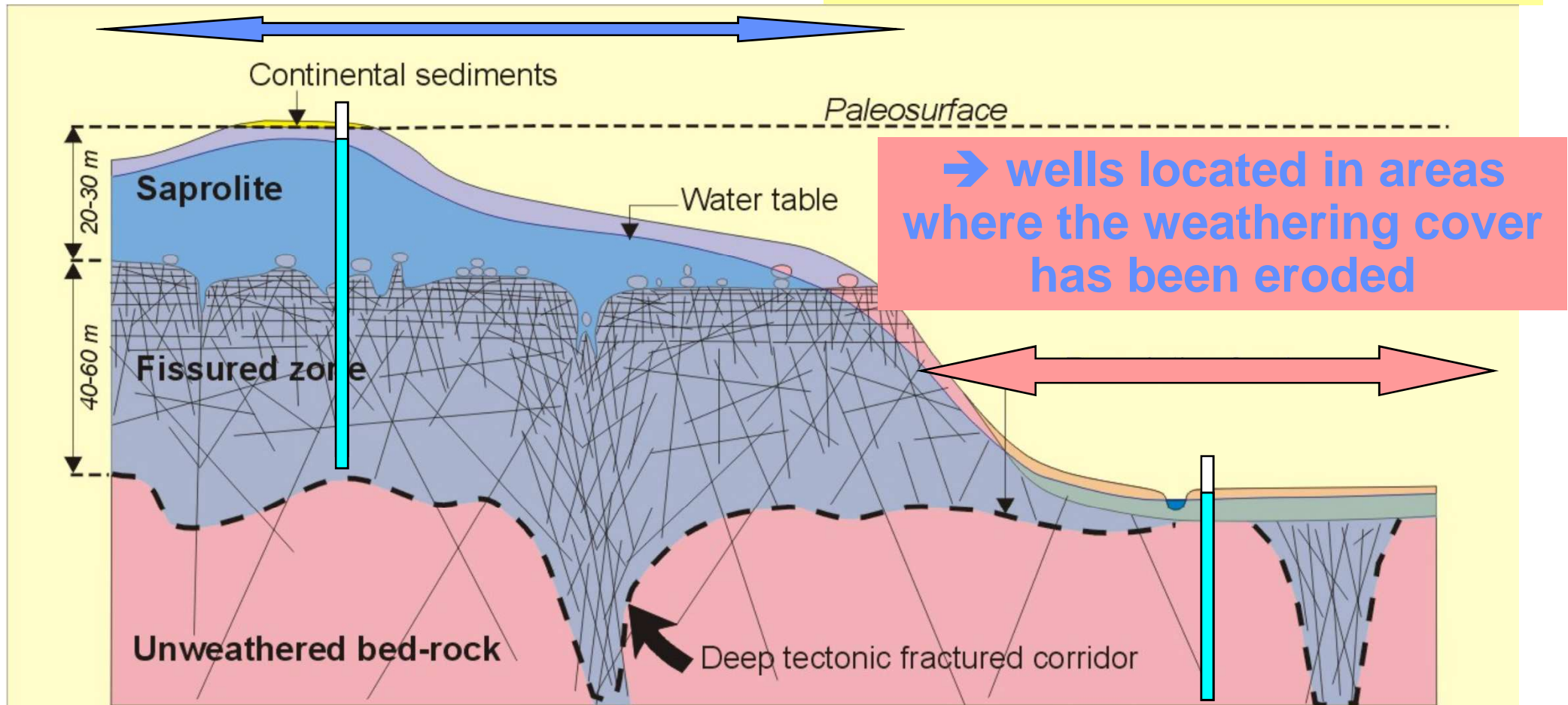


## 2. Structure of Hard Rock Aquifers (HRA)

### 2.3. How was it demonstrated ?

→ wells located in areas with a remaining weathering cover

→ 2 main samples of data were constituted, for the main different lithologies:



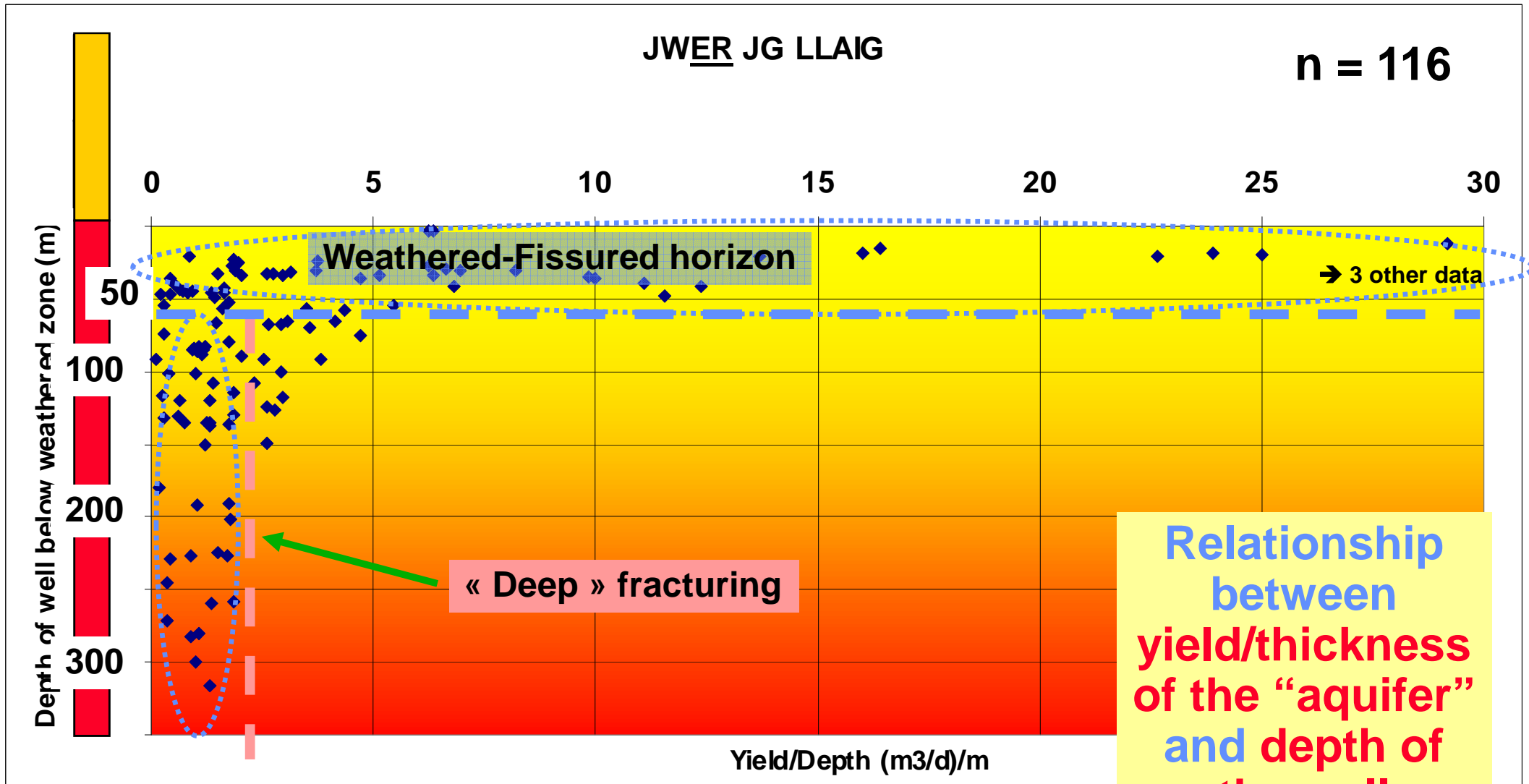
→ wells located in areas where the weathering cover has been eroded

Cho et al., 2003 – Proceedings Prag IAH Conference

Aquifères de socle. La Roche, 11 juin 2015 - P. Lachassagne *et al.*

# Ex: Granite :

## Wells located in areas with a remaining weathering cover

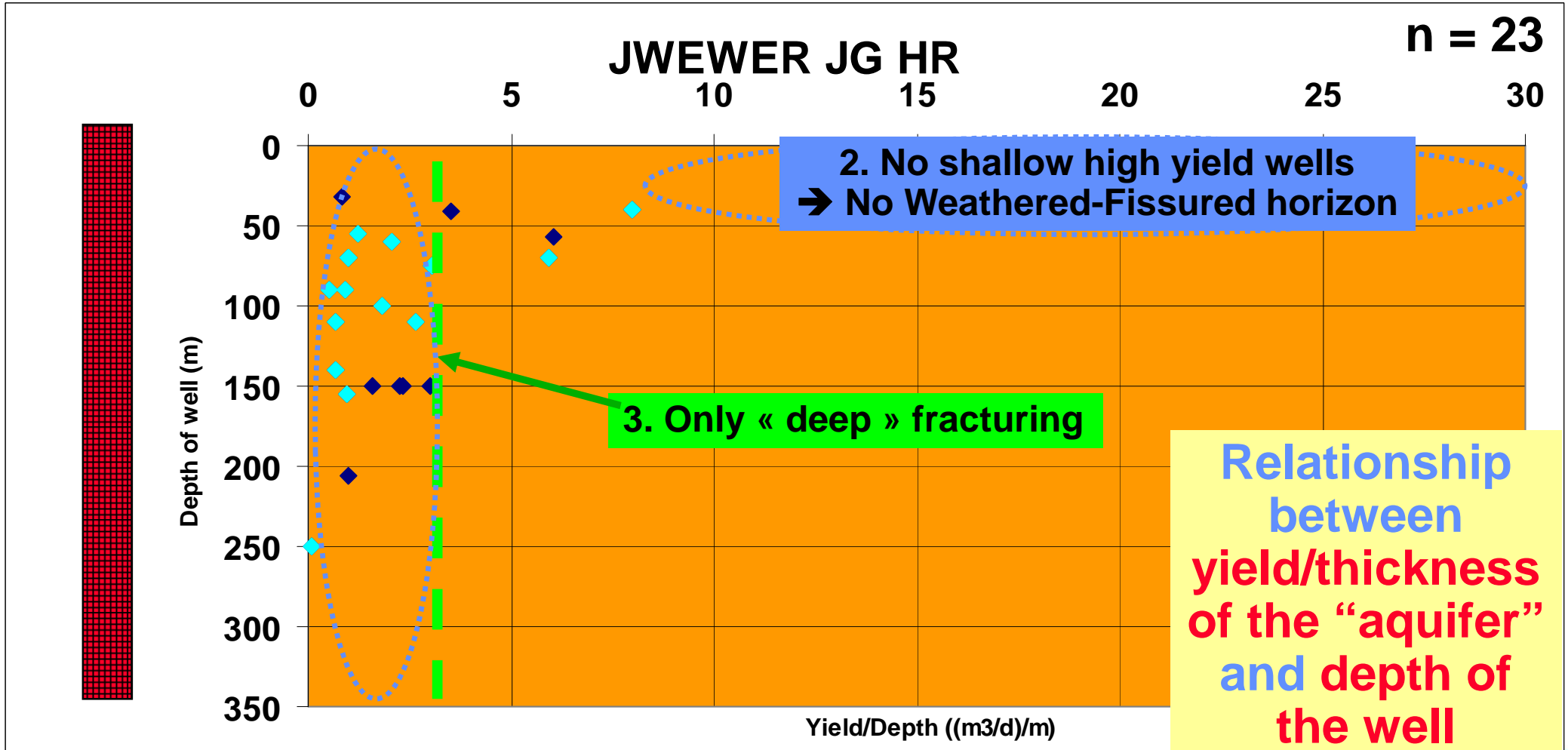


Relationship between yield/thickness of the "aquifer" and depth of the well

Cho et al., 2003 – Proceedings Prag IAH Conference

# Ex: Granite - Wells located in areas where the weathering cover has been eroded

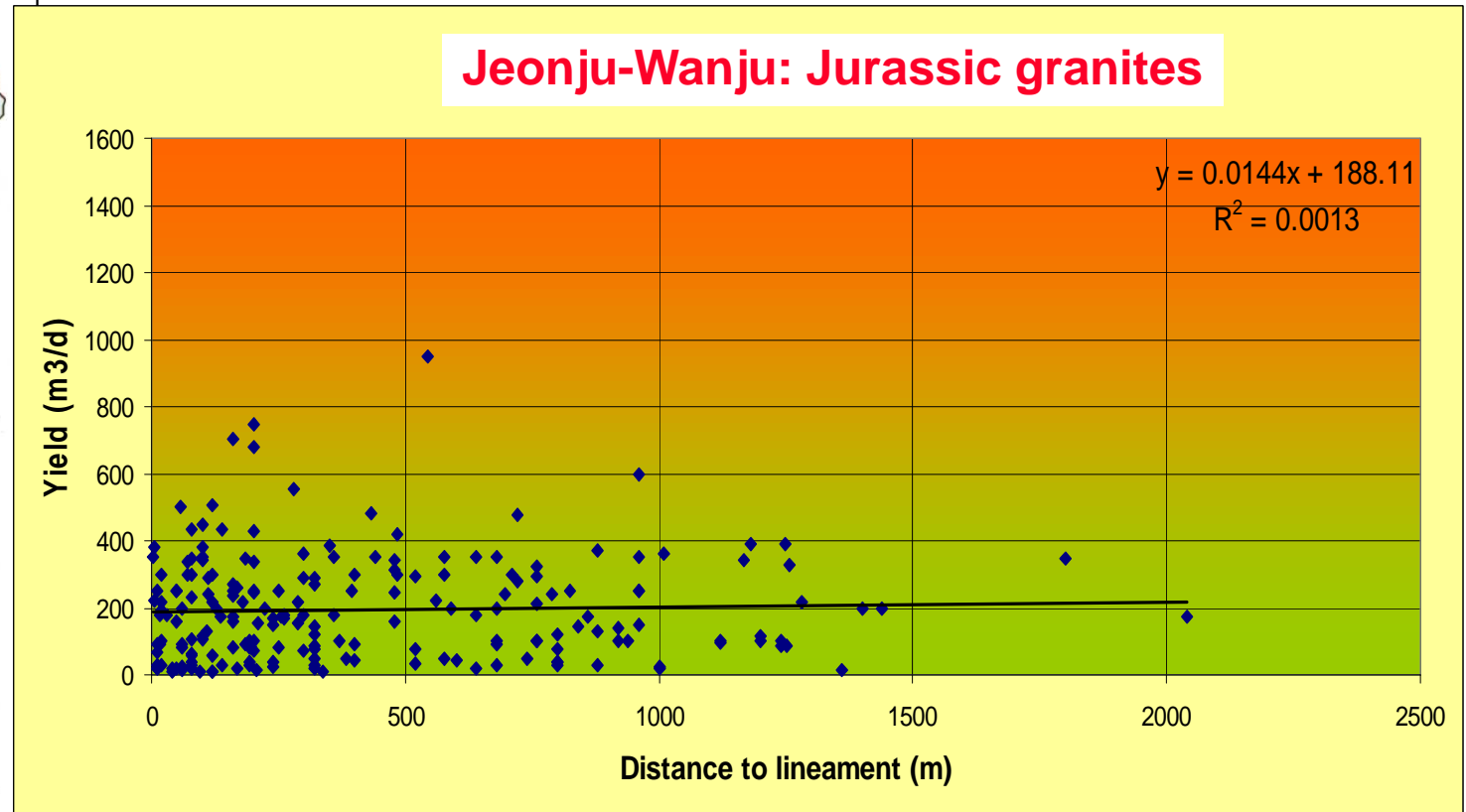
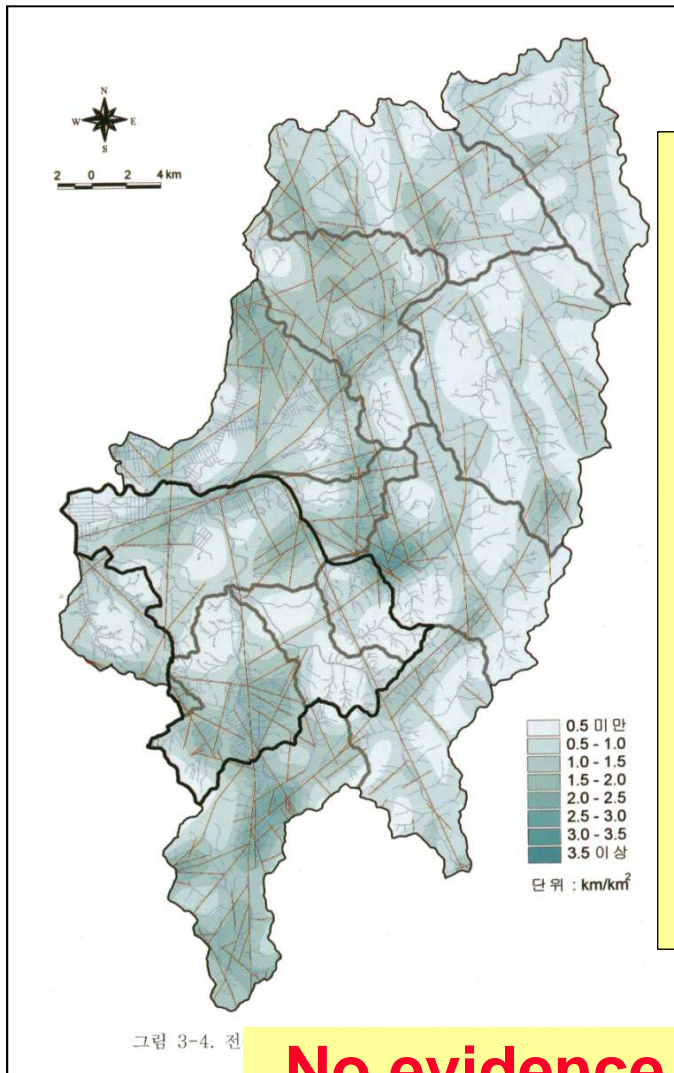
1. Low number of well and low number of shallow wells



