Igeotest

MRS HYDRAULIC CONDUCTIVITY AND GEOMECHANICS

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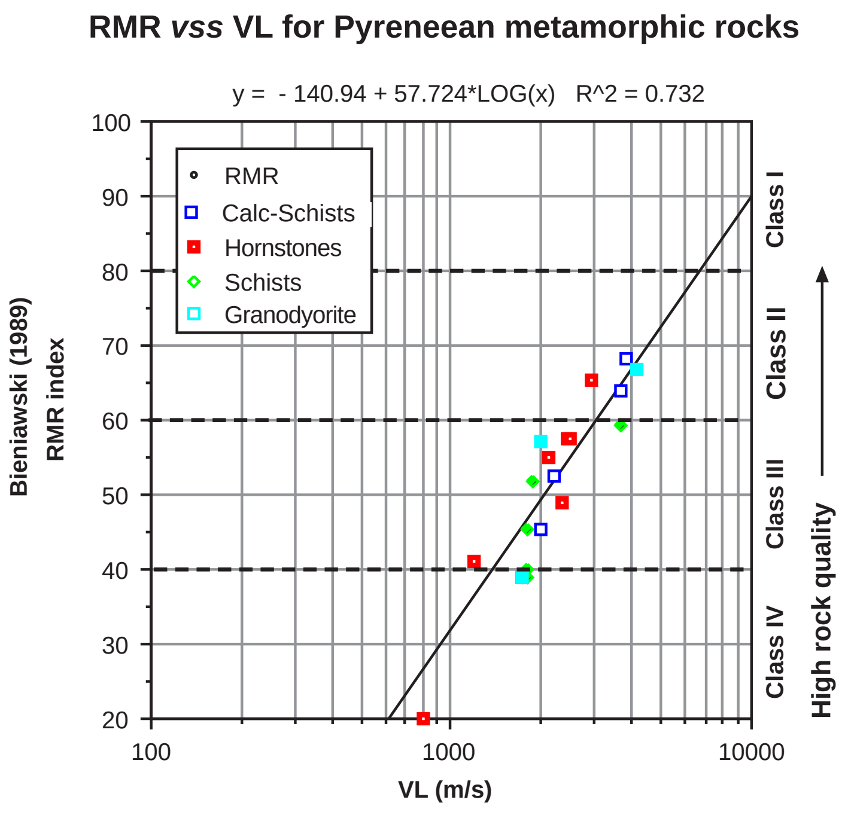
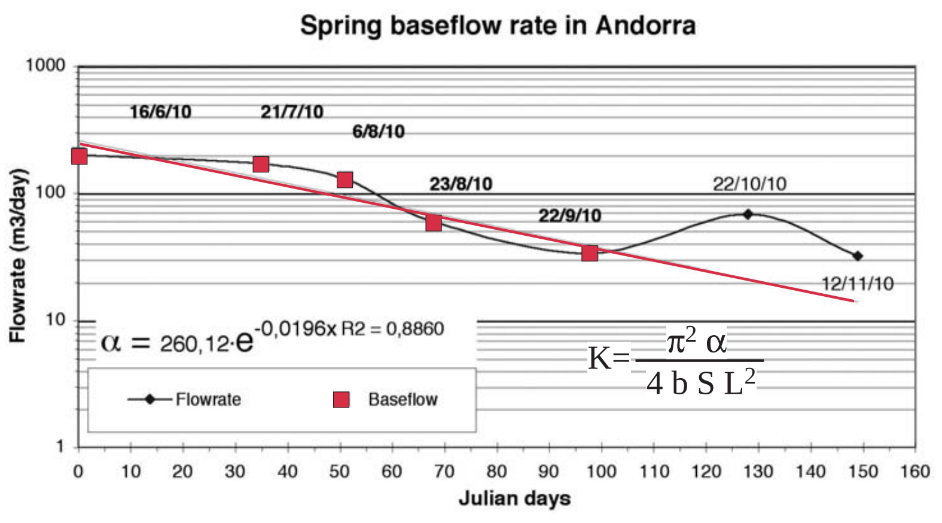
ABSTRACT

