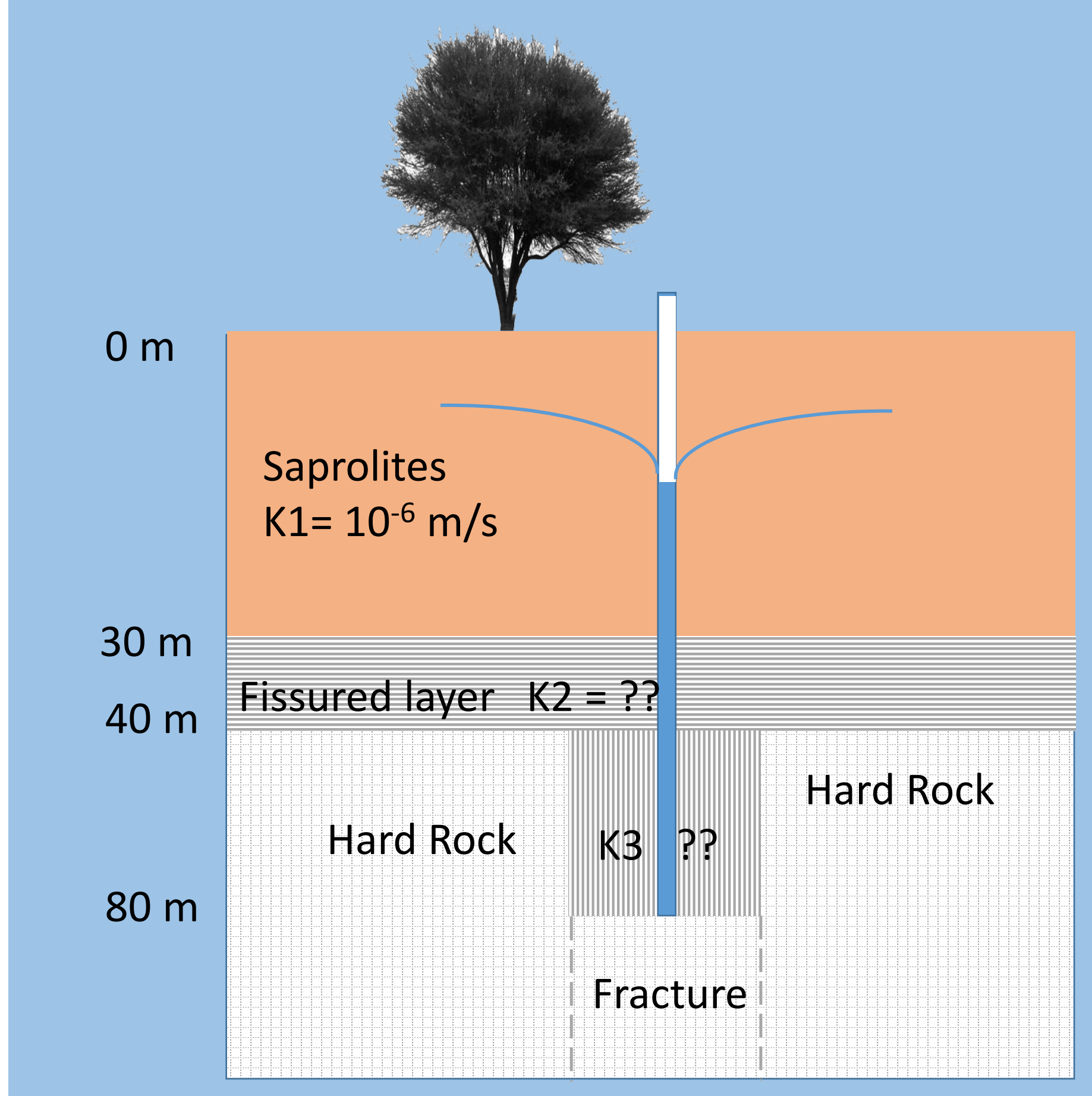
Hydraulic conductivity at the base of the weathering profile ?

