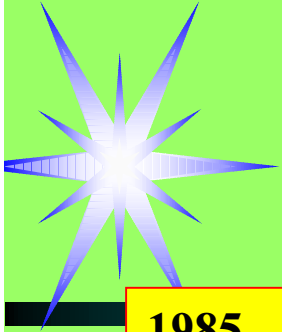


**LE PROGRESS RECENT DE LA SISMIQUE HAUTE RESOLUTION:
OUTIL COMPLEMENTAIRE EN GENIE CIVIL POUR LA RECONNAISSANCE
DU PROCHE SOUS-SOL**

Bogdan PIWAKOWSKI

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(IEMN DOAE UMR 9929 CNRS) 59651 Villeneuve d'Ascq, France
bogdan.piwakowski@ec-lille.fr*



Groupe Acoustique-Electronique, Ecole Centrale de Lille

Recherche depuis 1985

1985 Debut de la recherche : Demande de la Région Nord Pas de Calais

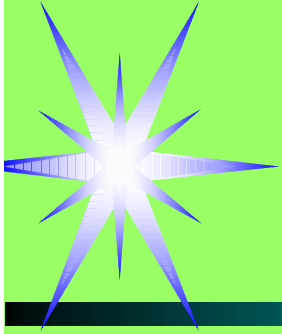
« est il possible de détecter des anciennes mines de craie »

1991 Démonstration de la faisabilité

**1992/1993 Validation par le Service Départemental (*Centre d'Inspection des
Carrières Souterraines de Douai*)**

Depuis 1992 :

- la mise au point du système d'imagerie sismique, sa validation, l'extension de la méthode à des applications différentes,
- 40 publications, reconnaissance internationale
- 15 contrats divers
- 3 thèses soutenues
- **collaborations** avec
- l'Université de Kansas (U.S.A), l'Université de Lausanne (Suisse), Université de Delft
- Académie des Mines de Cracovie (Pologne), l'USTLille, le LML Lille,
- le SDICS
- Le Laboratoire Central des Ponts et des Chaussées (LCPC),,
- l'INERIS (programme de recherche en cours)



Groupe Acoustique-Electronique, Ecole Centrale de Lille

Axes de Recherche

Imagerie sismique

**Modélisation
mathématique
par FEM (LML)**

**Developement du
materiel:**

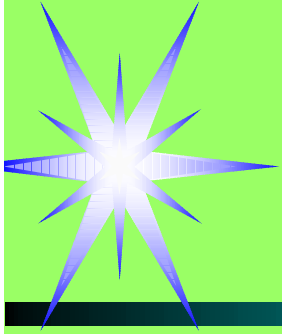
-Source betsy

-Source vibratoire

***-Radar acoustique
(en cours)***

Terrain

**Traitement
des signaux**



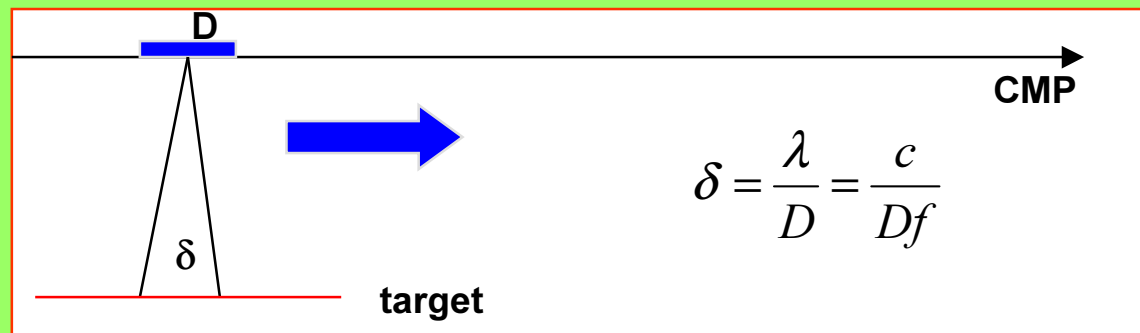
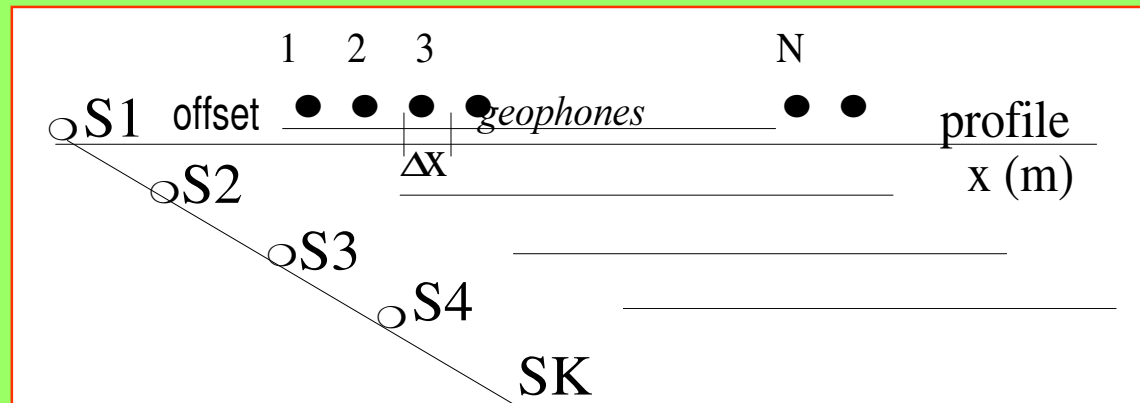
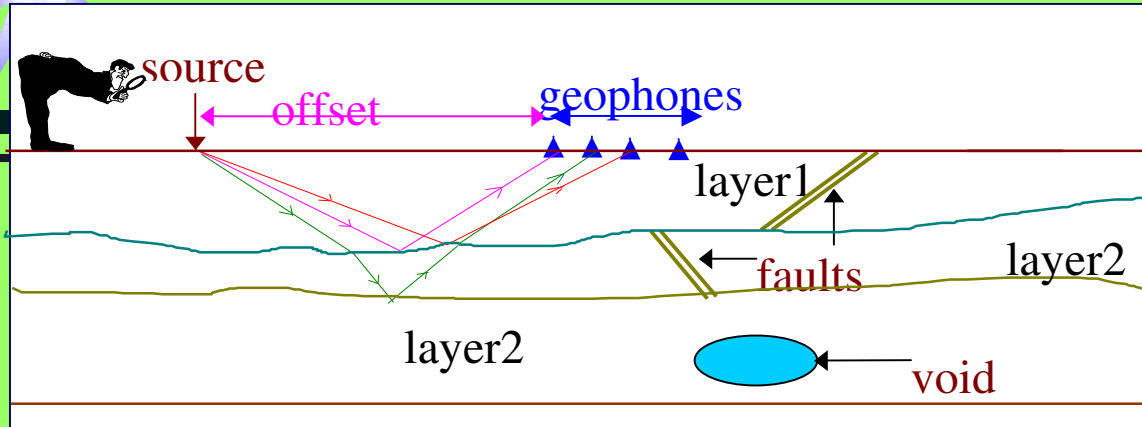
Plan :

- **Historique**
- **Principes et mise en oeuvre**
- **Exemples d'application**
 - Imagerie de la subsurface**
 - Détections des cavités**
 - Reconnaissance de l'état d'une cavité (saine-effondrée)**
 - Détection des terrains effondré**
 - Recherche archéologique**
 - Imagerie des failles de subsurface**
 - Recherche d'eau**
 - Imagerie des terrains après l'exploitation minière**
- **Conclusions**

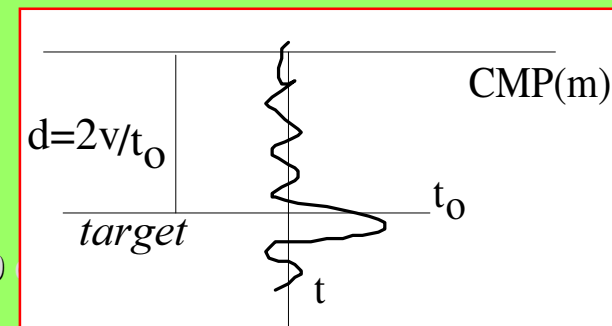
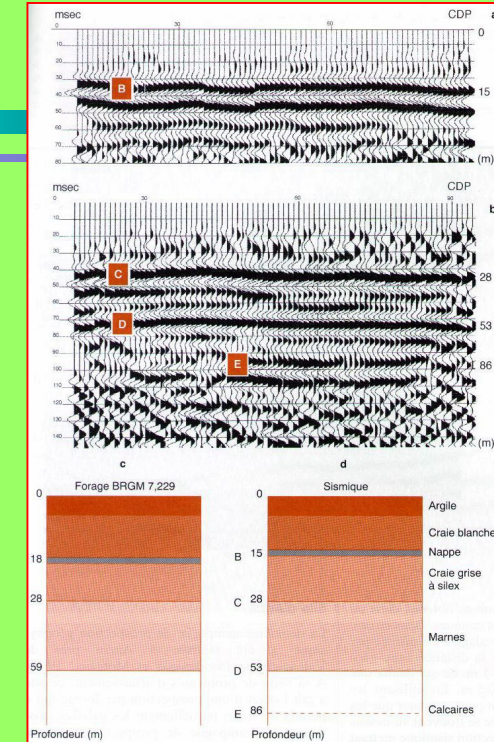
Field parameters and equipment



