Downward migration
Theory and application to **Najmah-Marrat** petroleum system

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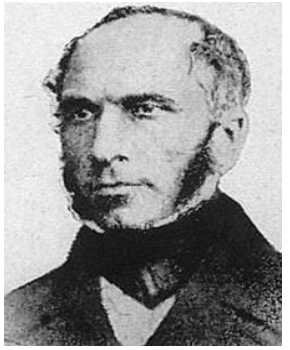
Downward Migration: What is that?

- Hydrocarbons accumulate in a layer which is structurally “below” the Source Rock, in close contact with it or not.
- It’s an ever-recurring issue, still debated among the community.
- Using **TemisFlow** on 2 examples, we will see that:
  - in some cases the migration is really vertical and downward,
  - whereas in other cases it is rather lateral migration….
  - And very often it’s both!
- Let’s start with some physical and geological “concepts”…
  - Migration’s first rule = **nothing is impervious given enough time.**
  - Migration’s second rule = **in geology we have a lot of time!**
  - Migration’s third rule = **fluids are lazy, the flow takes the easiest path.**

And all this is explained by the Darcy Law…

Fluid Flow - **Darcy's Law**

- **Polyphasic** Darcy's law for water and hydrocarbons flows in porous media
- Relates the **flow rate Ui** of phase i to the different driving forces (calculation of HCs and water movements within the porous media)



Henry Darcy (1803-1858)

Intrinsic permeability K=f(Φ, litho)

Relative permeability phase i kr_i=f(sat,Φ, litho)

$$\vec{U}_i = -\overline{\overline{K}} \frac{kr_i}{\mu_i} \left(\vec{\nabla}\left(P - \rho_w g z\right) + \vec{\nabla}\left(Pc\right) - \left(\rho_w - \rho_i\right) g \vec{\nabla}\left(z\right) \right)$$

(FLUID FLOW)

Viscosity phase I
μ=f(T,fluid)

Pore Pressure

Capillarity

Buoyancy

Some will say…

Maybe yes…

…Maybe not!

In fact the buoyancy is the only force that *usually* drives hydrocarbons upward (HCs are less dense than formation waters).
The orientation of the other forces is variable.

Equations to solve in the numerical model

$$\frac{\partial \sigma_z}{\partial z} = \left(\varphi\rho_f + (1-\varphi)\rho_s\right)g$$ **Mechanical equilibrum**

$$\frac{\partial \varphi}{\partial t} = -\beta(\varphi,\sigma)\frac{\partial \sigma}{\partial t} - \alpha(\varphi,\sigma)\sigma$$ **Elasto-visco-plastic law**

$$\frac{\partial}{\partial t}(\rho_w S_w \varphi) + div(\rho_w S_w \varphi \overrightarrow{V_w}) = \rho_w q_w$$ **Water mass conservation law**

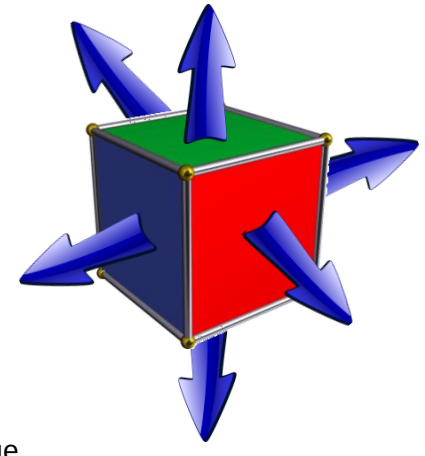
$$\frac{\partial}{\partial t}(\rho_o S_o \varphi) + div(\rho_o S_o \varphi \overrightarrow{V_o}) = \rho_o q_o$$ **HC mass conservation law**

$$\overrightarrow{U_w} = \varphi S_w(\overrightarrow{V_w} - \overrightarrow{V_s}) = -\frac{\overline{\overline{K}} Kr_w}{\mu_w}\left(\nabla P_w - \rho_w \overrightarrow{g}\right)$$ **Darcy Law for the water**

$$\overrightarrow{U_o} = \varphi S_o(\overrightarrow{V_o} - \overrightarrow{V_s}) = -\frac{\overline{\overline{K}} Kr_o}{\mu_o}\left(\nabla(P_w + Pc) - \rho_o \overrightarrow{g}\right)$$ **Darcy Law for the oil**

$$S_w + S_o = 1$$ **Closure law**

At each iteration, these laws are simultaneously computed in each cell of the discrete 3D model. Transfers may occurs in 6 directions.



avec : $\alpha \in \{s, w, o\}$ *(s = solide, w = eau, o = hydrocarbures)*

- φ *porosité du milieu*
- q_α *terme source de la phase α*
- $\overrightarrow{V_\alpha}$ *vitesse de la phase α*

