TOTAL
COMMITTED TO BETTER ENERGY

RECENT WORKFLOW IMPROVEMENT FOR QUANTITATIVE 4D SEISMIC

C. HUBANS

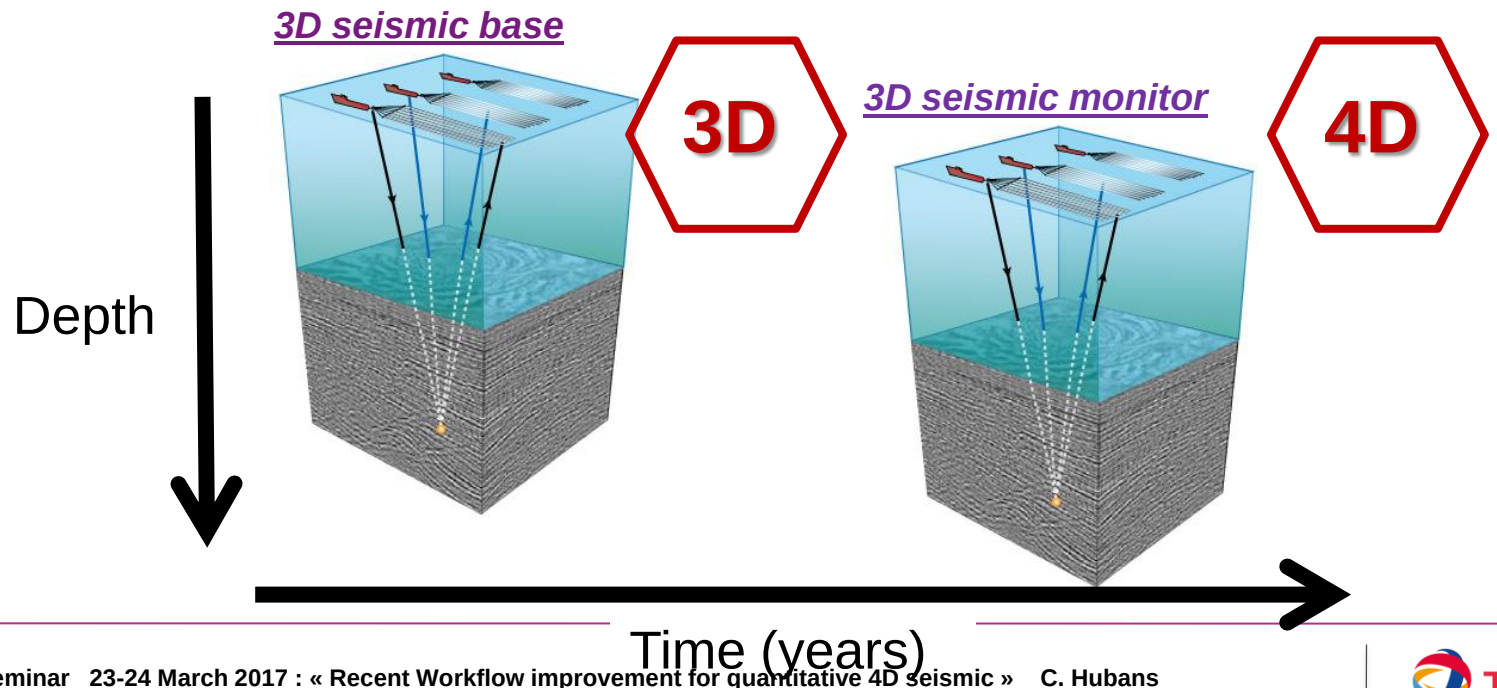
CONTENT

- 1. **What is 4D ?**
- 2. **Deep offshore success :**
- 3. **New challenges ?**
  - > 3.1 Carbonates
  - > 3.2 Complex structured area
- 4. **Conclusions on TOTAL's specificities.**

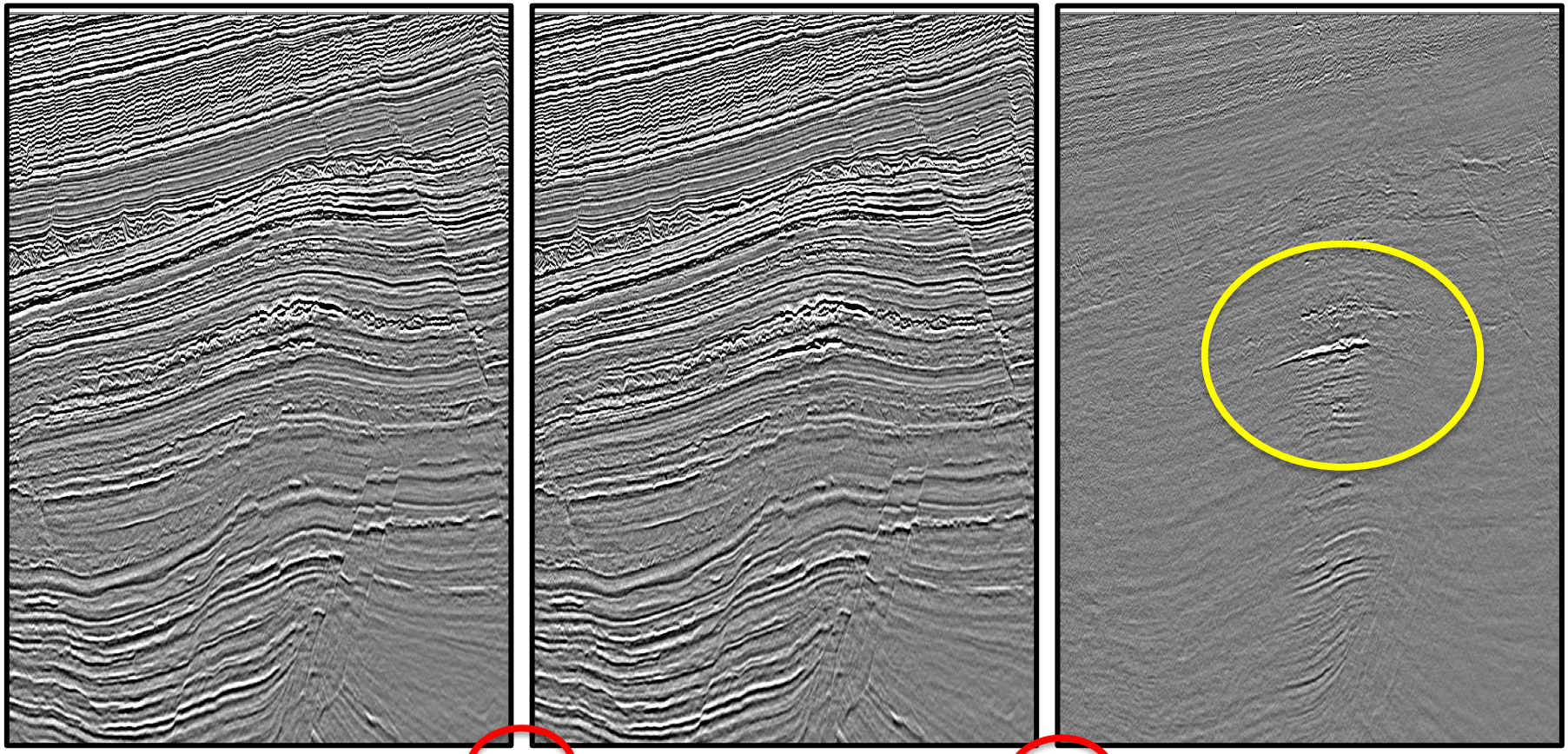
1 - WHAT IS 4D ?

WHAT IS 4D SEISMIC OR TIMELAPSE SEISMIC ?

- 4D Seismic corresponds to repeated seismic acquisition during the production of an oil field.
- Seismic acquisitions can be 1D, 2D or 3D
  - 1D seismic (VSP) = > Z or TWT
  - 2D seismic = > Z or TWT + X (or Y)
  - 3D seismic = > Z or TWT + X and Y



4D EFFECT EXAMPLE ON SEISMIC



Baseline 2011 − Monitor 2012 = 4D effect

+ 4D noise !

4D SEISMIC: WHO IS INVOLVED?

