THE FULLY INTEGRATED RESERVOIR

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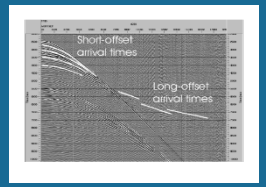
CONTENT OF THE TALK:

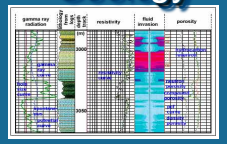
- **Introduction**
- **The Full Static Reservoir project**
- **The Full Dynamic Reservoir project**
- **Our background and previous achievements**

INFERENCE IN GEOSCIENCES

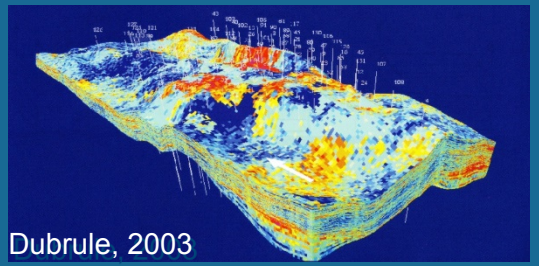


Seismic data

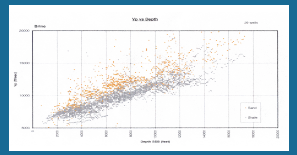
Geology



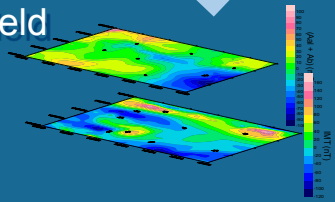
Structure and
medium properties

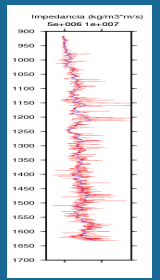


Rock physics



Potential field
data





Well-log data

Turn around lapses for completing a full reservoir model is about 1 or 2 years:

- Specialists analyze separately and sometime sequentially the various information components

Integrated quantitative inference processes:

- Reduce time in a factor of 6
- Increase precision and reliability
- Provide uncertainty description

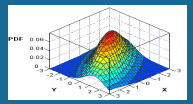
Methods involve:

- Inference knowledge networks
- Artificial intelligence

KNOWLEDGE NETWORK (AI): FORWARD DIRECTION

Types

Graph



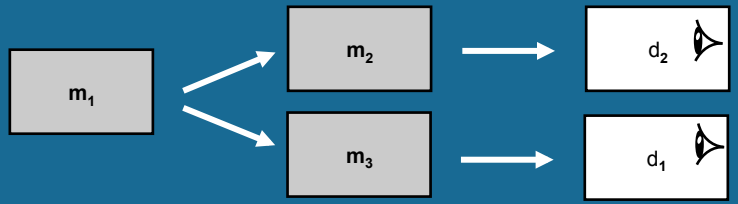
Posterior probability density

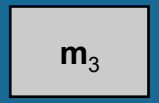
Plain / sigle

$$\sigma(\mathbf{m}) = c\ \rho(\mathbf{m})\ L(\mathbf{m})$$

Posterior | Prior | Data likelihood

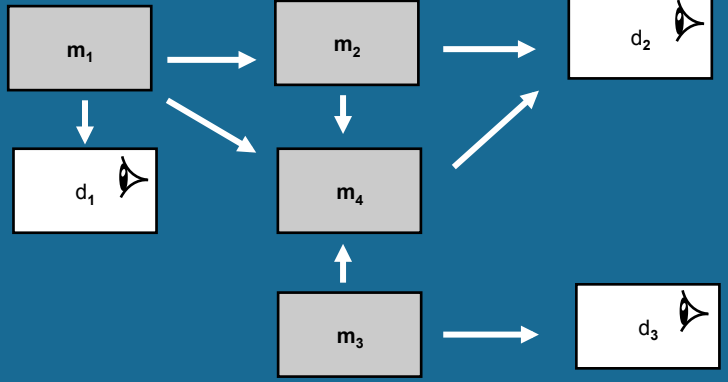
Complex / hierarchical





Model components are parameters describing reservoir (1) properties, (2) structure and (3) scale

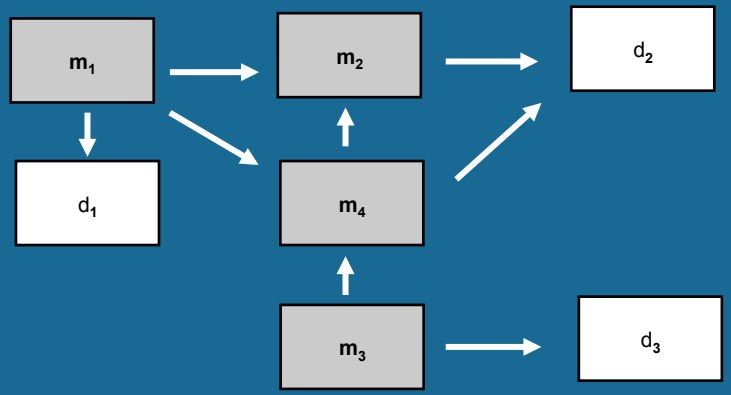
Even more complex / knowledge network



Data components are parameters that are mesured via surveys, instruments or direct observation

Modeled causal of statistical relationships across model components and data

KNOWLEDGE NETWORK BASED INFERENCE:



AI plays a role in assembling the network, calibrating functions and solutions in each specific reservoir case

Combined probability contribution

Primary ancestor — Prior PDF

$\mathbf{m}_3$ ..... $\rho(\mathbf{m}_3)$

Inner model links — Conditional PDF

$\mathbf{m}_4 \rightarrow \mathbf{m}_7$ .... $\rho(\mathbf{m}_7 \mid \mathbf{m}_4)$

