COLLOQUE ANNUEL DU GDR HYDROGEMM - 2024

MODÉLISATION NUMÉRIQUE DES « SYSTÈMES HYDROGÈNE »

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INTRODUCTION - NATURAL H_2 EXPLORATION

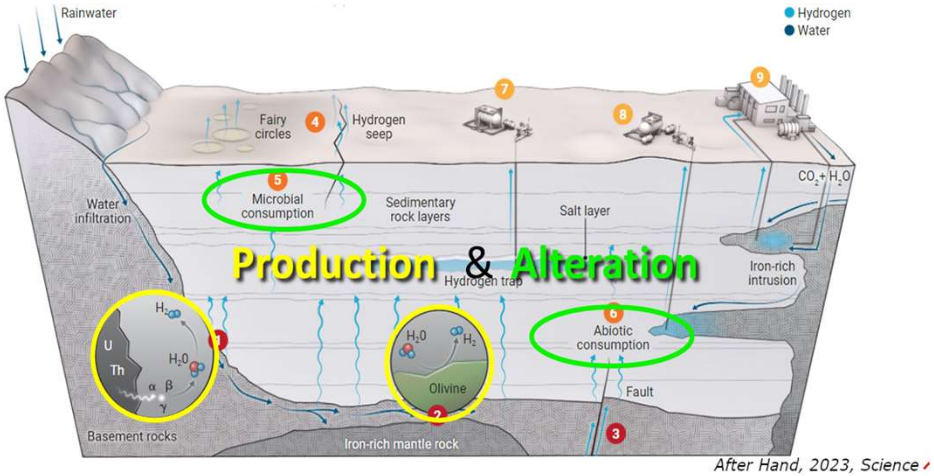
Renewable energies

- New challenges for basin geologists: significant differences between H_2 systems and petroleum systems

  - Multiple sources, poorly known

  - Migration:
    - **Dissolved flow**

      Advection as a component of a mixture of dissolved gases: H_2, He, CH_4, N_2
    - Possible **transition to free-gas flow**
    - Diffusion
    - **Alteration**



After Hand, 2023, Science

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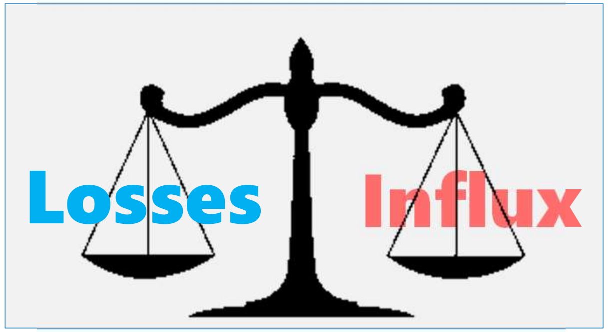
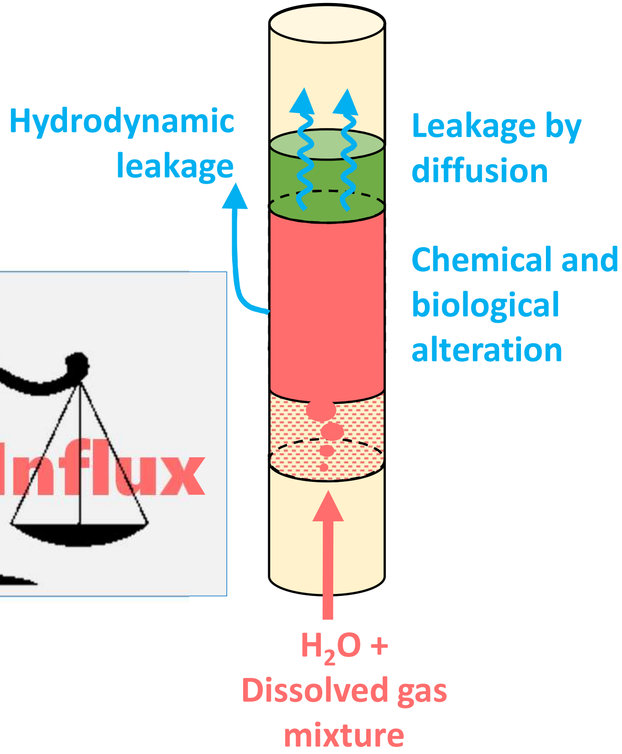
THE EXAMPLE OF NATURAL H2 EXPLORATION

Renewable energies

- What differences between H_2 systems and petroleum systems?

