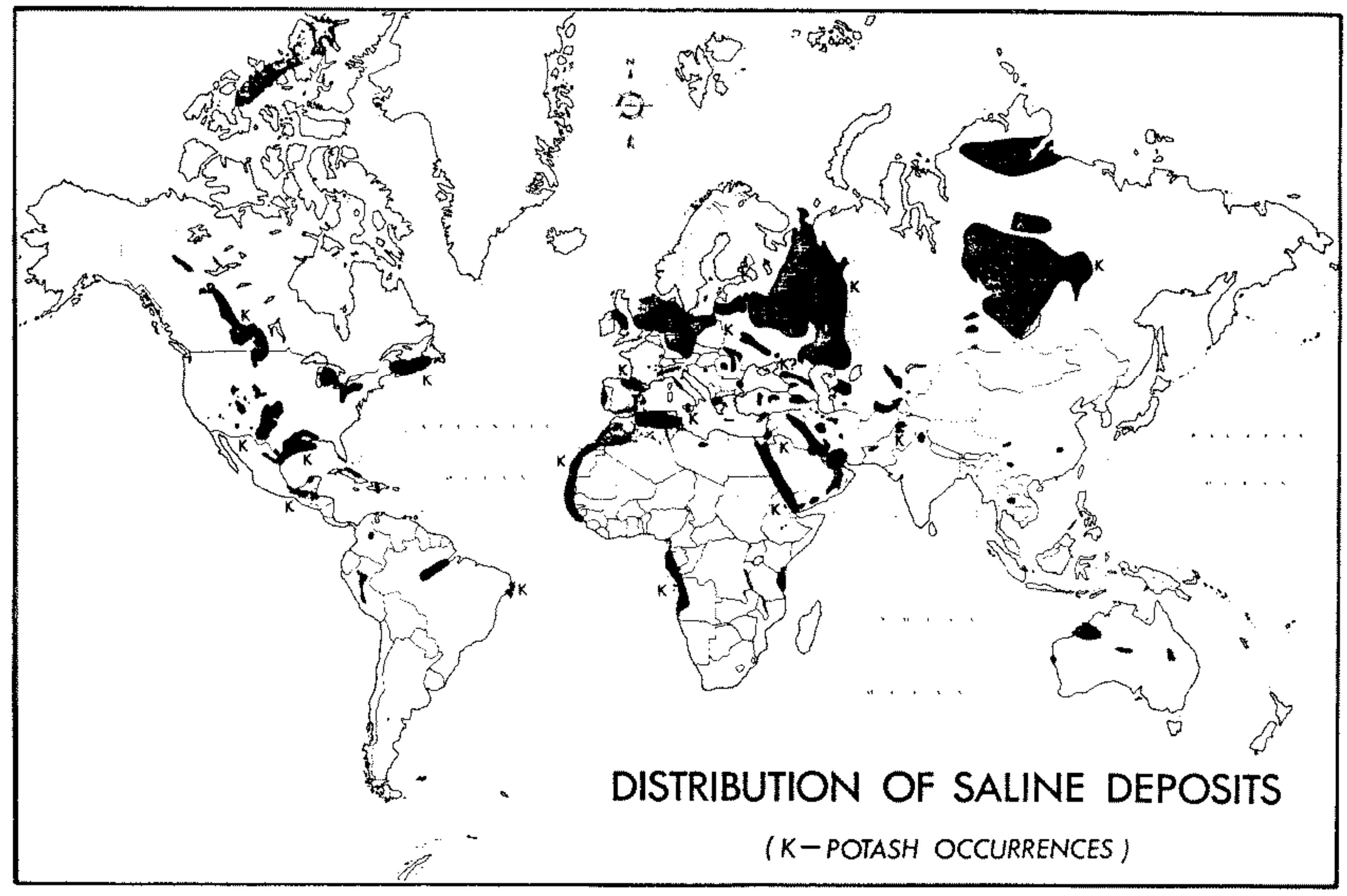
Société Belge de Géologie de l'Ingénieur et de Mécanique des Roches

Bruxelles, 13 juin 2014

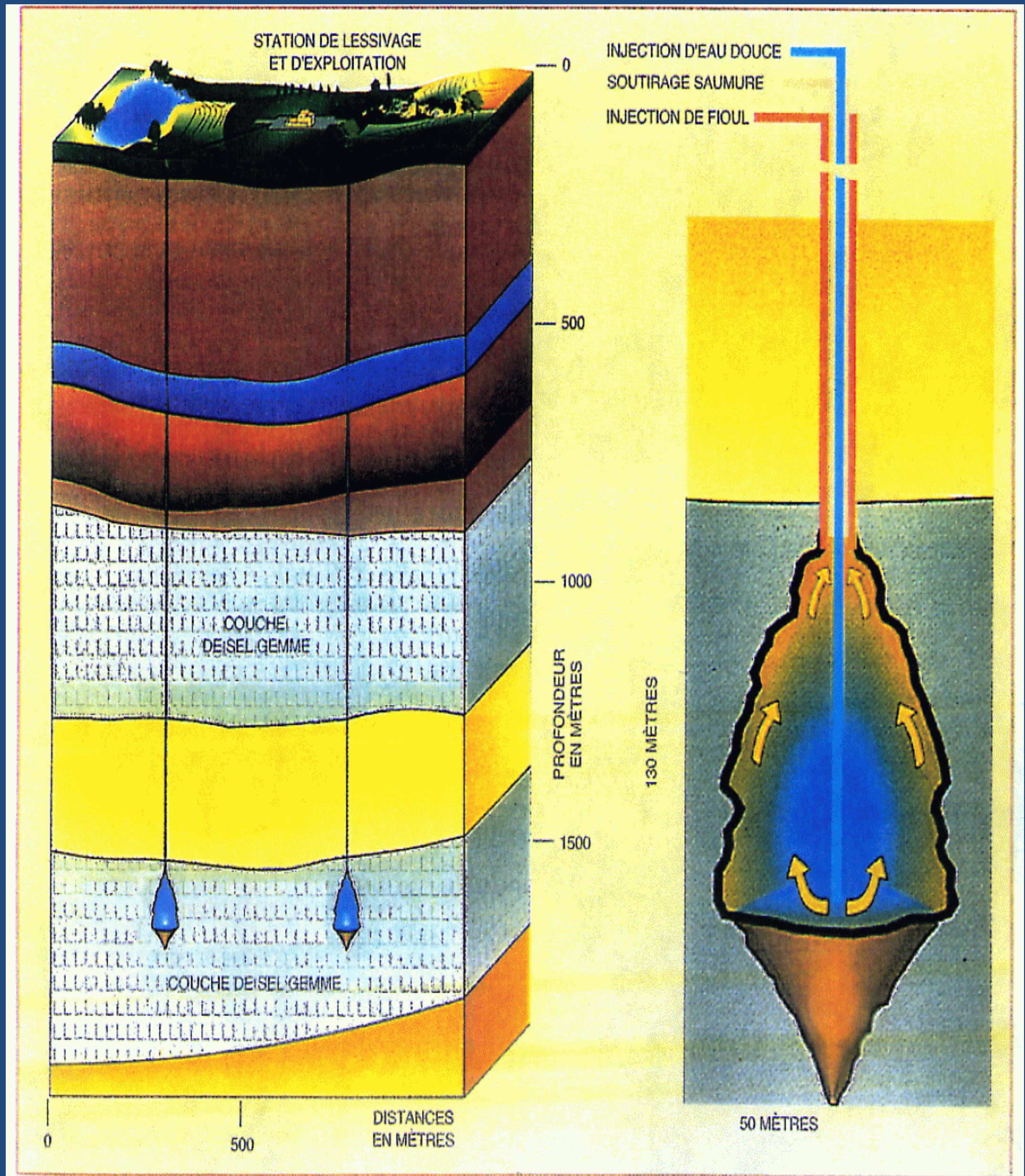
COMPORTEMENT À TRÈS LONG TERME DE CAVERNES RÉALISÉES DANS DES MASSIFS DE SEL

Pierre Bérest, LMS, Ecole Polytechnique, Palaiseau
Benoît Brouard, Brouard Consulting, Paris

DISTRIBUTION DES DÉPÔTS DE SEL DANS LE MONDE

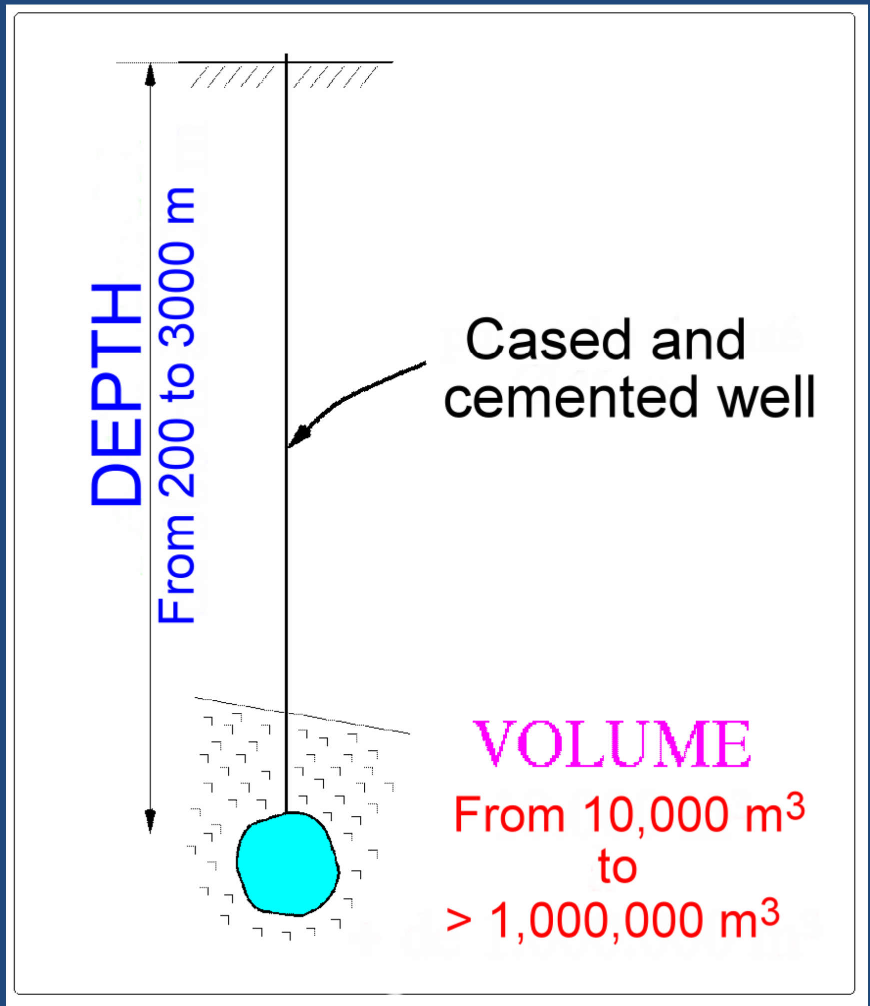


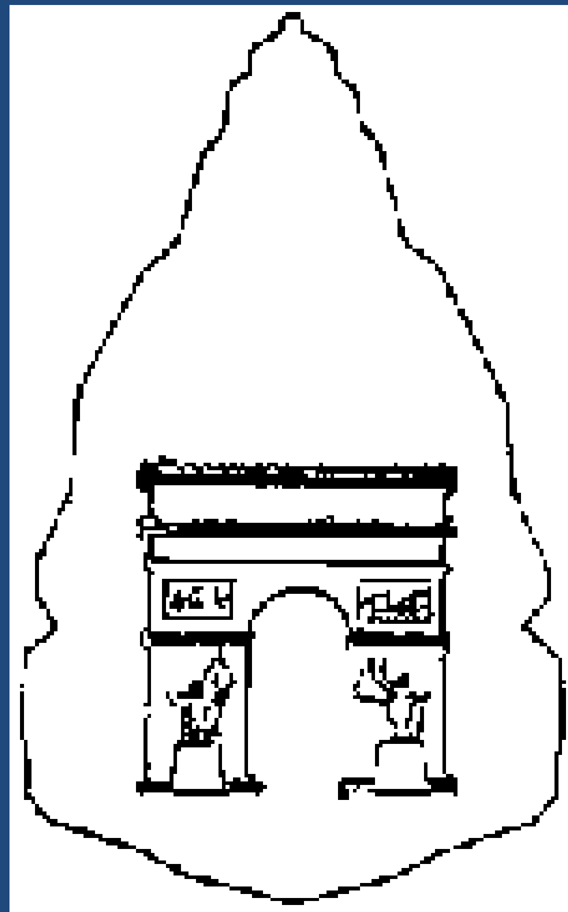
PRINCIPE DU LESSIVAGE



Production de saumure
Stockage d'hydrocarbures

Profondeur et dimensions

- 



CAVITÉS SALINES

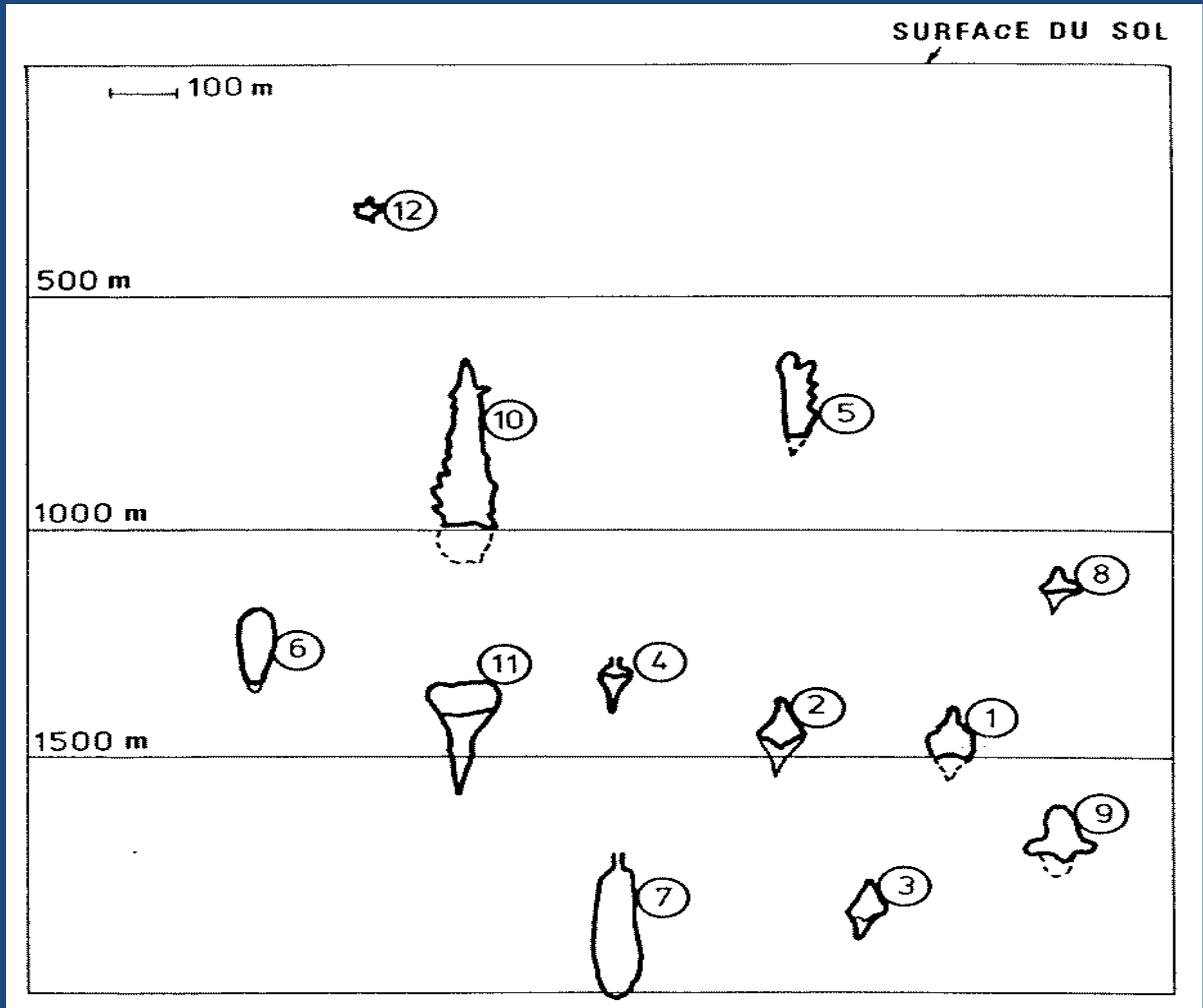
0 m

500 m

1000 m

1500 m

2000 m

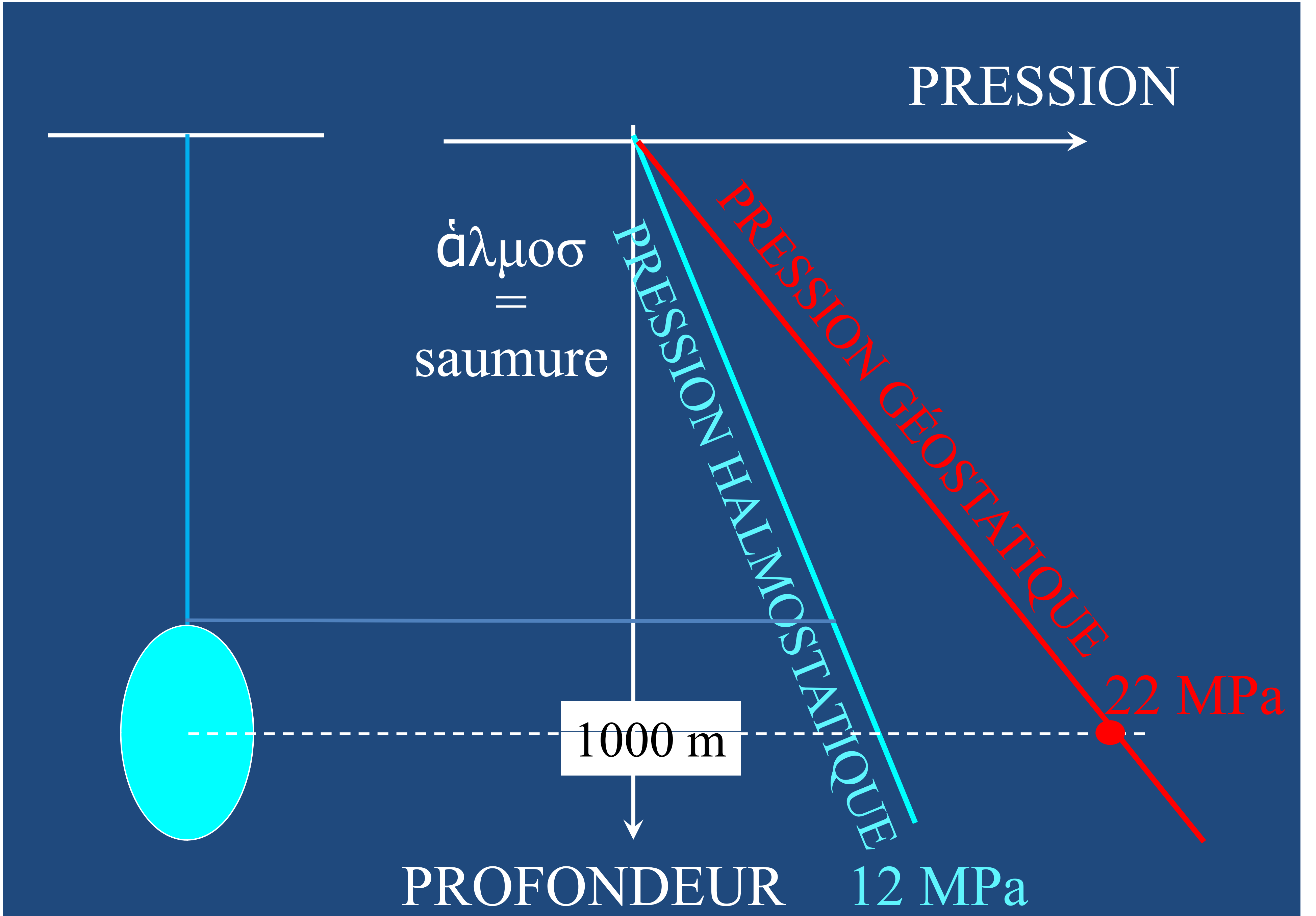


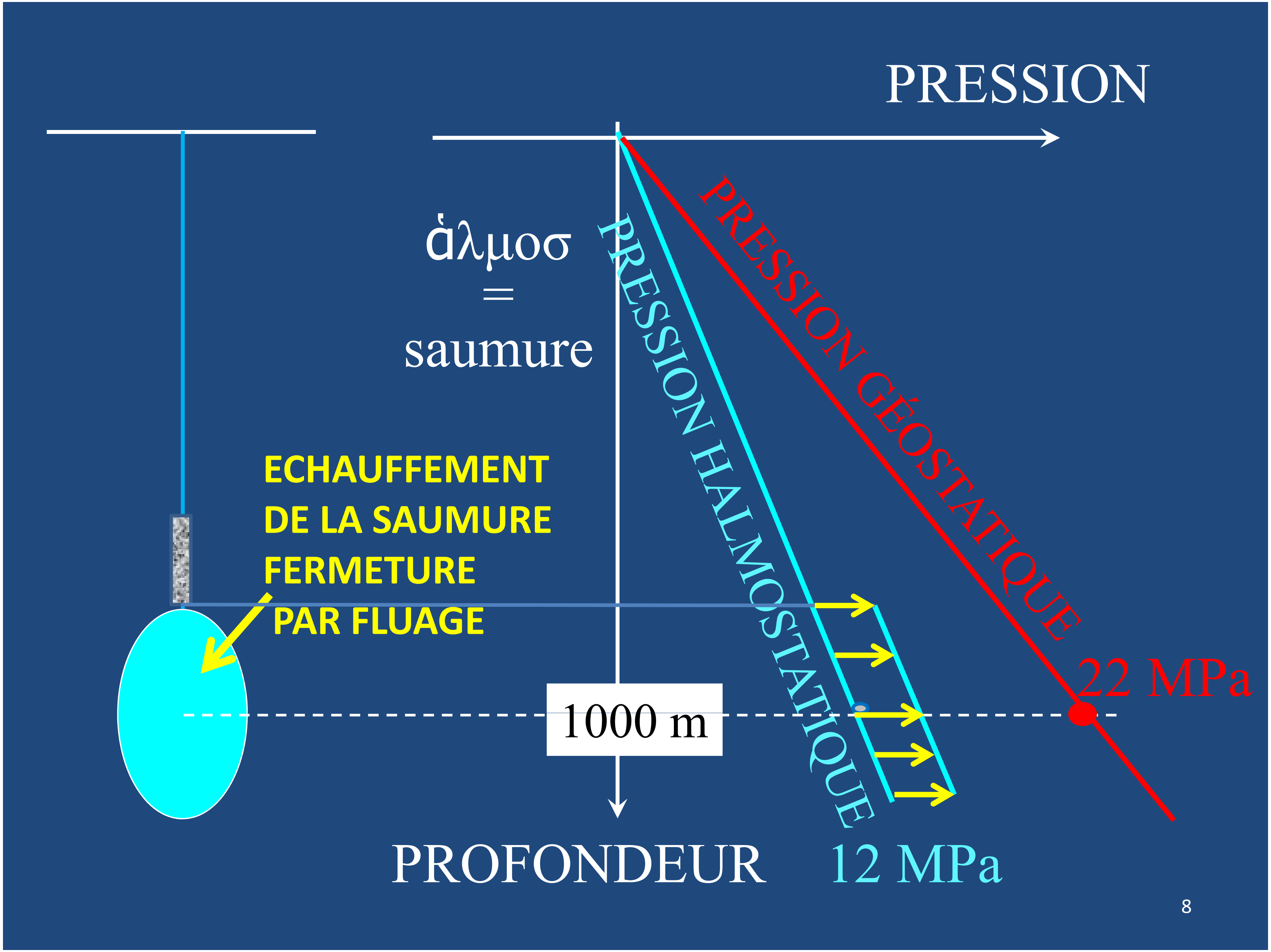
1. Tersanne (France)
2. Etrez (France)
3. Atwick (UK))
4. Kiel (Allemagne)
5. Huntorf (Allemagne)
6. Epe (Allemagne)
7. Eminence (USA)
8. Melville (Canada)
9. Regina (Canada)
10. Manosque (France)
11. Hauterives (France)
12. Salies de Béarn (France)

Les cavités seront fermées un jour. Elles seront remplies de saumure, un bouchon sera placé au voisinage du sabot du cuvelage, du ciment sera coulé dans le puits ...

... isolant une grande “bulle” de saumure.

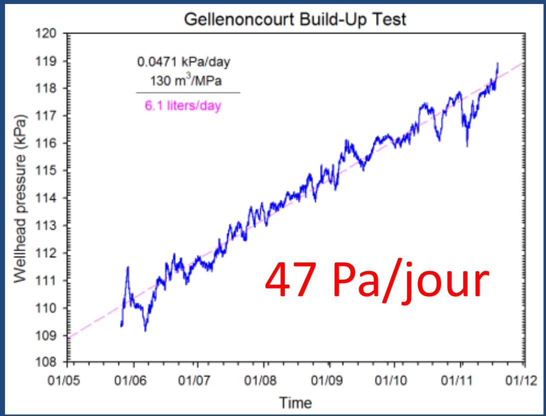
La pression de la saumure augmentera.


PRESSION
ἁλμοσ
=
saumure
PRESSION HALMOSTATIQUE
PRESSION GÉOSTATIQUE
22 MPa
1000 m
PROFONDEUR
12 MPa

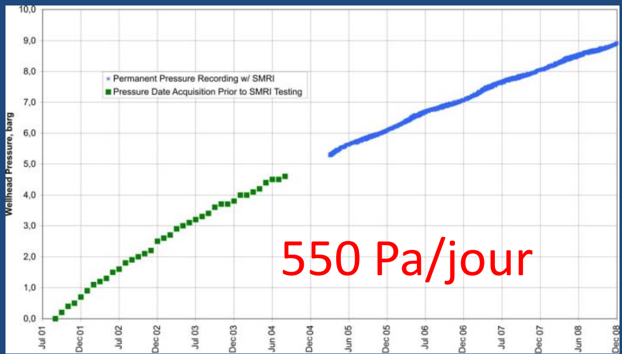

PRESSION
ἁλμοσ
=
saumure
PRESSION HALMOSTATIQUE
PRESSION GÉOSTATIQUE
ECHAUFFEMENT
DE LA SAUMURE
FERMETURE
PAR FLUAGE
22 MPa
1000 m
PROFONDEUR
12 MPa

ÉVOLUTION DE LA PRESSION EN CAVERNE FERMÉE

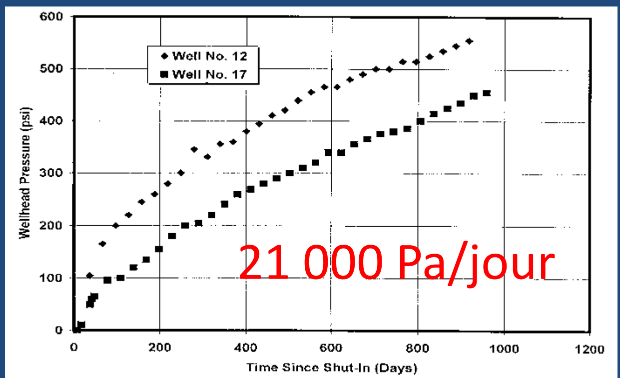
PEU PROFONDE



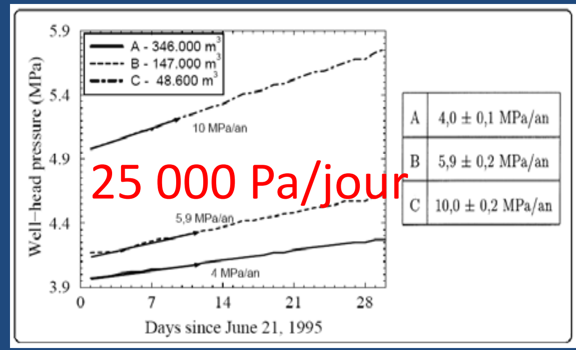
Gellenoncourt (CSME, 250 m)



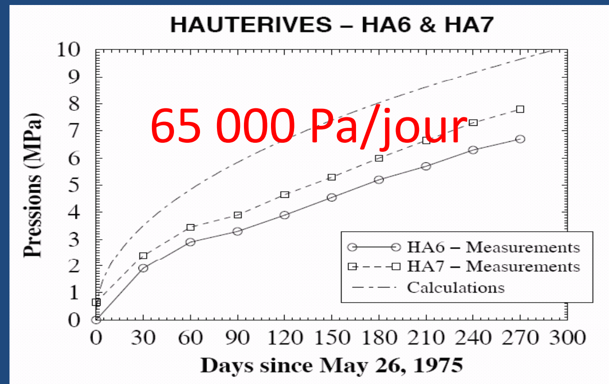
Stassfurt (Bannach & Klafki, 600 m)



Mont Belvieu (Van Sambeek)

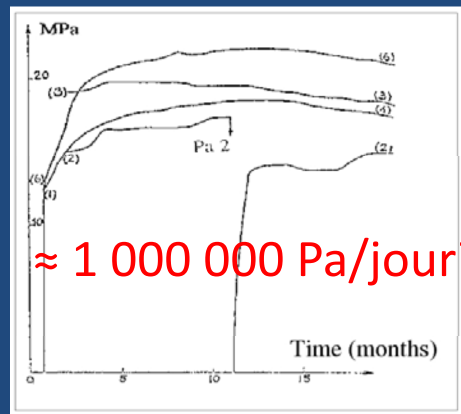


Etrez (Storengy, 1350 m)



Hauterives (1600 m)

TRÈS PROFONDE



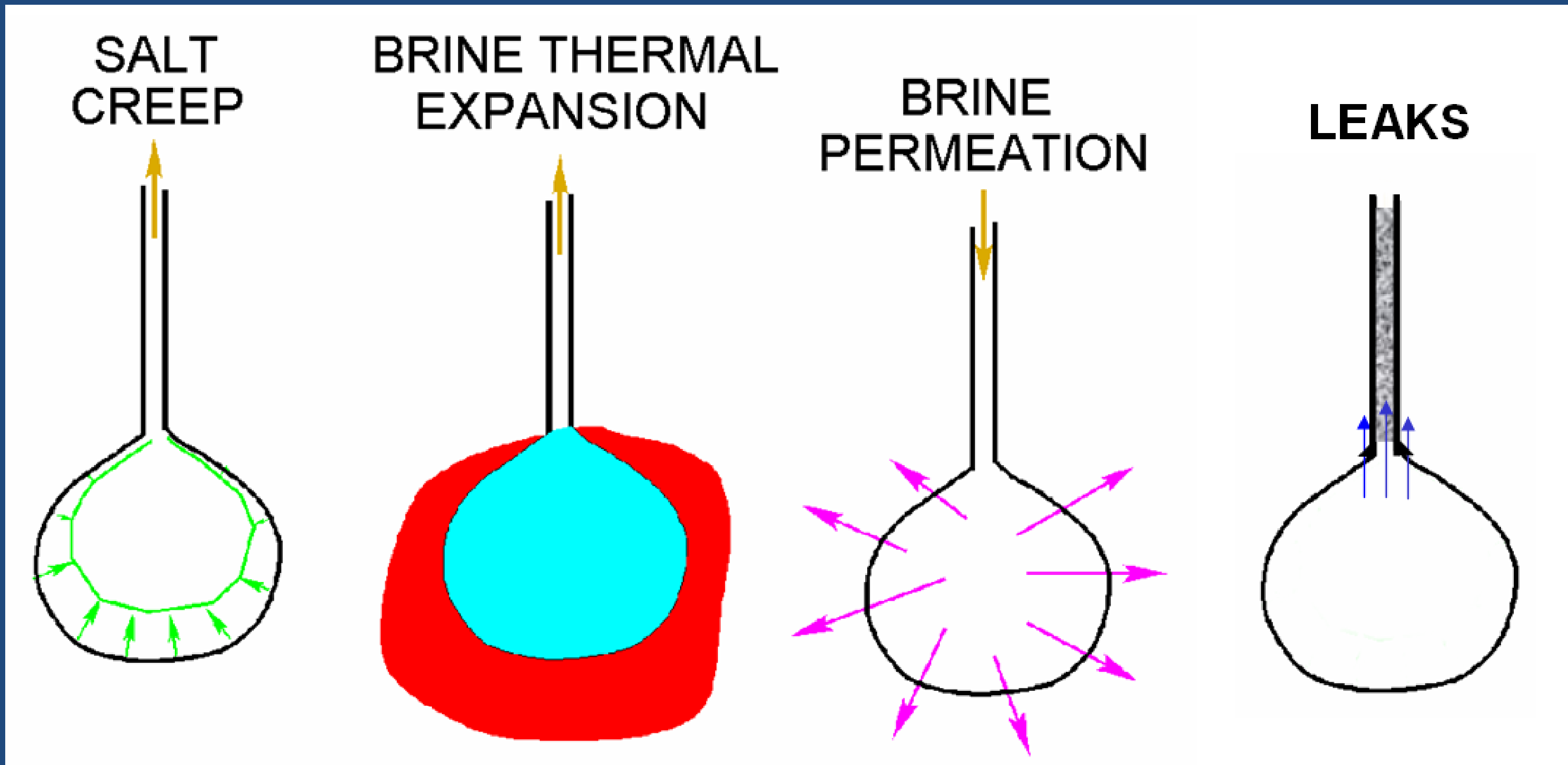
Vauvert (Kem One, 2000 m)

POURQUOI LA PRESSION AUGMENTE

POURQUOI LA PRESSION AUGMENTE

1. La saumure s’échauffe pour atteindre l’équilibre thermique avec le massif. Phénomène lent (sa durée varie comme le carré des dimensions) mais transitoire.