Data likelihood function

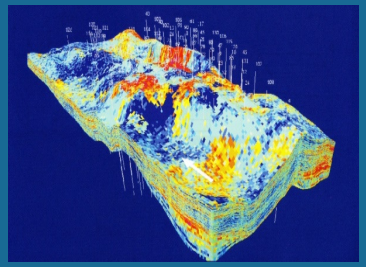
$\mathbf{m}_9 \rightarrow \mathbf{d}_2$ ..... $L(\mathbf{m}_9)$

$$\sigma(\mathbf{m}) = c\, \rho(\mathbf{m}_1)\, \rho(\mathbf{m}_3)\, \rho(\mathbf{m}_2 \mid \mathbf{m}_1, \mathbf{m}_4)\, \rho(\mathbf{m}_4 \mid \mathbf{m}_3)\, L_2(\mathbf{m}_2, \mathbf{m}_4)\, L_1(\mathbf{m}_1)\, L_3(\mathbf{m}_3)$$

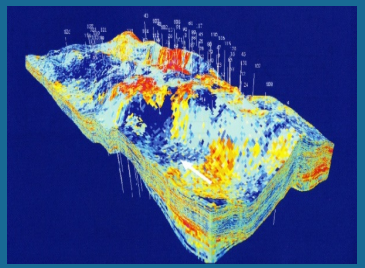
TRADITIONAL VS PROPOSED TECHNOLOGY

1-2 years for elaborating a reservoir quantitative model

- Separate specialists, studies, software, contractors
- Sequential procedures
- Progressive integration of the information
- User over workstations



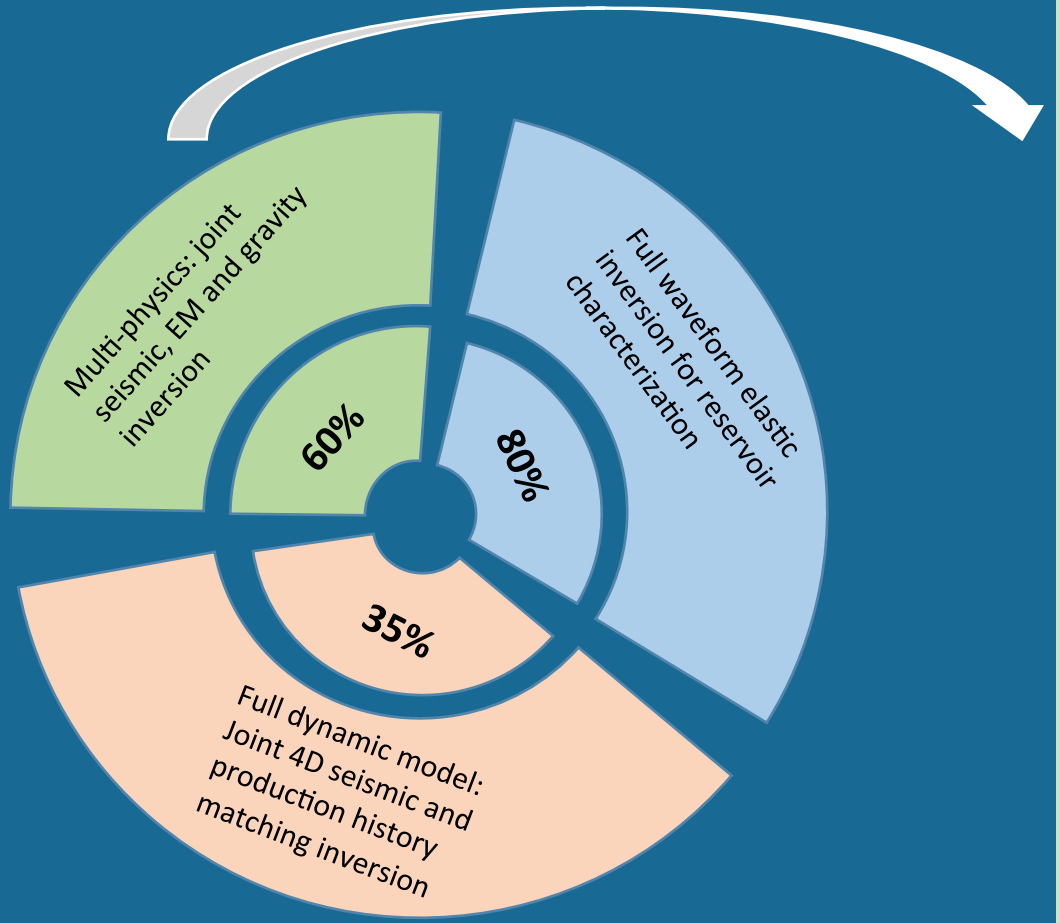
6 months for elaborating a reservoir quantitative model



- Faster availability
- Improved precision
- Uncertainty description
- Automatic update

- Smaller number of experts
- Joint procedures
- User over intelligent phones, workstations and 3D viewers
- Work assisted by the specialized cloud software

THE FULL STATIC RESERVOIR:



Developed components

- Seismic modeling
- Gravity modeling
- Geostatistical 3D modeling of model properties
- Markov chain technology
- Body geometric modeling