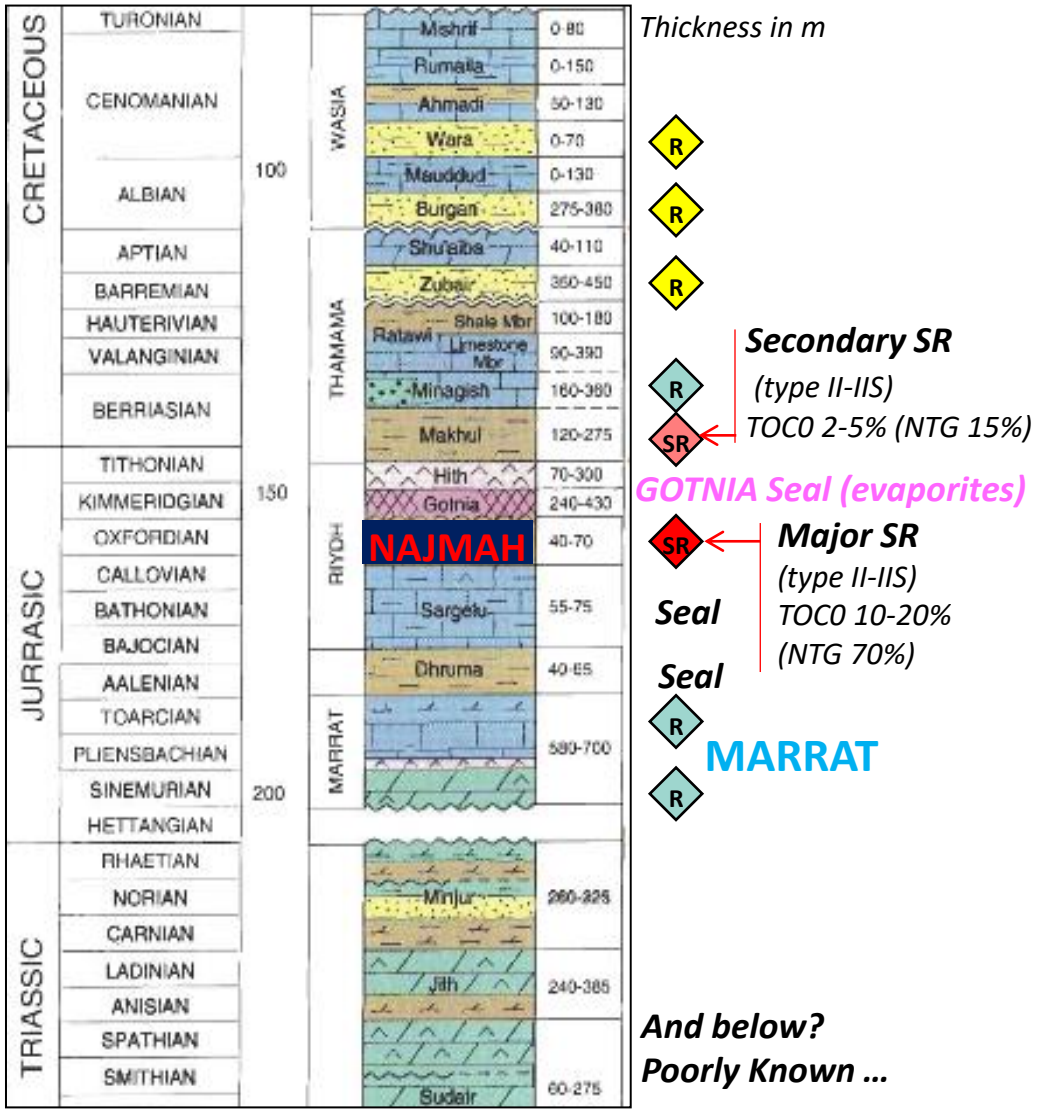
- ρ_f densité moyenne du fluide telle que $\rho_f = \rho_w S_w + \rho_o S_o$
- σ_z contrainte totale, supposée verticale
- σ contrainte effective telle que $\sigma = \sigma_z - P_f$

e.g. Pegaz-Fiornet, IFPen, 2011

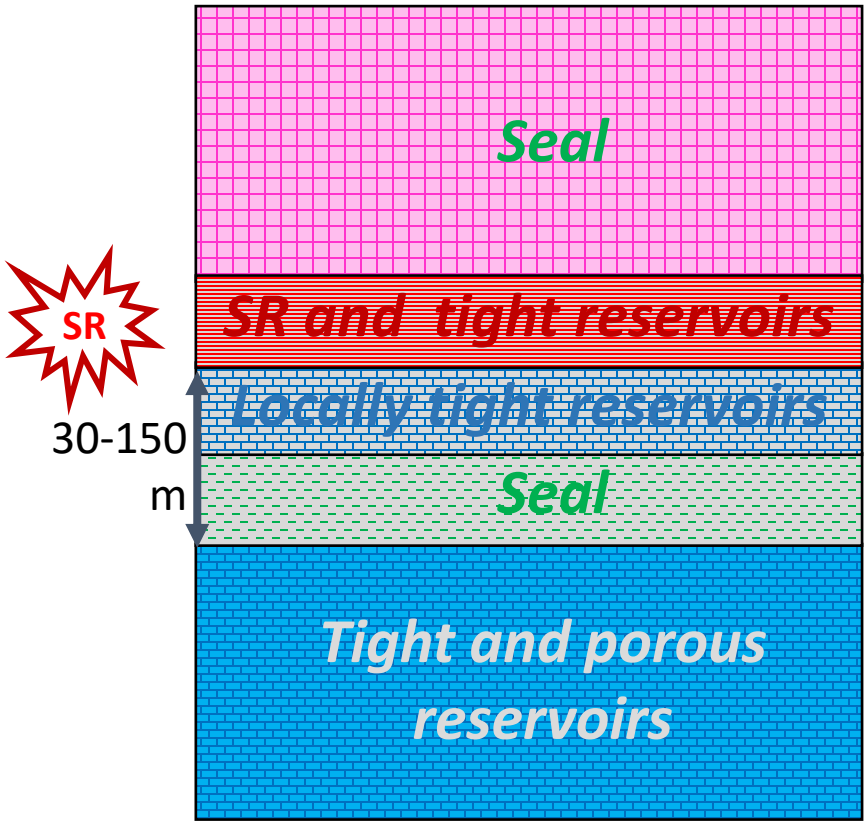
Case Study from **Kuwait**

- **Objective of the study:**
  Source rock characterization, pore pressure prediction, play fairway analysis including HC masses estimations.
- G&G study (petrophysics, sedimentology, geophysics, geochemistry, etc.)
- Basin scale petroleum system modeling (3D)

Marrat carbonates contains significant oil & condensates resources.
Where is the SR?



Environment of the Najmah SR



Gotnia: Thick evaporites (salt + anhydrite & carbonate stringers)

Najmah: Organic-rich mudstone and tight musdtone (HC saturated); High capillary pressure due to the HC Sat.

