GEOPHYSICAL INSTRUMENTS FOR GROUNDWATER INVESTIGATIONS

- ELECTRICAL RESISTIVITY SOUNDING:

SYSCAL equipment

- ELECTRICAL RESISITIVITY IMAGING:

SYSCAL Switch equipment

- MAGNETIC RESONANCE SOUNDING:

NUMIS equipment

IRIS instruments

IRIS Instruments:
designer, manufacturer and seller
of geophysical equipment for applied geology
Orléans, France

THE ELECTRICAL RESISTIVITY METHOD:

AN *INDIRECT* METHOD FOR DETECTING GROUNDWATER

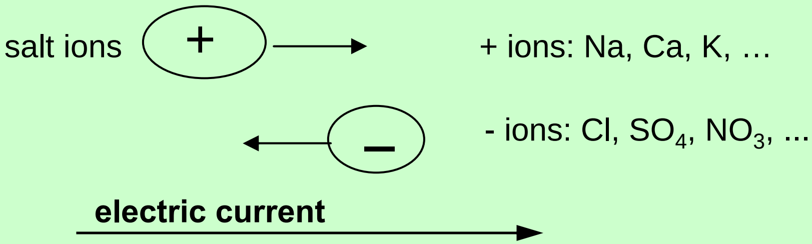
the Electrical Resistivity is a property of the ions of the salts dissolved in the groundwater

IRIS instruments

ELECTRICAL RESISTIVITY METHODS
for groundwater investigations

THE ELECTRIC CURRENT

FLOWS INTO THE GROUND THANKS TO THE IONS
OF THE SALTS DISSOLVED IN THE WATER

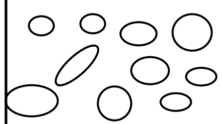
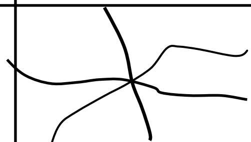
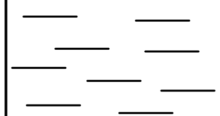


THE RESISTIVITY OF ROCKS DEPEND ON:

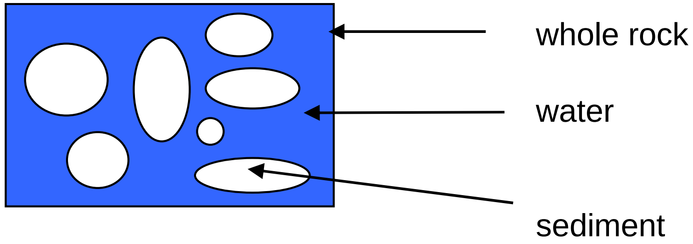
- THE WATER CONTENT (porosity)
- THE RESISTIVITY OF THE WATER
- THE CLAY CONTENT
- THE CONTENT IN METALLIC MINERALS

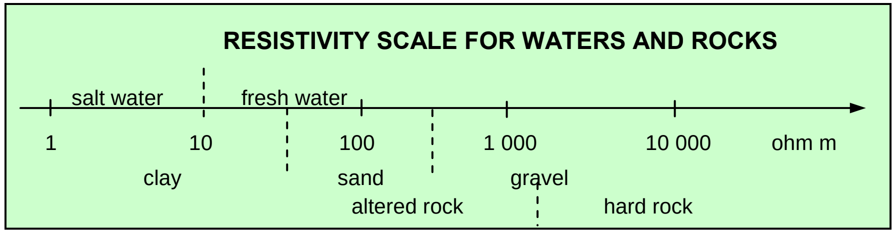
VALUES OF RESISTIVITY OF ROCKS:

0.1 ohm.m	SALTED WATER
1 ohm.m	MASSIVE SULPHIDE
10 ohm.m	CLAY
100 ohm.m	SAND, MARL
1 000 ohm.m	DRY SAND, LIMESTONE
10 000 ohm.m	HARD GRANITE, BASALT

TYPE OF POROSITY	TYPE OF WATER	TYPE OF ROCK	
matrix	free		sand, gravel
fracture	free		limestone, sandstone
adhesion	bound		clay

ELECTRICAL RESISTIVITY METHODS for groundwater investigations

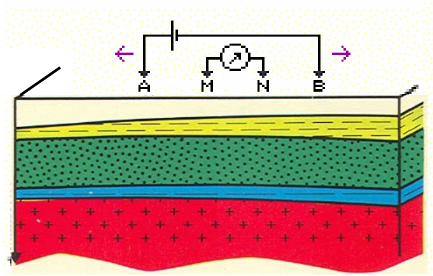




ROCK RESISTIVITY = F x WATER RESISTIVITY

F = Formation Factor = a / (porosity)^N

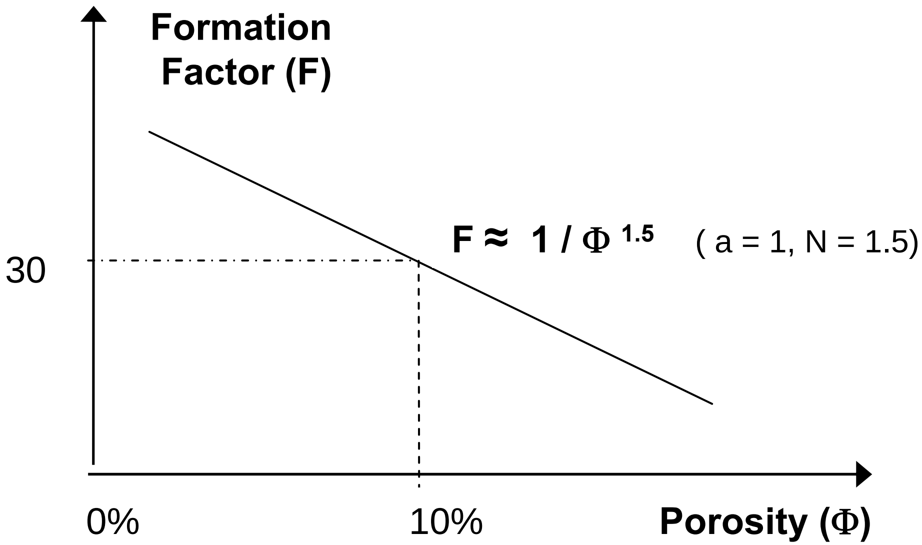
(ARCHIE FORMULA for non-clayey formations)



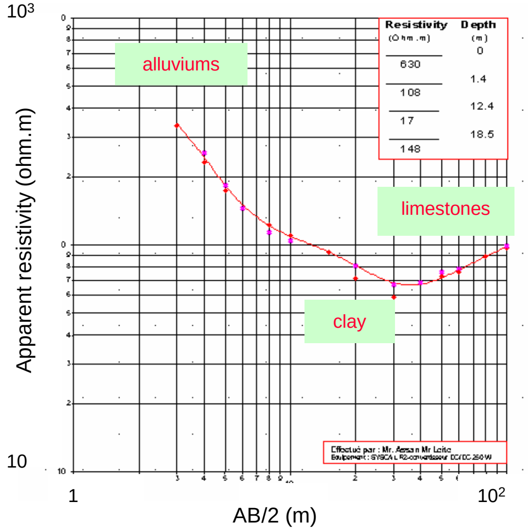
resistivity (ohm.m)

=

Rho = K x V_{MN} / I_{AB}



1D RESISTIVITY SOUNDING

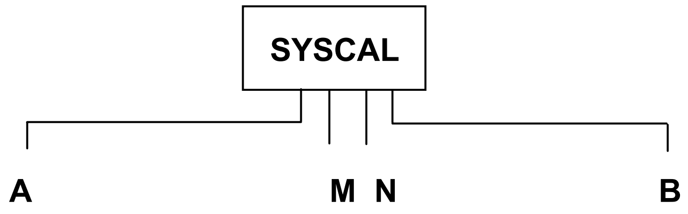


CLASSICAL RESISTIVITY AND MULTI-ELECTRODE RESISTIVITY

CLASSICAL RESISTIVITY

2 (A, B) electrodes : current transmission

2 (M, N) electrodes : potential measurement

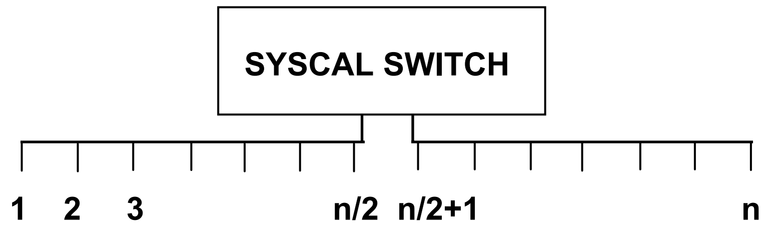


MULTI-ELECTRODE RESISTIVITY

"n" electrodes (n = 48, 72, 96, …)

successively "current" or "potential"

aim : to save time in the acquisition



$$\textbf{APPARENT RESISTIVITY} = \text{coefficient (A, B, M, N)} \times \frac{\text{(M, N) potential}}{\text{(A, B) current}}$$