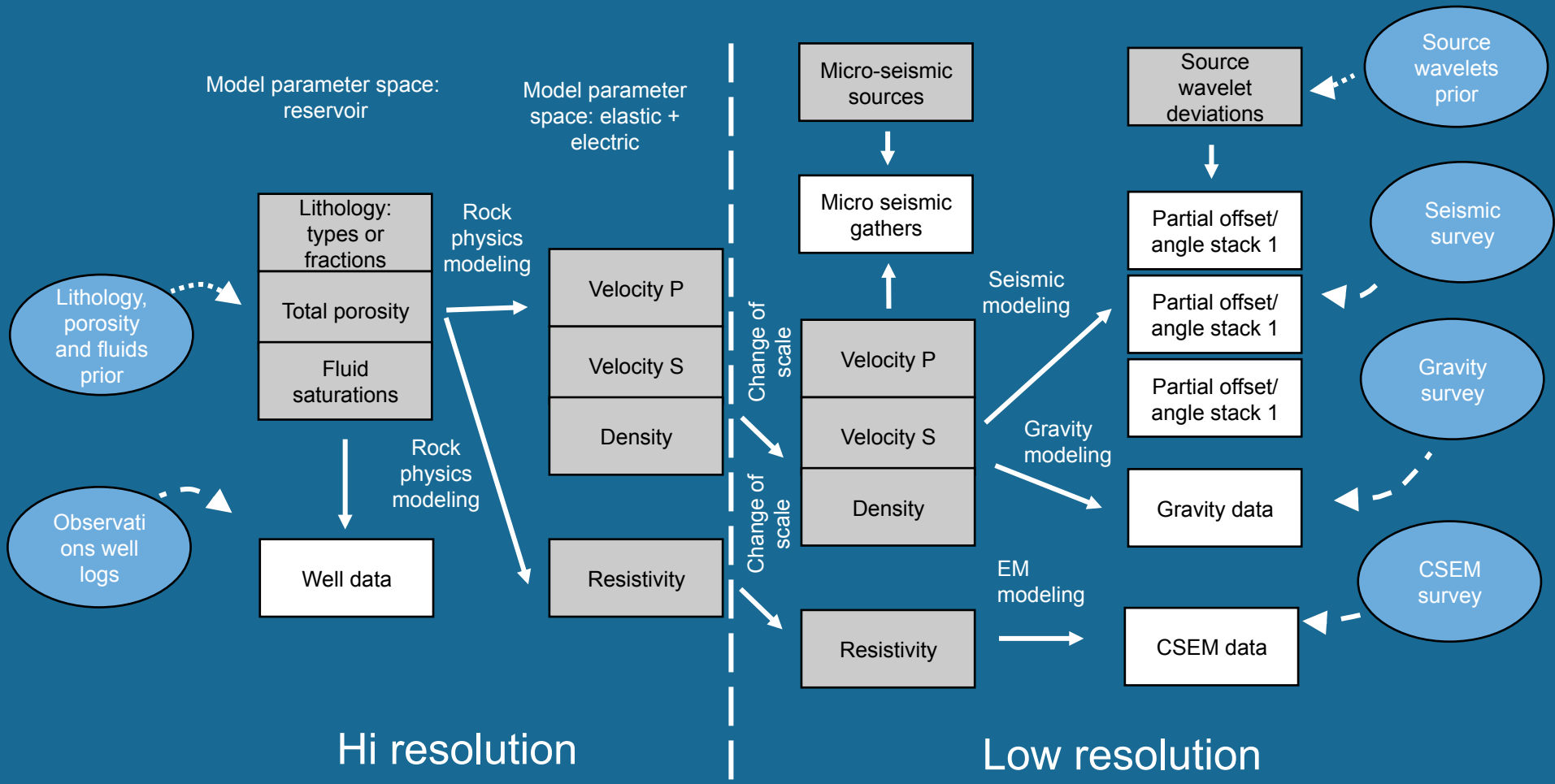
Components to add/develop

- CSEM modeling
- Improved geometric modeling
- Output formats / user interphase

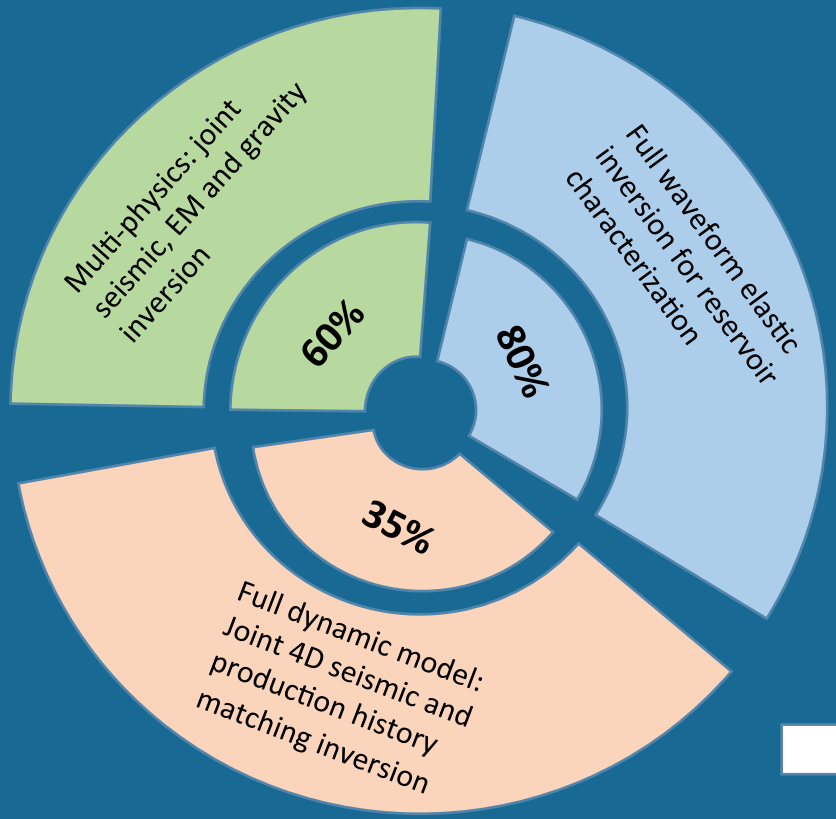
Time/resources

- 12 months
- 2 – 3 professionals
- 80 - 90% station + 20-10% cluster
- Target investment of **2 M USD**

FULL STATIC RESERVOIR: JOINT SEISMIC, CSEM AND GRAVITY INVERSION



THE FULL DYNAMIC RESERVOIR:



Developed components

- Seismic modeling and elastic inversion
- Geostatistical model for the properties
- Double scale model for the properties
- Geostatistical 3D modeling of model properties
- Body geometric modeling