Mise en œuvre de la SHR : procédure



$$\delta = \frac{\lambda}{D} = \frac{c}{Df}$$



Mise en oeuvre

Sources



Betsygun Shotgun



Vibrateur



Chute de poids



Dynamite

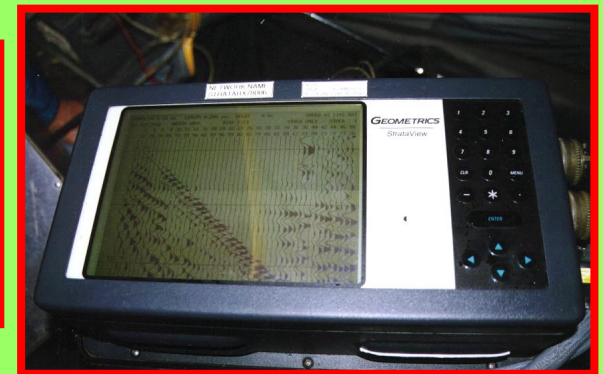
Profil sismique



Cable



Géophone



Sismographe

Stratigraphy of shallow subsurface: structure of cliff

50 m

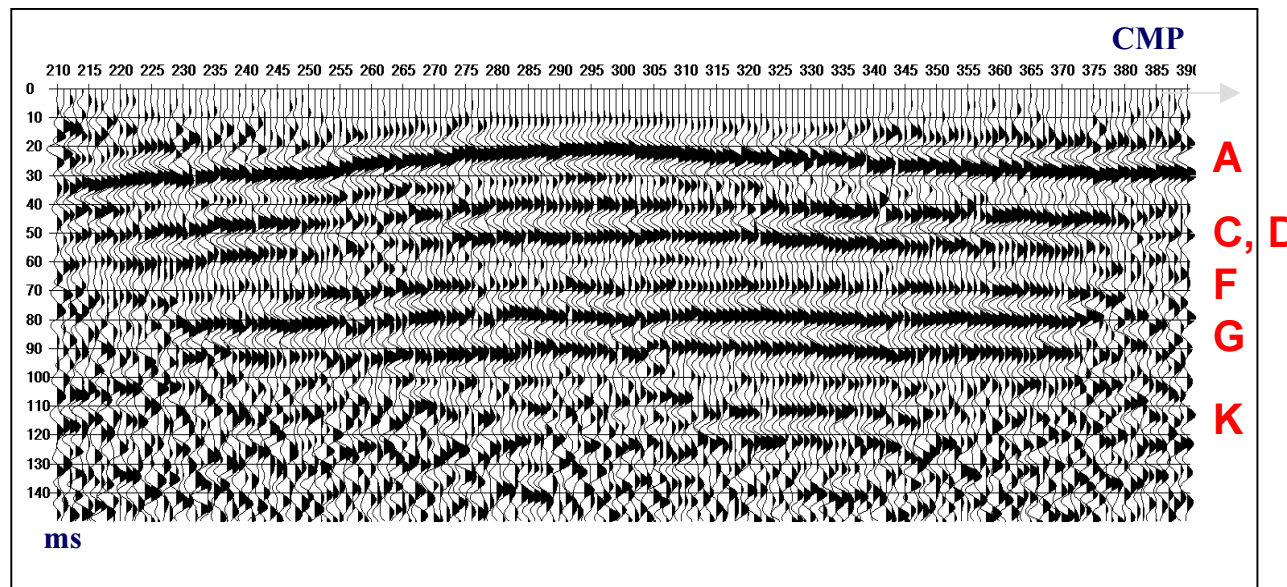


A

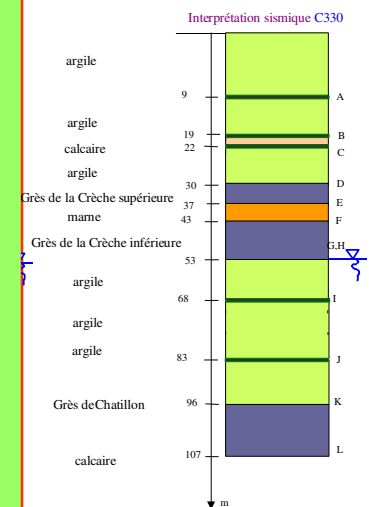
C,D

F

G



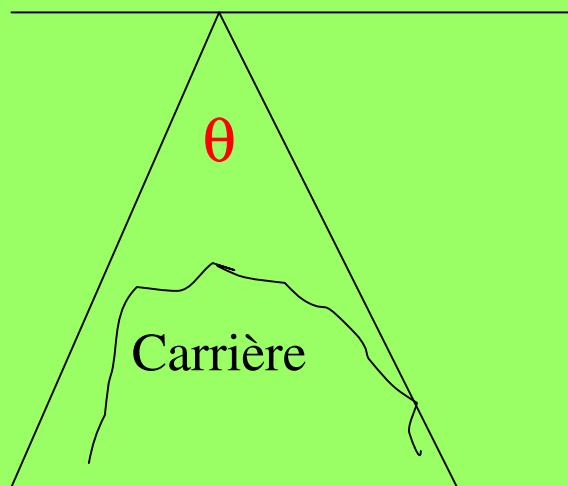
Structure



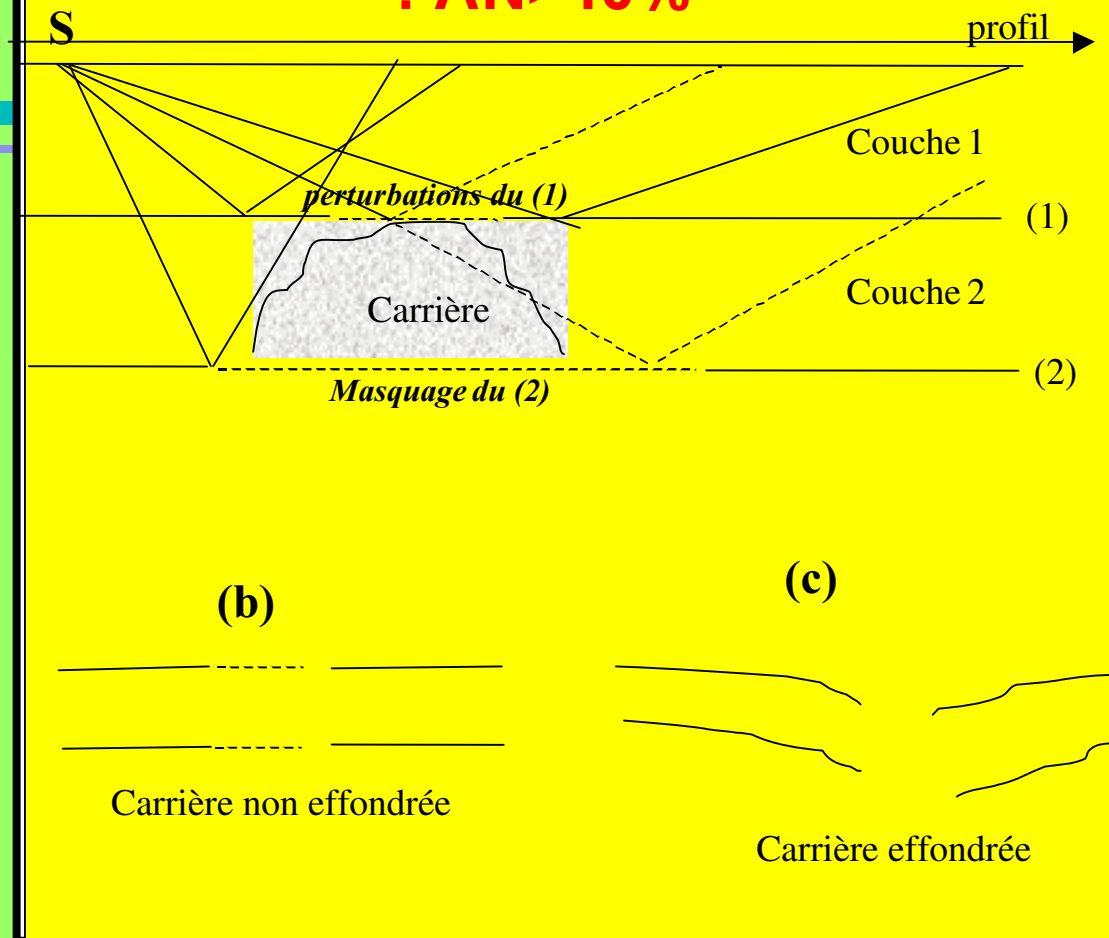
Détection des cavités (1):

Symptômes de présence d'une cavité

$$AN=f(\theta,\lambda)$$



Critère de détection
(a)
: $AN > 40\%$



Détection des cavités(2): « effet du masquage »

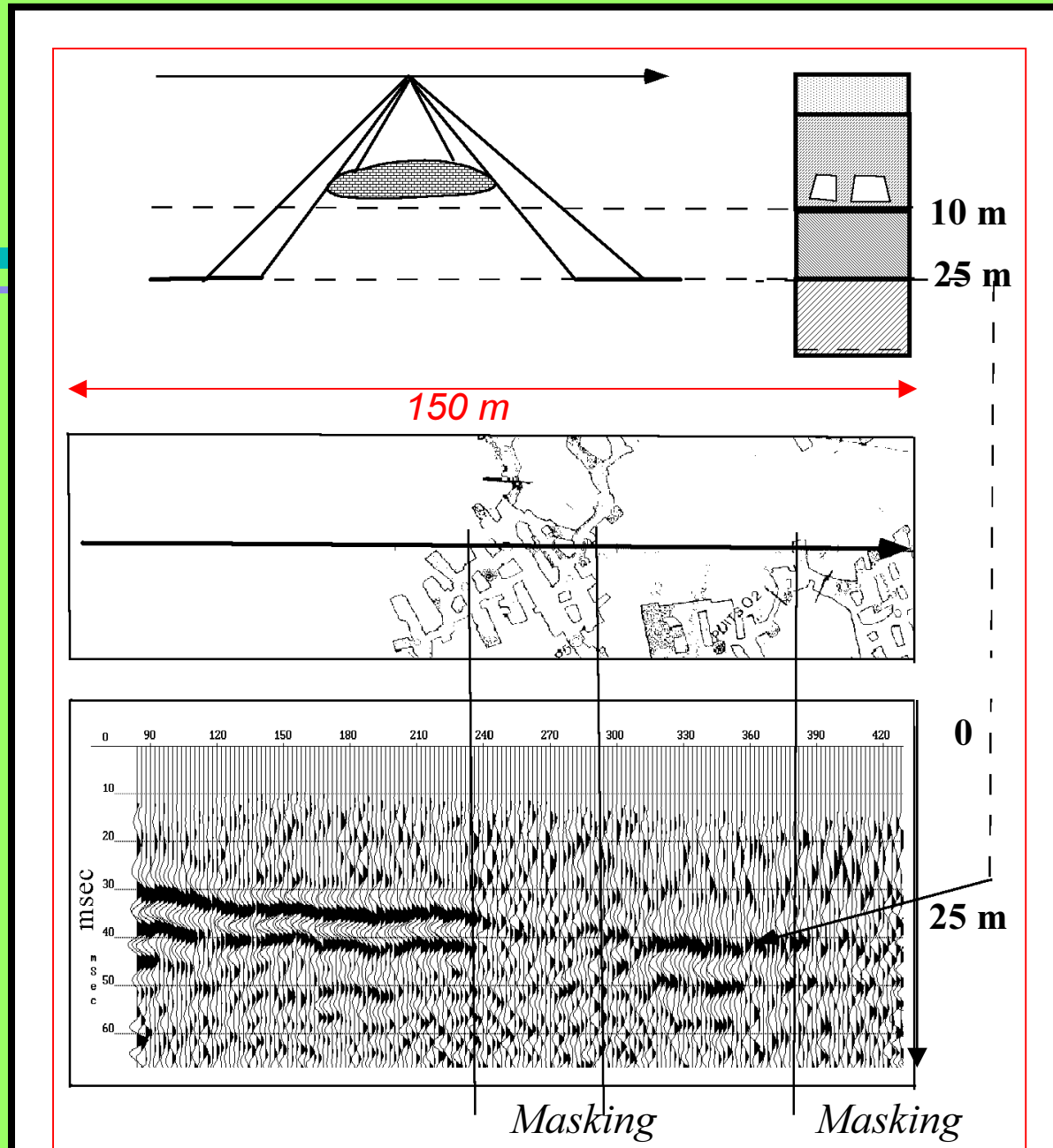
Parameters:

$\Delta\text{CDP}=1\text{ m}$

$f=250\text{ Hz}$

$\lambda=5\text{ m}$

$\delta=15\text{ deg}$



Détection des cavités (3):

Validation by comparison with
the known positions of tunnels

Parameters:

$\Delta\text{CDP}=0.5\text{ m}$

$f=200\text{ Hz}$

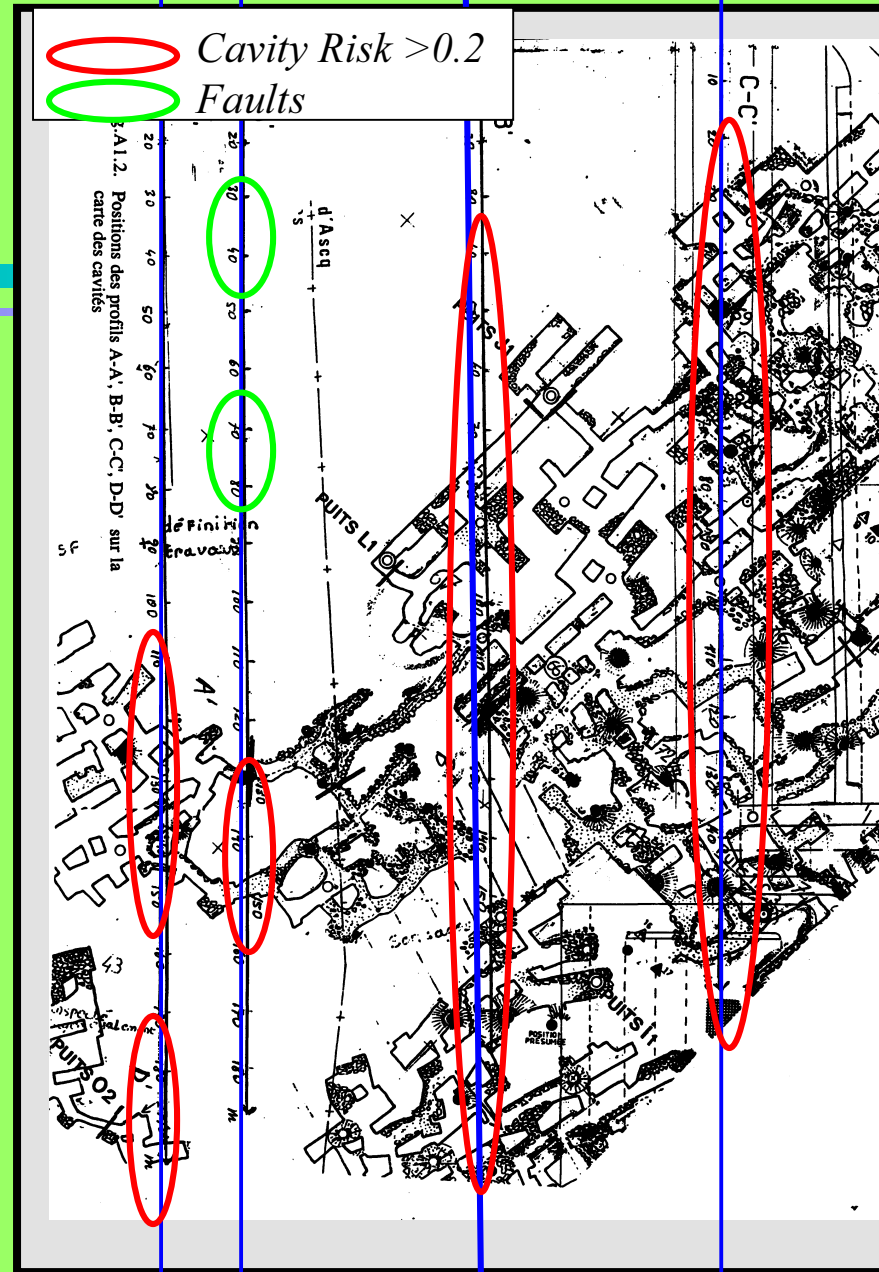
$\lambda=6\text{ m}$

$\delta=20\text{ deg}$

RESULTS

- 100% of tunnels detected

150 m



Détection des cavités: Validation par drilling

Parameters:

$\Delta\text{CDP}=0.5\text{ m}$

$f=200\text{ Hz}$

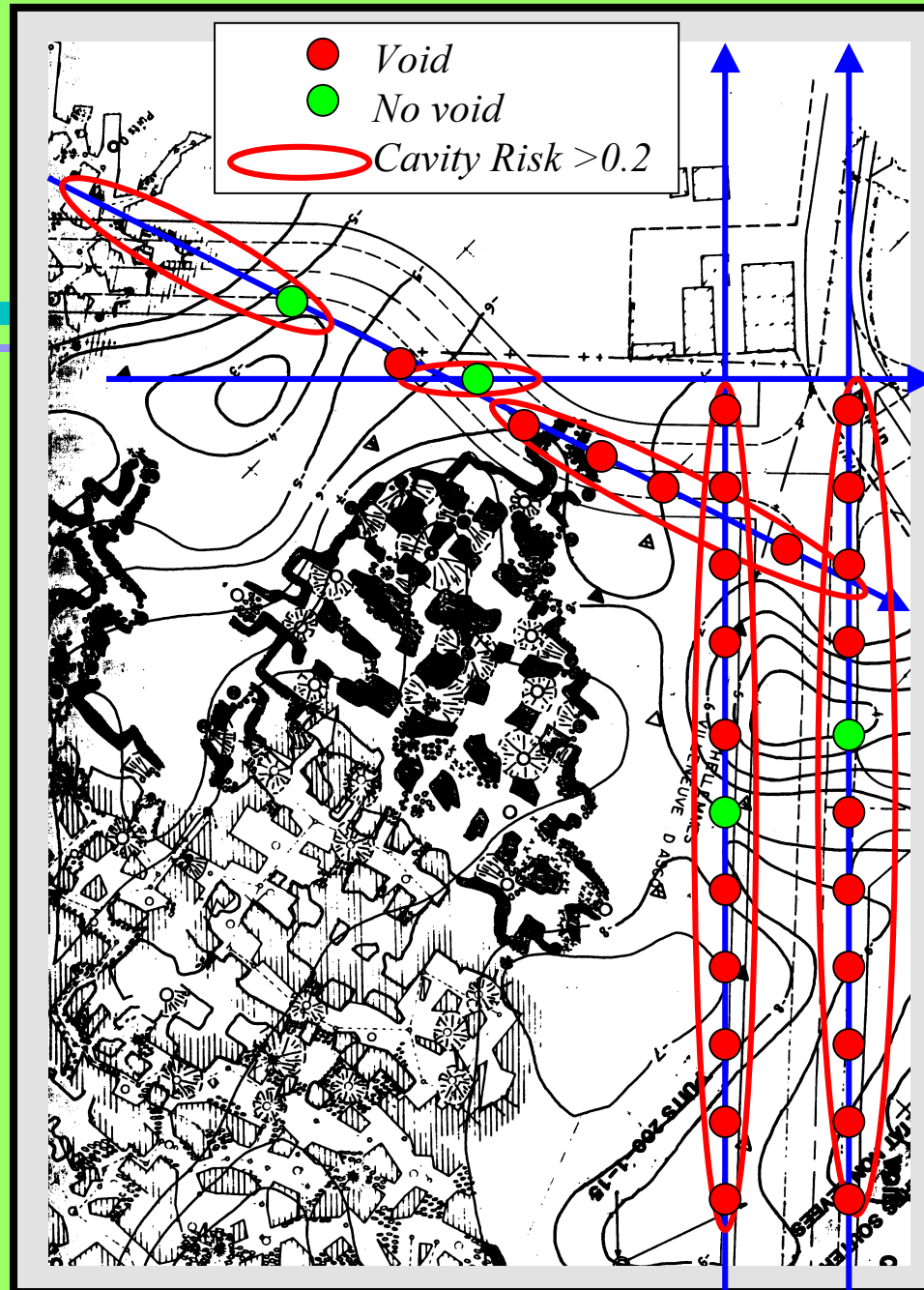
$\lambda=6\text{ m}$

$\delta=20\text{ deg}$

100 m

Validation by drilling

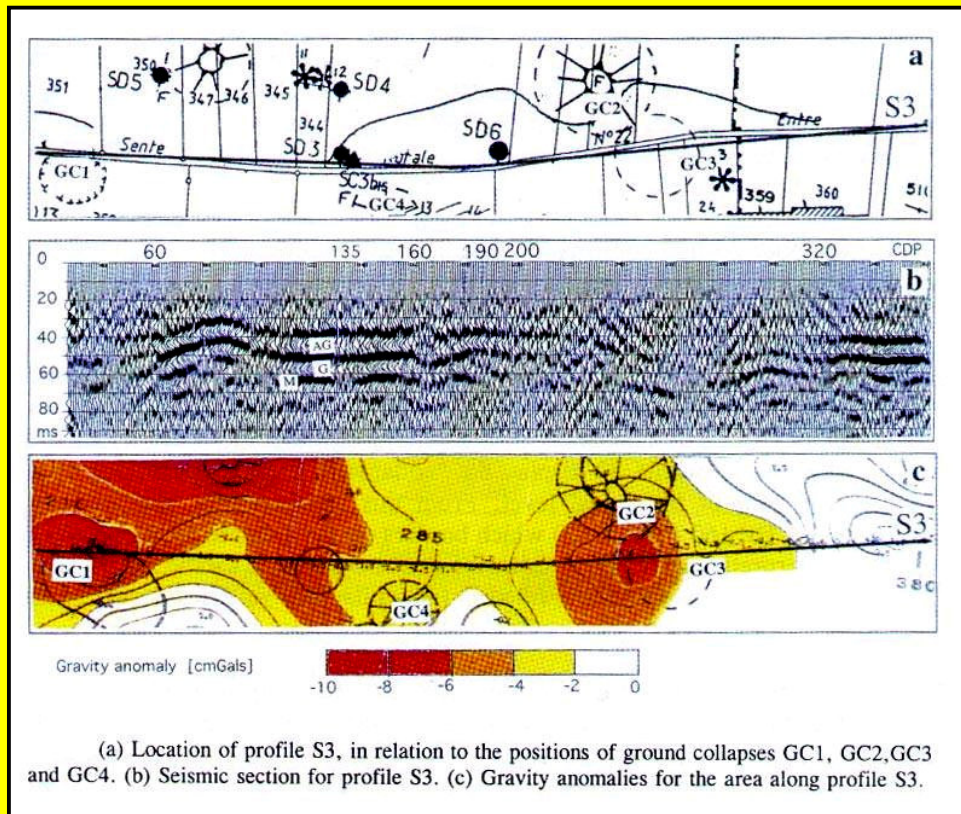
- 80% of detections confirmed
- precision of the depth of void greater than 15%



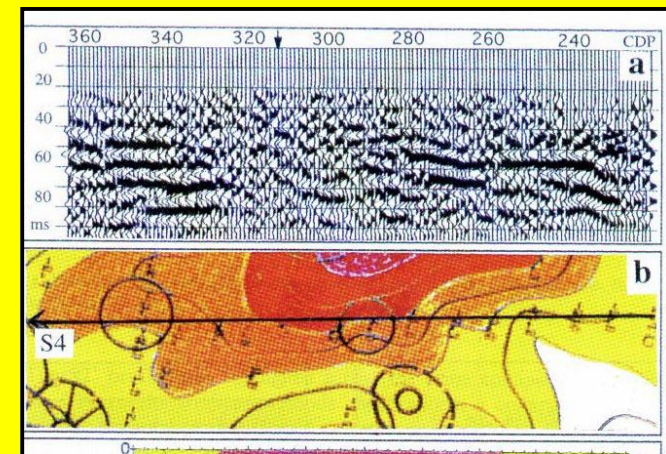
Détection d'anciennes carrières de gypse dans la région parisienne

Validation de différentes méthodes(1)

Carrière effondrée



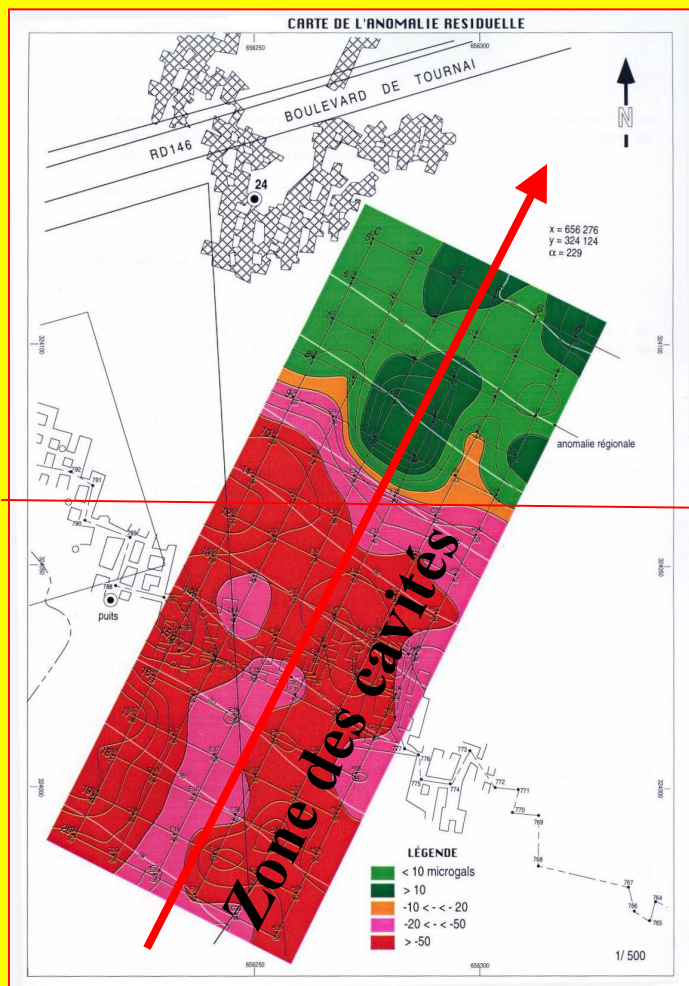
Carrière non effondrée



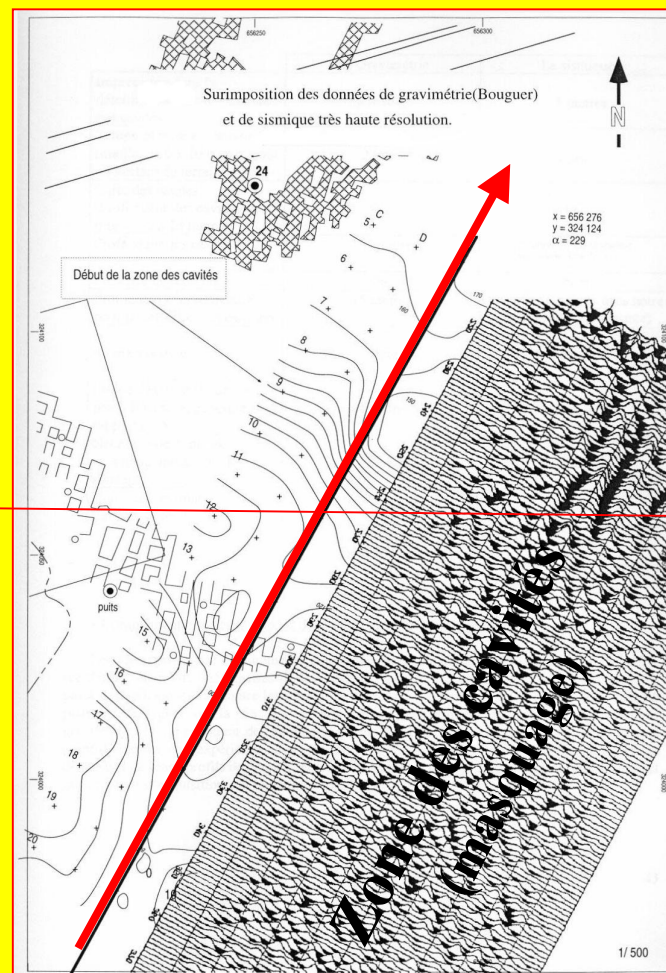
Détection d'anciennes carrières de gypse dans la Région du Nord

Validation de différentes méthodes (2)

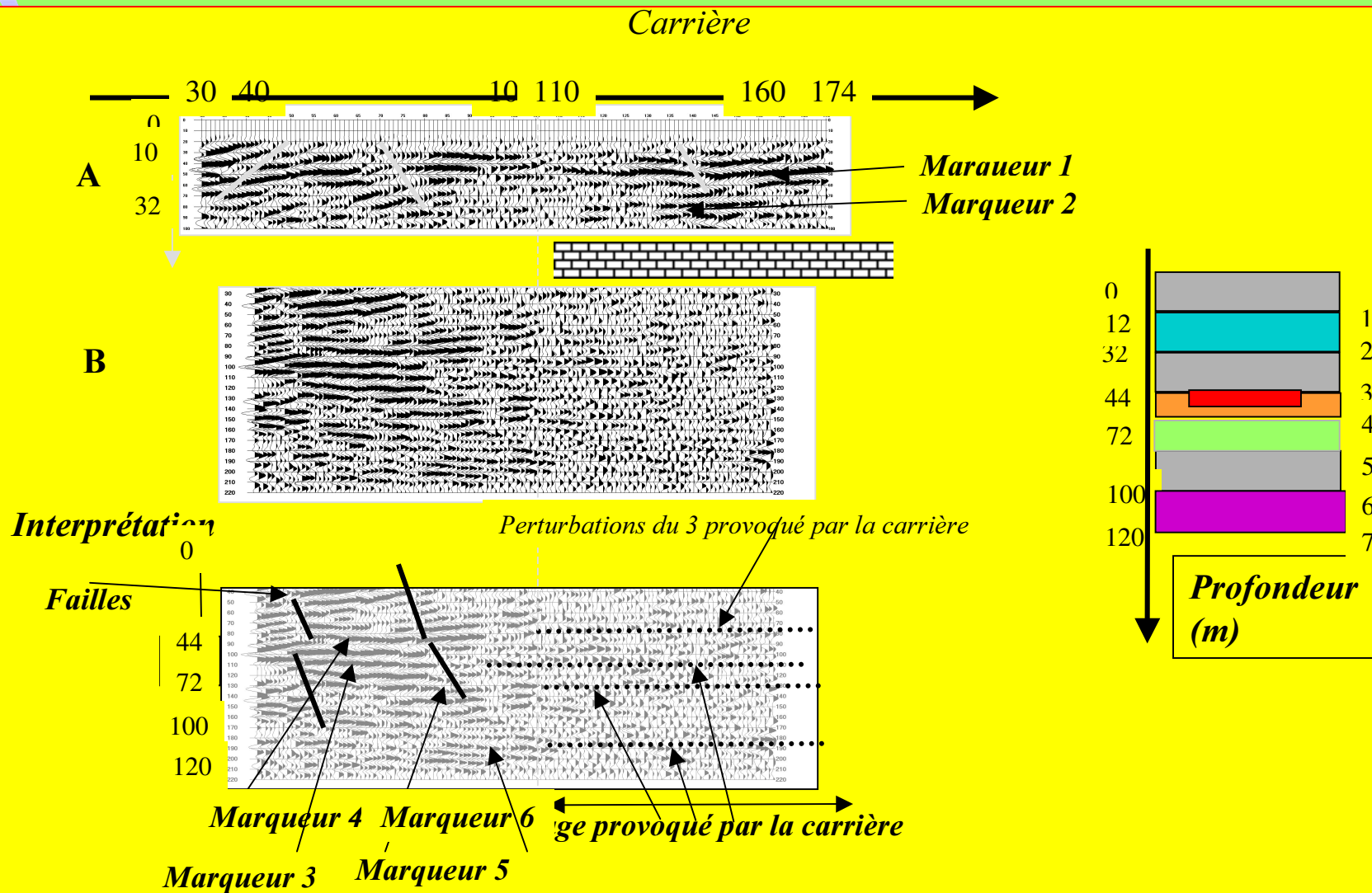
Gravité



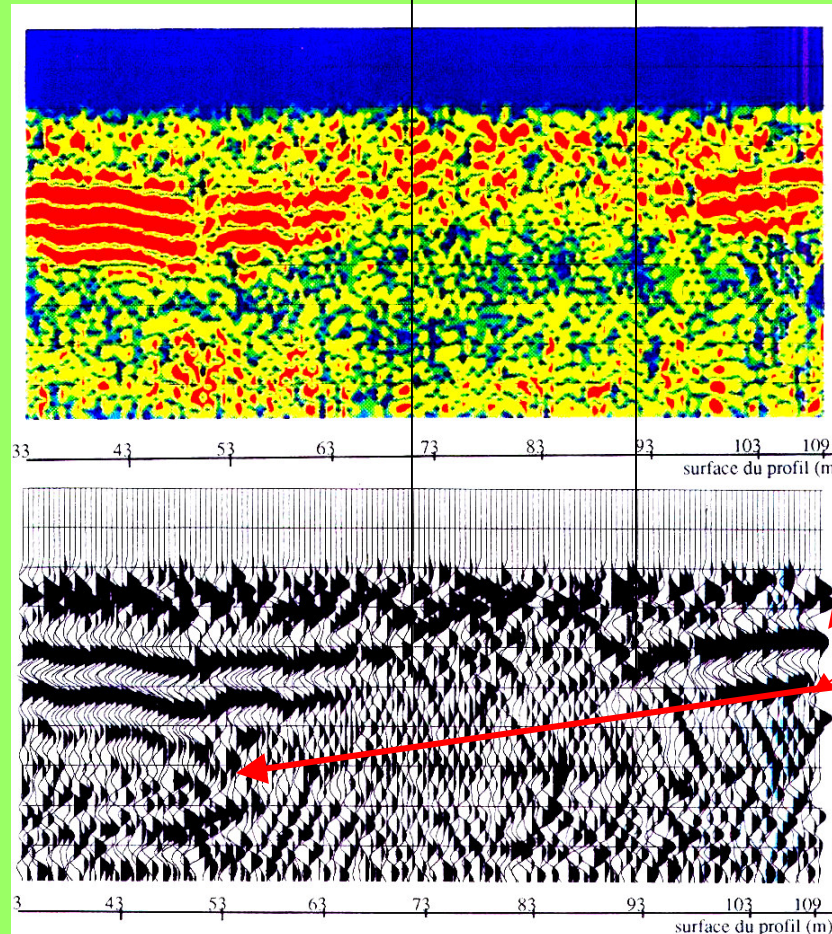
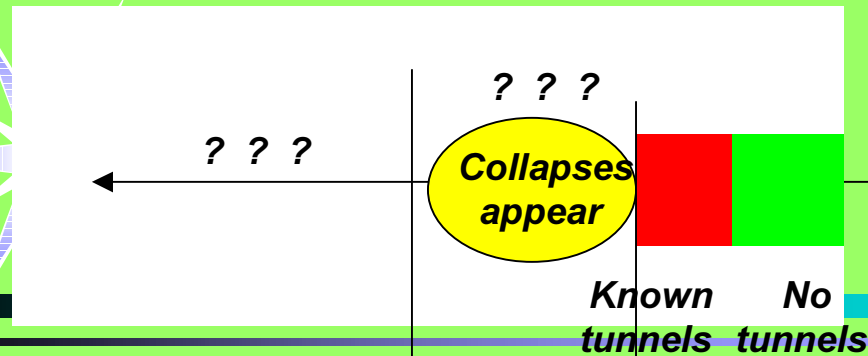
SHR