Gravimetric and leveling measurements for basement aquifers in West Africa

Ferhat Gilbert[1], Genthon Pierre[2], Mouhouyouddine Ali Houmadi[2-3], Hinderer Jacques[1], Hector Basile[5], Yameogo Suzanne[4]

[1] EOST- IPG Strasbourg-INSA
[2] HydroSciences Montpellier
[3] Comores University
[4] Hydrogeology and Remote Sensing, Univ. Ouagadougou, Burkina Faso
[5] LTHE Grenoble

THE MODEL
AQUIFER TESTING IN GRANITE AQUIFERS



Water level changes are computed in a simplified aquifer using the finite difference Modflow package and a variable grid (Δx = 0.4-2500 m). A constant pumping rate of 55 m^3/h is imposed during 7 days.

The geometry of the fissured layer inside the fault and outside the fault are supposed to be known from exploration geophysics. The width of the fracture zone is 40 m.

Subsidence

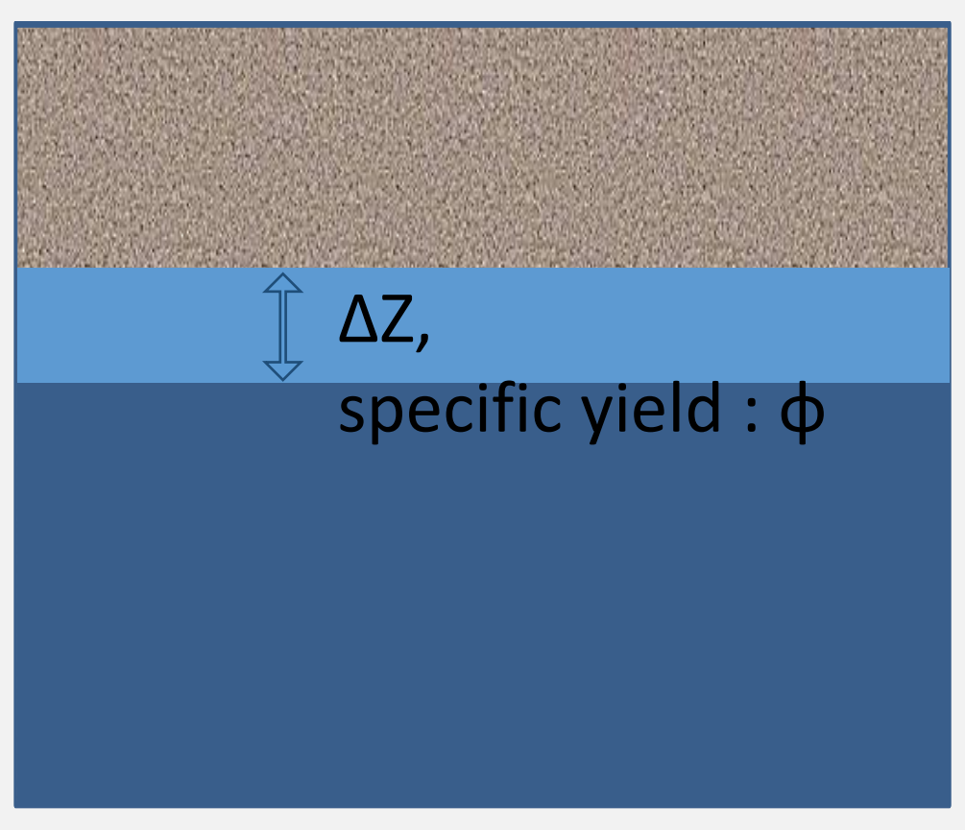
Clay present in the saprolite layer deforms when the water pressure decreases in the aquifer. The volume change is $\Delta V/V= \Delta P/E=\rho g\ \Delta h/E$, where ΔP is the pressure change induced by the drawdown Δh. With E in the range $[10^6 ; 10^7]$ Pa and a 2 m total clay content in the profile, the subsidence is in the range $[2\times10^{-3} ; 2\times10^{-2}]$ m / m.