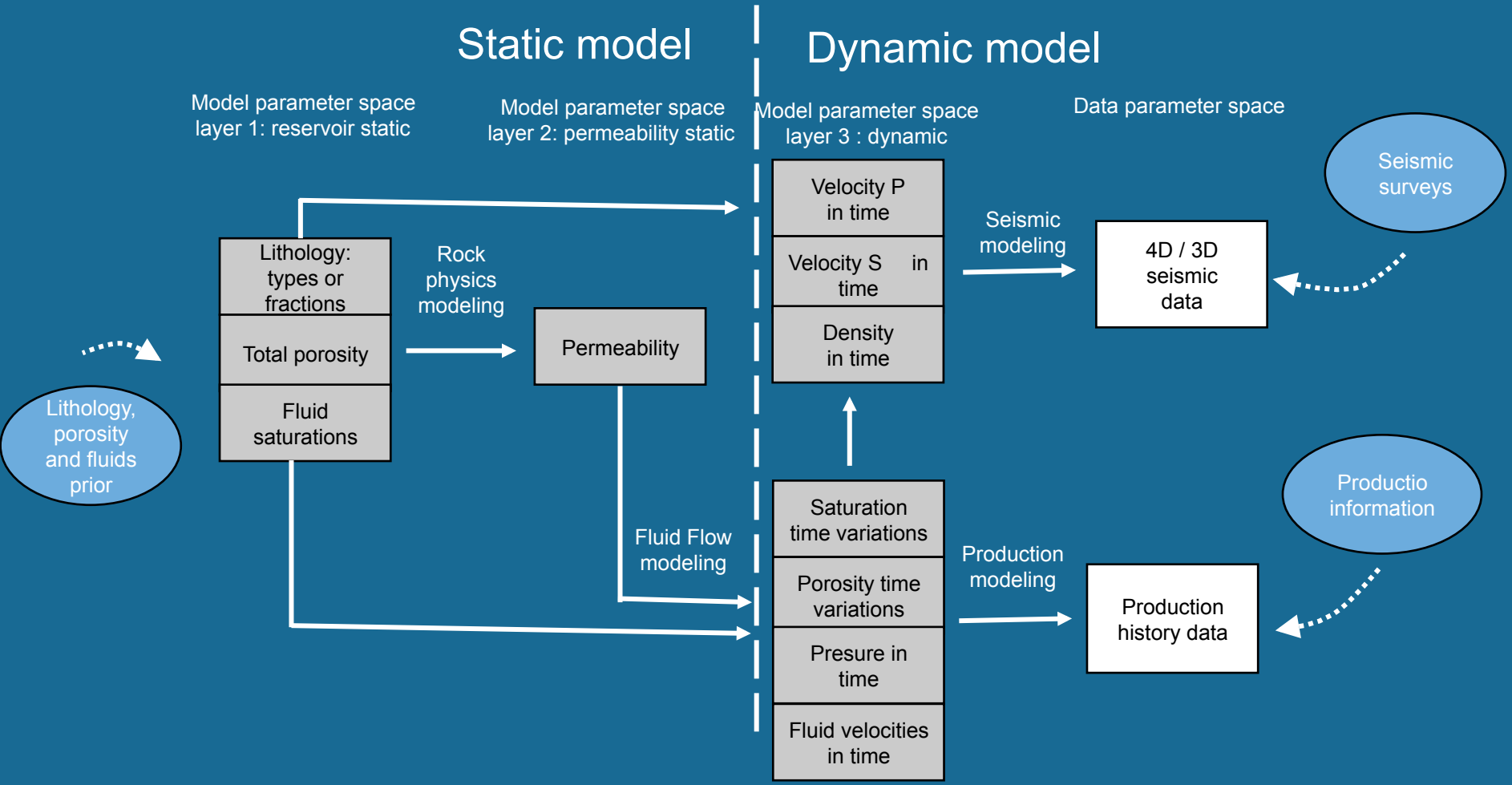
To develop

- Fluid flow modeling
- Fluid flow inverse component
- Combination of the seismic and flow inversion

Time/resources

- 12 months
- 4 – 5 professionals
- 50% station + 50% cluster
- Targeted investment of **3 M USD**

FULL DYNAMIC RESERVOIR: JOINT 4D SEISMIC AND PRODUCTION HISTORY MATCHING



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- Leads technical development to the oil and gas industry via Info Geosciences.
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- Ph. D. thesis in France, Institut de Physique du Globe working with Albert Tarantola
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- Associate Editor of the journal Geophysics for the area of Reservoir Geophysics

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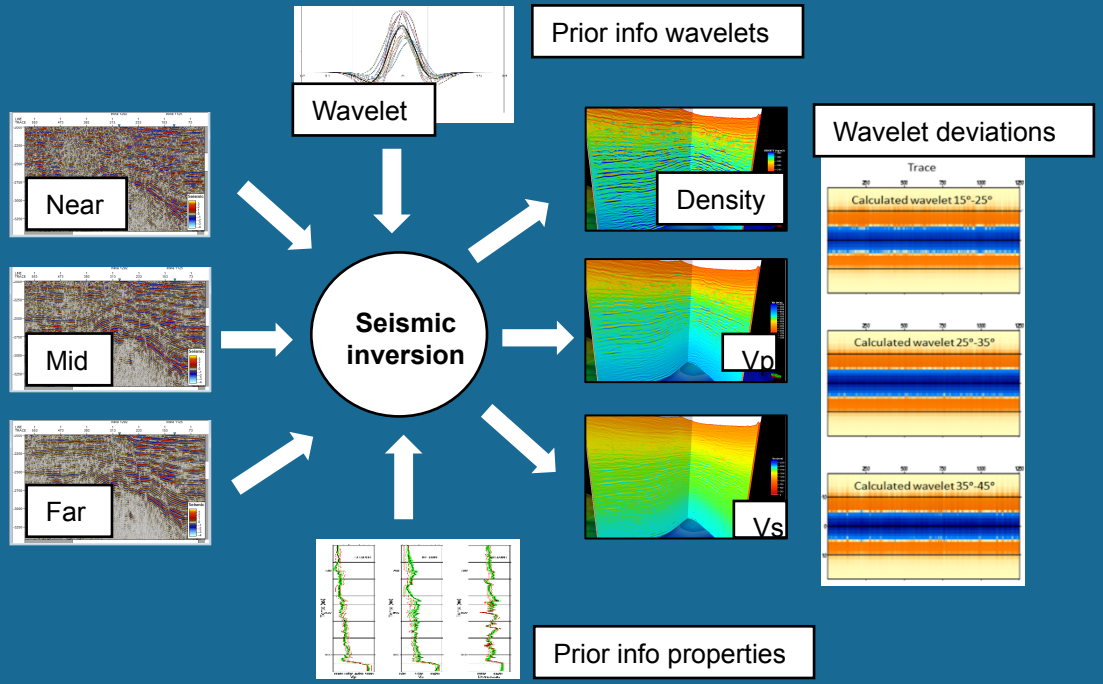
- Computer engineer from the Universidad Simon Bolivar in Caracas
- Master in Management of Technological Innovation in France, University of Paris VII
- Director of Informatics in the National Venezuelan Library
- Manager of Scientific Electronic Library Online Scielo – Venezuela