2. La caverne, dont la pression interne est inférieure à la pression géostatique, se referme en raison du fluage du sel.


SALT
CREEP
BRINE THERMAL
EXPANSION
BRINE
PERMEATION
LEAKS

Fluage stationnaire du sel au laboratoire

$$\dot{\varepsilon}^{ss} = A(T)\ \sigma^{n}$$

$$n = 3 - 6$$

Vitesse de fermeture d'une caverne

$$\dot{\varepsilon}^{ss} = A(T)\ \sigma^{n}$$

$$\dot{V} / V = A^{*}(T)\ (P_{géo} - P_{cav})^{n}$$

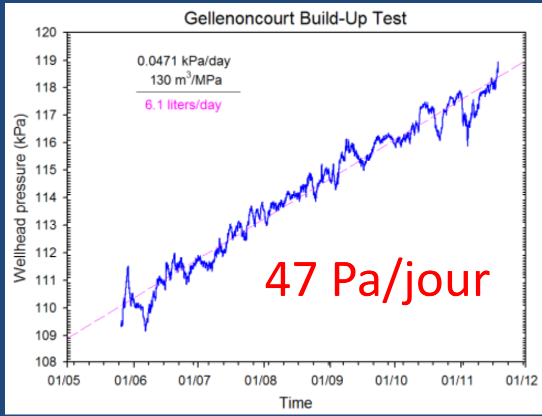
Augmentation de la pression dans une cavité fermée

$$\dot{\varepsilon}^{ss} = A(T)\ \sigma^{n}$$

$$\dot{V} / V = A^{*}(T)\ (P_{géo} - P_{cav})^{n}$$

$$\beta \dot{P}_{c} = A^{*}(T)\ (P_{géo} - P_{cav})^{n}$$

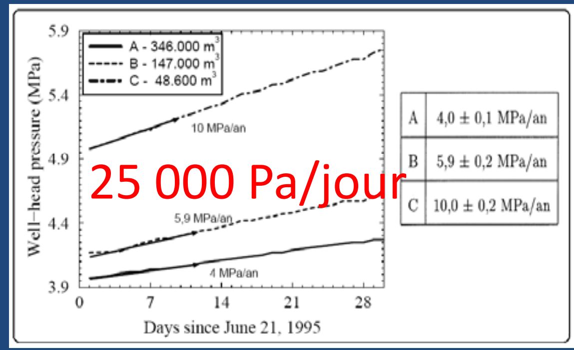
« Compressibilité de la caverne », $1/\beta \approx 2500$ MPa



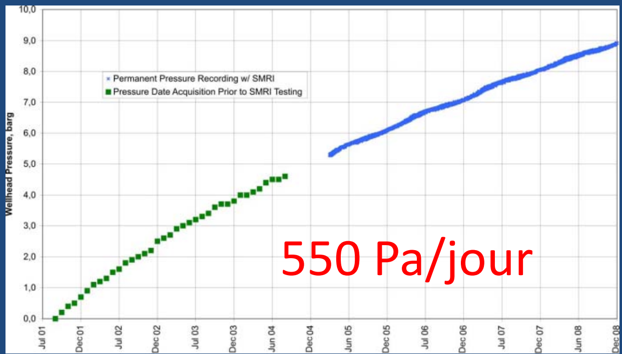
Gellenoncourt (CSME, 250 m)

PEU

PROFONDE



Etrez (Storengy, 1350 m)



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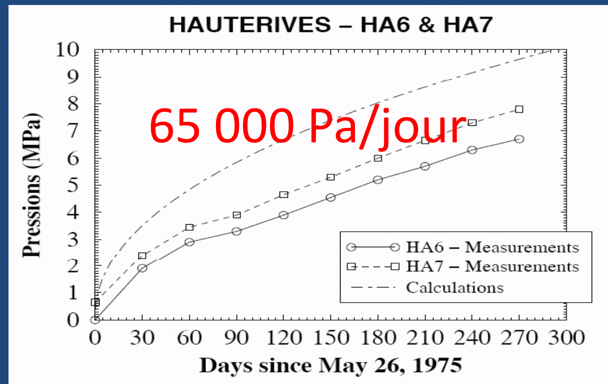
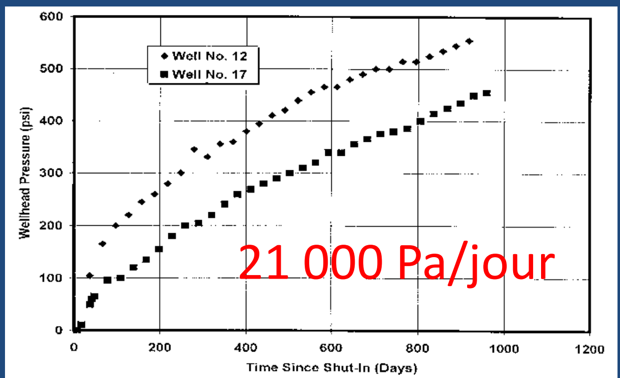


Hauterives (1600 m)

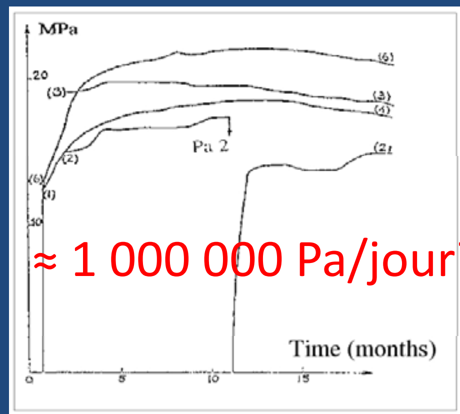
$$\beta \dot{P}_{cav} = A^*(T)\ (P_{géo} - P_{cav})^n$$



Mont Belvieu (Van Sambeek)

TRÈS

PROFONDE

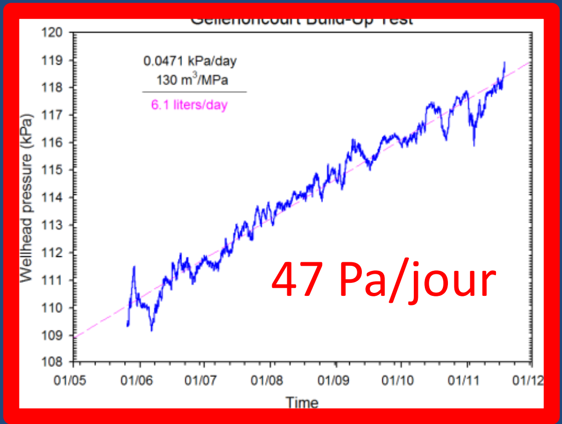


Vauvert (Kem One, 2000 m)

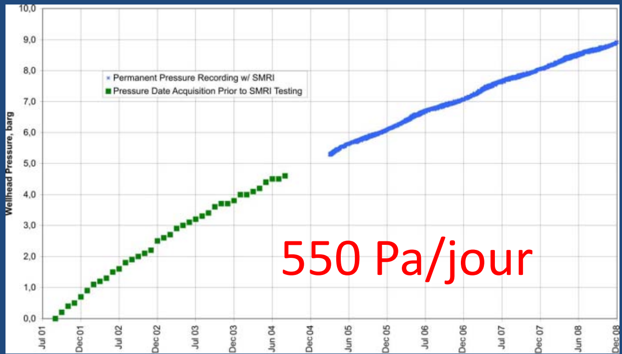
ÉVOLUTION DE LA PRESSION EN CAVERNE FERMÉE

PEU PROFONDE

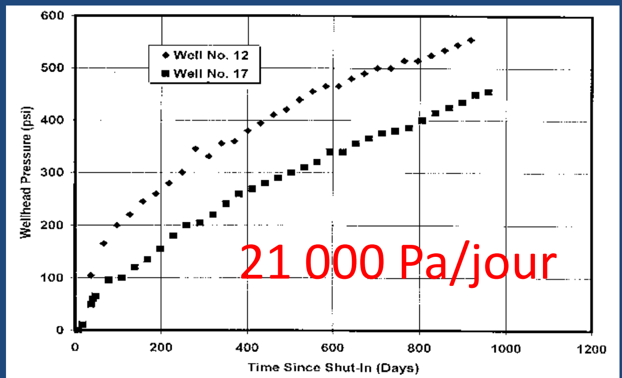
TRÈS PROFONDE



Gellenoncourt (CSME, 250 m)



Stassfurt (Bannach & Klafki, 600 m)



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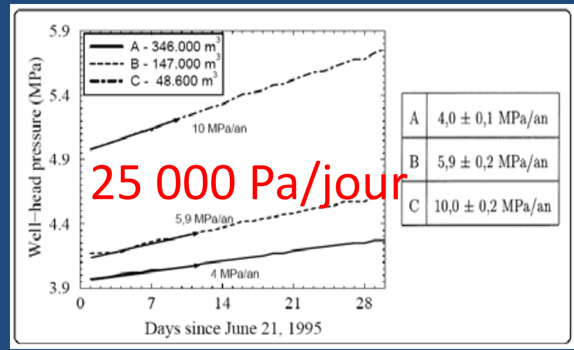
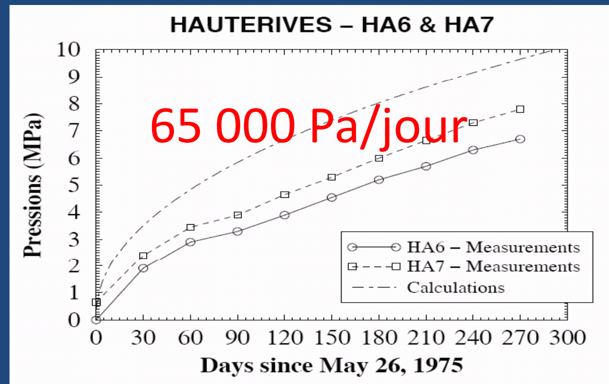
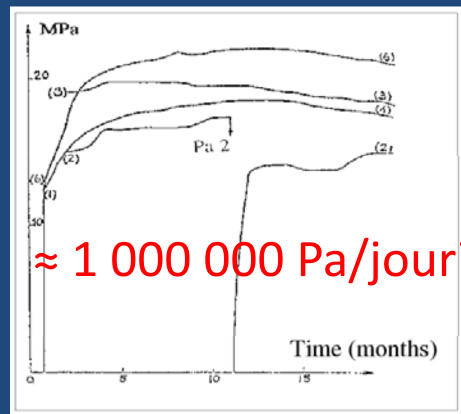


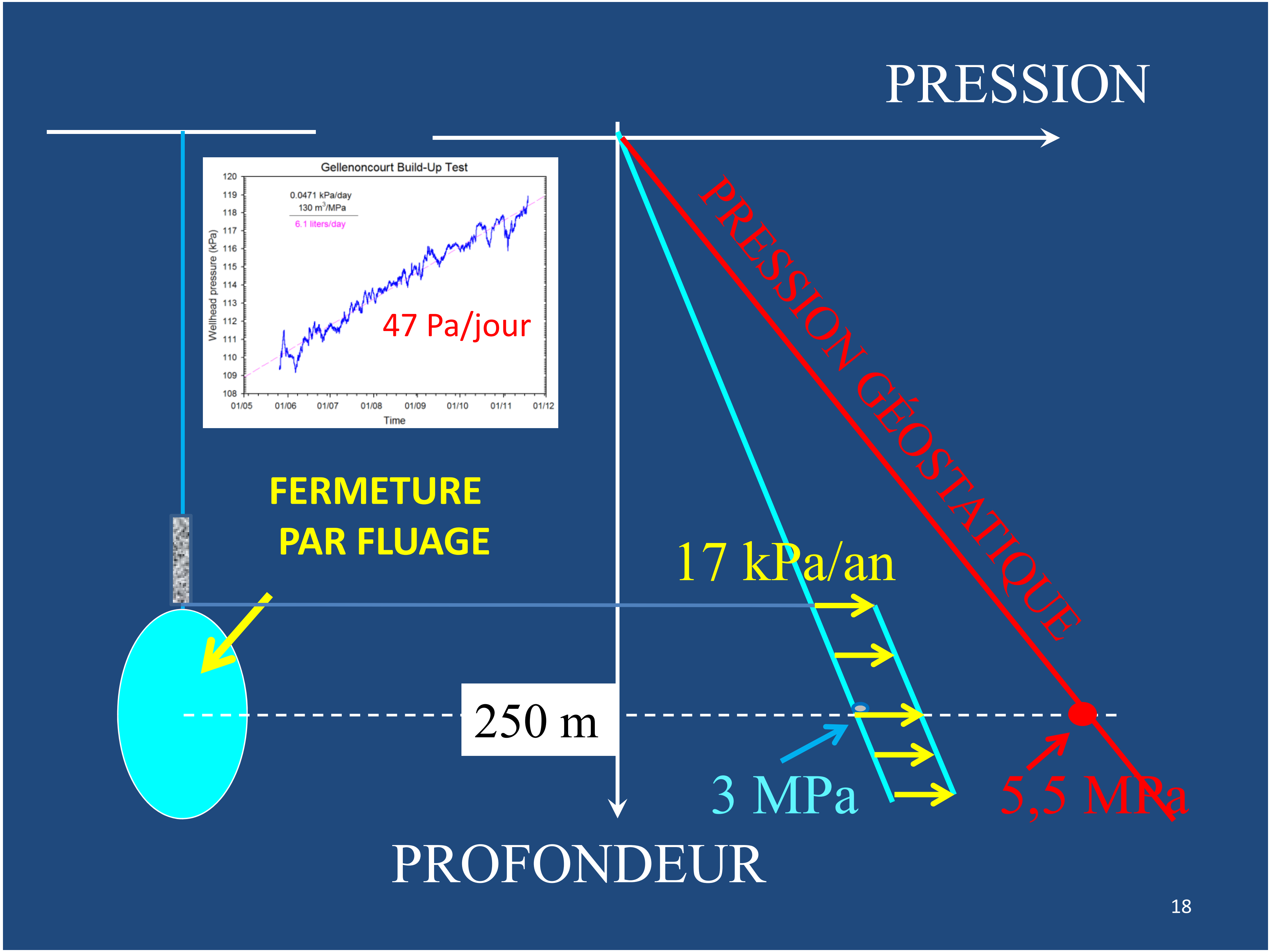
Etrez (Storengy, 1350 m)

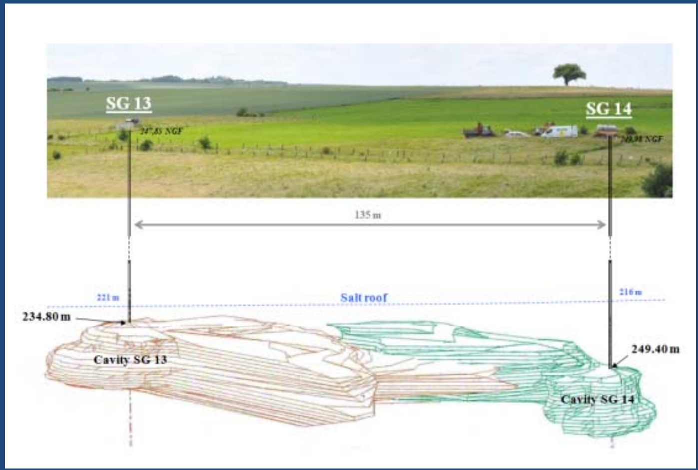


Hauterives (1600 m)

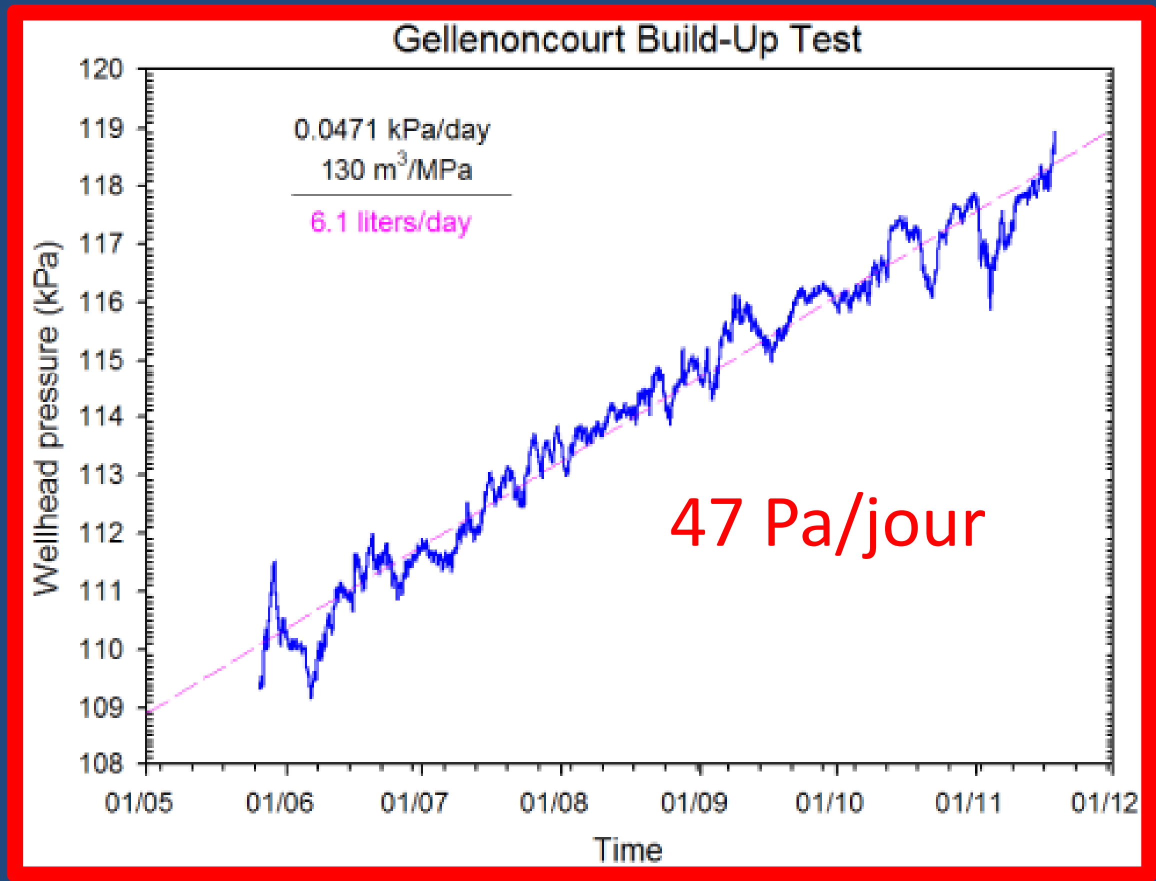


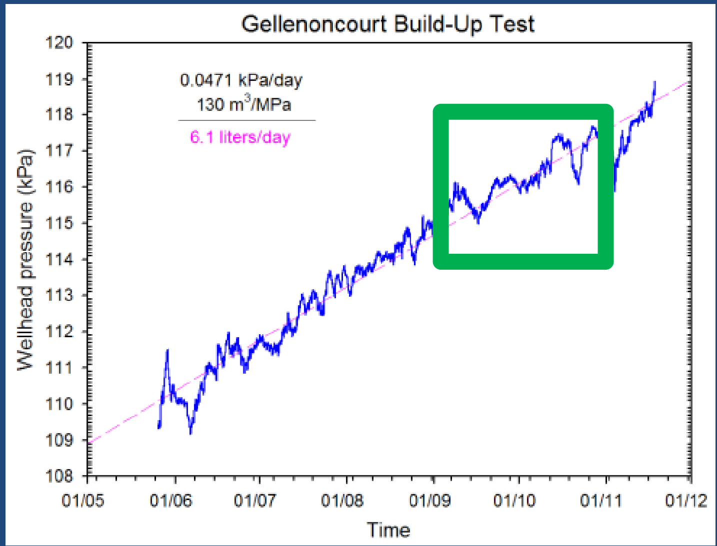
Vauvert (Kem One, 2000 m)

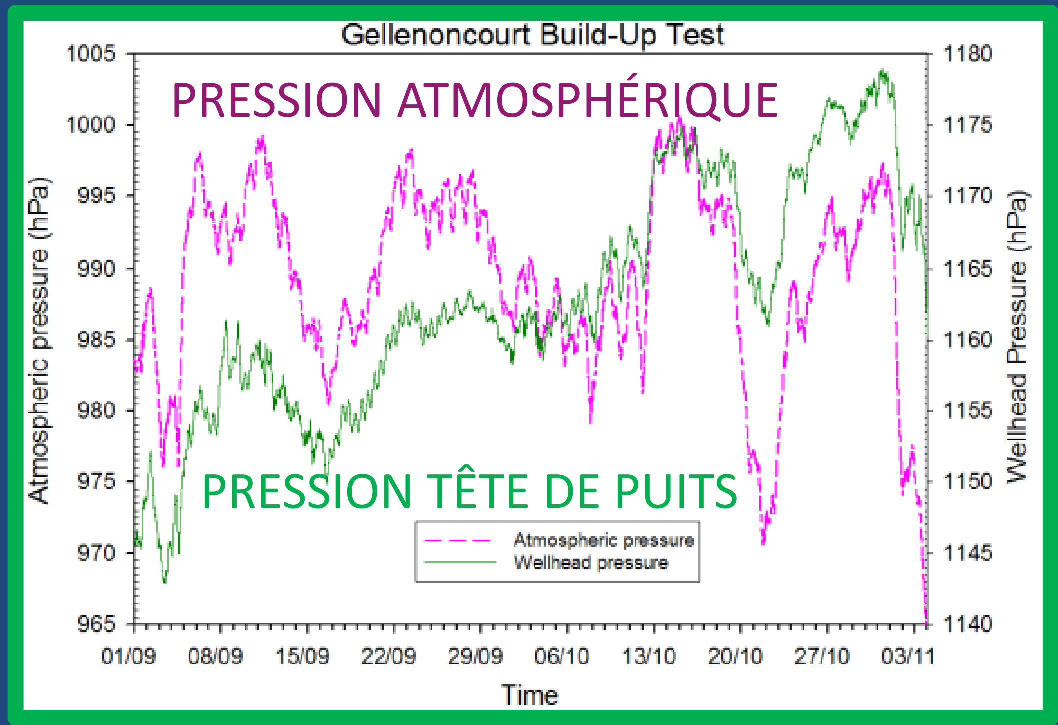

PRESSION
Gellenoncourt Build-Up Test
0.0471 kPa/day
130 m3/MPa
6.1 liters/day
Wellhead pressure (kPa)
Time
47 Pa/jour
PRESSION GÉOSTATIQUE
FERMETURE
PAR FLUAGE
17 kPa/an
250 m
3 MPa
5,5 MPa
PROFONDEUR


SG 13
SG 14
135 m
221 m
Salt roof
216 m
234.80 m
249.40 m
Cavity SG 13
Cavity SG 14

H = 250 M


Gellenoncourt Build-Up Test
0.0471 kPa/day
130 m³/MPa
6.1 liters/day
Wellhead pressure (kPa)
120
119
118
117
116
115
114
113
112
111
110
109
108
01/05
01/06
01/07
01/08
01/09
01/10
01/11
01/12
Time
47 Pa/jour

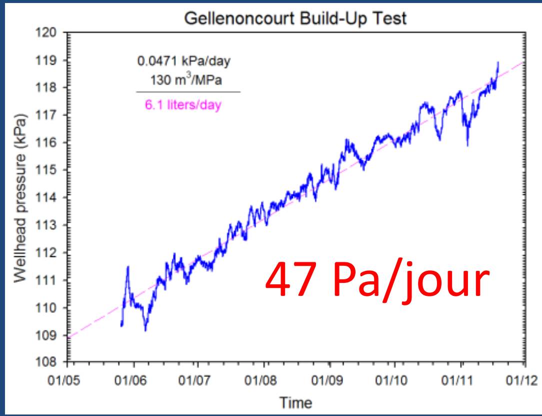

Gellenoncourt Build-Up Test
0.0471 kPa/day
130 m3/MPa
6.1 liters/day
Wellhead pressure (kPa)
Time


Gellenoncourt Build-Up Test
PRESSION ATMOSPHÉRIQUE
PRESSION TÊTE DE PUITS
Atmospheric pressure
Wellhead pressure
Atmospheric pressure (hPa)
Wellhead Pressure (hPa)
Time

E = 54%

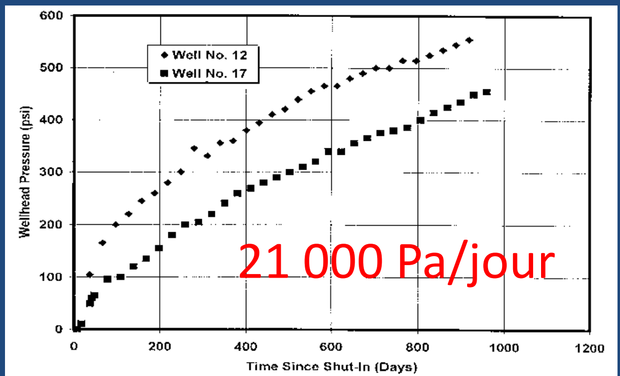
ÉVOLUTION DE LA PRESSION EN CAVERNE FERMÉE

PEU PROFONDE



Gellenoncourt (CSME, 250 m)

Stassfurt (Bannach & Klafki, 600 m)



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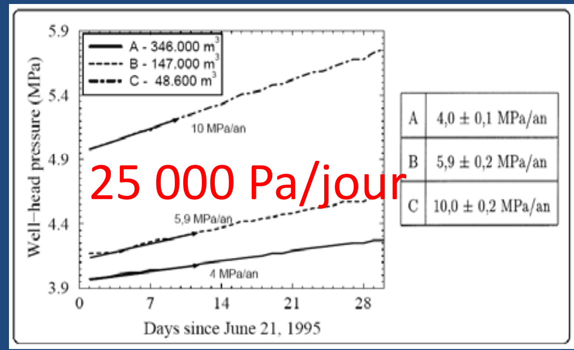
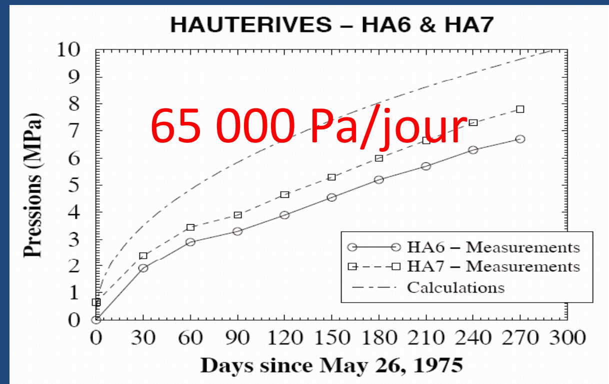
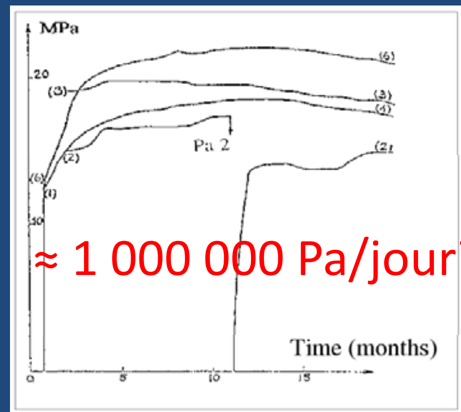


Etrez (Storengy, 1350 m)



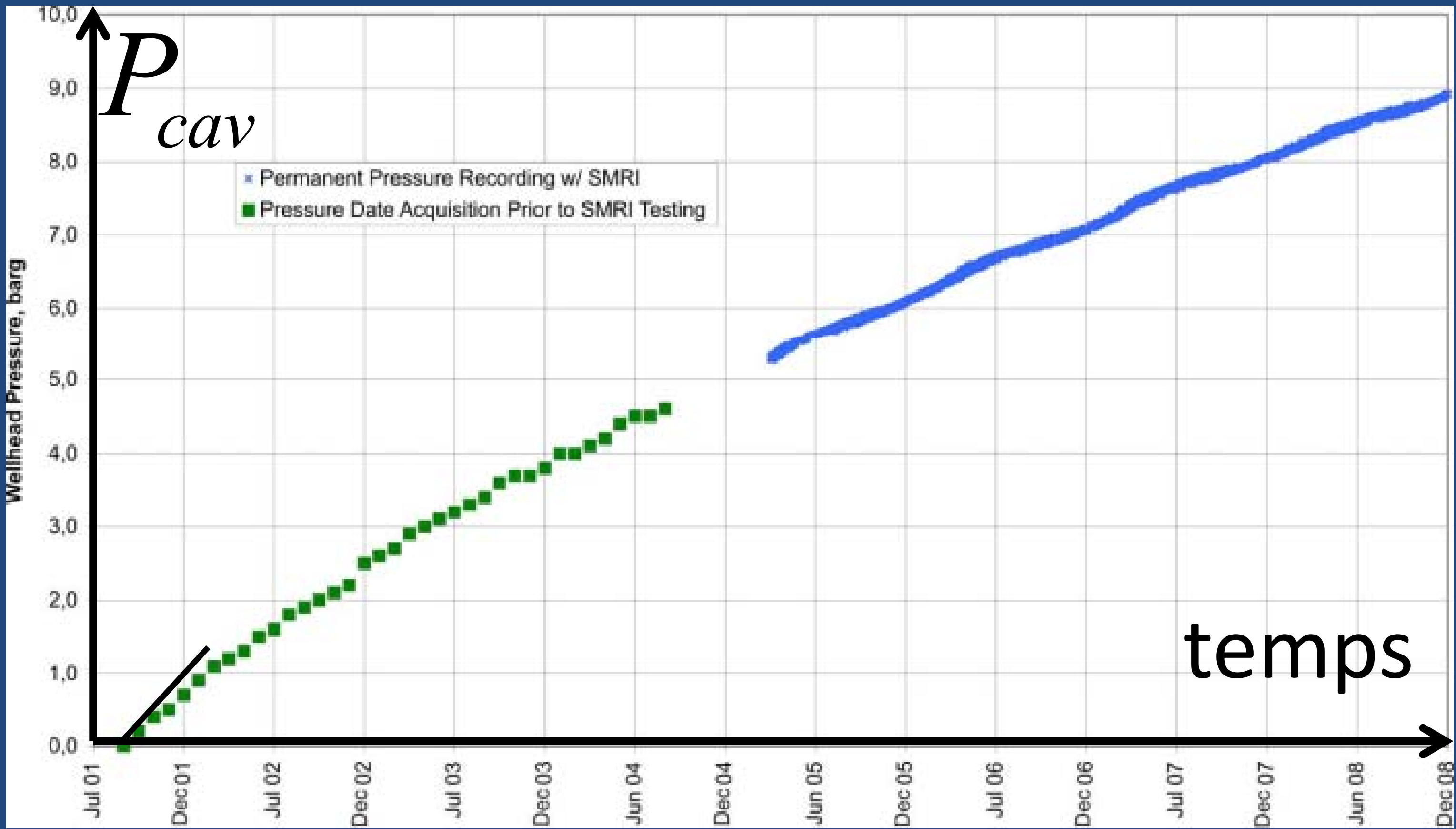
Hauterives (1600 m)

TRÈS PROFONDE

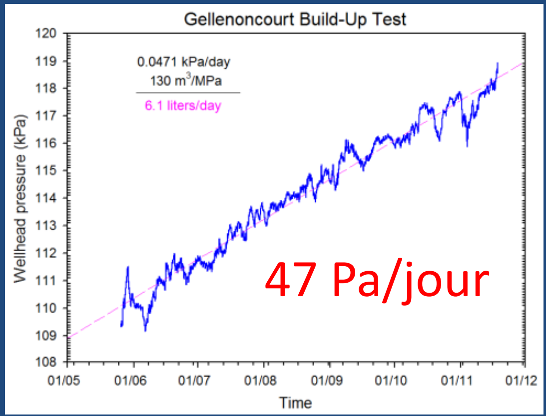


Vauvert (Kem One, 2000 m)

Stassfurt (Bannach & Klafki, 600 m)

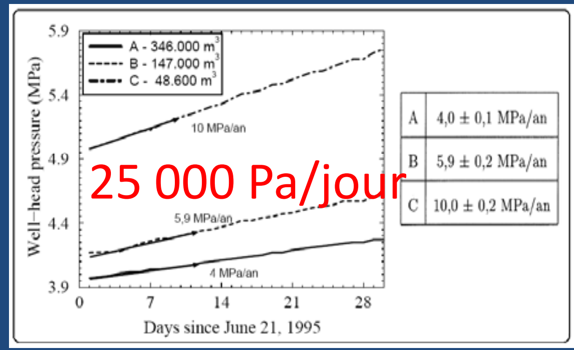


$$\beta \dot{P}_{cav} = A^*(T)\,(P_{géo} - P_{cav})^n$$



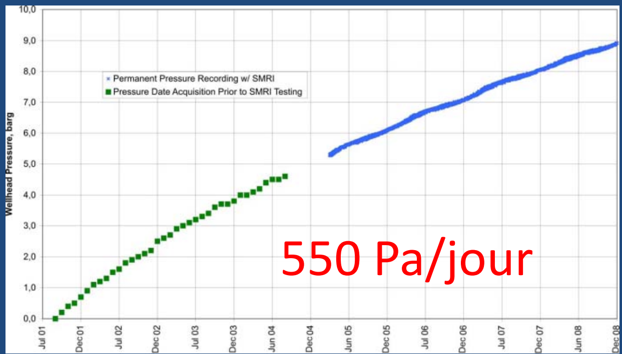
Gellenoncourt (CSME, 250 m)

PEU PROFONDE



Etrez (Storengy, 1350 m)

ÉVOLUTION DE LA PRESSION EN CAVERNE FERMÉE



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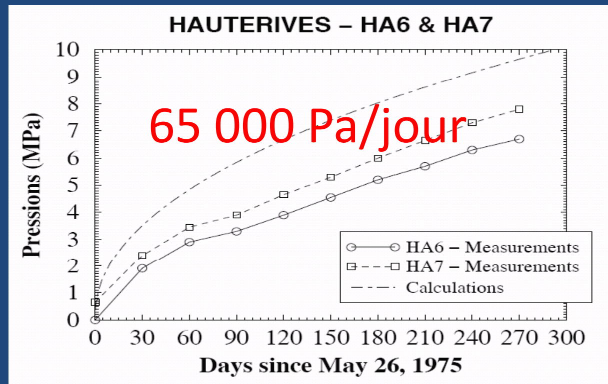
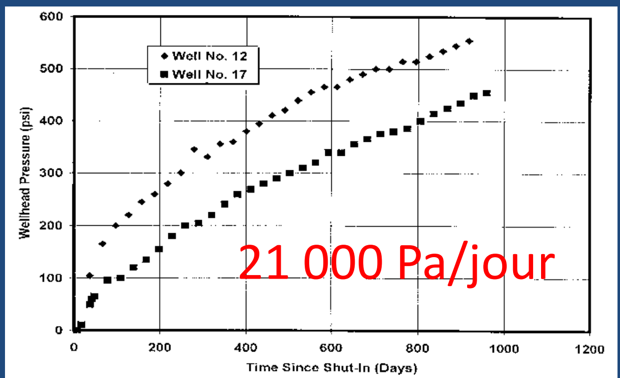
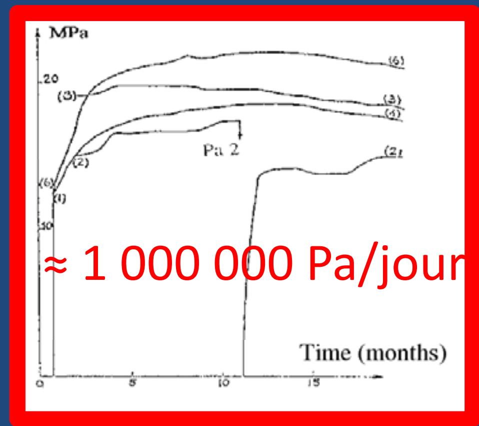


Hauterives (Vencorex, 1600 m)

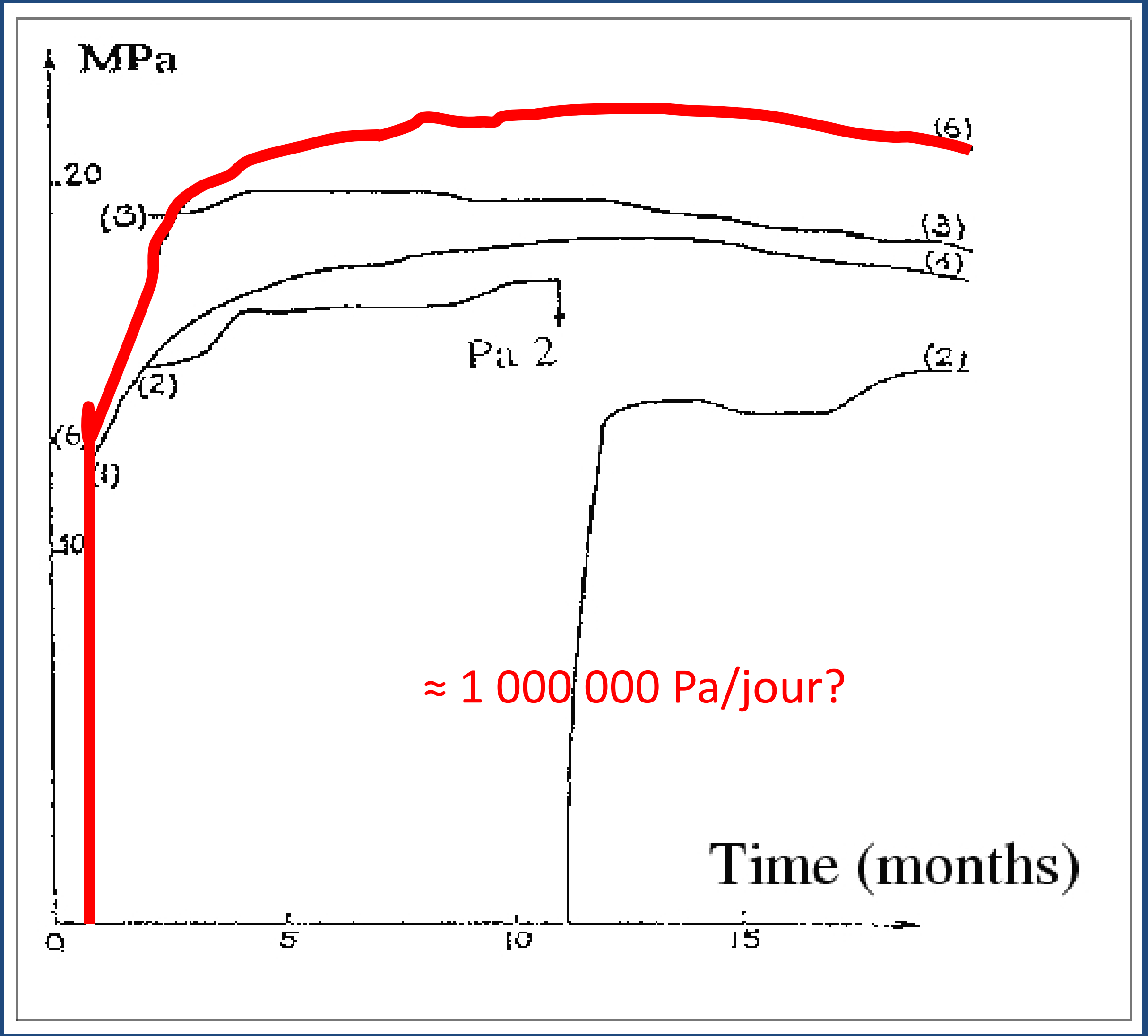


Mont Belvieu (Van Sambeek)

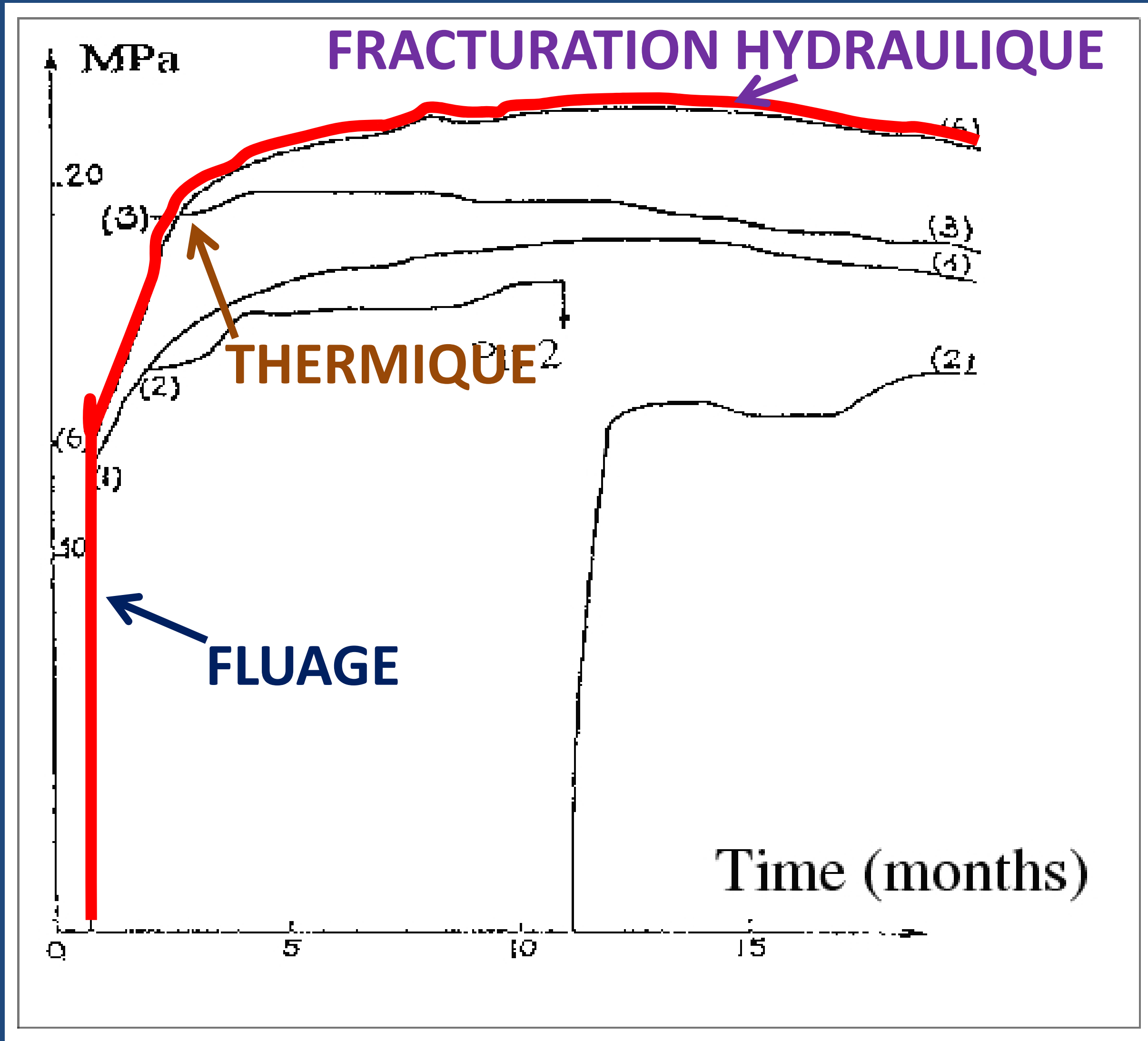
TRÈS PROFONDE



Vauvert (Kem One, 2000 m)



Vauvert (Kem One, 2000 m)



Vauvert (Kem One, 2000 m)

Les cavités seront fermées un jour. Elles seront remplies de saumure, un bouchon sera placé au voisinage du sabot du cuvelage, du ciment sera coulé dans le puits ...