  - Accumulation:
    - Need a better cap rock
    - Chemical and biological alteration
    - Most probably **dynamic accumulations**:
      - Leakage balanced by influx
      - **Recharge rate needs to be considered**





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FOCUS ON USEFUL FUNCTIONNALITIES

Renewable energies

- **Water ⇆ Vapor exchange**

  H_2 solubility from an analytic model calibrated with Sorreide & Whitson

$$solubility = e^{(a1.m^2+a2.m)}.\left(b1.PT + b2.\frac{P}{T} + b3.P + b4 * P^2\right)$$

- Diffusion

$$\vec{j} = -D_{eff}\,\overrightarrow{\nabla}\,c \quad \text{with} \quad D_{eff} = D_0(T).\varphi.\frac{1}{\tau}$$

Only in water;

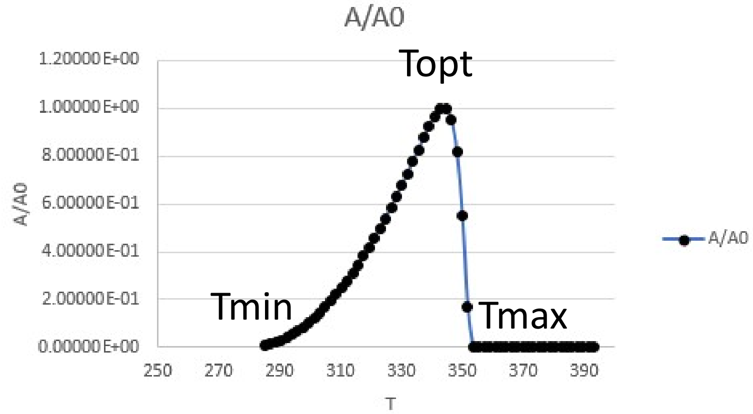
low solubility & low D_0 ➡ limited flux

- **Alteration**

$$\frac{dx_{H2}}{dt} = -A\,x_{H2}$$

with

$$A = A_0 * \left\{\frac{T - Tmin}{Topt - Tmin}.\frac{(1 - e^{c(T-T\quad)})}{(1 - e^{c(Topt-Tmax)})}\right\}^2$$



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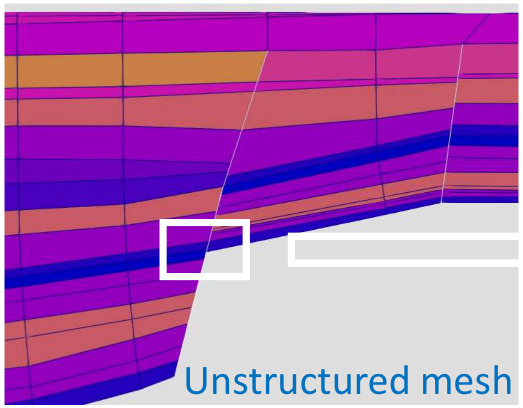
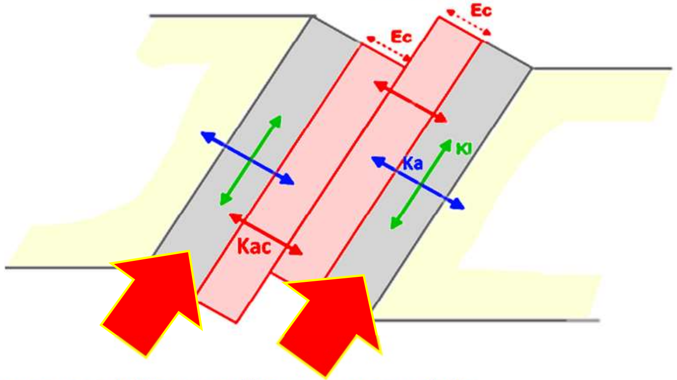
FOCUS ON USEFUL FUNCTIONNALITIES