THE SYSCAL RESISTIVITYMETER RANGE

SYSCAL type	power W	voltage V	channel number	electrode number (imaging mode)	electrode spacing (imaging mode)
Kid	25	200	1	24	3m
Junior	100	400	1	48, 72	5m
R1 Plus	200	600	1	48, 72	5, 10m
Pro	250	800	10	48, 72, 96	5, 10m

SYSCAL Kid

SYSCAL Junior / R1 Plus

SYSCAL Pro

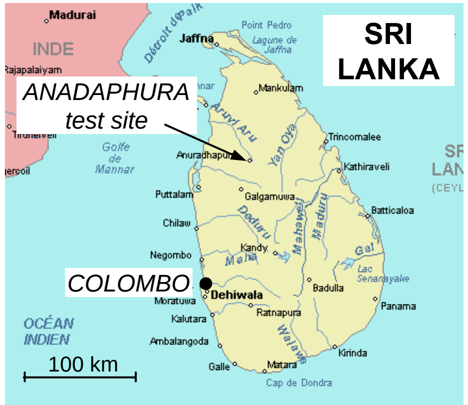
FRACTURE DETECTION IN A BASEMENT

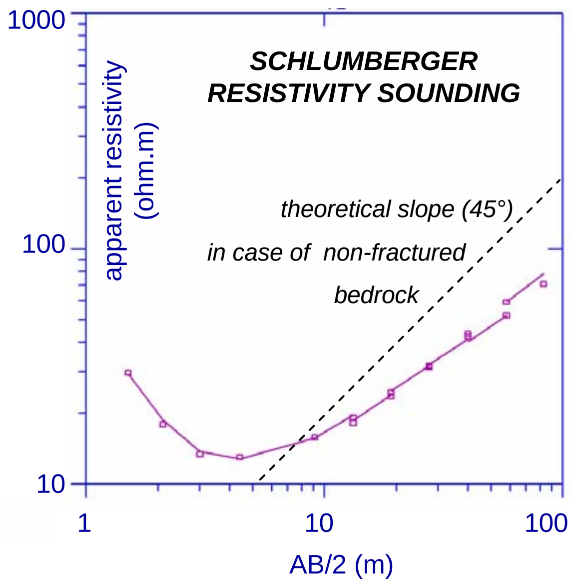
end user:
Groundwater Supply & Drainage

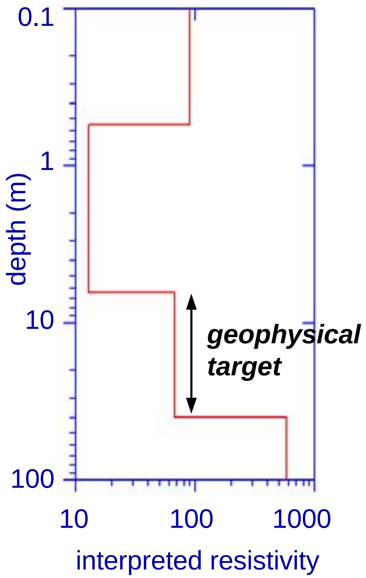
project:
fresh water supply to population

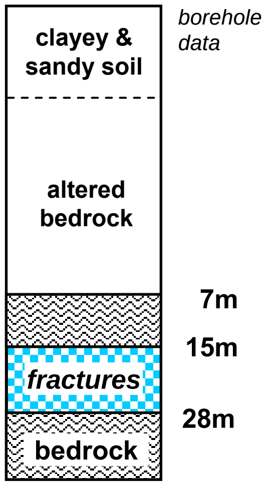
equipment:
5 units SYSCAL Junior

electrode array:
Schlumberger vertical electrical sounding (VES)







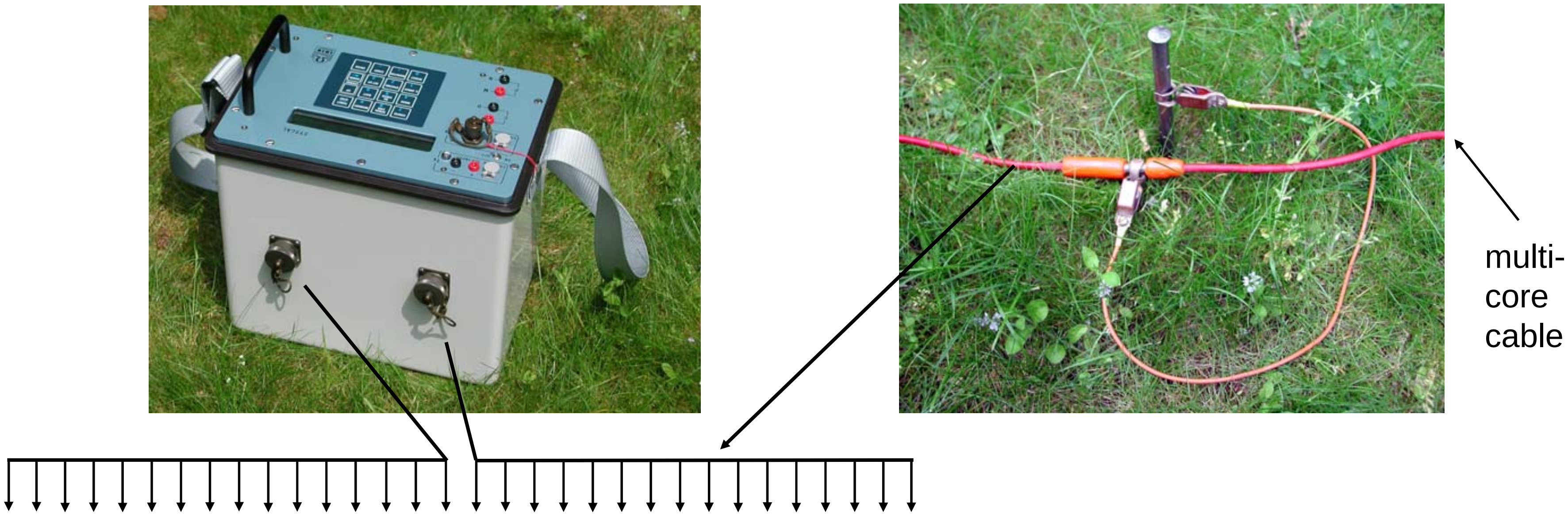


bedrock = precambrian gneiss & migmatite

borehole yield: 42 m^3/h water conductivity: 800 µS/cm (max accepted: 2 500 µS/cm)

(aquifer resistivity= 80 Ω.m) & (water resistivity= 12 Ω.m) ➔ (equivalent porosity ≈ $\sqrt{R_a / R_w}$ = 38%)

MULTI-ELECTRODE RESISTIVITY IMAGING



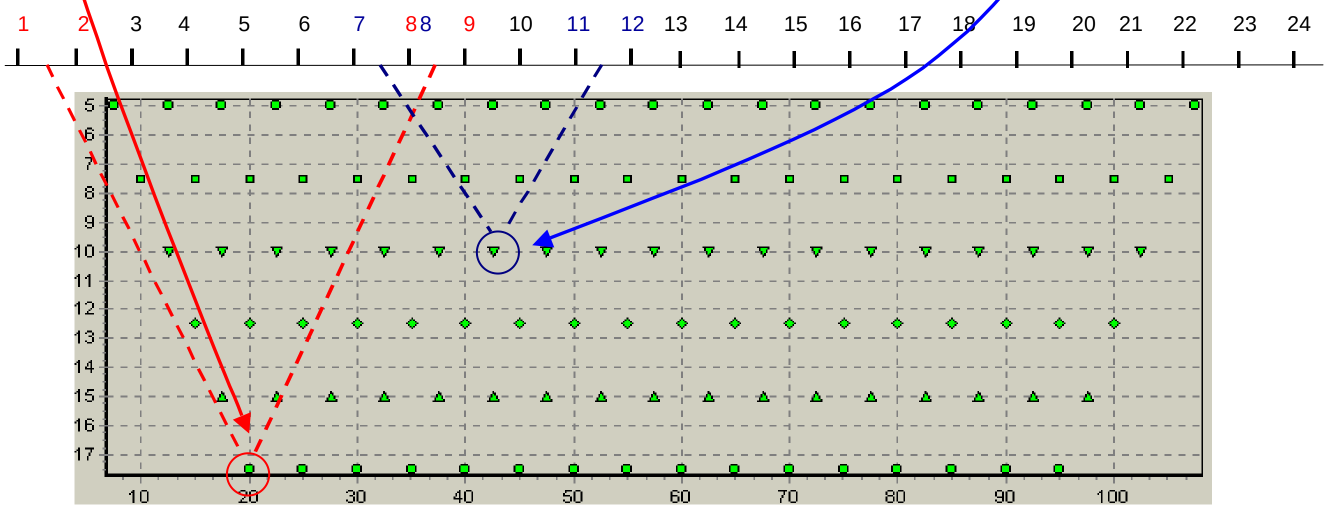
- Direct connection of cables to **SYSCAL** unit
- Seismic type of cables (reversible)
- 24, 48, 72, 96 electrodes with fixed spacing, + ***Switch Plus*** extension units
- internal memory for the storage of the sequence file and of the data file