Petrophysicists
- Build RPM for 4D feasibility
- Check & update RPM with 4D

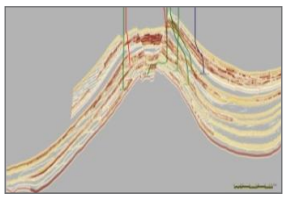
Geophysicists
- Perform 4D feasibility
- Acquire 4D seismic data
- Process 4D seismic data
- Interpret 4D seismic data

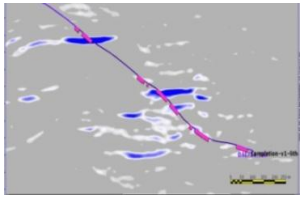
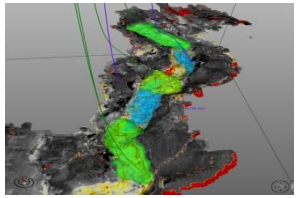
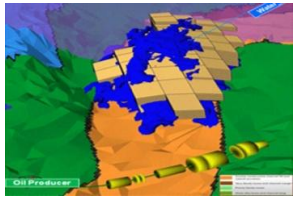
Geologists
- Participate to 4D feasibility
- Participate to 4D interpretation
- Update geological model according to 4D interpretation results

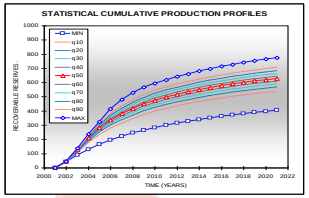
Reservoir engineers
- Define monitoring needs
- Participate to 4D feasibility
- Participate to 4D interpretation
- Integrate 4D for reservoir model update and into the dynamic synthesis

Managers
- Define monitoring needs
- Participate to 4D feasibility
- Integrate 4D inside the industrial project

4D TOTAL WORKFLOW



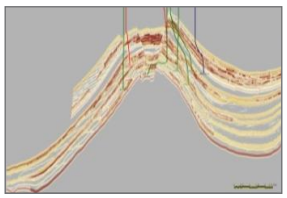




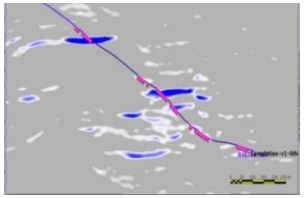
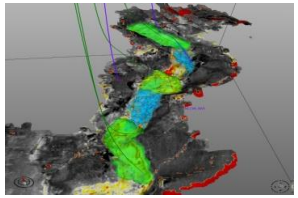
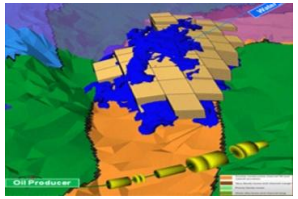


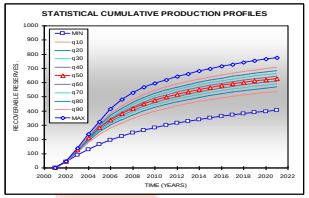
4D feasibility | 4D acquisition & processing | 4D warping & inversion | 4D interpretation | 4D integration into geomodels | 4D History Match

2 – DEEP OFFSHORE SUCCESS :

4D TOTAL WORKFLOW



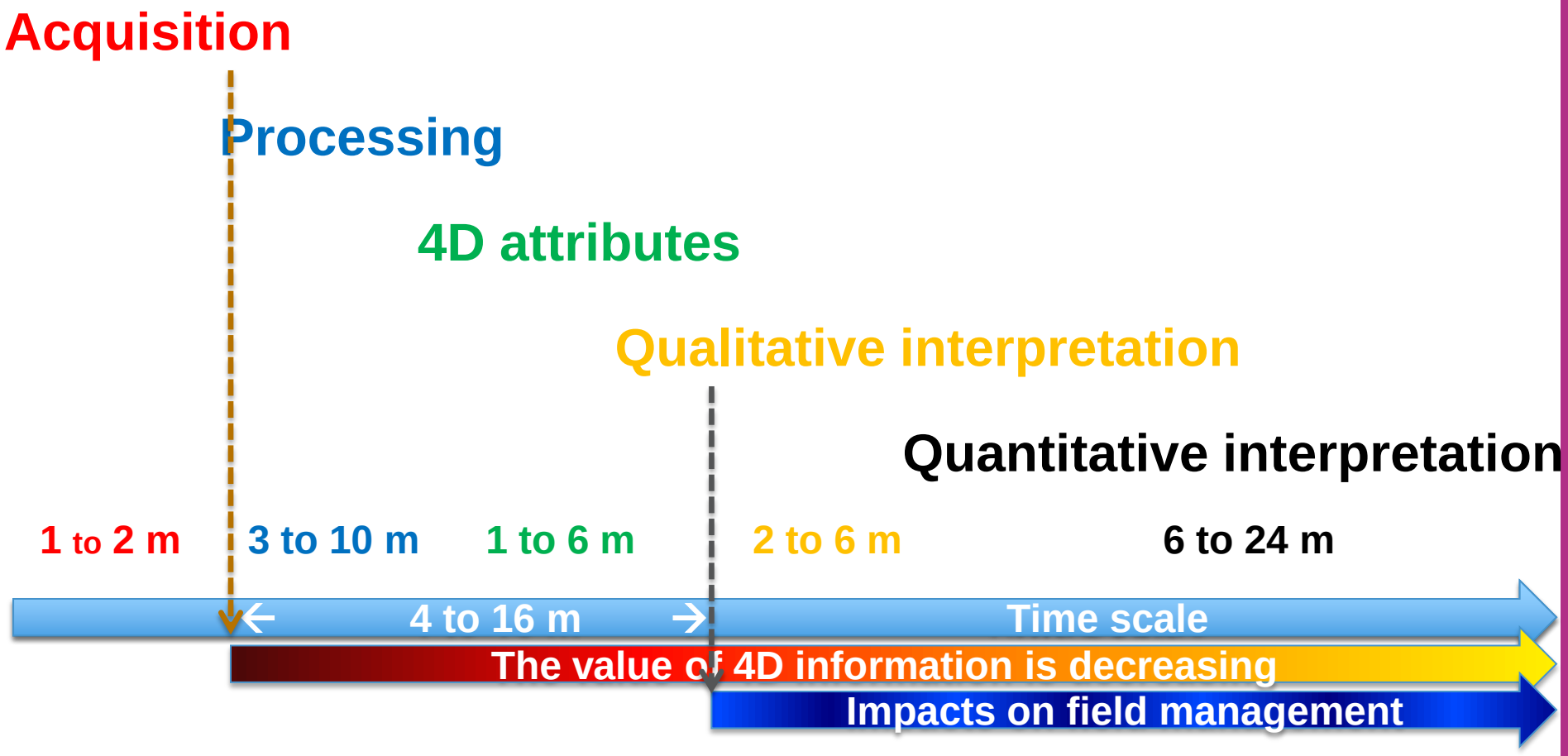






4D feasibility | 4D acquisition & processing | 4D warping & inversion | 4D interpretation | 4D integration into geomodels | 4D History Match

- **4D processing:** Several new processing approaches for different situations and to reduce costs & delay.