- Source terms:
  - Thermogenic
  - Imposed concentration
  - Imposed input gas rate (kg/Myrs)
  - Imposed input flow rate with imposed concentration

- Fault flow modeling:





Imposed input flow rate with imposed concentration

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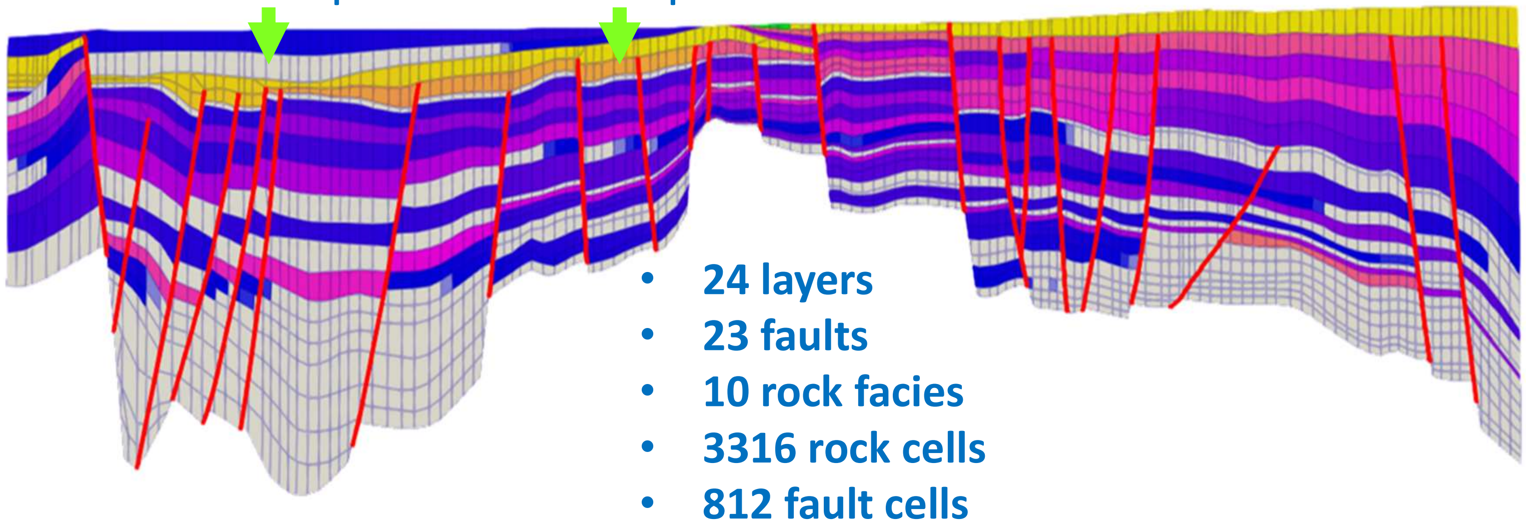
APPLICATION EXAMPLE

NEW ENERGIES

Potential cap rock

Aquifer

7000 m



- **24 layers**
- **23 faults**
- **10 rock facies**
- **3316 rock cells**
- **812 fault cells**

142 km

Permeability (Darcys)