DEFINITION OF A READING SEQUENCE

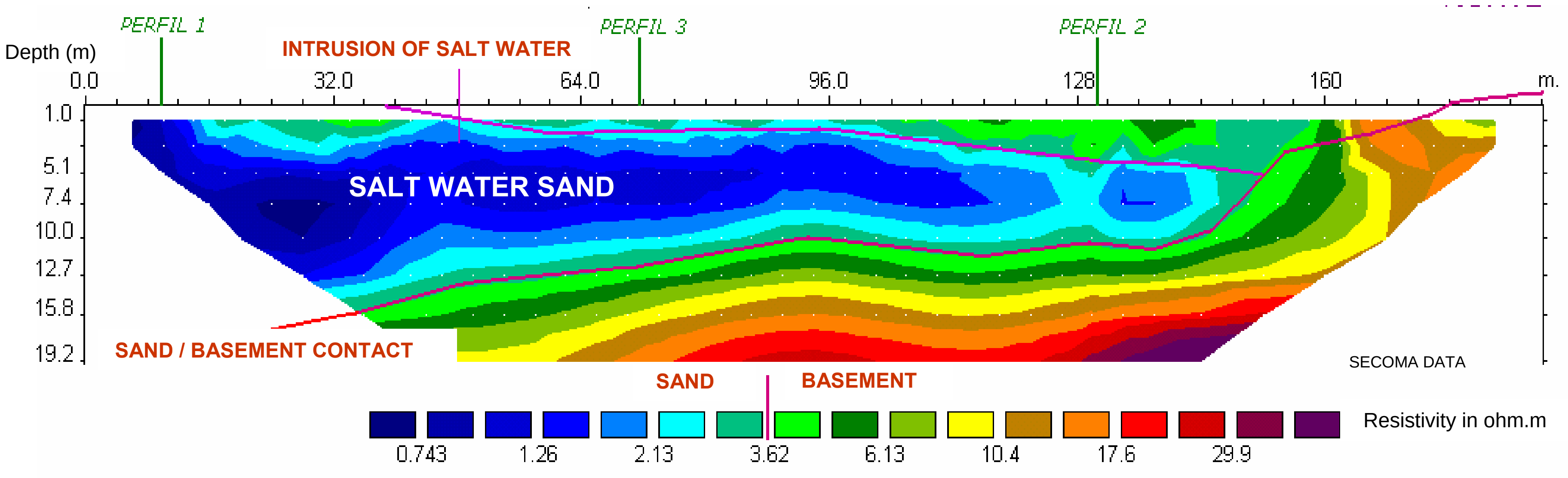
A, B : electrodes for current transmission

#	A	B	M	N
1	1	2	3	4
2	1	2	4	5
3	1	2	5	6
4	1	2	6	7
5	1	2	7	8
6	1	2	8	9
7	2	3	4	5
8	2	3	5	6
.				
.				
.				
37	7	8	9	10
38	7	8	10	11
39	7	8	11	12
.				
.				
.				

M, N : electrodes for potential measurement



SALT WATER INTRUSION WITHIN SEDIMENTS



EQUIPMENT: SYSCAL R1 Plus *SWITCH*-48

CONFIGURATION: Schlumberger-Wenner

NUMBER OF READINGS: 362

SPACING BETWEEN ELECTRODES: 4 m

SITE: Spain

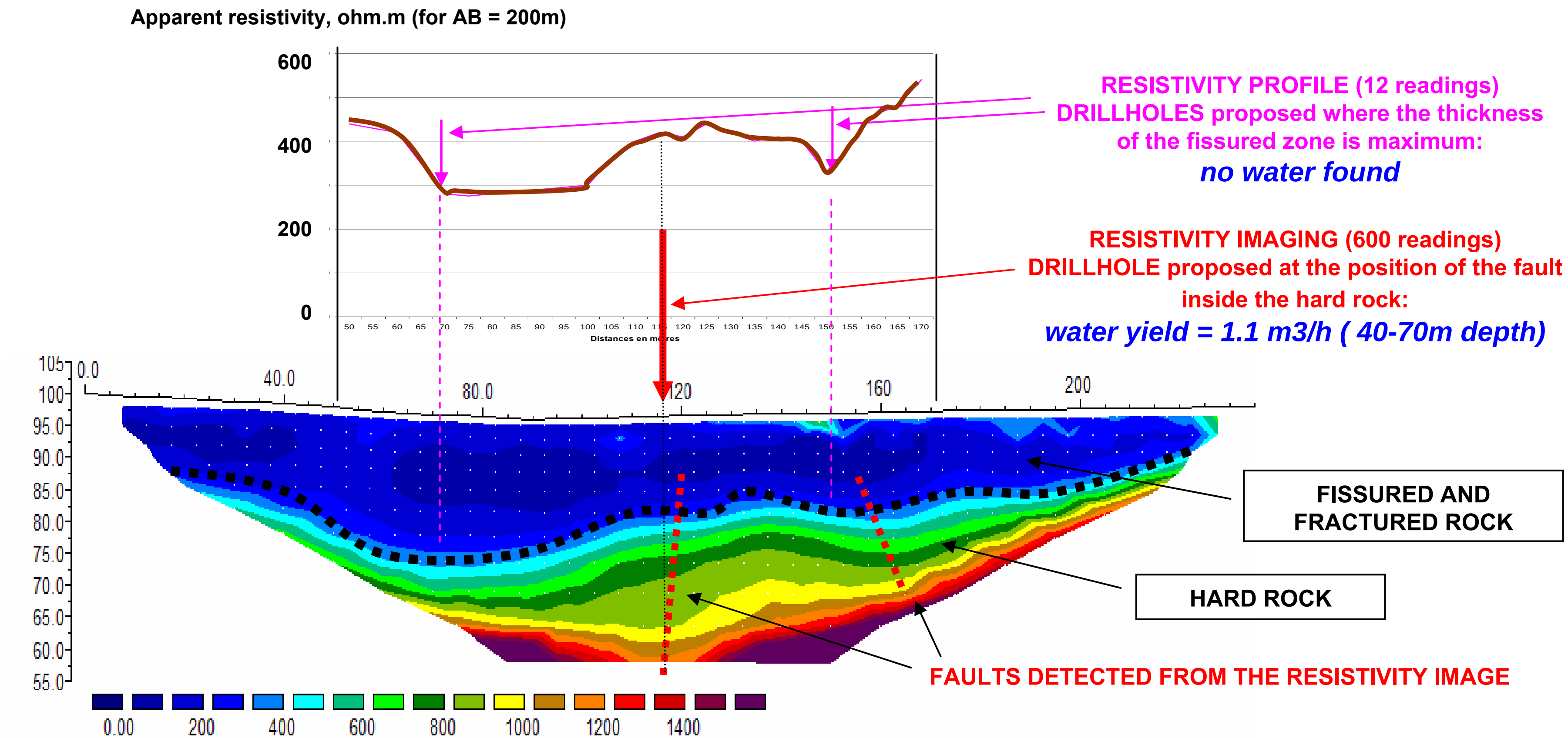
GEOLOGY: Coastal sand

DURATION OF MEASUREMENTS: 1 hour (system set-up + reading taking)

salt water sand: less than 1 ohm.m

non satured zone: about 20 ohm.m

FAULT DETECTION WITHIN A BASEMENT



EQUIPMENT: SYSCAL R1 Plus *SWITCH* 48

CONFIGURATION: Wenner-Schlumberger

NUMBER OF READINGS: 600

SPACING BETWEEN ELECTRODES: 5 m

SITE: East part of CHAD, Ouaddaï area

GEOLOGY: hard rock area with fissures, fractures and faults

DATA: GEOGEOPHY / HYDROTECH

THE MAGNETIC RESONANCE METHOD (MRS):