Permeability in MRS can be obtained from T2* or from T1 (Lubczynski & Roy, 2007; Voillamoz et al. 2007; Plata & Rubio 2007) related with a geological dependent coefficient (Cpx). Since Cpx coefficient and the confined/elastic storativity are both involved, a geomechanical approach can be attempted. In that sense aquifer compressibility is the main factor that leads in the confined/elastic storavity for a given water drop. The propagation velocity of seismic waves depends on density and elasticity of the medium. Since longitudinal seismic velocity is related with compressibility the Cpx coefficient can be obtained with a n empirical related law. That is so because seismic waves only transmit small pressures variations in porous aquifers, similar to those produced via pumping tests or by seasonal water level variations. For that purpose selected MRS data from different sites in Europe and Africa has been used to plot together Cpx and VL data obtaining a semi logarithmic law. Under development that approach needs to be tested in many other places by many others researchers, but it seems to be robust, being specially useful for hydrogeologists.



Geomechanical classification



Baseflow in Andorra

Sampling in Tanzania

INTRODUCTION

For hydrogeologist MRS technique is a very attractive since is able to inform about aquifers porosities and permeabilities. For hydrogeophysicists is well known that the permeability can be obtained from T_2* (in FID mode, Free Induction Decay) or from T_1 (in Spin Echo mode) following the general equation:

$$K_{MRS} = Cpx\ \theta_{MRS}{}^{a}T_n{}^{2}$$

where θ_{MRS} is porosity and “a” can be 1 if T_1 is used, or 4 if T_2* is used. The Cpx coefficient is geological dependent and in that sense some data tables exist to obtain it (see for example Vouillamoz, Legchenko, Lubczynski, Roy, Plata & Rubio among others), which is obviously very useful especially when pumping tests are scarce. Since Cpx coefficient and the confined/elastic storativity ($Sc \approx Se$) are related with aquifer and water compressibility (α & β respectively) by:

$$Sc \approx Se = \rho\ g\ \Delta z\ (\alpha + \theta_{MRS}\ \beta) \approx Cpx\ (\theta_{MRS}\ \Delta z)$$

a geomechanical approximation can be attempted (the aim of this work). That is so because aquifer compressibility is the main factor that leads in the confined/elastic storavity for a given water drop (Δz).

THE GEOMECHANICAL APPROACH

Well known since the first half of the XX century by Meinzer, Theis and Jacob amongst others, the water volume from an confined aquifer varies by varying the pressure therein due to the water compressibility, but also because the aquifer deform when water pressure vary, changing its porosity and therefore its volume. Seasonally piezometric fluctuations happen and aquifer vertical deformation can occur (Δz). This vertical deformation can be irreversible (consolidation) if pumping is exceeding a yield governed by the static constrained modulus (D). So if we know D (via geomechanical testing) we also obtain the compressivity because:

$$\alpha^{-1} = D\cdot(1-\theta)$$

THE WAY THOUGH

The propagation velocity of seismic waves depends on density (ρ) and elasticity of the medium. The two well known Primary waves (VL) and secondary waves (VT) permit calculate easily the dynamic Young modulus (E) and the dynamic Poisson ratio (v) of the aquifer. With both parameters all different kind of deformation modulus can be known:

$$v= \frac{(V_L{}^2-2V_T{}^2)}{2(V_L{}^2-V_T{}^2)} \qquad E= \frac{(1-v)\ (1+v)}{(1-v)}\ VL^2 \qquad D= \frac{E\ (1-v)}{(1+v)\ (1-2v)}$$

Since VL is directly proportional to the deformation modulus is possible to obtain the Cpx coefficient from a given VL related law.
Seismics only makes grain to grain elastic deformations and for that reason that dynamic and static modulus may differ. In geotechnical tests the applied pressure is high enough to produce grain to grain sliding. Nevertheless for small pressures variations like those produced by seasonal water level variation, both are closer after several load-unload cycles. In hard rocks and consolidated terrains (glacial, landslides) both modulus are closer, it depends on fracturation and the consolidation state.