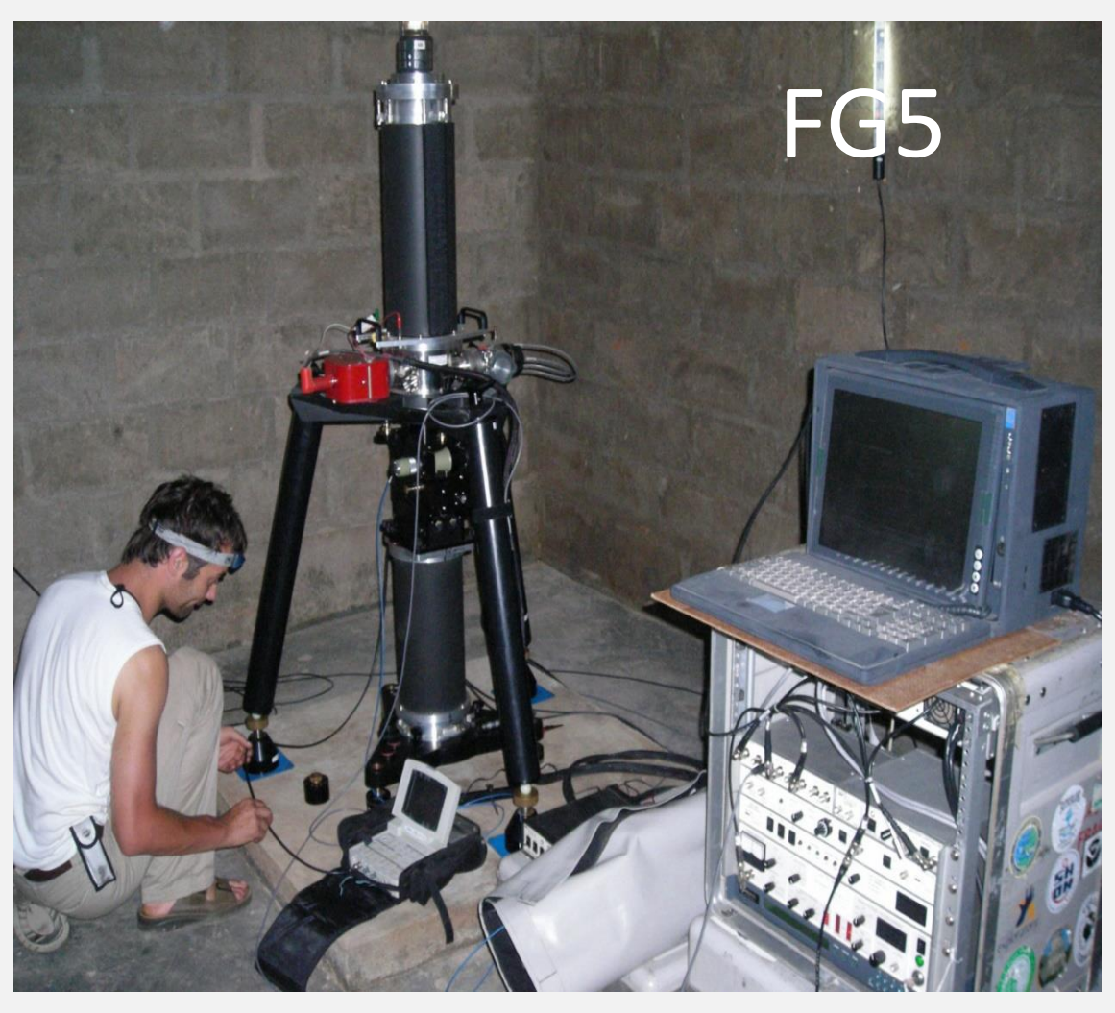
Gravity effects

- Direct effect -400 nms^{-2}/m for each drawdown meter
- Indirect effect [+6 ; +60] nms^{-2} for each drawdown meter (using free air gradient of 3000 nms^{-2}/m)