ADVANCED ELASTIC INVERSION (OPTIMIZATION)

PRESTACK MIGRATED ELASTIC SEISMIC INVERSION

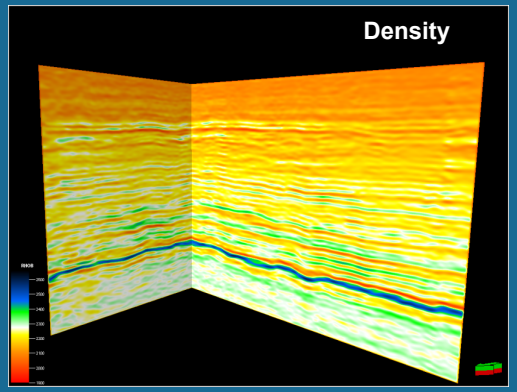


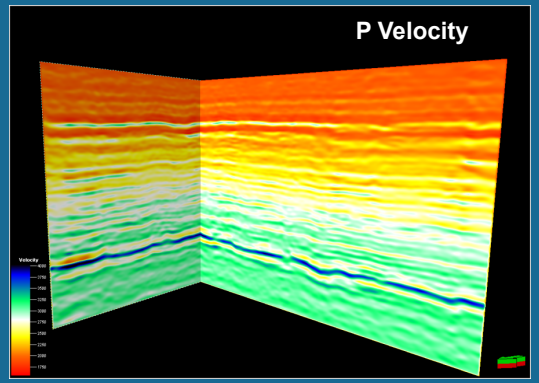
Our improvements:

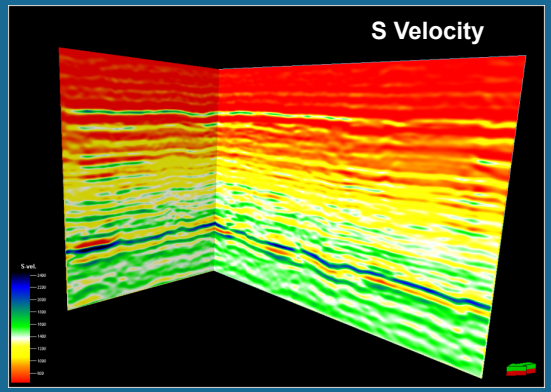
- Appropriate joint resolution of the elastic parameters, including the mass density.
- Estimation of spatial source variations,
- Reflectivity calculated via exact solution of the Zoeppritz equations.
- Appropriate use of prior information based on well geostat characterization
- Optimized numerical solvers

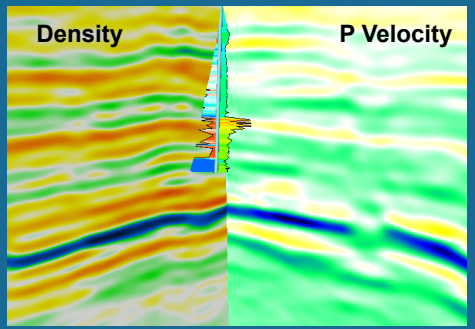
$$f(\mathbf{m},\mathbf{s}) = \underbrace{(\mathbf{d}-\mathbf{d}_{obs})^T \mathbf{C}_d^{-1}(\mathbf{d}-\mathbf{d}_{obs})}_{\text{Seismic data misfit}} + \underbrace{(\mathbf{m}-\mathbf{m}_{prior})^T \mathbf{C}_m^{-1}(\mathbf{m}-\mathbf{m}_{prior})}_{\text{Elastic properties deviations from the prior}} + \underbrace{(\mathbf{s}-\mathbf{s}_{prior})^T \mathbf{C}_s^{-1}(\mathbf{s}-\mathbf{s}_{prior})}_{\text{Source parameters deviations from the prior}}$$

THE LLANOS BASIN IN COLOMBIA:



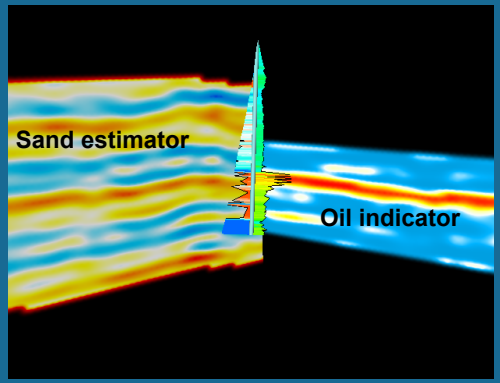






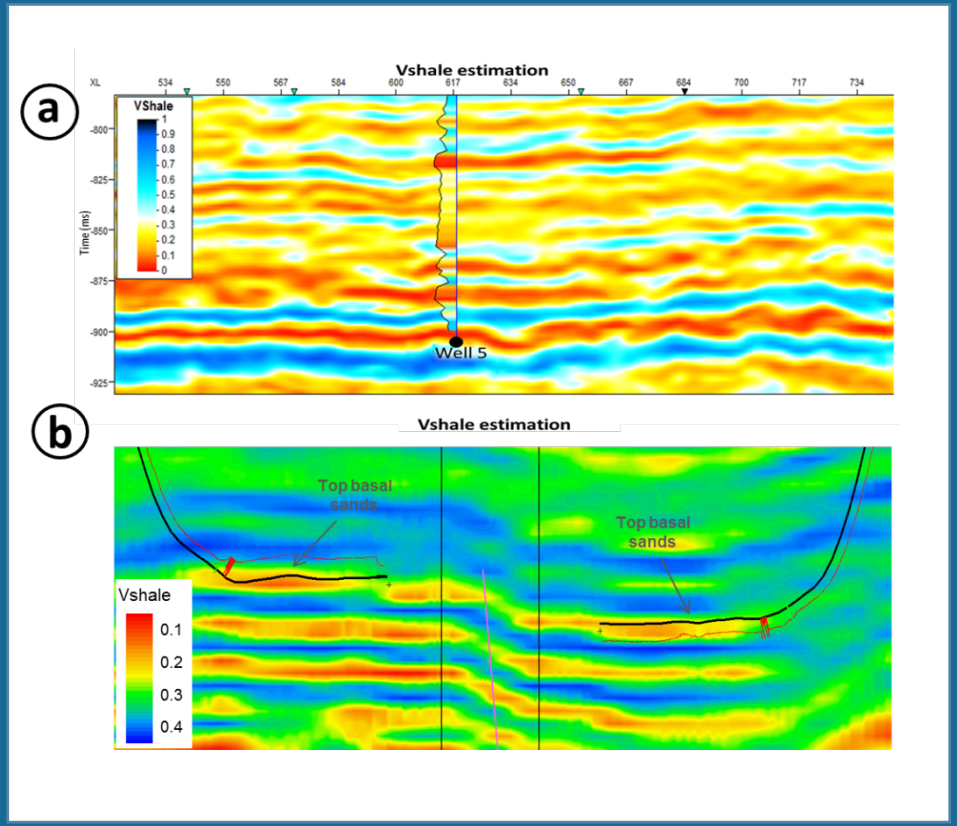
Target sand basal sand characterized by low density