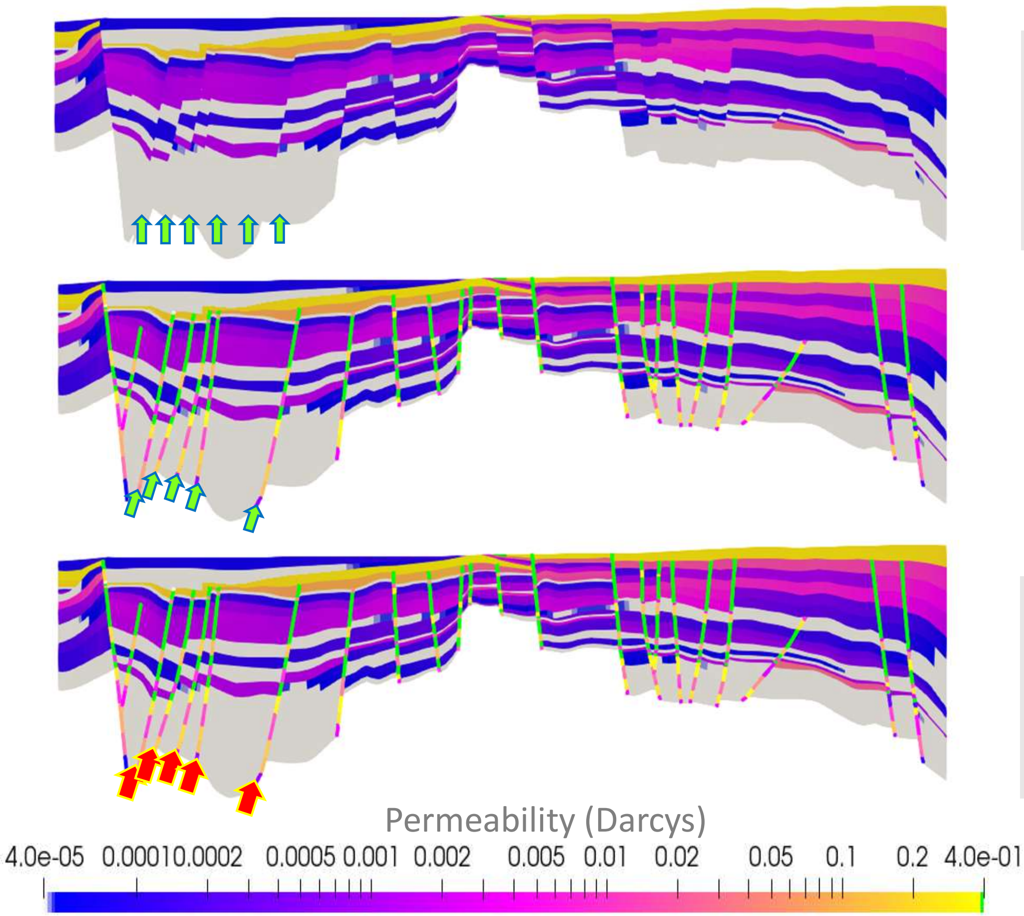
Present

K	Ages	Geological Units/Horizons
24	0.0000	Top Sediment
		Top_Sed
23	10.0000	
		Post_Jurassic
22	15.0000	
		Yarragadee_1
21	20.0000	
		Yarragadee_2
20	25.0000	
		Yarragadee_3
19	30.0000	
		Yarragadee_4
18	35.0000	
		Yarragadee_5
17	40.0000	
		Yarragadee_6
16	45.0000	
		Top_Cadda
15	50.0000	
		Top_Cattamarra_1
14	55.0000	
		Cattamarra_2
13	60.0000	
		Top_Eneabba
12	65.0000	
		Eneabba_2
11	70.0000	
		Eneabba_3
10	75.0000	
		Top_Lesueur
9	80.0000	
		Top_Woodada_1
8	85.0000	
		Woodada_2
7	90.0000	
		Top_Kockatea_1
6	95.0000	
		Kockatea_2
5	100.0000	
		Kockatea_3
4	105.0000	
		Base_Kockatea_1
3	110.0000	
		Base_Kockatea_2
2	115.0000	
		Top_IRCM_1
1	120.0000	
		IRCM_2
	150.0000	Top Basement

150 Myrs

3 SCENARIOS

NEW ENERGIES



- A geologic-time-scale system
- **Neutral faults**
- Injection rate = 800l/year, 90ppm, starts at 50 Myrs