Gravity monitoring of aquifers

Large experience in West Africa on sedimentary as well on basement aquifers was obtained thanks to the GHYRAF project (2008-2011, Hinderer et al., 2011)





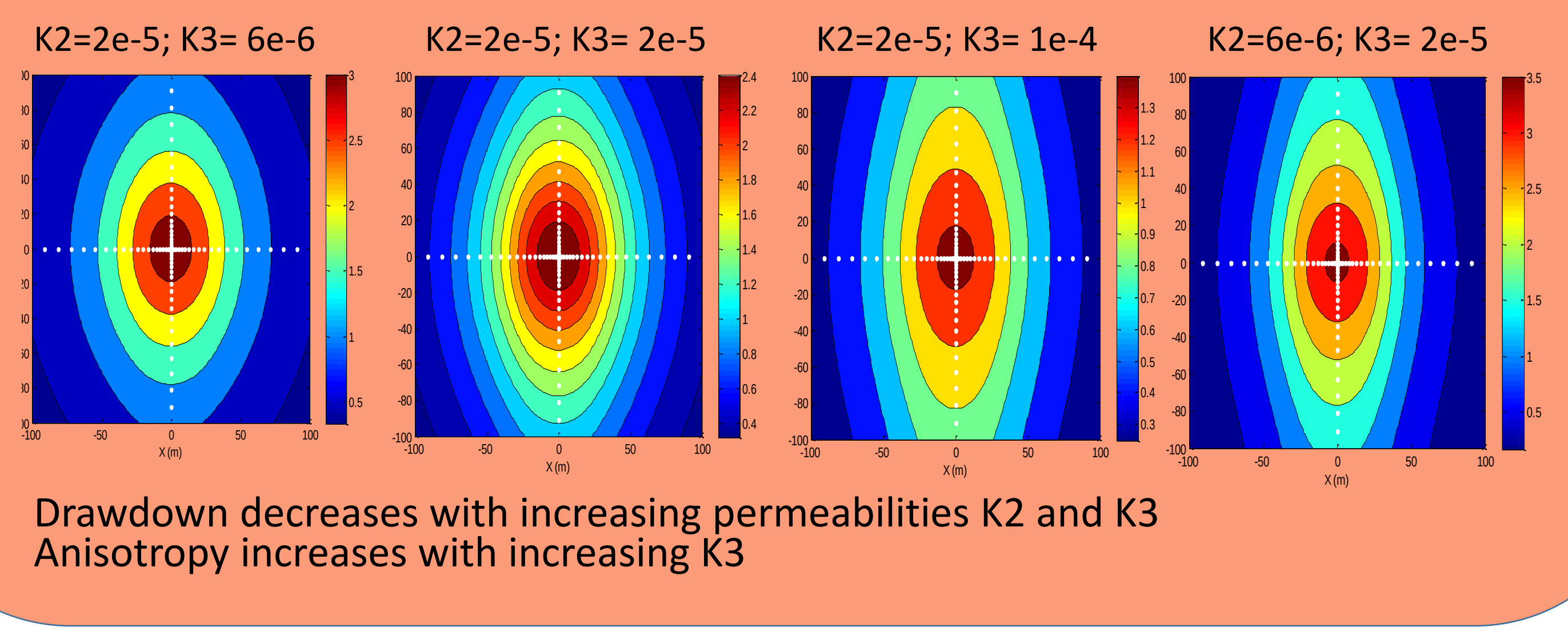
gravimeter	CG5 relative	FG5	SG superconducting
portability	good	fair	some
Sensitivity (nms^{-2})	20-50	20	0.1-1
Water level sensitivity (m) ϕ=0.1	0.5-1.2	0.5	0.002-0.02