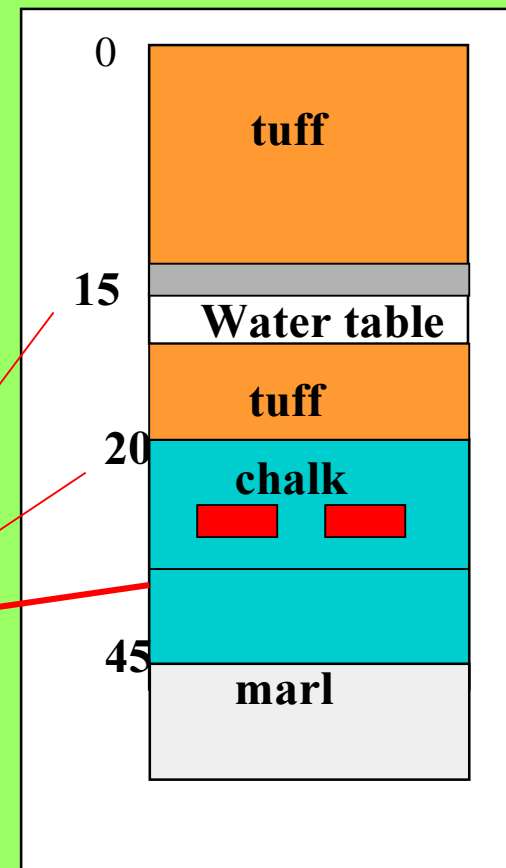
Detection des les marnières de la Haute Normandie avec l'NERIS, & la Sovep (2002)



Evaluation of risk of collapse of an underground chalk pit (1)

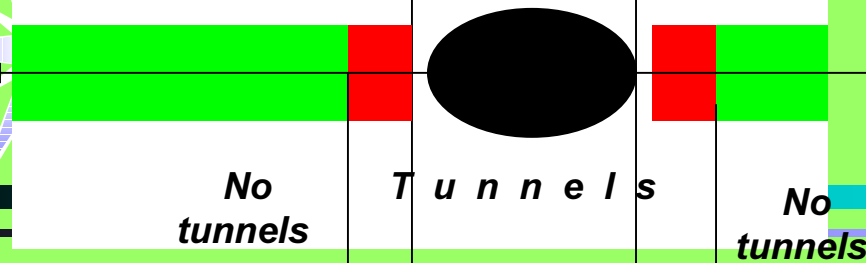


Geological structure



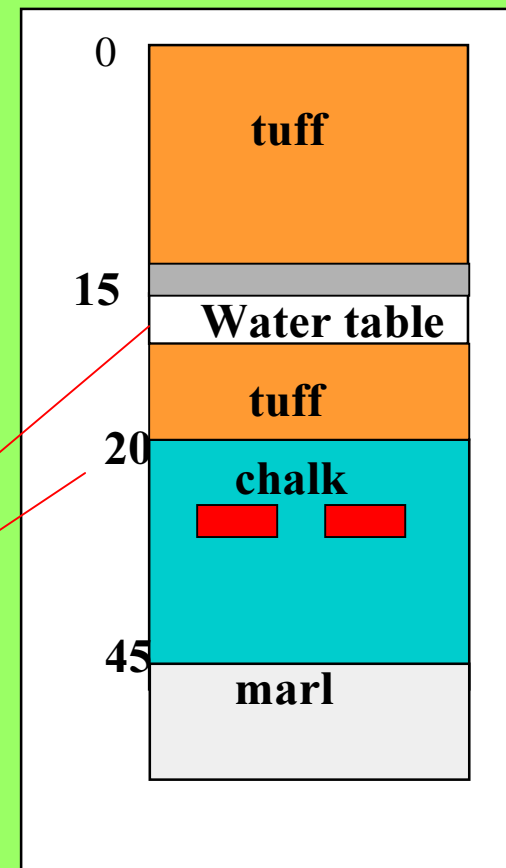
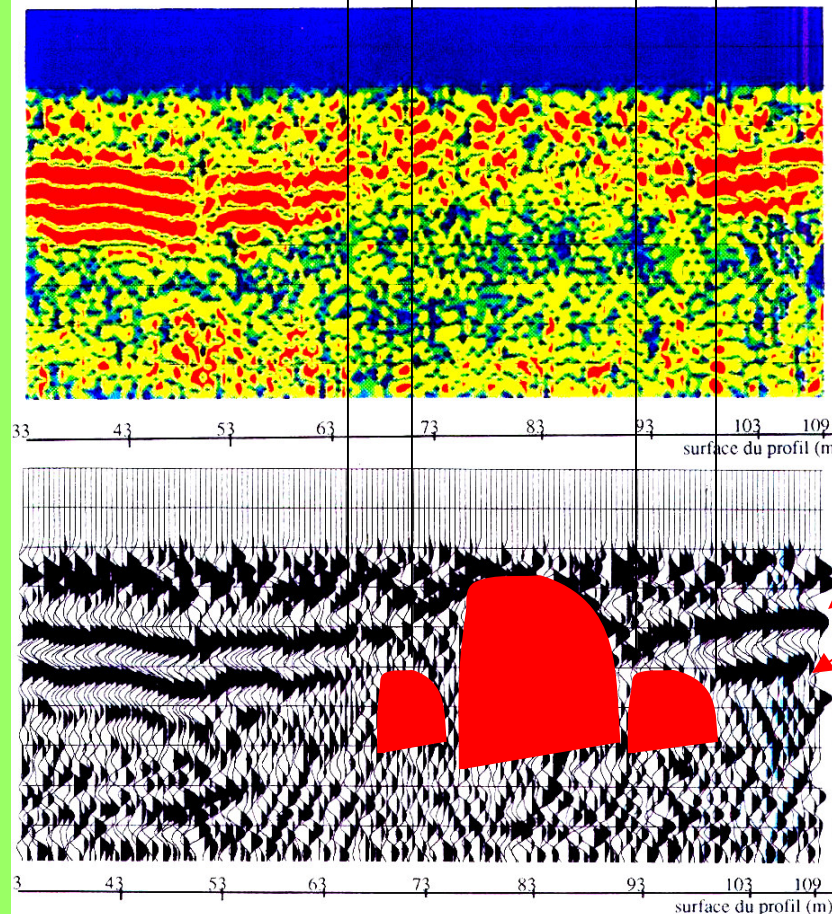
Interpretation

Risk of collapse



Evaluation of risk of collapse of an underground chalk pit (2)

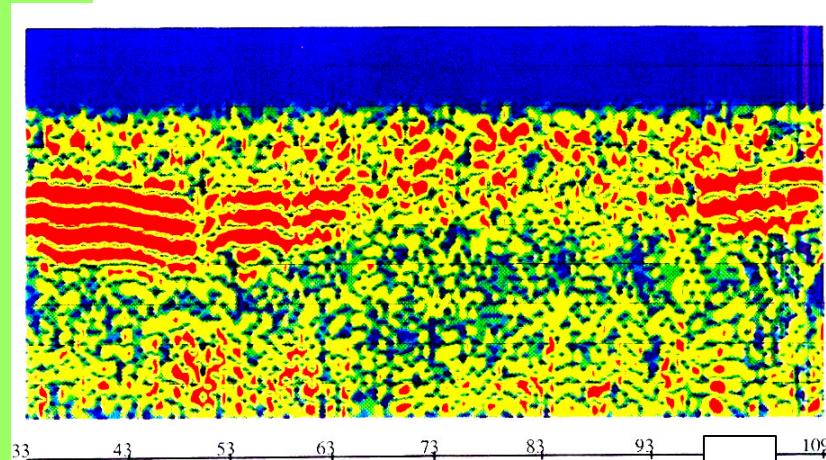
Geological structure



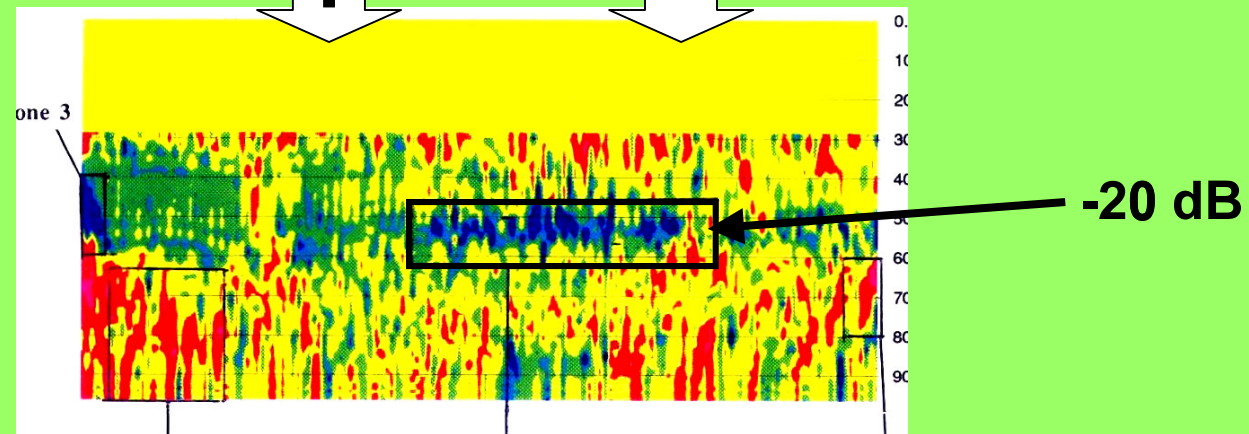
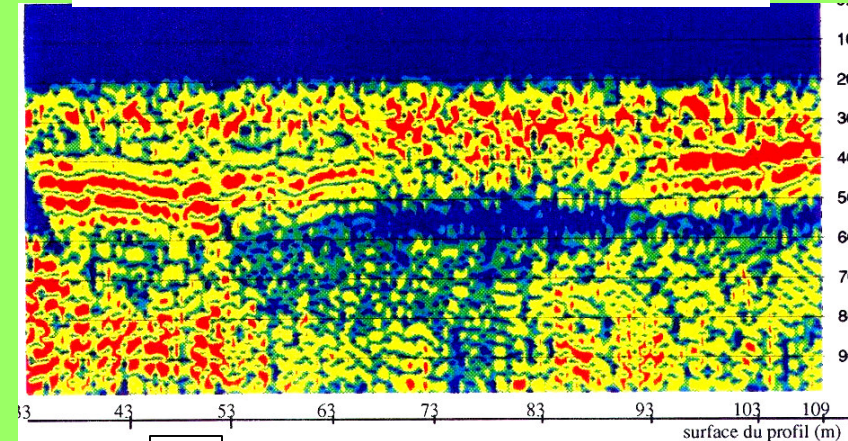
Evaluation of risk of collapse of an underground chalk pit (2)

Verification of the filling in of tunnels

Before filling-in the tunnels

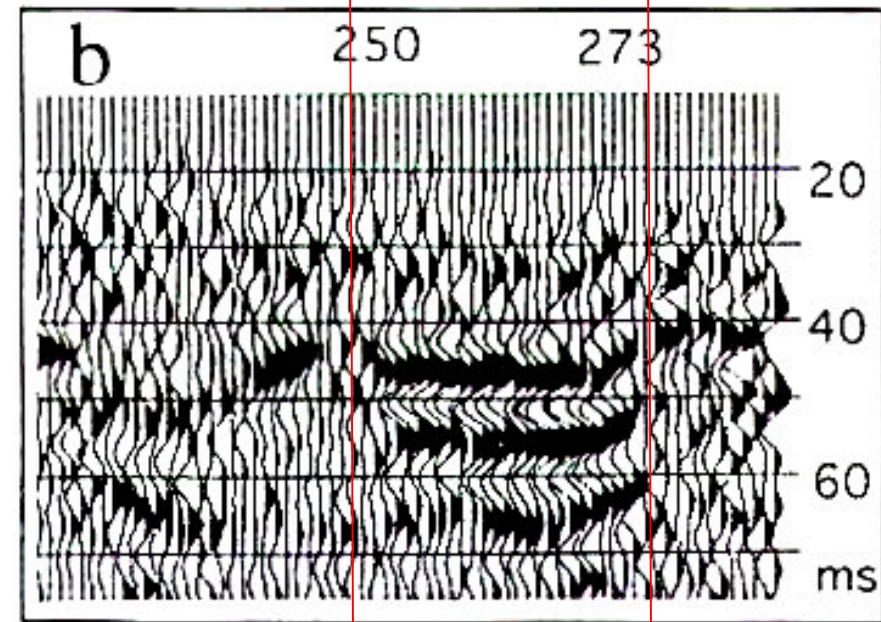
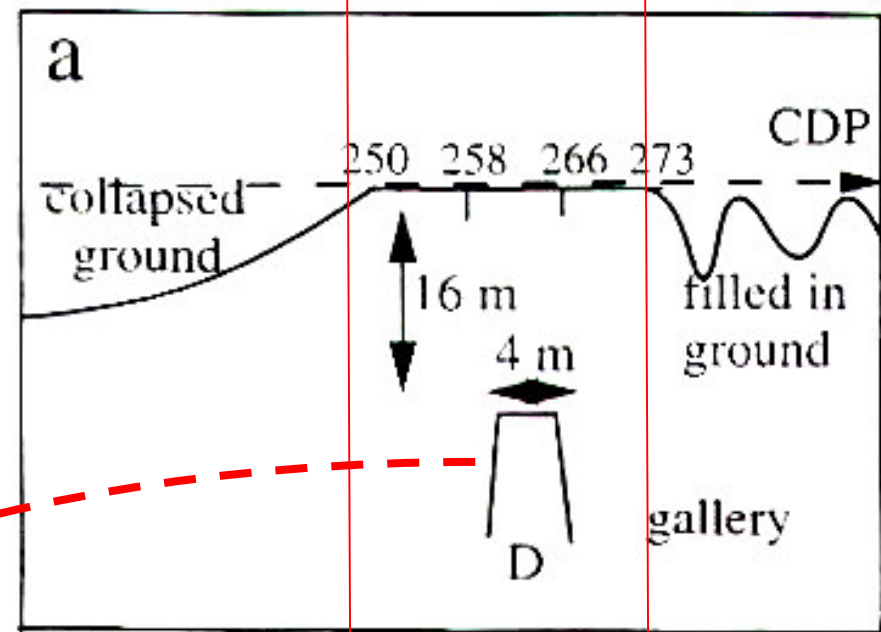
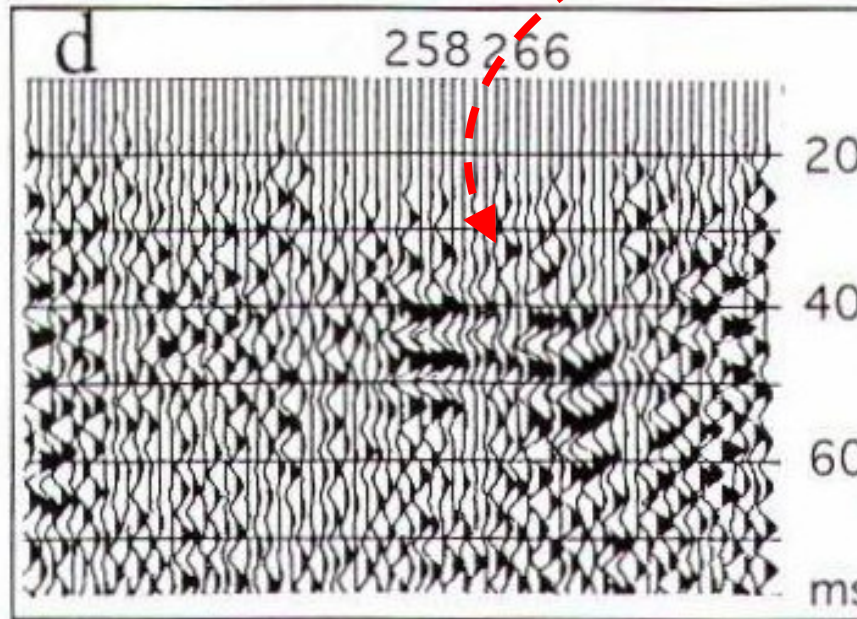