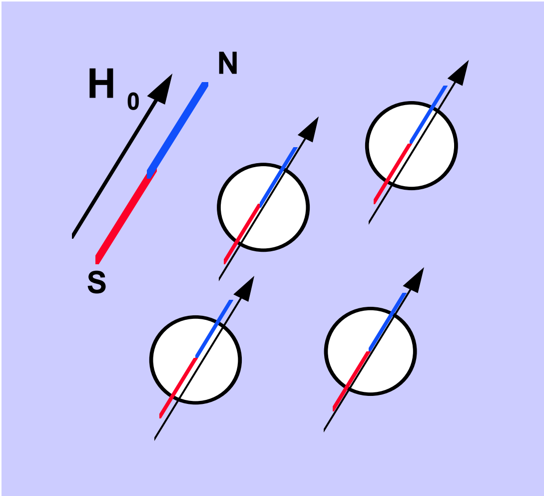
A *DIRECT* METHOD FOR DETECTING GROUNDWATER

the Magnetic Resonance is a property of H protons of H_2O groundwater molecules

IRIS instruments

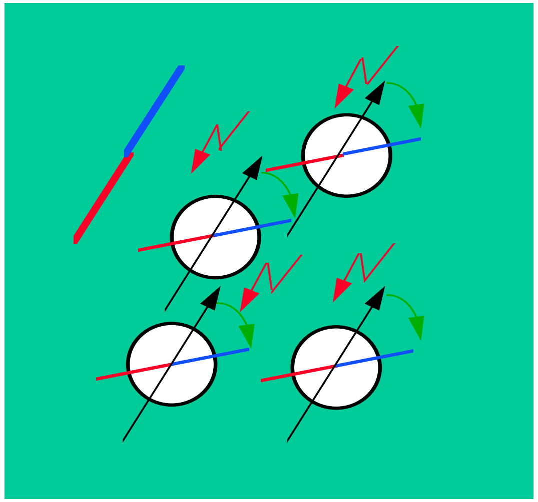
MAGNETIC RESONANCE METHOD (MRS): WATER EXCITATION

1) **Natural equilibrium**



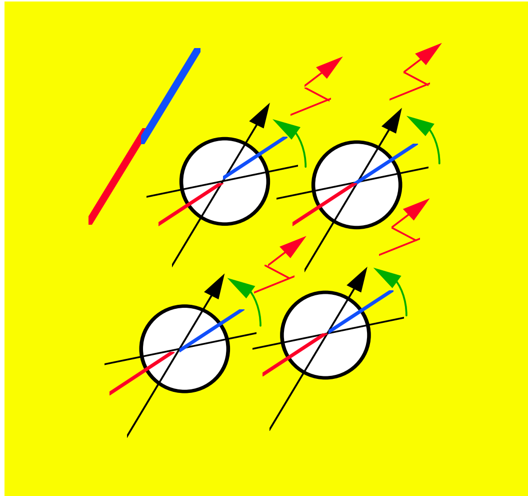
At the equilibrium, water molecules are orientated towards the magnetic North

2) **Wave transmission**



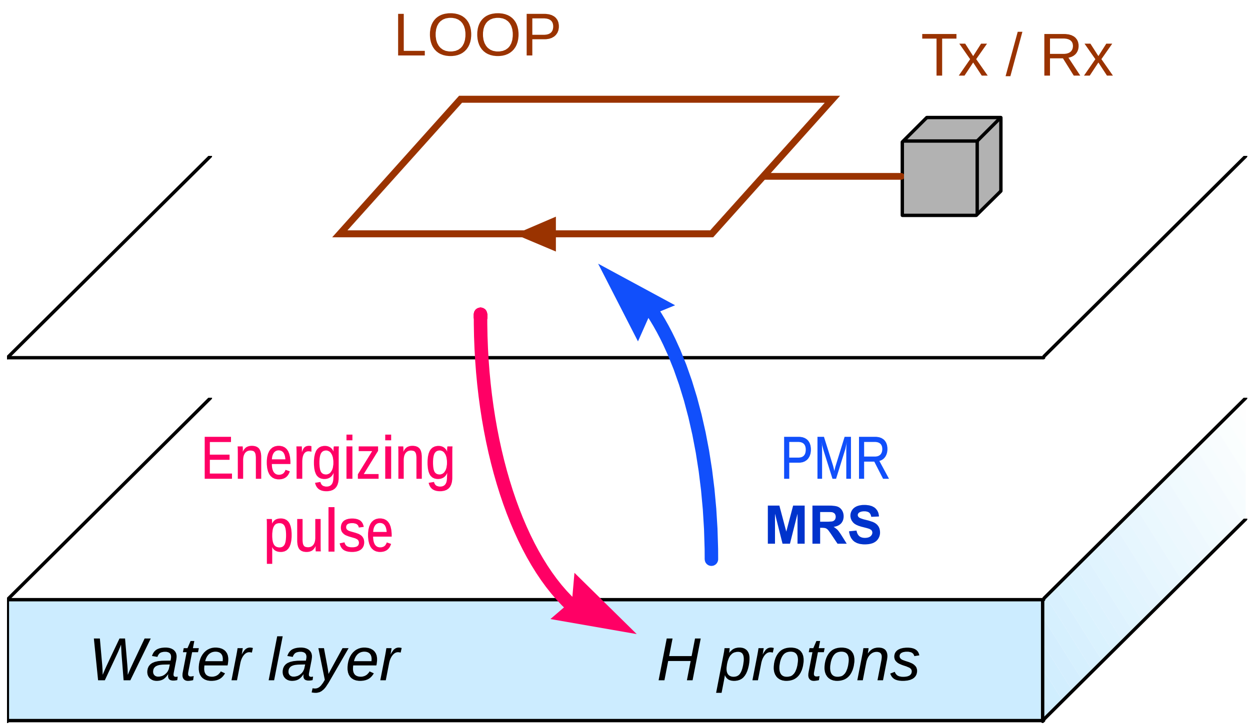
Waves transmitted at a specific frequency excite the water molecules

3) **Signal reception**



When the waves are stopped, the water transmits a magnetic signal recorded on the surface, during the come back to equilibrium