Cho et al., 2003 – Proceedings Prag IAH Conference

Aquifères de socle. La Roche, 11 juin 2015 - P. Lachassagne *et al.*

# Role of the tectonic fracturing ?



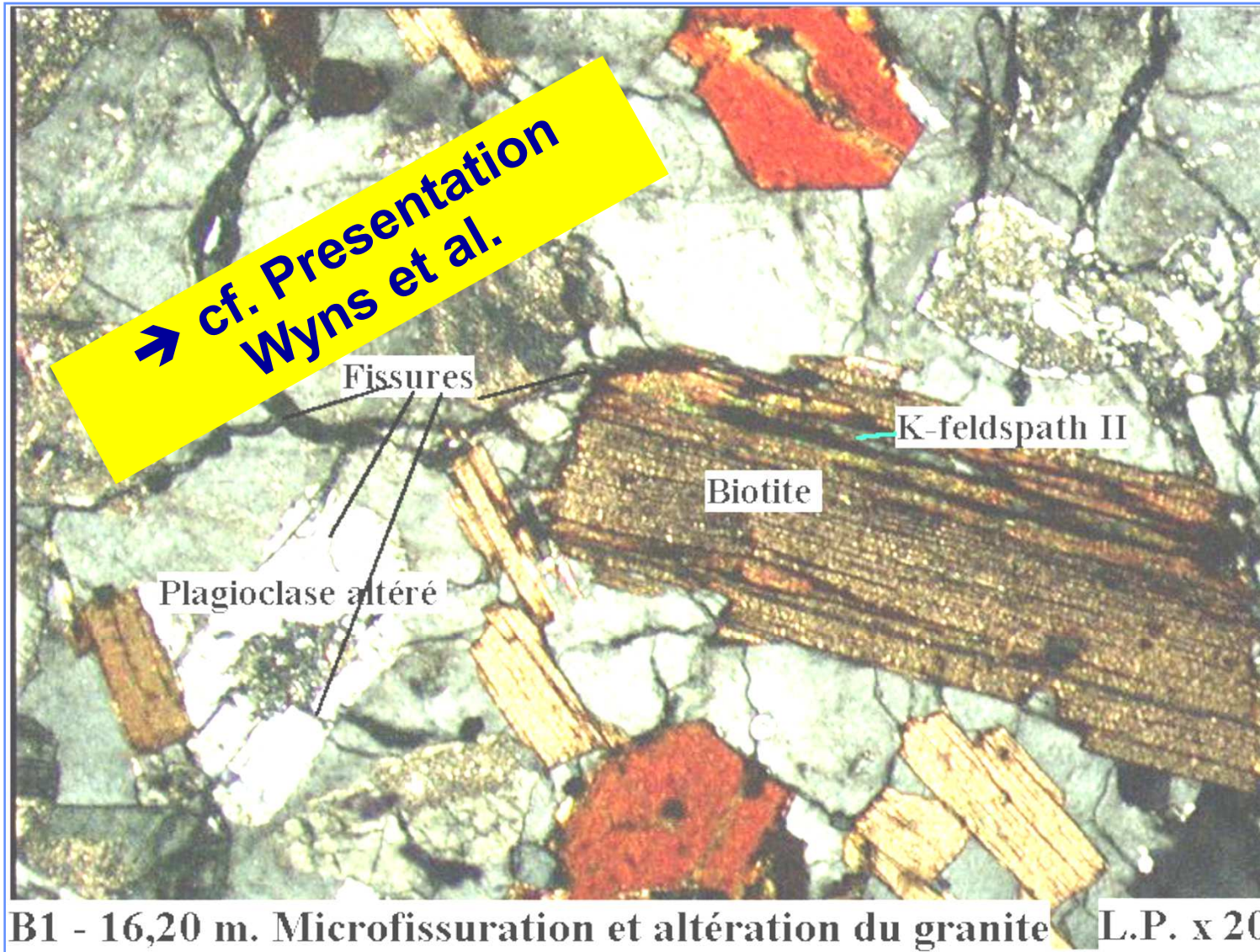
**No evidence of a relationship between well yields and distance to lineaments**

Cho et al., 2003 – Proceedings Prag IAH Conference

Aquifères de socle. La Roche, 11 juin 2015 - P. Lachassagne *et al.*

## 2. Structure of Hard Rock Aquifers (HRA)

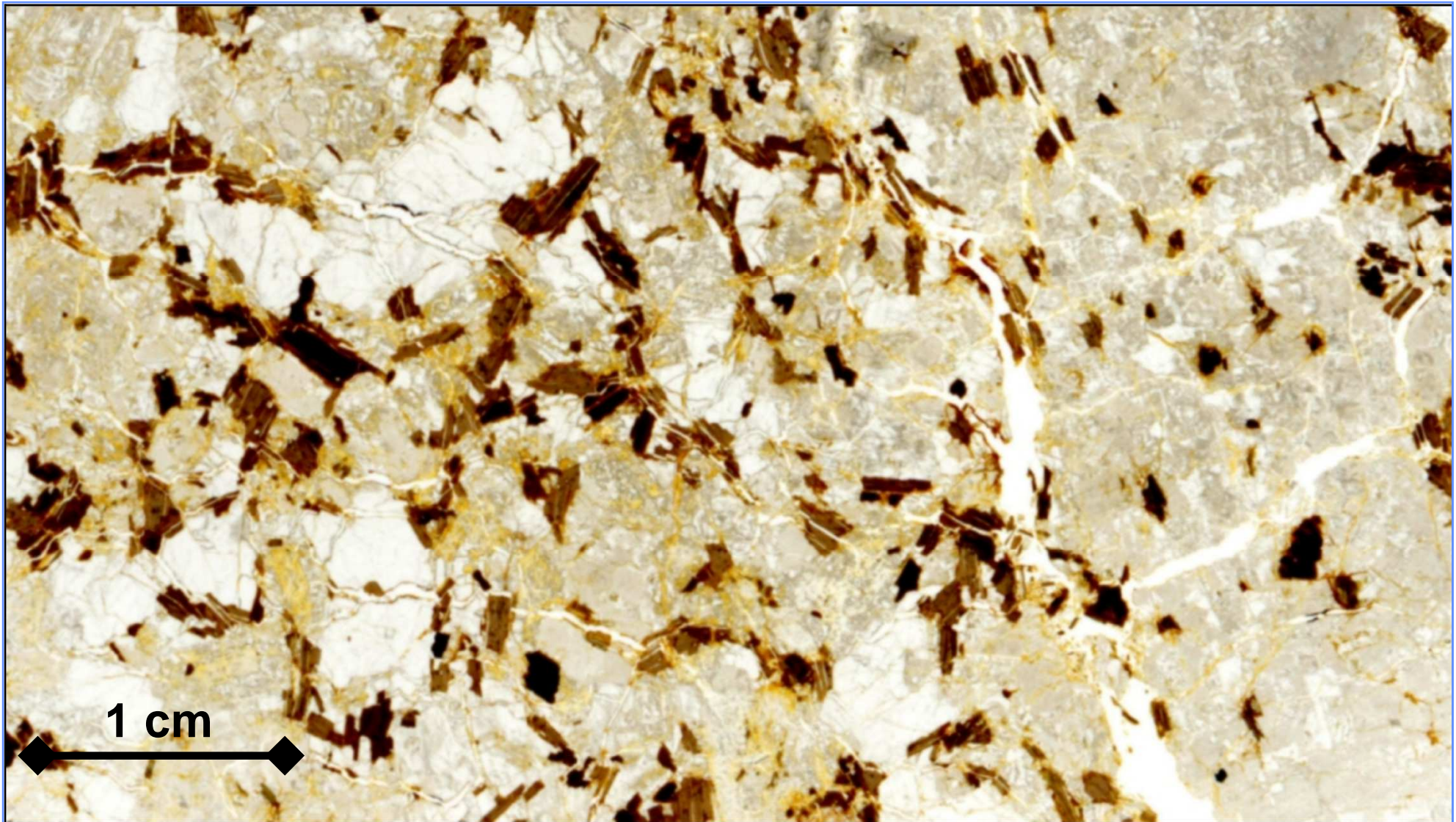
### 2.4. Mechanism of weathering-induced fracturation



#### 1. Mineral scale

In early stage of weathering, interaction between water and rock induces biotite's swelling

**This swelling generates stresses that cause the breaking-up of the host rock**



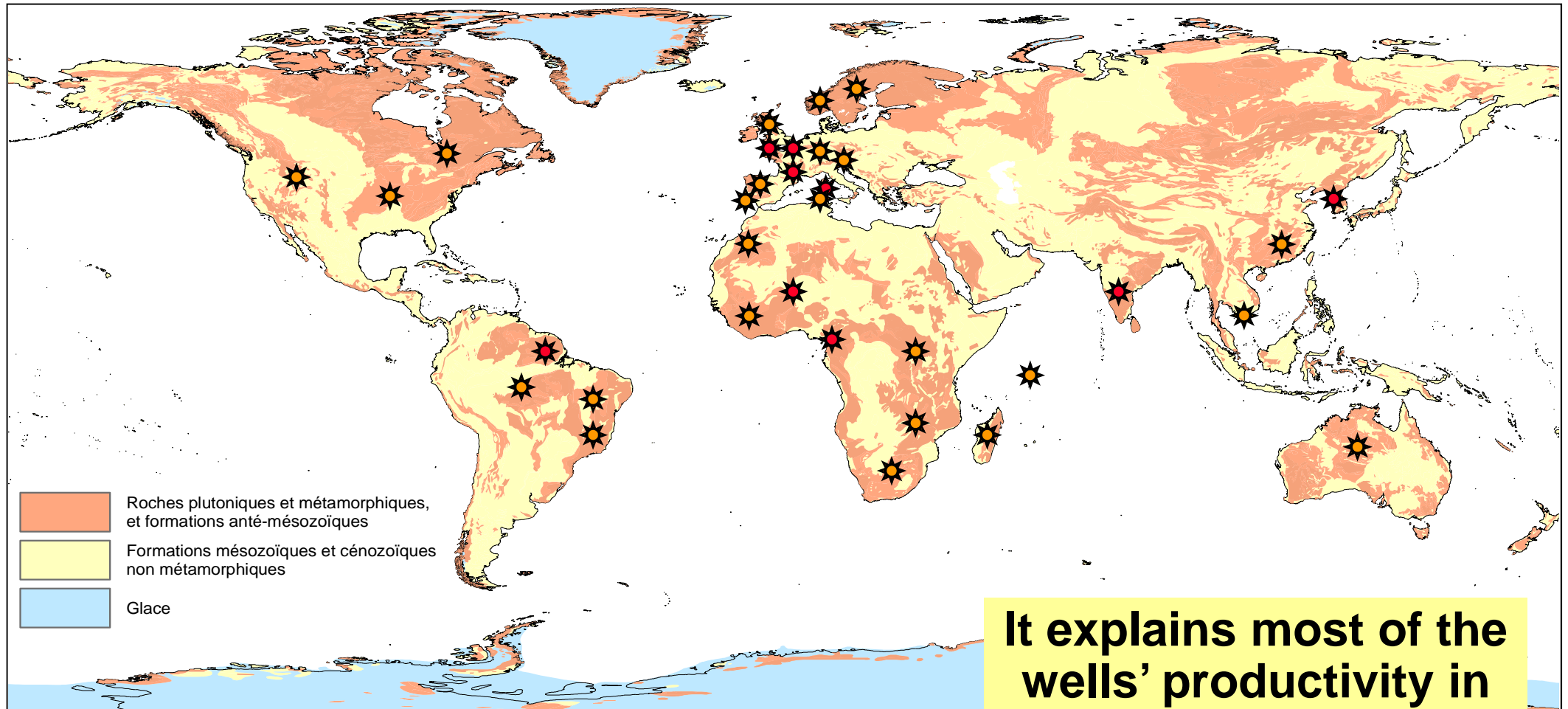
**This swelling generates stresses that cause the breaking-up of the host rock, with mostly horizontal fractures (in granite) perpendicular to the less stress**



**the fractures  
towards the top**

# This process has been observed or described world-wide

- ★ Our case studies
- ★ Some evidences from the literature



**It explains most of the wells' productivity in HR, all over the world. 0,5 --> 3 - 5 +... m<sup>3</sup>/h**



### 3. Mapping the weathering profiles

1. Weathering is not recent  
("Quaternary")

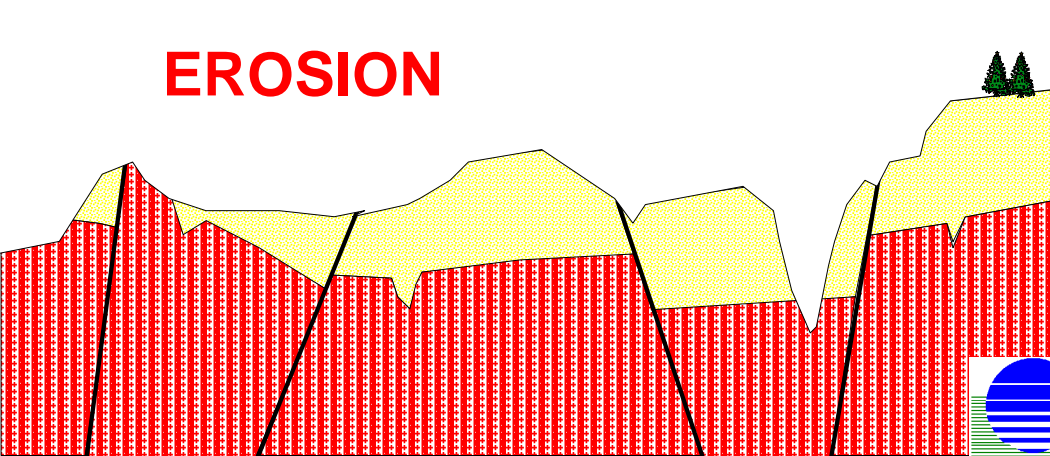
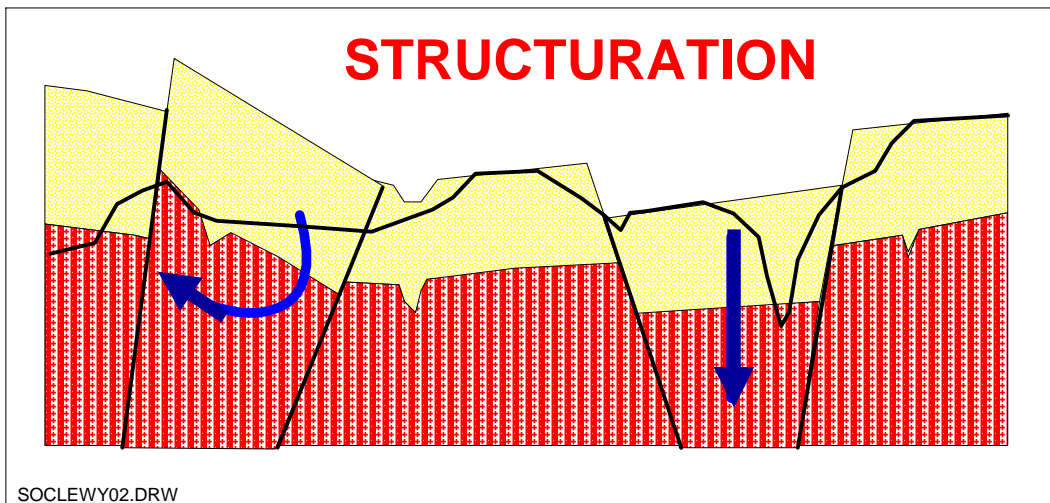
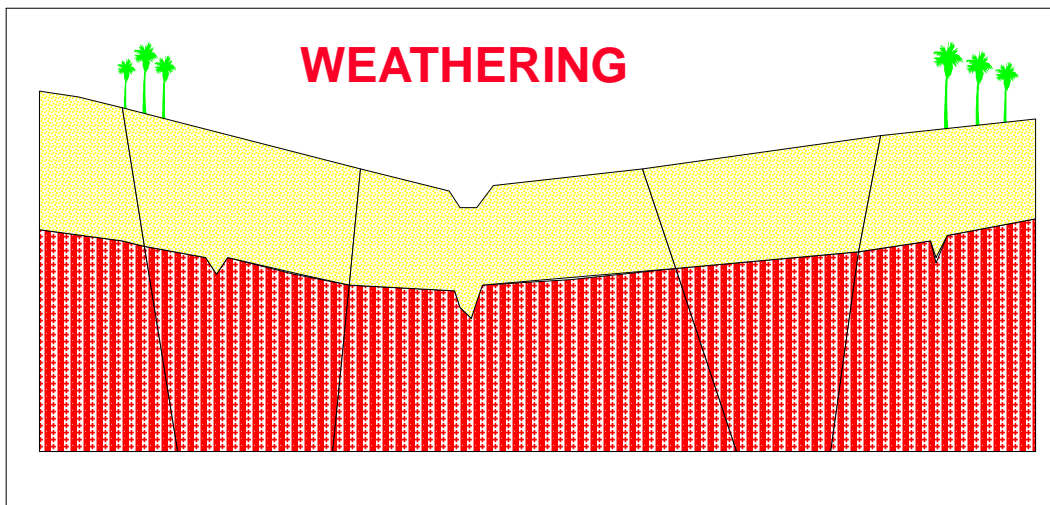
Oligocene  
sediments