After filling-in the tunnels

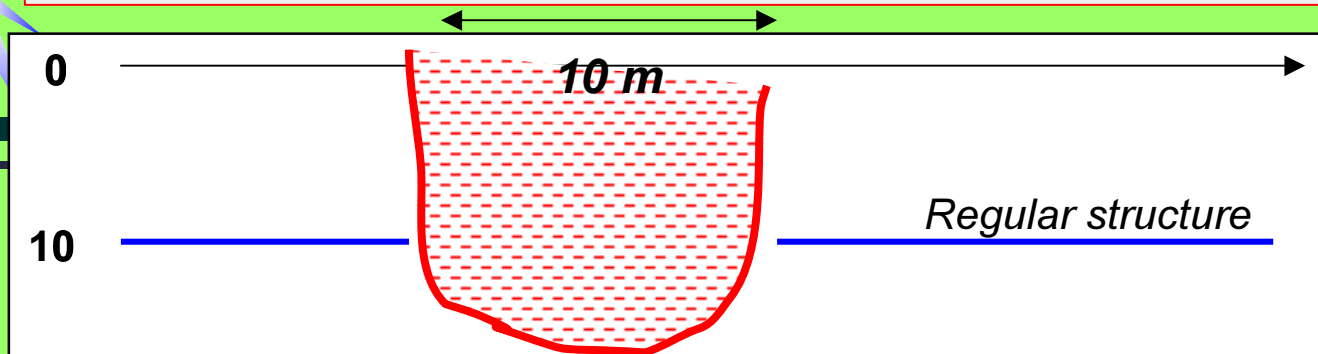


Diagnostic de terrain l'effondré(1)

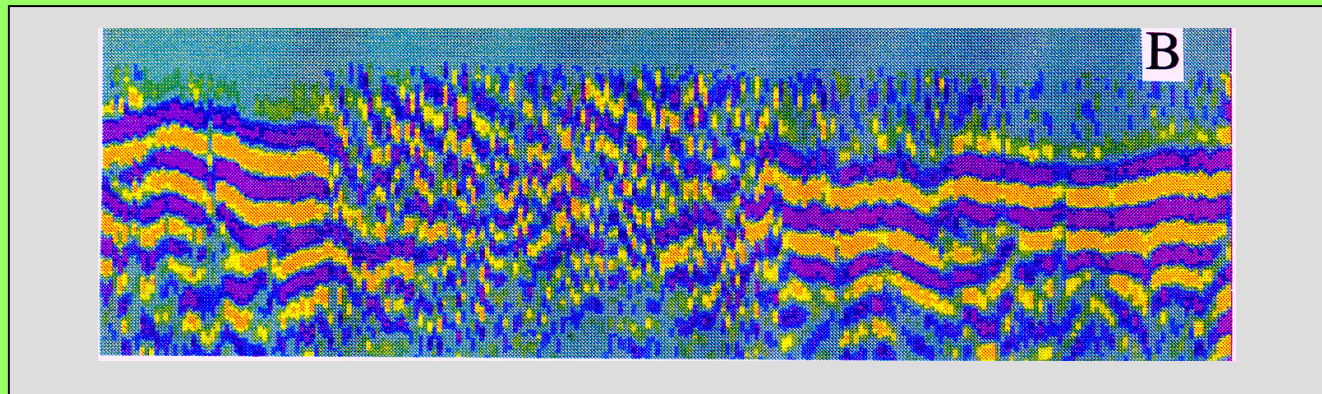
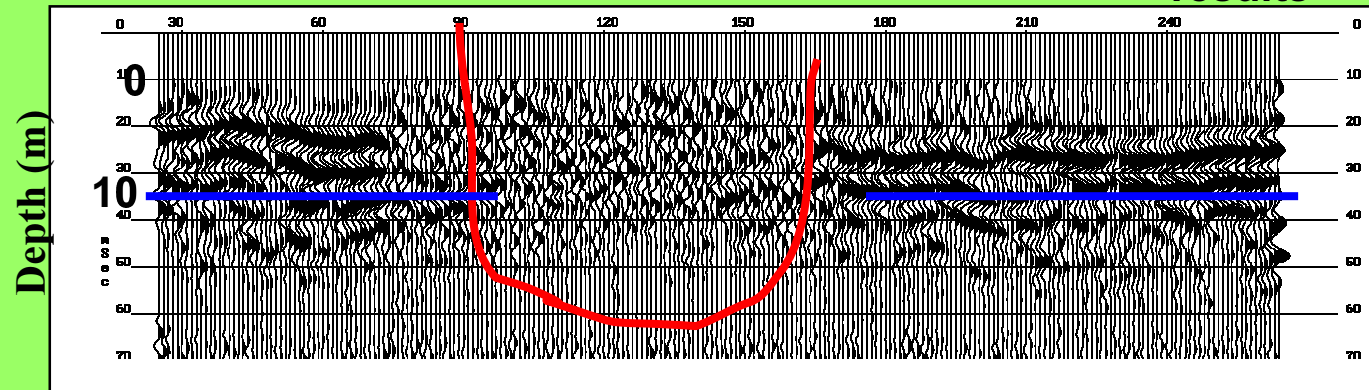
Détection d'anciennes carrières de gypse dans la région parisienne
(avec l'Ineris 1996)



Diagnostic de terrain l'effondré (2) : imaging of an old collapsed and filled in tunnel



results



Parameters:

$\Delta\text{CDP}=0.5\text{ m}$

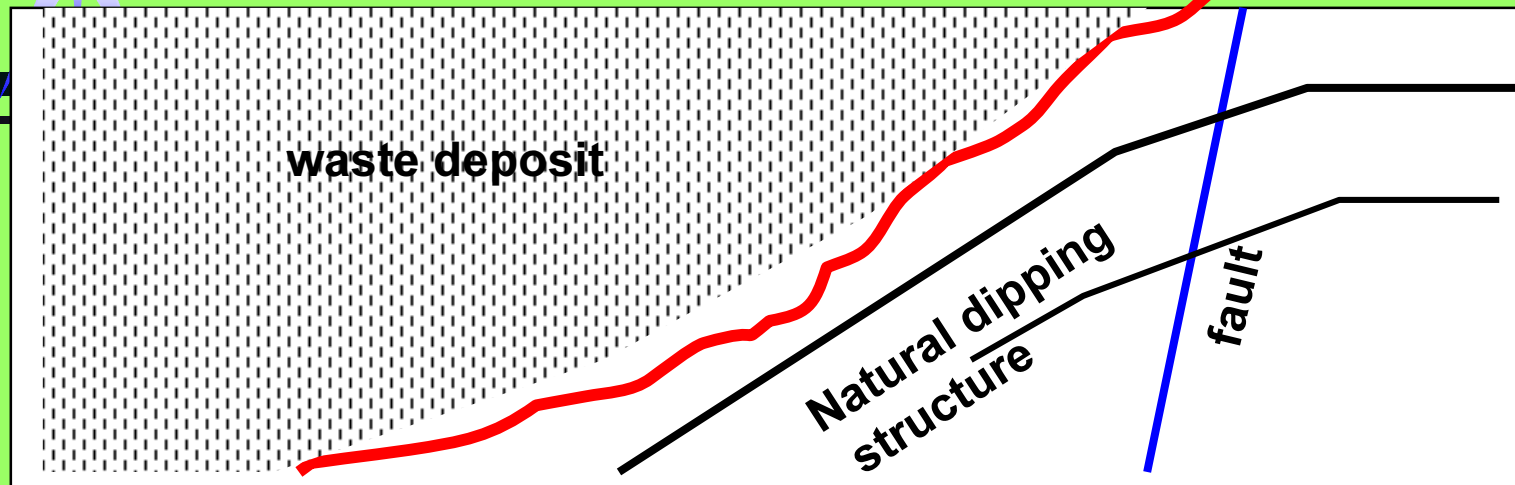
$f=200\text{ Hz}$

$\lambda=7\text{ m}$

$\delta=15\text{ deg}$

Diagnostic de terrain l'effondré (3) : old waste deposit imaging

interpretation



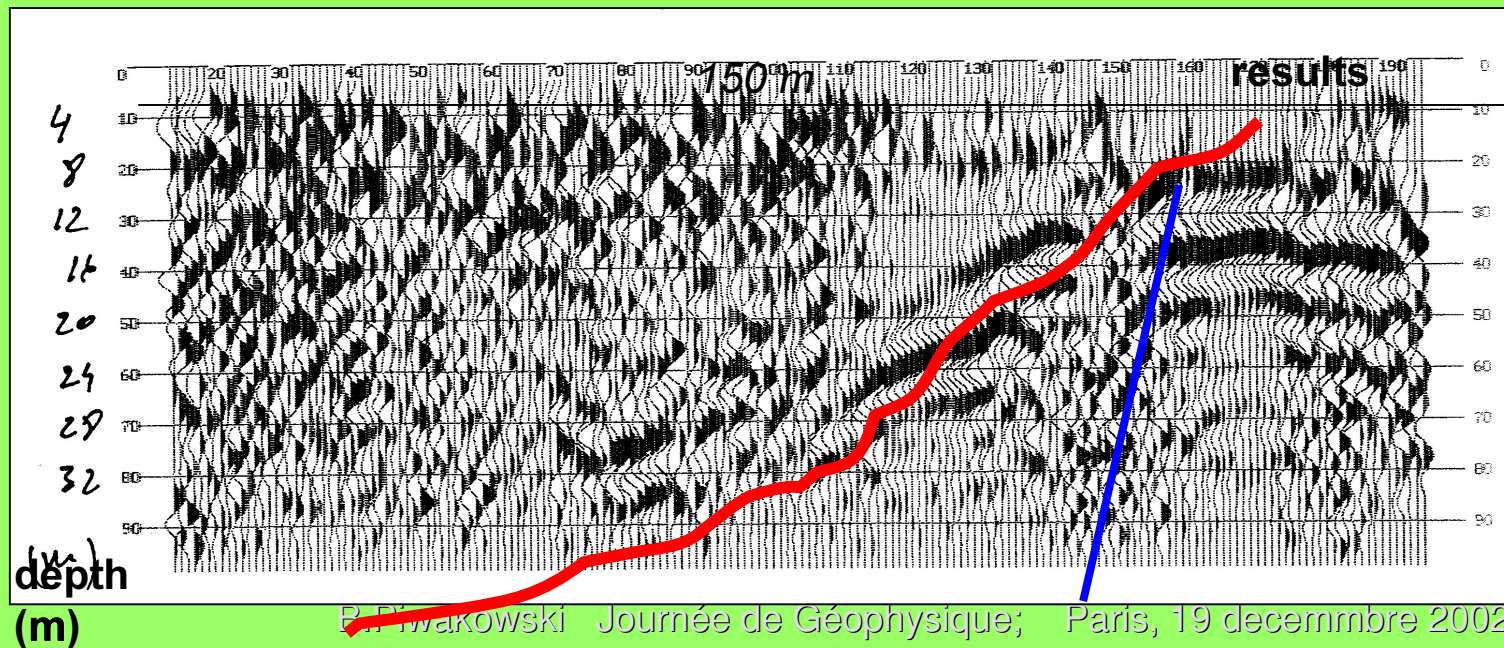
Parameters:

$\Delta\text{CDP}=1\text{ m}$

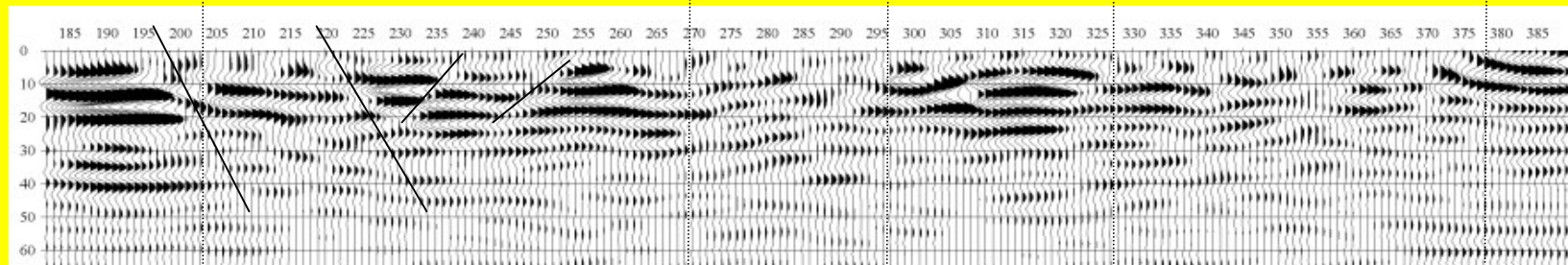
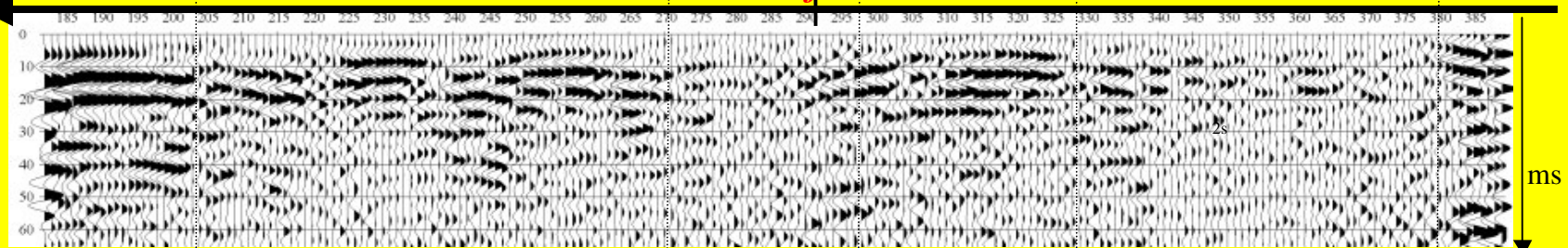
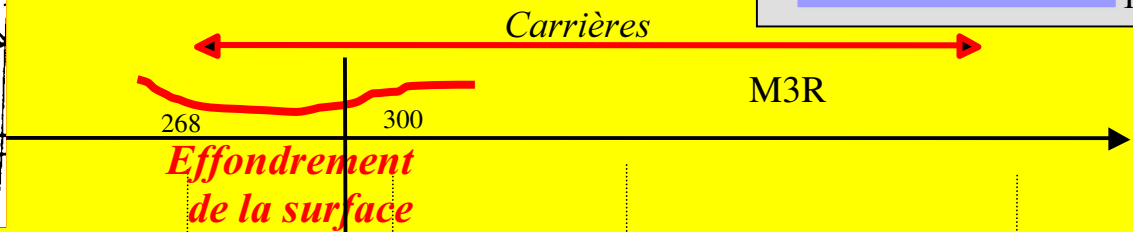
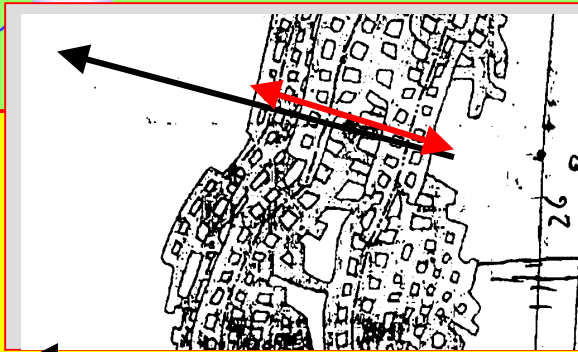
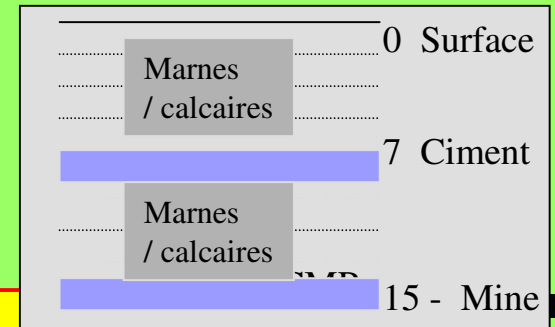
$f=100\text{ Hz}$

$\lambda=10\text{m}$

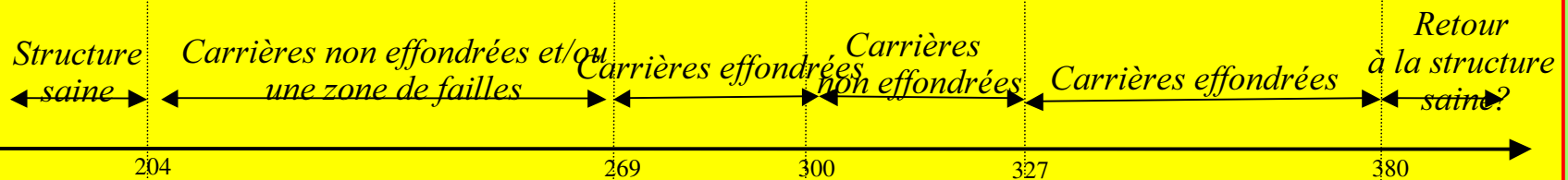
$\delta=20\text{ deg}$



Évaluation de l'état (saine – effondrée) Détection des anciennes carrières de ciment (l'INERIS EC-Lille SOVEP 2000)

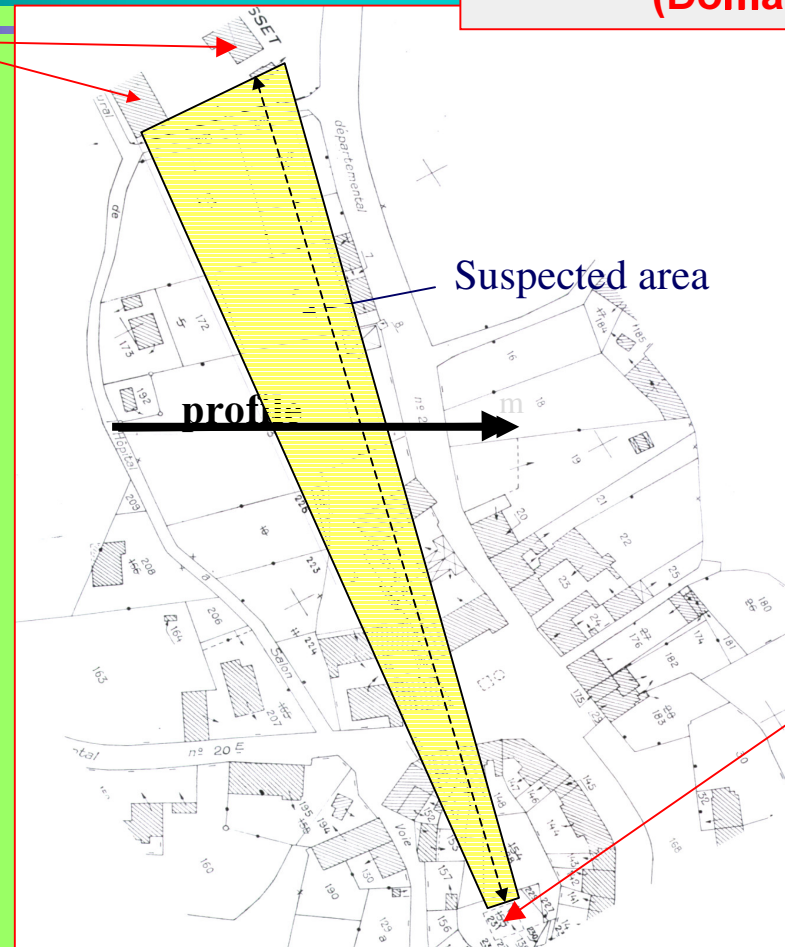


Interprétation des profils sismiques



Archaeological research (1)

15th Century Castle



Objective:

to find the underground tunnel linking the castle with the keep

(Domain of the use of GPR)

12 th Century Keep



Archaeological research (1)



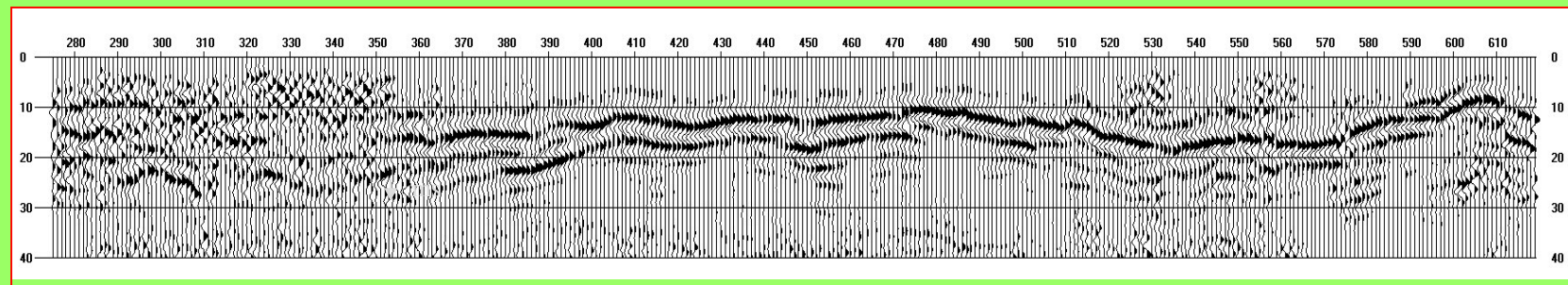
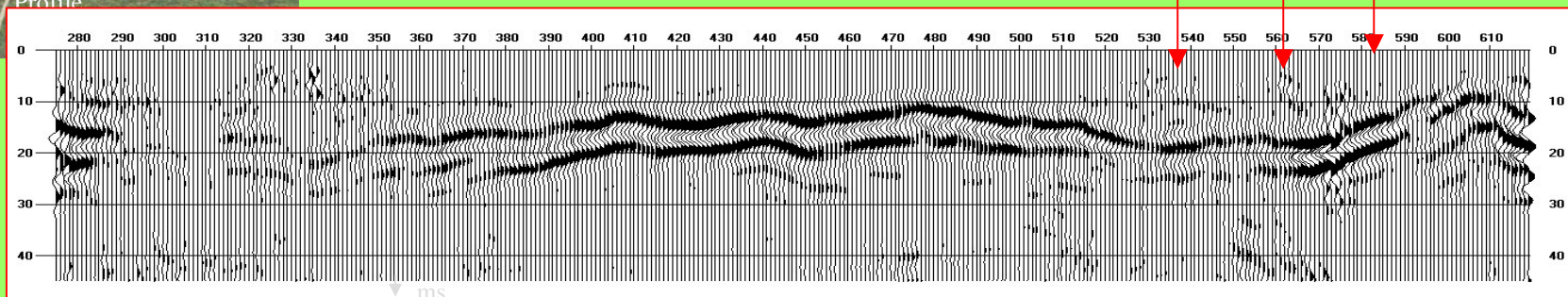
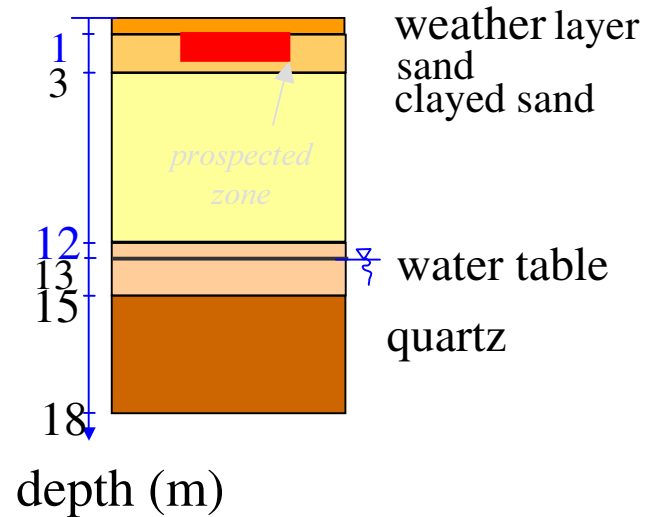
Parameters:

$\Delta\text{CDP}=0.25\text{ m}$

$f=300\text{ Hz}$

$\lambda=3\text{ m}$

$\delta=18\text{ de}$



Archaeological research (2° : Detection of the underground aqueduct (built in 96 A.C).

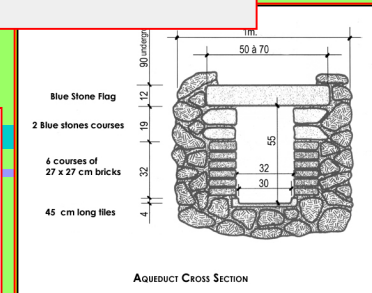
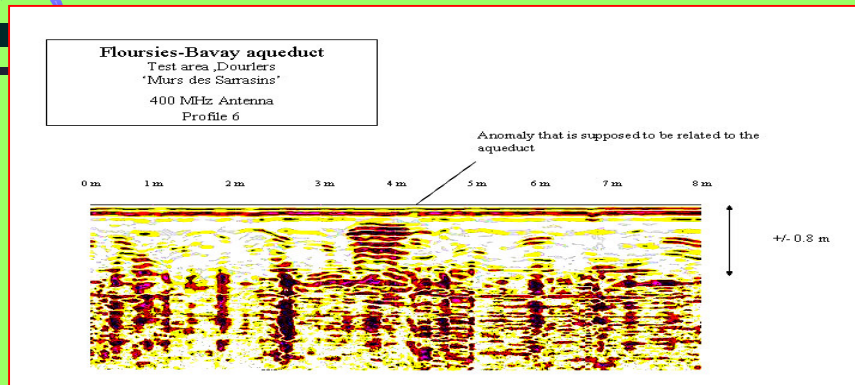