... isolant une grande “bulle” de saumure.
La pression de la saumure augmentera.

La valeur finale atteinte par la pression de la saumure dans la caverne est essentielle du point de vue de la protection de l’environnement.

Dans certaines circonstances, cette pression peut atteindre une valeur supérieure à la pression géostatique, engendrer une hydrofracturation, un écoulement de saumure vers les aquifères potables peu profonds et leur pollution.

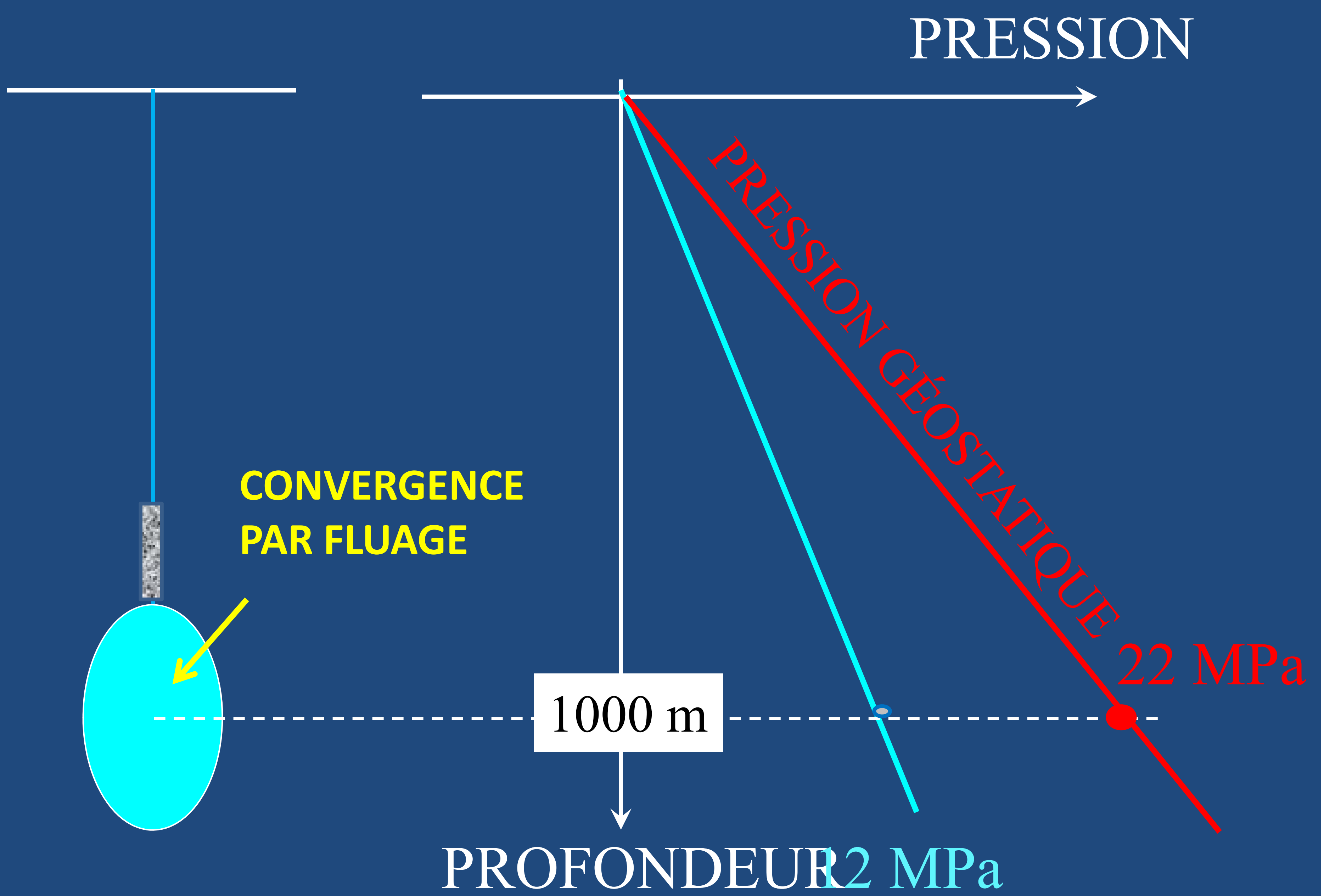
EST-CE QUE LA PRESSION AUGMENTE RÉÉLLEMENT JUSQU'À LA PRESSION GÉOSTATIQUE ?

UN SCÉNARIOPESSIMISTE

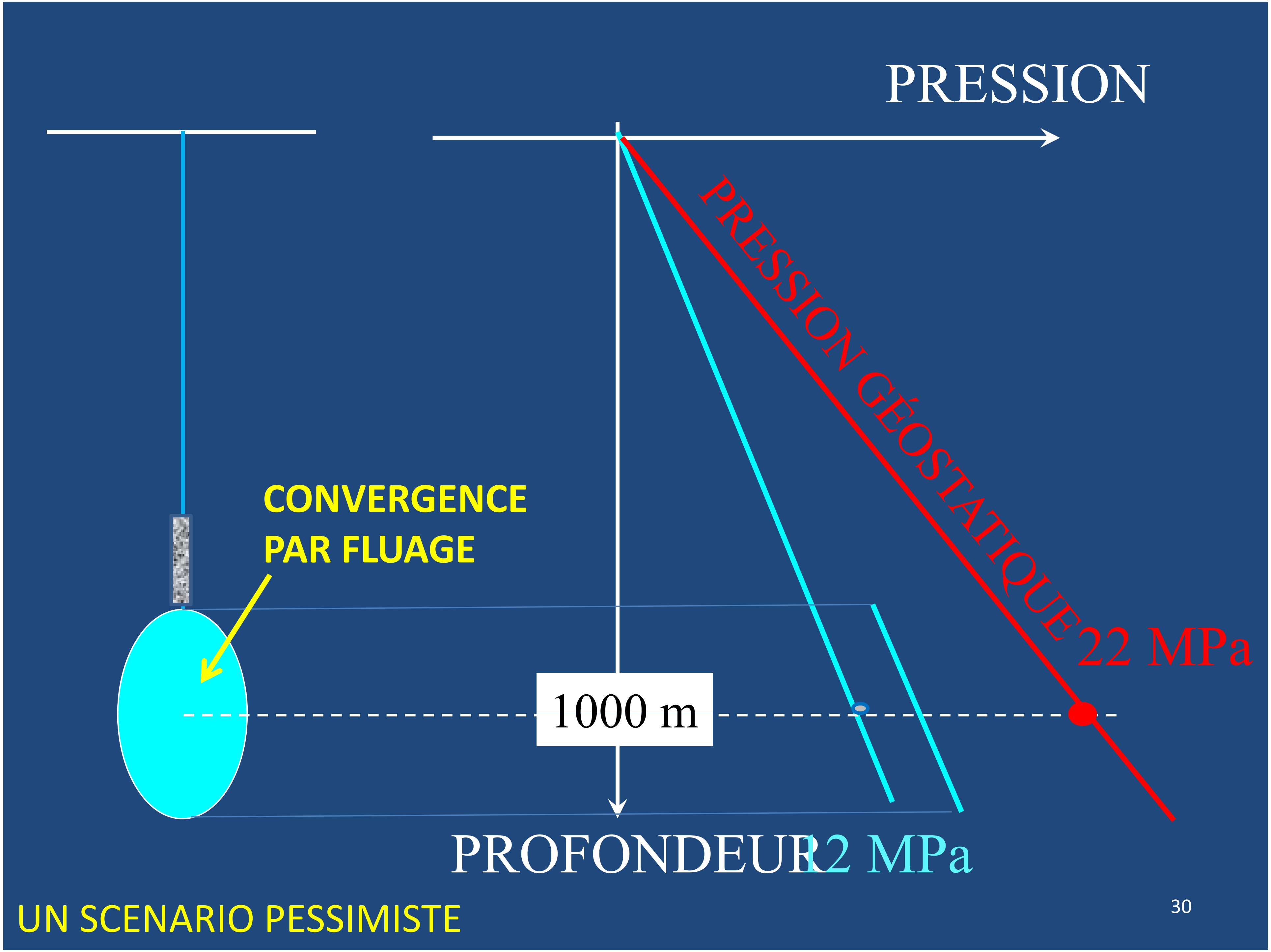
LA CAVITÉ EST PARFAITEMENT ÉTANCHE

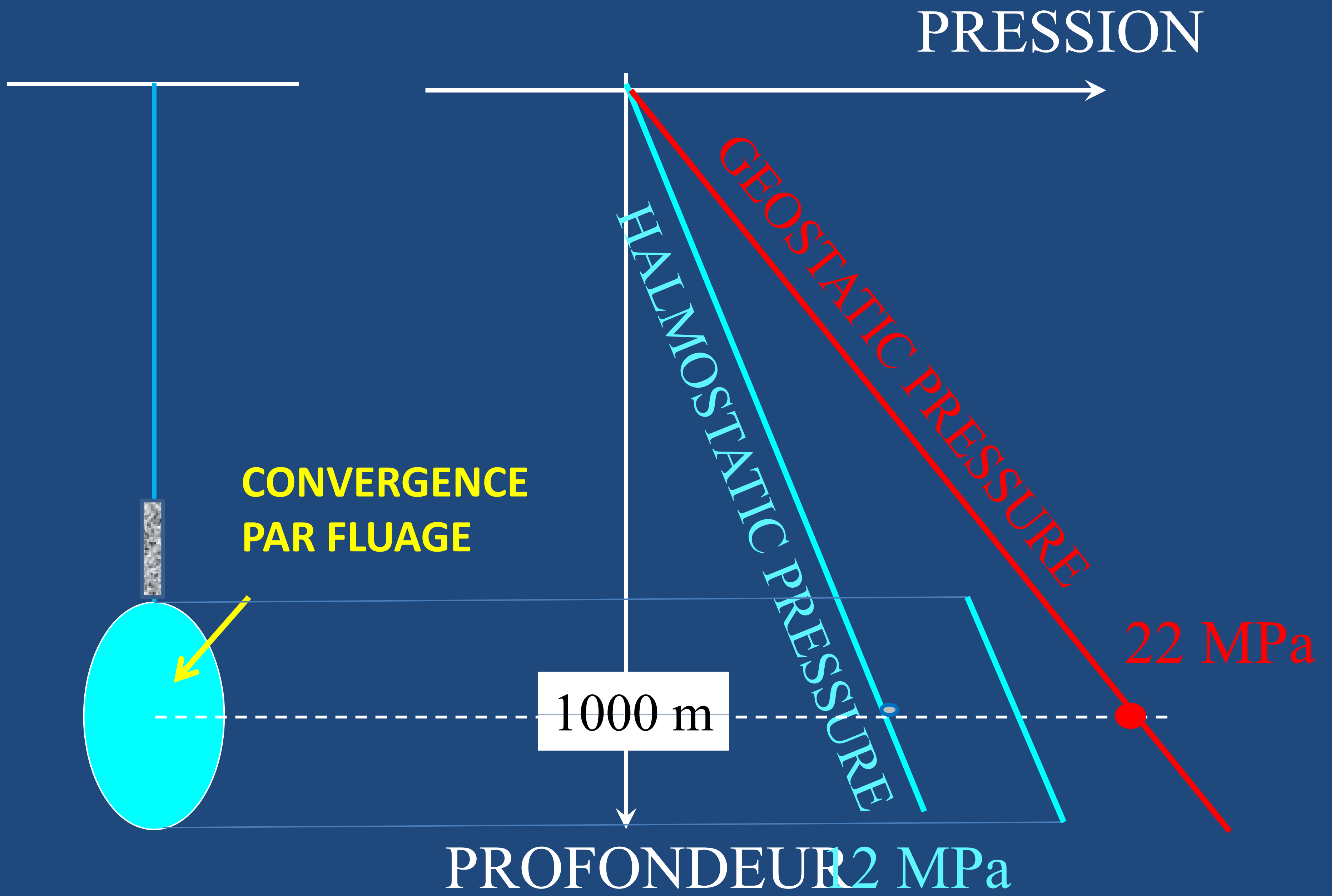
LA CONVERGENCE PAR FLUAGE EST ACTIVE (QUOIQUE DE PLUS EN PLUS LENTE) JUSQU'À CE QUE LA PRESSION DANS LA CAVERNE (P_{cav}) ATTEIGNE LA PRESSION GÉOSTATIQUE$(P_{géo})$

$$\beta \frac{dP_{cav}}{dt} = A\,(P_{géo} - P_{cav})^n$$

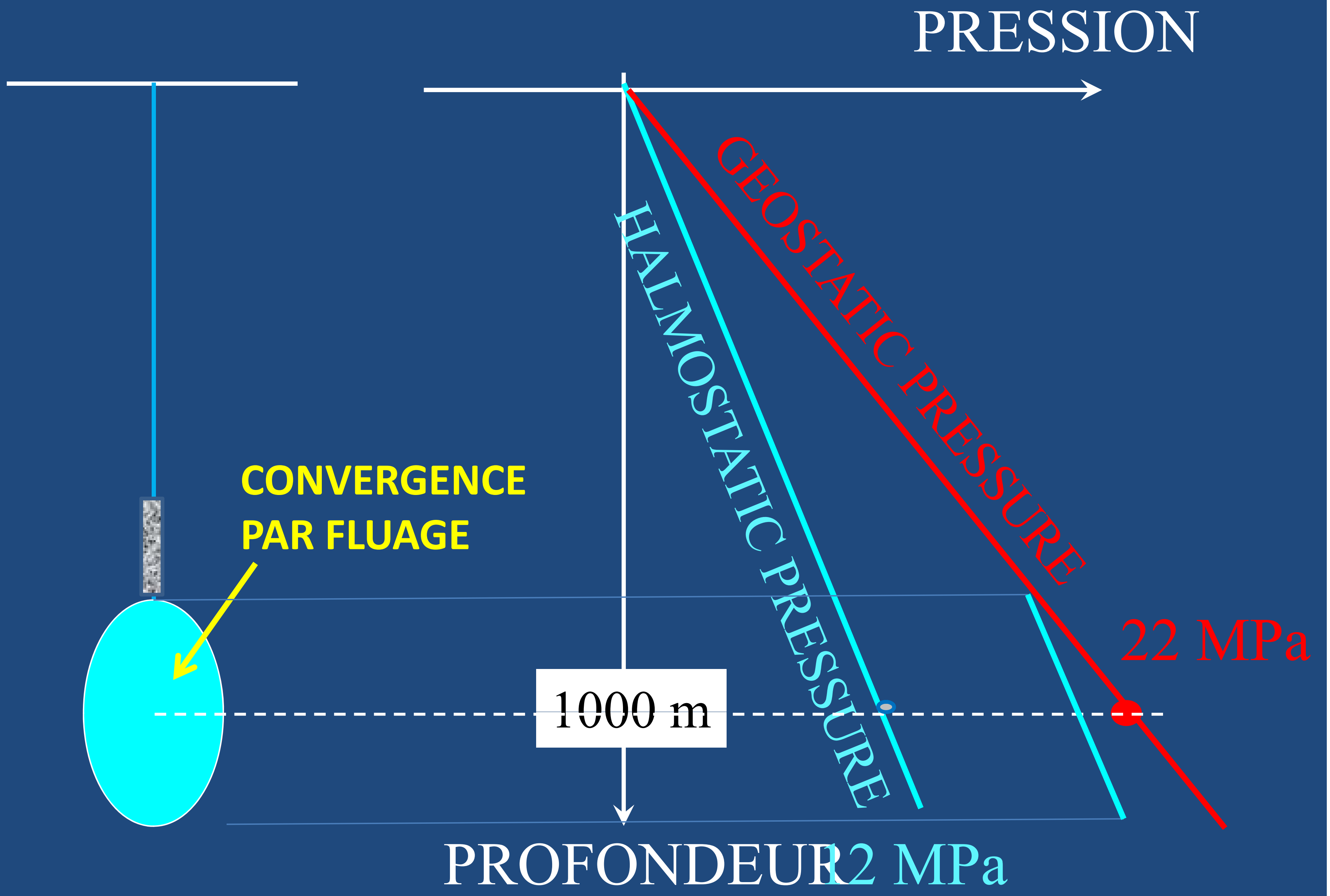


UN SCENARIO PESSIMISTE

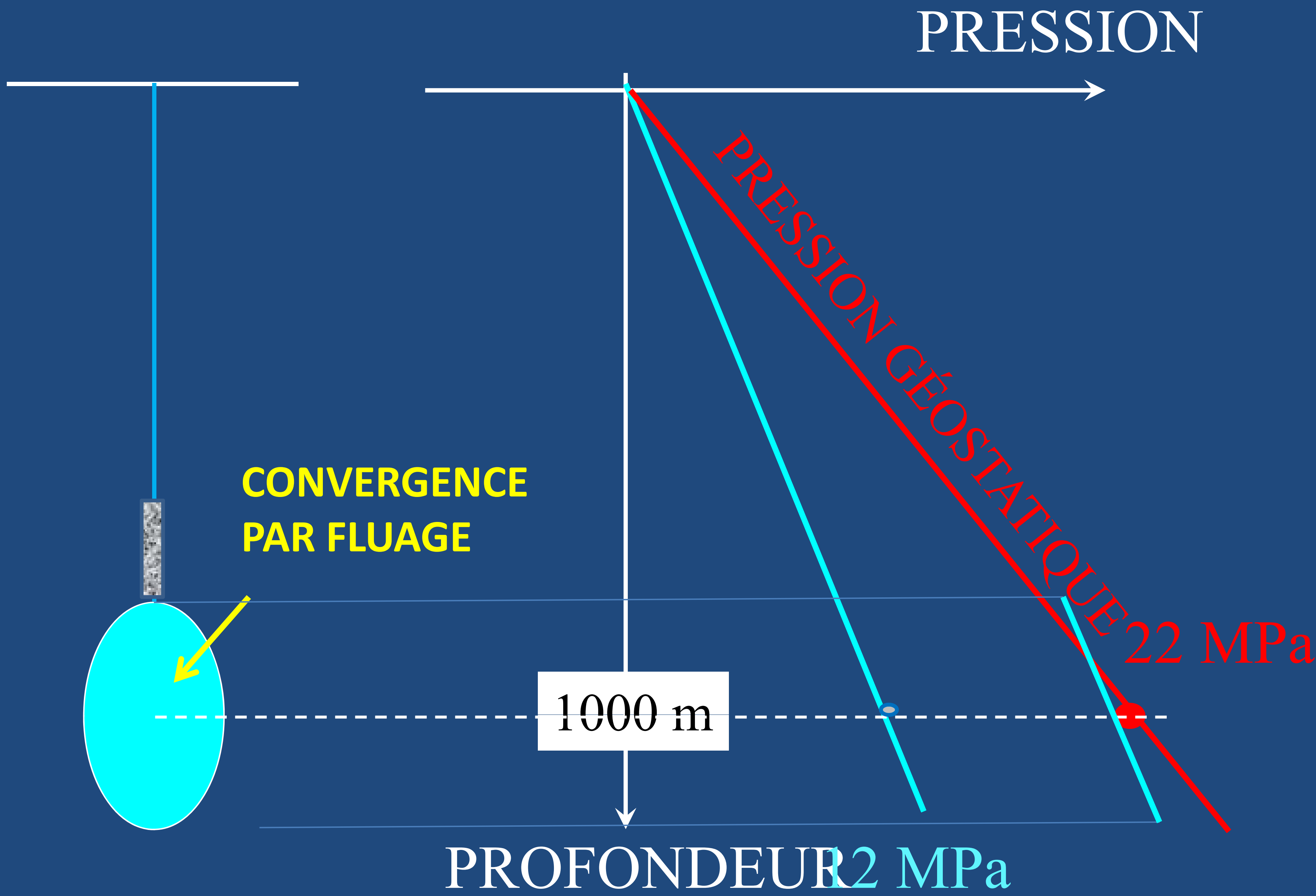

PRESSION
PRESSION GÉOSTATIQUE
22 MPa
CONVERGENCE
PAR FLUAGE
1000 m
PROFONDEUR
12 MPa
UN SCENARIO PESSIMISTE



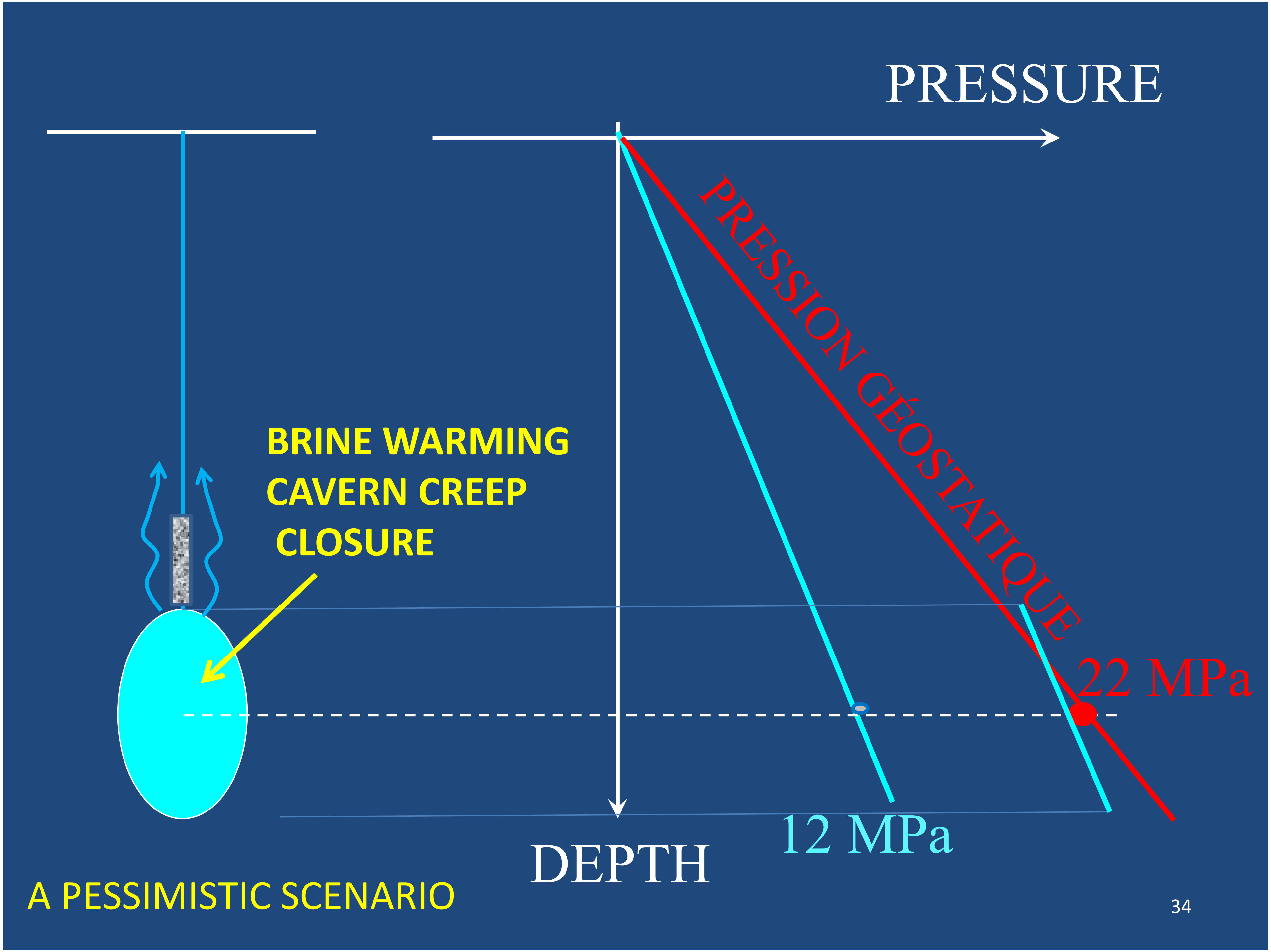
UN SCENARIO PESSIMISTE

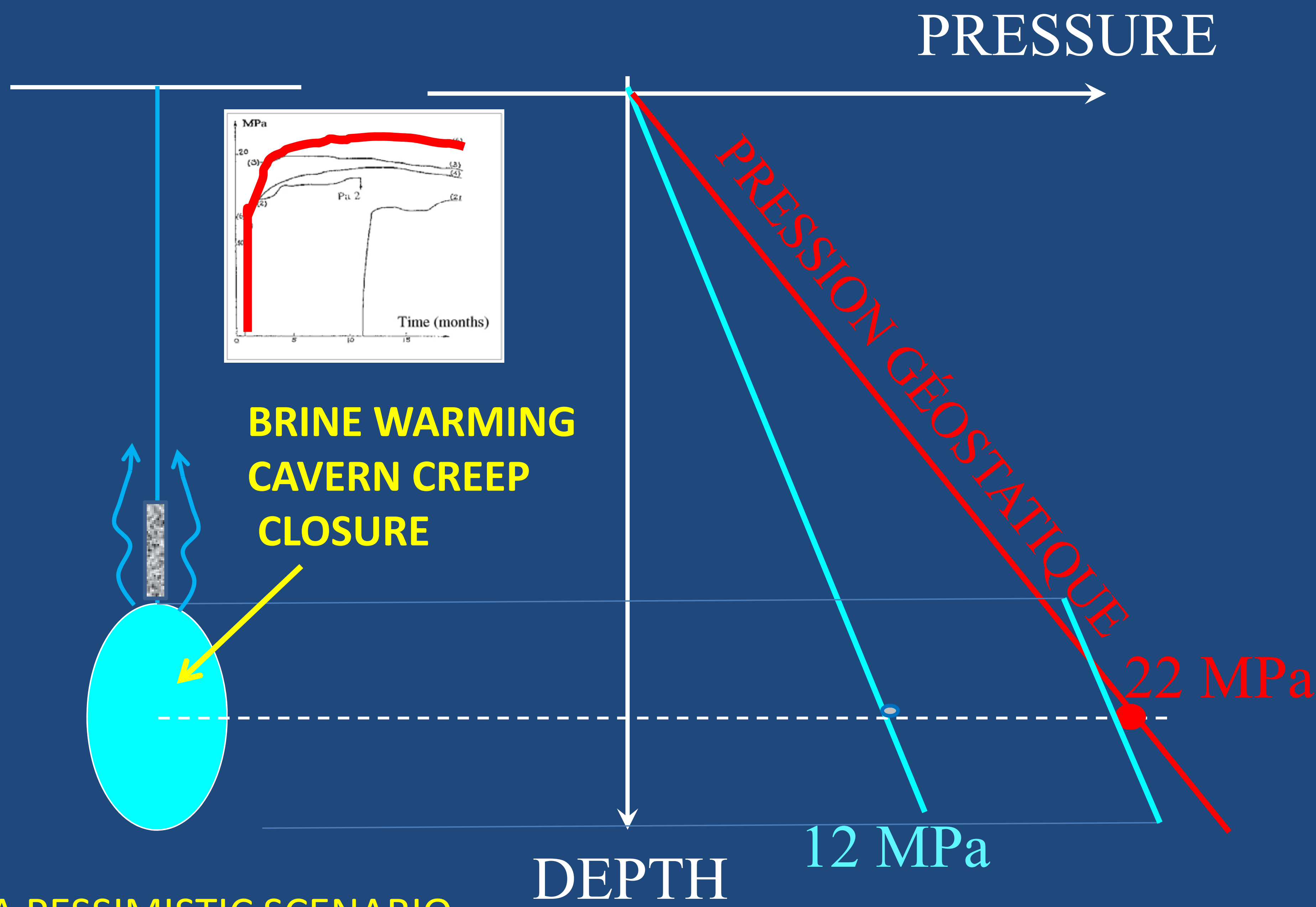


UN SCENARIO PESSIMISTE



UN SCENARIO PESSIMISTE


PRESSURE
BRINE WARMING
CAVERN CREEP
CLOSURE
PRESSION GÉOSTATIQUE
22 MPa
12 MPa
DEPTH
A PESSIMISTIC SCENARIO



A PESSIMISTIC SCENARIO

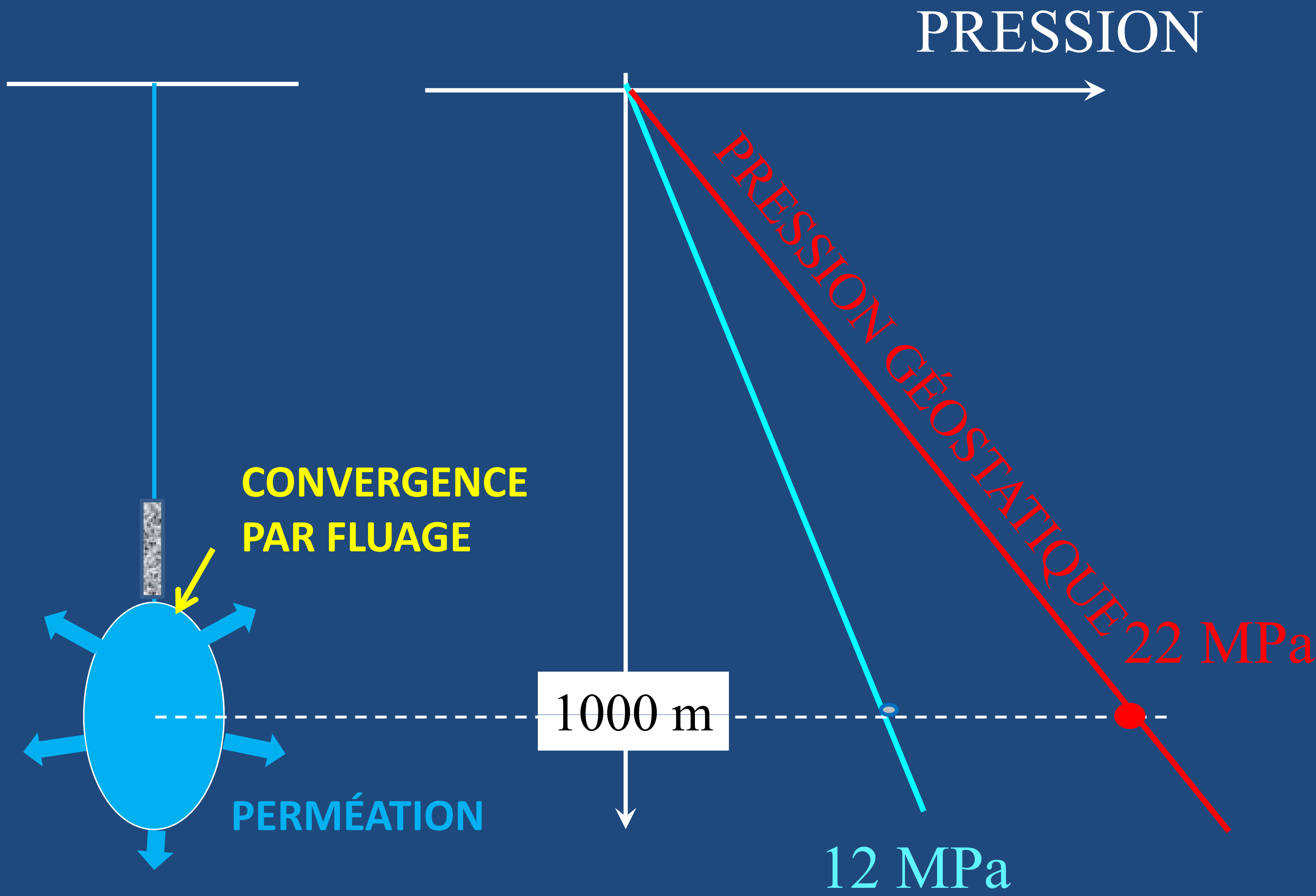
UN SCÉNARIO MOINS PESSIMISTE

UN SCÉNARIO MOINS PESSIMISTE

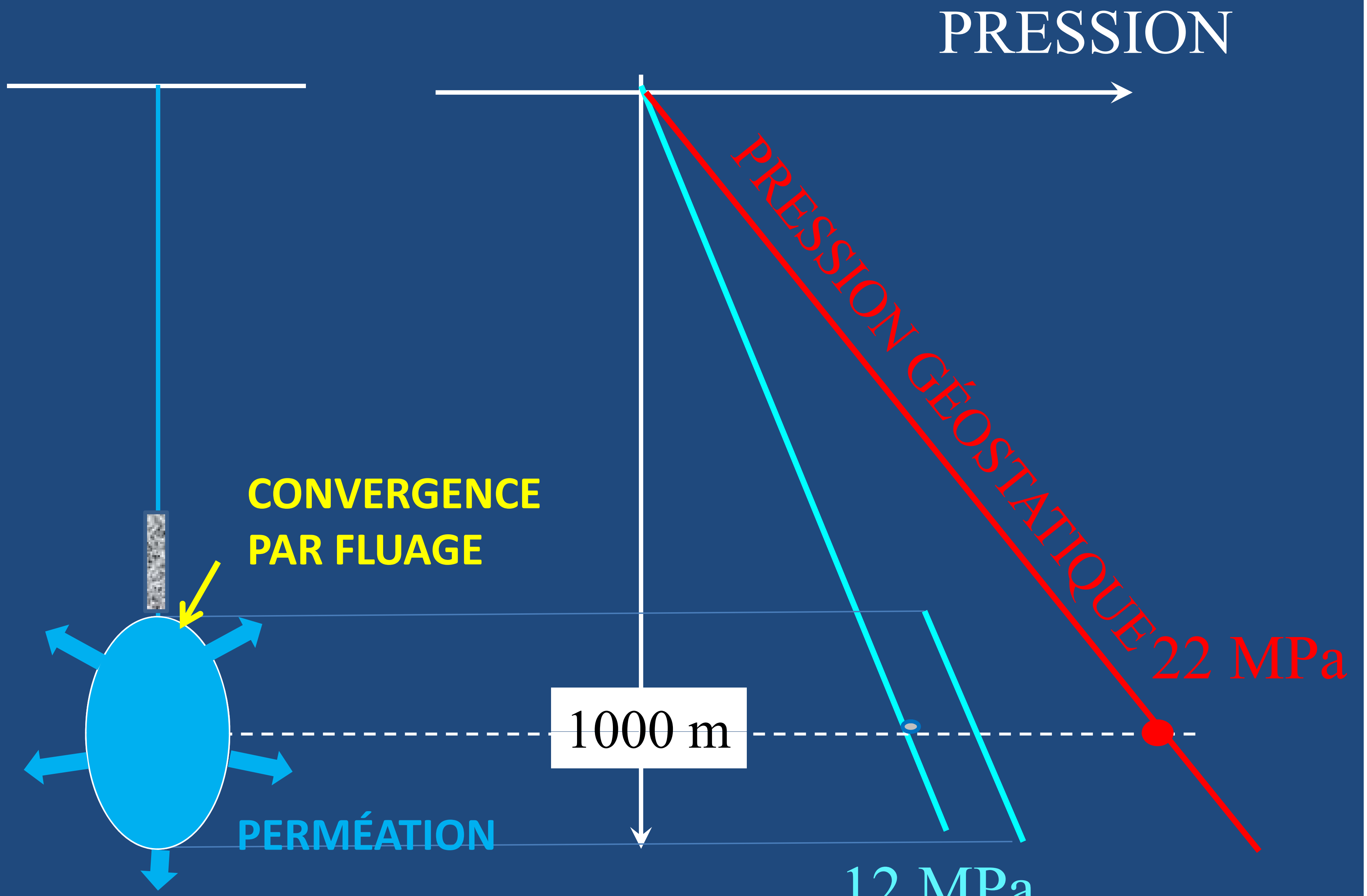
LE SEL EST (MICRO) PERMÉABLE

et fait « soupape »