Oil bearing sands characterized by low Vp/Vs and low Vp

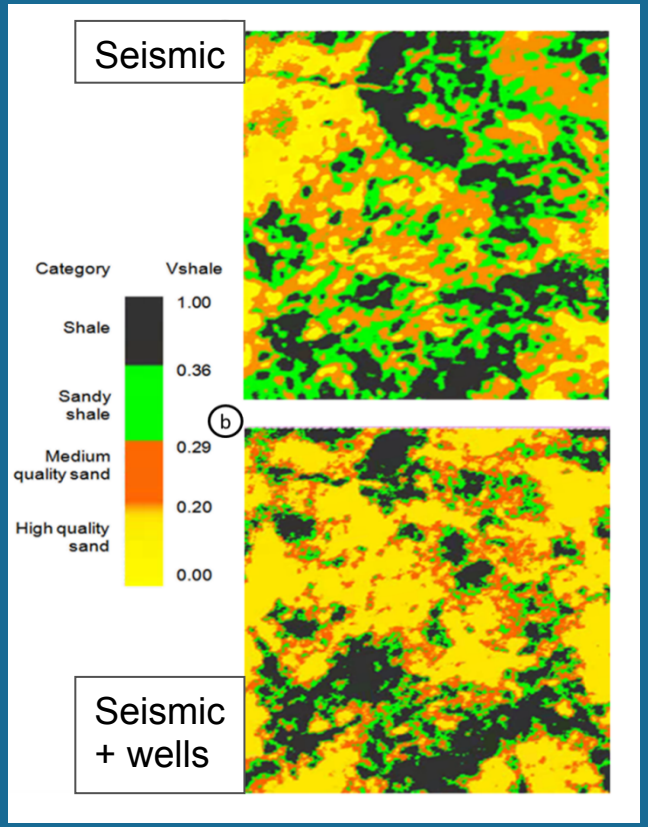


SEISMIC LITHOLOGY ESTIMATOR FROM MASS DENSITY

Estimated shale fraction

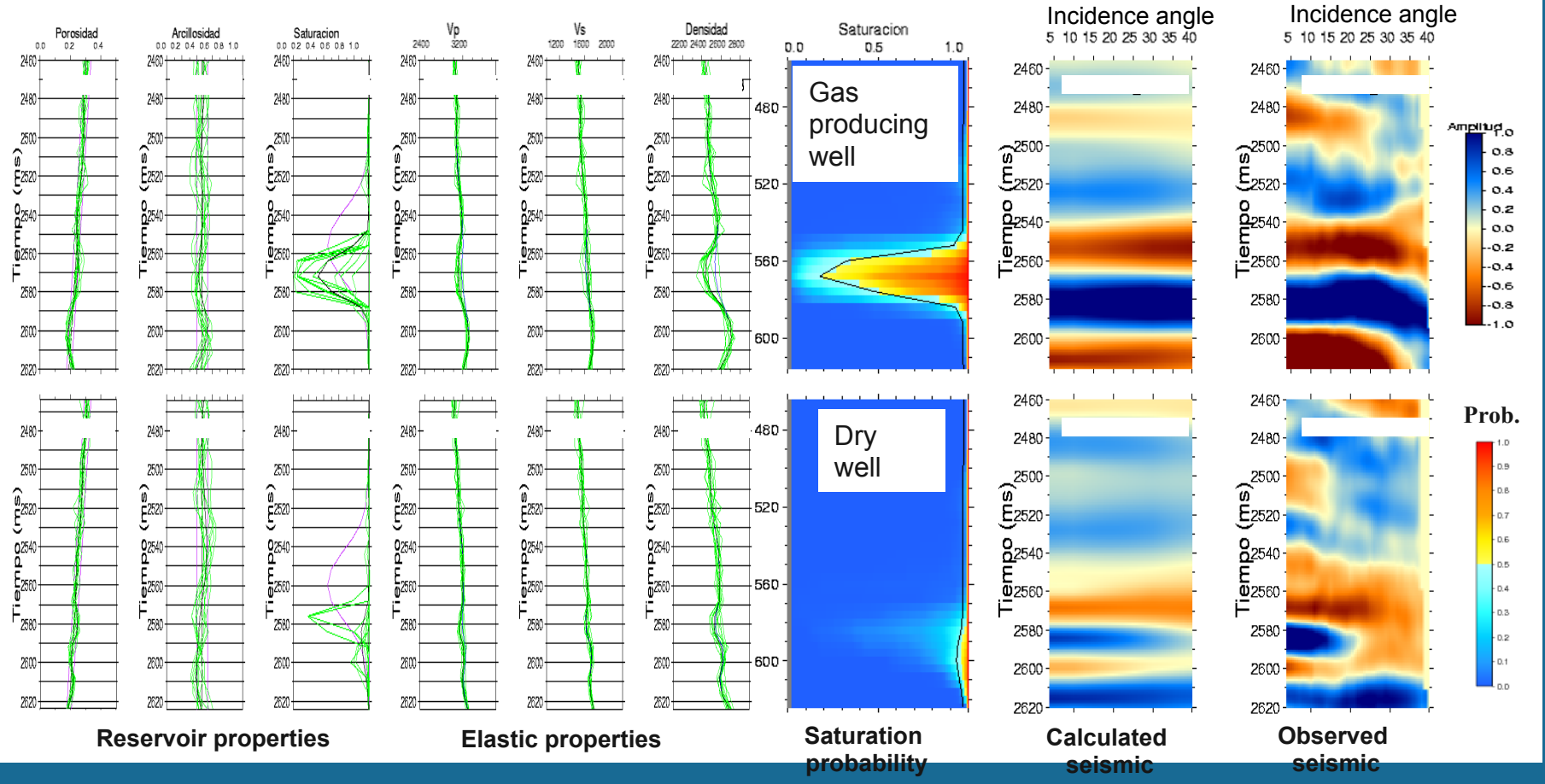


Seismic + well info



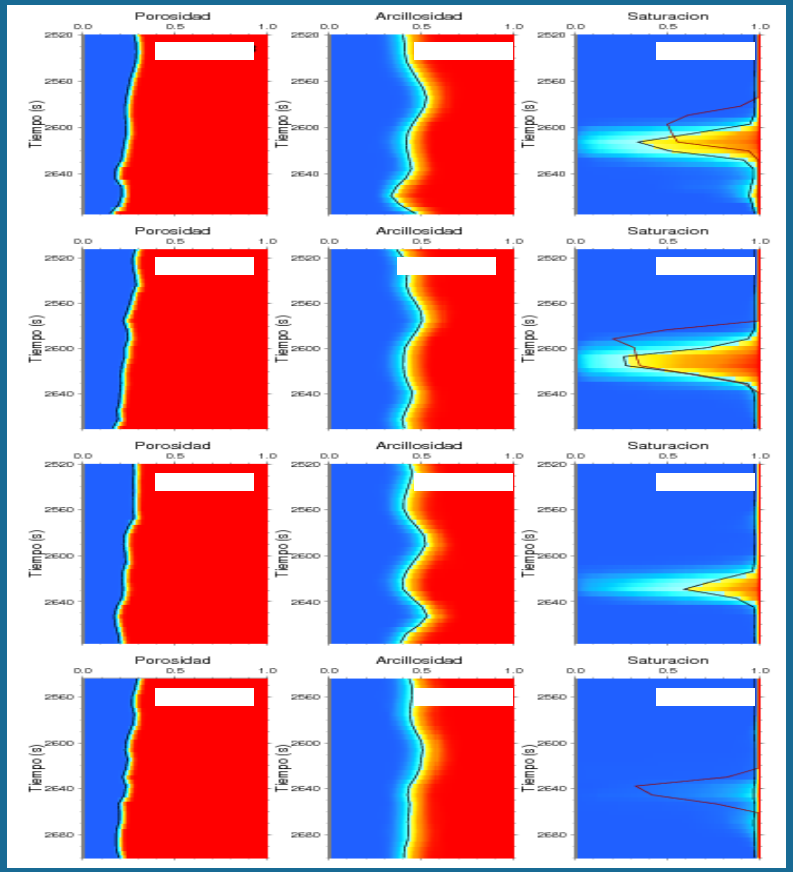
PETROPHYSICAL SEISMIC INVERSION (SAMPLING SOLUTION)