Grus (sandy  
regolith)

Lozère – French Massif Central

### 3. Mapping the weathering profile

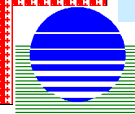


SOCLEWY02.DRW

## Principles of evolution

- ✓ water
- ✓ time: >10 Million years
- ✓ weathering rate > erosion (slopes)
- ✓ temperature (speed)

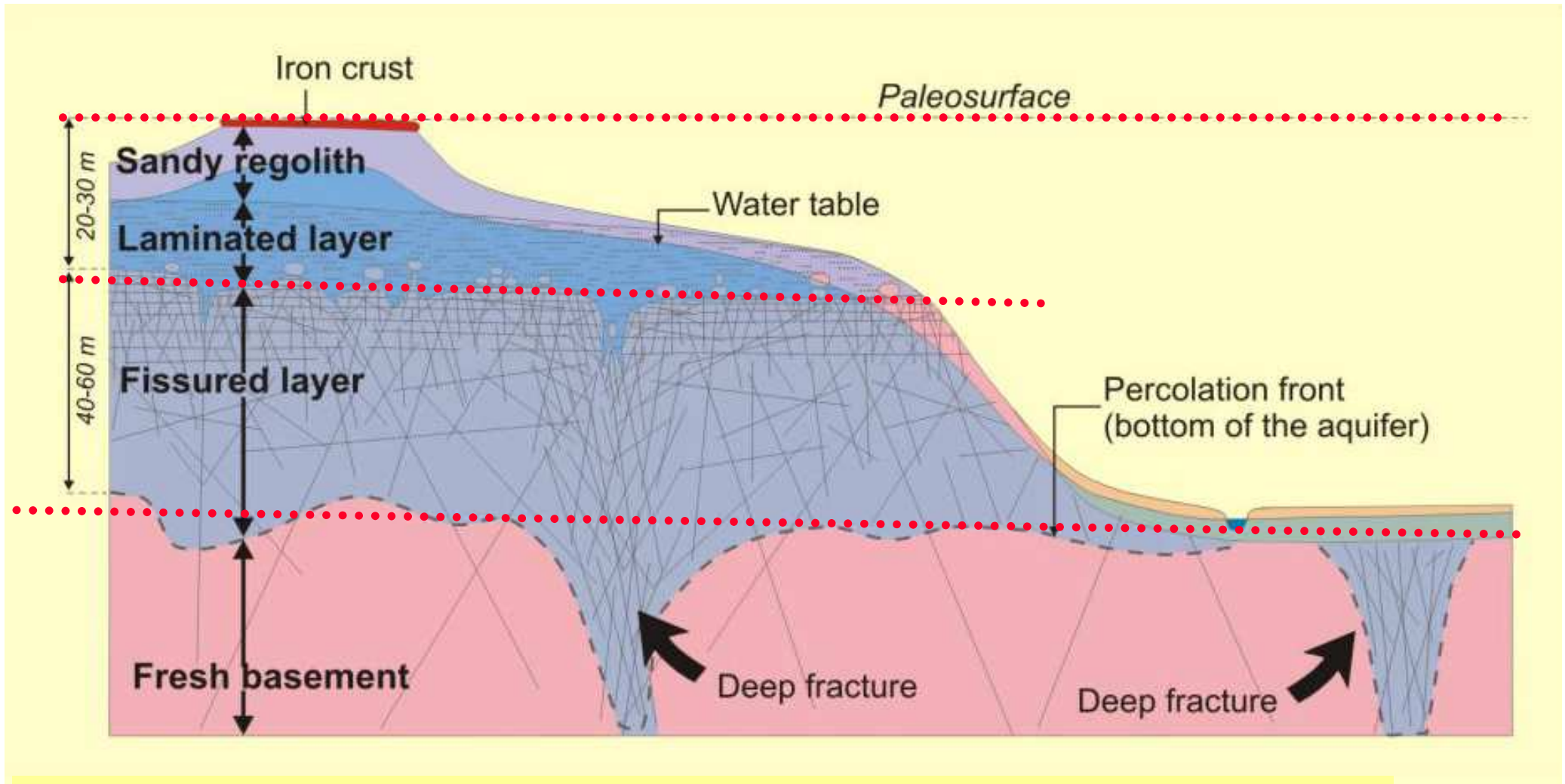
## Present day structure



in 2015 - P. Lachassagne *et al.*

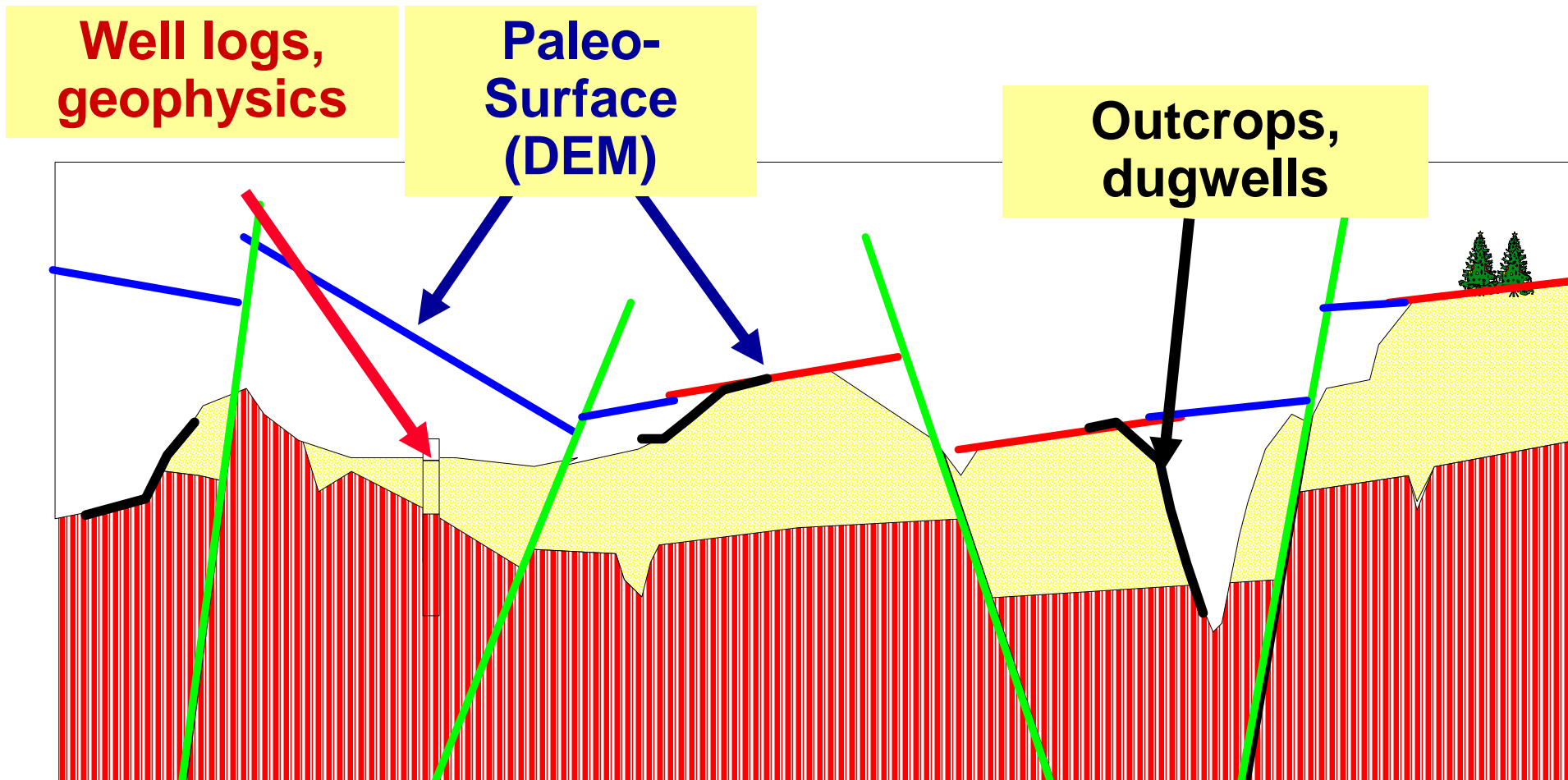
**edw**  
evian volvic world

### 3. Mapping the weathering profile Geometry of the weathering profiles



Ancient weathering → Paleo-surfaces  
Subsequent erosion  
→ mapping of the weathering profiles/horizons

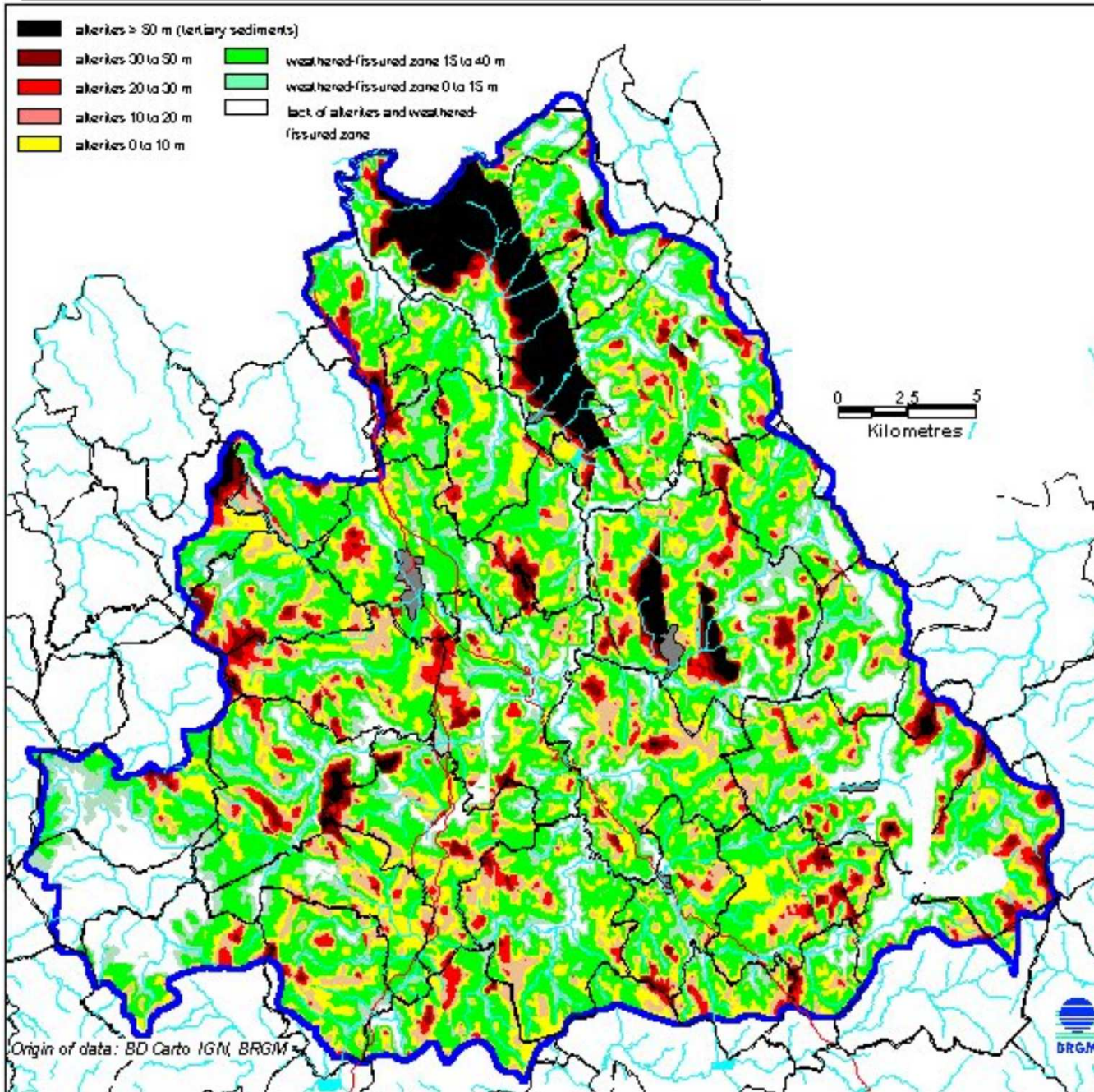
### 3. Mapping the weathering profile Reconstruction of the paleosurfaces



### 3. Mapping the weathering profile

## Example : Truyère river watershed (France)

Lachassagne, Wyls et al., 2001 – Ground Water



700 km<sup>2</sup>

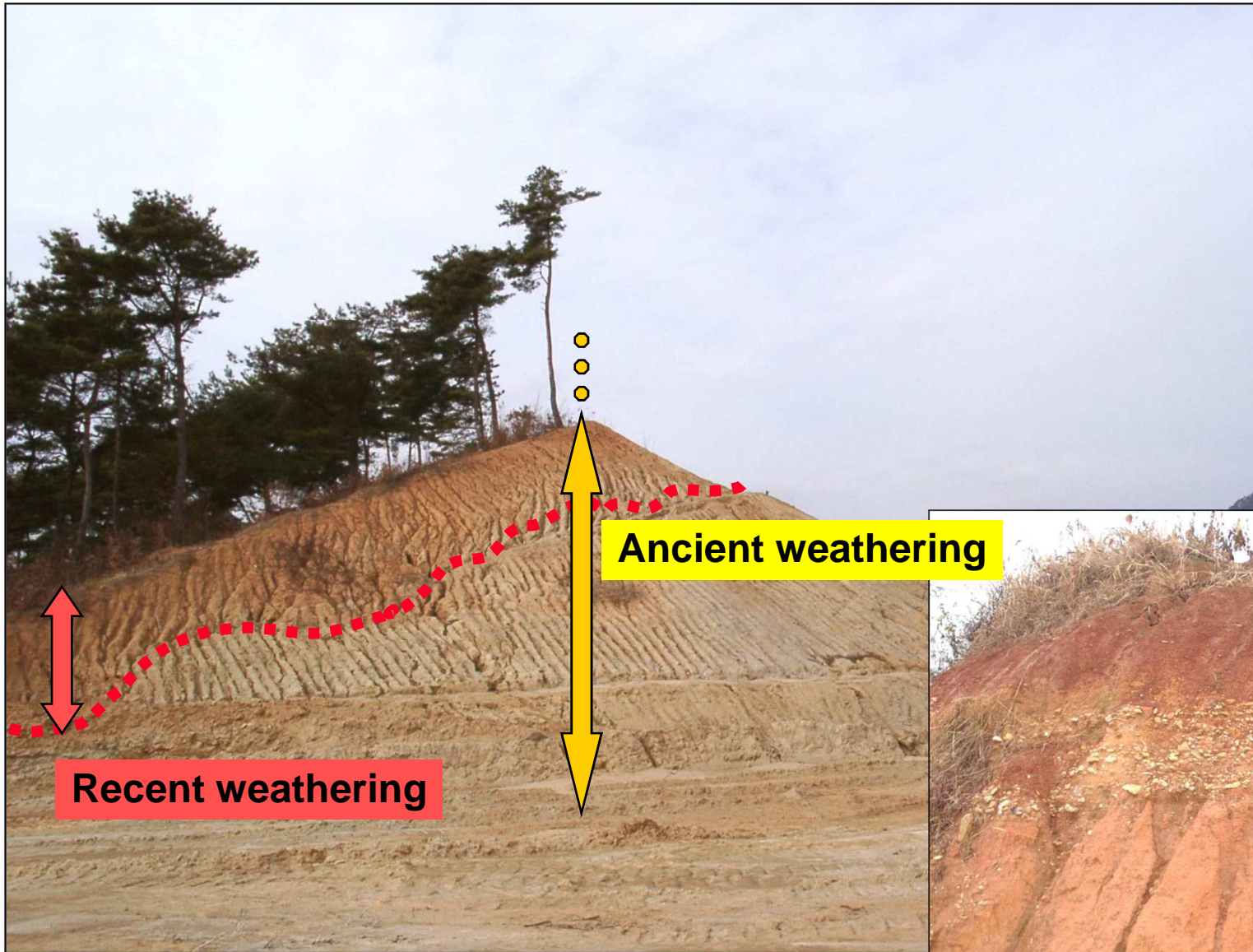
Residual thickness  
of the **saprolite** and  
of the **weathered-  
fissured layer**