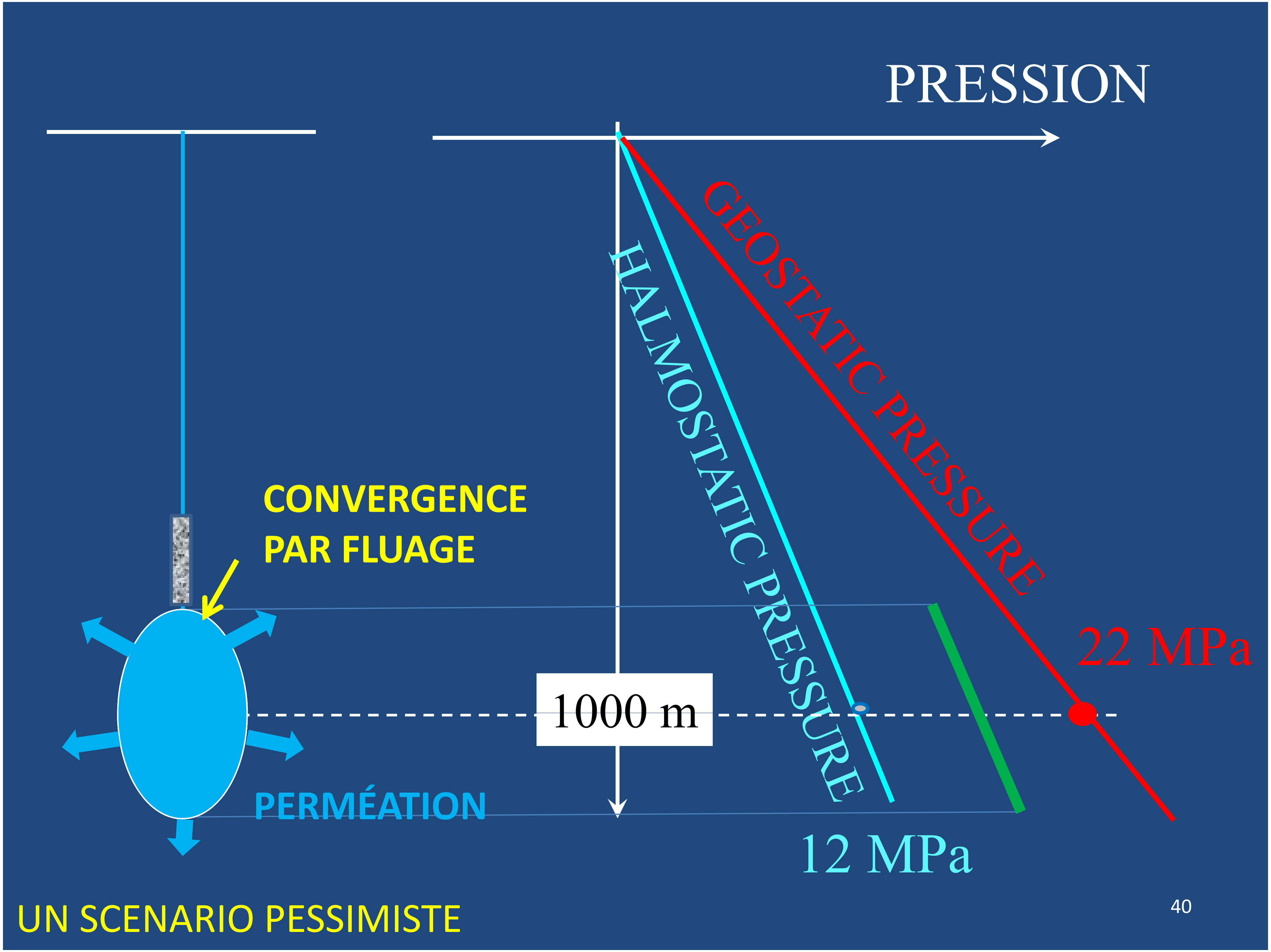
$$\beta \frac{dP_{cav}}{dt} = A\,(P_\infty - P_{cav})^n - \chi(P_{cav} - P_0)$$

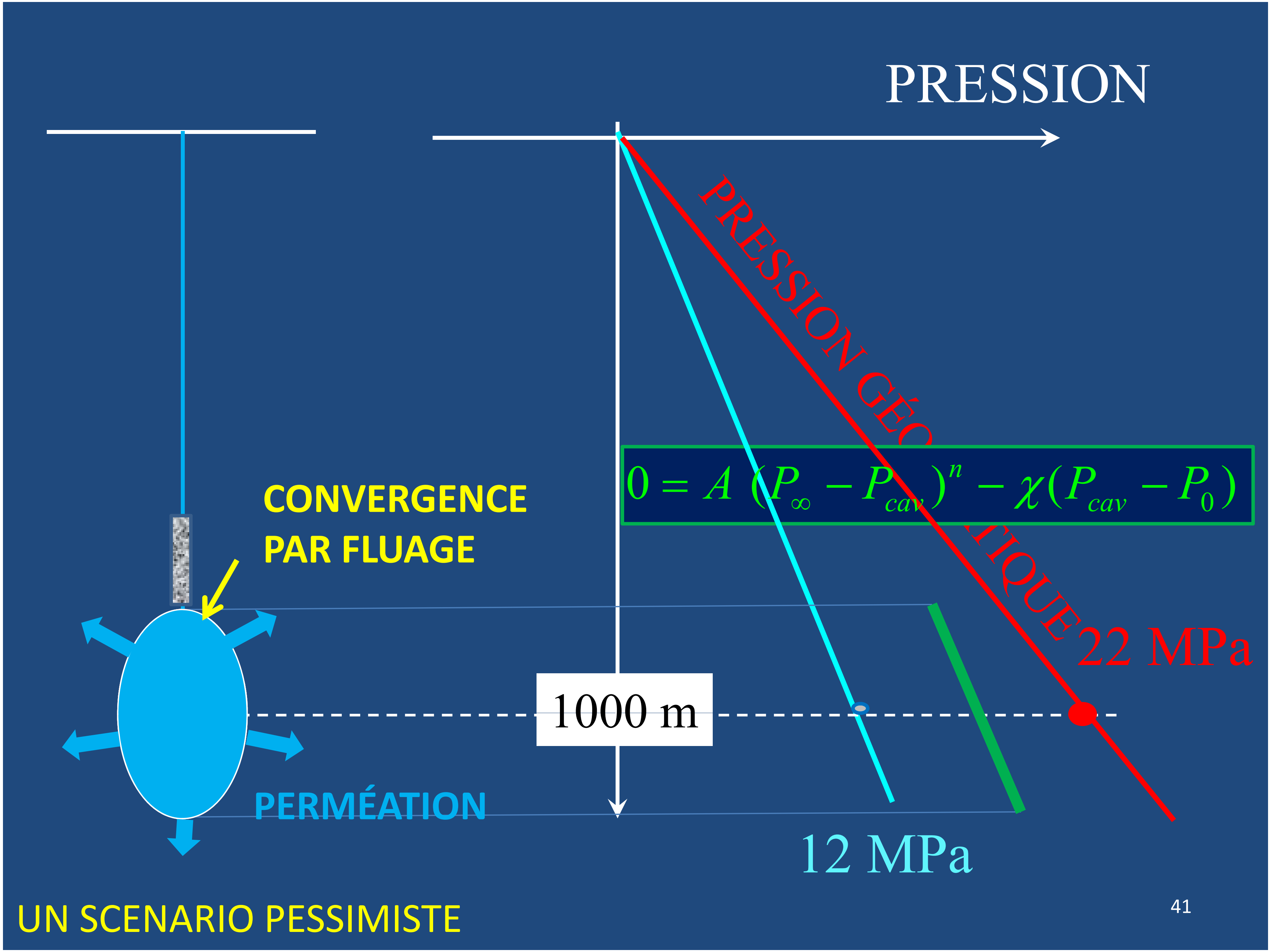


UN SCENARIO MOINS PESSIMISTE

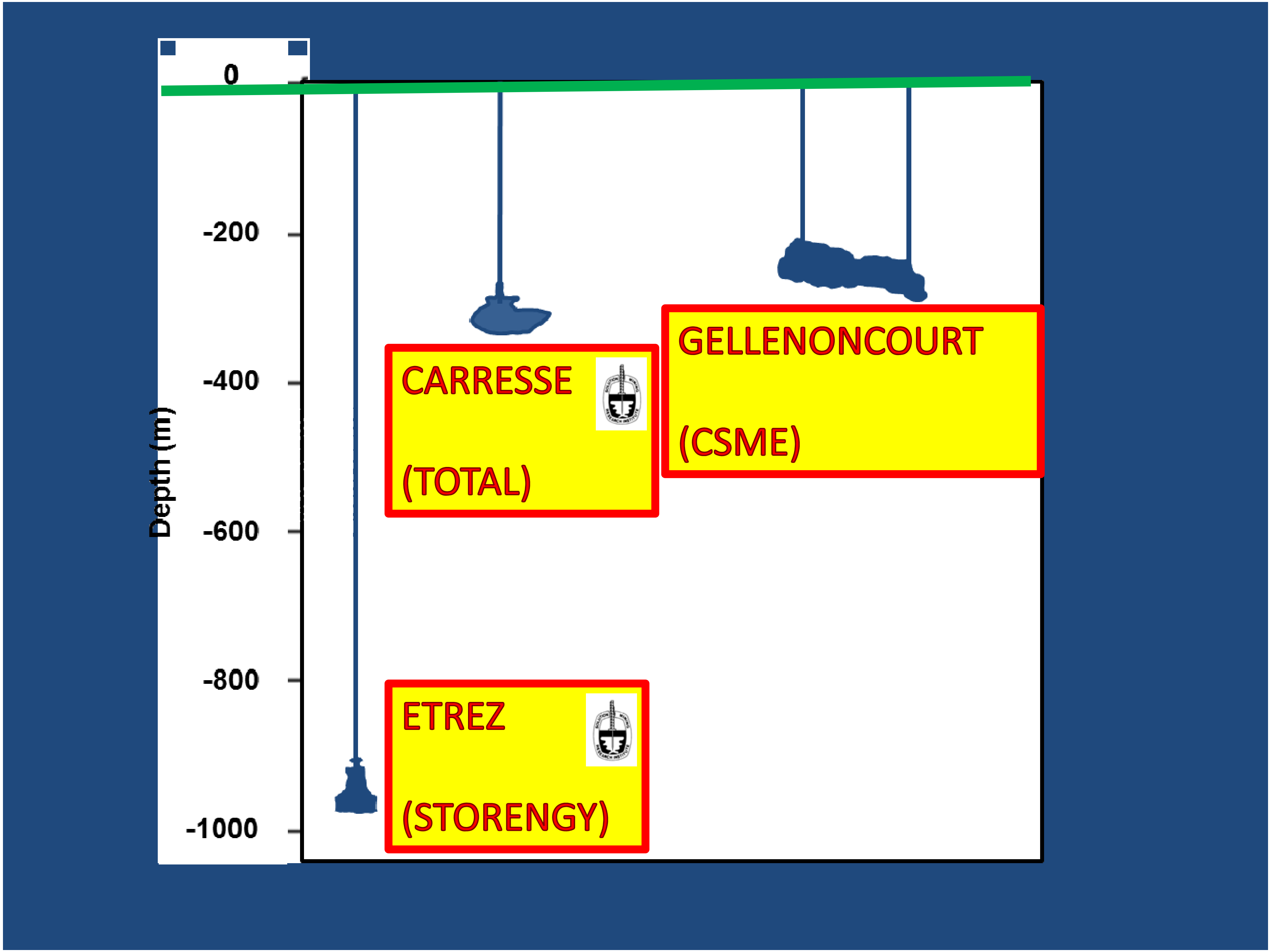


UN SCENARIO PESSIMISTE


PRESSION
GEOSTATIC PRESSURE
HALMOSTATIC PRESSURE
CONVERGENCE
PAR FLUAGE
22 MPa
1000 m
PERMÉATION
12 MPa
UN SCENARIO PESSIMISTE


PRESSION
PRESSION GÉO
TIQUE
$0 = A\,(P_\infty - P_{cav})^n - \chi(P_{cav} - P_0)$
CONVERGENCE
PAR FLUAGE
22 MPa
1000 m
PERMÉATION
12 MPa
UN SCENARIO PESSIMISTE

TROIS CAVITÉS

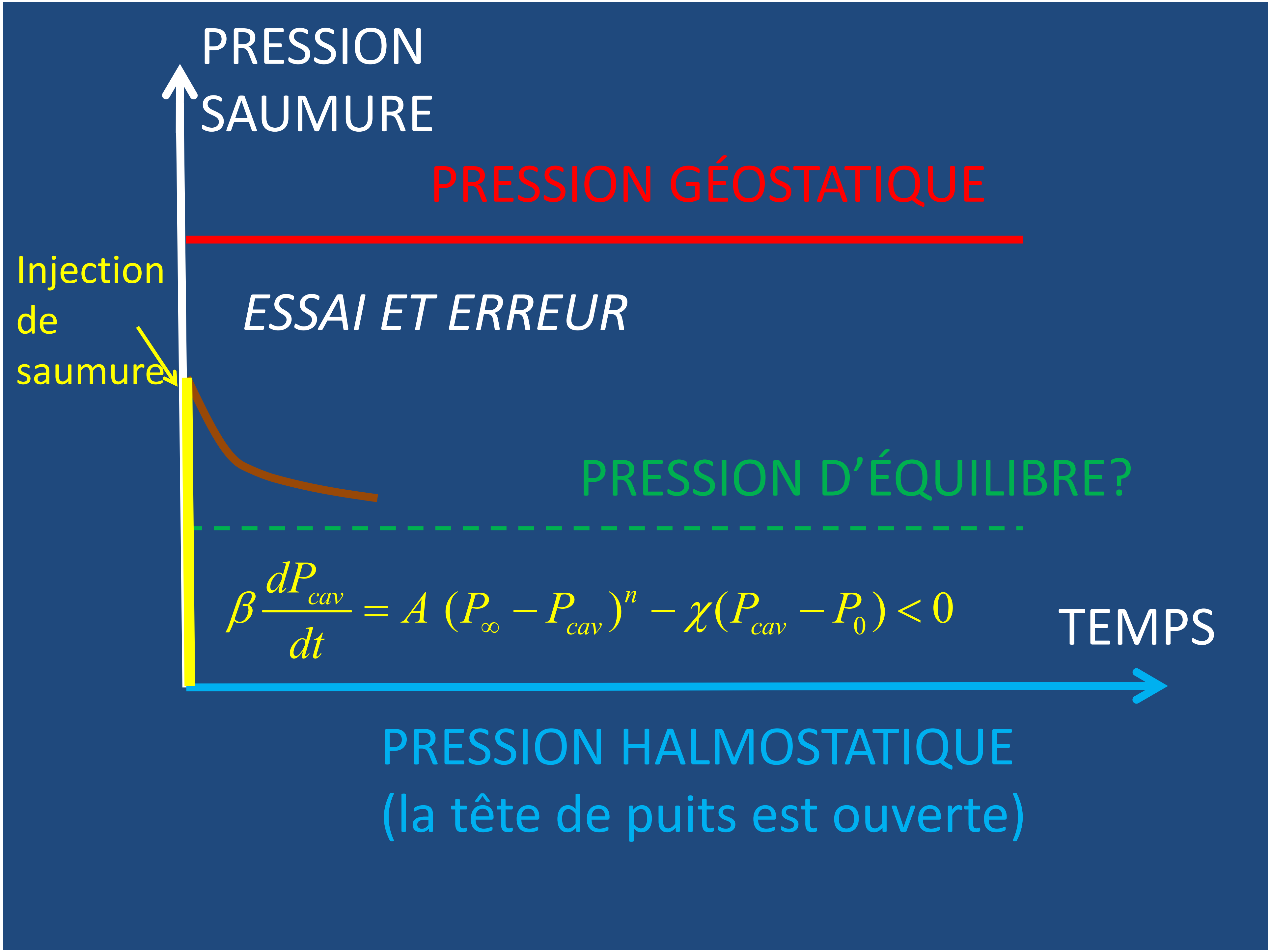


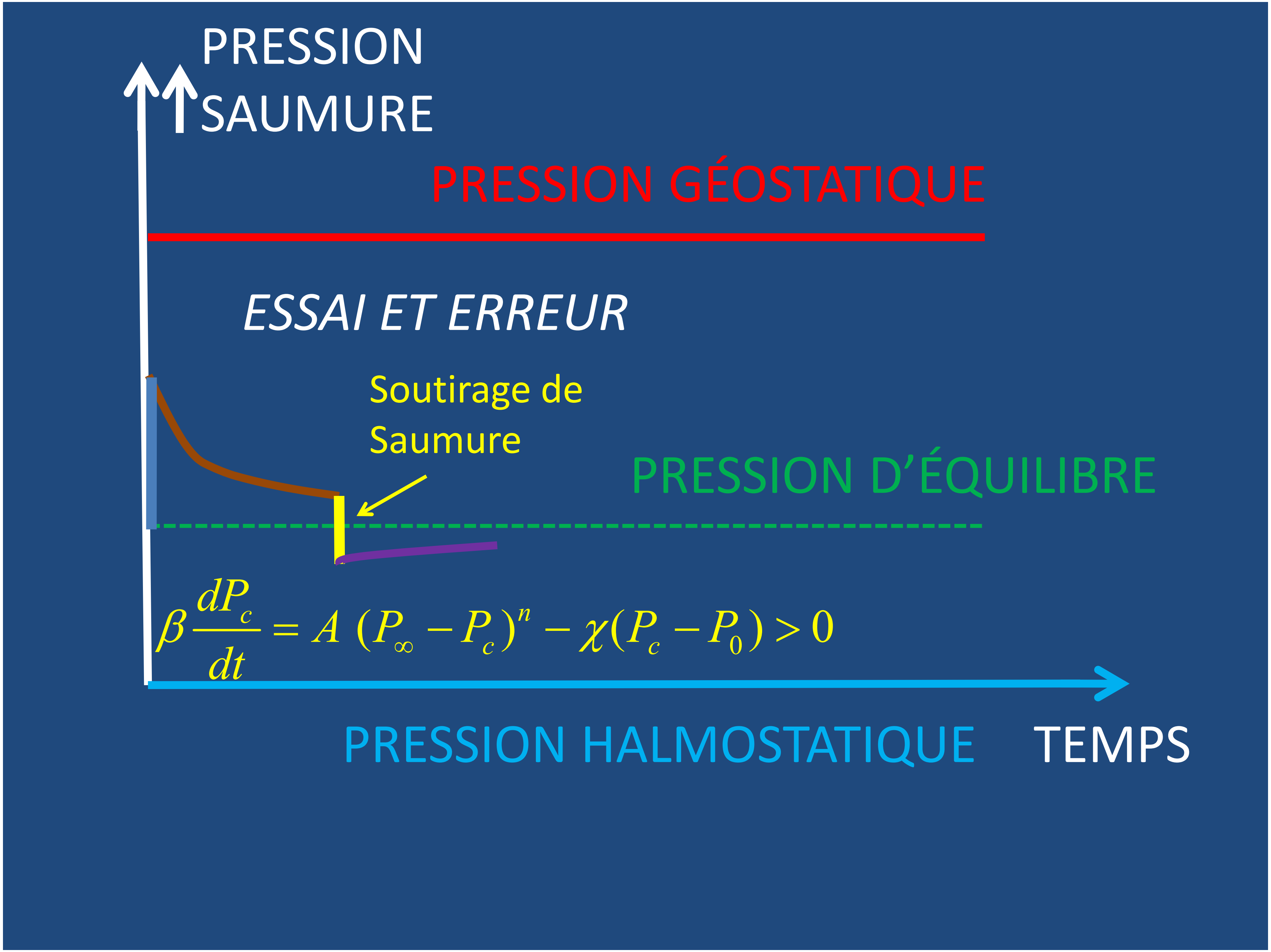
0
-200
-400
-600
-800
-1000
Depth (m)
CARRESSE
(TOTAL)
GELLENONCOURT
(CSME)
ETREZ
(STORENGY)

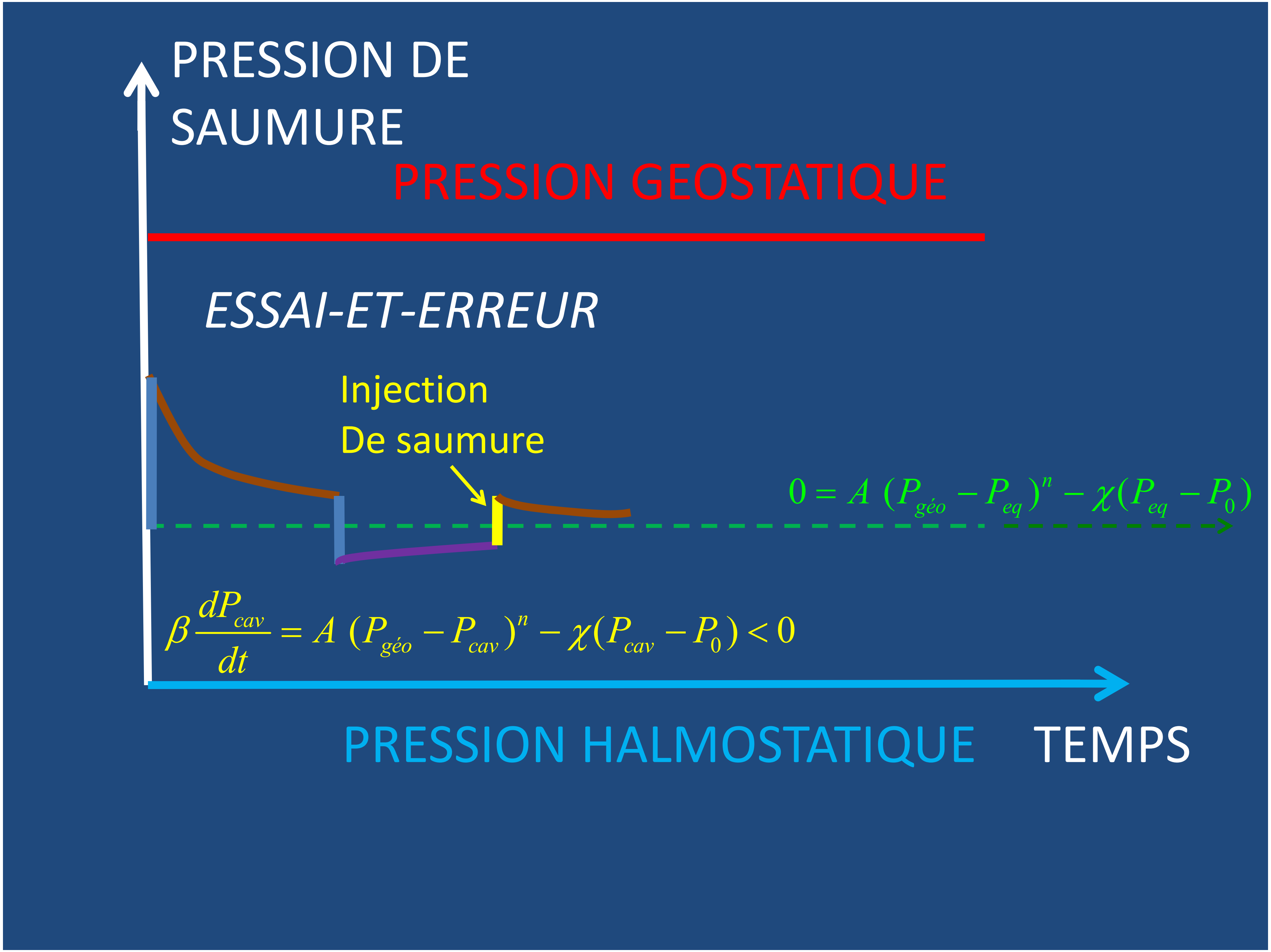
À LA RECHERCHE DE LA PRESSION D'ÉQUILIBRE

Essai et erreur

(borne supérieure – borne inférieure)


PRESSION SAUMURE
PRESSION GÉOSTATIQUE
Injection de saumure
ESSAI ET ERREUR
PRESSION D'ÉQUILIBRE?
$\beta \frac{dP_{cav}}{dt} = A\,(P_\infty - P_{cav})^n - \chi(P_{cav} - P_0) < 0$
TEMPS
PRESSION HALMOSTATIQUE
(la tête de puits est ouverte)

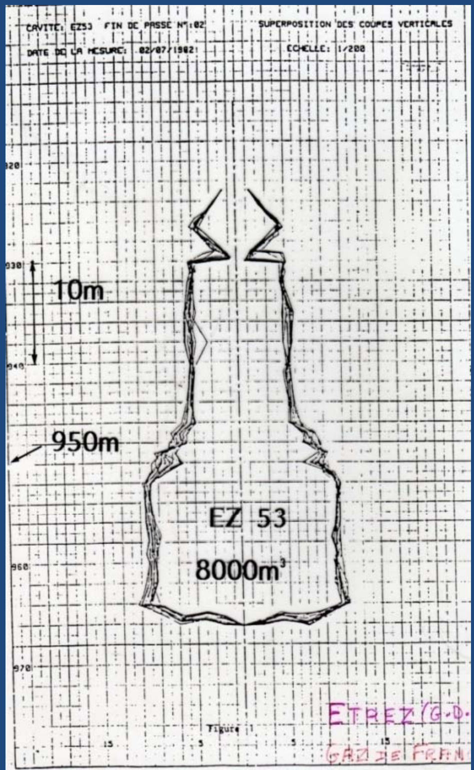

PRESSION
SAUMURE
PRESSION GÉOSTATIQUE
ESSAI ET ERREUR
Soutirage de
Saumure
PRESSION D'ÉQUILIBRE
$\beta \frac{dP_c}{dt} = A\,(P_\infty - P_c)^n - \chi(P_c - P_0) > 0$
PRESSION HALMOSTATIQUE
TEMPS

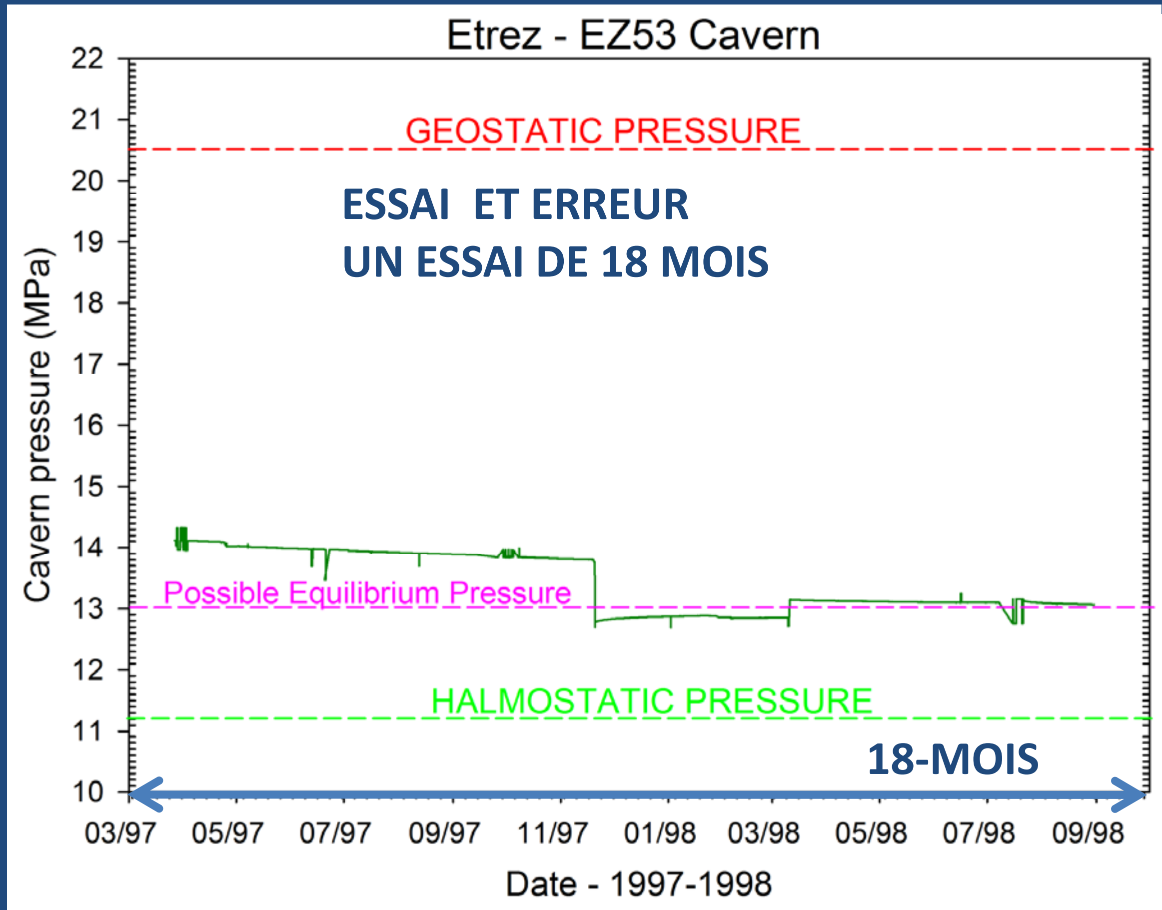

PRESSION DE
SAUMURE
PRESSION GEOSTATIQUE
ESSAI-ET-ERREUR
Injection
De saumure
$0 = A\ (P_{géo} - P_{eq})^n - \chi(P_{eq} - P_0)$
$\beta \dfrac{dP_{cav}}{dt} = A\ (P_{géo} - P_{cav})^n - \chi(P_{cav} - P_0) < 0$
PRESSION HALMOSTATIQUE
TEMPS

EZ 53 (ETREZ, STORENGY)

1997-2013

EZ53: ESSAI ET ERREUR

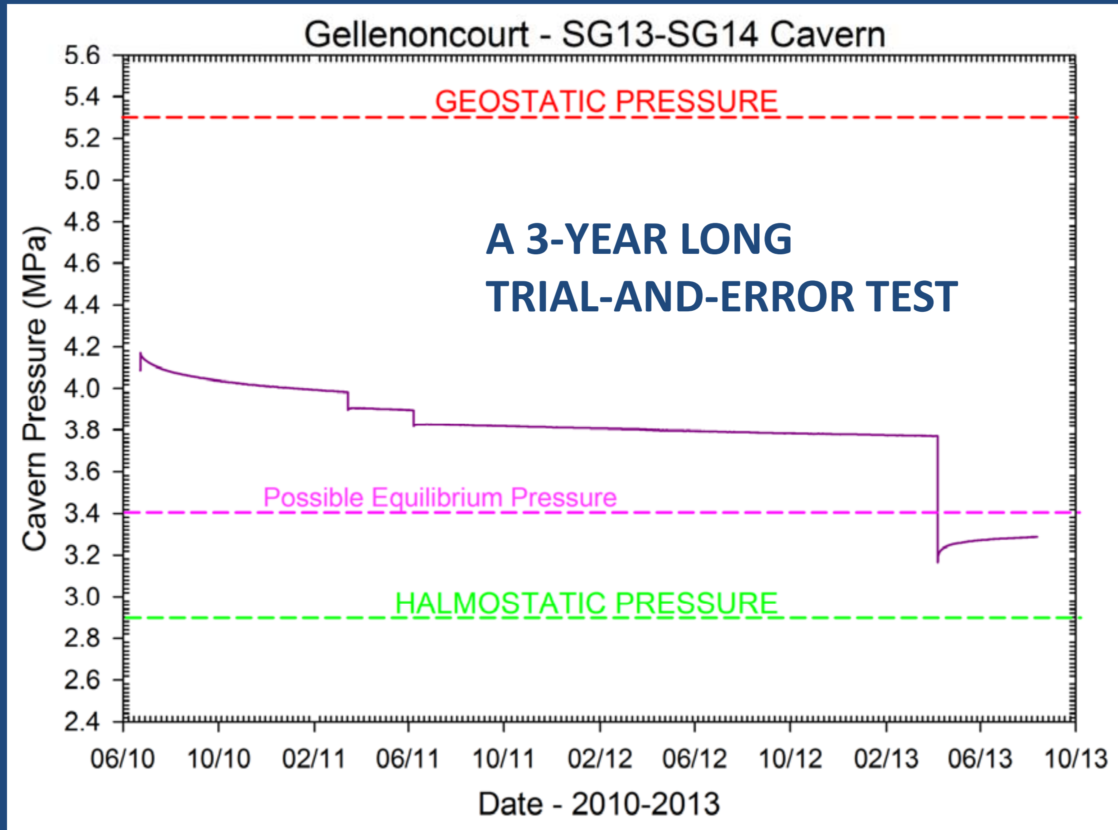




EZ53 (STORENGY, 950 M DE PROFONDEUR, 0.003/an)