$\Delta g(nms^{-2})=400\ \phi\Delta x(m)$

Presently, a gravimeter can be considered as a poor tool for measuring water levels (0.5 m for 10 % porosity), but this will change with the new generation of portable superconducting gravimeters (iGrav) (better than 0.02 m)

DRAWDOWN RESULTS

Drawdown after 7 days (m)


K2=2e-5; K3= 6e-6 — K2=2e-5; K3= 2e-5 — K2=2e-5; K3= 1e-4 — K2=6e-6; K3= 2e-5

Drawdown decreases with increasing permeabilities K2 and K3
Anisotropy increases with increasing K3

INVERSION WITH GRAVITY DATA

Experimental design

It consists of 6 gravity points and 12 leveling points distributed along the fault and parallel to it. These points can be measured in one day by an experienced team.

The objective function

It is defined as the RMS of the differences of actual observations with those of a **reference case ($K2=8\times10^{-6}$ m/s, $K3=4\times10^{-5}$ m/s, $E=3\times10^6$ Pa)** normalized by the standard error of each measurement ($\Delta g=20nms^{-2}$, Δl=1 mm, Δh= 0.5 m for the central borehole, and 0.02 m otherwise).

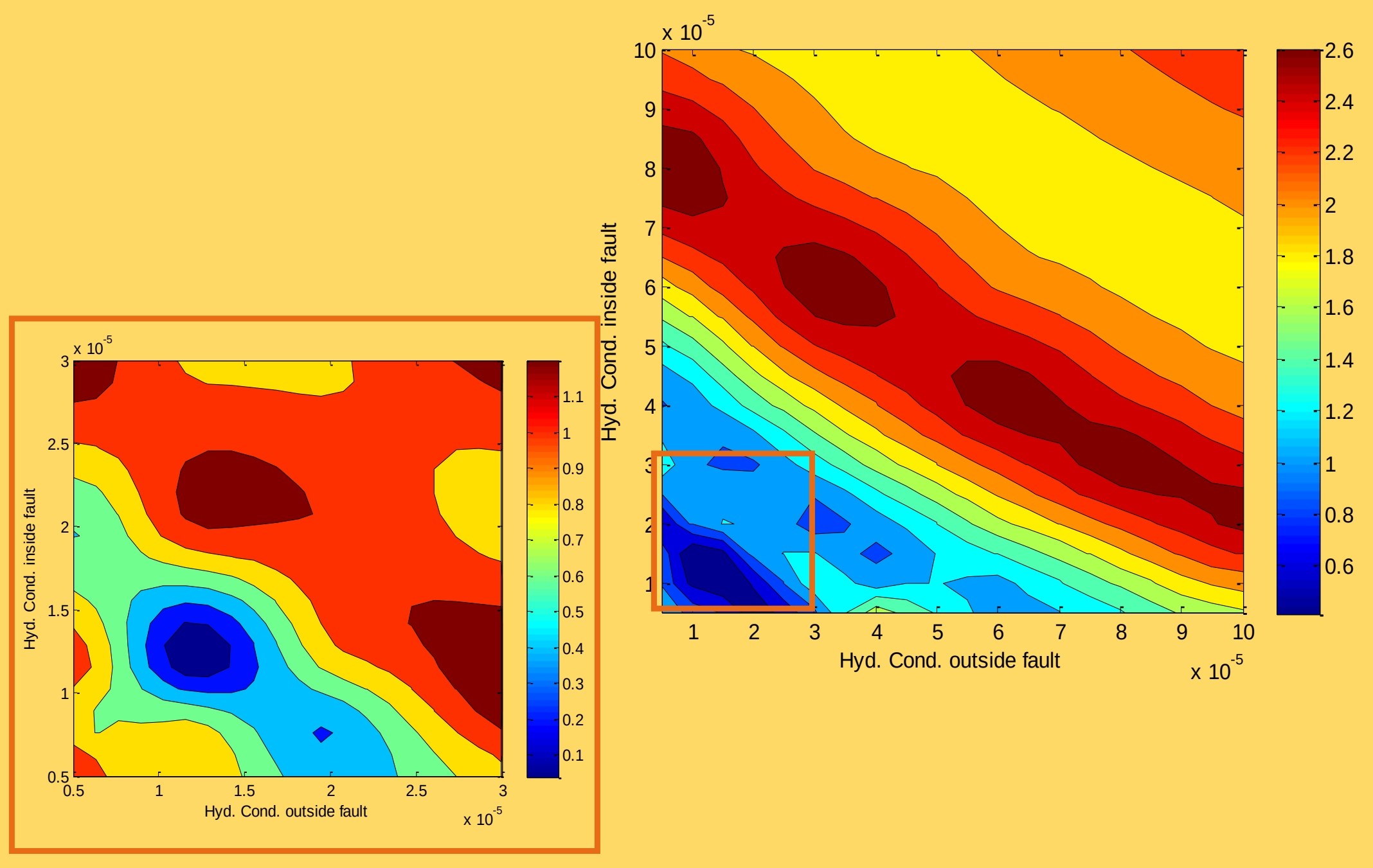
$$OF=\frac{1}{\sqrt{n}}\times \mathbf{SQRT}\left(\sum_{1}^{n_g}\frac{(g_i-g_{0i})^2}{\Delta g^2}+\sum_{1}^{n_l}\frac{(l_i-l_{0i})^2}{\Delta l^2}+\sum_{1}^{n_h}\frac{(h_i-h_{0i})^2}{\Delta h^2}\right)$$