P. Lachassagne *et al.*

**euw**  
evian volvic world

### 3. Mapping the weathering profile Multiphase weathering

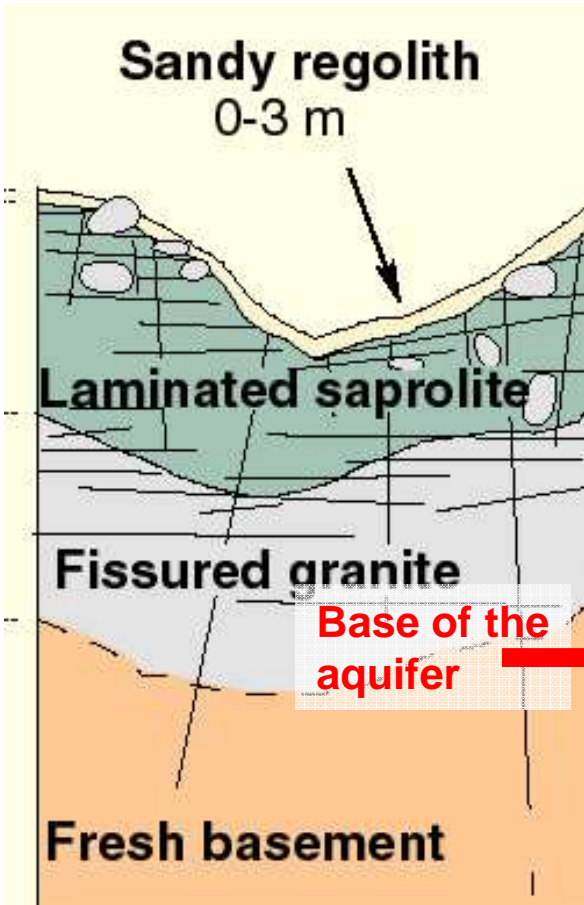
Korea; 2  
main  
weathering  
phases, the  
most  
important  
one being  
ancient



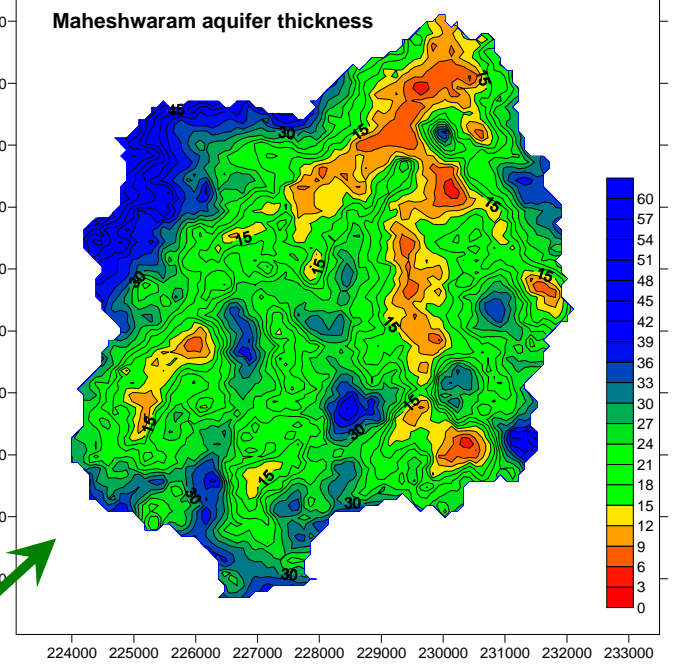
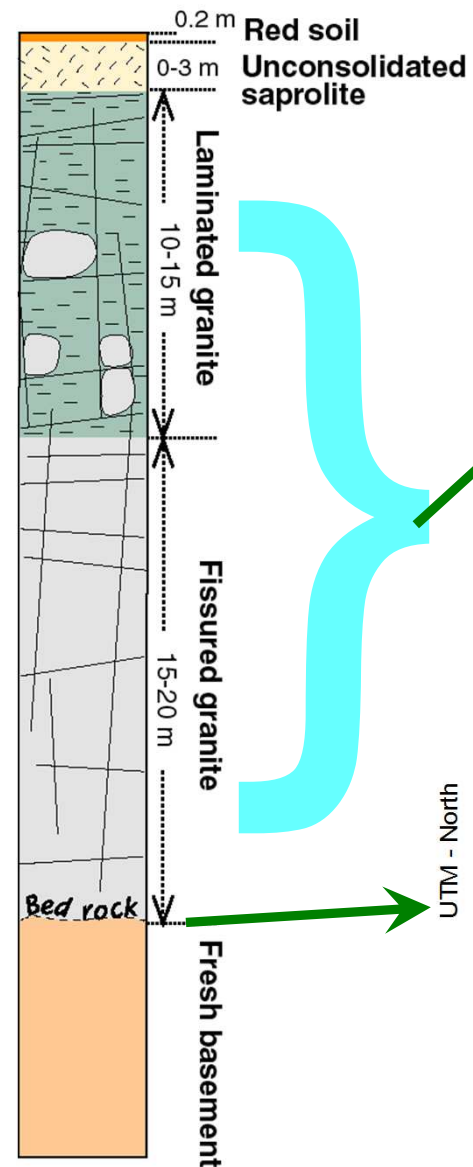
# 4. Hydrogeological mapping **constitu**

Total aquifer thickness

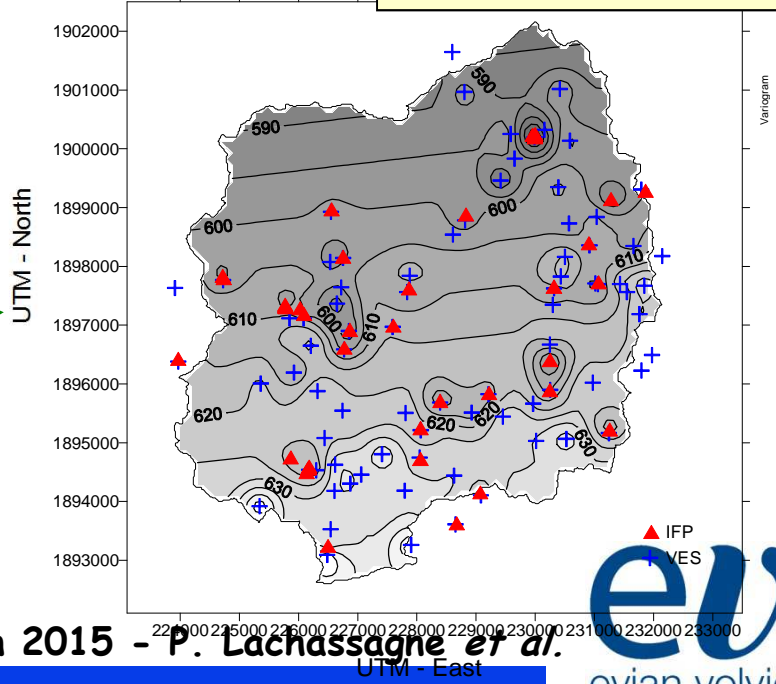
Dewandel, Lachassagne et al., 2006 – JoHydro. - South India



**Base of the aquifer**



**Bottom of the aquifer (mamsl)**



# 4. Hydrodynamic conceptual model of the weathered-fissured layer

1. Many Hor. and less Vert. Fractures:  
 $K_h = 10 K_v$

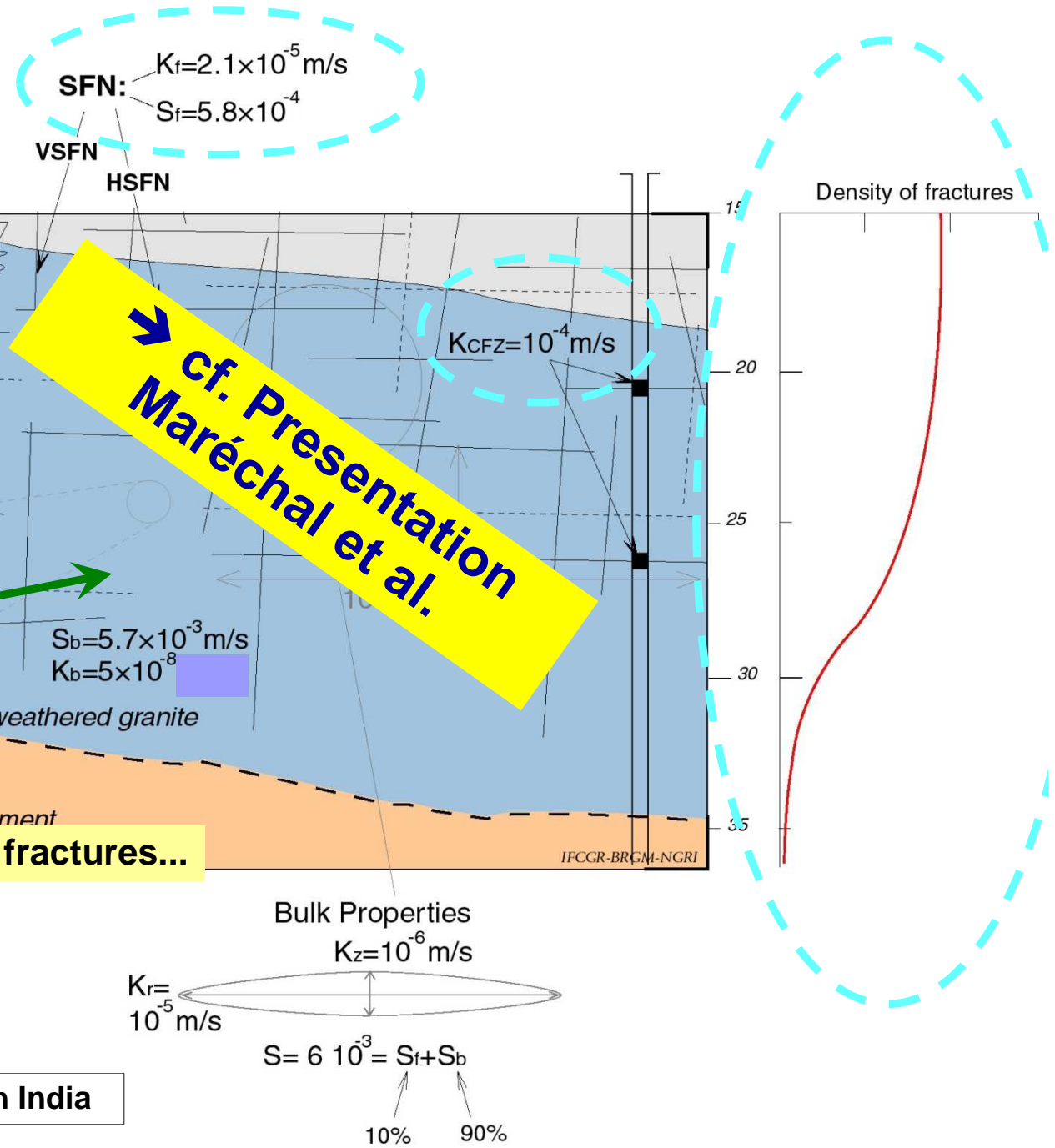
2. Decreasing with depth  
 distribution of permeable fract.

3. No highly conductive  
 fracture, but number  
 of fractures  
 → Transmissivity



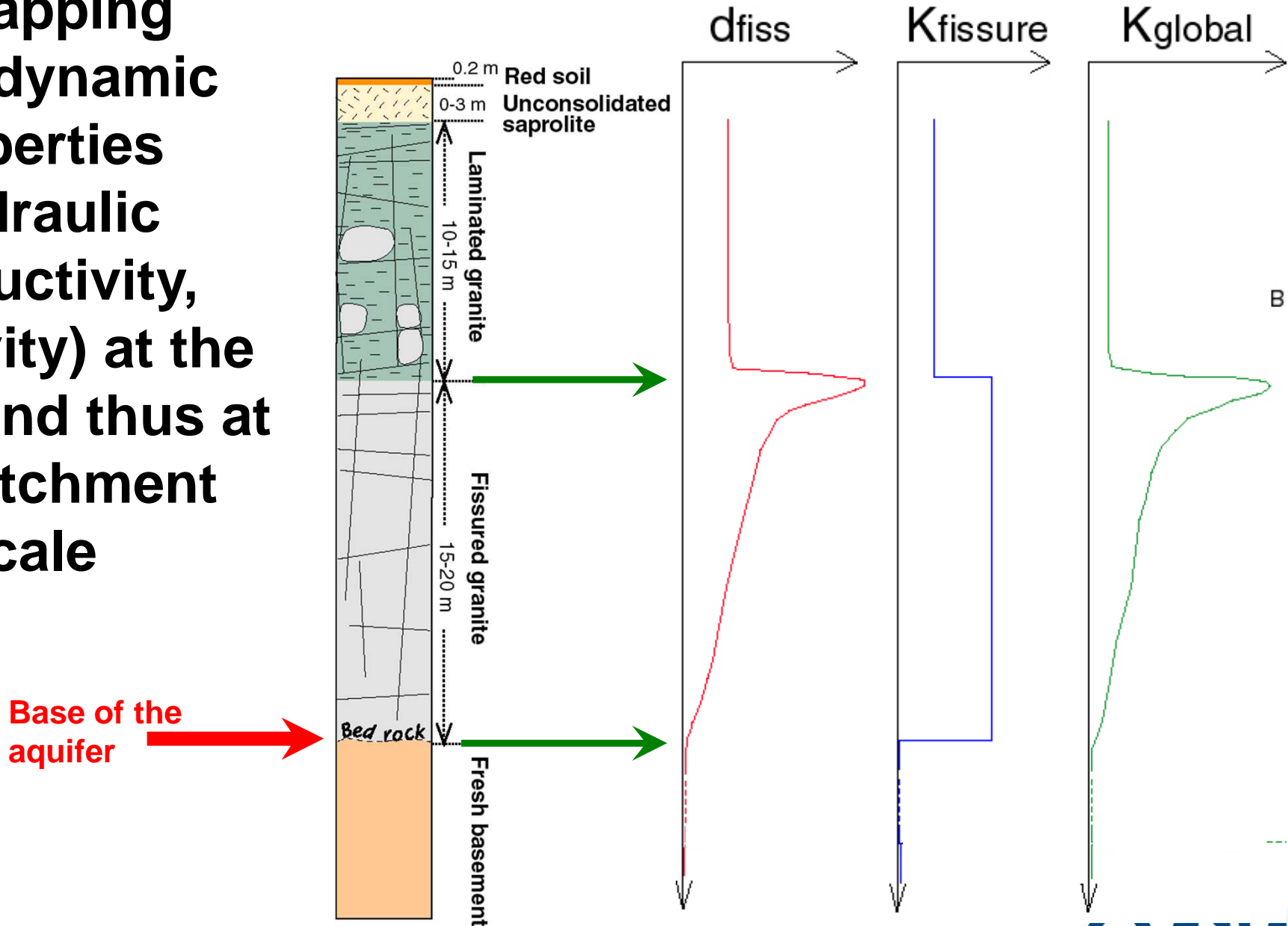
Origin: weathering

4. Additional data: porosity, extension of fractures...





# 4. Mapping hydrodynamic properties (hydraulic conductivity, storativity) at the profile and thus at the catchment scale