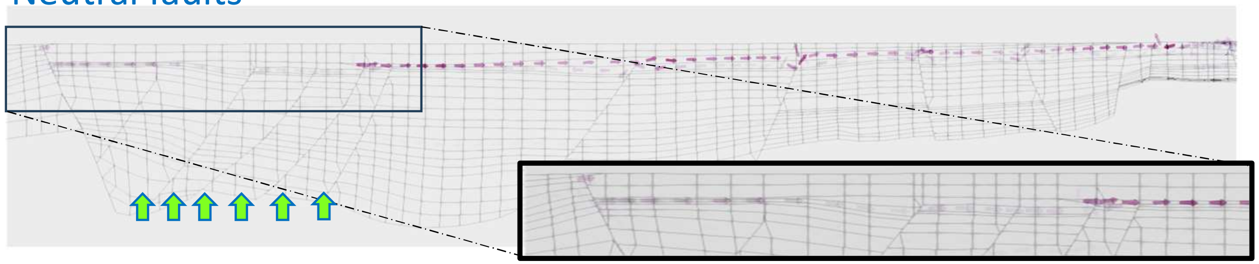
- Same as above, but **enhanced permeability faults**
- $K_{faults} = K_{facies}$ X 10000
- Fluid is injected at fault roots

- Same as above but a **dynamic system**
- Injection rate = 800 m^3/year, 10 ppm (160 kg H_2/year), starts at 1 Myr

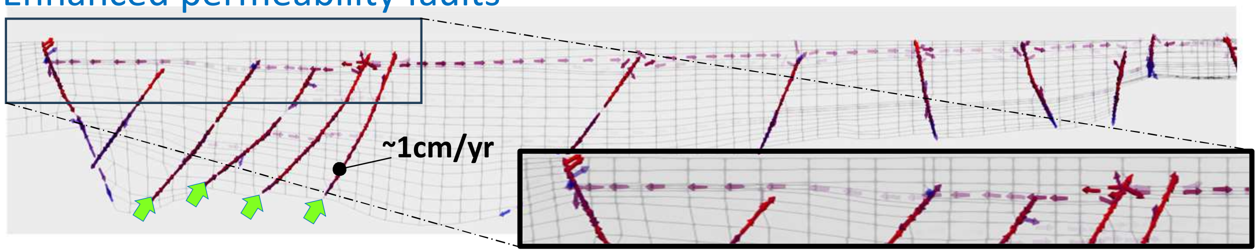
REGIONAL HYDRODYNAMISM, **WATER VELOCITY**

NEW ENERGIES

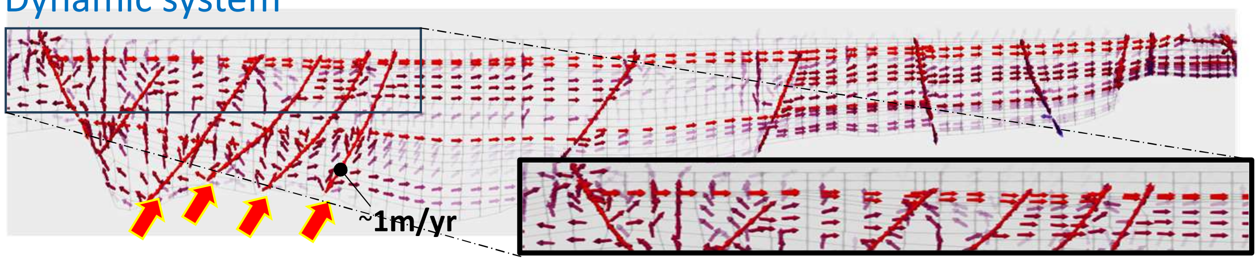
Neutral faults



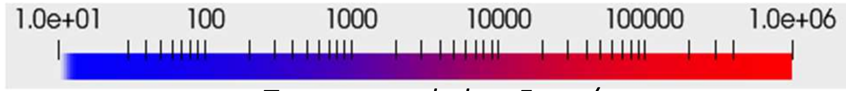
Enhanced permeability faults



Dynamic system



Water Darcy velocity (m/Myrs)



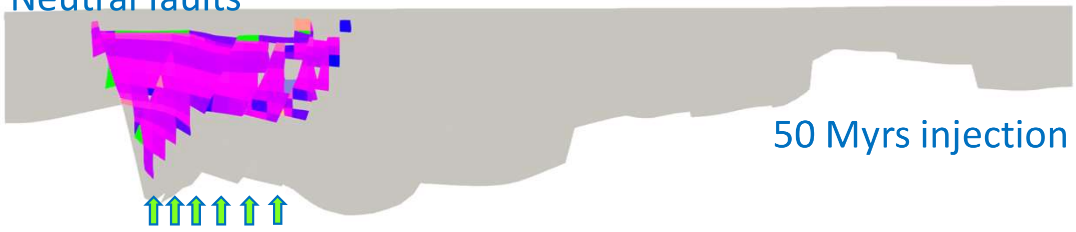
Transparent below 5mm/year

- Regional hydrodynamism is **very sensitive to faults properties**
- Regional hydrodynamism is **very sensitive to the hydrothermal influx**, even if it is very small at 1rst glance