STANDARD 4D SEISMIC WORKFLOW



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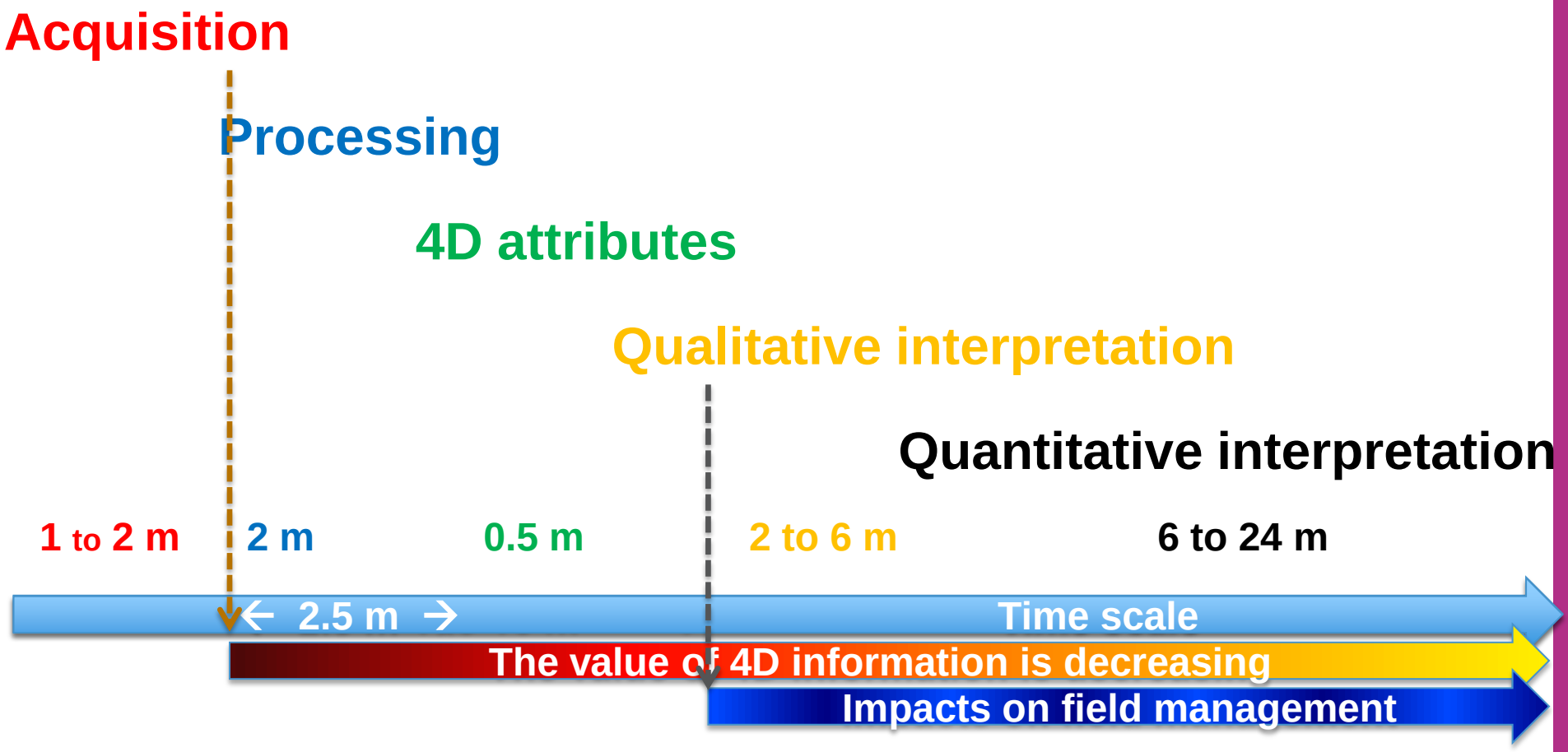
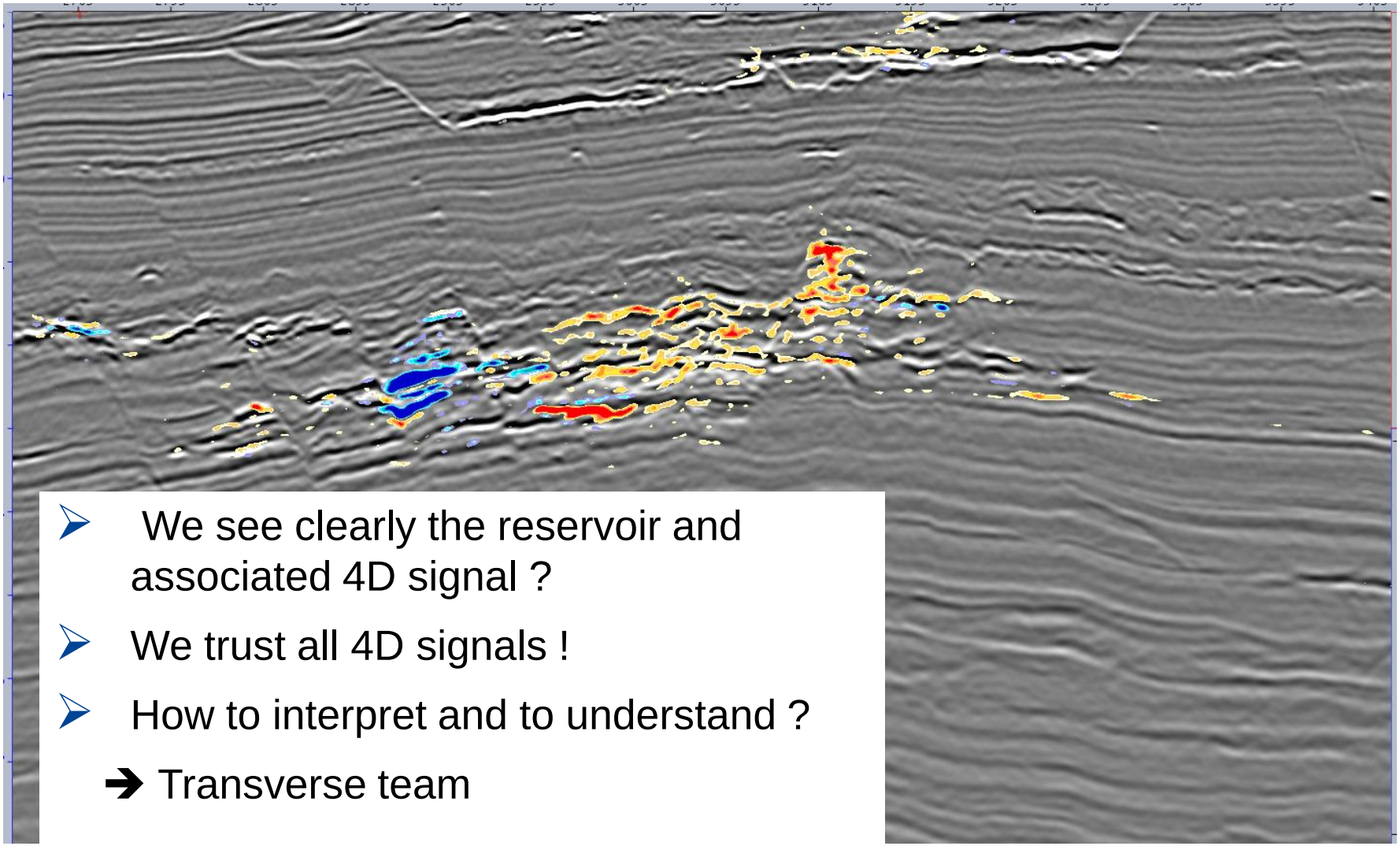


One example in deep offshore



- We see clearly the reservoir and associated 4D signal ?
- We trust all 4D signals !
- How to interpret and to understand ?

➔ Transverse team

3 – NEW CHALLENGES ?

NEW CHALLENGES FOR 4D ?

- 1. Carbonates.
- 2. Onshore fields.
- 3. Complex structural context (subsalt)
- 4. Non conventional
- And very often 2 or 3 challenges are mixted !

NEW CHALLENGES FOR 4D ?

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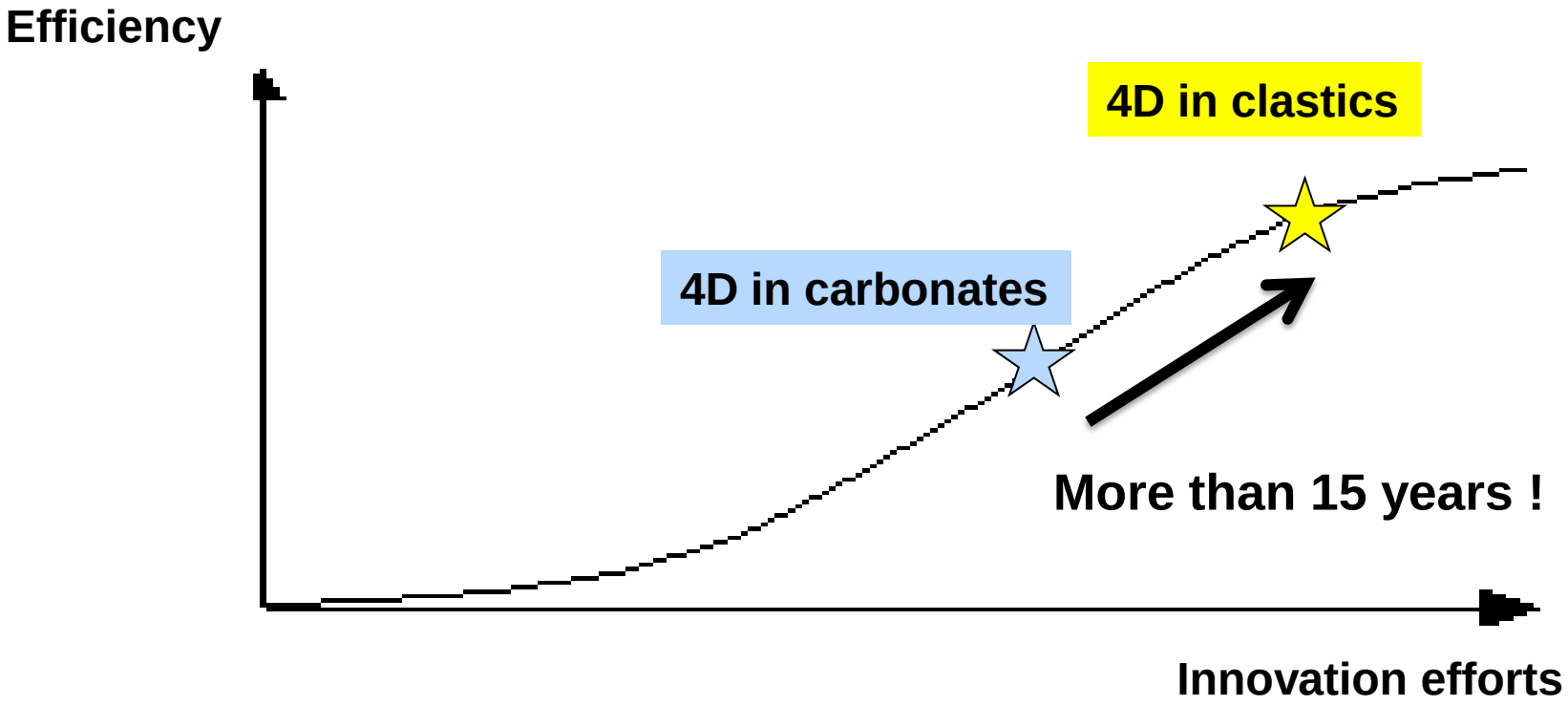
3.1 – CARBONATES