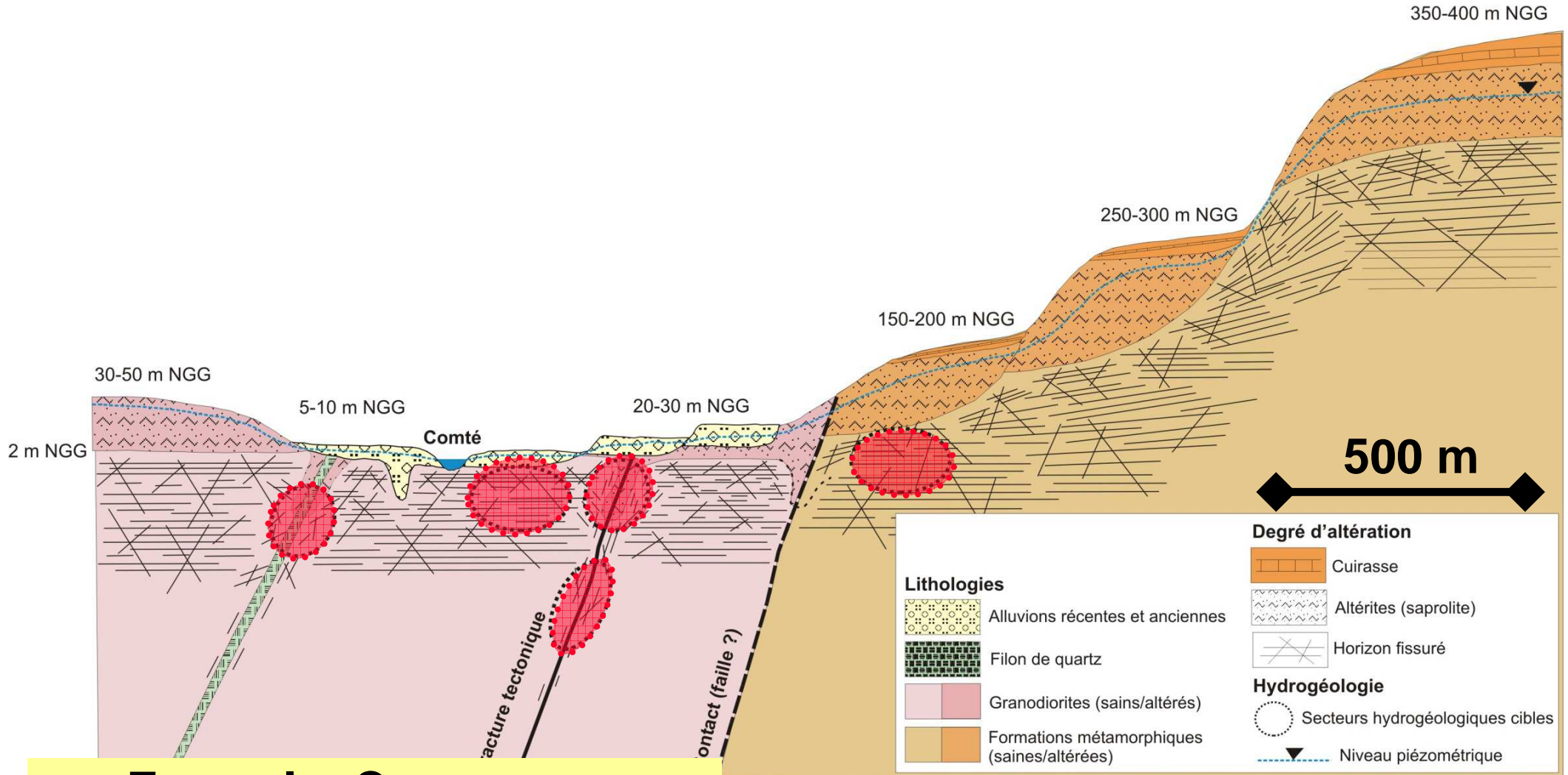


# 5. Applications at various scales

## Mapping groundwater potentialities at local scale

Ouest

Est

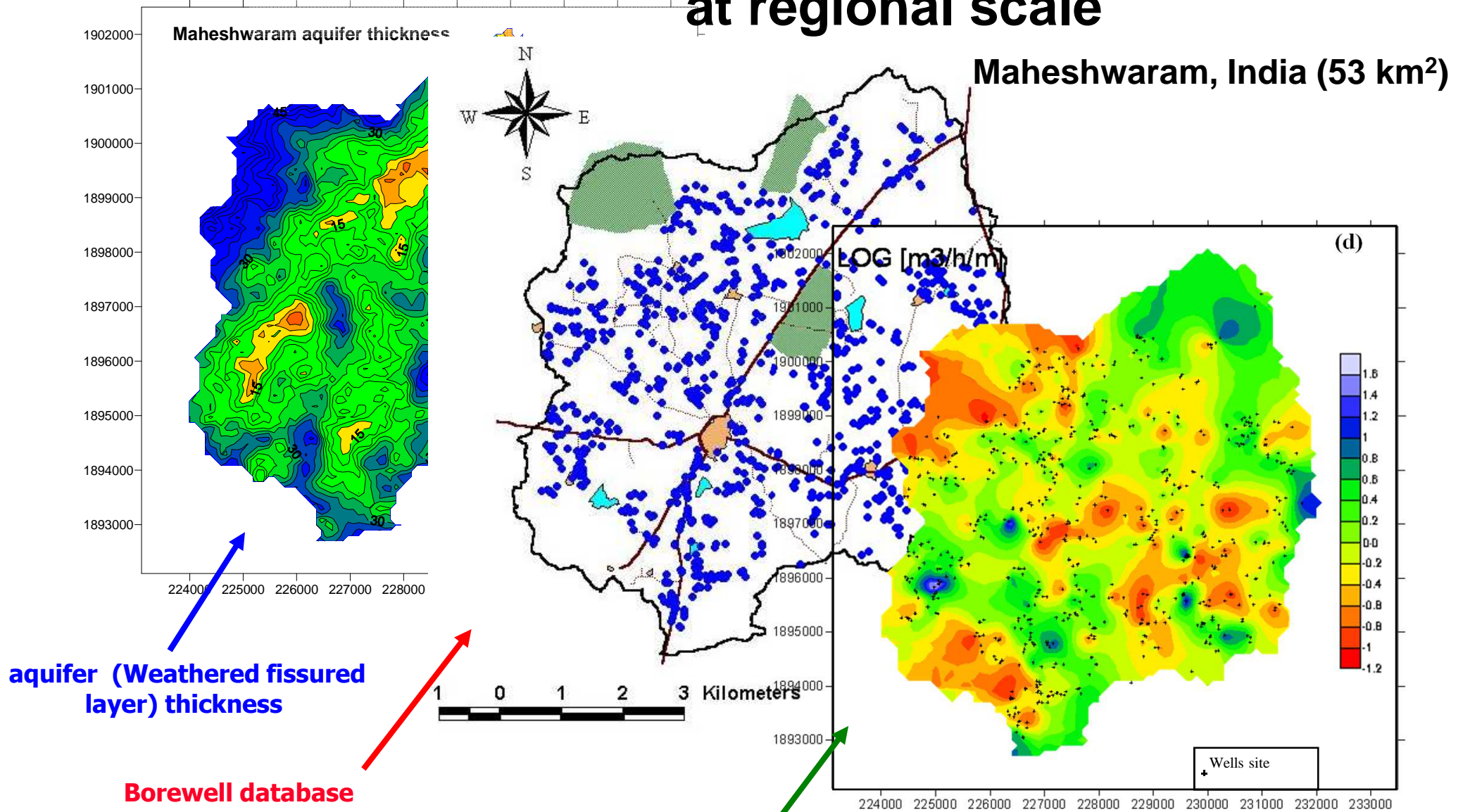


**Example: Cacao area,  
French Guyana**

che, 11 juin 2015 - P. Lachassagne *et al.*

# 5. Applications at various scales

## Mapping groundwater potentialities at regional scale



**aquifer (Weathered fissured layer) thickness**

**Borewell database**

**Aquifer productivity map**

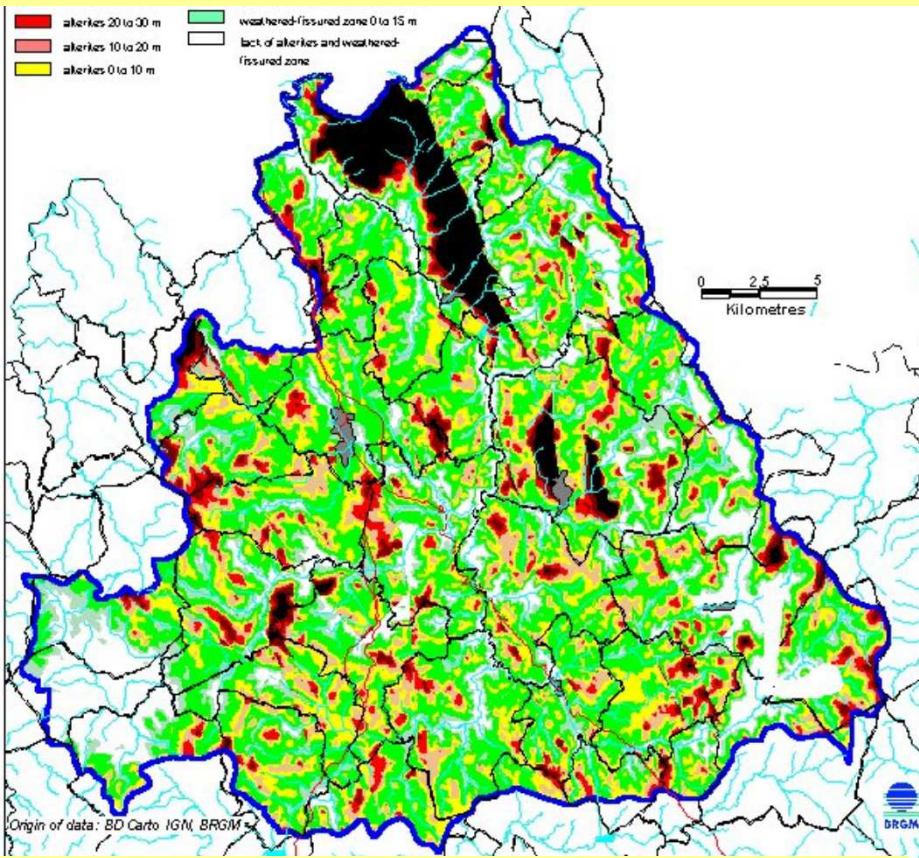
Aquifères de socle. La Roche, 11 juin 2015 - P. Lachassagne *et al.*

# 5. Applications at various scales

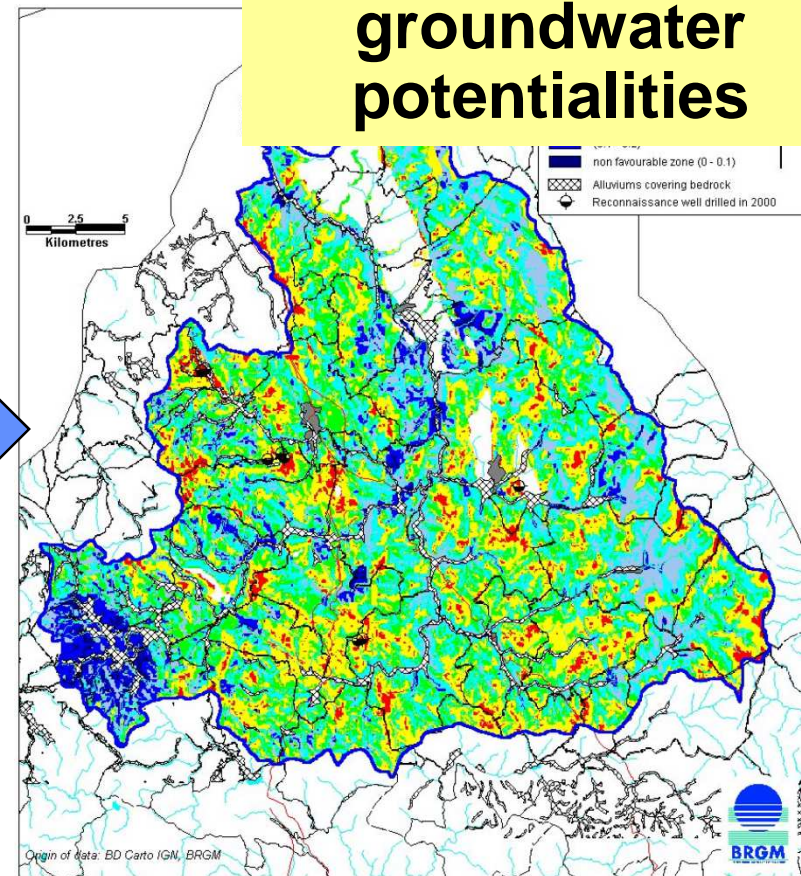
## Mapping groundwater potentialities at regional scale

Lachassagne, Wyns et al., 2001 – Ground Water

From the mapping of the residual thickness of the **saprolite** and the **weathered-fractured horizon**