SG13-14 (CSME)

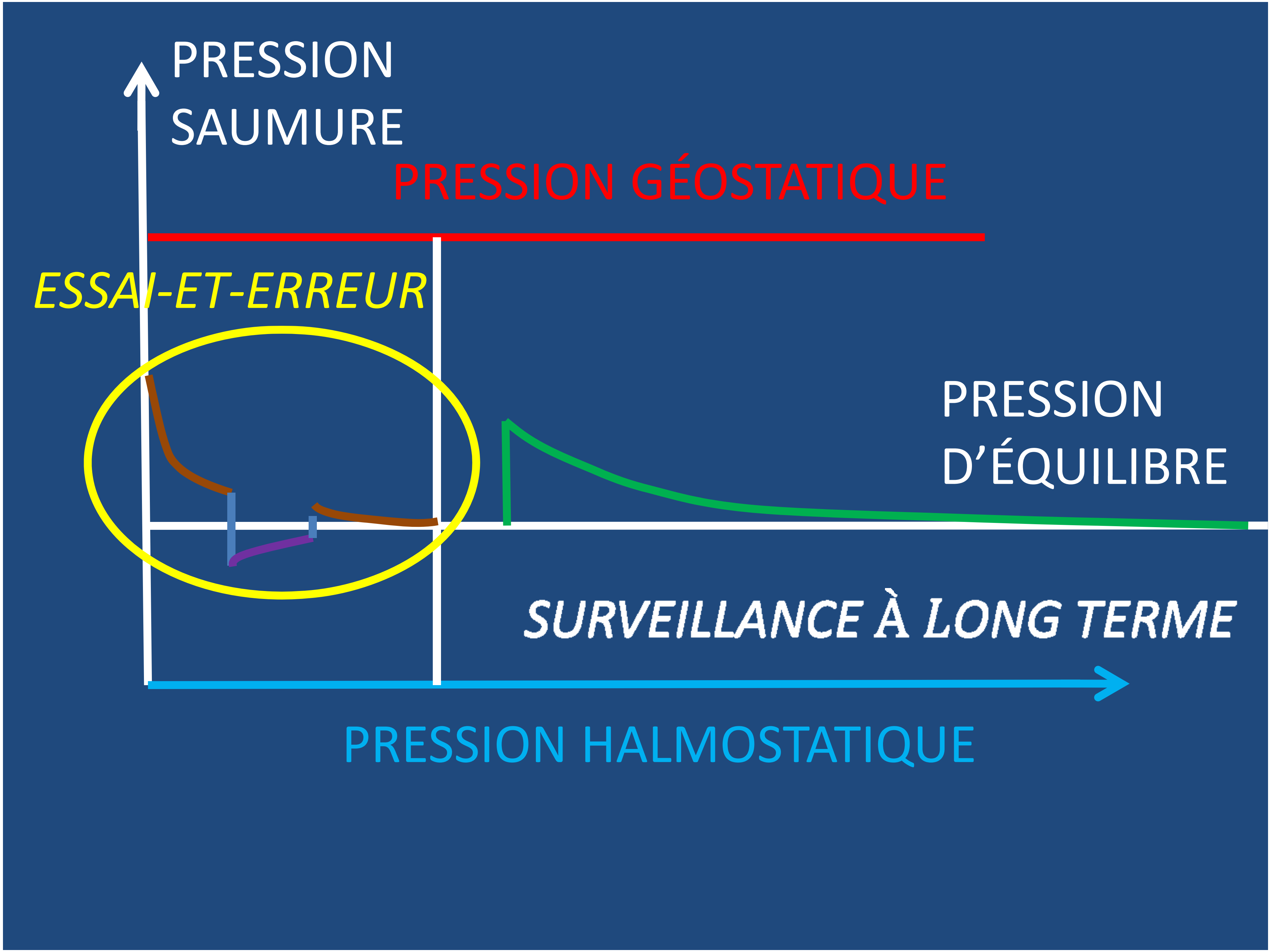
2010-2013 …



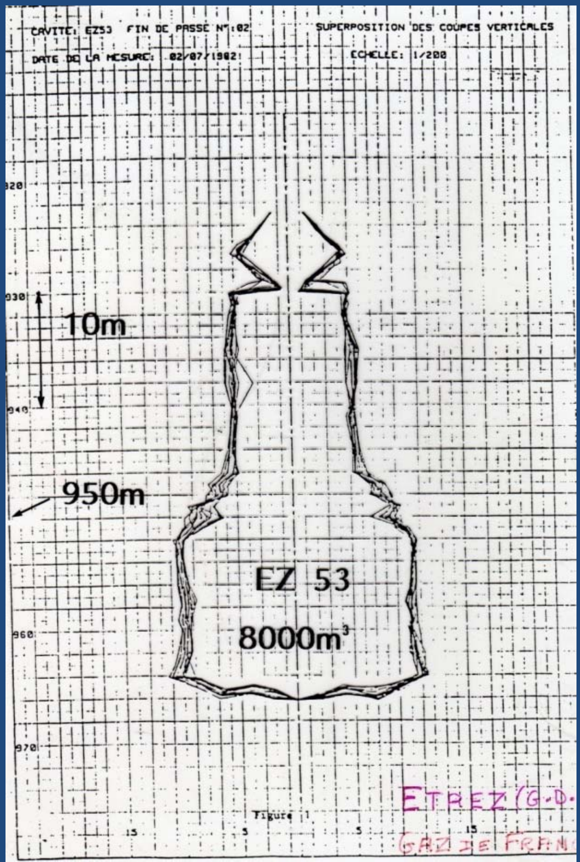
SG13-14 (CSME, 250-M DE PROFONDEUR, 0.00001/AN)

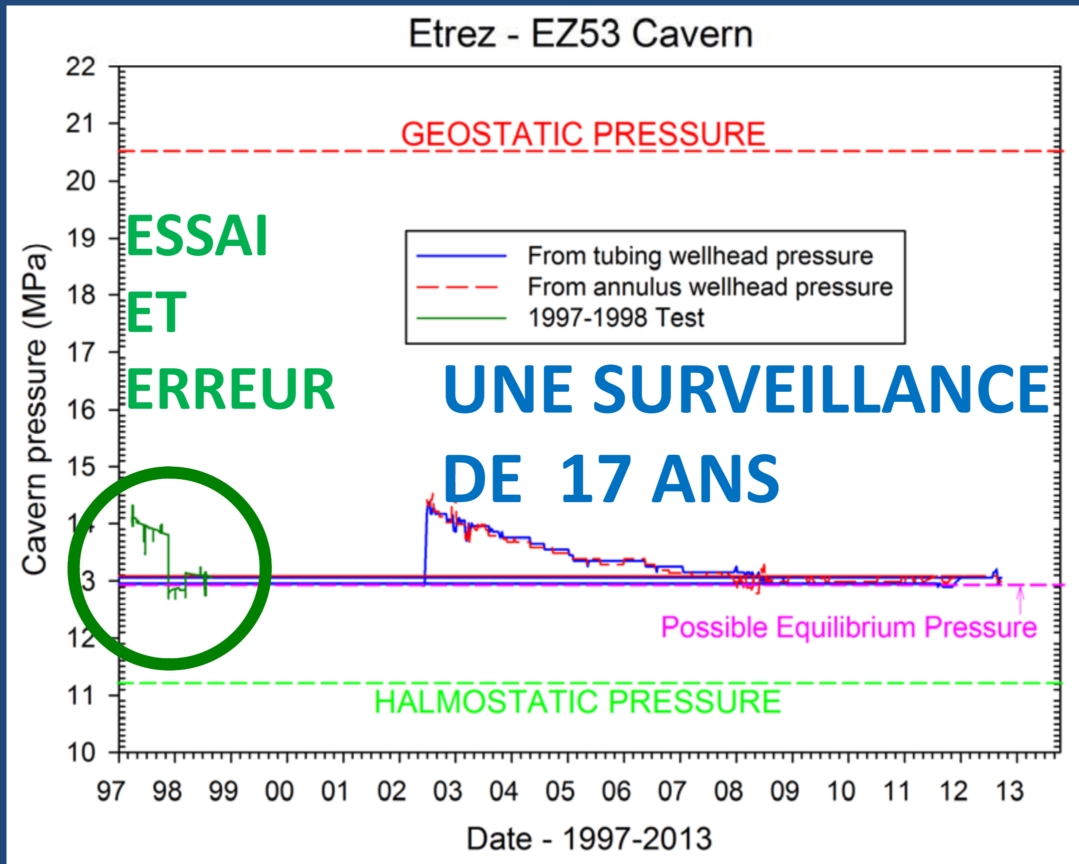
CONFIRMATION DE LA VALEUR DE LA PRESSION D'ÉQUILIBRE

SURVEILLANCE À LONG TERME


PRESSION
SAUMURE
PRESSION GÉOSTATIQUE
ESSAI-ET-ERREUR
PRESSION
D'ÉQUILIBRE
SURVEILLANCE À LONG TERME
PRESSION HALMOSTATIQUE

EZ53 : ESSAI DE SURVEILLANCE DE LA PRESSION





CONCLUSIONS

A très long terme, la pression dans la cavité atteint une valeur d'équilibre telle que :

0 = Vitesse de convergence – vitesse de perméation

$$0 = A\,(P_\infty - P_{eq})^n - \chi(P_{eq} - P_0)$$

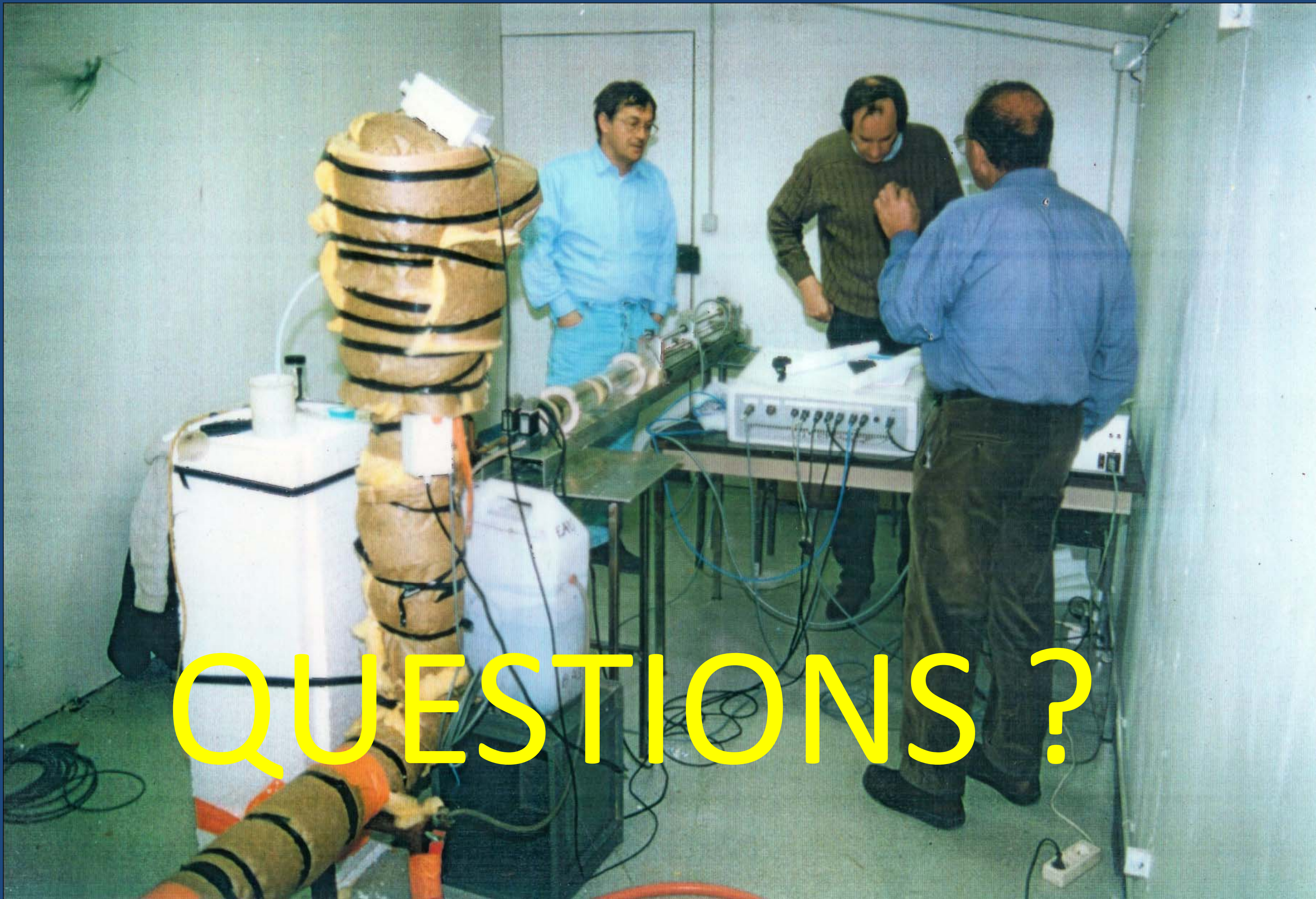
Quand la loi de fluage est bien connue,

On peut en déduire la valeur de la perméabilité à grande échelle ($K = 2\times10^{-19}\,\mathrm{m}^2$ à Etrez)

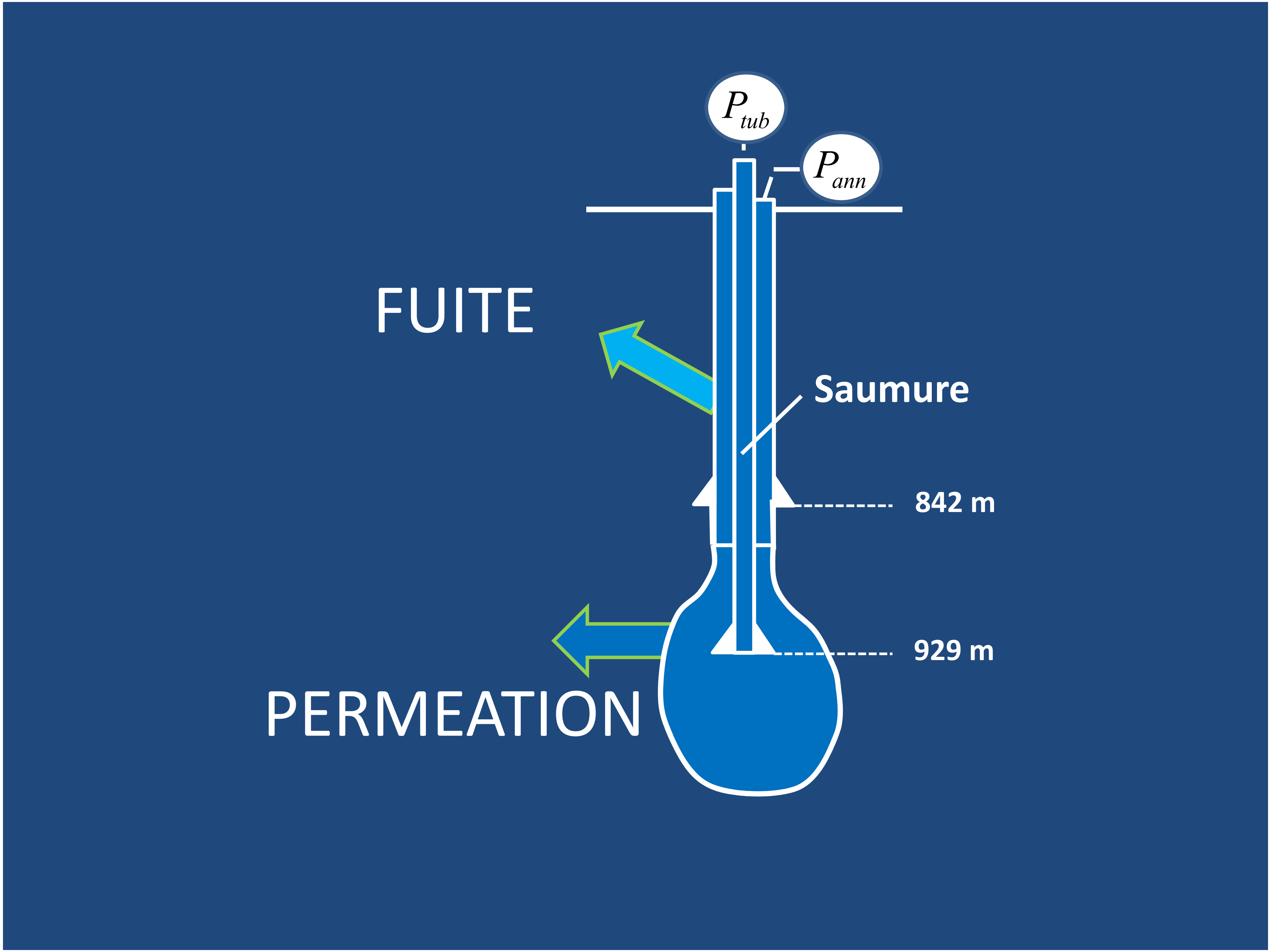
REMERCIEMENTS: SMRI

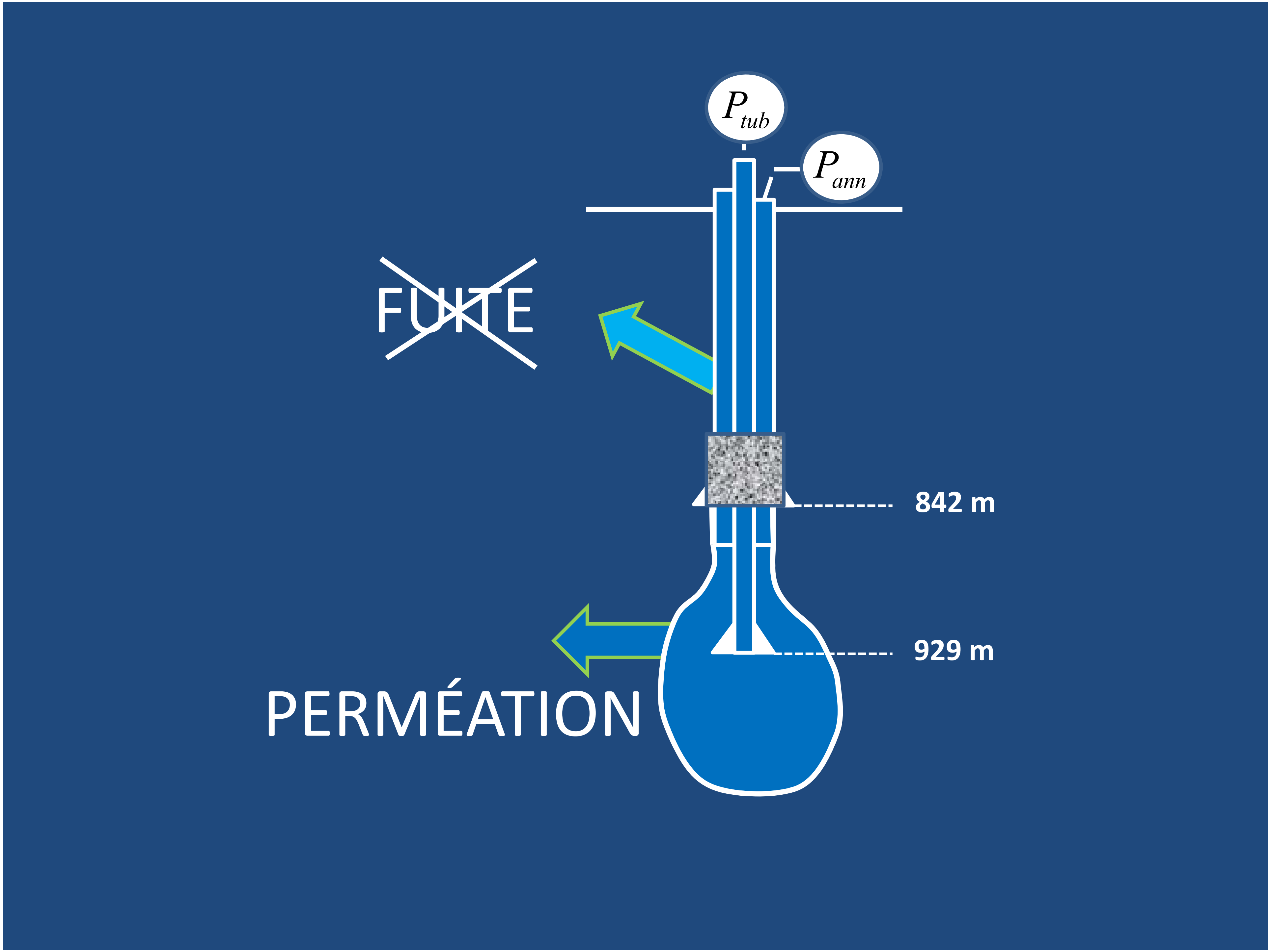
« The SMRI and its member companies have long recognized the complex issues associated with high fluid pressures in solution-mined caverns – particularly the high pressures that develop in sealed and abandoned caverns … in 1996, the SMRI intiated a multiproject program focused on addressing the complex issues of sealing and abandonment … »

Joe Ratigan, *The SMRI S&A Program 1996 through 2002*, SMRI 2003 Spring Meeting, Houston.

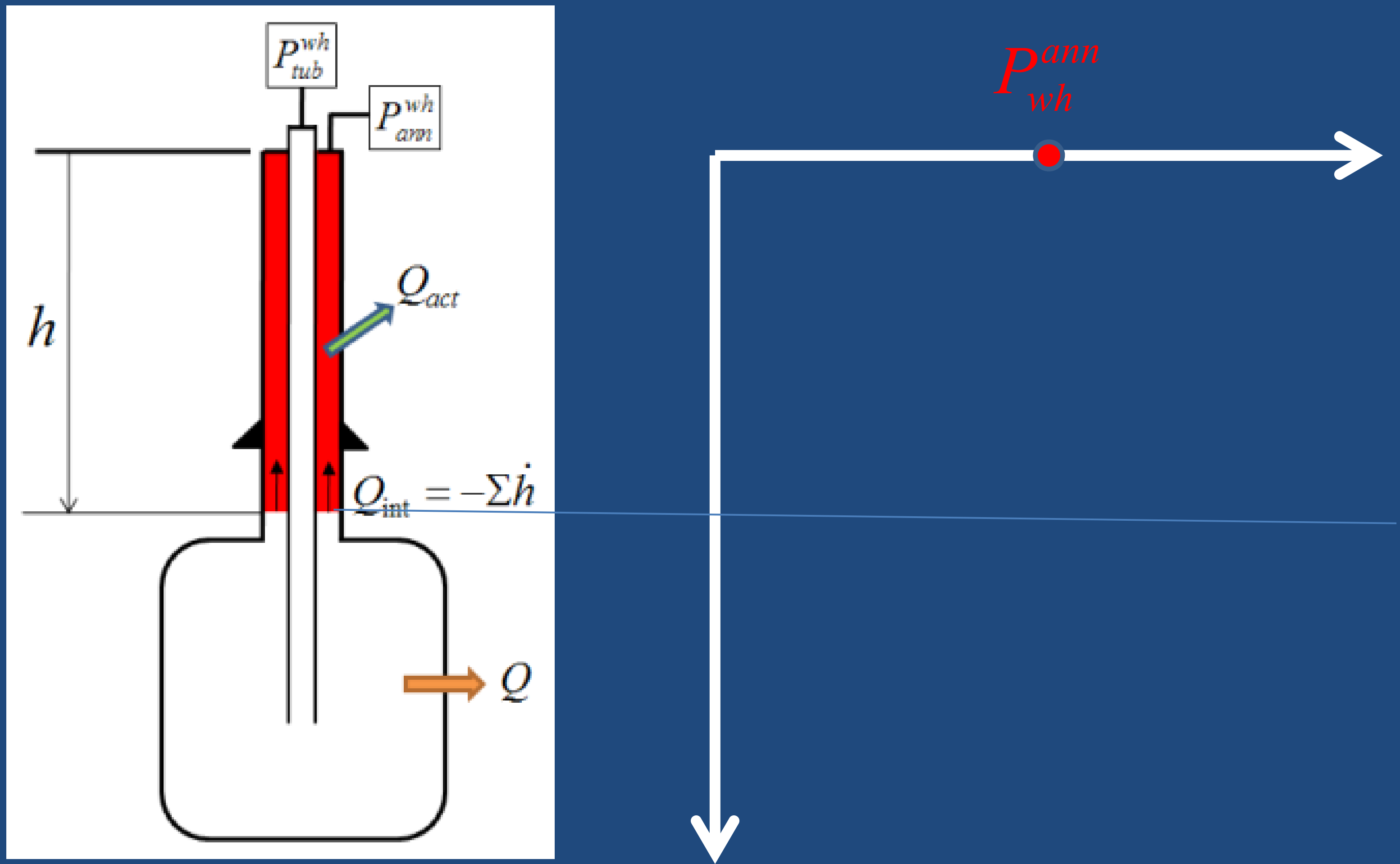

QUESTIONS ?

FUITE ET PERMÉATION

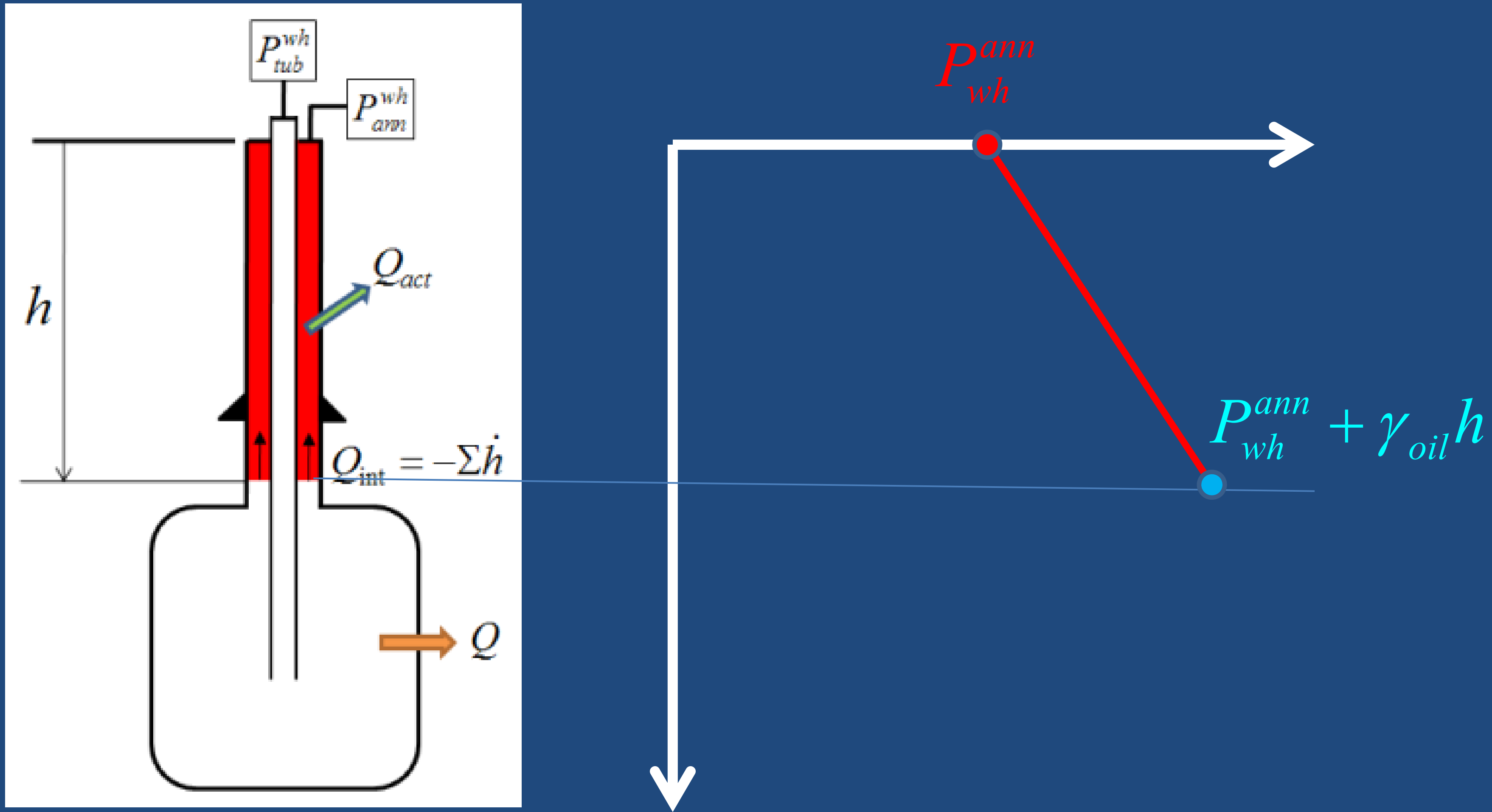

P_{tub}
P_{ann}
FUITE
Saumure
842 m
929 m
PERMEATION



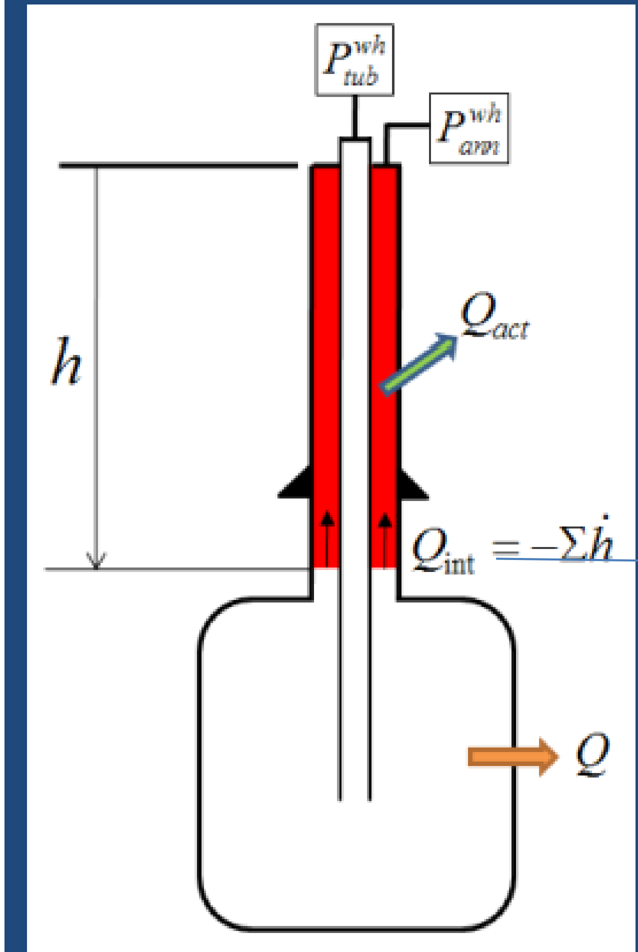
P_{tub}
P_{ann}
~~FUITE~~
842 m
929 m
PERMÉATION

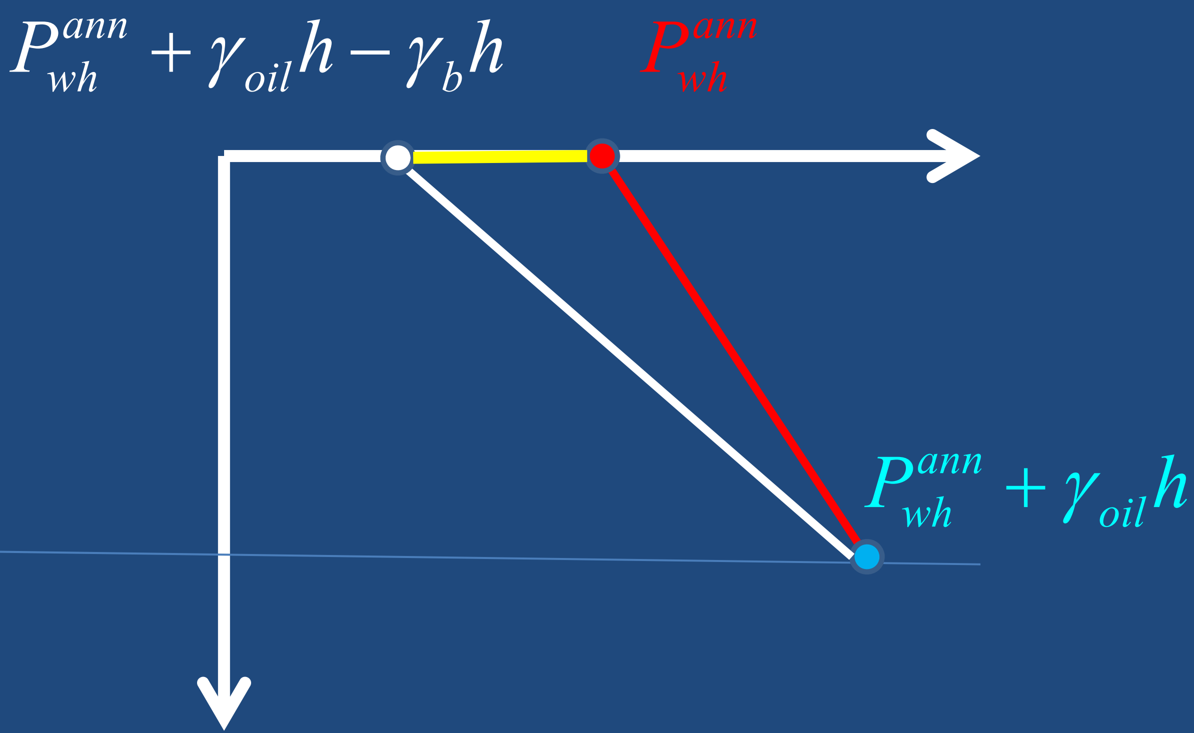


P_{tub}^{wh}
P_{ann}^{wh}
h
Q_{act}
$Q_{int} = -\Sigma \dot{h}$
Q
P_{wh}^{ann}

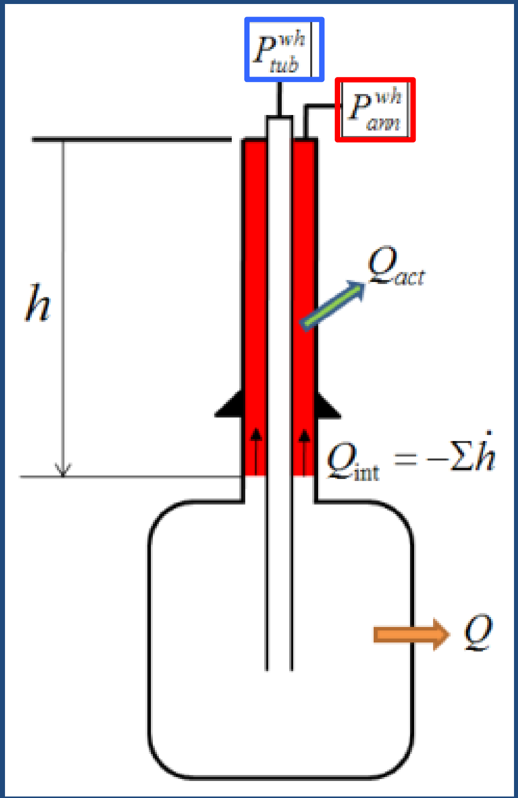


P_{tub}^{wh}
P_{ann}^{wh}
h
Q_{act}
$Q_{int} = -\Sigma \dot{h}$
Q
P_{wh}^{ann}
$P_{wh}^{ann} + \gamma_{oil} h$