4D SITUATION TO DAY



4D in clastics

Late 80's ⇔ first acquisition
Late 90's ⇔ Many field acquisitions

4D in carbonates

Late 90's ! ⇔ feasibility studies
2005 ⇔ first field pilots
2007-16 ⇔ full field acquisitions

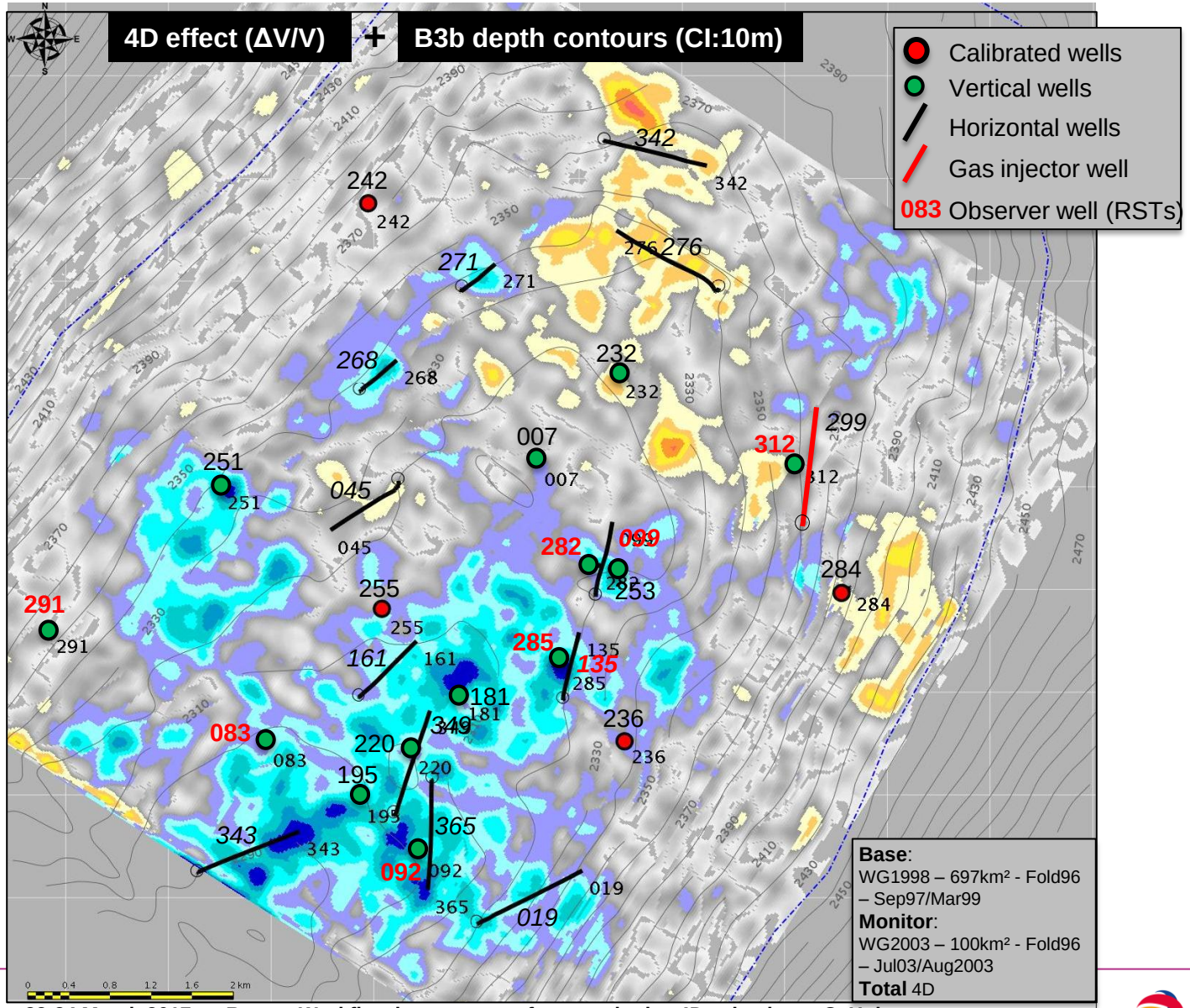
WHY CARBONATES ARE MORE DIFFICULT ?

- **Higher stiffness of the matrix** ⇔ **smaller fluid sensitivity !**
  ➔ **but non zero !**

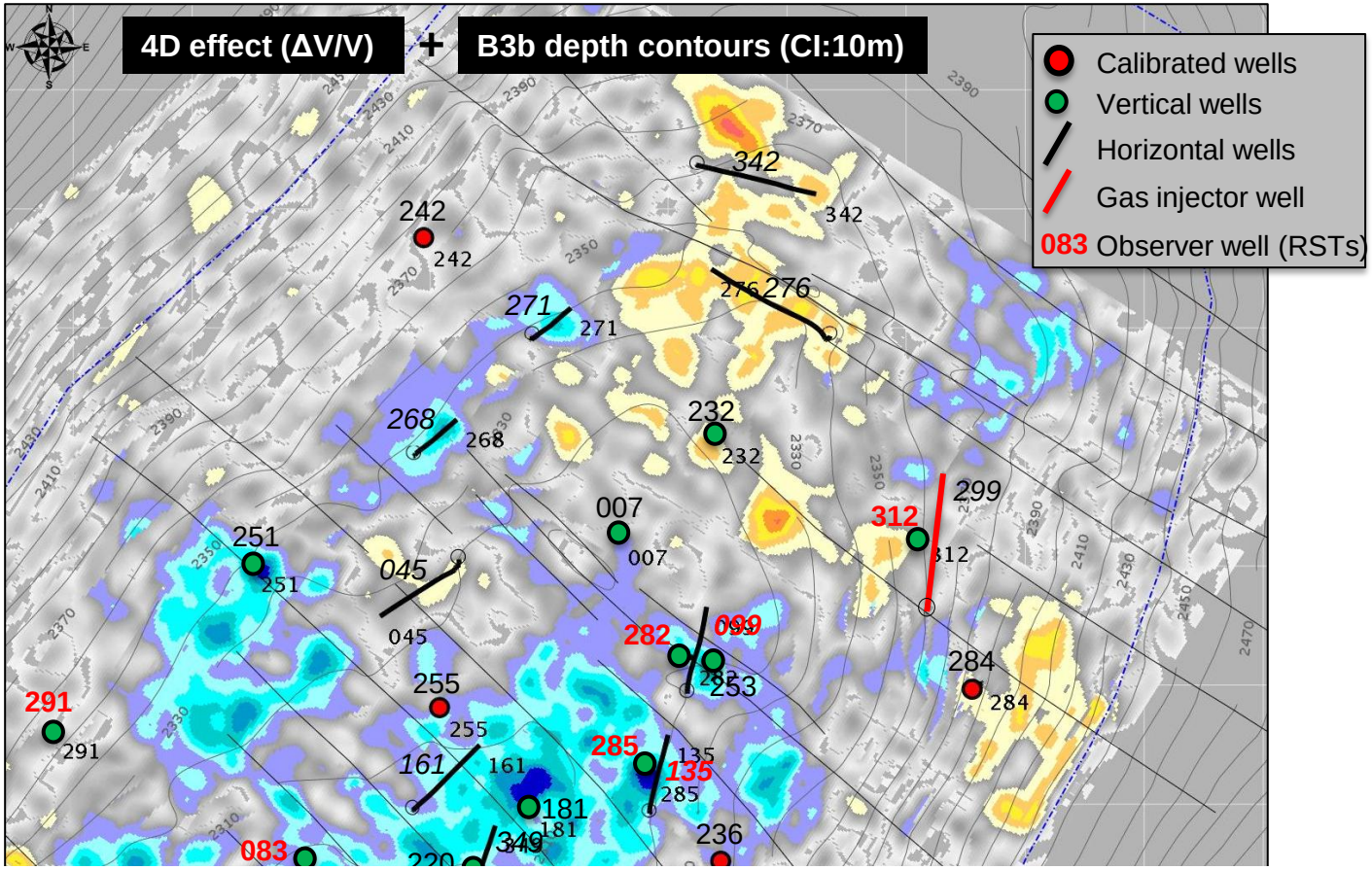
  ⇔ **smaller pressure impact !**

4D signal is smaller than for turbidites !