Multicriteria analysis: map of groundwater potentialities

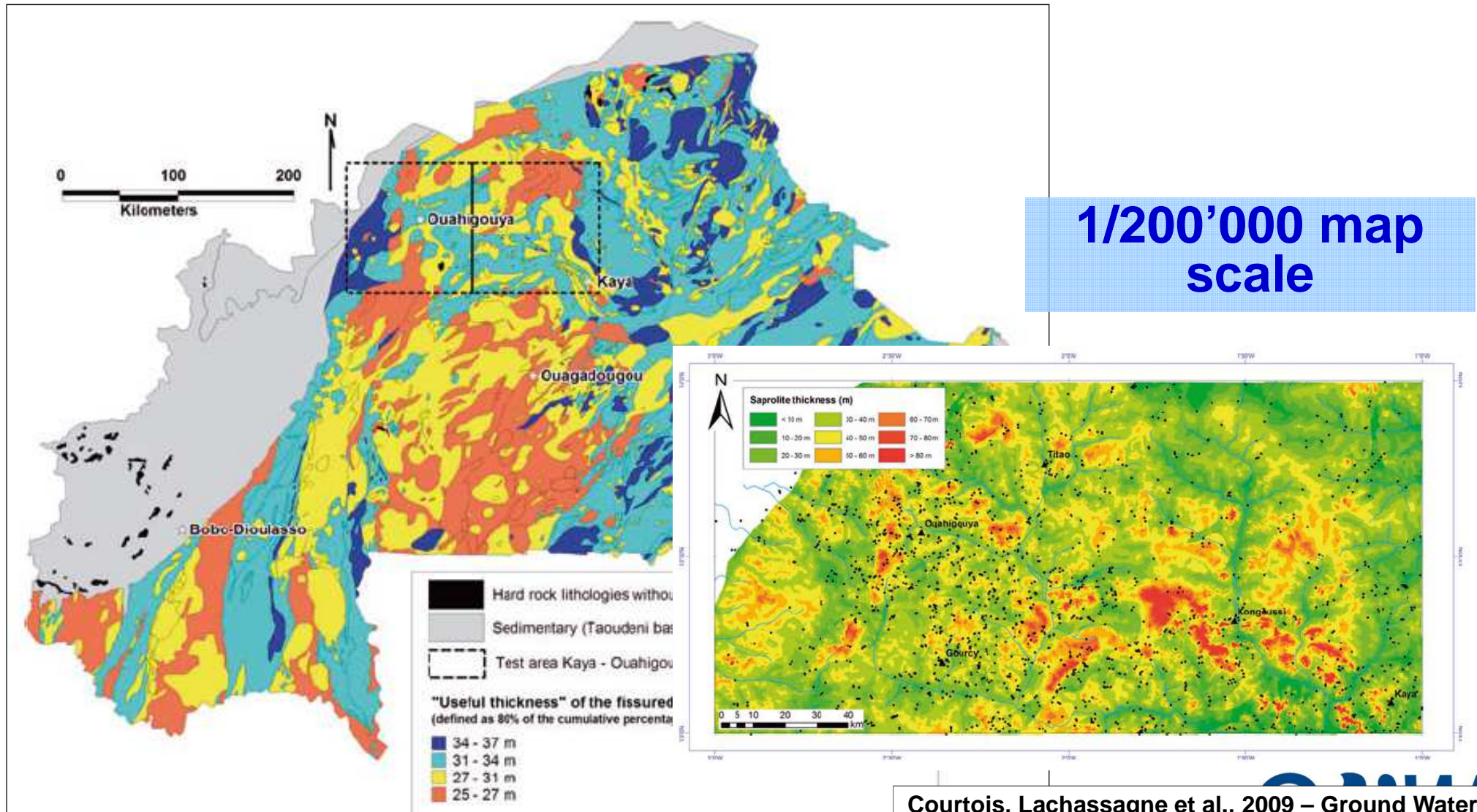


Example: Lozère, Margeride granite, 700 km<sup>2</sup>

# 5. Applications at various scales

## Mapping groundwater potentialities at country scale

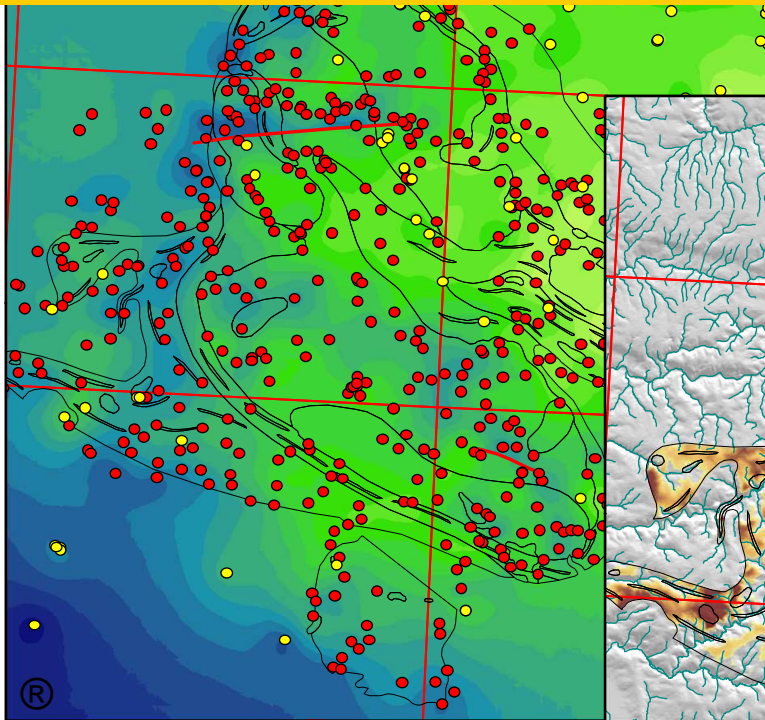
### Country scale



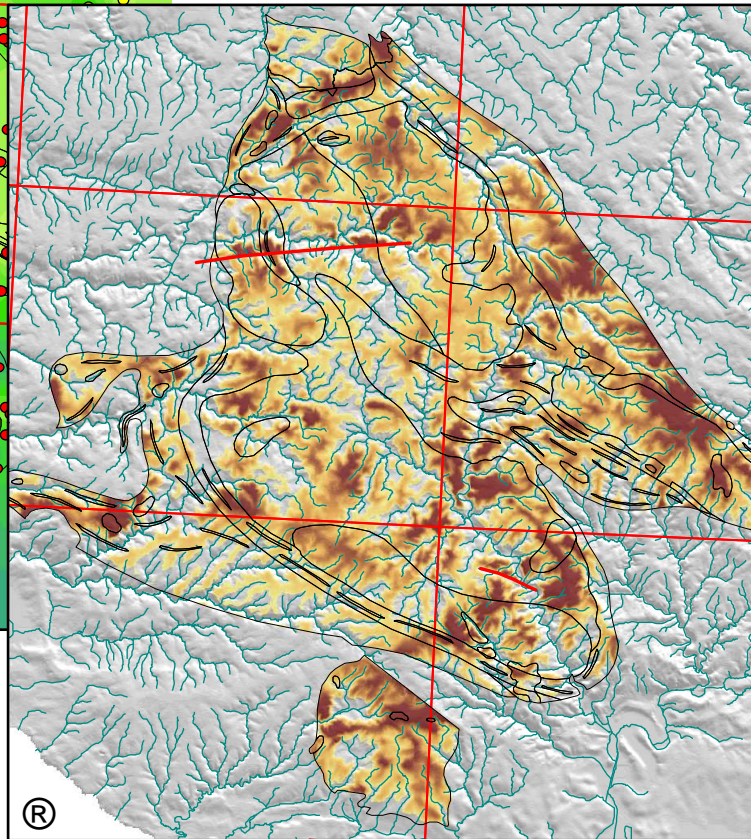
# 5. Applications at various scales

## Mapping of groundwater reserve

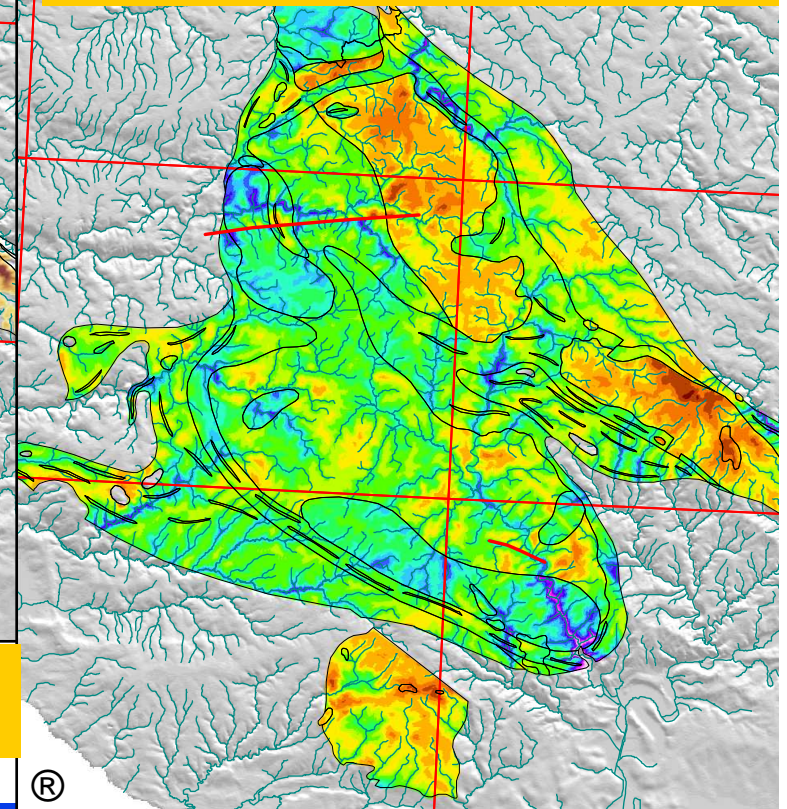
1. Elevation of the base of the saprolite



Structure of the aquifer : PMR + wells + outcropts



3. Thickness of the fractured layer



2. Thickness of the saprolite

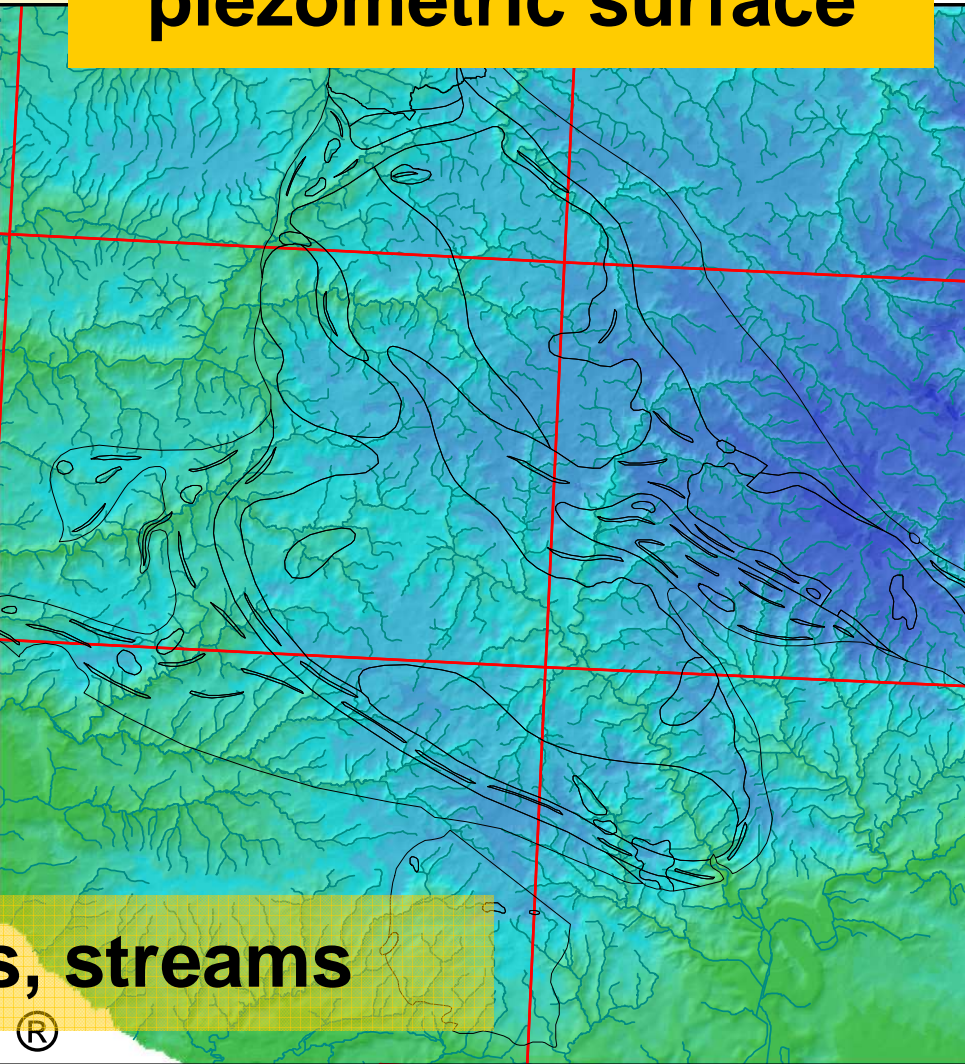
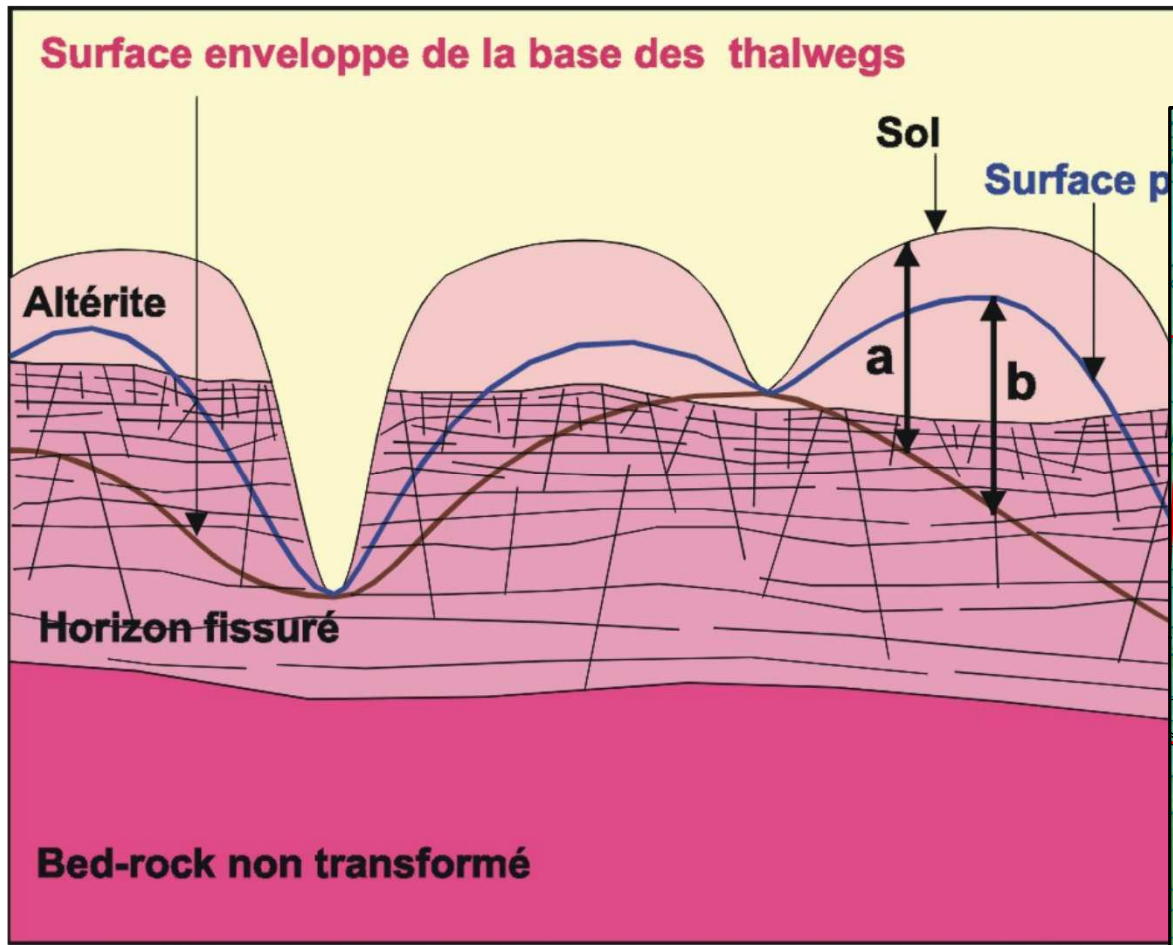
La Roche sur Yon Granite, France ( about 100 km<sup>2</sup> )

Aquifères de roche - La Roche - 11 juin 2015 -

# 5. Applications at various scales

## Mapping of groundwater reserve

### 4. Elevation of the piézometric surface



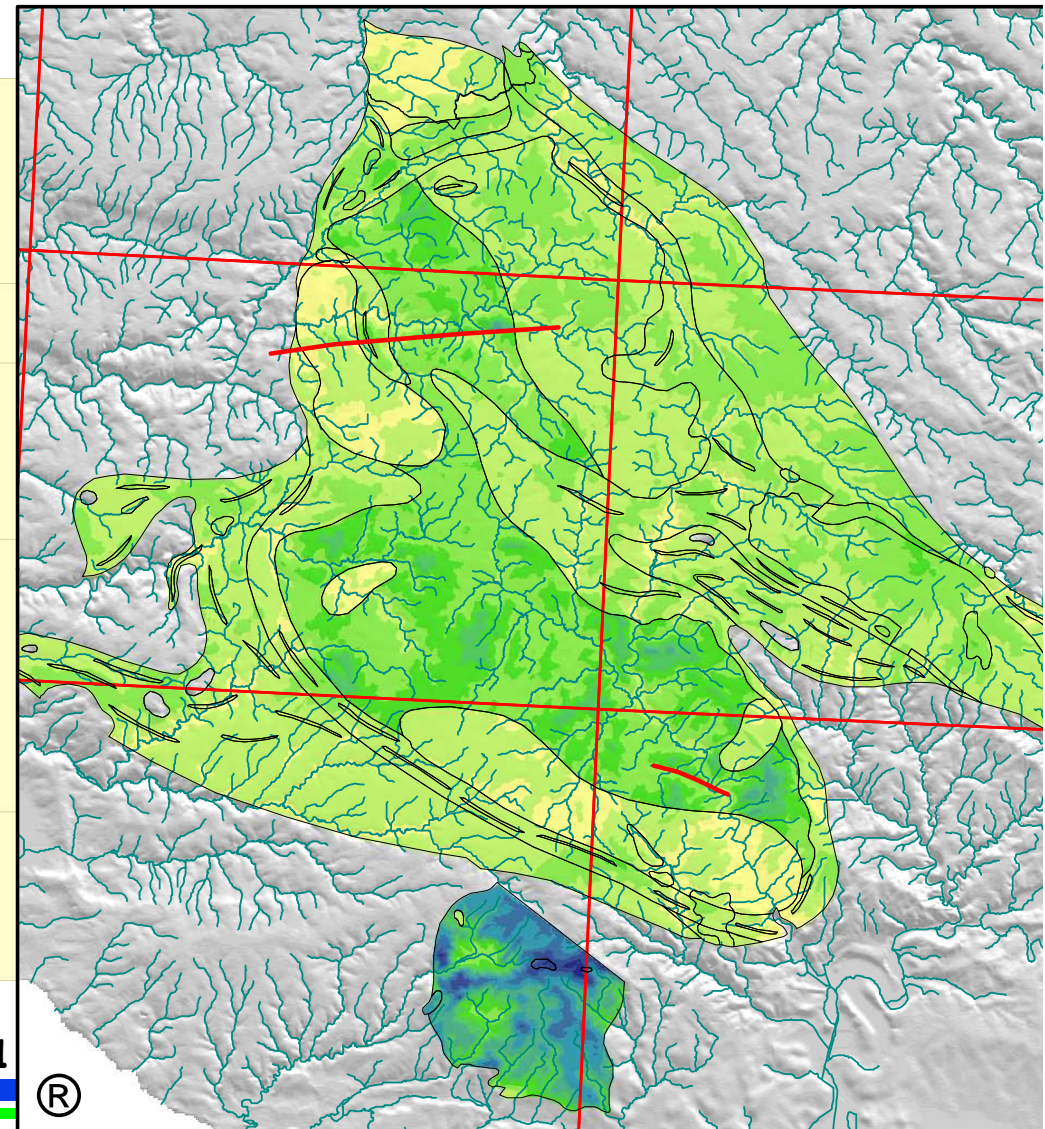
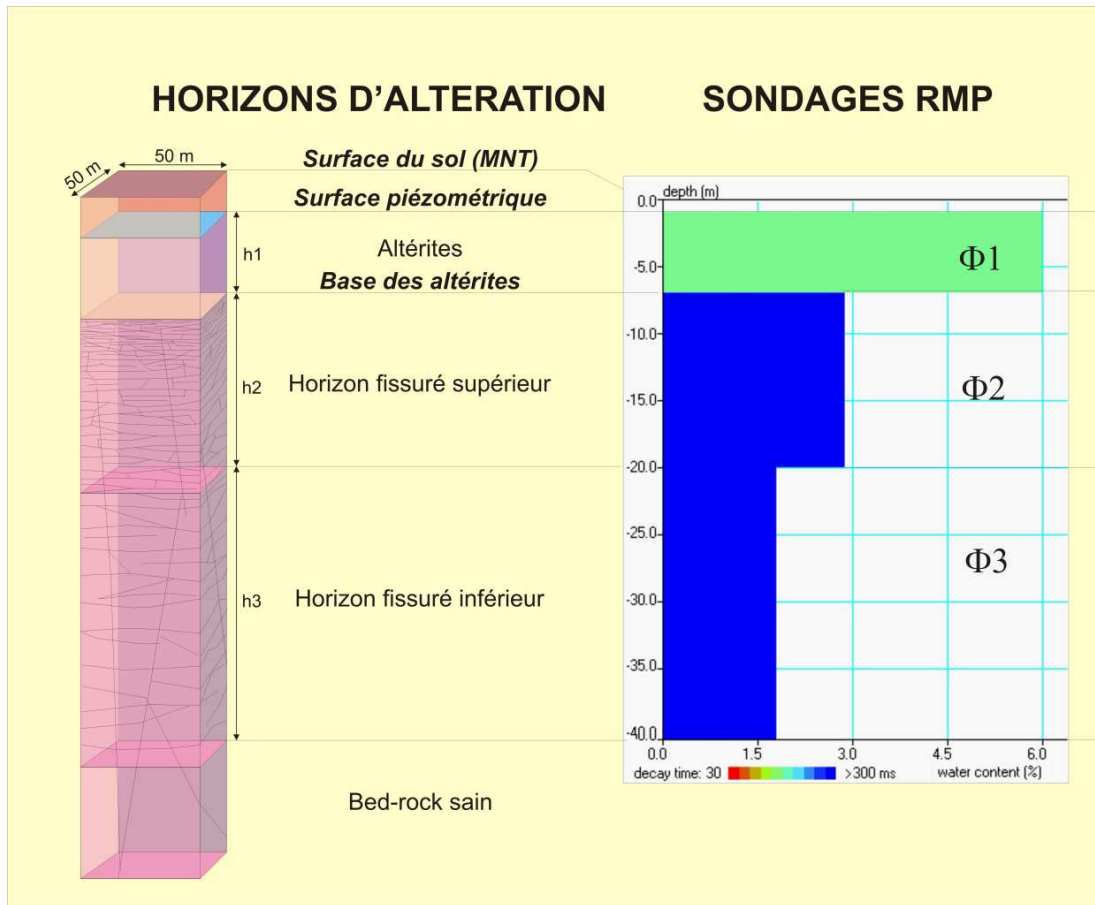
**Piezometric level: PMR, wells, streams**