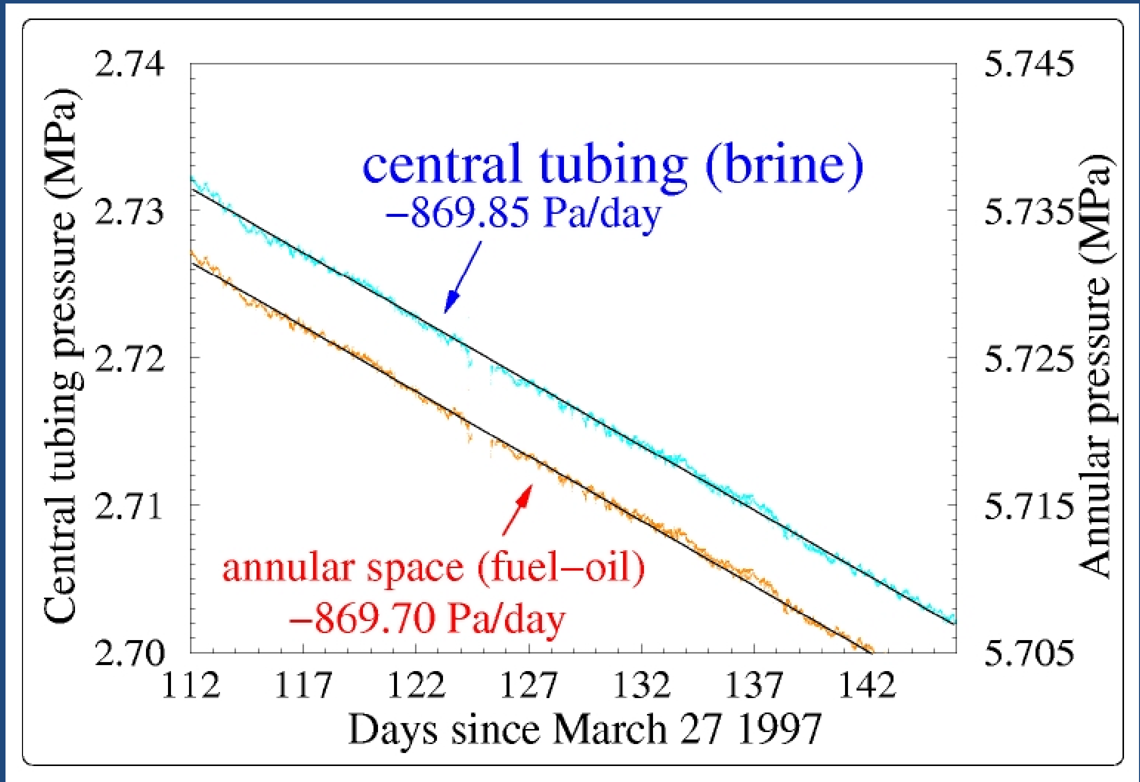




$$P_{wh}^{ann} - P_{wh}^{tub} = (\gamma_b - \gamma_{oil}) h$$

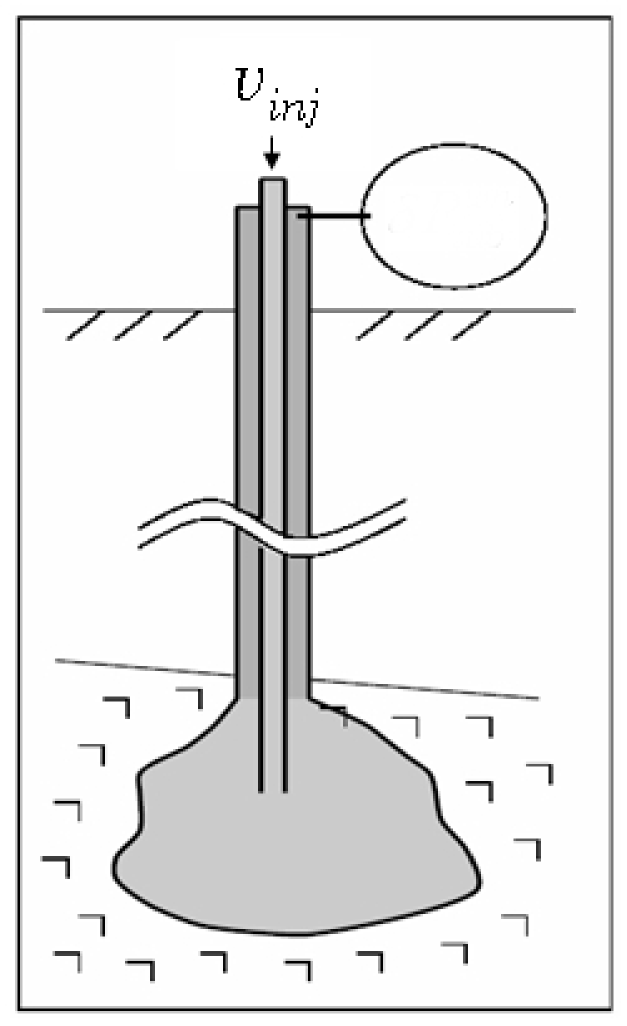


P_{tub}^{wh}
P_{ann}^{wh}
h
Q_{act}
$Q_{int} = -\Sigma\dot{h}$
Q



central tubing (brine)
−869.85 Pa/day
annular space (fuel−oil)
−869.70 Pa/day
Central tubing pressure (MPa)
Annular pressure (MPa)
Days since March 27 1997
2.74
2.73
2.72
2.71
2.70
5.745
5.735
5.725
5.715
5.705
112
117
122
127
132
137
142

CAVERN COMPRESSIBILITY



$$v^{inj} = \beta V \cdot \Delta P$$

Room is created to accommodate the injected volume, or v^{inj} :

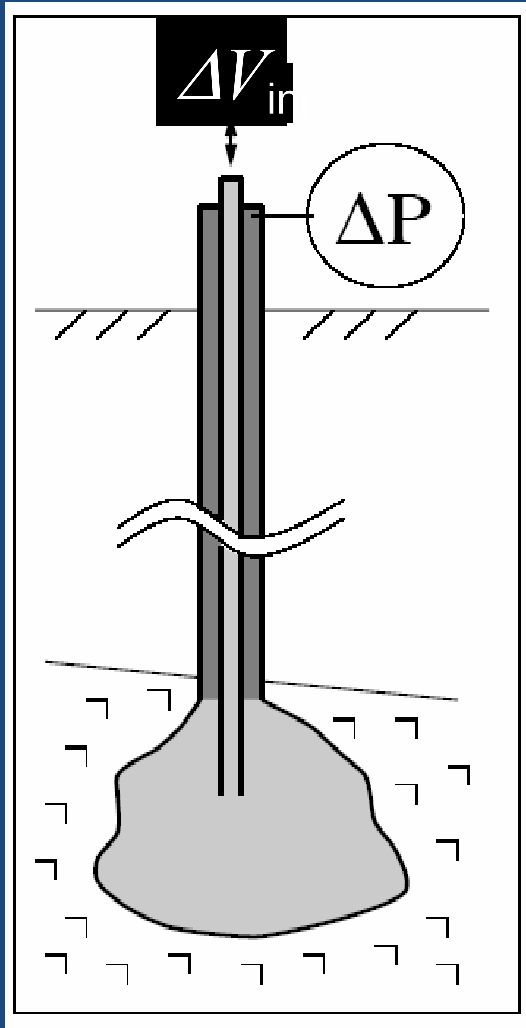
Fluid volume decreases by $-\beta_f V \Delta P$

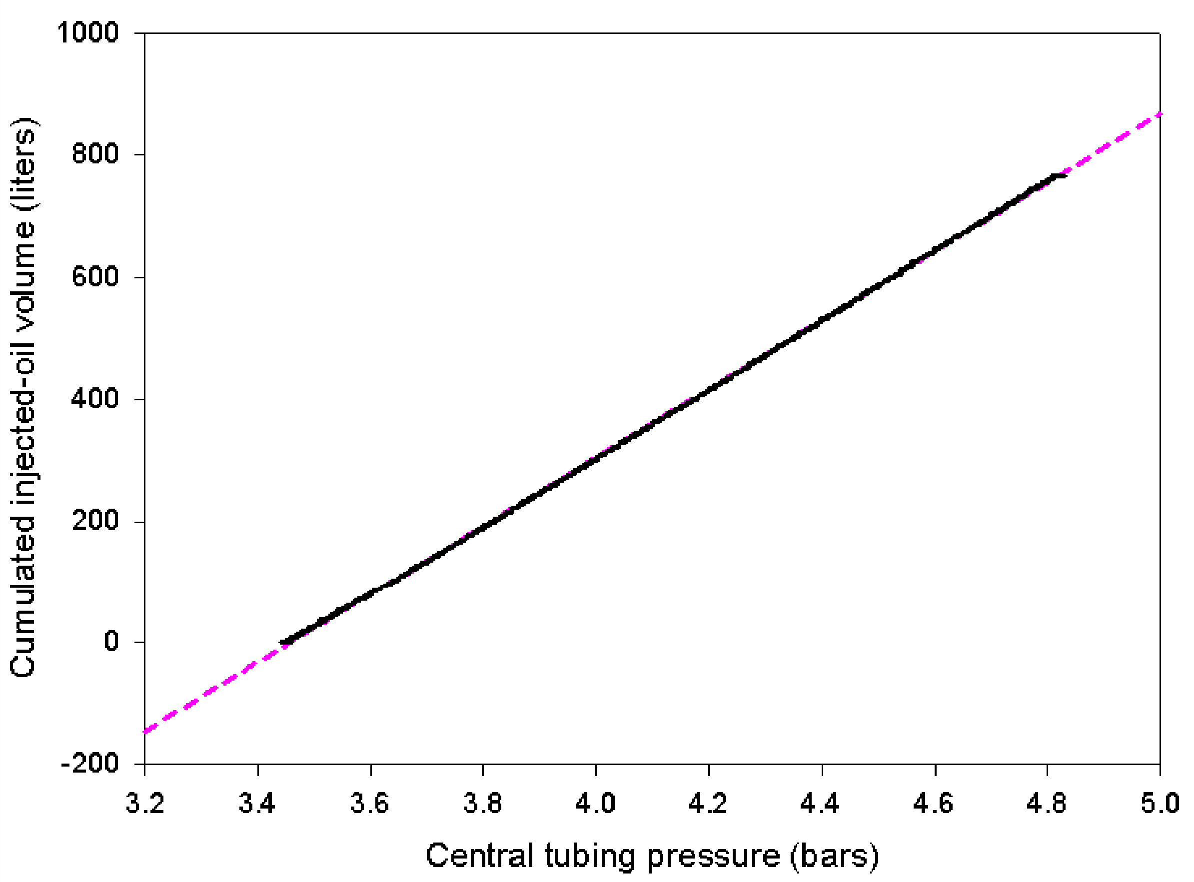
Cavern volume increases by $+\beta_c V \Delta P$

$$v^{inj} = \left(\beta_c + \beta_f\right) V \cdot \Delta P$$

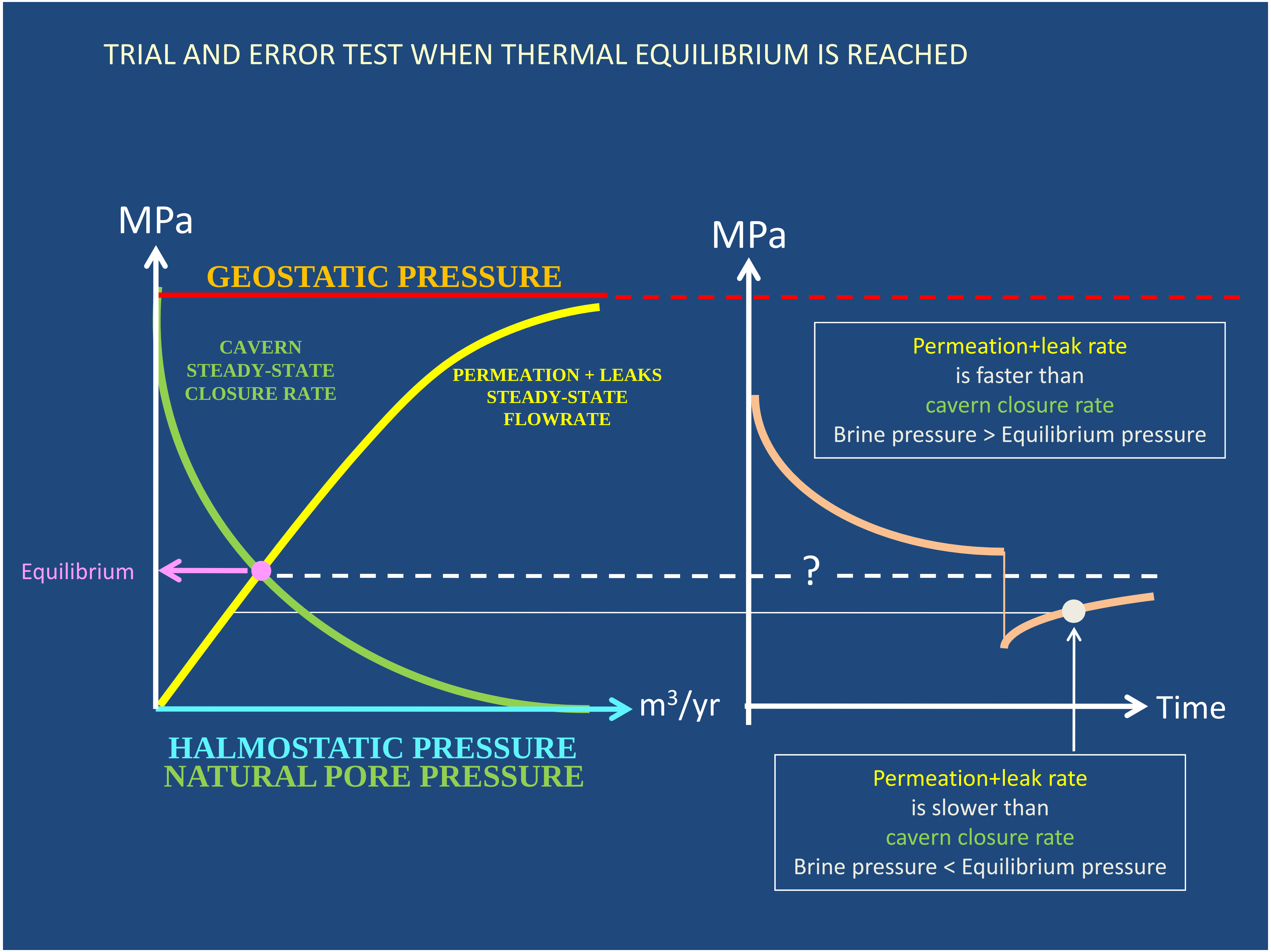
β_c = cavern compressibility factor
β_f = fluid compressibility factor

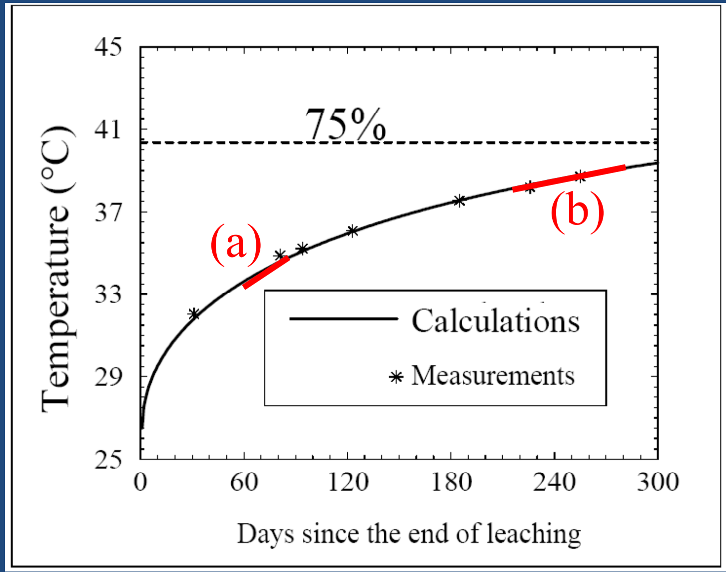
Cavern compressibility

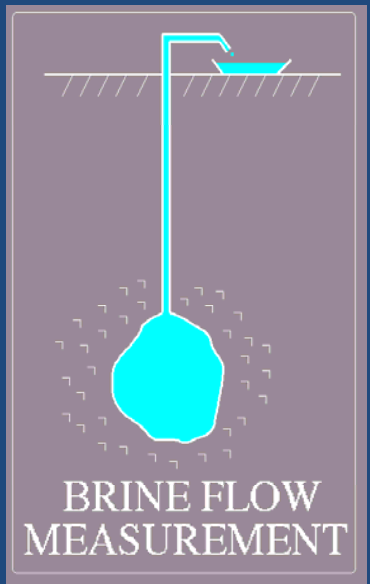


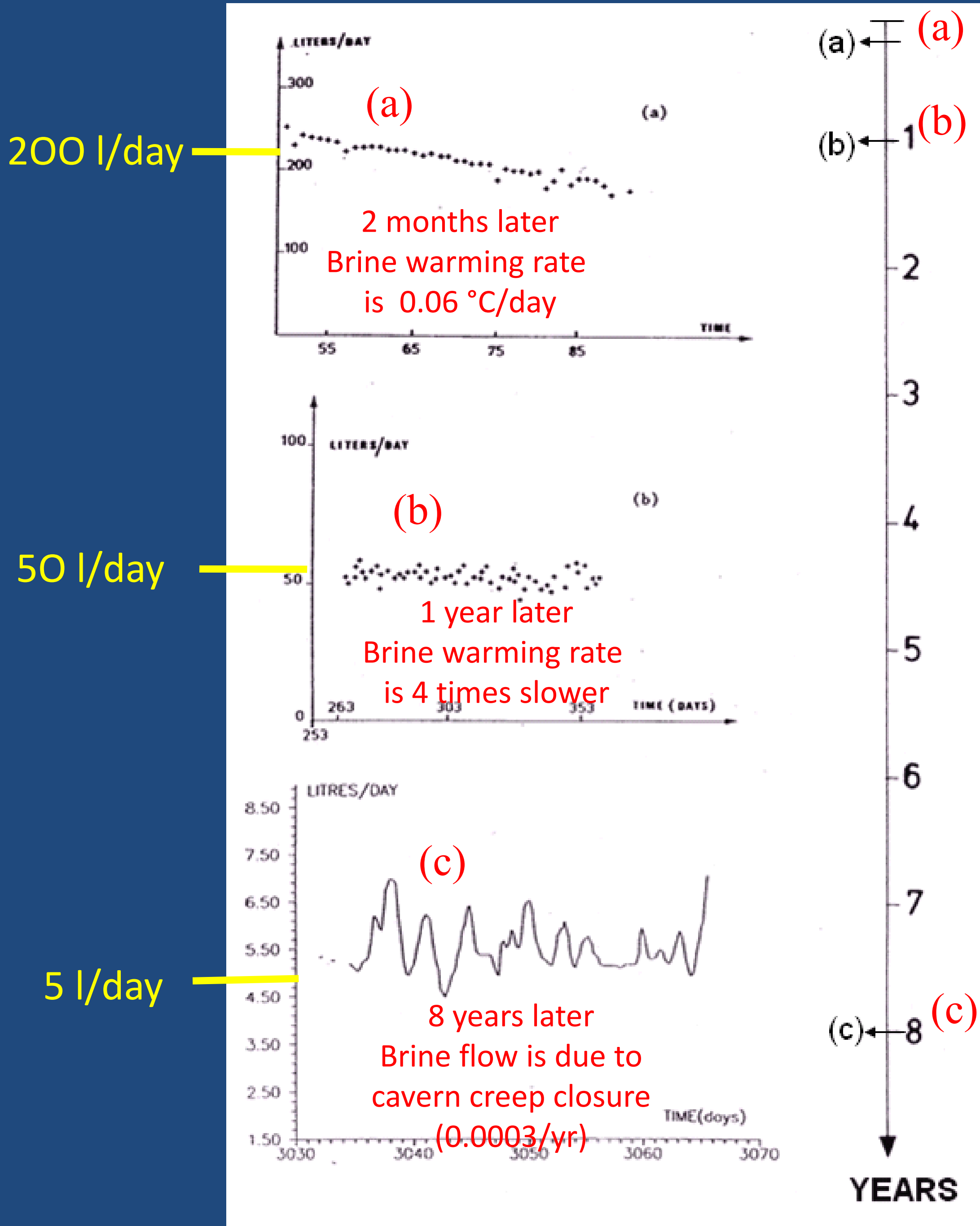


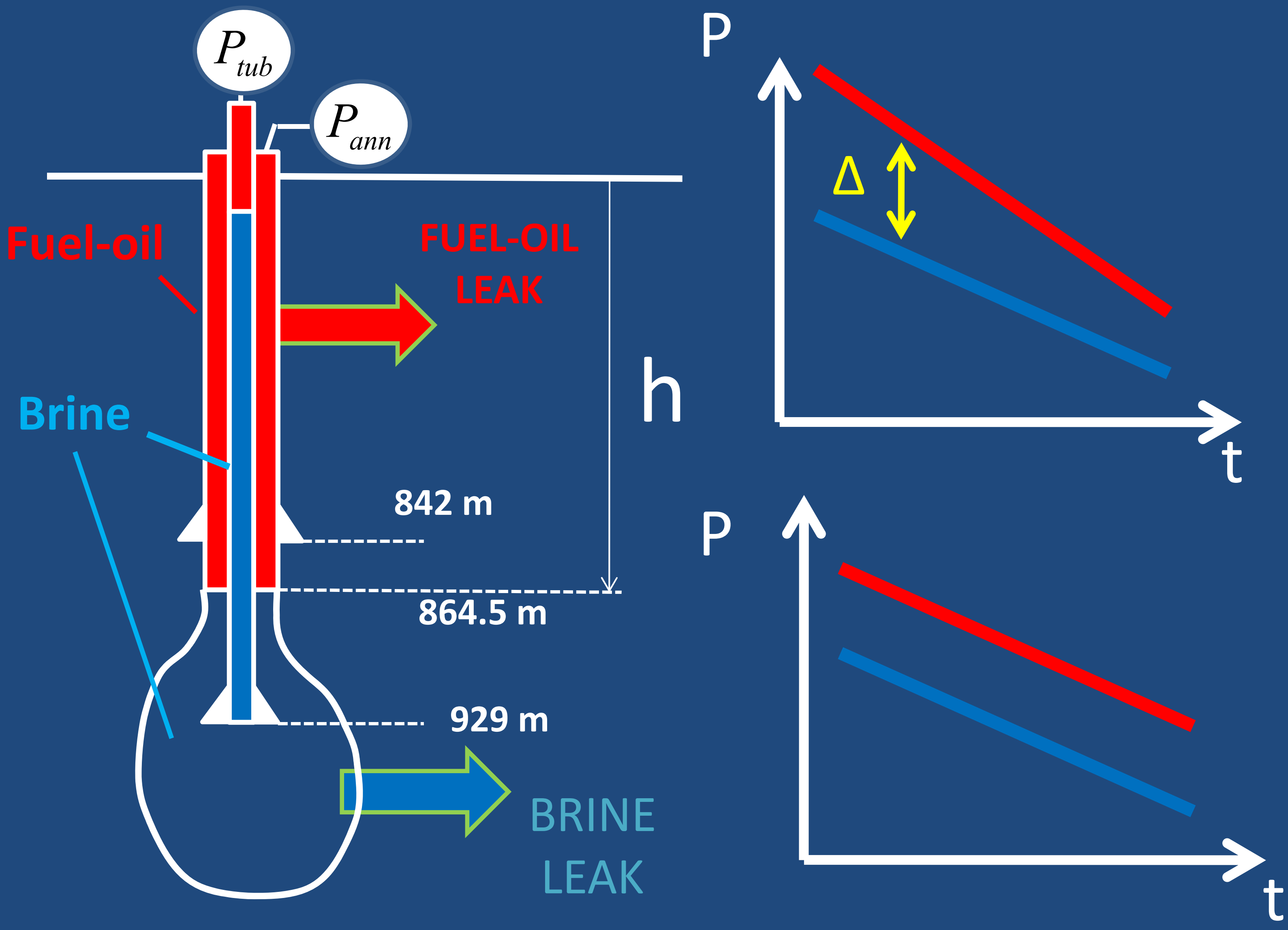
SPR3 cavern (Carresse)


TRIAL AND ERROR TEST WHEN THERMAL EQUILIBRIUM IS REACHED
MPa
GEOSTATIC PRESSURE
CAVERN
STEADY-STATE
CLOSURE RATE
PERMEATION + LEAKS
STEADY-STATE
FLOWRATE
Equilibrium
m³/yr
HALMOSTATIC PRESSURE
NATURAL PORE PRESSURE
MPa
Permeation+leak rate
is faster than
cavern closure rate
Brine pressure > Equilibrium pressure
?
Time
Permeation+leak rate
is slower than
cavern closure rate
Brine pressure < Equilibrium pressure


45
41
37
33
29
25
Temperature (°C)
75%
(a)
(b)
Calculations
Measurements
0
60
120
180
240
300
Days since the end of leaching


BRINE FLOW
MEASUREMENT

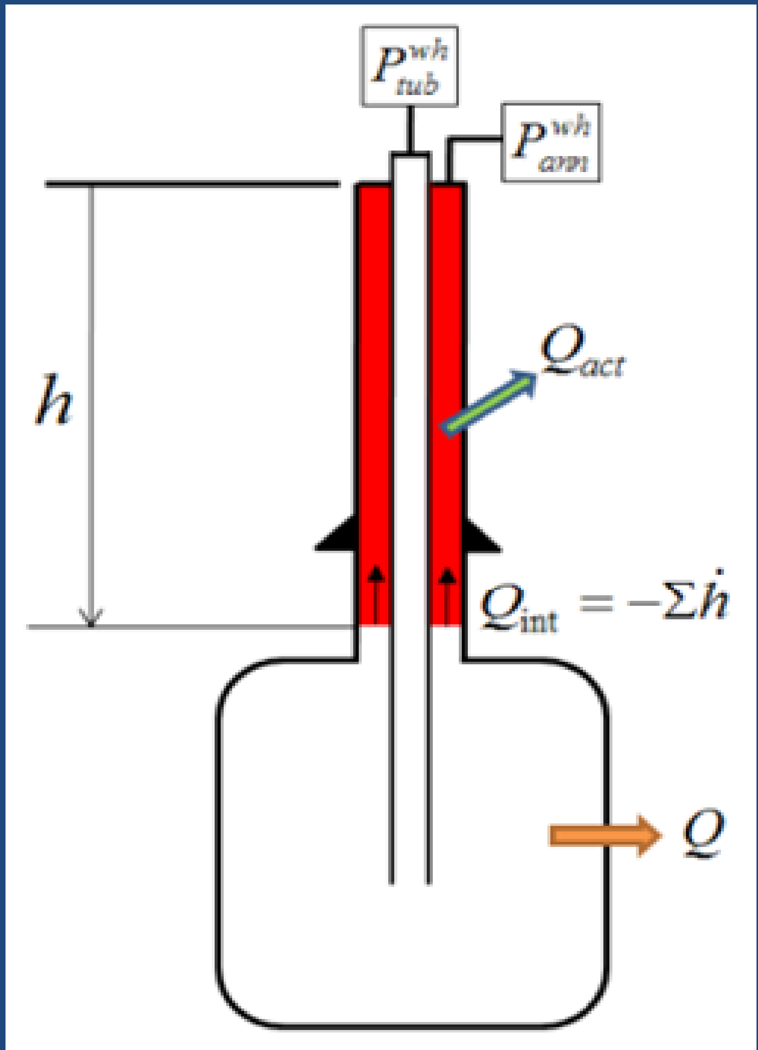

200 l/day
50 l/day
5 l/day
(a)
2 months later
Brine warming rate
is 0.06 °C/day
(b)
1 year later
Brine warming rate
is 4 times slower
(c)
8 years later
Brine flow is due to
cavern creep closure
(0.0003/yr)
LITRES/DAY
TIME(days)
(a)
(b)
(c)
1
2
3
4
5
6
7
8
YEARS



Δ = (γb – γo) δh = (0.52 psi/ft – 0.37 psi/ft) δh = 0.15 psi/ft

LESSONS DRAWN DURING THE TESTS

- Conclusions are more difficult to draw when thermal equilibrium between geothermal and cavern brine temperature was not reached before the test began.
- The initial trial-and-error test allows definition of a lower and upper bound for the equilibrium pressure that will be reached over the long-term.
- The long-term monitoring period allows to confirm the value of the equilibrium pressure
- Test interpretation is made easier when the composition of the liquid columns in the borehole experiences no or small changes or, still better, when pressure and temperature gauges are set in the cavern (rather than at the wellhead).
- During a trial-and-error test, pressure steps must be long enough to allow the transient phenomena that follow each pressure change to vanish.
- Interpretation is more certain when a leak detection system is installed in the well.



ETREZ TEST (LESSON 1) :