THE DATA

For that purpose selected MRS data from different studied sites (11) in Spain, Andorra, France and Tanzania was used. In such sites aquifer permeability (pumping tests, infiltration tests, spring baseflow discharge) and typology (confined, unconfined, or multilayer) were known. Seismic and geomechanical data were also collected and allowed us to assess VL. In that sense the Rock Mass Rating of Bieniawski (1989) demonstrate to be easy and quick to classify fissured rocks, and a semi logarithmic law among the RMR geomechanical classification value and the longitudinal seismic velocity (VL).

THE EMPIRICAL LAW

In all surveyed site the Cpx coefficient was obtained using the free software Samovar 6.2 from Legchenko-BRGM. Plotting Cpx versus VL data (in meters par second) we obtain the following empirical law:

$$\text{Log } 1/Cpx = 0{,}002\ VL + 6{,}096\ (R^2=0{,}99)$$

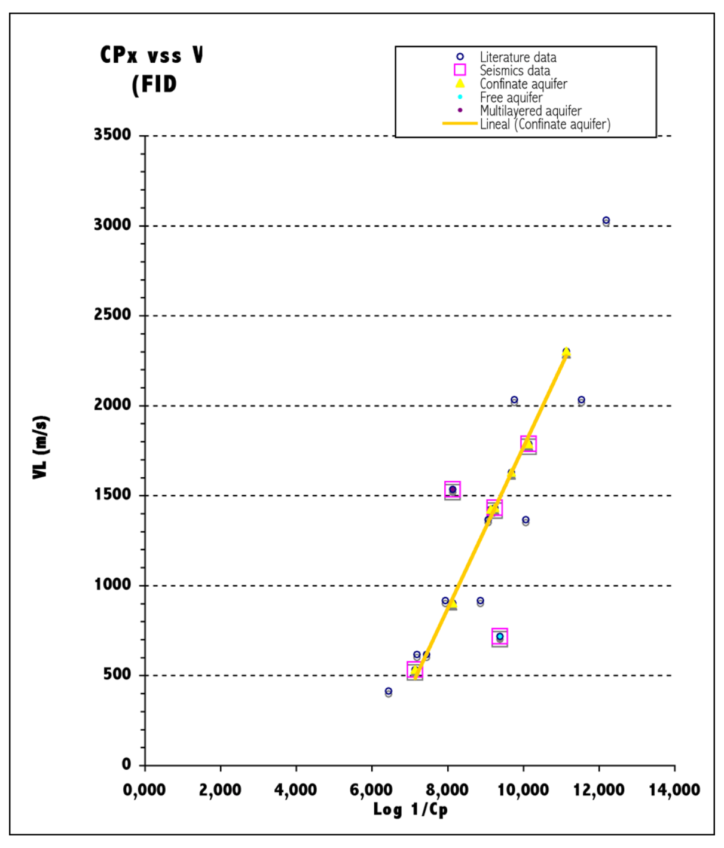
This equation runs only for confined aquifers and has been obtained in diverse lithologies (carbonates, granites, metamorphic slates and unlithified sediments). For no confined aquifer deviations occur (lower R^2) because storativity are not leaded only by elastic properties.

CONCLUSIONS

In essence the exposed semi logarithmic law is under development and needs to be tested in many other places, but this geomechanical approximation seems to be robust and useful.