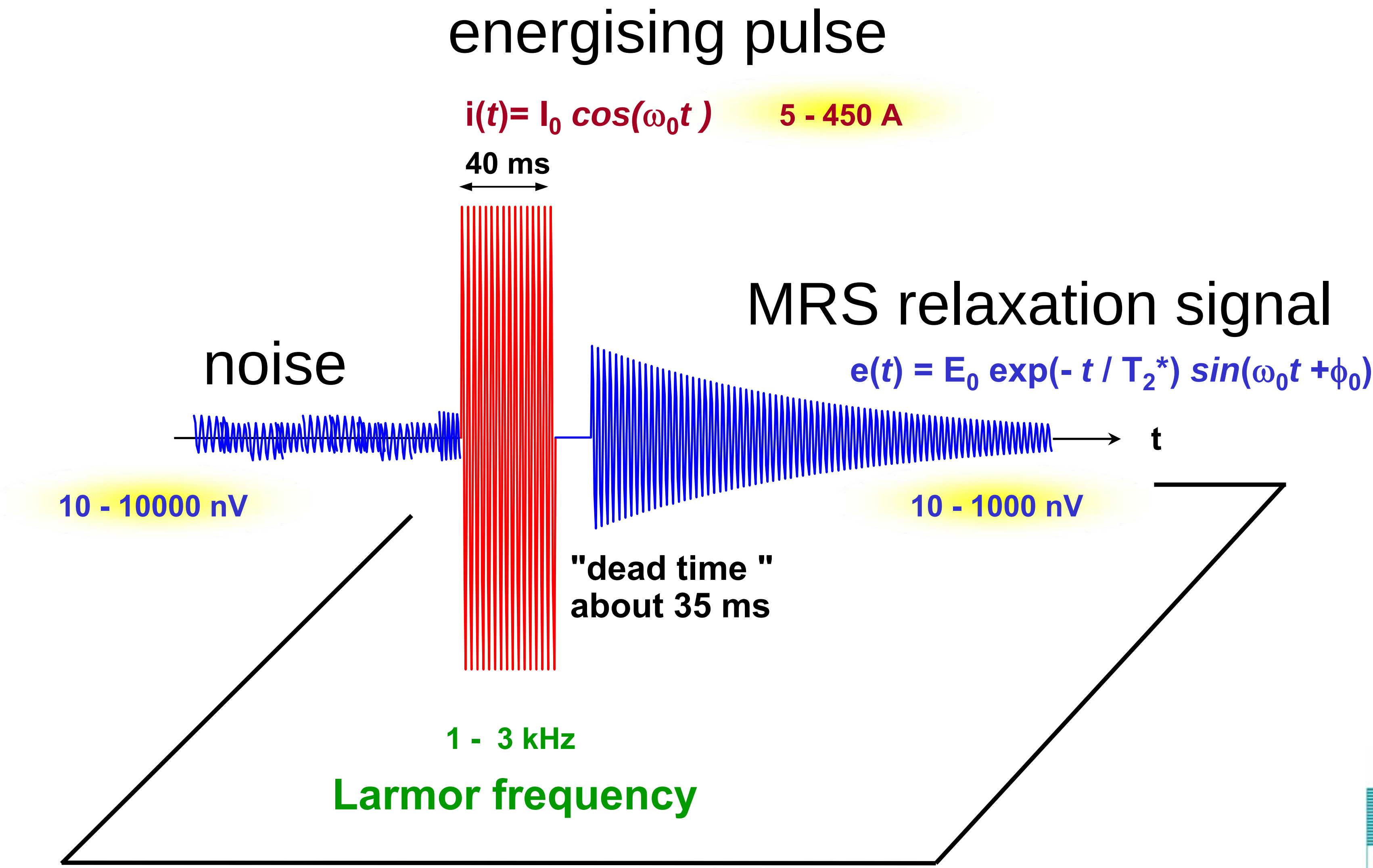
MAGNETIC RESONANCE METHOD (MRS): FIELD SET-UP



EARTH MAGNETIC FIELD: **B_0 (nT)**

EXCITATION FREQUENCY: **F_0 (Hz) = 0.04258 B_0 (nT)**

MAGNETIC RESONANCE METHOD (MRS): PRINCIPLE OF MEASUREMENT



MAGNETIC RESONANCE METHOD (MRS): MEANING OF PARAMETERS

E_0 : Initial amplitude (nV)

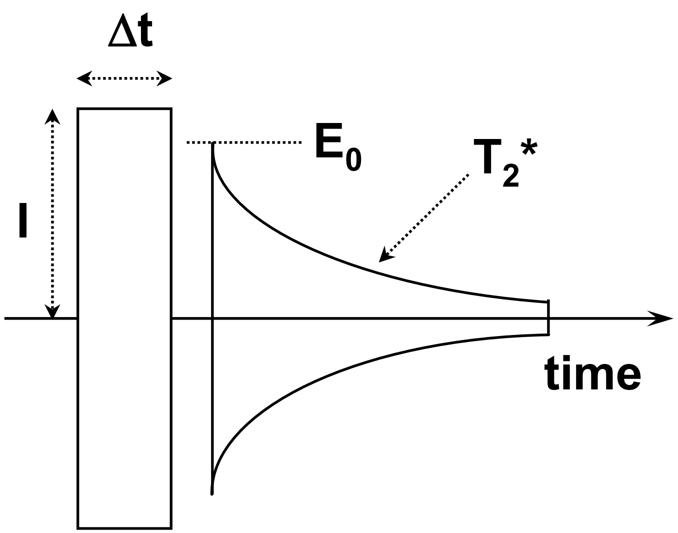
Proportional to the **water content** (%)

T_2^* : Decay time constant (ms)

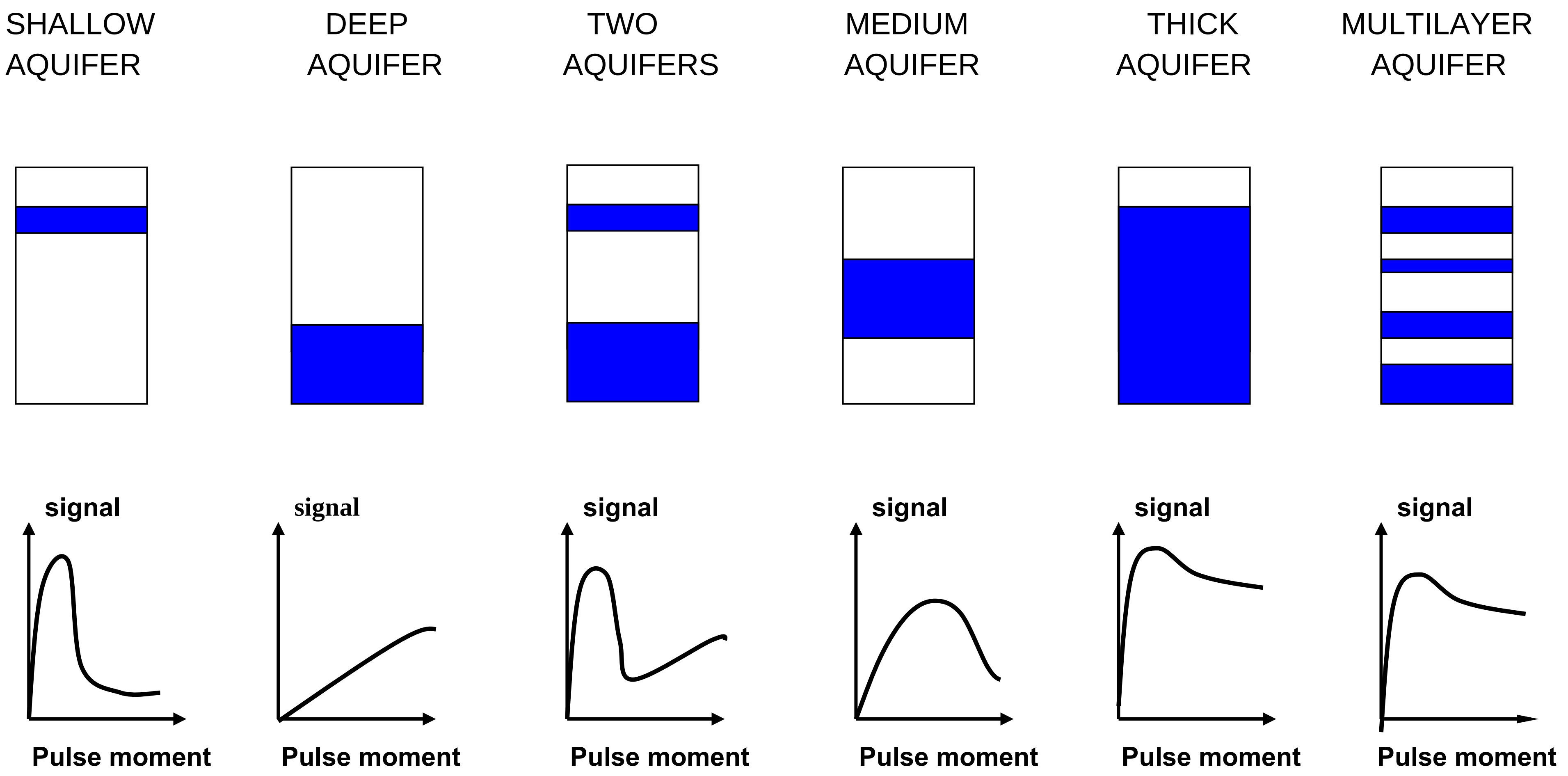
Related to the **mean pore size**

I.Δt : Pulse moment (A.ms)

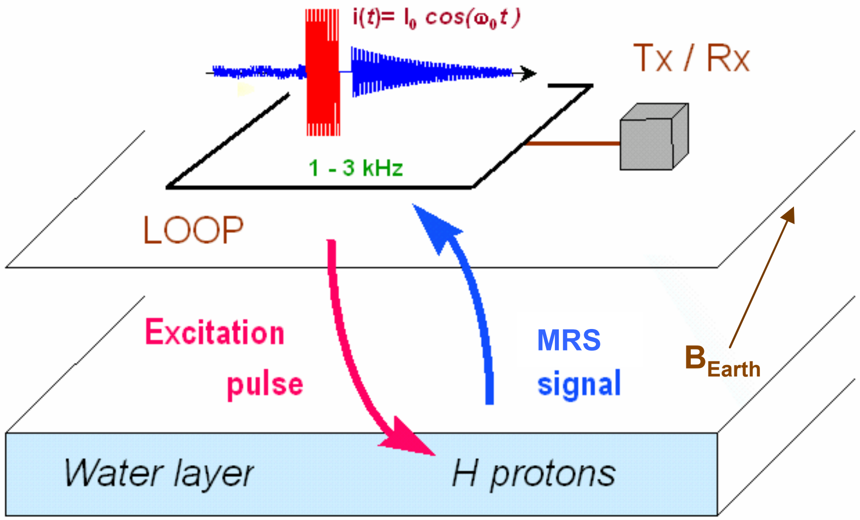
Related to the **investigation depth**



MAGNETIC RESONANCE METHOD (MRS): THEORETICAL SOUDING CURVES



MAGNETIC RESONANCE SOUNDINGS & HYDROGEOLOGICAL PARAMETERS



POROSITY scale

0%: hard rock

1%: fractured rock

10%: sand, alteration

30%: gravel, alluvium

PERMEABILITY scale

10^{-9} m/s: clay

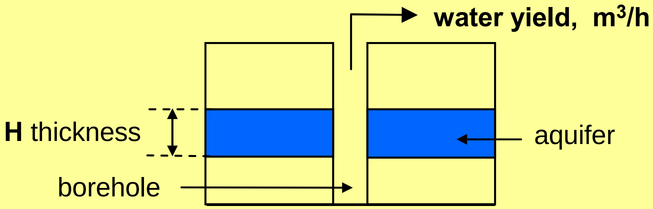
10^{-6} m/s: low

10^{-3} m/s: high

10^{0} m/s: extreme

TRANSMISSIVITY:

permeability x thickness in m²/s



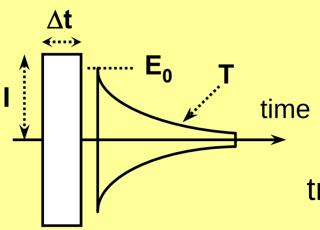
WATER YIELD:

proportional to the transmissivity of the aquifer layer, in m³/h

yield = k x transmissivity

ex: 10 m³/h (or about 2.8 l/s)

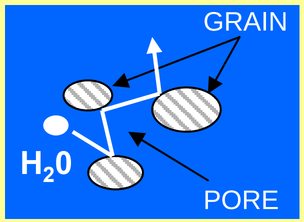
ESTIMATION OF HYDROGEOLOGICAL PARAMETERS FROM MRS DATA



porosity $\approx$ E_0

permeability $\approx$ $E_0 \cdot T^2$

transmissivity $\approx$ $H \cdot E_0 \cdot T^2$

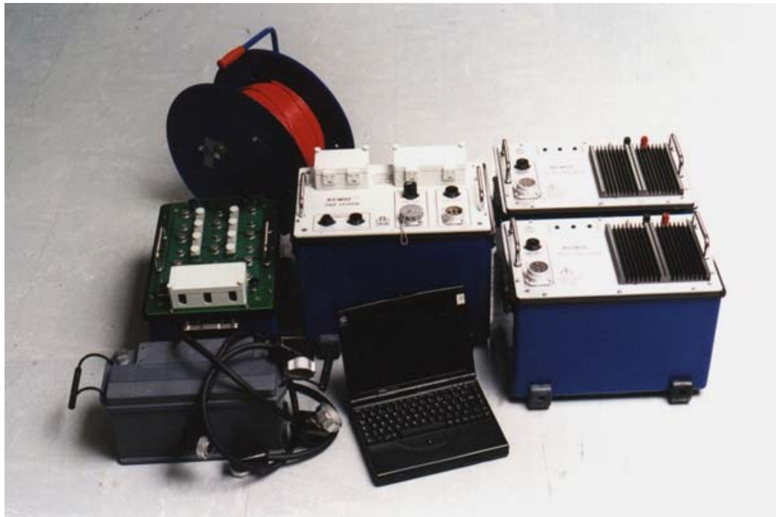


low permeability
➔small pores
➔quick decrease of energy
➔ short time constant

THE NUMIS MAGNETIC RESONANCE EQUIPMENT RANGE

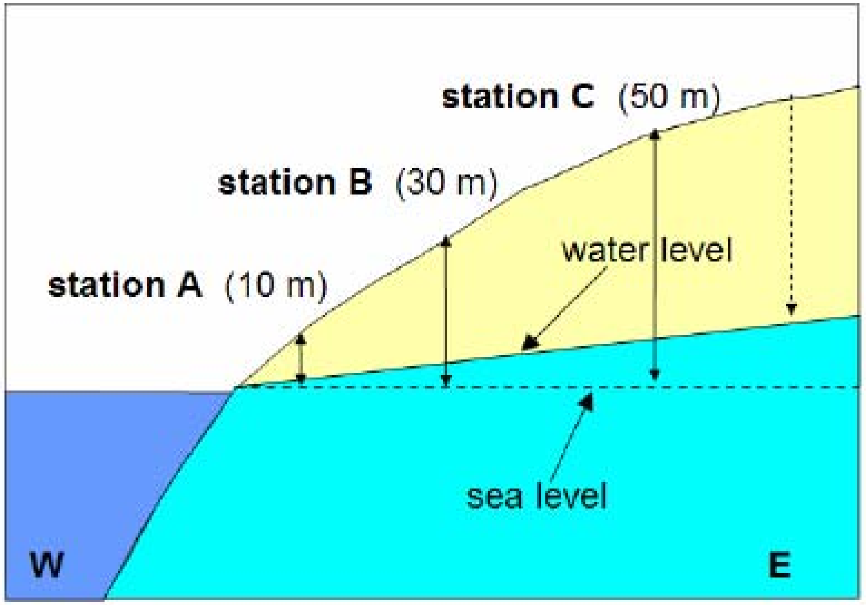
NUMIS type	current (A)	voltage (V)	maximum investigation depth (m)
Lite	100	1 500	50
Plus (1 converter)	300	3 000	100
Plus (2 converters)	450	4 000	150

NUMIS Lite



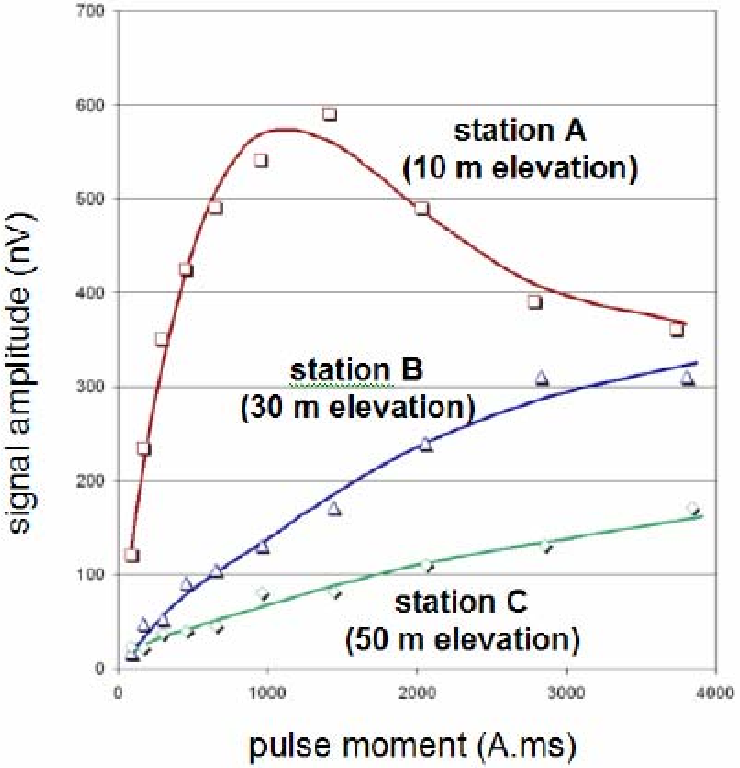
NUMIS Plus

MRS SOUNDING ON A SAND DUNE IN FRANCE

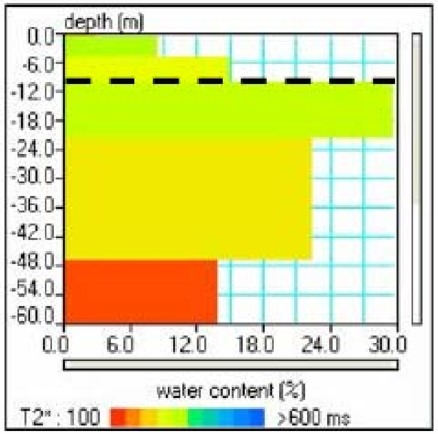


IRIS instruments

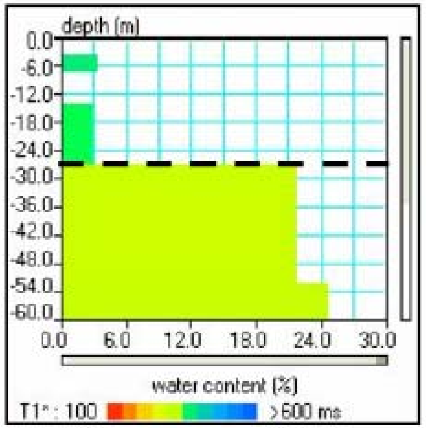
MRS SOUNDING ON A SAND DUNE IN FRANCE



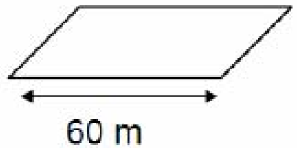
Pyla sand dune, France, NUMIS Lite

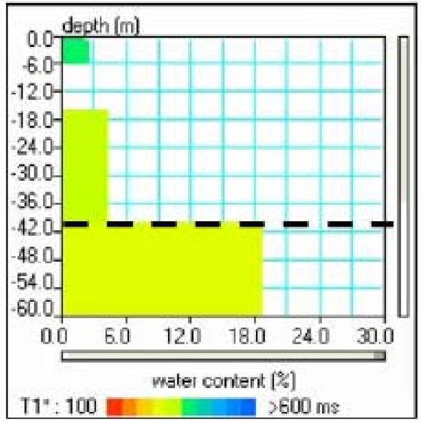


station A (10 m)



station B (30 m)