THE LEAK-DETECTION SYSTEM

FUEL OIL IS INJECTED IN THE ANNULAR SPACE BELOW THE CASING SHOE

ANY FUEL-OIL LEAK RESULTS

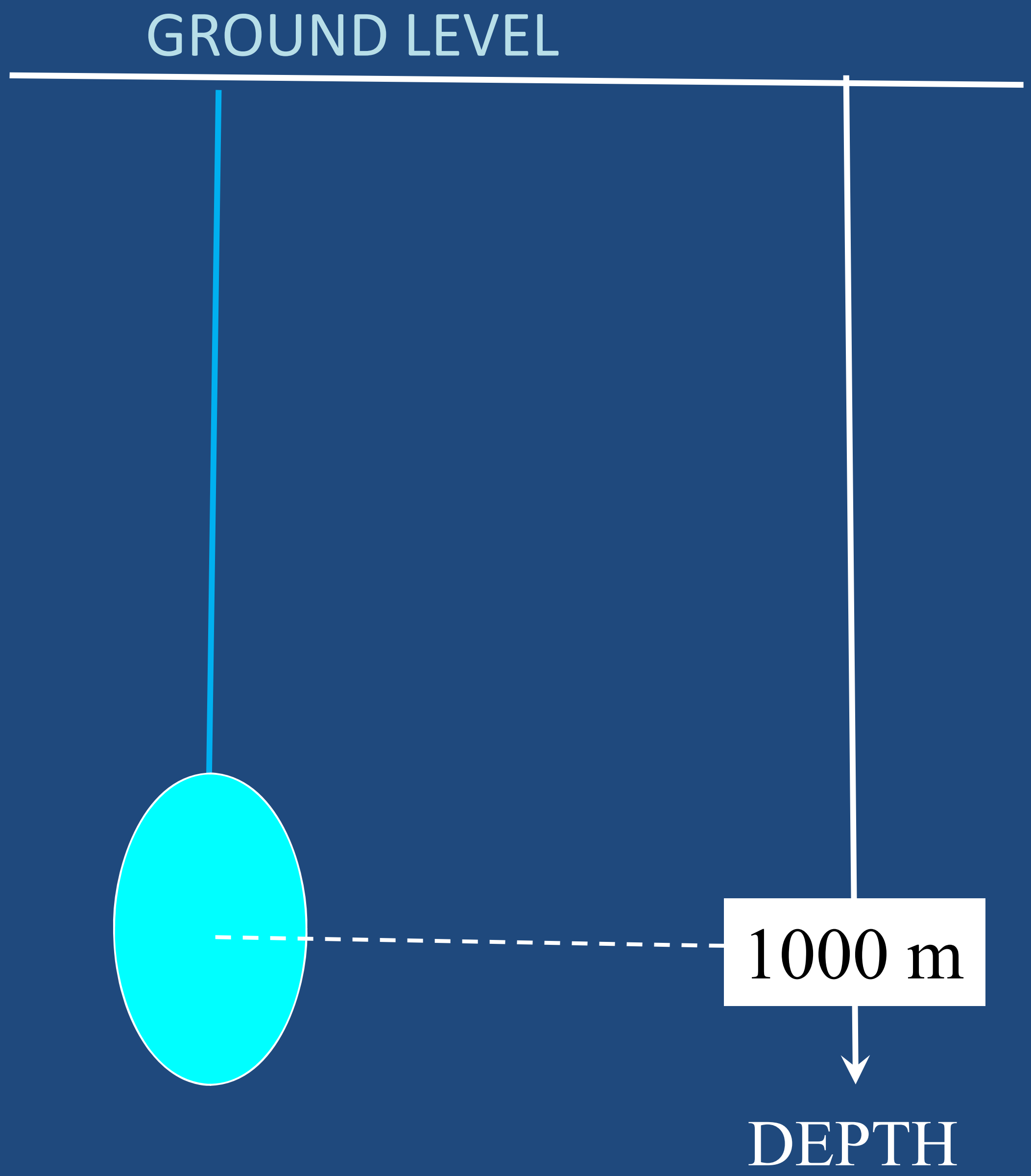
IN A BRINE-OIL INTERFACE RISE

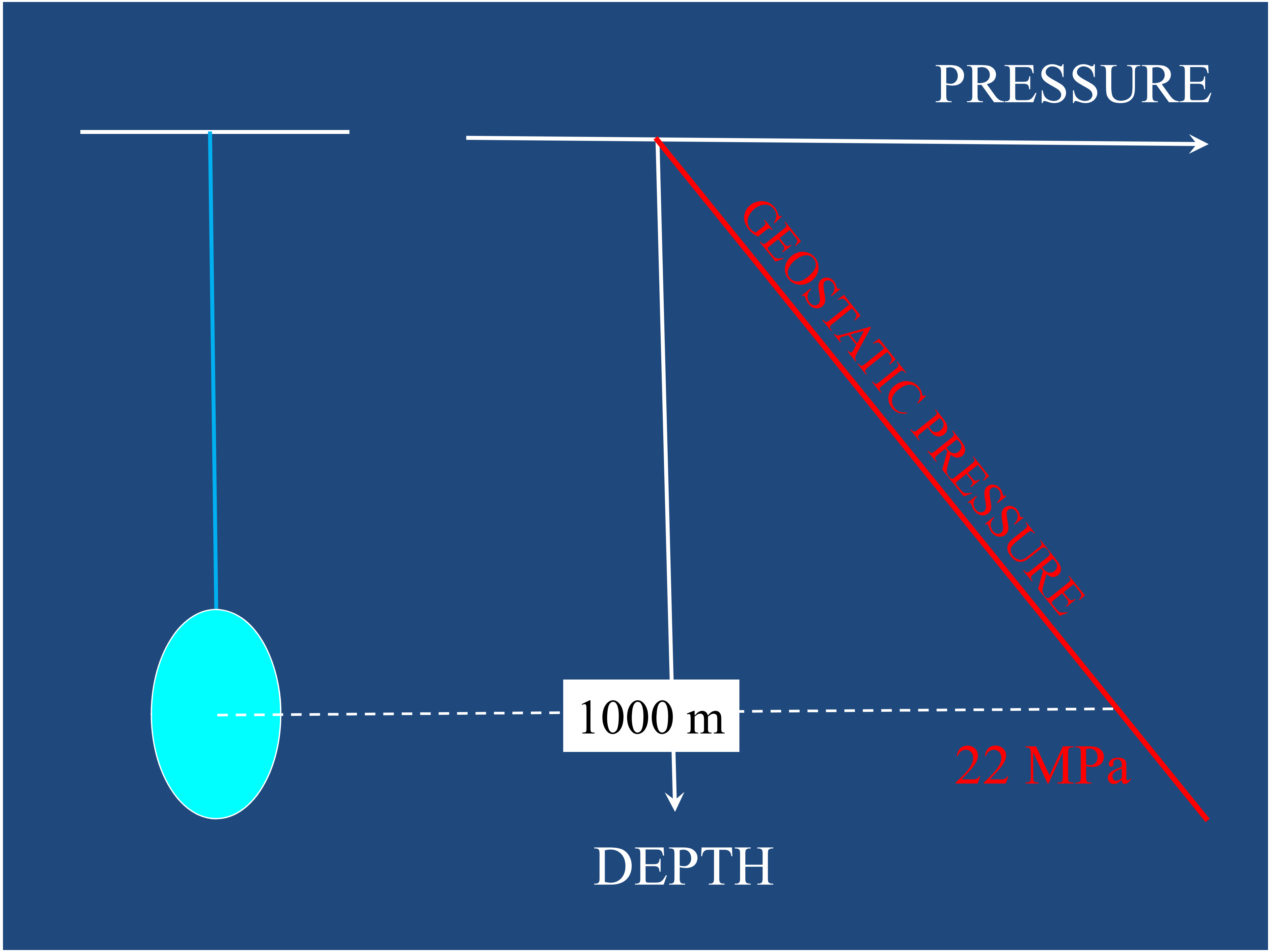
AND IN A DIFFERENTIAL EVOLUTION

OF THE STRING AND ANNULAR SPACE

PRESSURES

GEOSTATIC AND HALMOSTATIC PRESSURES

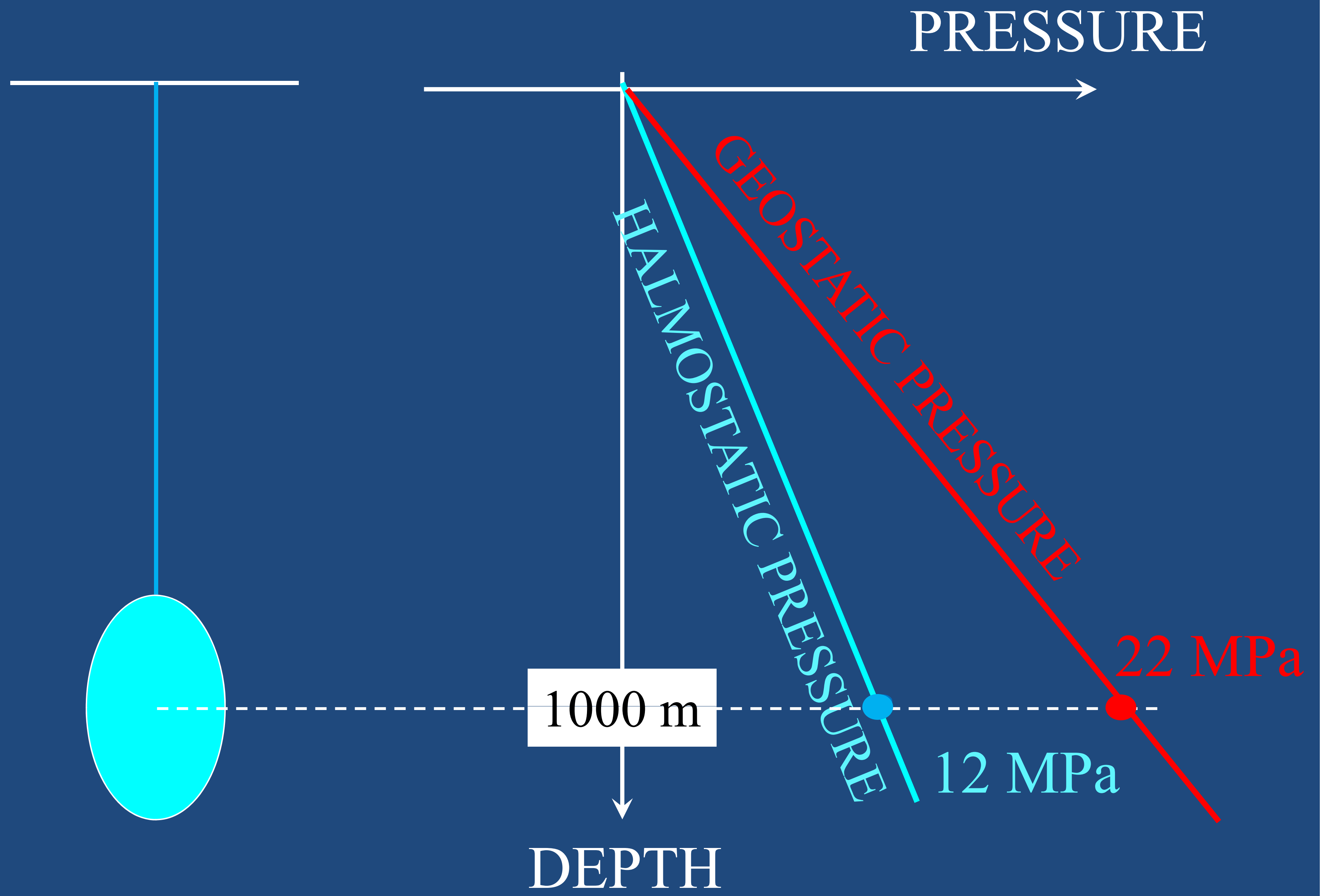

GROUND LEVEL
1000 m
DEPTH


PRESSURE
GEOSTATIC PRESSURE
1000 m
22 MPa
DEPTH

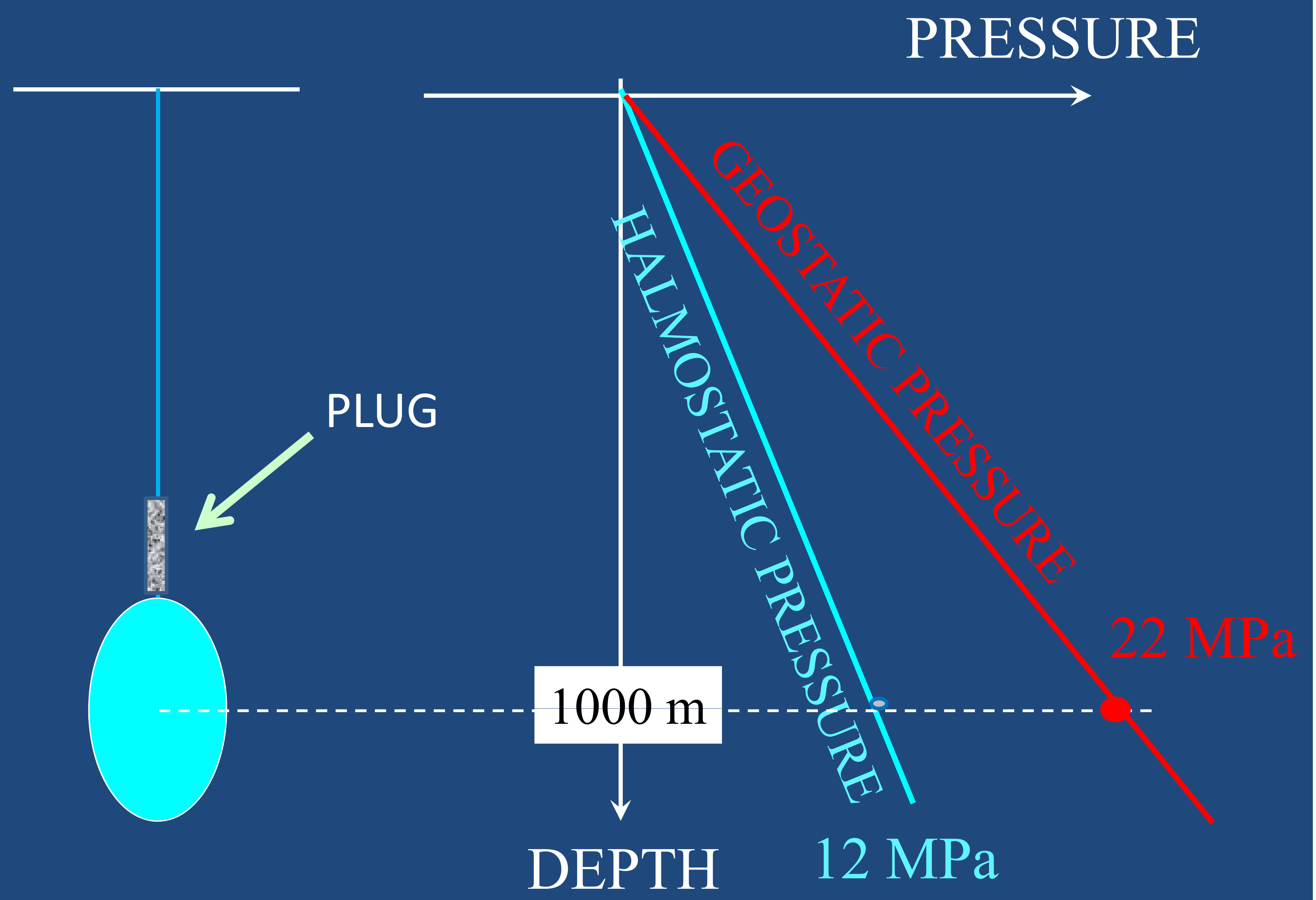
ἅλμοσ

=

brine

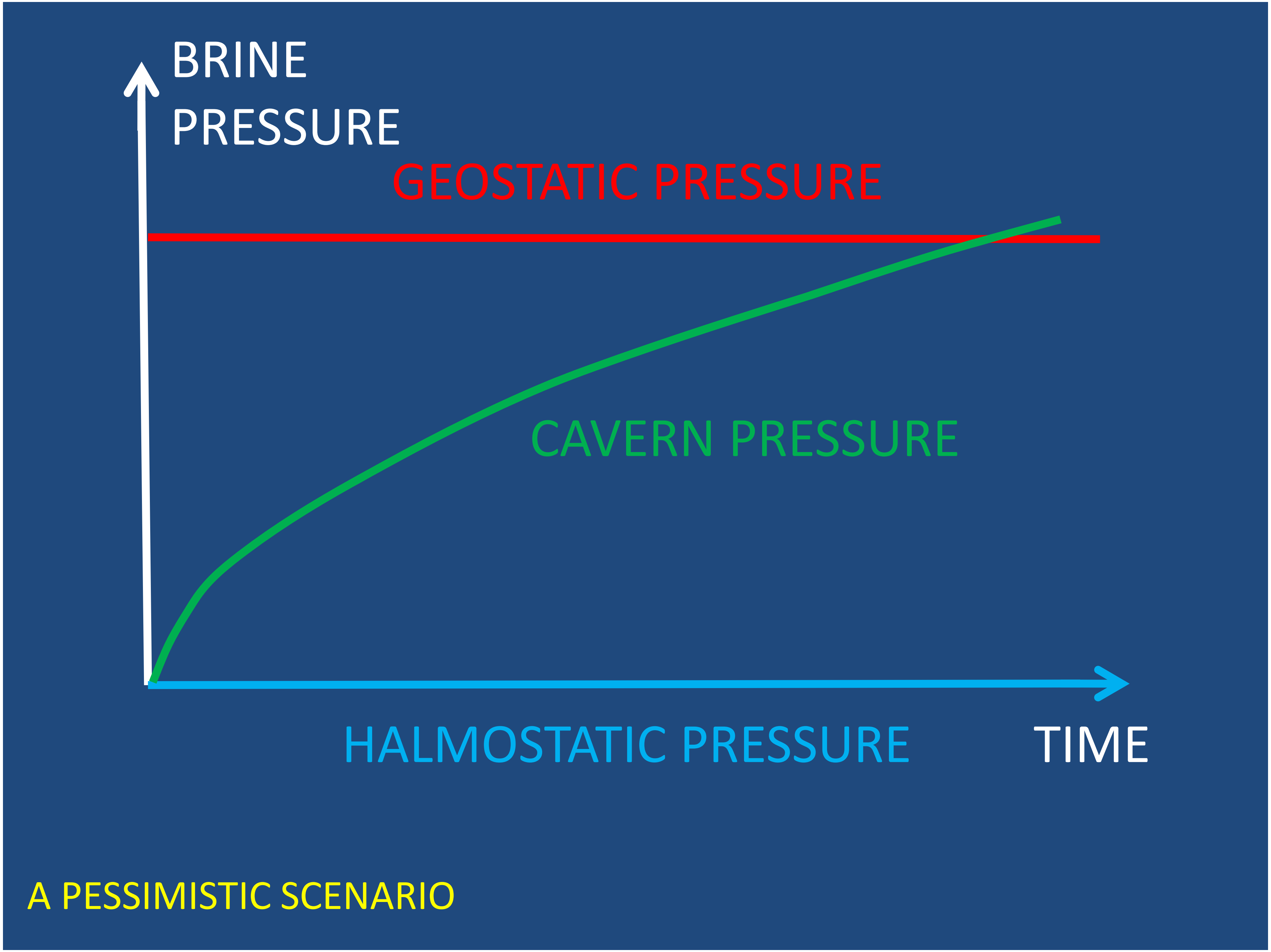

PRESSURE
GEOSTATIC PRESSURE
HALMOSTATIC PRESSURE
22 MPa
1000 m
12 MPa
DEPTH

Cavern abandonment

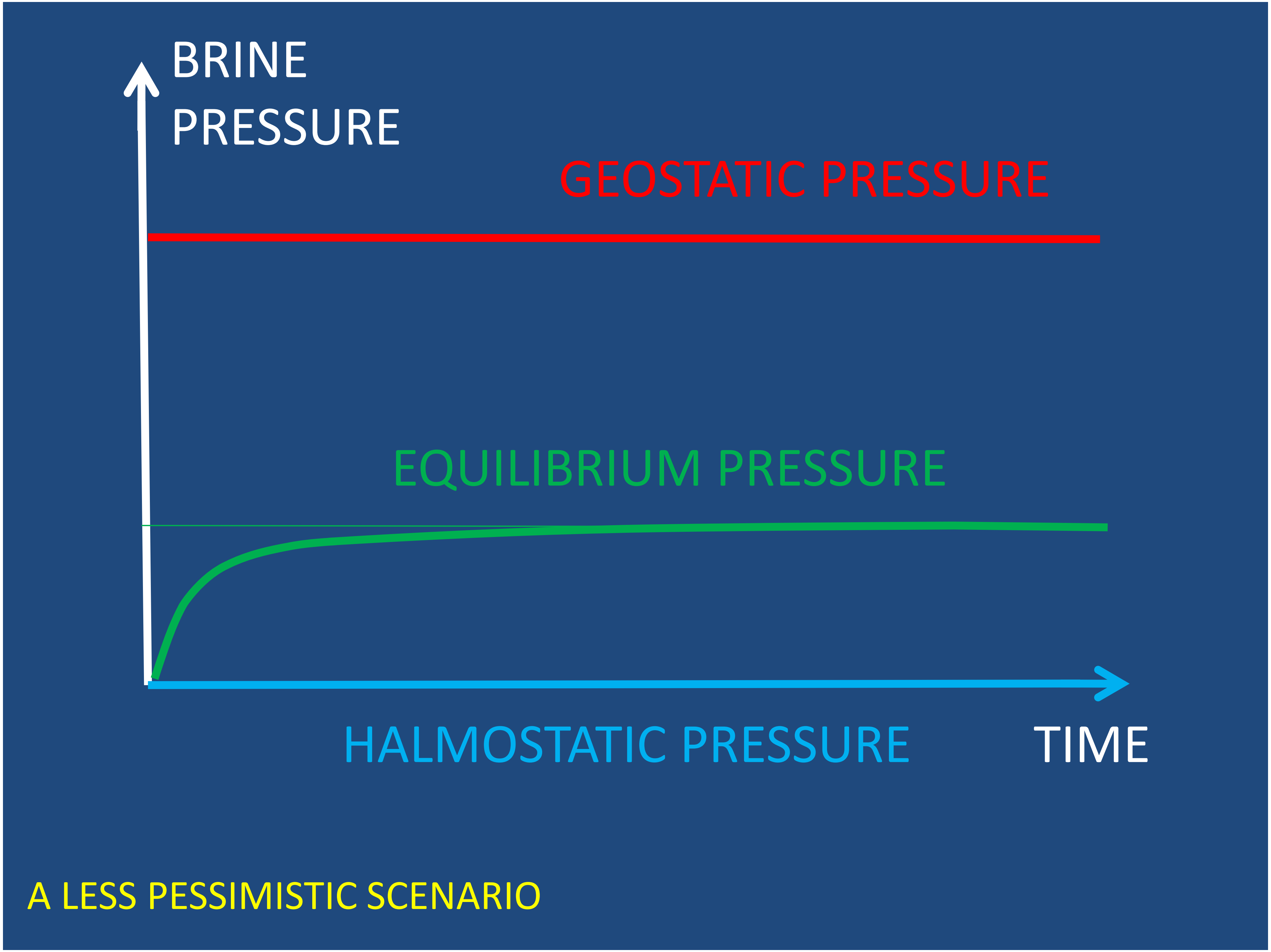

PRESSURE
PLUG
GEOSTATIC PRESSURE
HALMOSTATIC PRESSURE
22 MPa
1000 m
DEPTH
12 MPa

A PESSIMISTIC SCENARIO

THE PESSIMISTIC SCENARIO

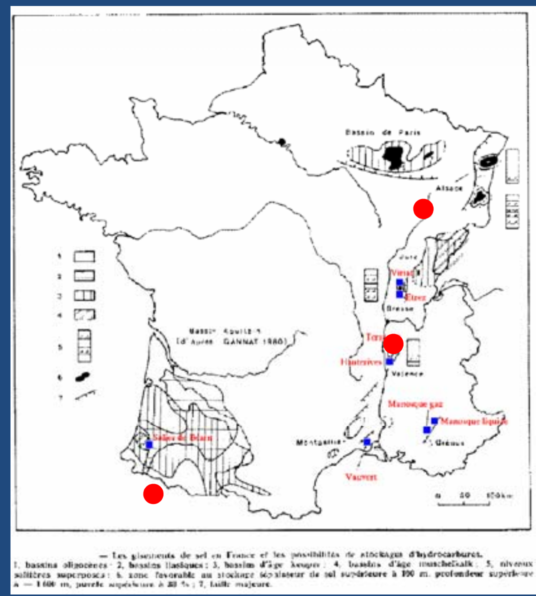

BRINE
PRESSURE
GEOSTATIC PRESSURE
CAVERN PRESSURE
HALMOSTATIC PRESSURE
TIME
A PESSIMISTIC SCENARIO

THE LESS PESSIMISTIC SCENARIO


BRINE
PRESSURE
GEOSTATIC PRESSURE
EQUILIBRIUM PRESSURE
HALMOSTATIC PRESSURE
TIME
A LESS PESSIMISTIC SCENARIO

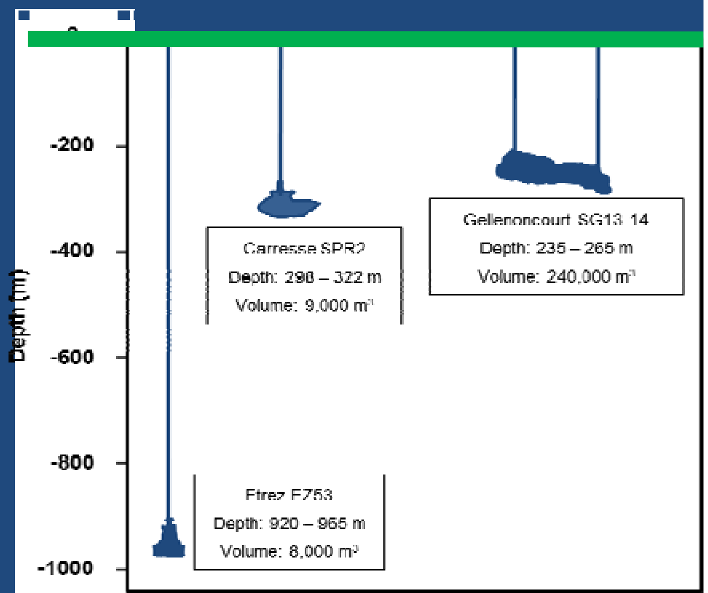
These caverns are relatively shallow :

Cavern creep closure is not very fast
(0.0003/yr at Etrez,
0.00001/yr at Gellenoncourt)



These caverns are relatively small
They had been kept idle for a long time

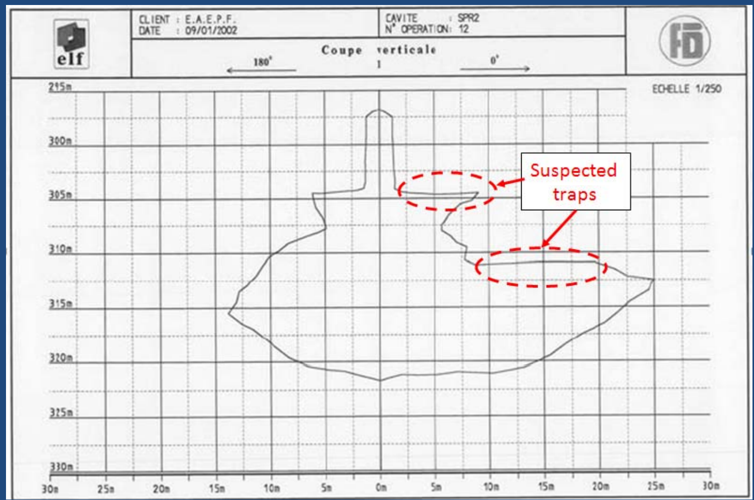
Thermal equilibrium was reached
When the T&A test began

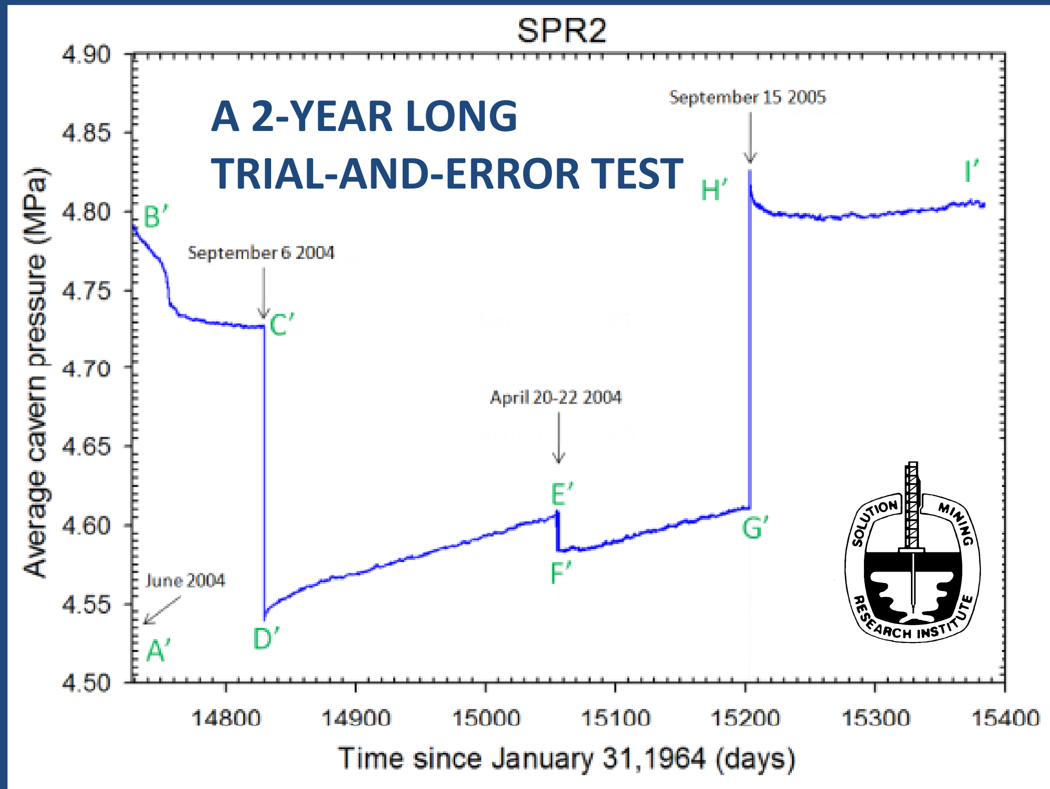


SPR2 (TOTAL)

2004-2013

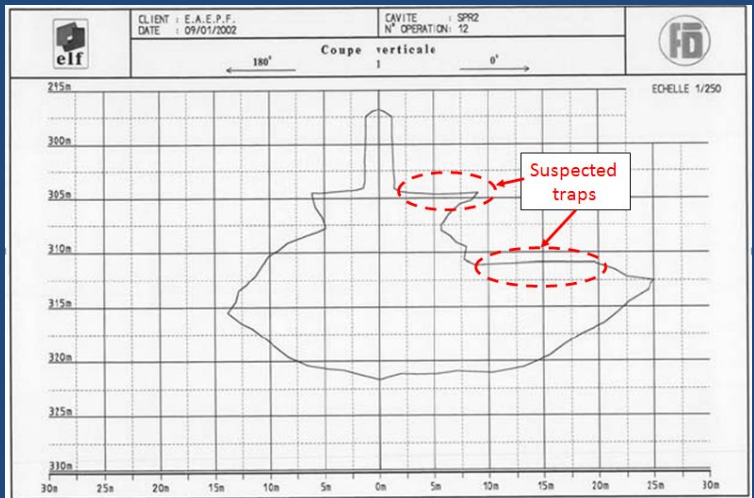
SPR2: A TRIAL-AND –ERROR TEST

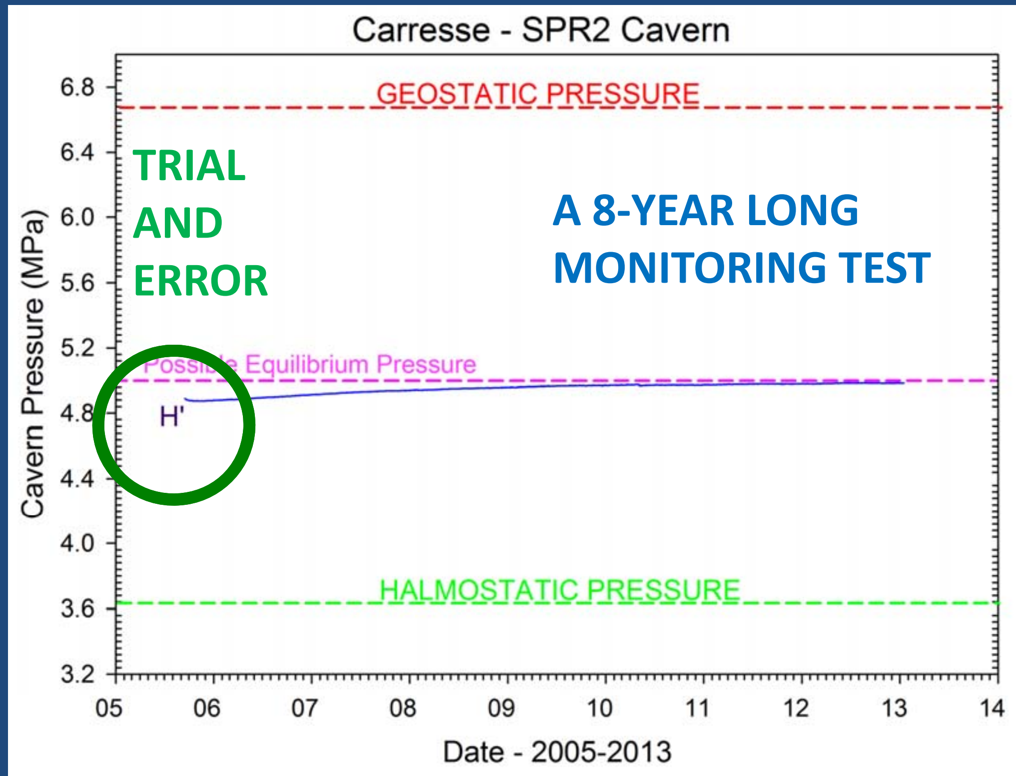


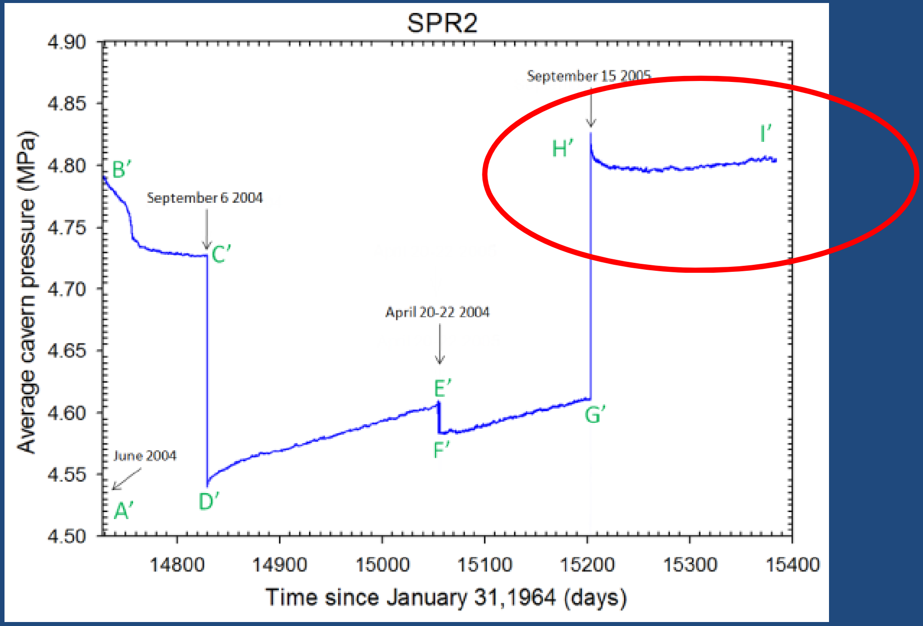


CARRESSE (TOTAL and GEOSTOCK)

SG13-14: A PRESSURE MONITORING TEST







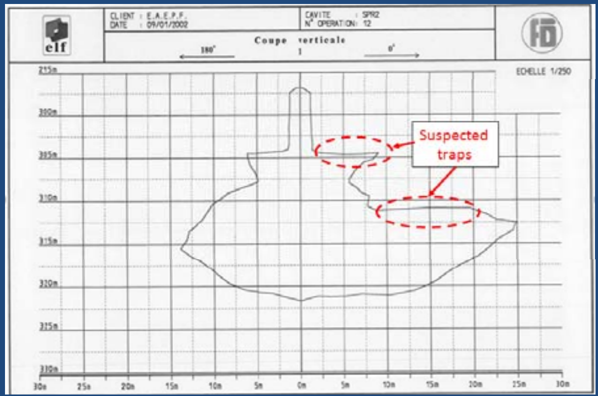
CARRESSE TEST (LESSON 2) :

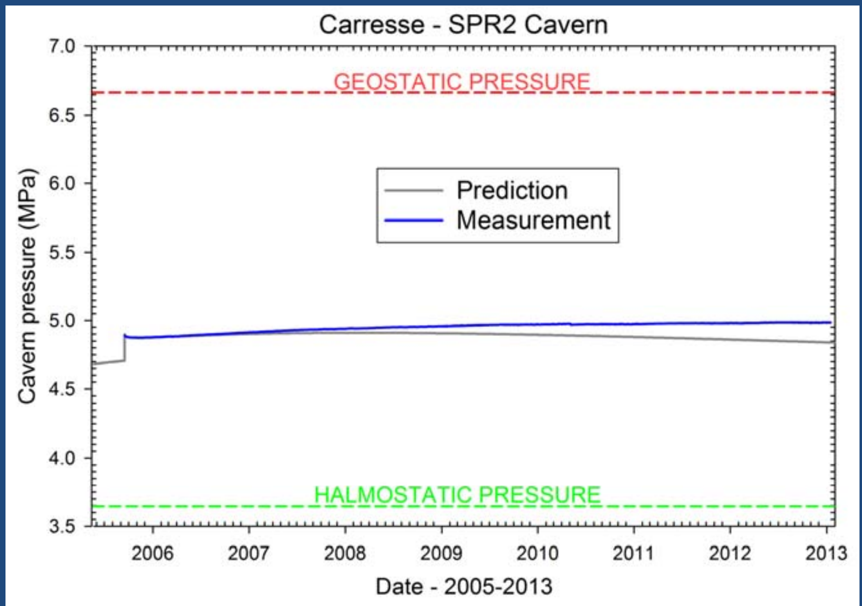
DURING THE TRIAL-AND-ERROR TEST

EACH PHASE MUST BE LONG ENOUGH

TO ALLOW

TRANSIENT EFFECTS TO VANISH





CARRESSE TEST (LESSON 3) :

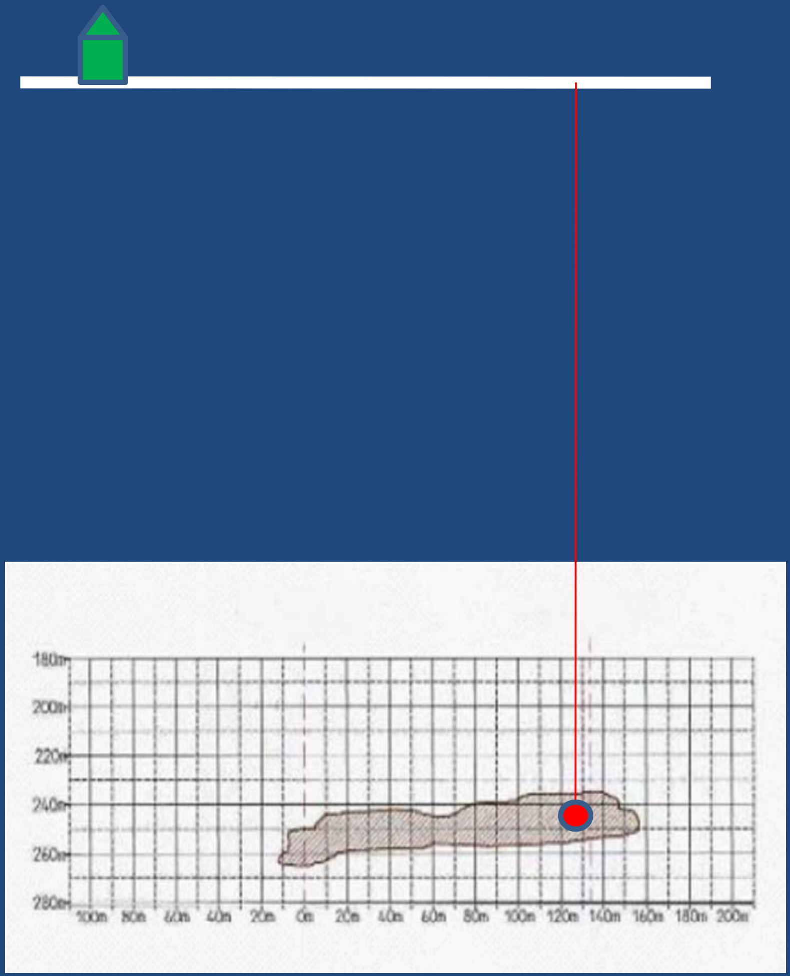
THE SIGNIFICANCE OF THERMAL EXPANSION

BEFORE THE TEST

GEOTHERMAL TEMPERATURE

WAS UNDERESTIMATED BY 0.1 °C

RESULTING IN POOR PREDICTION



GELLENONCOURT TEST (LESSON 4) :