BIBLIOGAFHY

BIENIAWSKI, Z.T. (1989) Engineering rock mass classifications: a complete manual for engineer and geologists in mining, civil and petroleum engineerig; Wiley-Interscience, 40-47
LUBCZYNSKI, M. & ROY, J. (2007) Use of MRS for hydrogeological system parametrization and modeling; BoletÌn Geológico y Minero de España, 118, 3, 509-530
PLATA, J.L. & RUBIO, F.M. (2007) Basic theory of the magnetic resonance sounding method; Boletín Geológico y Minero de España, 118, 3, 441-458
VOUILLAMOZ, J.M.; BALTASSAT, J.M.; GIRARD, J.F.; PLATA, J.L. & LEGCHENKO, A. (2007) Hydrogeological experience in the use of MRS; *Boletín Geológico y Minero de España*, 118, 3, 531-550

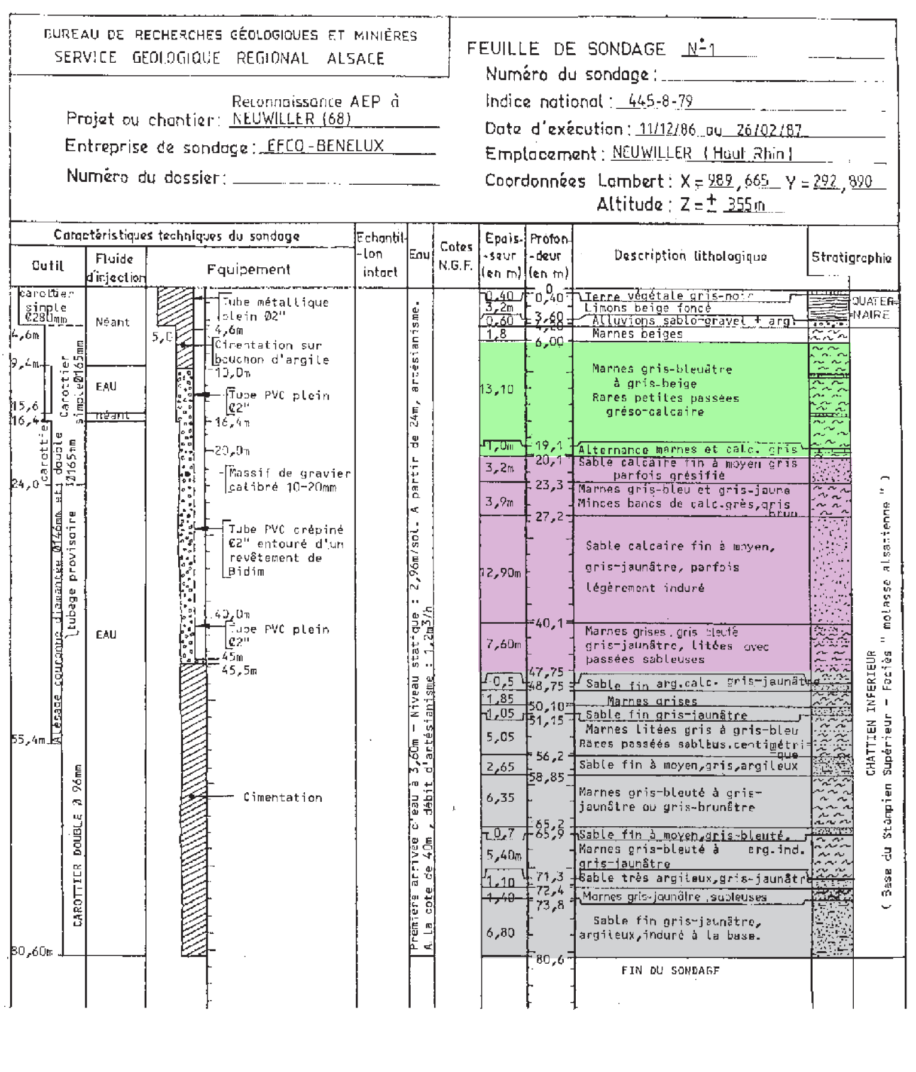


The empirical law

Reference	Site	Country	Lithology	Aquifer	Hydro data	StD	K	MRS K	MRS StD	VL	RMR	VL calc.	Density*	CPx	Log 1/CPx	Ed*	Poisson*(v)	θ MRS	θ StD
F-033.11.08	Caspach	France	Marls	Confined	Pumping test	0,78	1,93	1,86	1,50	N/A	30	900	25	7,00E-09	8,155	1369,4	0,24	2,65	0,42
F-035.12.08	Darvoy	France	Carbonates	Confined	General data	21,50	64,50	37,00	11,00	N/A	45	1625	25	2,00E-10	9,699	4468,7	0,13	16,00	1,41
F-004.03.09	Newiller	France	Marls	Confined	Pumping test	?	8,64	10,78	4,55	1784	44	1784	25	7,00E-11	10,155	6454,6	0,27	3,50	1,08
A-013.11.09	Boïgues	Andorra	Non consolided	Confined	Infiltration tests	3,47	15,18	5,00	N/A	1428	35	1428	18	5,50E-10	9,260	2481,2	0,33	44,00	N/A
A-010.06.10	Clot Menera	Andorra	Granits	Confined	Pumping test	0,25	0,35	0,45	0,38	N/A	50	1420	27	7,00E-10	9,155	5092,6	0,16	23,51	1,08