Sargelu: Tight mudstone (and wackestone-packstone)

Dharuma: Calcareous shale (organic-lean)

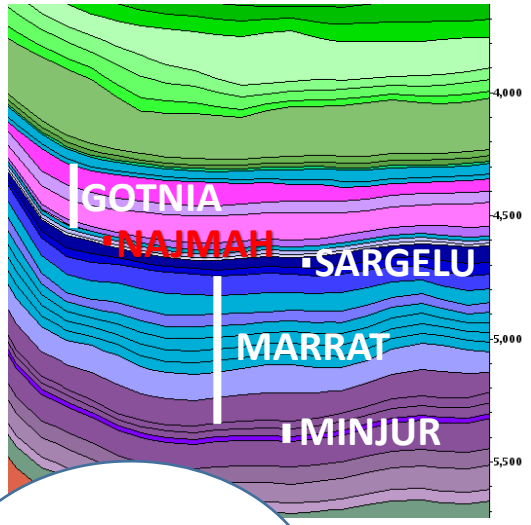
Marrat: Mostly tight carbonates, anhydrite, shale, with local intercalation of porous dolostone or grainstone (Best reservoir, mainly in the Middle Marrrat)

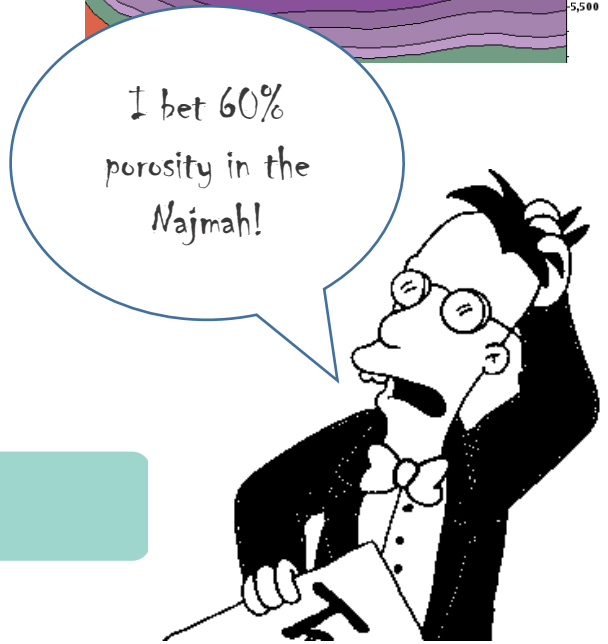
Both lateral and vertical migrations are difficult

HC Mass Balance in the Najmah SR

According to the Petroleum System model:

- The **Najmah SR is mature** (Type II-IIS, VR0=0.7-1.1%). It has **generated hundreds billion barrels** within the study area, mostly oils and condensates.
- Generated HCs take more space than the initial kerogen.
- For accumulating all these HC, the Najmah should have a **porosity of 60-70%**... Obviously absurd.
- It is estimated that about **10% of the HC is remaining** in this SR, which is consistent with geochemical (S1) and petrophysical data (PHI about 4-8%, including organic porosity).
- Only small quantities can be stored in the tight mudstones of Upper Najmah and Sargelu Fms.



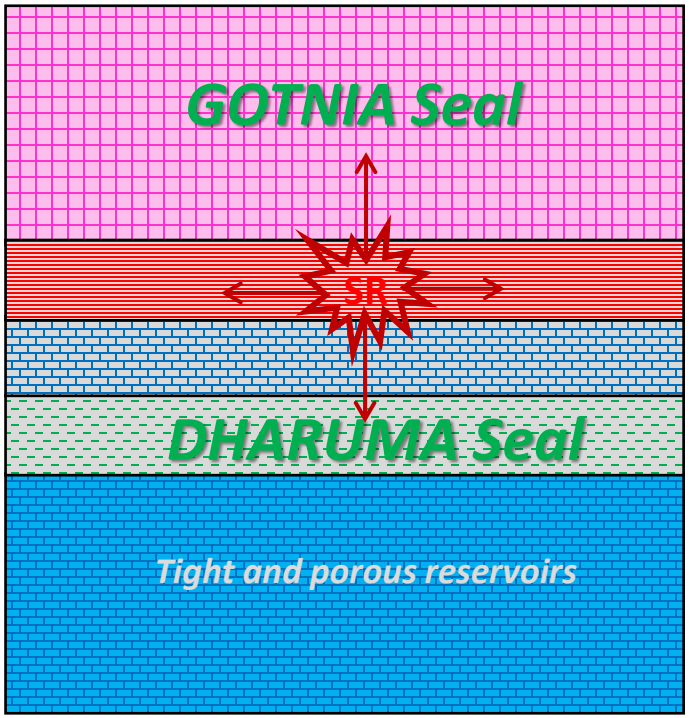


Where are these hydrocarbons?

Gotnia vs. Dharuma: Which is the **Best Seal**?

NAJMAH SR

Orientation & direction of the HC expulsion and migration?