CAVERN PRESSURE MEASUREMENT

IT IS BETTER TO SET

PRESSURE AND TEMPERATURE GAGES

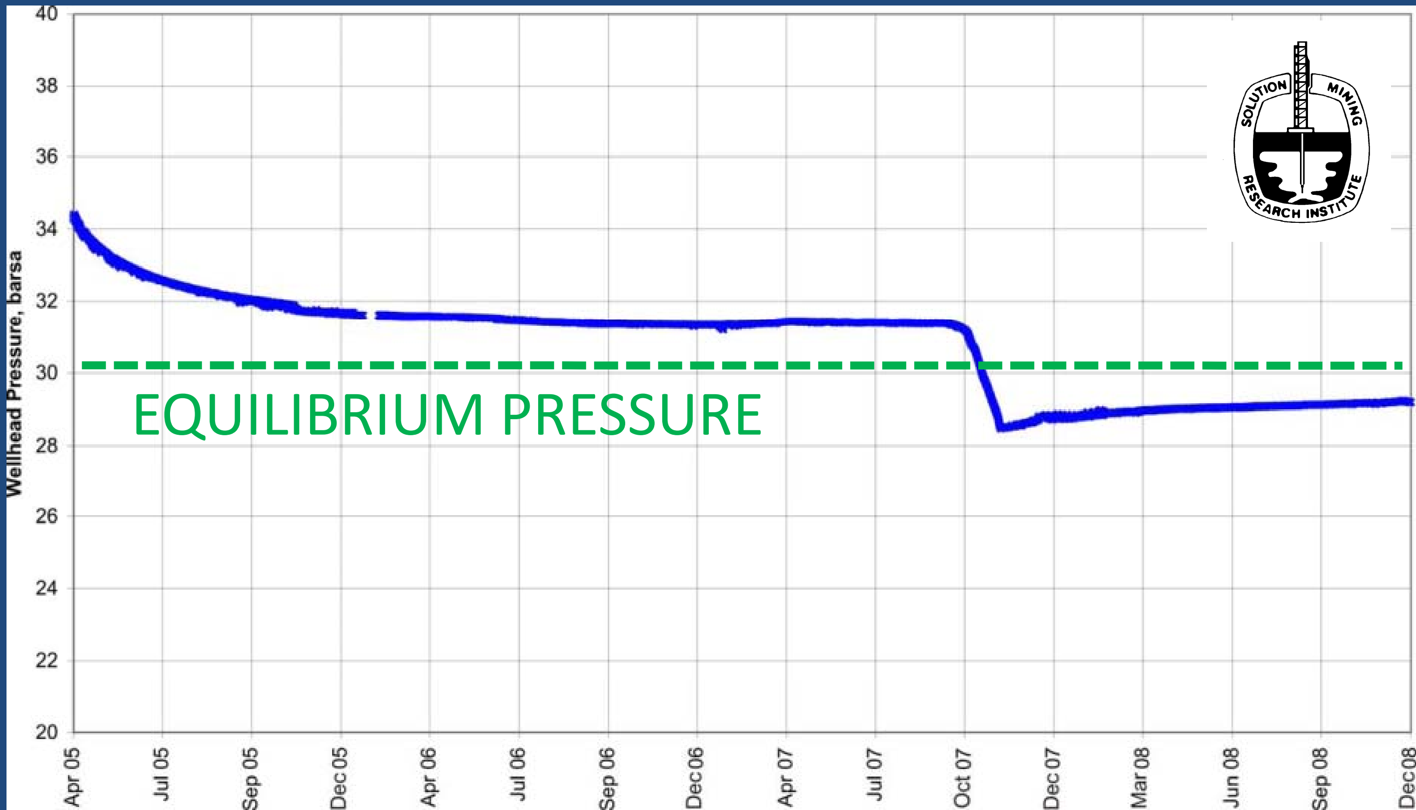
IN THE CAVERN

(RATHER THAN AT THE WELL HEAD)

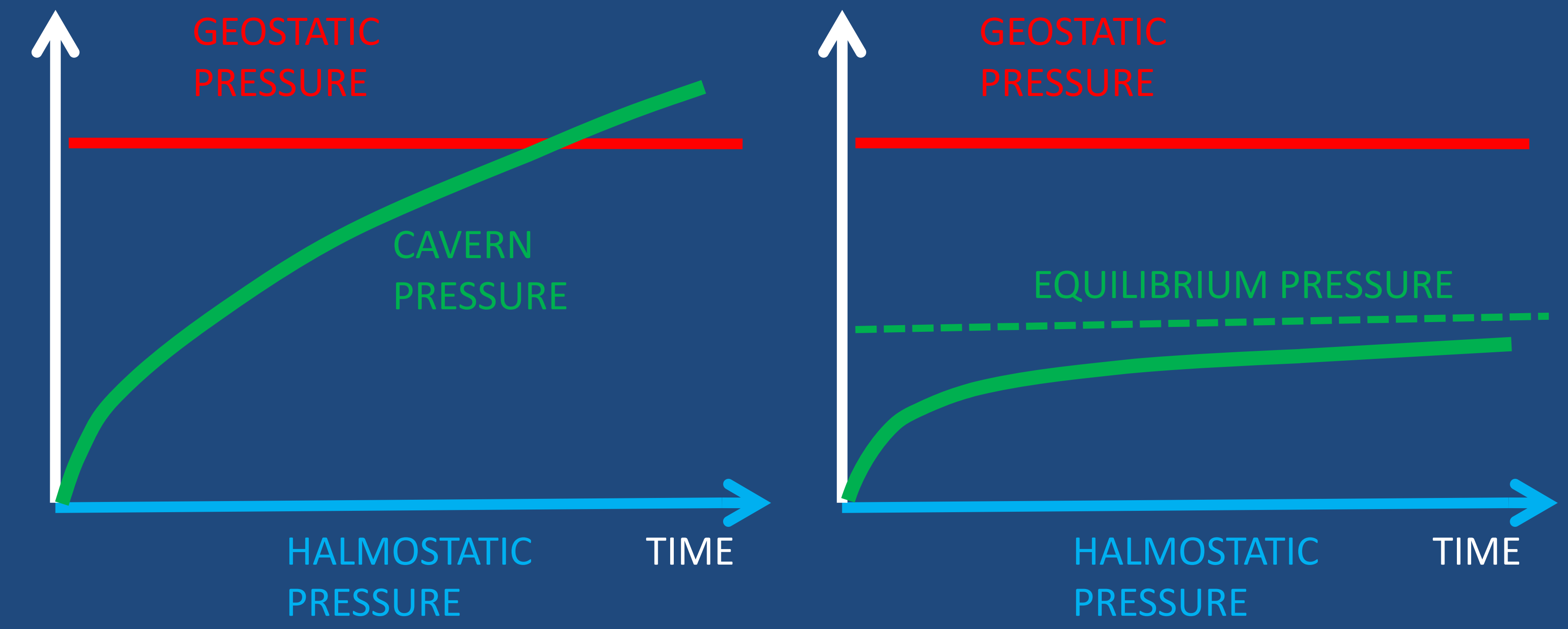
Bottom temperature gauge accuracy can be checked as follows:
a pressure increase by 1 MPa generates a 0.03°C temperature increase

SIMILAR RESULTS WERE OBTAINED BY
A. BANACH & M. KLAFKI
DURING A TEST PERFORMED IN TWO CAVERNS
AT STASSFURT, GERMANY
(SMRI Research Report RR 2009-01)

SIMILAR RESULTS WERE OBTAINED BY
A. BANACH & M. KLAFKI
DURING A TEST PERFORMED IN TWO CAVERNS
AT STASSFURT, GERMANY
(SMRI Research Report RR 2009-01)



CONCLUSIONS

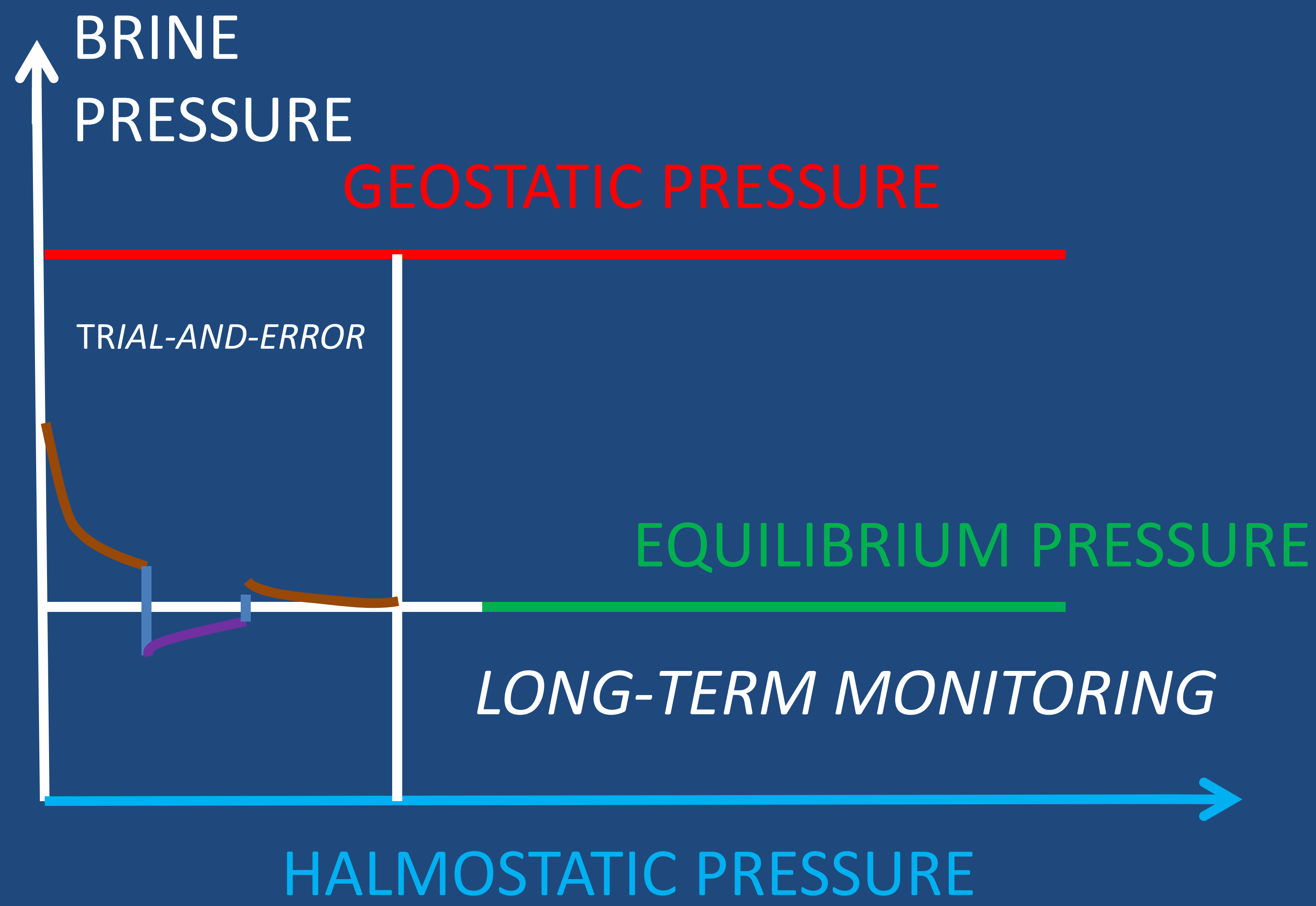


IN THESE 4 EXAMPLES

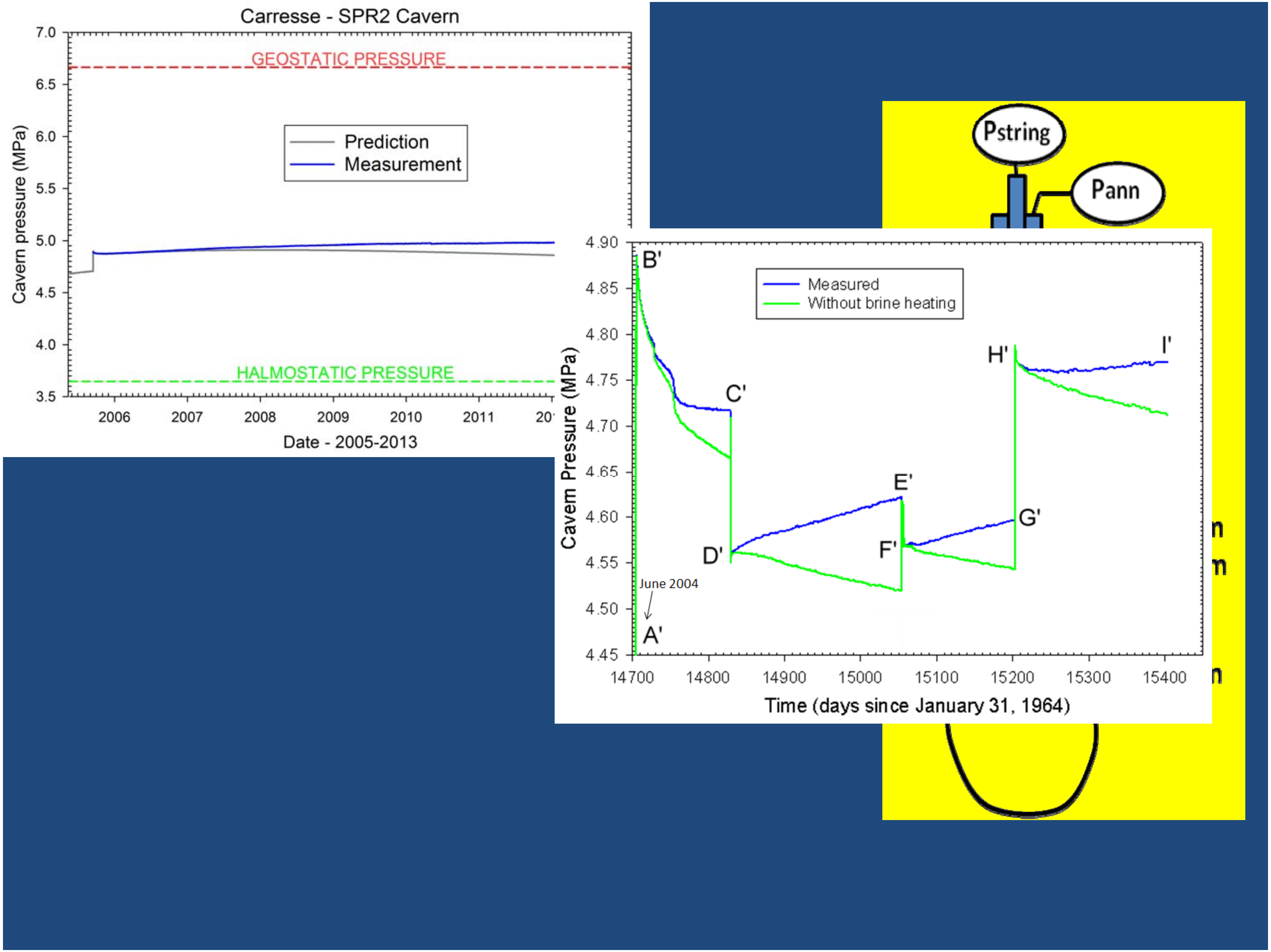
THERMAL EQUILIBRIUM WAS REACHED

THE « OPTIMISTIC » SCENARIO IS CORRECT:

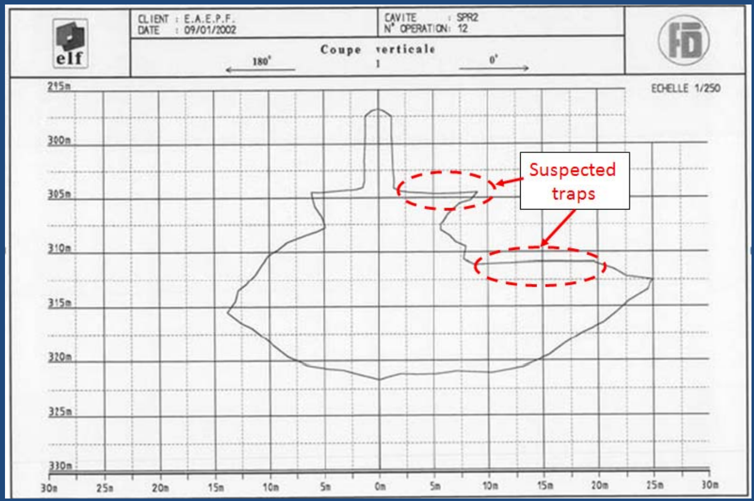
LONG-TERM CAVERN PRESSURE IS SMALLER THAN GEOSTATIC

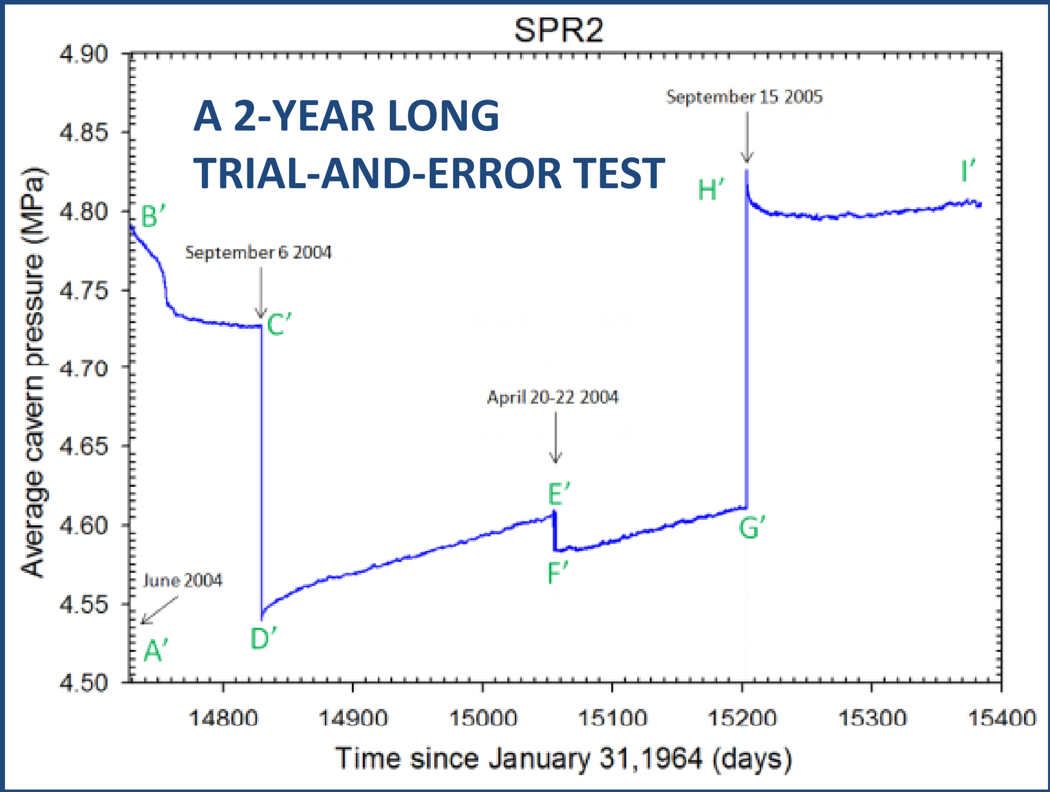


4 *in situ* tests confirmed the « optimistic » scenario

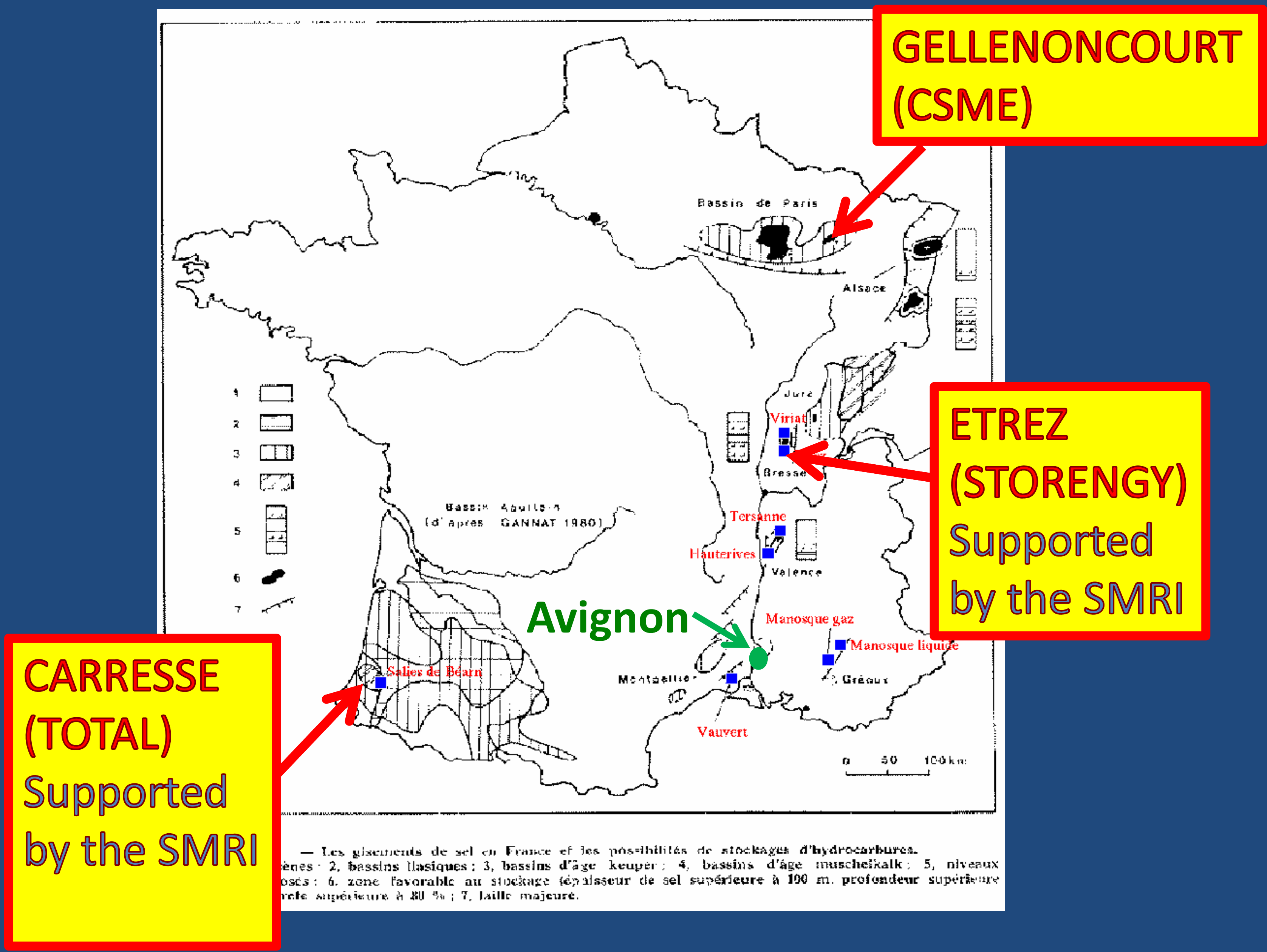

Carresse - SPR2 Cavern
GEOSTATIC PRESSURE
HALMOSTATIC PRESSURE
Prediction
Measurement
Cavern pressure (MPa)
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
2006
2007
2008
2009
2010
2011
Date - 2005-2013
Pstring
Pann
Measured
Without brine heating
Cavern Pressure (MPa)
4.90
4.85
4.80
4.75
4.70
4.65
4.60
4.55
4.50
4.45
A'
B'
C'
D'
E'
F'
G'
H'
I'
June 2004
14700
14800
14900
15000
15100
15200
15300
15400
Time (days since January 31, 1964)

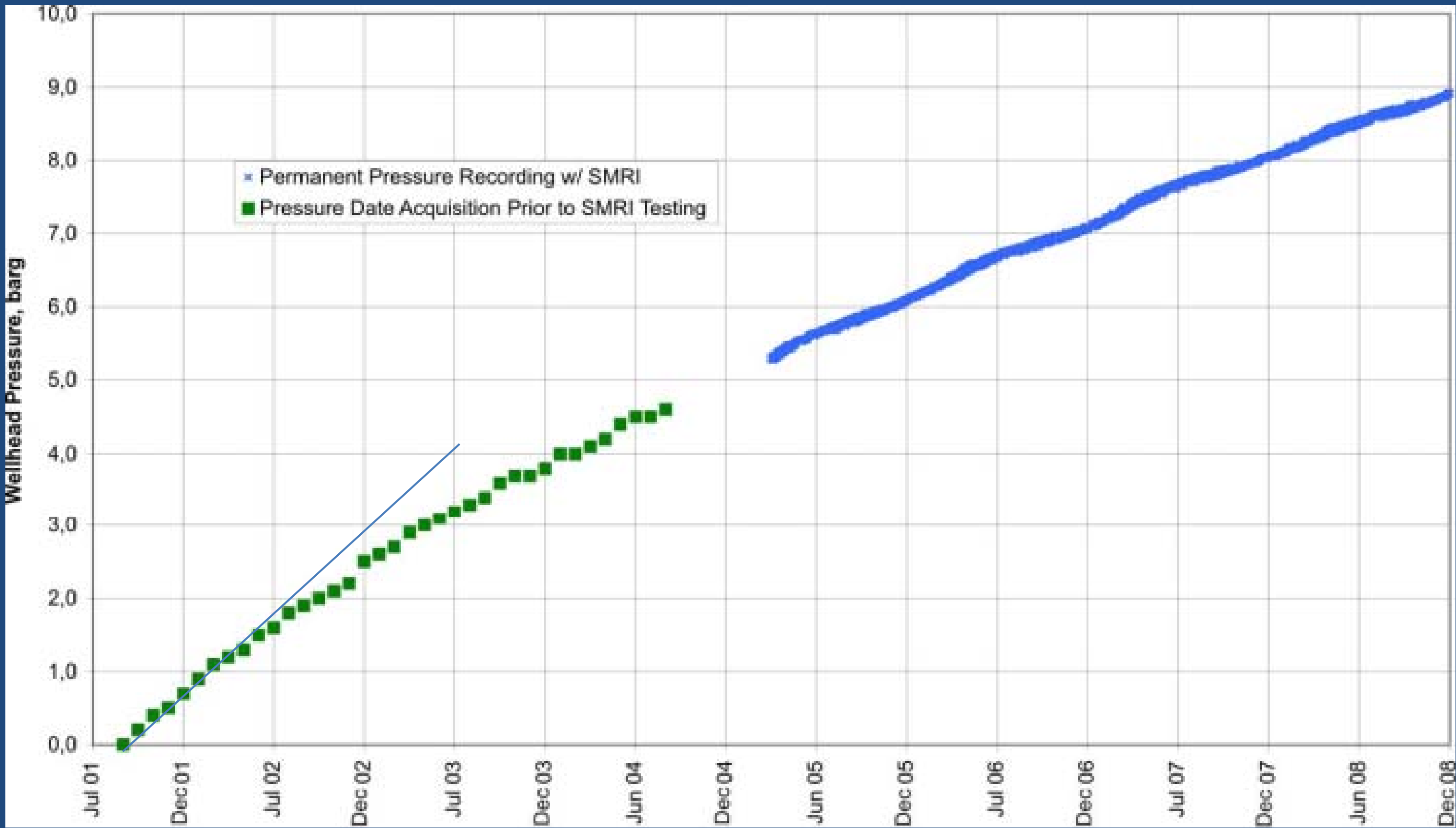
SPR2: A TRIAL-AND –ERROR TEST



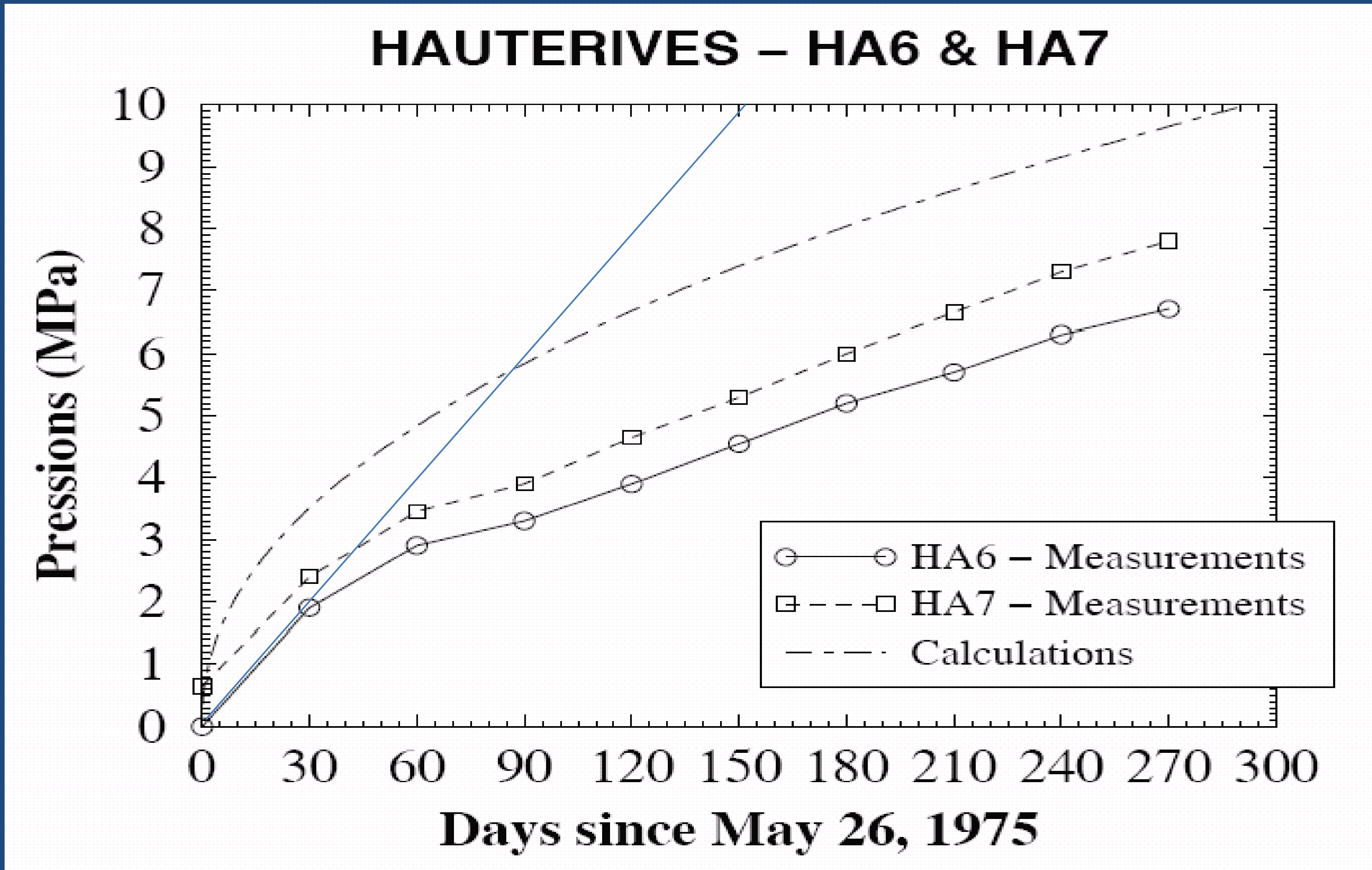


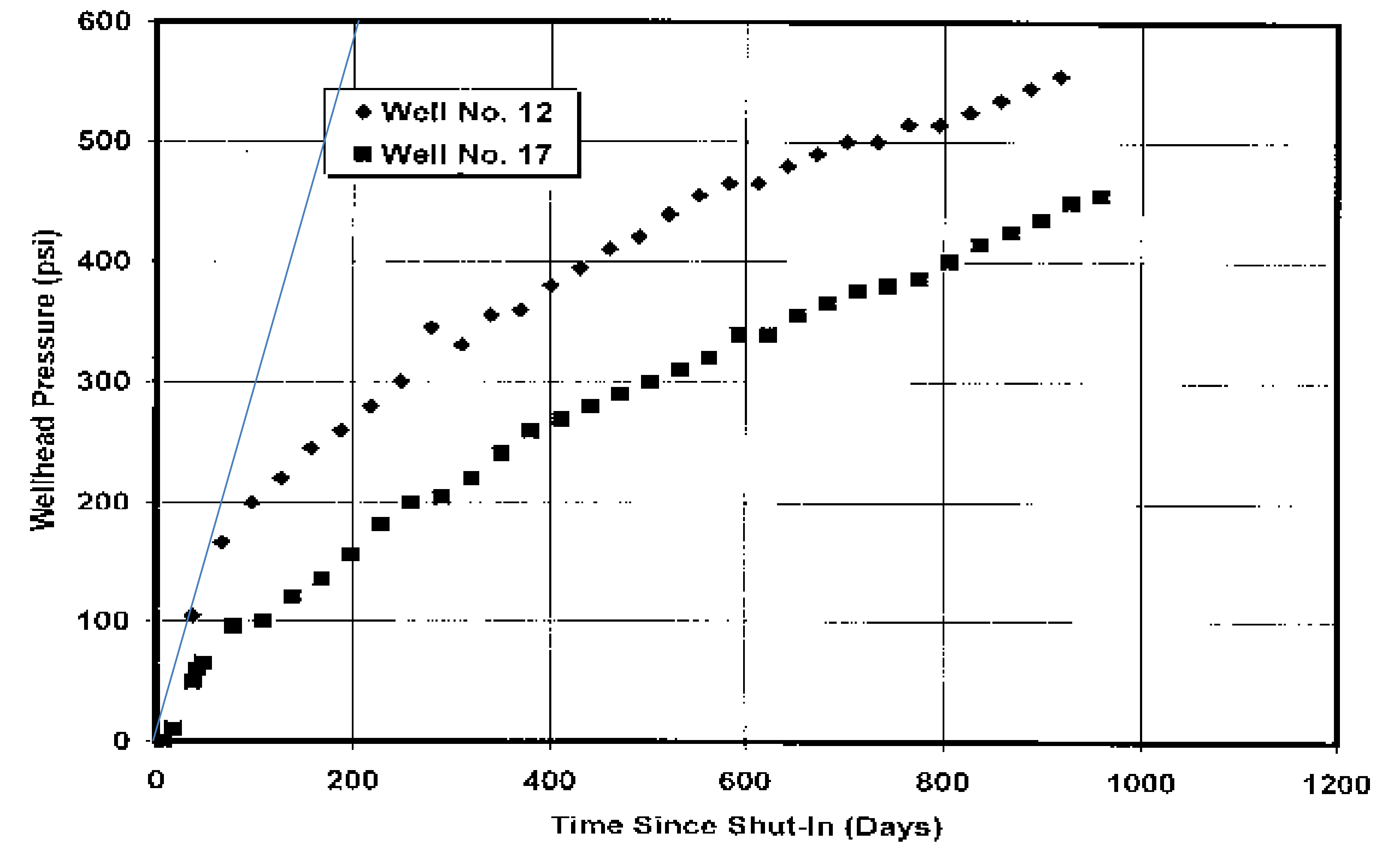
CARRESSE (TOTAL and GEOSTOCK)


GELLENONCOURT (CSME)
ETREZ (STORENGY) Supported by the SMRI
CARRESSE (TOTAL) Supported by the SMRI
Avignon
Bassin de Paris
Alsace
Jura
Viriat
Bresse
Tersanne
Hauterives
Valence
Bassin Aquitain (d'après GANNAT 1980)
Manosque gaz
Manosque liquide
Gréoux
Montpellier
Vauvert
Salies de Béarn
1
2
3
4
5
6
7
0 50 100 km
— Les gisements de sel en France et les possibilités de stockages d'hydrocarbures.
ènes : 2, bassins liasiques ; 3, bassins d'âge keuper ; 4, bassins d'âge muschelkalk ; 5, niveaux
osés : 6. zone favorable au stockage (épaisseur de sel supérieure à 100 m, profondeur supérieure
rele supérieure à 80 % ; 7, faille majeure.



10,0
9,0
8,0
7,0
6,0
5,0
4,0
3,0
2,0
1,0
0,0
Wellhead Pressure, barg
Permanent Pressure Recording w/ SMRI
Pressure Date Acquisition Prior to SMRI Testing
Jul 01
Dec01
Jul 02
Dec 02
Jul 03
Dec03
Jun 04
Dec04
Jun 05
Dec 05
Jul 06
Dec 06
Jul 07
Dec07
Jun 08
Dec 08


HAUTERIVES – HA6 & HA7
Pressions (MPa)
Days since May 26, 1975
0
1
2
3
4
5
6
7
8
9
10
0
30
60
90
120
150
180
210
240
270
300
HA6 – Measurements
HA7 – Measurements
Calculations



Well No. 12
Well No. 17
Wellhead Pressure (psi)
Time Since Shut-In (Days)
0
100
200
300
400
500
600
0
200
400
600
800
1000
1200