Energies nouvelles

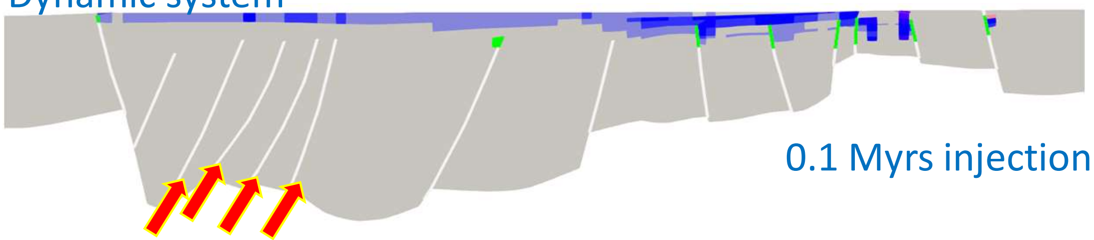
FREE-PHASE HYDROGEN **SATURATION**

Neutral faults



Enhanced permeability faults

Dynamic system



Cell vapor saturation

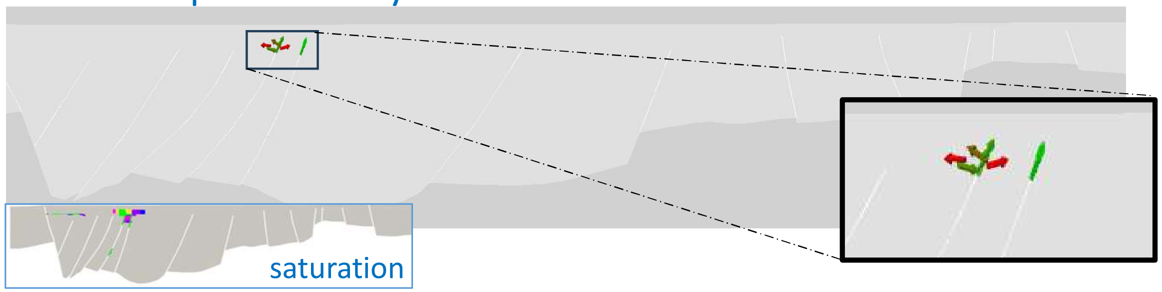
- Vapor accumulates below the cap rock in the geologic time scale scenarios
- High vapor saturations observed only at fault terminations in the dynamic system
- **Very different vapor-phase hydrogen distributions** in the 2 systems

FREE PHASE FLOW RATE

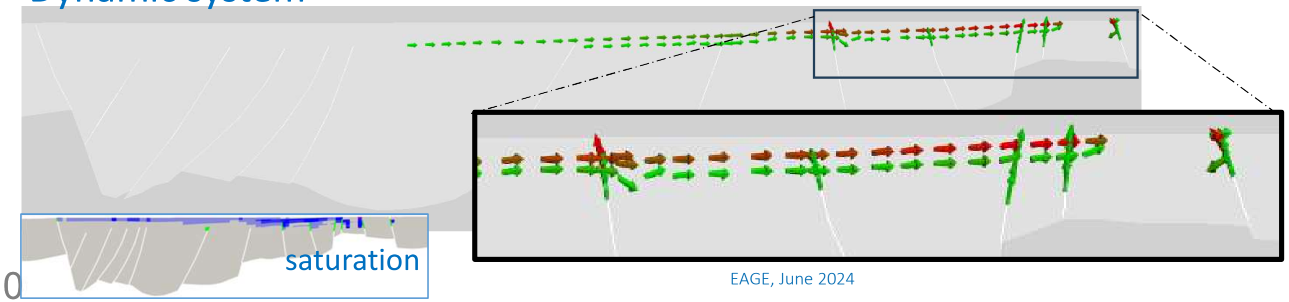
NEW ENERGIES

Neutral faults

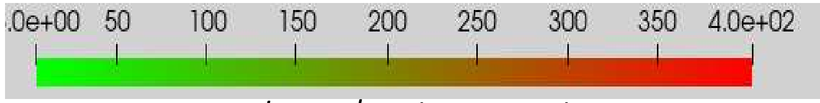
Enhanced permeability faults



Dynamic system



Flux of H_2 vapor (g/m²/year)