Hydrocarbons are expelled…

Obviously…

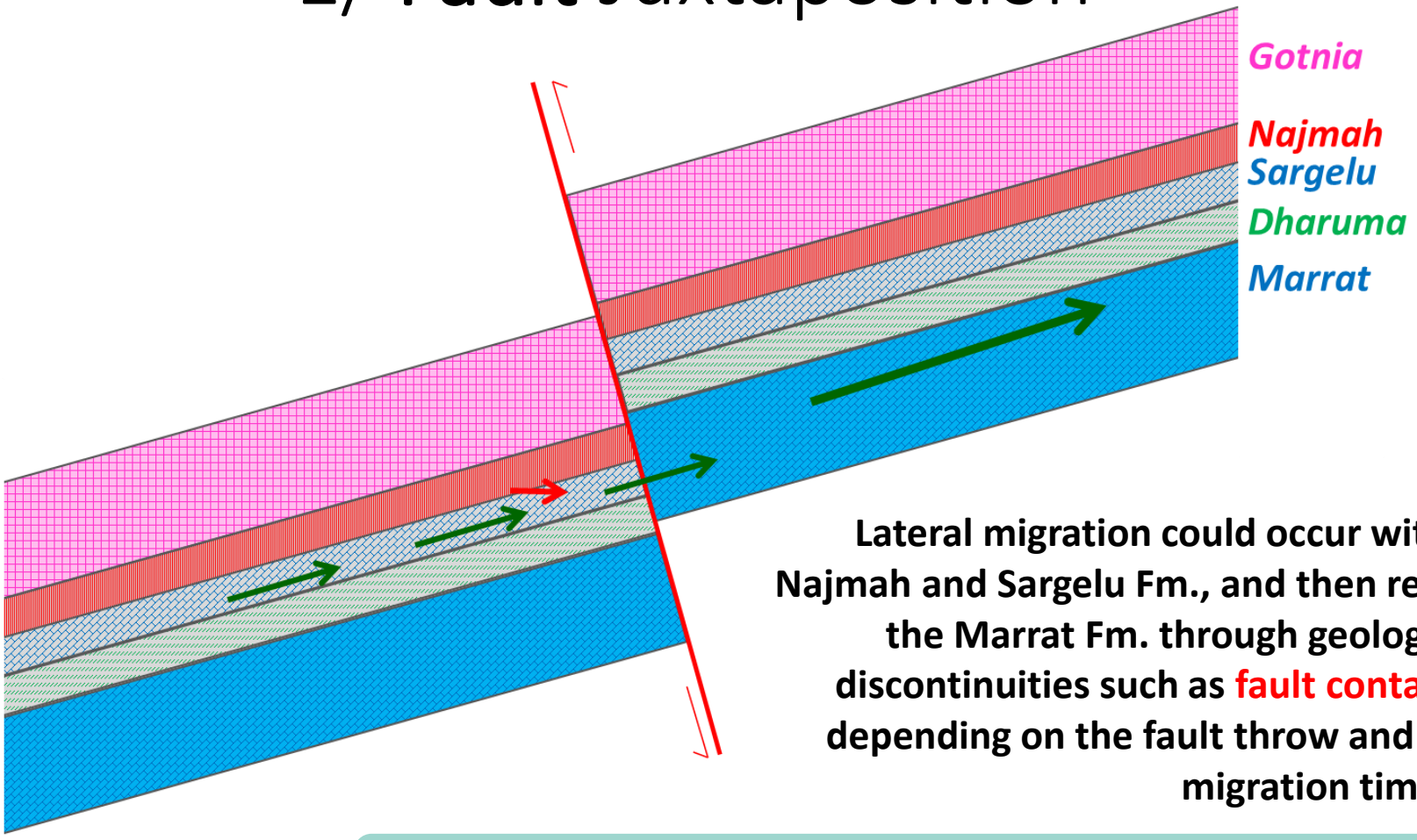
GOTNIA Salt!

Is Downward Migration Possible?

Need a « nuclear weapon » to explain downward migration?

We will see that!

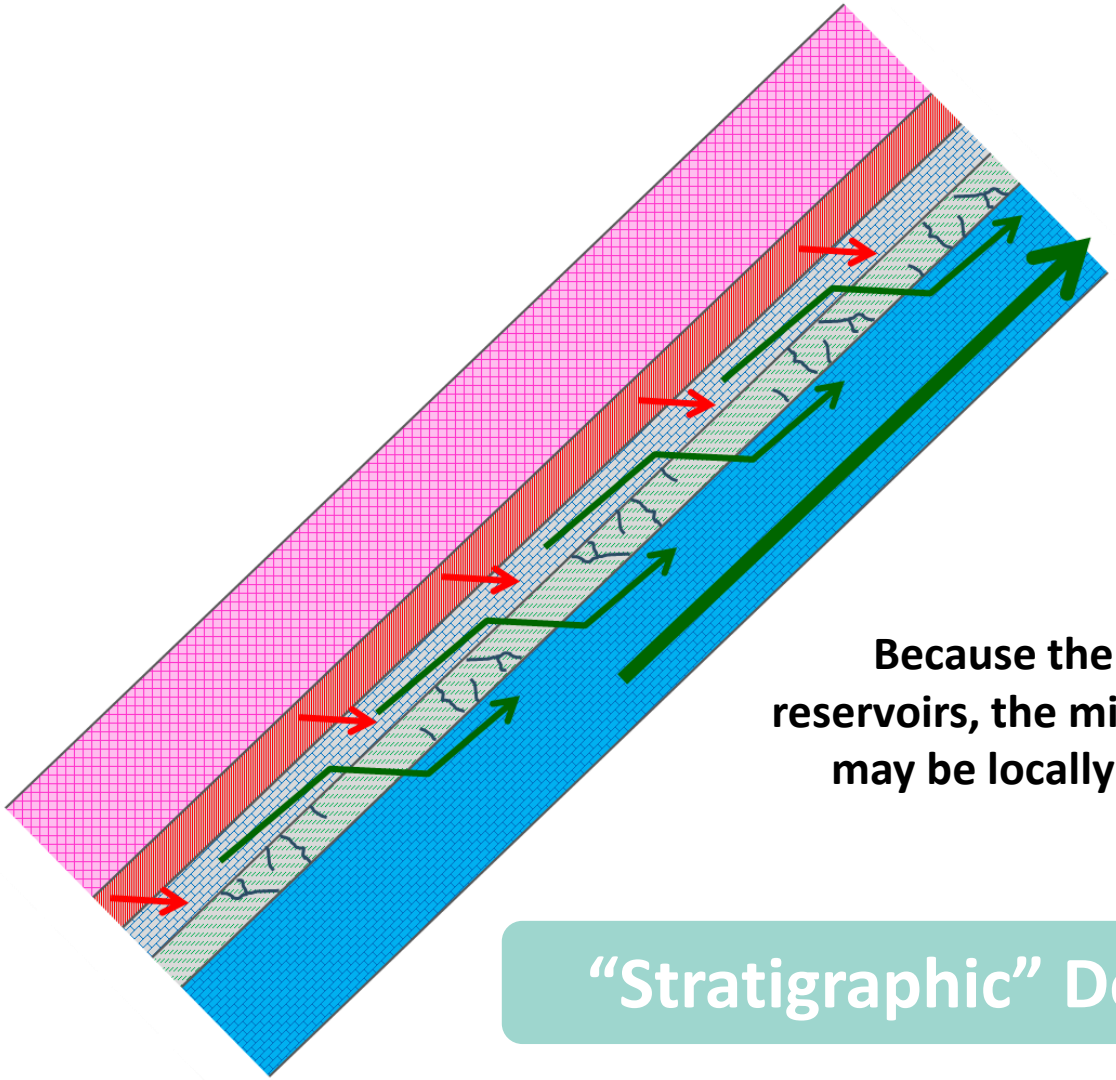
1/ **Fault** Juxtaposition



Lateral migration could occur within Najmah and Sargelu Fm., and then reach the Marrat Fm. through geological discontinuities such as fault contacts, depending on the fault throw and the migration timing.