Where 0 indices refer to the reference case, g is the gravity signal, l refer to leveling, and h to the water level in the aquifer. An objective function > 1 only can be achieved with current experimental methods. A n_g, n_l, n_h are the number of gravity, leveling and water level points and n= $n_g+n_l+n_h$

INVERSION RESULTS
(objective function OF)

Gravity + leveling

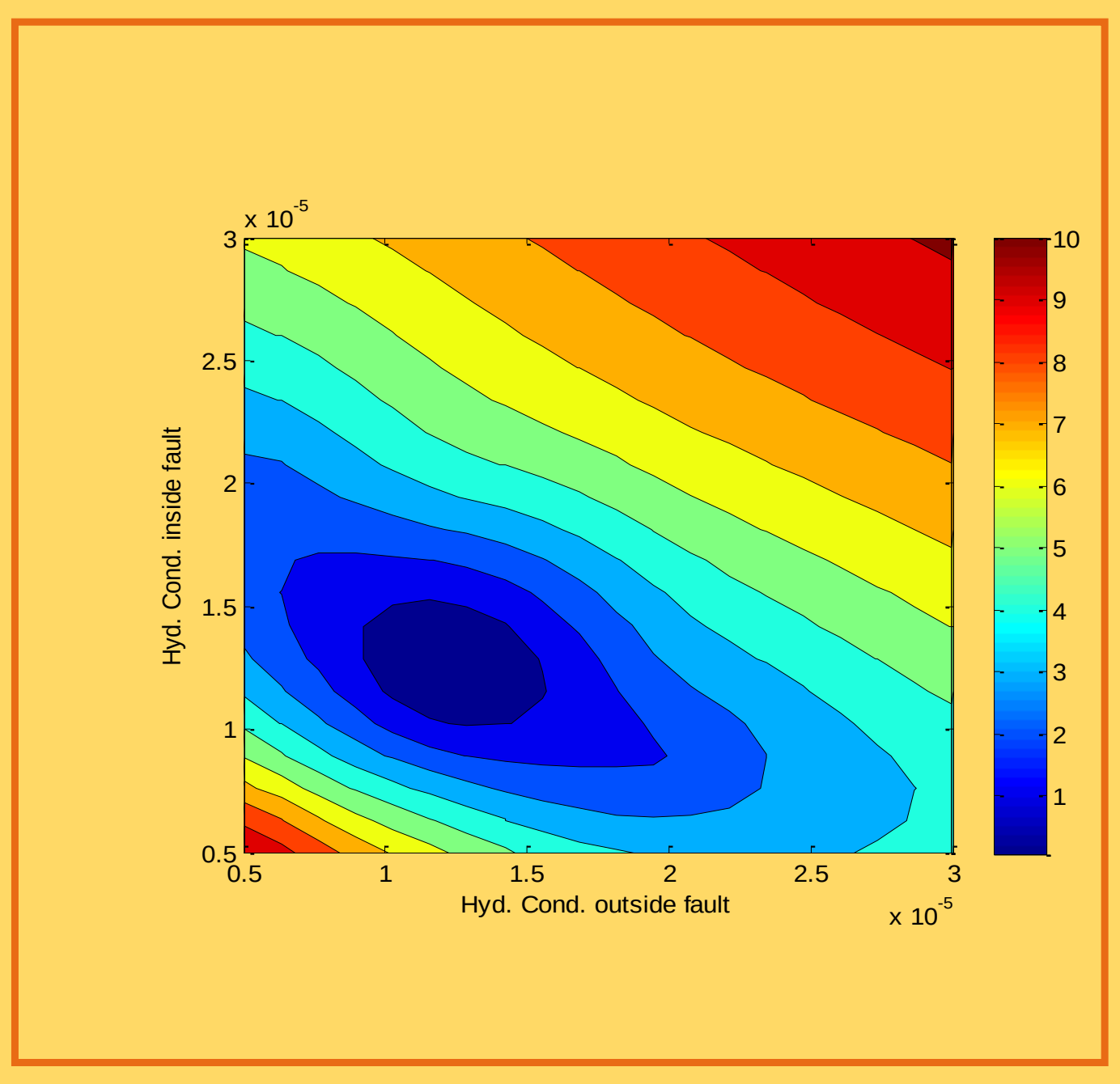
K2+K3 is well defined, however K2-K3 is poorly resolved



Note the change in the color scale

+ 2 boreholes 55 m away (Δh=0.02 m)

The two additional boreholes provide **a strong constraint on the mean value of K2 and K3, but poorly resolve the difference between K2 and K3** (probably due to the poor definition of anisotropy of drawdown with only 2 boreholes)



CONCLUSION

- Gravity data provide information on water level fluctuations, but only a few points can be measured in one day. For weathering profiles including highly deformable clays, we propose to use combine gravity and high precision leveling.
- With current gravimeter precision, a fair constraint can by brought on the mean value of the high permeability fractured layer with a 7 days aquifer testing experiment. However the geometry of this layer must be known (for example by exploration geophysics).
- The difference of permeability in the fault zone and outside the fault zone (K2-K3) is poorly constrained.
- 2 additional borehole provide a stronger constraint on the mean permeability, but not on the K2-K3 difference.
- With 2 nm/s^2 precise gravity data, both K2 and K3 could be resolved. This order of magnitude of precision fall in the range of future portable gravimeters.
- These results stand for an idealized granitic aquifer including heterogeneities relying on an idealized weathering profile and should be therefore confirmed by field experiments.

References

Hinderer et al., 2011. Land water storage from ground and space geodesy; first results from the GHYRAF (Gravity and Hydrology in Africa) experiment, Pure Appl. Geophys., doi: 10.1007/s00024-011-0417-9
Damiata, B.N., Lee, T.C., 2006. Simulated gravitational response to hydraulic testing of unconfined aquifers, J. of Hydrol., 318, 348-359.
Herckenrath, D., Aucken, E., Christiansen, L., Behroozmand, A.A., Bauer-Gottwein, P., 2012. Coupled hydrogeophysical inversion using time-lapse magnetic resonance sounding and time-lapse gravity data for hydraulic aquifer testing: Will it work in practice? Wat. Res. Res., doi: 10.1029/2011WR010411.