Fig 2 - Aqueduct cross-section

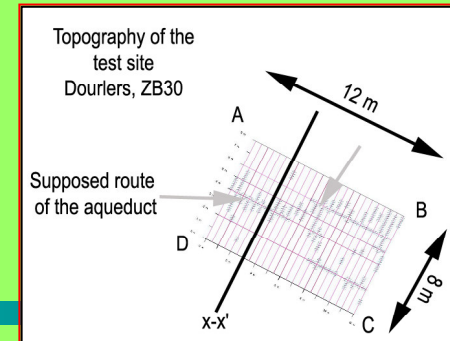
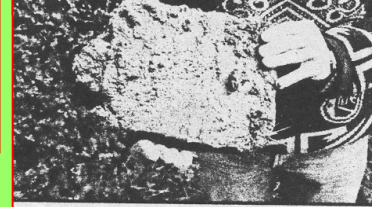
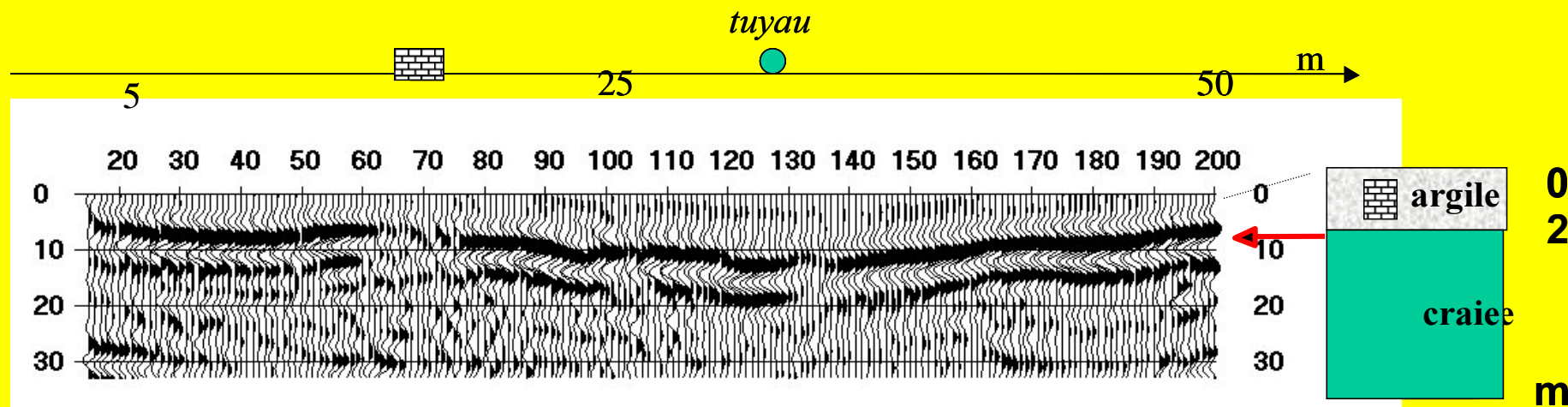
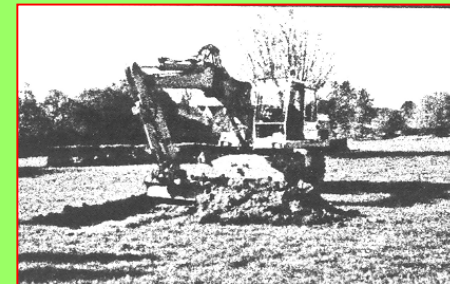
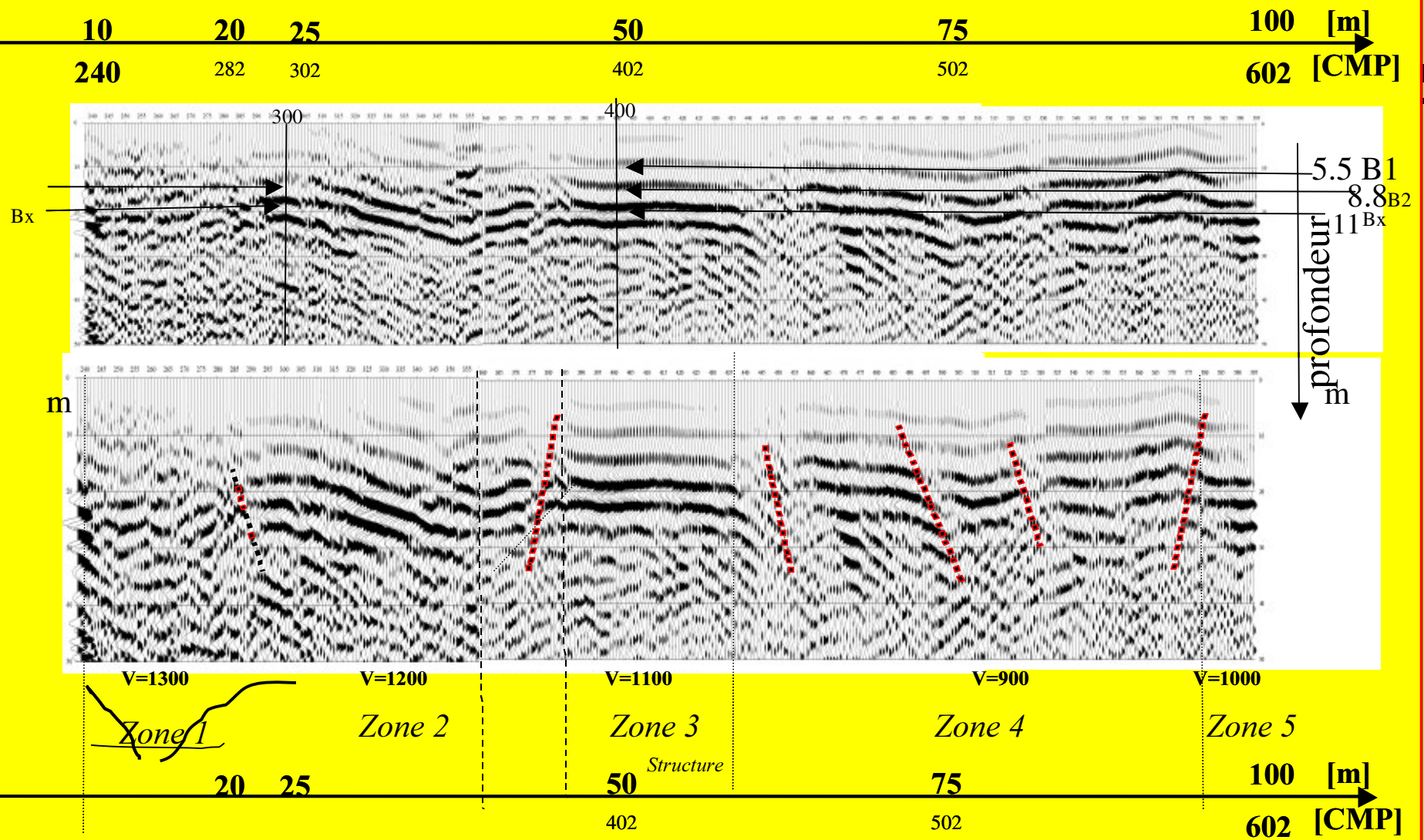


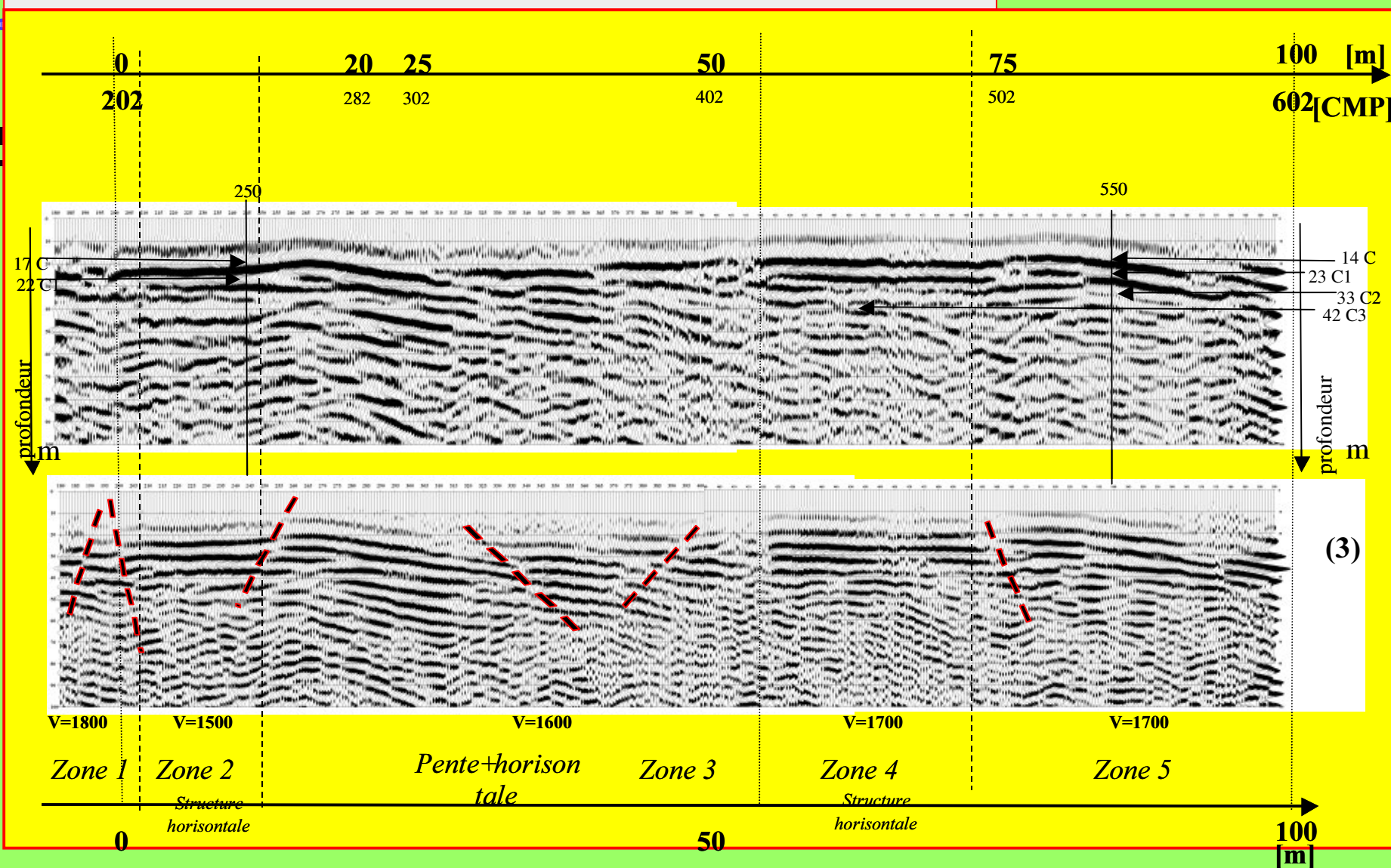
Fig.3 - Supposed location of the aqueduct on the test site.



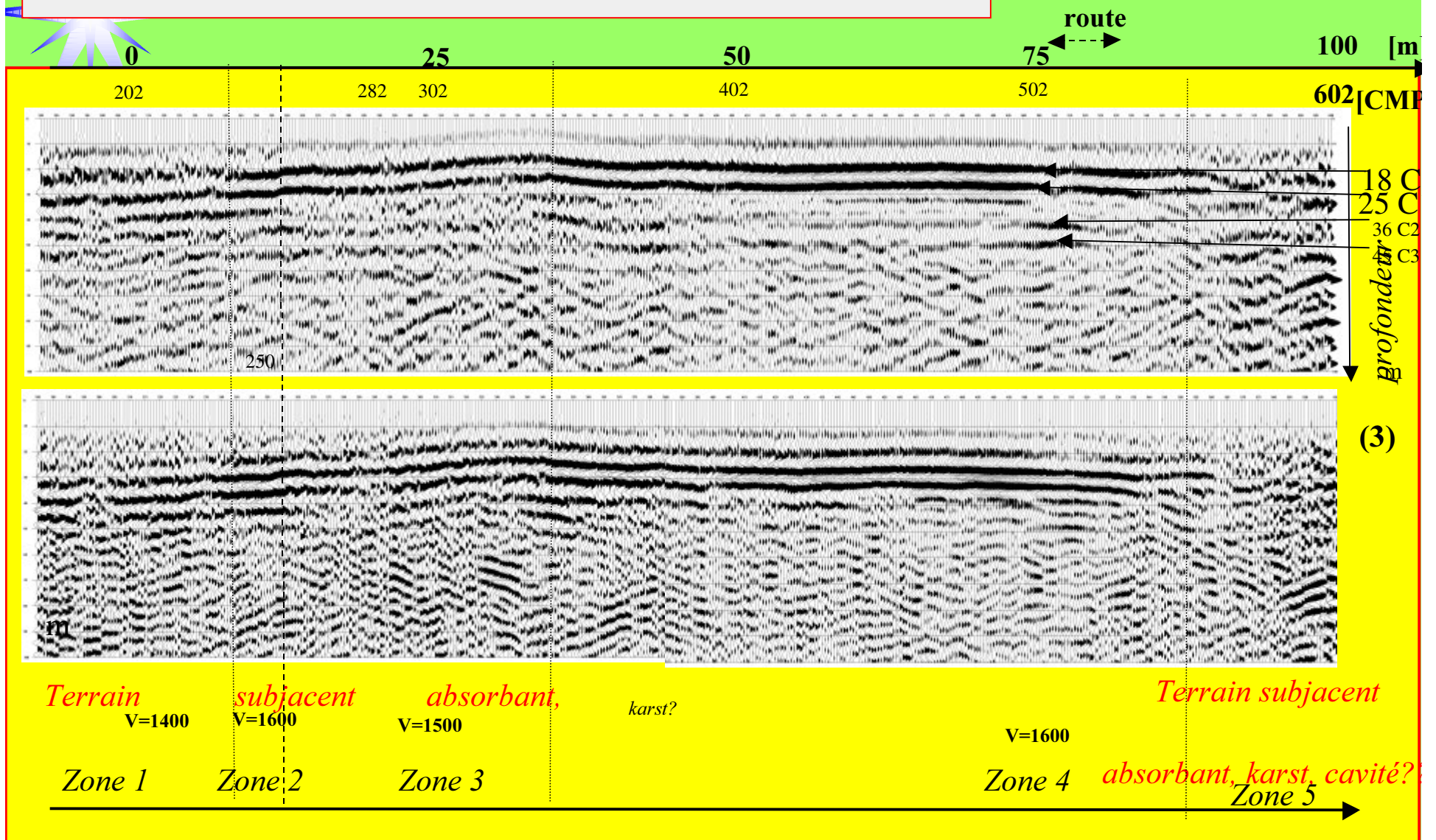
**Imagerie des failles de subsurface (1);
Profile 1 , profondeur 3 – 10 m
(avec la Sovep 2002)**

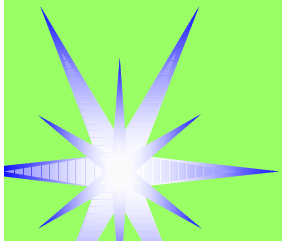


Imagerie des failles de subsurface (2) profile 1 : profondeurs 14-35 m



Imagerie des failles de subsurface (3) Profile 3: profondeurs 14-35 m



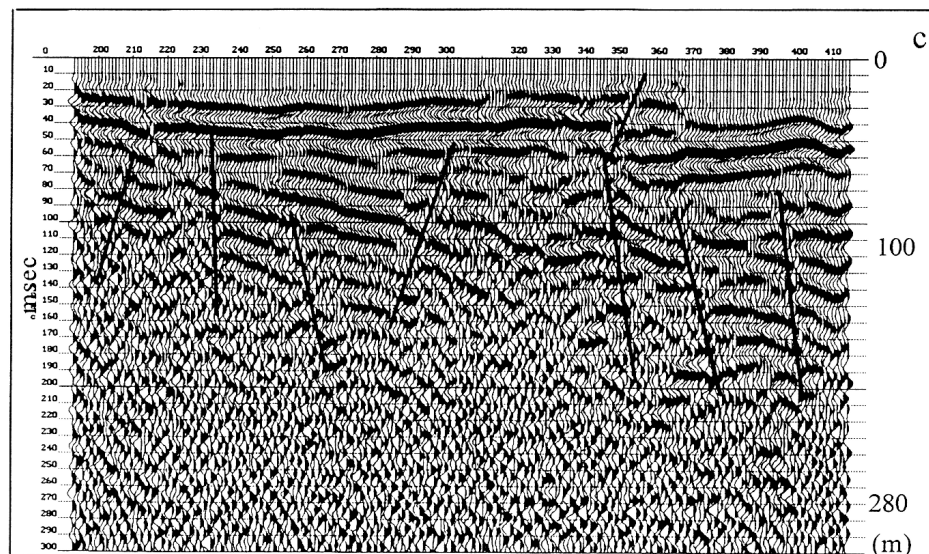
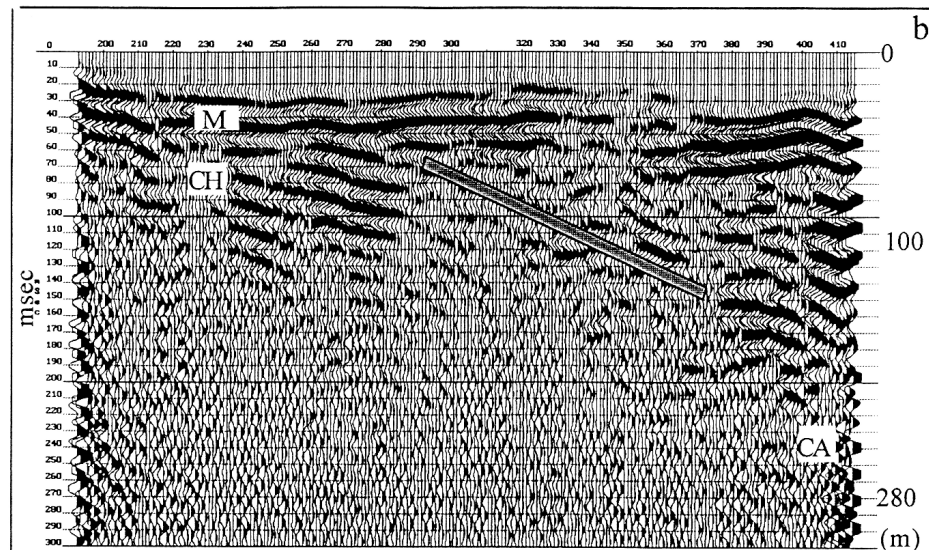


Site minier (1)

-Image de l'ancienne mine de charbon (profondeur de 30 à 120 m)

- Effondrement?