# 5. Applications at various scales

## Mapping of groundwater reserve

### 5. Spécific yield (from PMR)

→ Groundwater storage



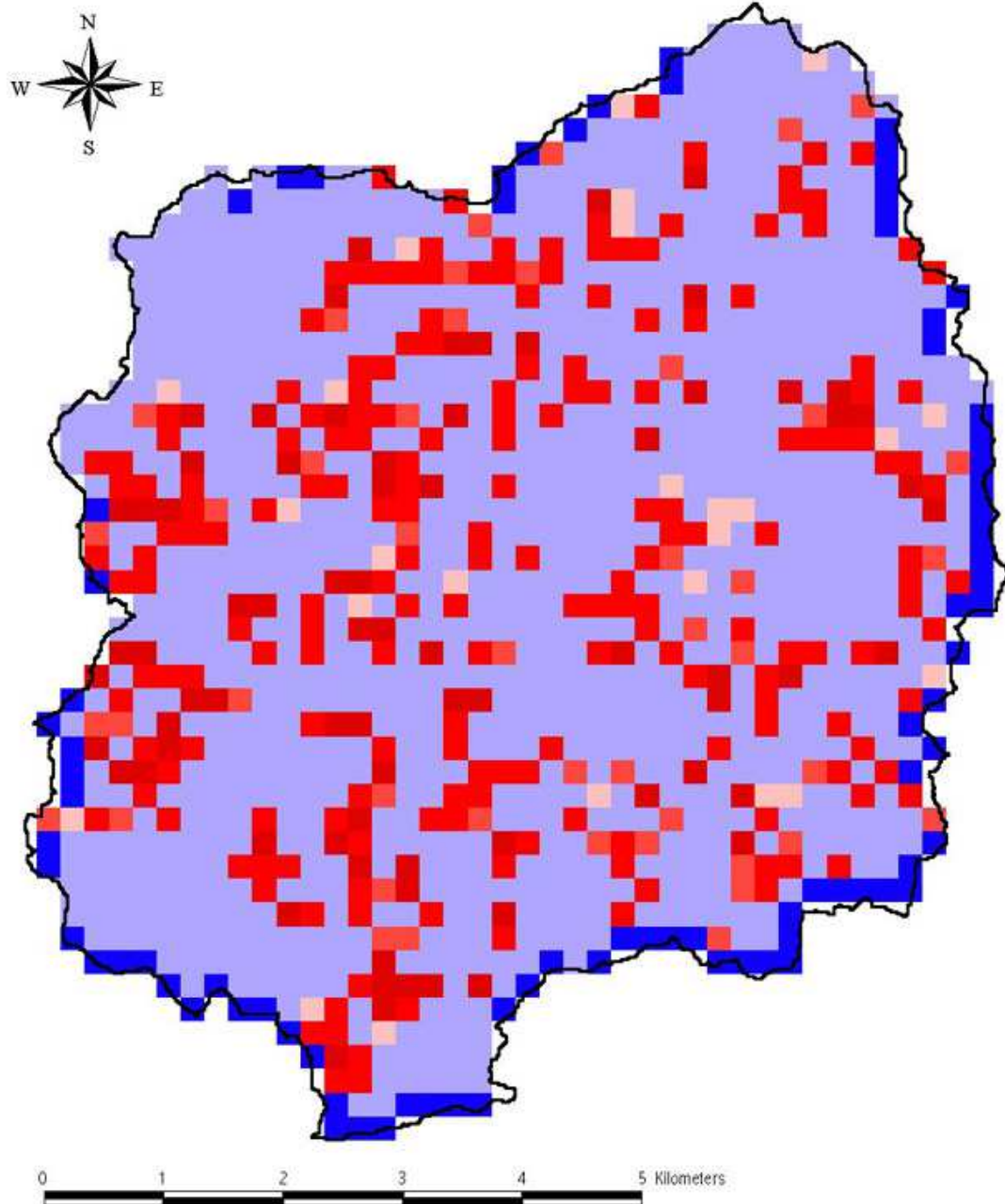
La Roche sur Yon, France ( about 100 km<sup>2</sup>) 1



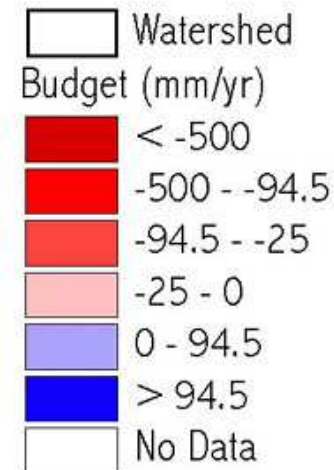
# 5. Applications at various scales

## Development of a groundwater budget methodology

Maréchal, Dewandel al., 2006 – Jour. of Hydrol.



Linking changes in piezometric level to GW storage:  
- Recharge  
- Specific yield



# 5. Applications at various scales

## Development of a groundwater budget methodology - DST

Dewandel, Gandolfi et al., 2007 – Cur. Sc.

→ Decision Support Tool adapted to the management of the water resource in Hard Rock aquifers

**DECISION SUPPORT TOOL FOR GROUNDWATER SCENARIOS**  
**UNDER VARIABLE AGRO-CLIMATIC CONDITIONS**

Water Table Fluctuation Method

Importance of changing cropping pattern and artificial recharge on groundwater level

Help for building up scenarios?  Yes  No

**Change parameters ?**

- Aquifer characteristics
- Inflow, outflow from the watershed
- Irrigated crops characteristics

**Simulations**

- Changing the irrigated crop areas at the beginning of the modelling
- Changing cropping pattern and/or artificial recharge each year

Groundwater budget memo

Annual rainfall & recharge model

Information about the watershed

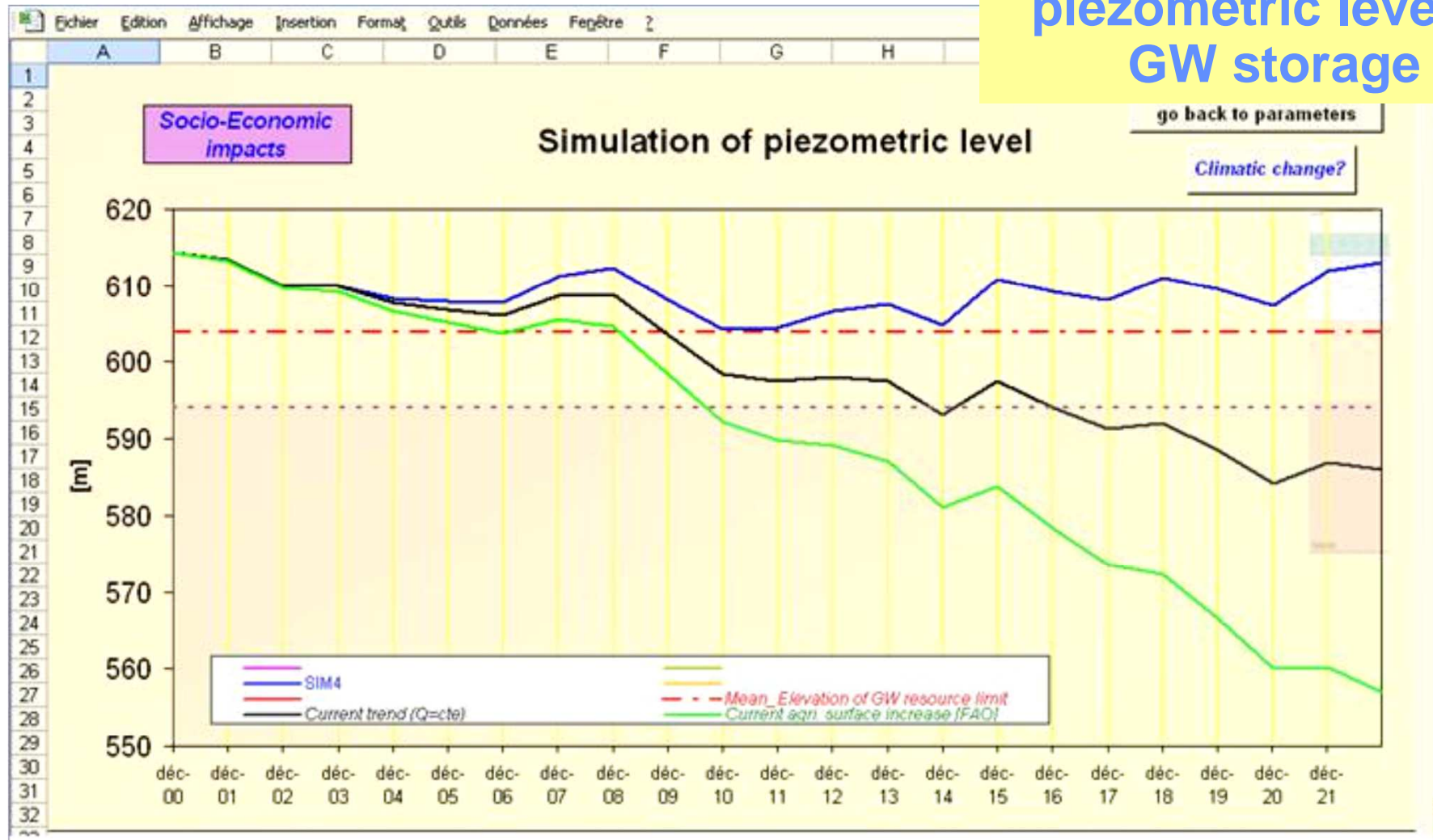
developed by Indo-French Centre for Groundwater Research

# 5. Applications at various scales

## Development of a groundwater budget methodology - DST

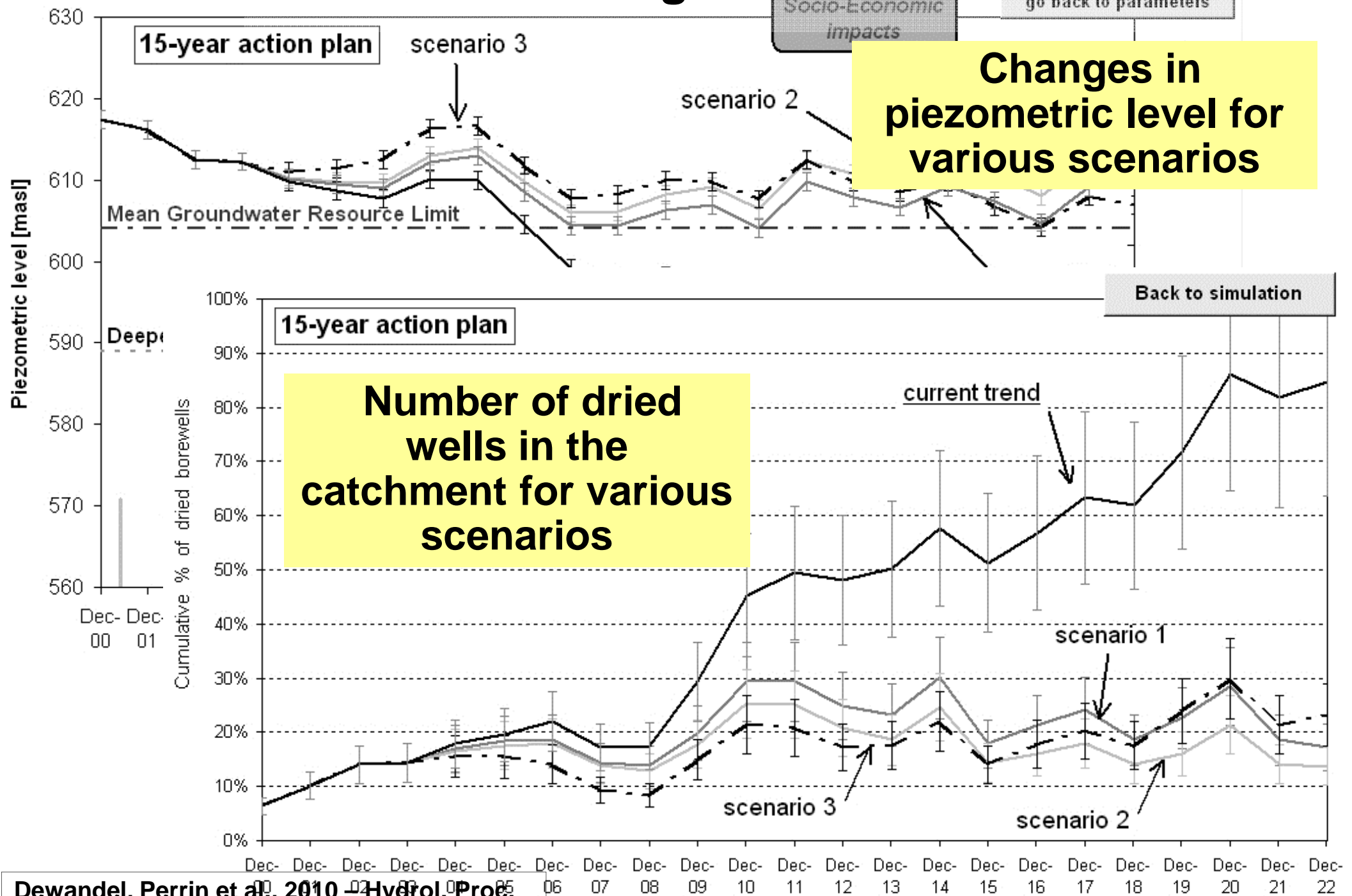
Dewandel, Perrin et al., 2010 – Hydrol. Proc.