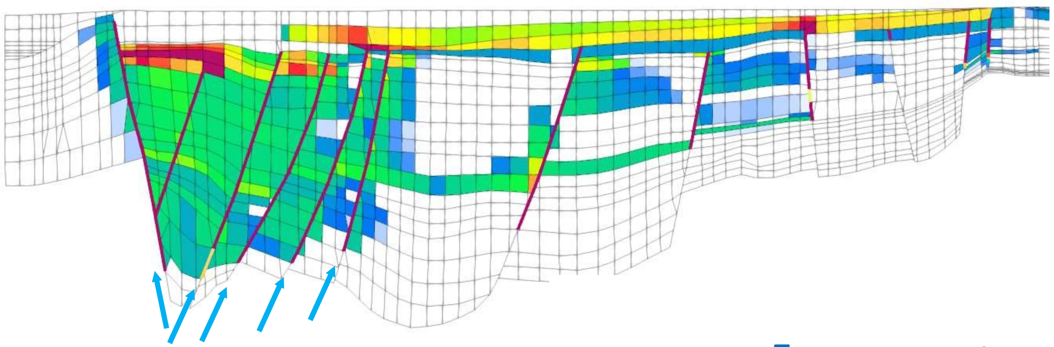


Low values transparent

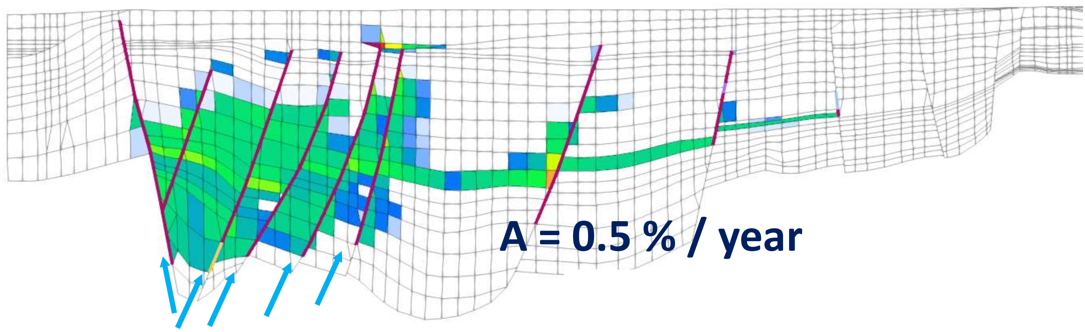
- Diffuse and very low vapor flux with neutral faults
- No significant vapor flux in the western reservoir inscenario #2
- The dynamic scenario gives significant **vapor-phase hydrogen flux above 400g/m²/year**

MICROBIAL DEGRADATION

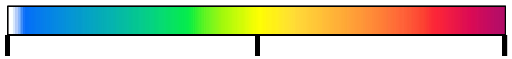
Dynamic system with an increased hydrogen supply, **no microbial degradation**



with microbial degradation



Free gas saturation in %



- No more free gas in the biotic interval with a degradation rate > 0.5% per year

CONCLUSION

- H_2 migration is very different from HC migration
- It is more difficult to have an intuition of the migration paths:
  - Very sensitive to the water « plumbing system », especially fault flow properties
  - May migrate over long distances by « dissolved flow »
  - Transition from « dissolved flow » to vapor flow controled by gas concentration in the water, pressure, temperature and salinity
- Basin simulation is a tool which integrates all these parameters and physical processes
- Although not yet predictive, it is a **useful tool to assess different hypotheses about H_2 sources, migration paths, H_2 accumulations and recharge rate**

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