"Stratigraphic" Downward Migration

2/ **Steep Slope** Juxtaposition



Fractures in Dharuma and Sargelu, even if they are scattered and small, may help the process.

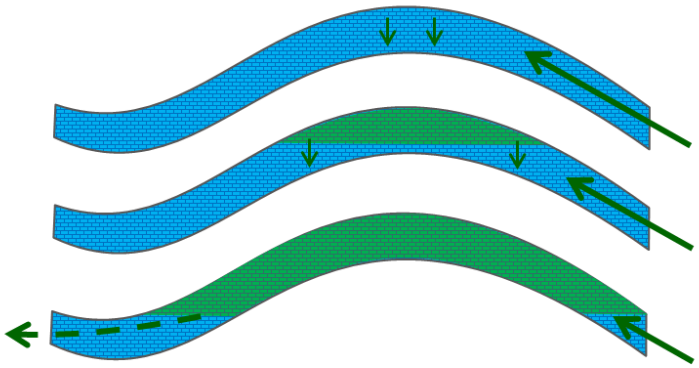
The oil saturation in Dharuma and Sargelu may be localized, low in average, difficult to observe.

In this example, no need of faults. Because the Najmah and Sargelu Fm. are tight reservoirs, the migration through the Dharuma Fm. may be locally easier, especially where there are fractures.

"Stratigraphic" Downward Migration

3/ Fill and Spill

« Classical » fill and spill of a reservoir layer



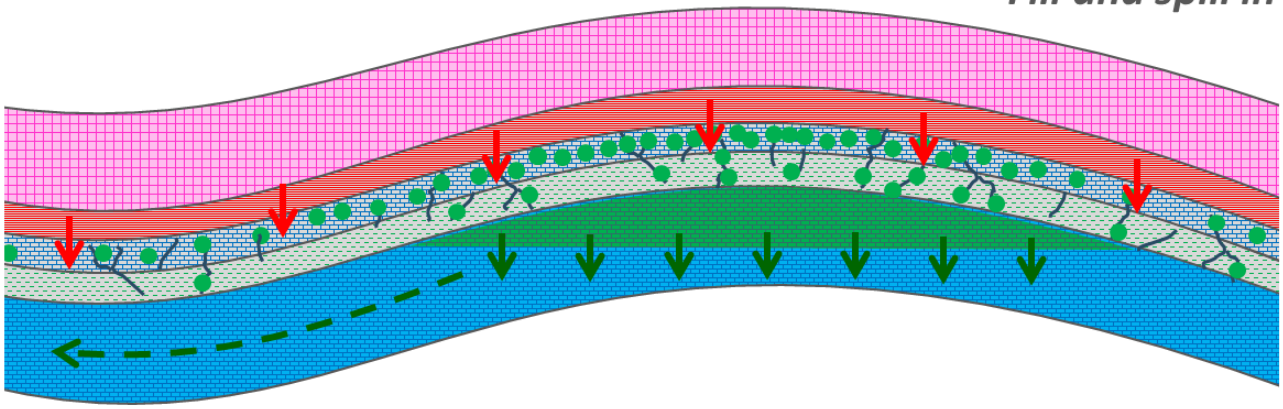
The oil saturation in Dharuma and Sargelu may be localized, low in average, difficult to observe.

It's a key process in Najmah/Marrat system.

It likely occurs in the Marrat Fm.

Hard way but… 100 My for completing it!

Fill and spill in case of low porous facies



No escape way in the Gotnia

Limited porous space in Najmah Sargelu-Dharuma Fms.

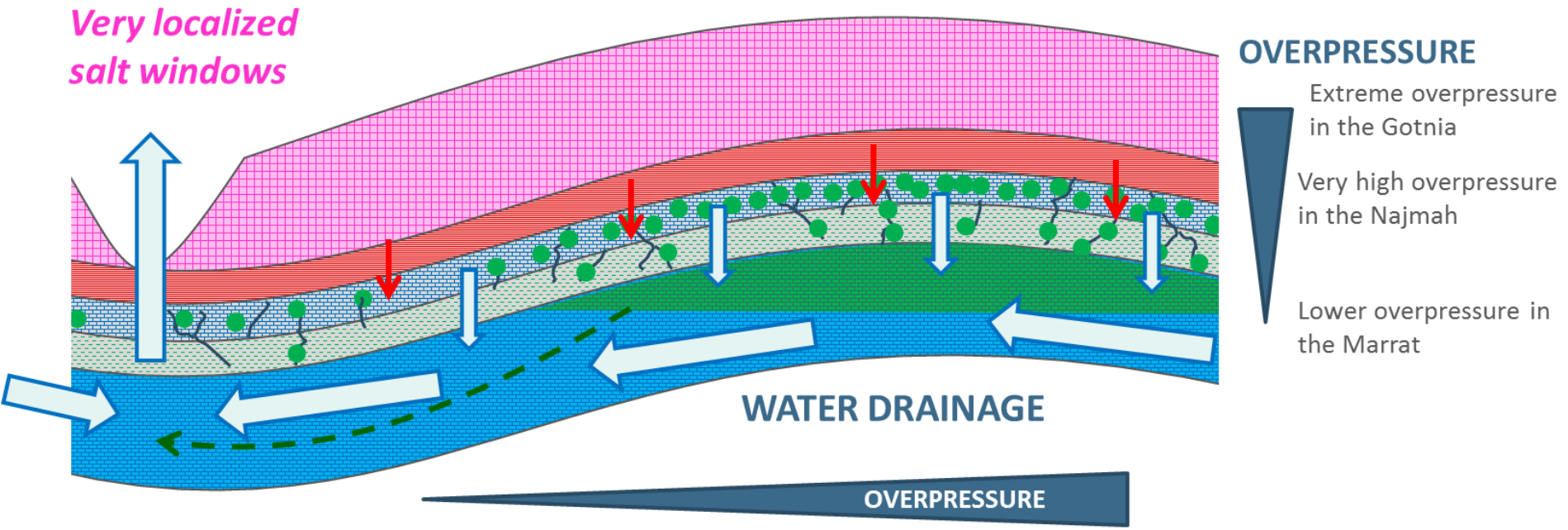
Progressive filling of the available porous space until the oil reaches the Marrat