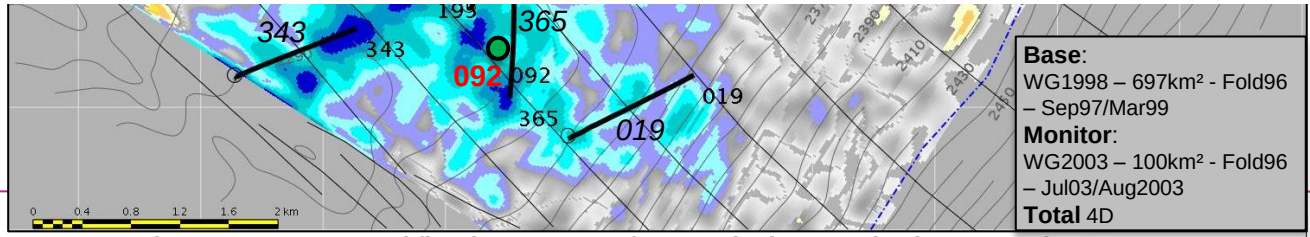
4D IN CARBONATES : MAP OF 4D ANOMALIES



MAP OF 4D ANOMALIES + FAULT NETWORK



Faults drive the water sweeping : different fault transmissivity



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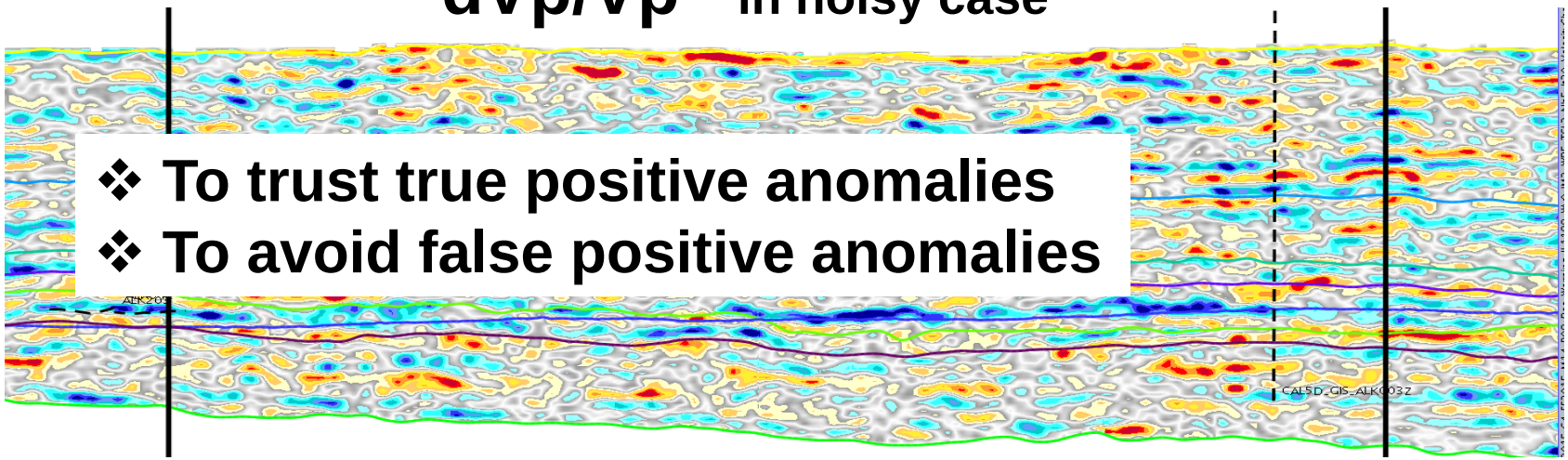
- **High internal multiples energy :**

  4D coherent noise is larger than for deep offshore

4D CAN ALSO LOOKS LIKE :

dVp/Vp **in noisy case**



- Questions :
  - ➔ Where is the reservoir ?
  - ➔ Are all these anomalies true ?
  - ➔ How to recognize them ?
  - ➔ Can we trust ?
- Answers :
  - ➔ **picked on 3D, calibrated on wells.**
  - ➔ **There is certainly true anomalies.**
  - ➔ **Consistency with geology ?**
  - ➔ What is the noise ?

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  4D signal is smaller than for turbidites !

- **High internal multiples energy :**

  4D coherent noise is larger than for deep offshore

- **Complexity of porous media ⇔ difficulty to understand**

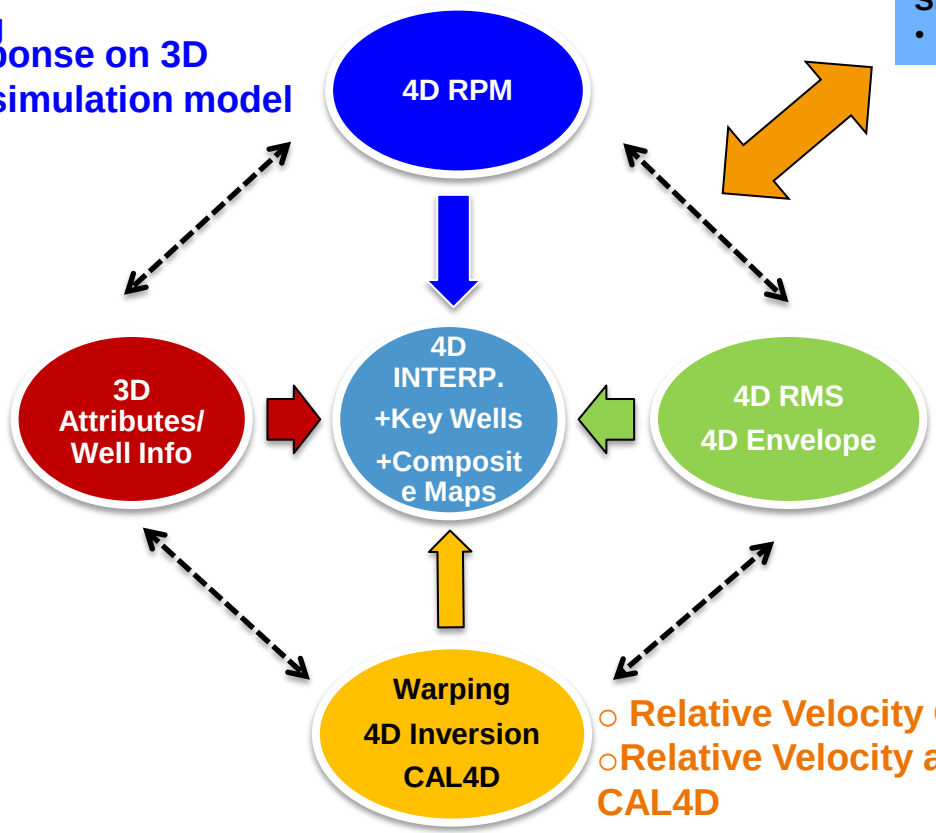
  4D signal less readable than for turbidites

WORKFLOW: An Integrated Interpretation Approach

Field Production/ Monitoring Data
- ○ Well Flowing Pressure
- ○ Producers GOR /BSW/WaterCut
- ○ DST/PLT results
- ○ Static Pressure (MDT/RCI)

Simulation Model (History Match)
- D1V1 (Pressure & Saturation)