- Failles



Site minier (2)

Effondrements de surface



Objective of study:

Verify how HRS may help in:

- Imaging of structure modification
- Imaging of collapsed zones
- Check for the faults presence

Site minier (2)

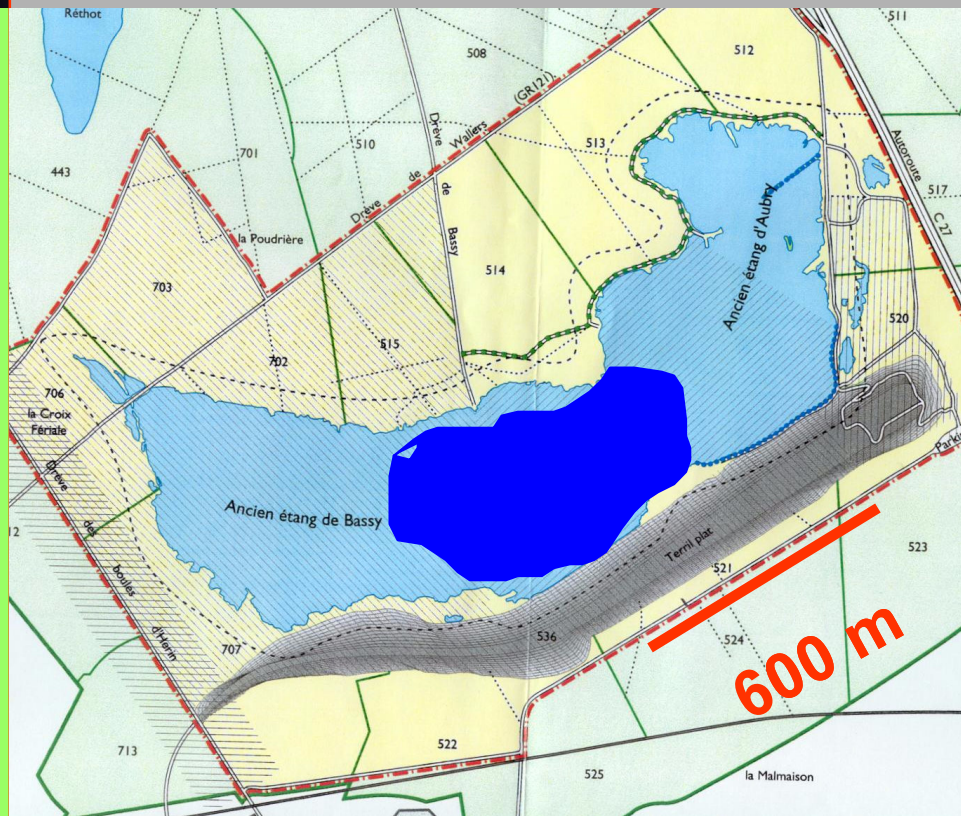
Collapsing mines occurring at depth varying from 120 to 400 m

- Intensive coal exploration
- Ground collapses

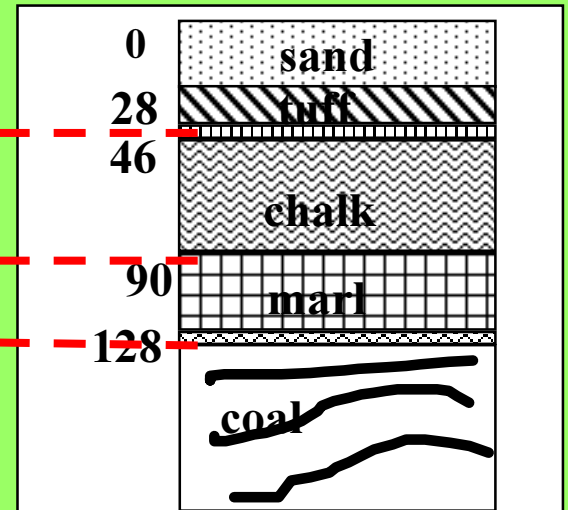
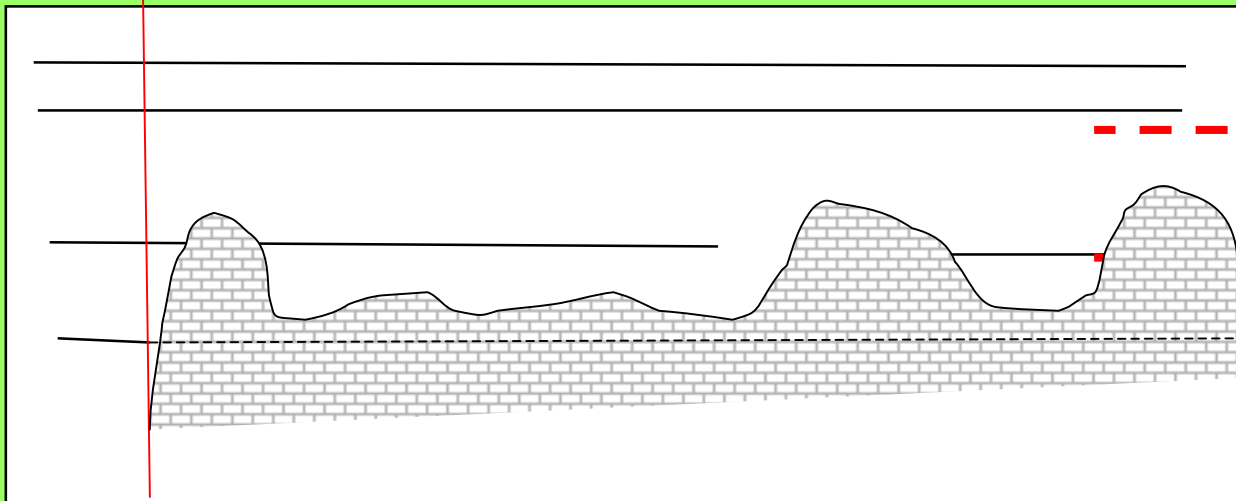
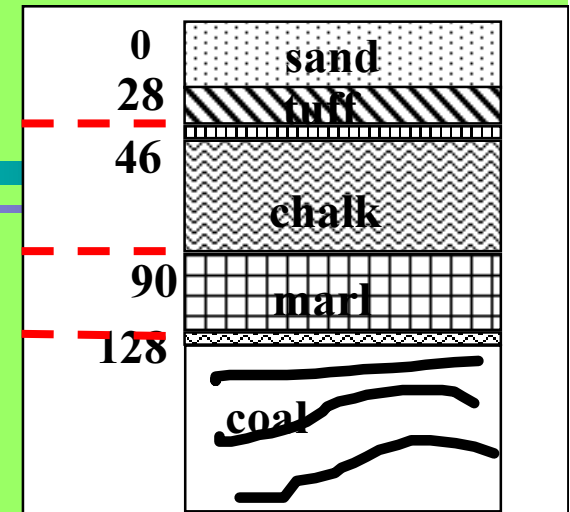
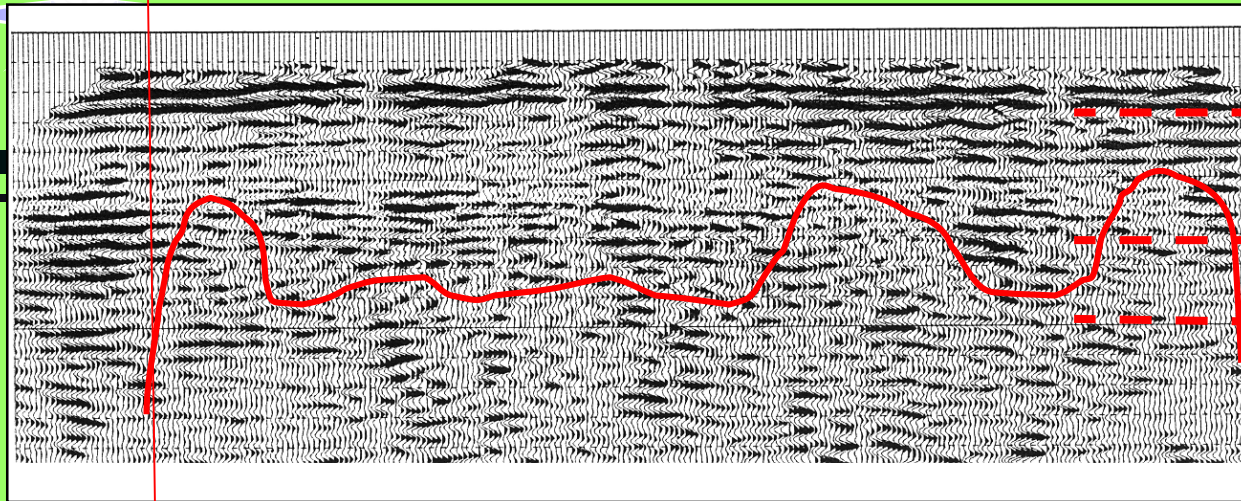


Surface of the lake has increased three times during last 80 years

plan of site

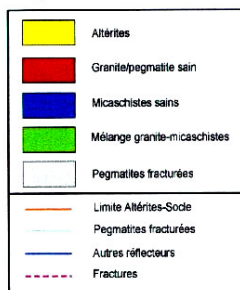


Site minier (2) : Interpretation

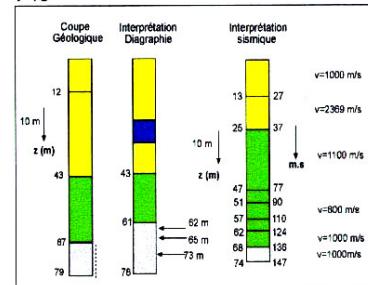


Caractérisation hydrogéologique d'un aquifère en sol fracturé (Bretagne 1996)

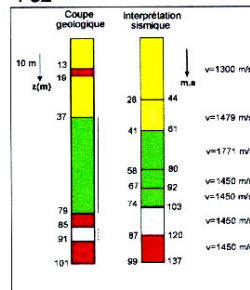
Legende :



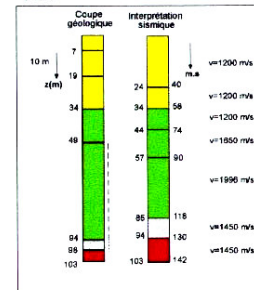
F19



F32

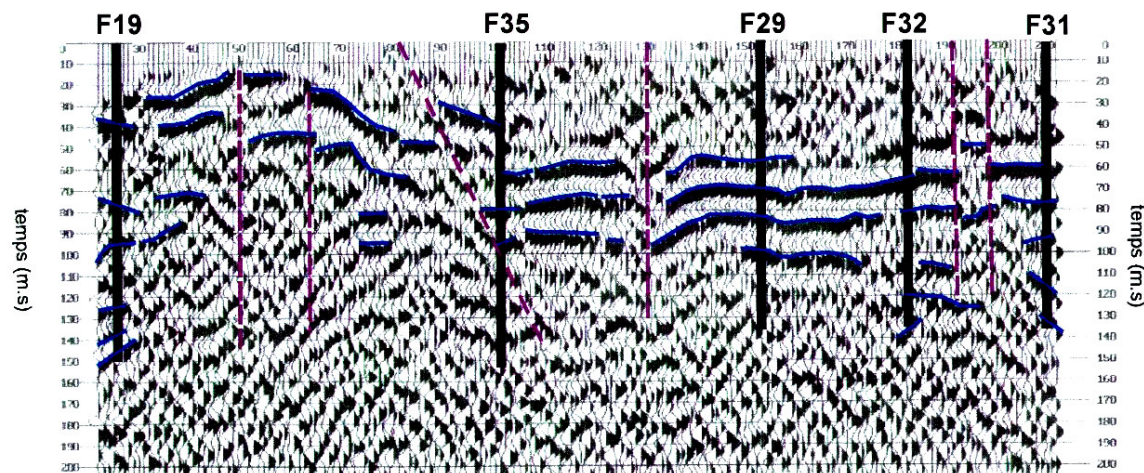


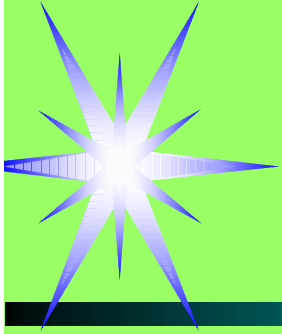
F31



SUD

NORD

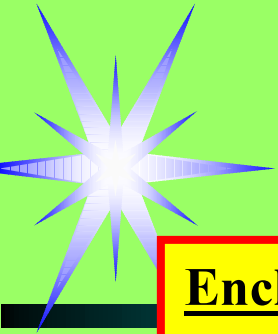




Coûts ?

-Fonction de:

- longueur du profile**
- résolution (couches ou cavités?)**
- résolution**
- accessibilité du site**
- profondeur**
- traitement**



Conclusions

Enclosed examples cover :

- stratigraphy of shallow subsurface
 - detection and location of underground tunnels
 - detection of filled in /collapsed grounds
 - evaluation of the state of a void (collapsed/sound)
 - archaeological research
 - imaging of shallow faults
 - imaging of mines and associated collapses
 - hydrogeology
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- wavelengths exploited: $\lambda = 5 - 15 \text{ m}$
 - angular resolution obtained: $\delta = 10 - 20 \text{ deg}$
 - depth resolution obtained: $\delta_r = \lambda/4 = 1 - 4 \text{ m}$
 - depths exploited: $2 - 400 \text{ m}$