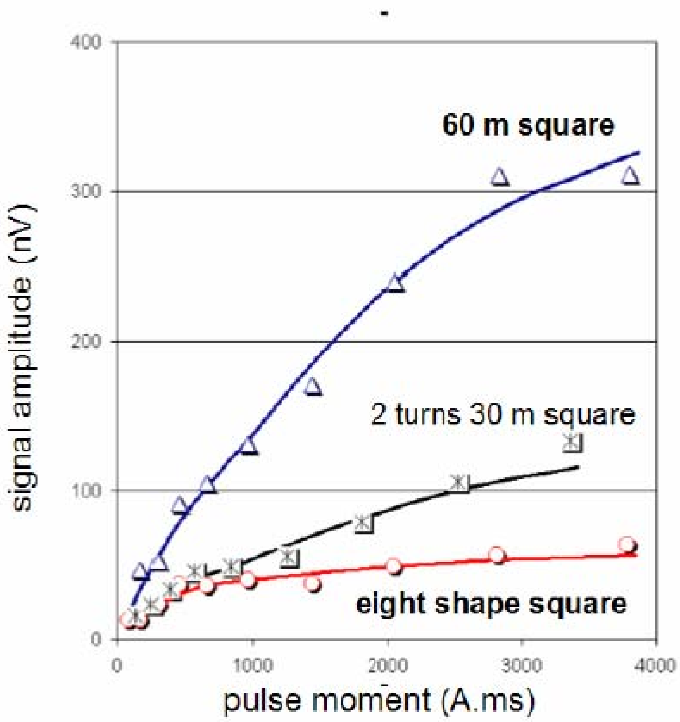


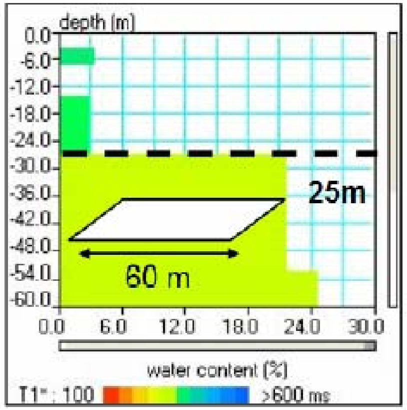


station C (50 m)

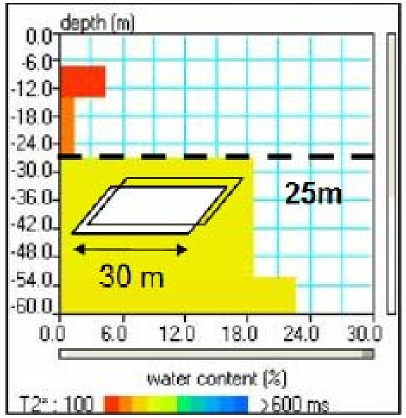
MRS soundings for a 60m side square loop,
at various elevations:
station A (10m), station B (30m), station C (50m)

MRS SOUNDING ON A SAND DUNE IN FRANCE



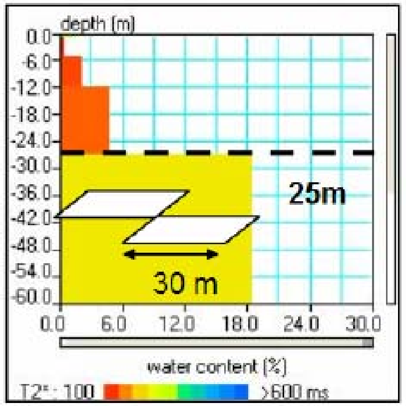


60 m square loop



2 turns 30 meters square loop

interpreted water level



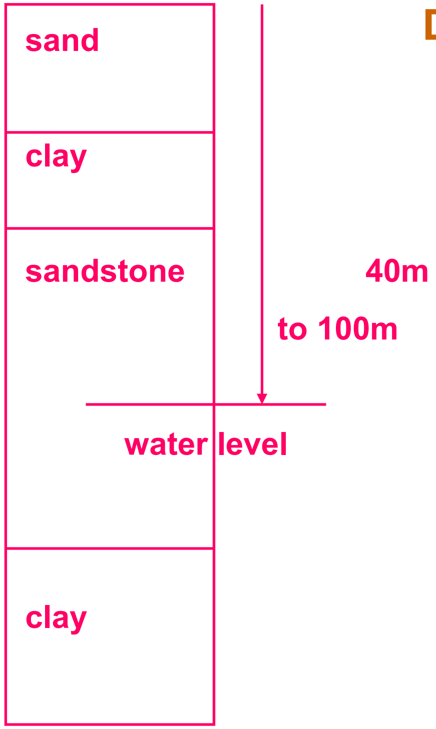
eight shape square loop

Pyla sand dune, France, NUMIS Lite

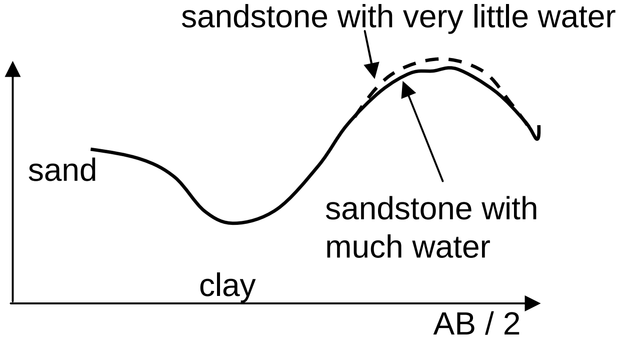
MRS soundings with various loop shapes,

at the same elevation (station B, 30m)

MRS SOUNDING IN SANDSTONES IN MAURITANIA

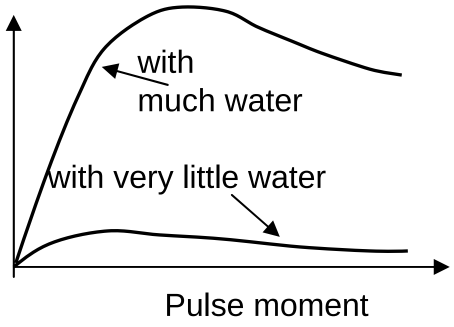


DC RESISTIVITY



water resistivty = 100 ohm.m
sand resistivity ~ Water resistivity / (porosity)²
= 2 500 ohm.m
clay resistivity = 20 ohm.m

MAGNETIC RESONANCE SIGNAL



loop dimensions = 100 x 100 m
signal amplitude = 200 nanoVolts
porosity = 20%
water depth = 40m
water thickness ~ 60m