Rock Physics Modelling
PEM Response on 3D dynamic simulation model

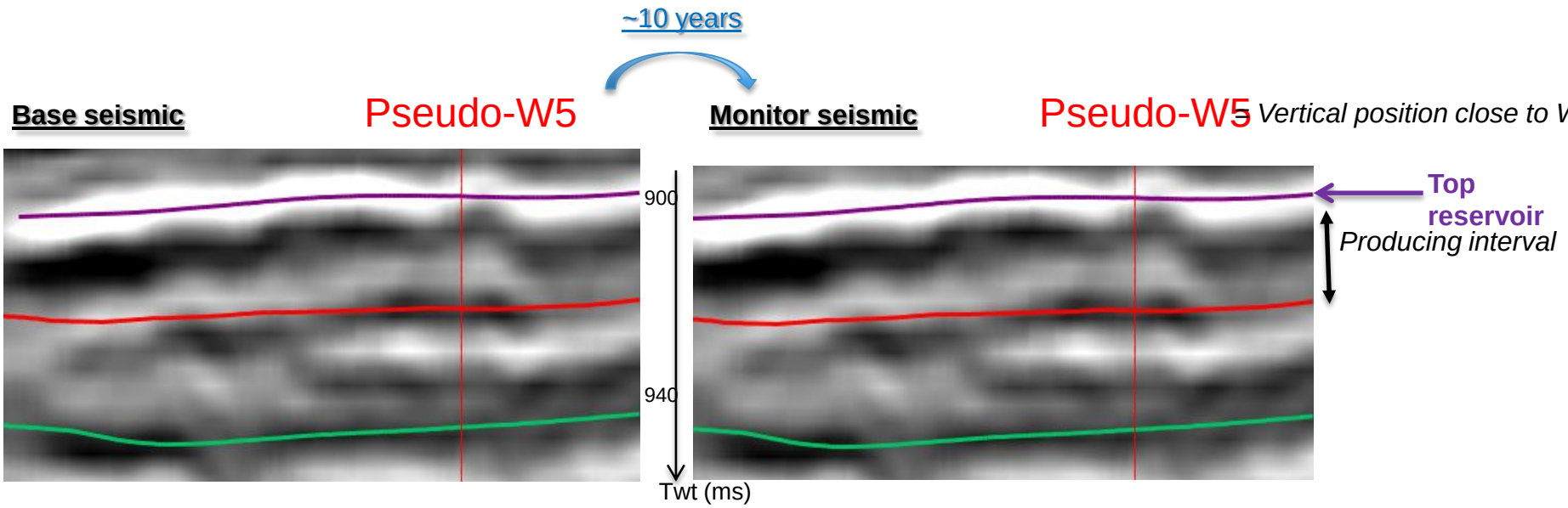


- **Structural Attributes**
  - ○ Gradient Coherency
- **Geology Constraints**
  - ○ 3D Acoustic Impedance
  - ○ Seismic Pseudo-porosity
  - ○ Effective Porosity logs

○ **Traditional 4D Attributes**

- ○ **Relative Velocity Changes from warping**
- ○ **Relative Velocity and Density Changes from CAL4D**
- ○ **Relative Impedance Changes from 4D Impedance Inversion.**

EXAMPLE IS A CARBONATE RESERVOIR



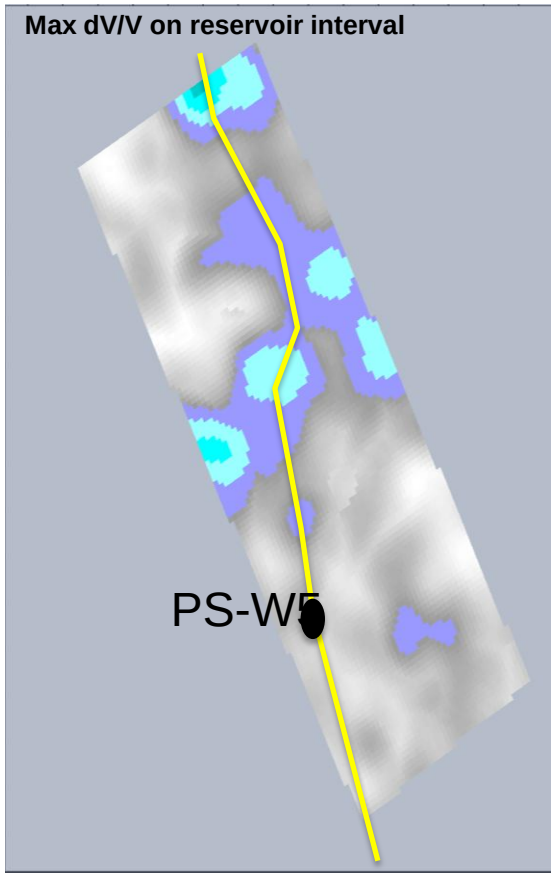
Complete inversion chain :

1 - pure Data driven inversion : Warping ➔ dVp/Vp

2 - 4D seismic inversion @ wells to integrate well knowledge.

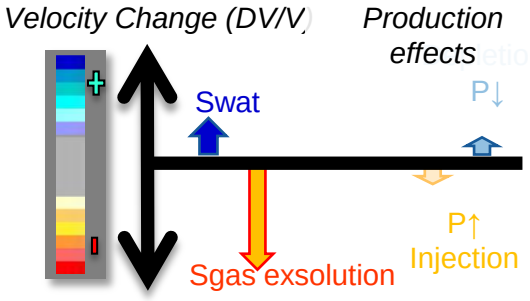
3 - 4D seismic inversion on stratigraphic model ➔ dIp/Ip

VELOCITY CHANGE INTERPRETATION & LIMITS

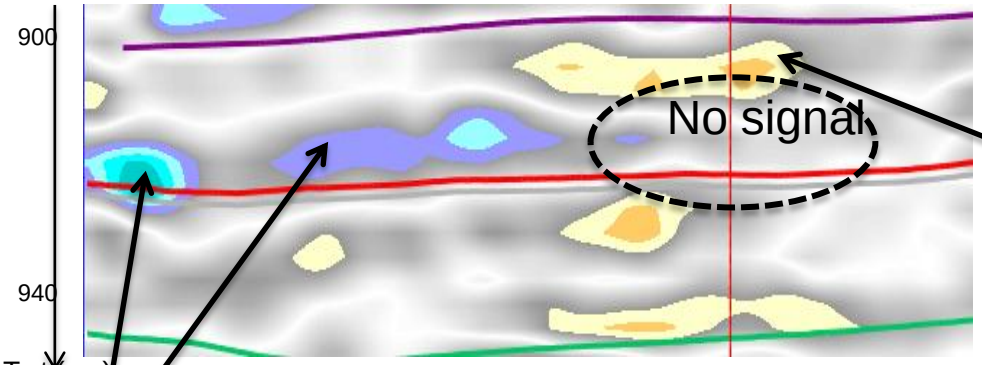


DV/V color scale:

-3.5% 0 +3.5%



Pseudo-W5 ∋ *Vertical position close to W5*

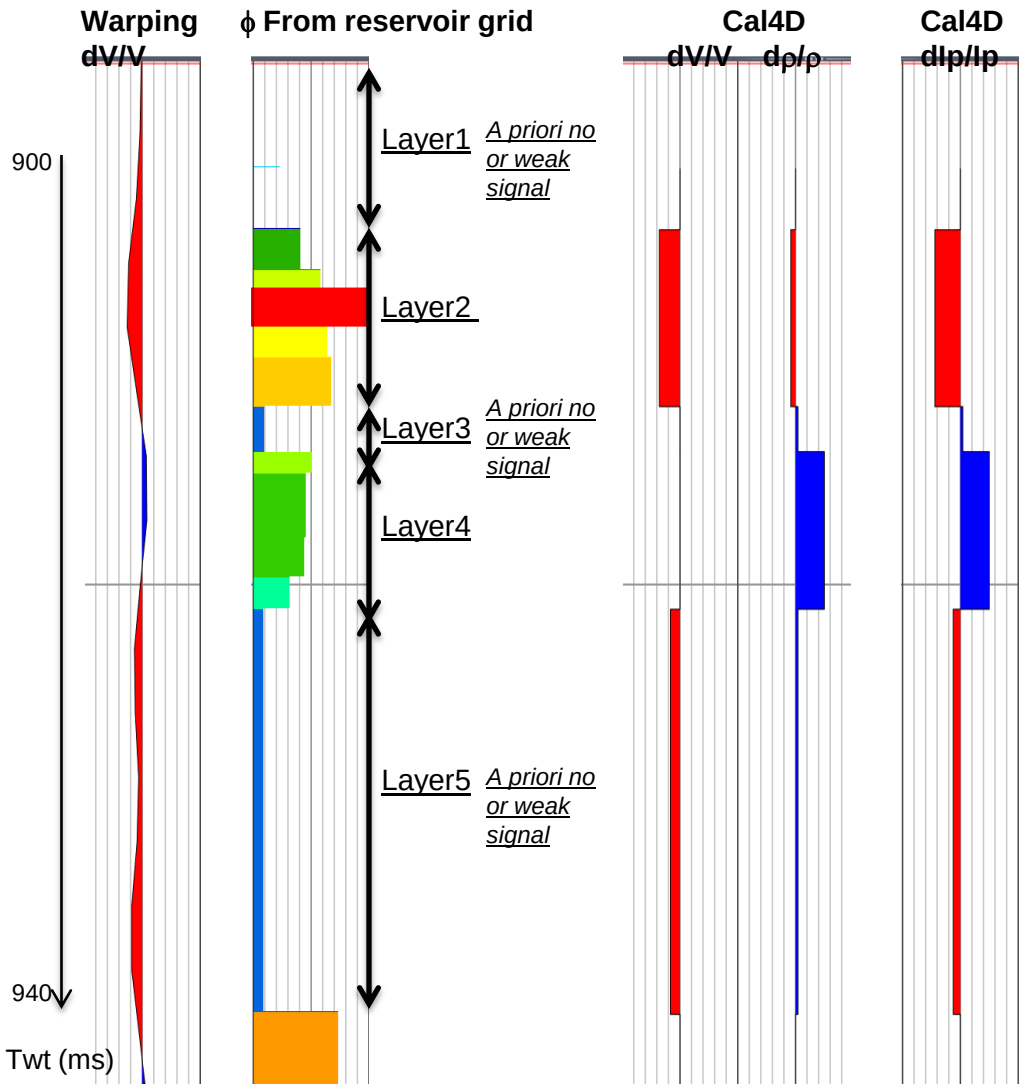


Negative dV/V interpreted as gas in solution
P@monitor < Bubble Pressure

Positive dV/V
Interpreted as water sweeping

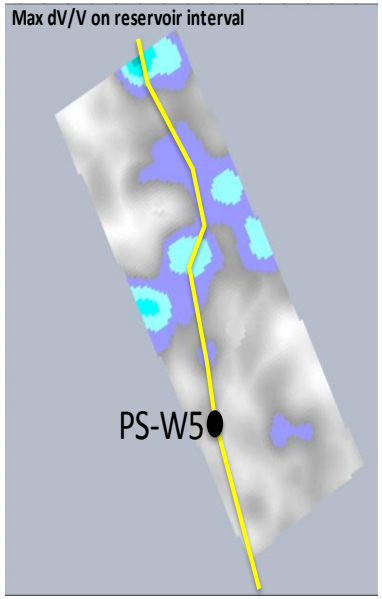
- W5 is producing water @ monitor time!
- Are we really able to monitor the water front?

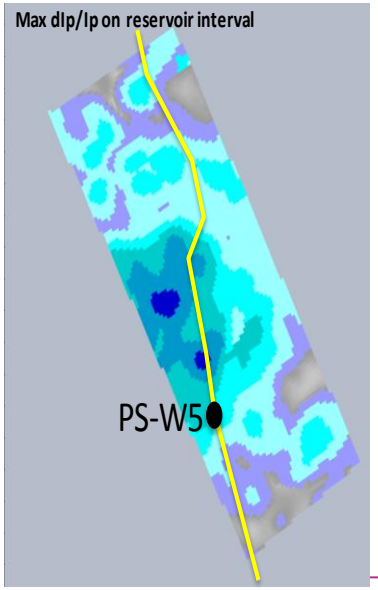
CAL4D INVERSION AT PSEUDO-W5 LOCATION



- Cal4D: layer-based inversion
  - Less artifacts:
    - no tuning effect
    - no side lobes
- Velocity and density changes inversion, even from low angle stacks

IMPEDANCE CHANGE INTERPRETATION

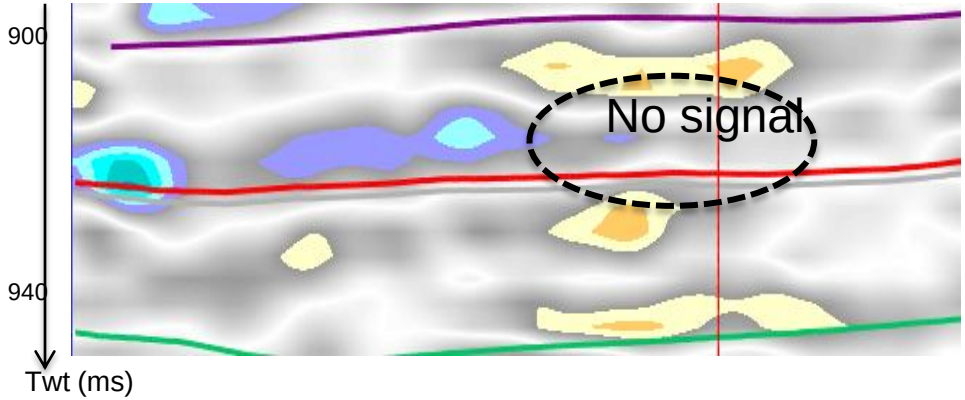




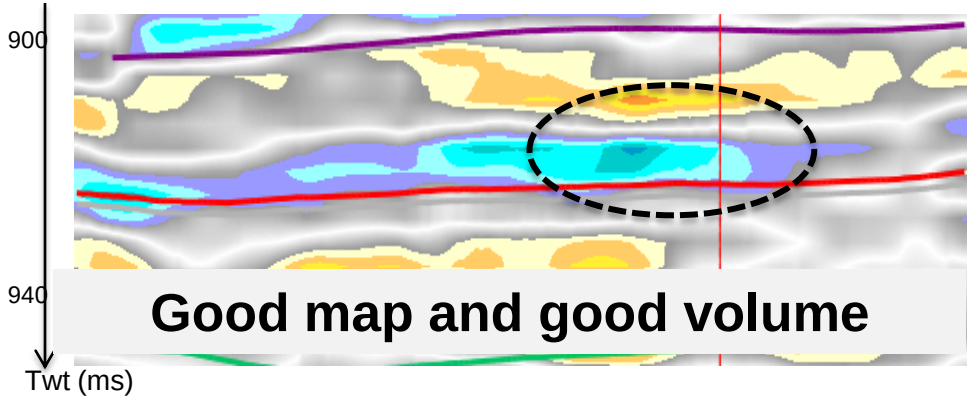
DV/V color scale:

DIp/Ip color scale:

Pseudo-W5 *Vertical position close to W5*



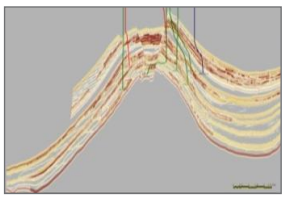
Water seeping not visible on velocity change
Compensation effect

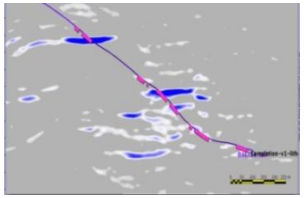
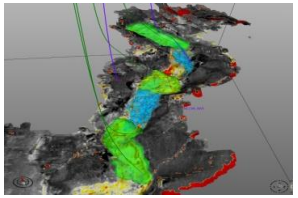
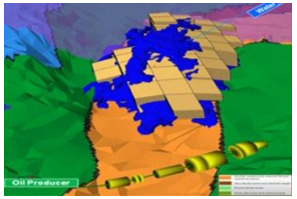


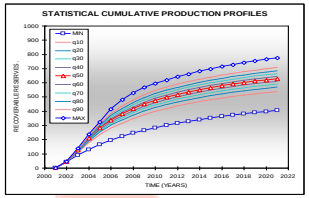
Water seeping visible on impedance change
Density effect

3.2 – COMPLEX STRUCTURAL CONTEXT

4D TOTAL WORKFLOW





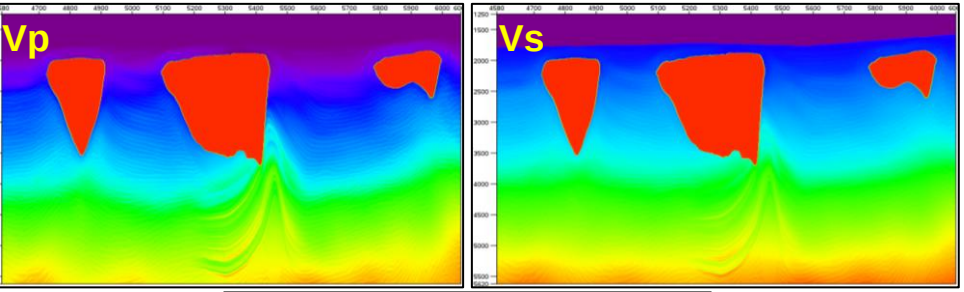
4D feasibility | **4D acquisition & processing** | **4D warping & inversion** | **4D interpretation** | **4D integration into geomodels** | **4D History Match**

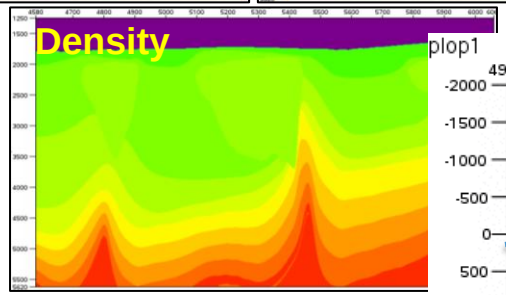
- **4D signal feasibility:** Evaluation of 4D signal in the complex context

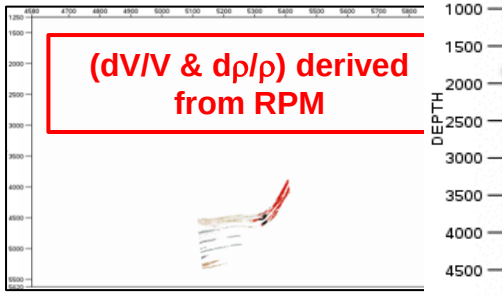
- **4D acquisition feasibility:** at the same time big issue on acquisition design : Wide azimuth, VL offsets, Nodes, PRM