Linking changes in piezometric level to GW storage



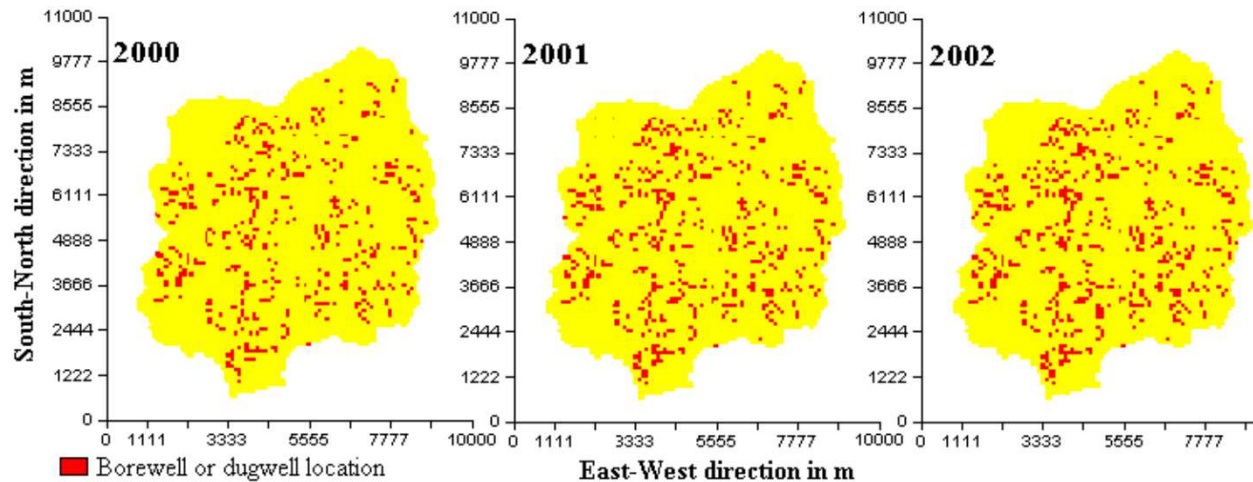
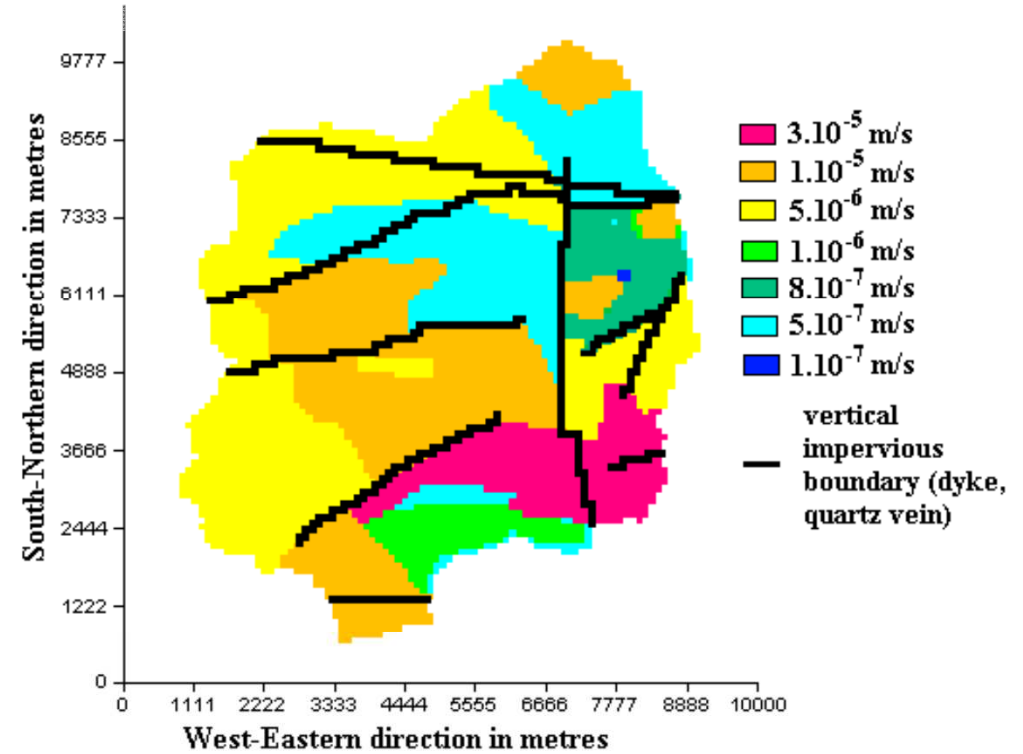
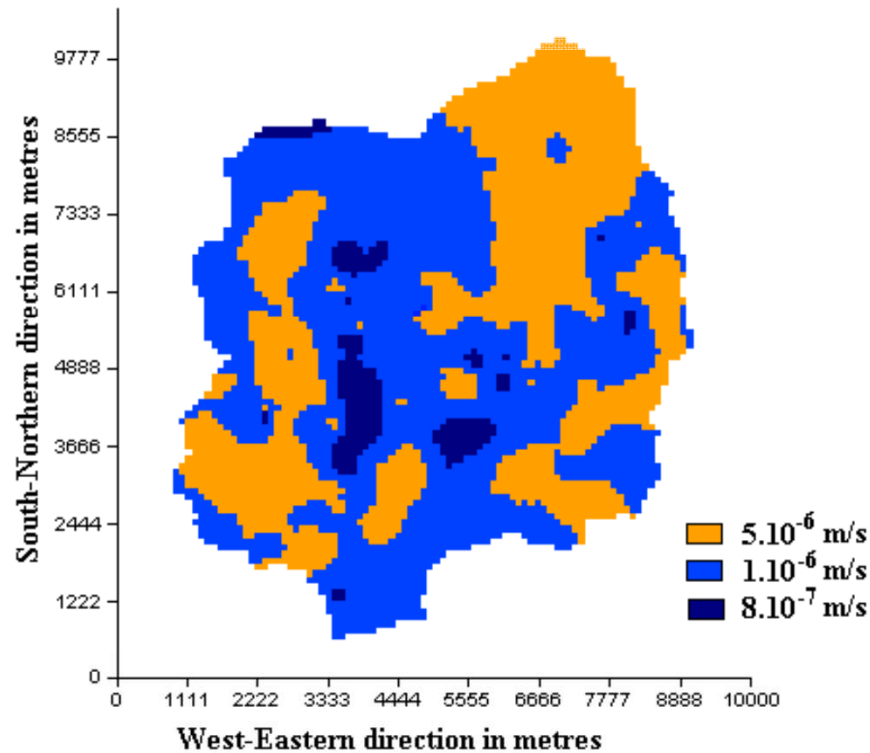
# 5. Applications at various scales

## Long term simulations



# 5. Applications at various scales

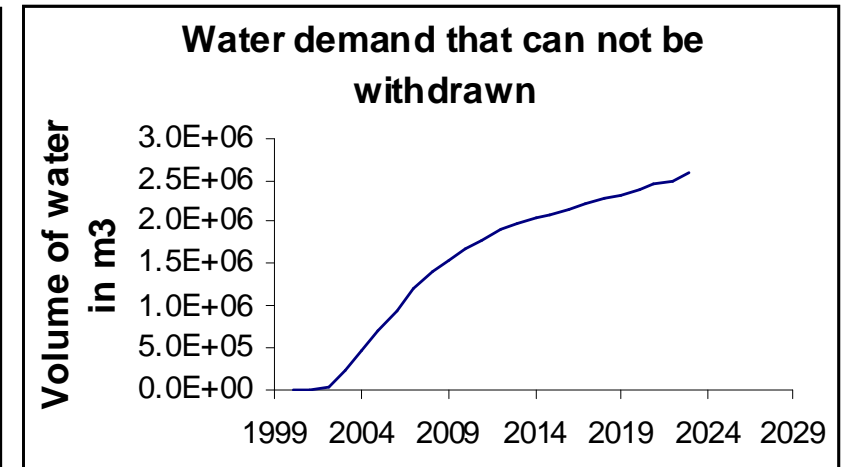
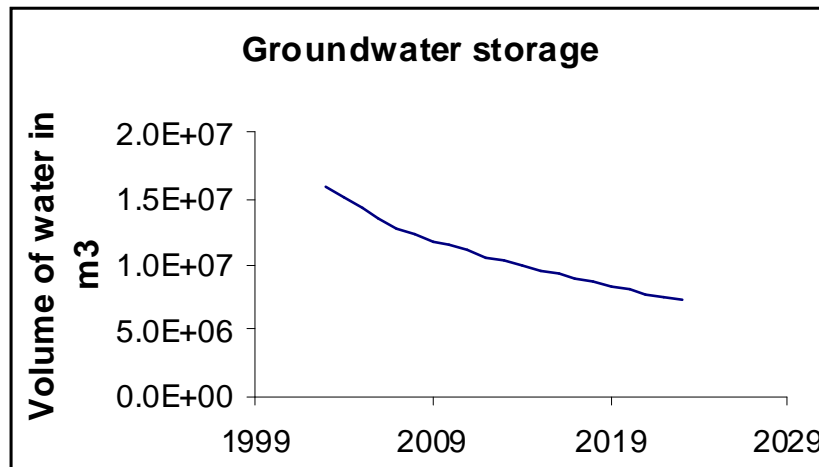
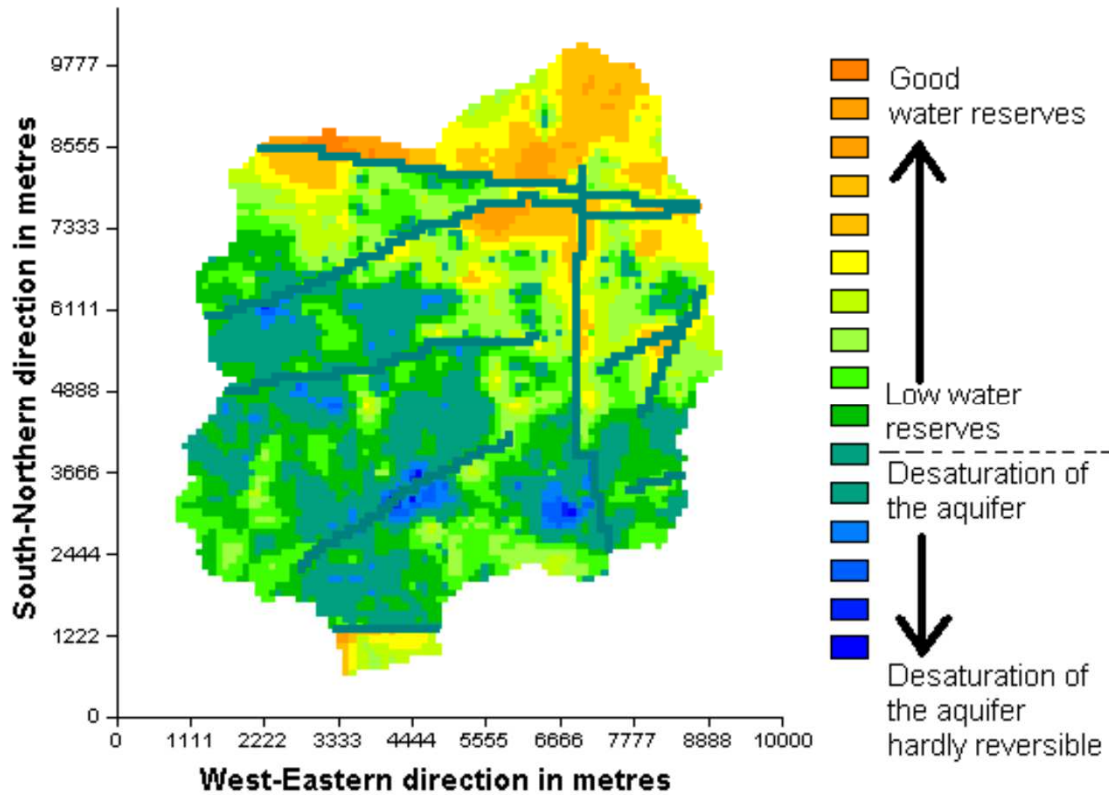
## Deterministic aquifer modeling



Aquitères de socle. La Roche, 11 juin 2015 - P. Lachassagne *et al.*

# 5. Applications at various scales

## Deterministic aquifer modeling



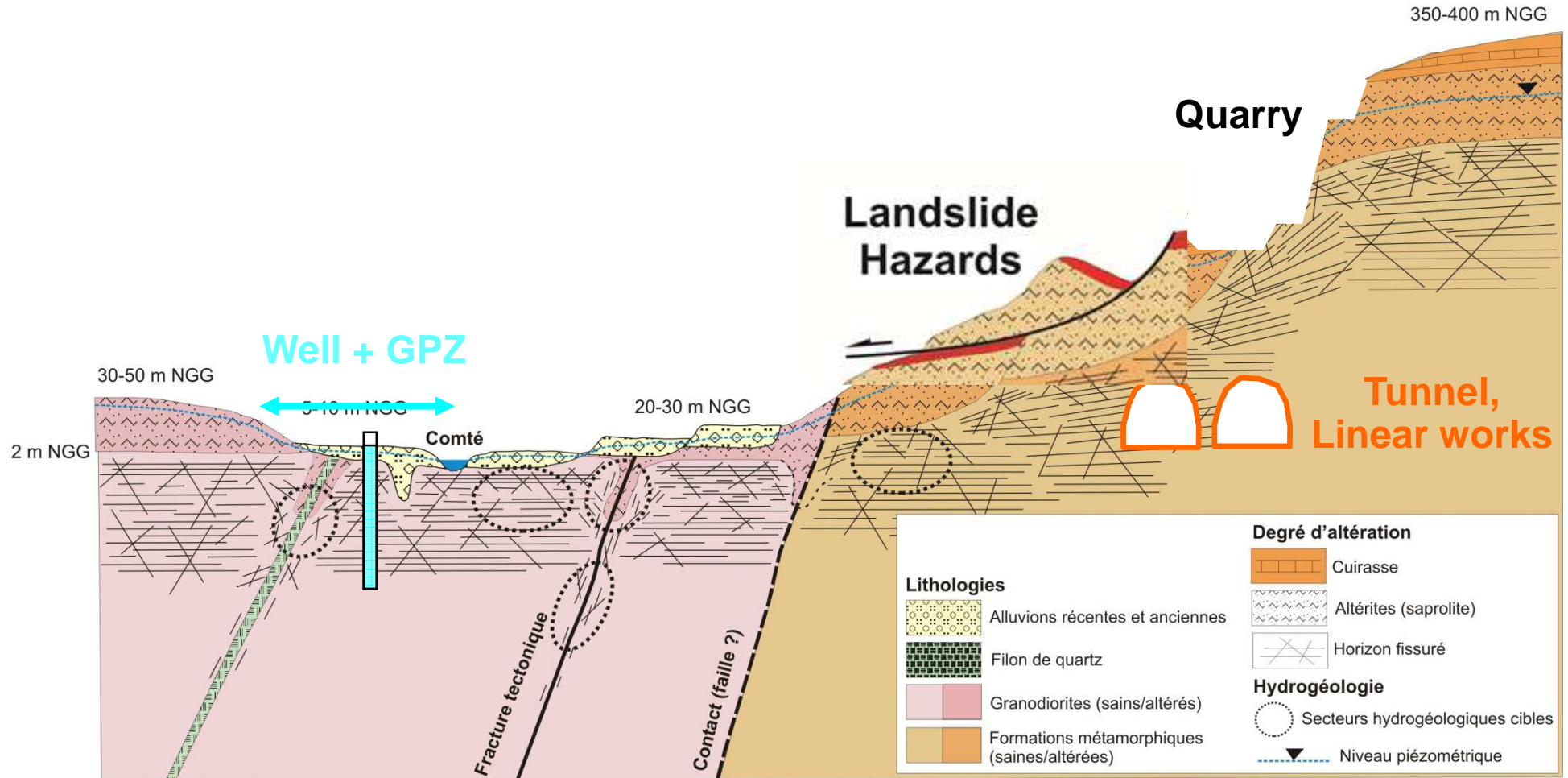
Aquifères de socle. La Roche, 11 juin 2015 - P. Lachassagne *et al.*

# 5. Applications at various scales

## Town and country planning

Ouest

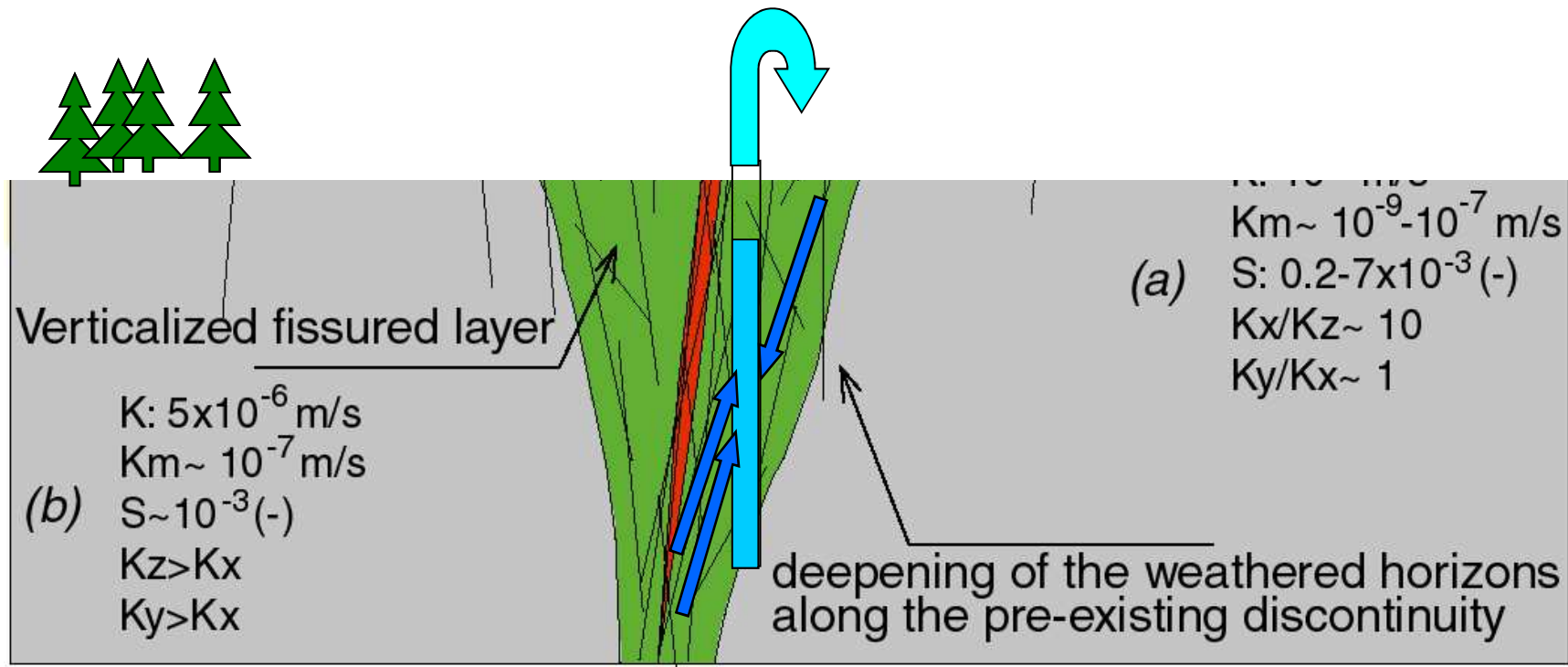
Est



Les échelles verticale et horizontale sont approximatives

# 6. And the vertical fractures? The lineaments?

→ cf. Presentation  
Dewandel et al.



GRANITE

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Ancient joint, fault, vein,  
lithological discontinuity

Dewandel, Lachassagne et al. 2011 (Jour of Hydrol.)





## 6. Conclusion

- HR aquifers properties are inherited from weathering processes
- links with “tectonics” are indirect, and also related to weathering
- from these results, a large part of the complexity and “mystery” of such aquifers disappears
- several practical applications emerge from these results