G3-001.03.12	Kilimanjaro	Tanzania	Volcanic ash	Confined	Pumping test	?	256,00	492,00	316,08	N/A	25	900	18	7,00E-09	8,155	972	0,33	9,53	0,76
A-010.09.09	Nogueres	Andorra	Glaciotectonite	Confined	Pumping test	600,0	900,00	900,00	622,25	529	Not possible	529	23	7,00E-08	7,155	336,8	0,33	1,85	1,06
E-006.02.08	Ortedó	Spain	Lacustrine	Confined	Pumping test	?	0,11	0,18	0,04	N/A	Not possible	2300	25	7,00E-12	11,155	9522	0,33	2,10	1,13
A-009.05.10	Grau-Roig	Andorra	Milonite	Confined	Pumping test	?	8,90	5,00	0,38	N/A	25	900	23	7,00E-09	8,155	1350	0,33	5,00	0,71
A-015.11.10	Estadium	Andorra	Glaciotectonite	Multilayer	Pumping test	104,4	100,00	20,00	N/A	1532	Not possible	1532	23	7,00E-09	8,155	4607,2	0,23	9,95	11,04
A-015.03.08	Rabassa	Andorra	Metamorphic slates	Unconfined	Pumping test	0,50	0,80	0,35	0,15	714	25	714	27	4E-10	9,398	781,3	0,35	6,97	6,78
-	-	-	-	-	-	-	m/d	m/d	-	m/s	-	m/s	KN/m3	-	-	MPa	-	-	e

Data from different studied places

Newiller (France, Alsace)



BUREAU DE RECHERCHES GÉOLOGIQUES ET MINIÈRES
SERVICE GEOLOGIQUE REGIONAL ALSACE

FEUILLE DE SONDAGE N°1
Numéro du sondage:
Indice national: 445-8-79
Date d'exécution: 11/12/86 au 26/02/87
Emplacement: NEUWILLER (Haut Rhin)
Coordonnées Lambert: X = 989,665 Y = 292,890
Altitude: Z = ± 355m

Projet ou chantier: Reconnaissance AEP à NEUWILLER (68)
Entreprise de sondage: EFCO-BENELUX
Numéro du dossier:

Borehole hydrogeological description

GEOLOGIE ET HYDROLOGIE DU FORAGE DE NEUWILLER

Interprétation du essai de pompage par Theim:

$$s = 0{,}366\frac{Q}{T}\lg\frac{R}{r_p}$$

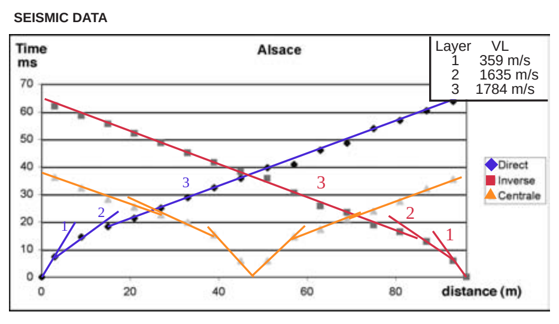
Captage AEP (Neuwiller)
Méthode: Theim

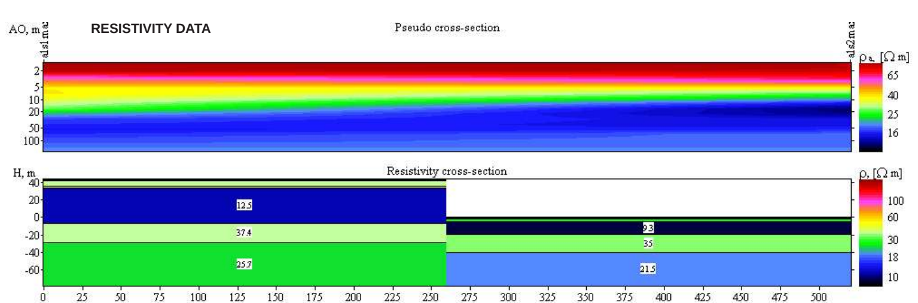
s	0,83	m
r_p	0,25	m
R	700	m
Q	4,79	m3/jour
T	174,78	m2/jour
K	**8,64**	**m/Jour**
b	20	m

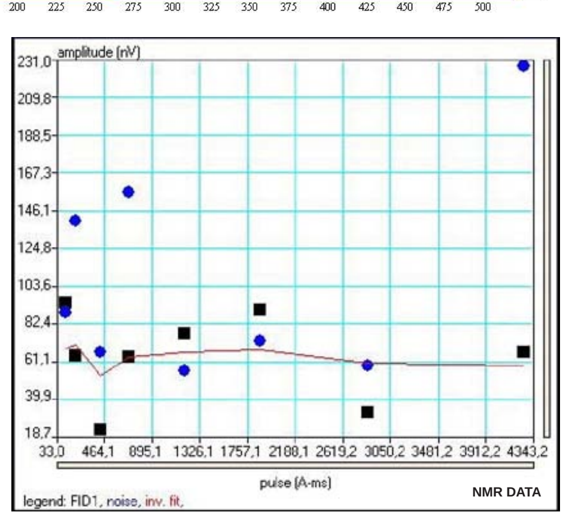
s = Rabat
r_p = Rayon du puit
R = Rayon d'influénce
Q = Débit
b = Épaisseur saturé
T = Transmissibité
K = Perméabilité

Pompage d'essai				
Durée partielle (heure)	Durée cumulée (heure)	Débit (m^3)	Niveau dynamique forage (m/repère à +0,45 m/sol)	Niveau dynamique pézomètre (m/repère à +1m/sol)
3	3	4,8	3,35	0,41
4	7	4,8	3,51	0,59
14	21	4,74	3,77	
2	23	5,13	3,76	0,83