NO DISTINCTION DRY / WET

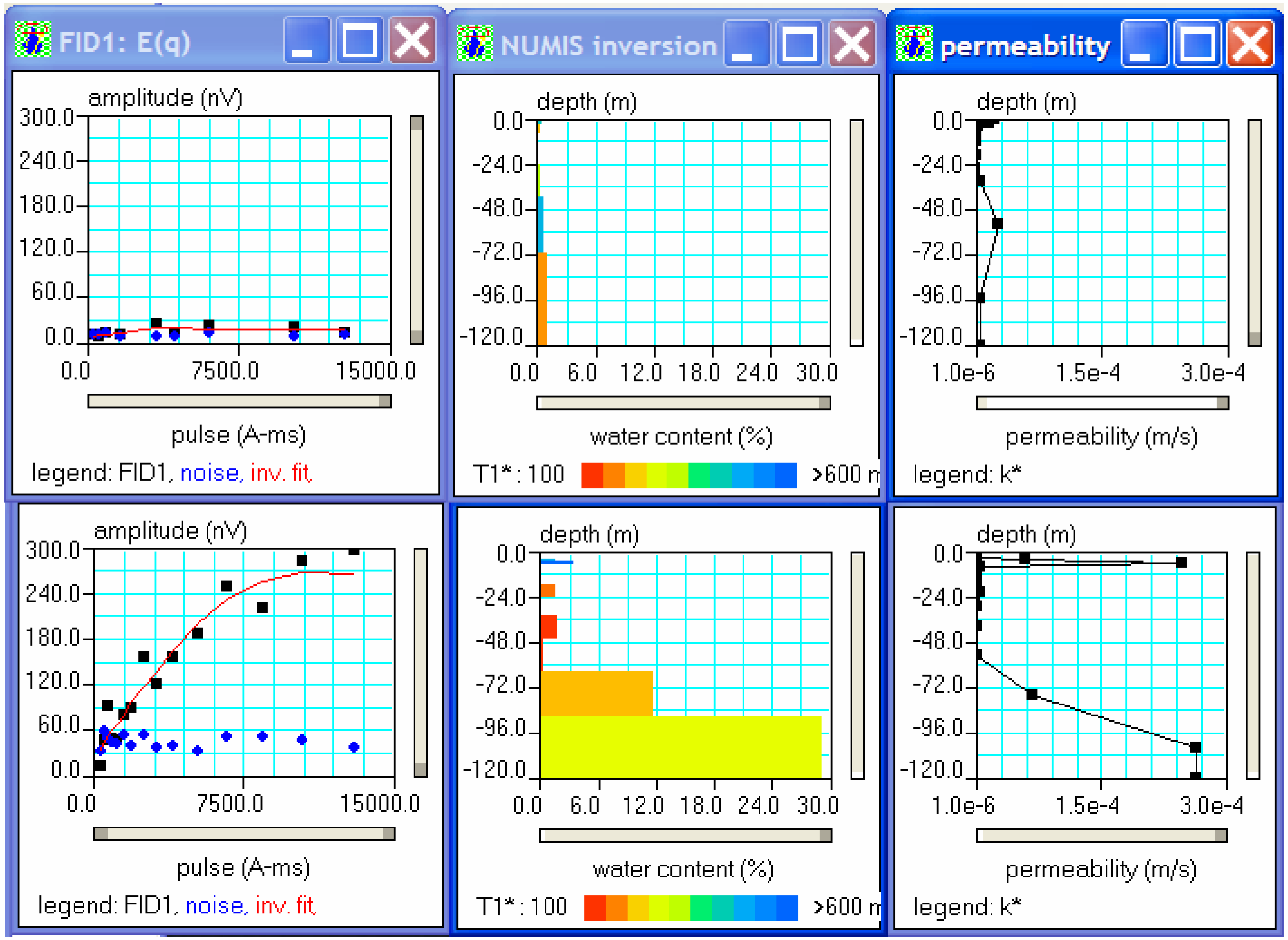
DC Sounding

CLEAR DISTINCTION DRY / WET

MR Sounding

IRIS instruments

MRS SOUNDING IN SANDSTONES IN MAURITANIA

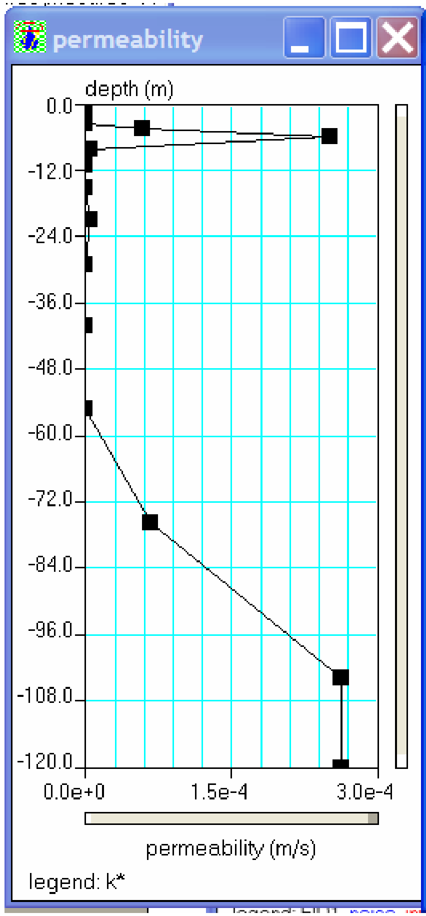


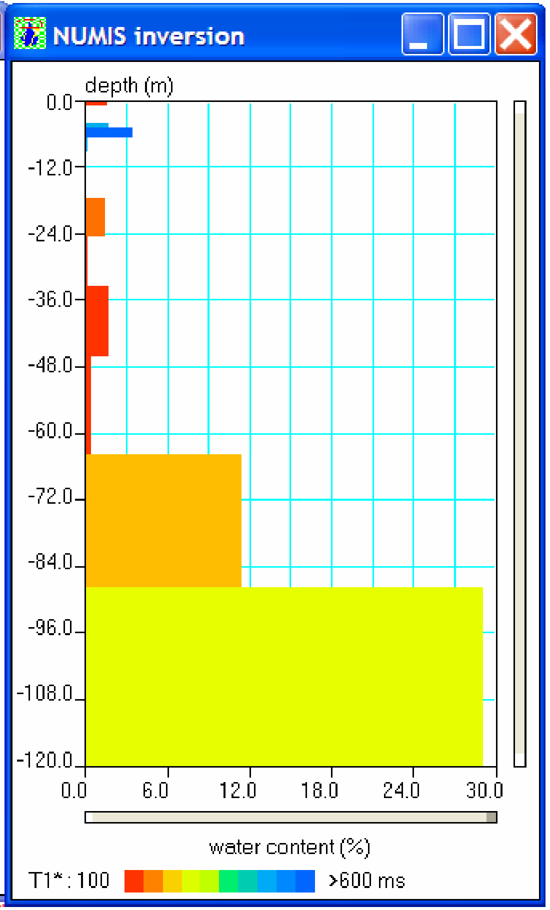
**MRS ref N19,
located
in the <u>dry area</u>**

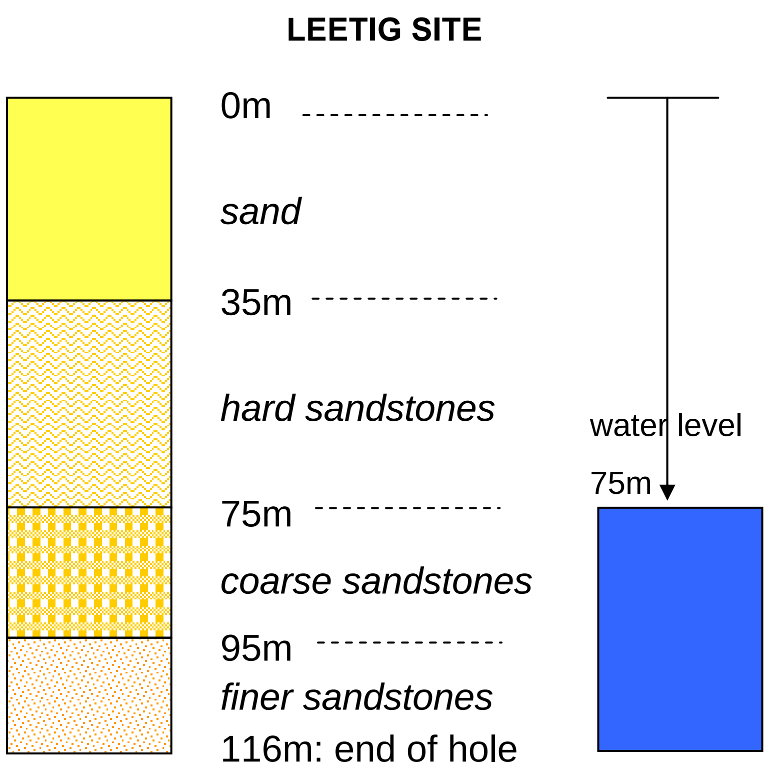
**MRS ref N31,
located
in the <u>aquifer area</u>**

(Leetig site)

MRS SOUNDING IN SANDSTONES IN MAURITANIA







Borehole airlift yield: 14 m^3/h

MRS transmissivity: about 0.01 m²/s *(estimated before any calibration)*

THE MAGNETIC RESONANCE METHOD (MRS):

A NEW TOOL FOR GEOPHYSICISTS FOR DETECTING GROUNDWATER

SOME LIMITATIONS OF MRS:

- SENSITIVITY TO EM NOISE (power lines, …)
- DIFFICULTY TO APPLY IN MAGNETIC ROCKS (volcanics, …)
- MAXIMUM DEPTH: about 150m

IRIS instruments

THE SUCCESS OF GEOPHYSICS REQUIRES TO USE EACH TIME THE METHOD(S) BEST SUITED TO THE SPECIFICITIES OF THE SITES TO INVESTIGATE

IRIS instruments