"Structural" Downward Migration

4/ Pressure Gradient and Water Flow

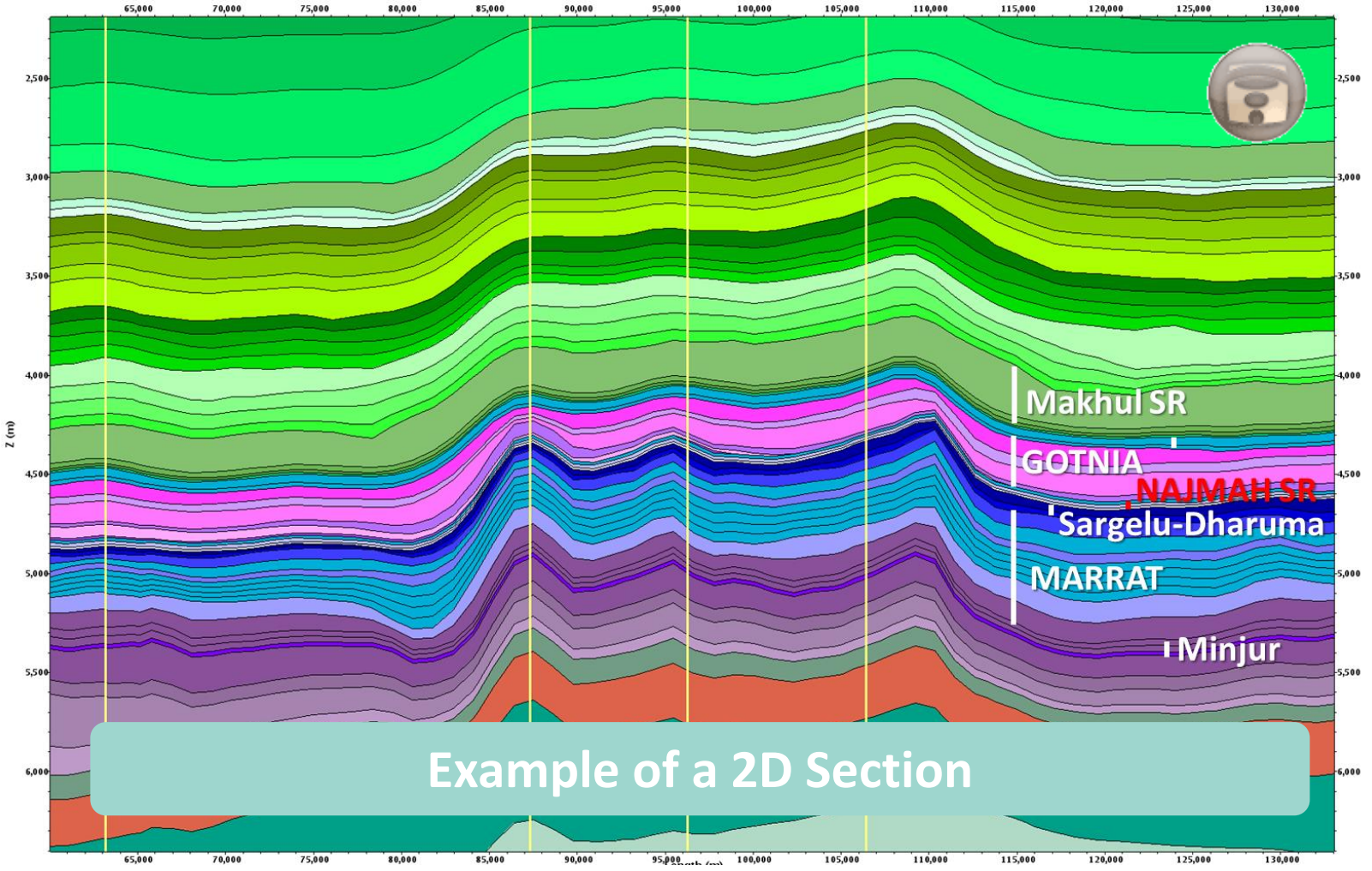
The pressure field suggests the existence of slow water flows (weak hydrodynamism) which converge toward localized salt windows. The carrier bed would be the Marrat Fm.

This water flow enhance the hydrocarbon migration.