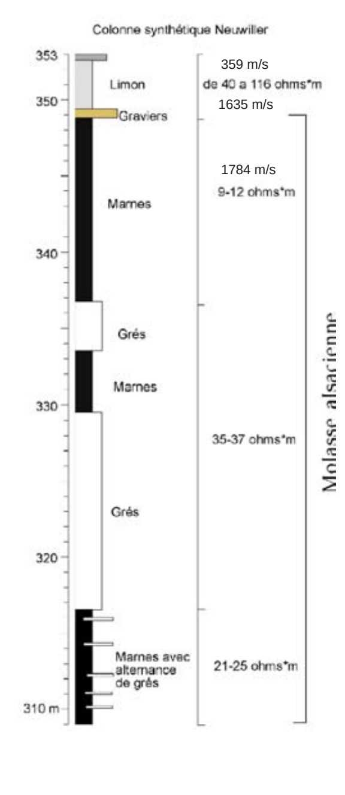
Hydrogeological data from pumping tests



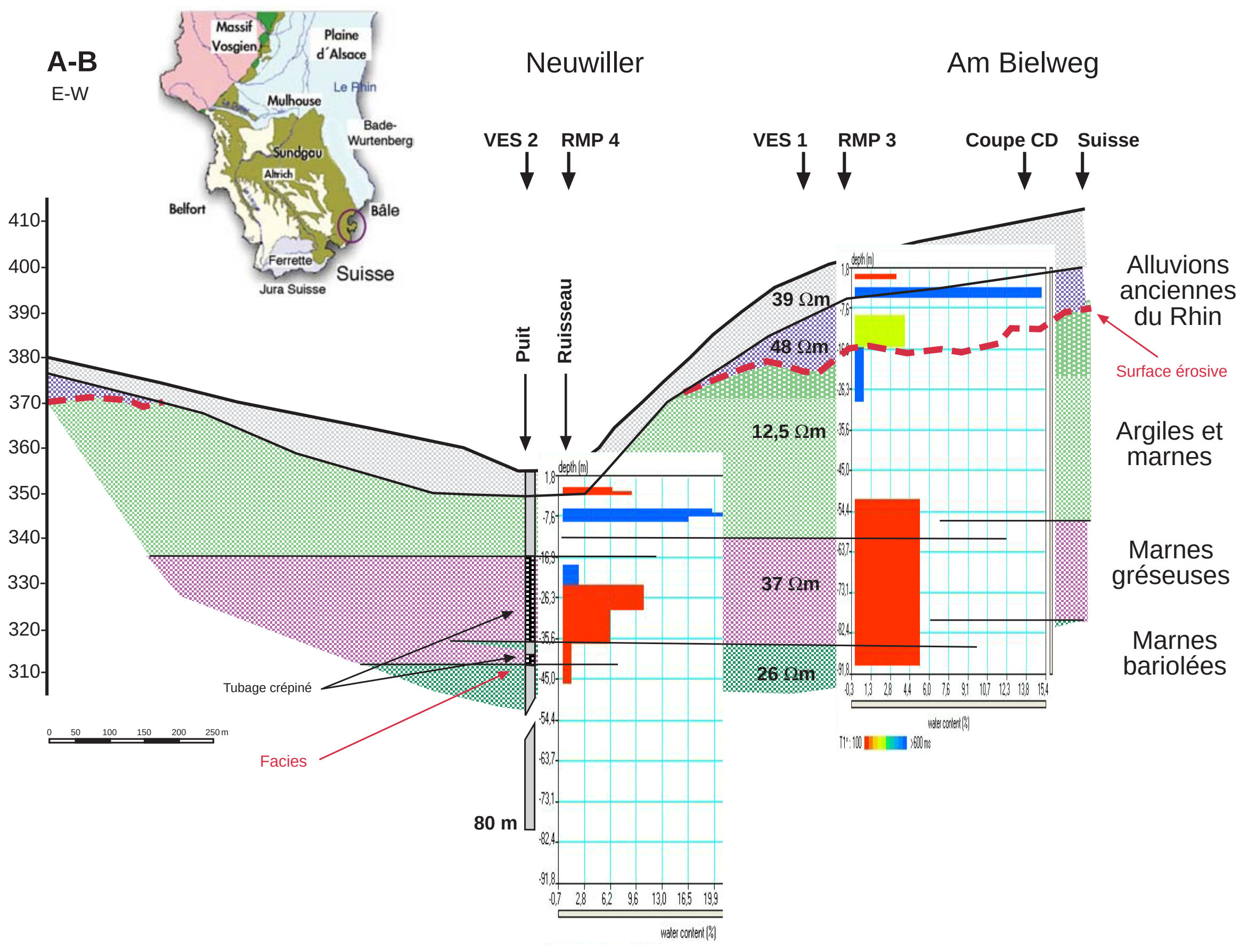




Hydrogeophysical data



Synthetic data



Conceptual model