FULLWAVE MODELING

Base and monitor models



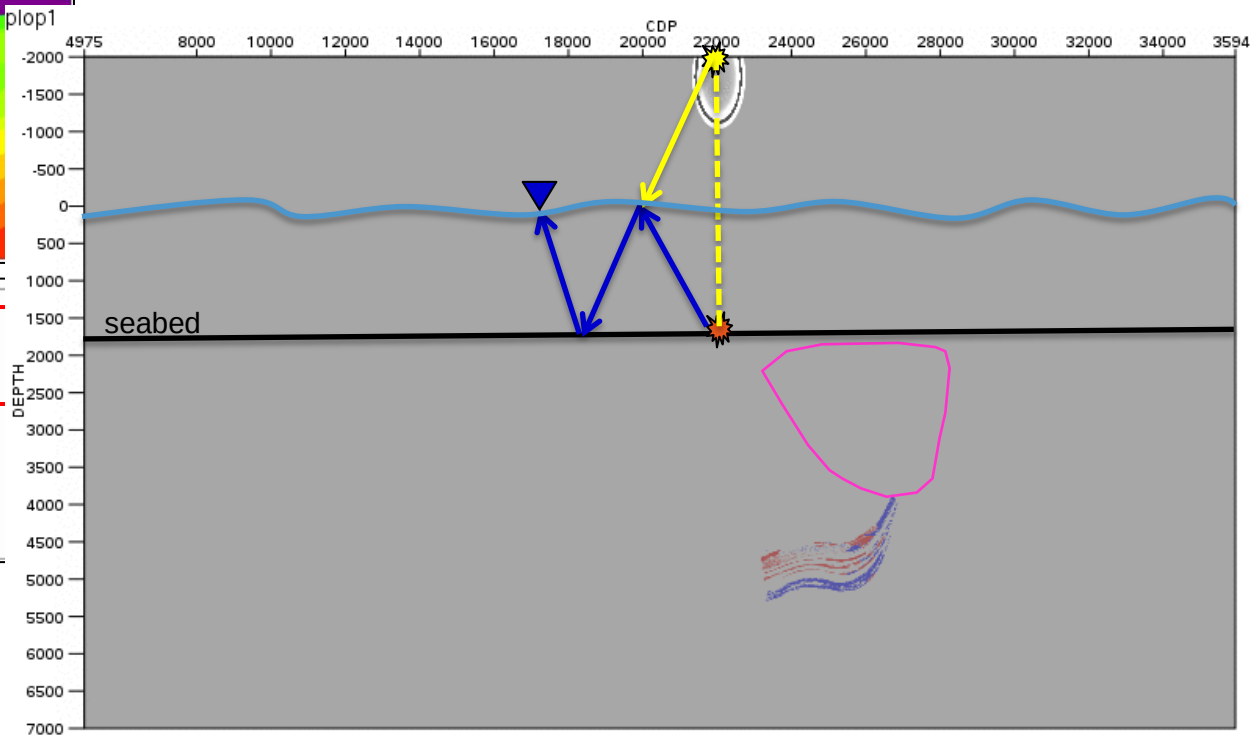




2D & 3D acoustic & elastic to validate.

S-R are inverted.

For downgoing wave modeling we compute the node image as a source



Exploding Reflector

TOTAL

CONCLUSIONS OF THIS FEASIBILITY STUDY

Evaluation of 4D signal and non repeatability impact !

- 4D signal is small
- We can detect it by very good repeatability design :
  - Nodes on seabed
  - PRM

- For imaging very strong dips below salt we need very far offsets

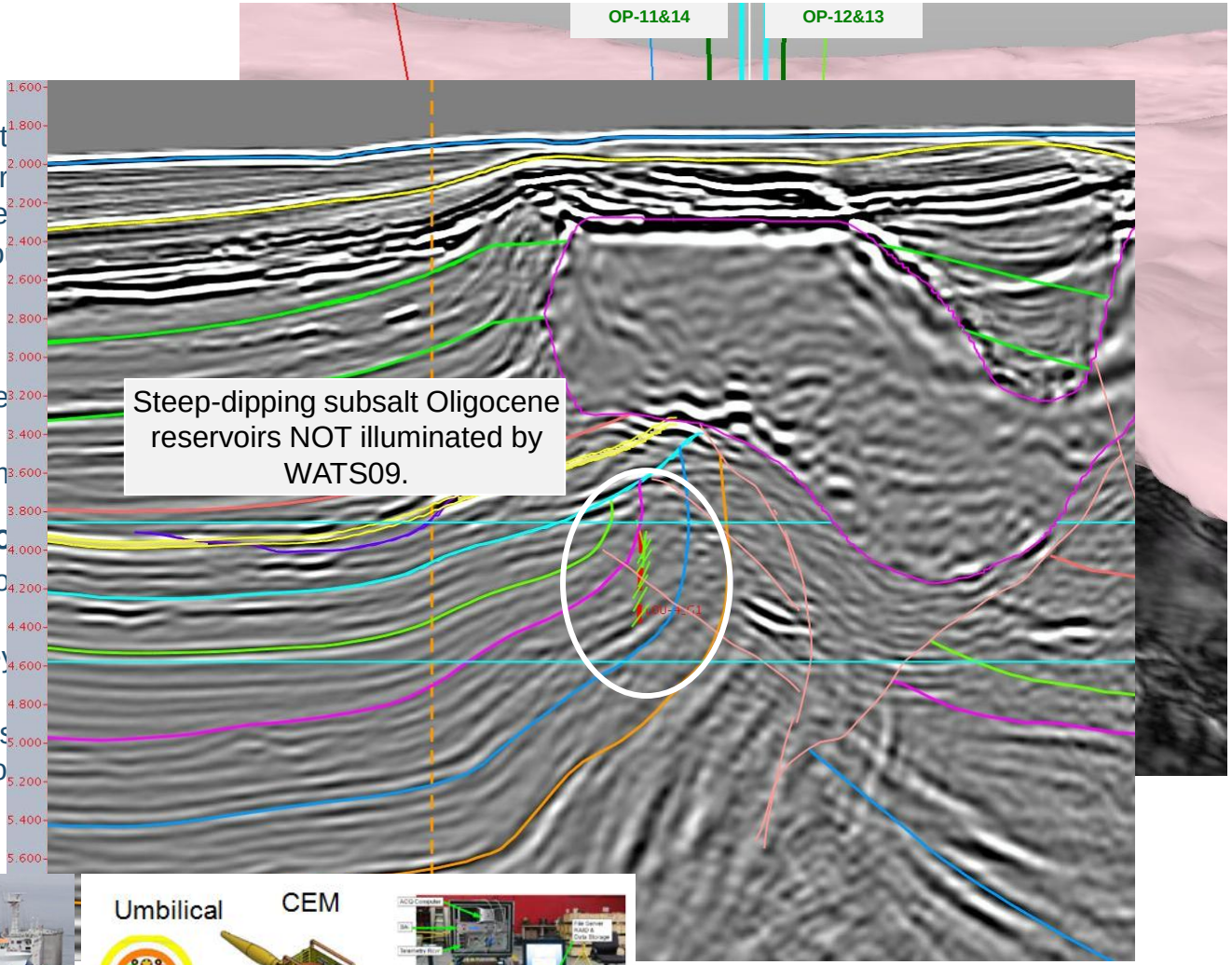
- Business shows that retrievable nodes and/or PRM is expensive,
  - ➔ V.O.I. study
  - ➔ cost reduction ?

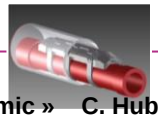
- Original solution : 3D repeated VSP with permanent design.

SUBSURFACE CONTEXT AND 3D VSP RATIONALES

- Improved 3D VSP illumination and resolution than surface seismic. Effective and cost efficient 4D monitoring

- **Subsurface context:**
  - Field underneath allocht
  - HC stakes towards poor to 70-80° have been me
  - Development layout aro channel complexes
- **3D VSP Purpose:**
  - De-risk development we possibilities
  - Field recovery managem
- **Acquisition Means: wo**
  - Permanent installation o well UC (W12)
  - Streamer less 3D survey only is required
  - Rig less borehole acquis via an umbilical cable (o





TOTAL

TOTAL'S SPECIFICITIES

- Total has developped a very wide and transverse workflow for 4D interpretation.
- The detailed and quantitative interpretation results are possible thank to the 4D attributes quality :
  - Acquisition & processing care.
  - Warping and 4D inversion patented technics.

  ➢ This is a marvellous opportunity to gather all geosciences people in front of the same workstation and data to build the best possible understanding of reservoir behavior. (4D Toolbox..!)

- Research program are going on to reduce cost & delay and to adapt this workflow in different geological context as :
  - ➢ Subsalt
  - ➢ Carbonates

ACKNOWLEDGEMENTS/THANK YOU/QUESTIONS

- Thank you for your attention !