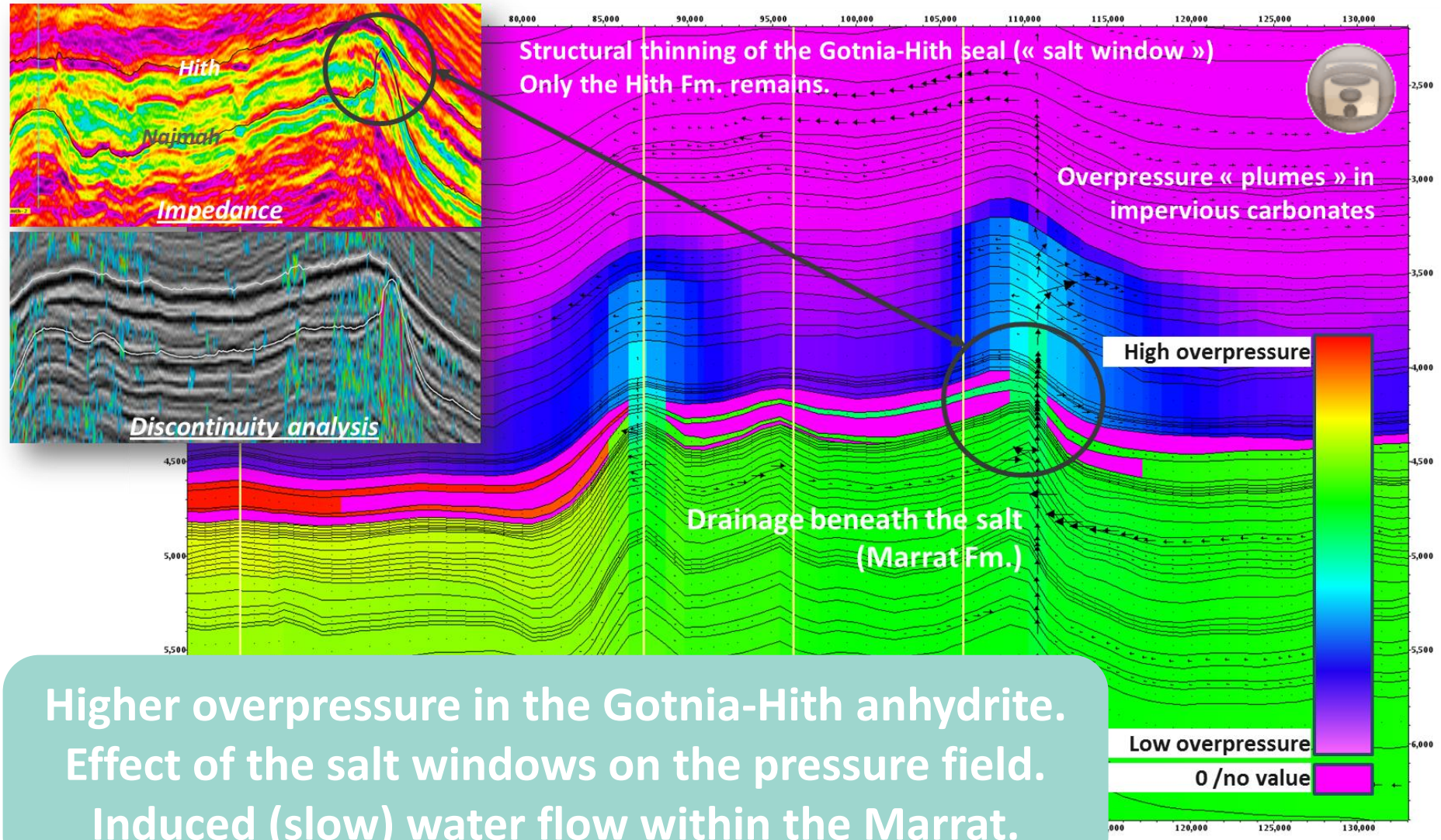


"Structural" Downward Migration

Now, what doesTemisFlow say?

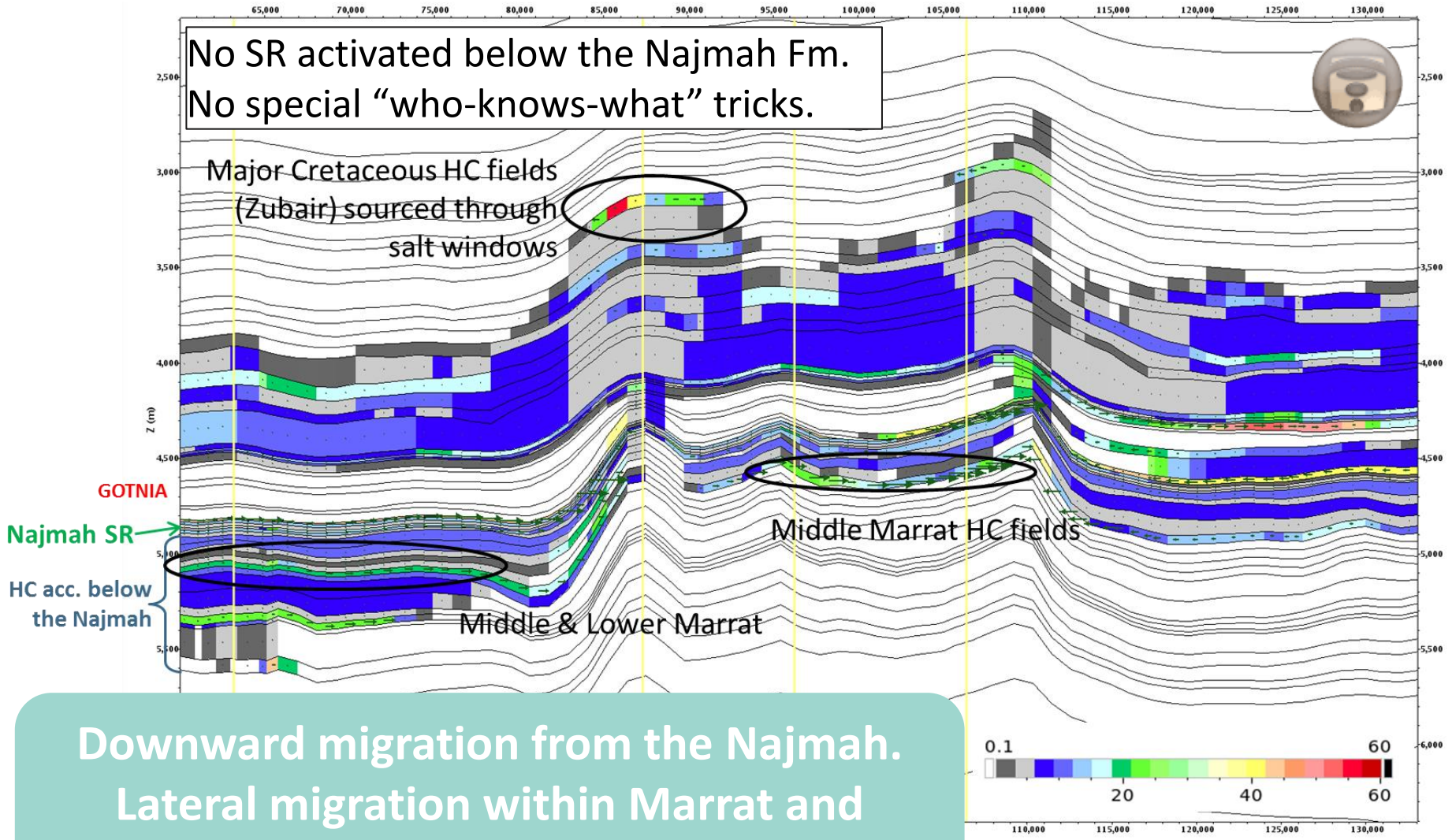


Pressure Field – Water Flow



Higher overpressure in the Gotnia-Hith anhydrite.
Effect of the salt windows on the pressure field.
Induced (slow) water flow within the Marrat.

HC Saturations – HC Flow



Downward migration from the Najmah. Lateral migration within Marrat and Najmah.

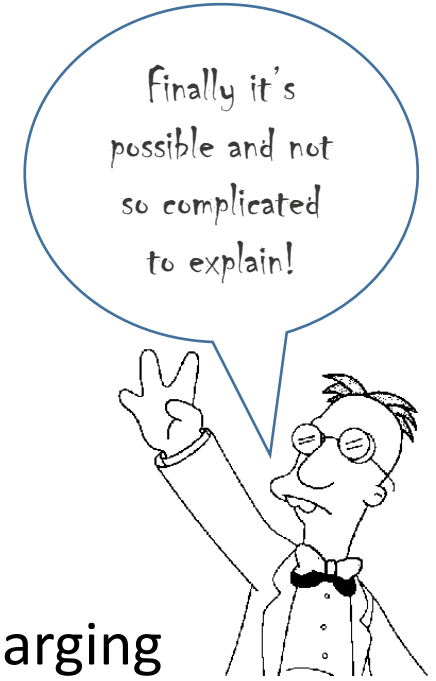
Other Geochemical Evidences

- There is **no other significant SR layer** identified in Marrat and Minjur Fms. Deeper potential SRs would be fully in the gas window, whereas Marrat reservoirs rather contain oils and condensates (33-47 API in general).
- The **model** gives correct HC composition trends.
- Najmah SR extracts and Marrat oils have **compatible molecular signatures.**
- Mixing with other hydrocarbons – deeper oils and gas – is possible, but only in minor proportions, and not everywhere. It may explain abnormally high GOR observed in some wells.

More over **the global HC mass balance** accumulated vs. generated can be explained by the **Najmah petroleum system alone** (3D modeling), at least in the Jurassic.

Migration Results from Subtle Equilibriums

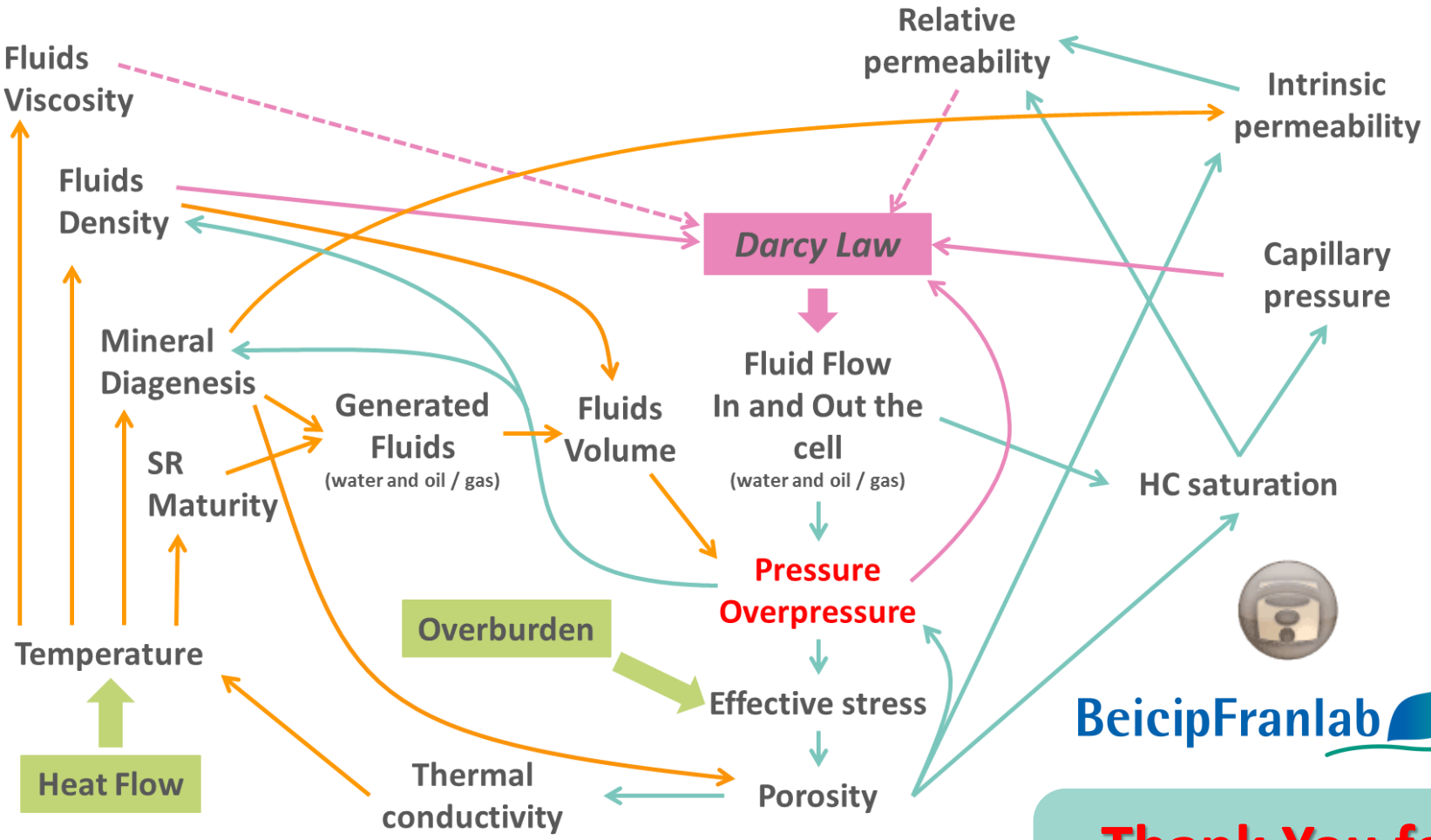
- Maybe there is not always “real” downward migration, but oil can easily migrate in stratigraphically and structurally deeper horizons by many ways:
  - **Abnormal contact** (« juxtaposition through faults),
  - **Lateral migration** (rather than just vertical migration),
  - **Fill and spill,**
  - **Stimulated by pressure gradient and capillary forces...**
- All these processes are possibly acting simultaneously over million years.
- It clearly depends on many parameters.



A born-again basin modeler

- Finally, it’s mostly a question of **available space** for charging generated HCs, and of **equilibrium between different forces**. The presence of a **powerful seal** above the SR helps a lot!

Full Physics Simulator… Just for Fun!



Thank You for your Attention