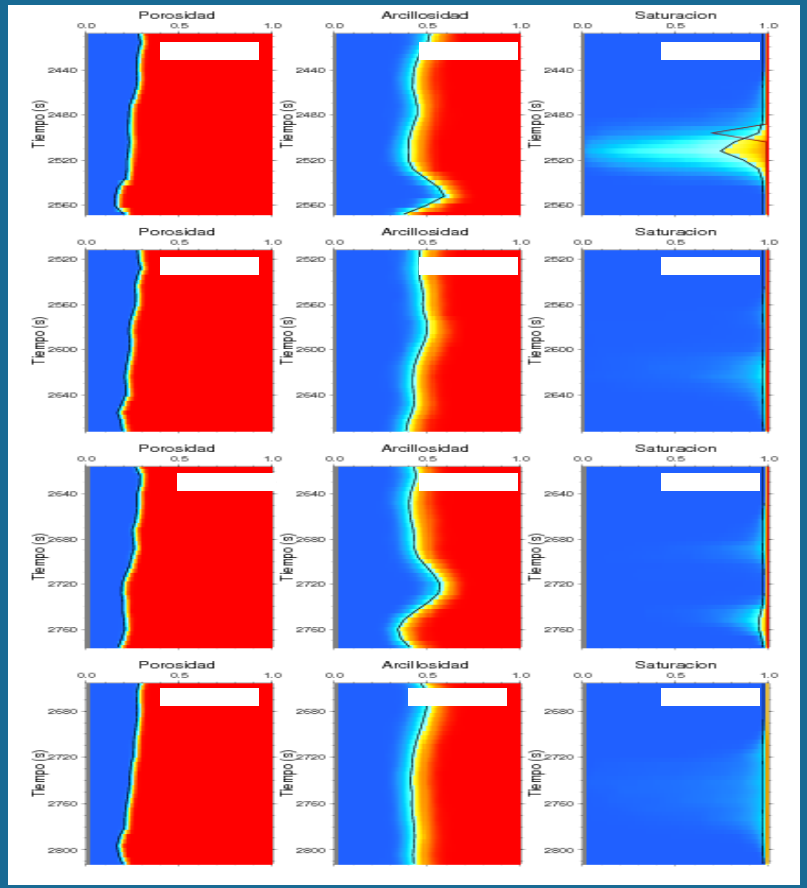
GAS SATURATION PREDICTION: ROCK PHYSICS SEISMIC INVERSION

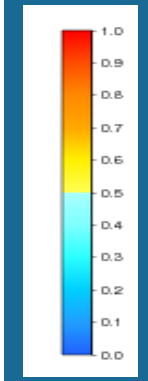


GAS SATURATION PREDICTION: ROCK PHYSICS SEISMIC INVERSION

Cumulative probability distribution functions







Cumulative probability

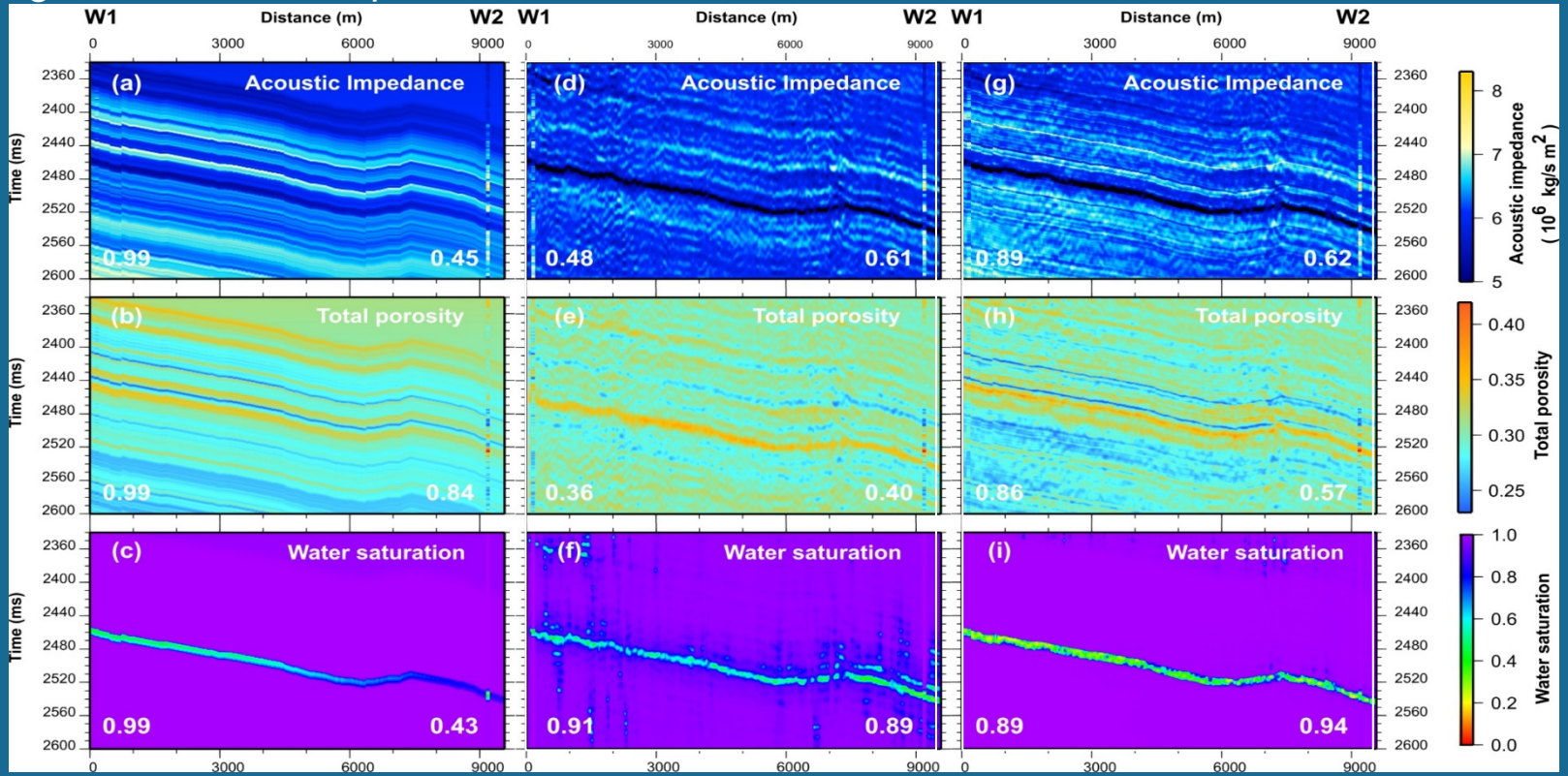
GEOSTATISTICAL PETROPHYSICAL SEISMIC INVERSION (CONDITIONED TO WELL LOGS)

GEOSTATISTICAL AND ROCK PHYSICS SEISMIC INVERSION CONDITIONED TO WELLS

Well log W1 geostatistical extrapolation

Seismic inversion

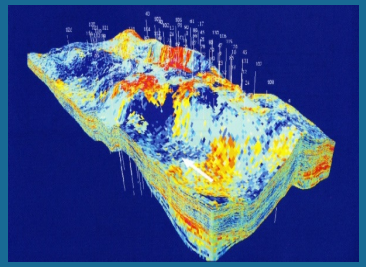
Seismic inversion conditioned by well W1



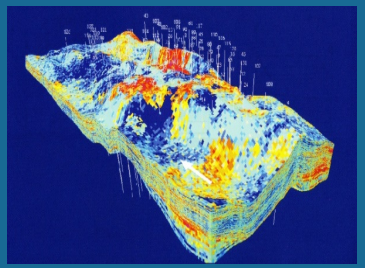
TRADITIONAL VS PROPOSED TECHNOLOGY

1-2 years for elaborating a reservoir quantitative model

- Separate specialists, studies, software, contractors
- Sequential procedures
- Progressive integration of the information
- User over workstations



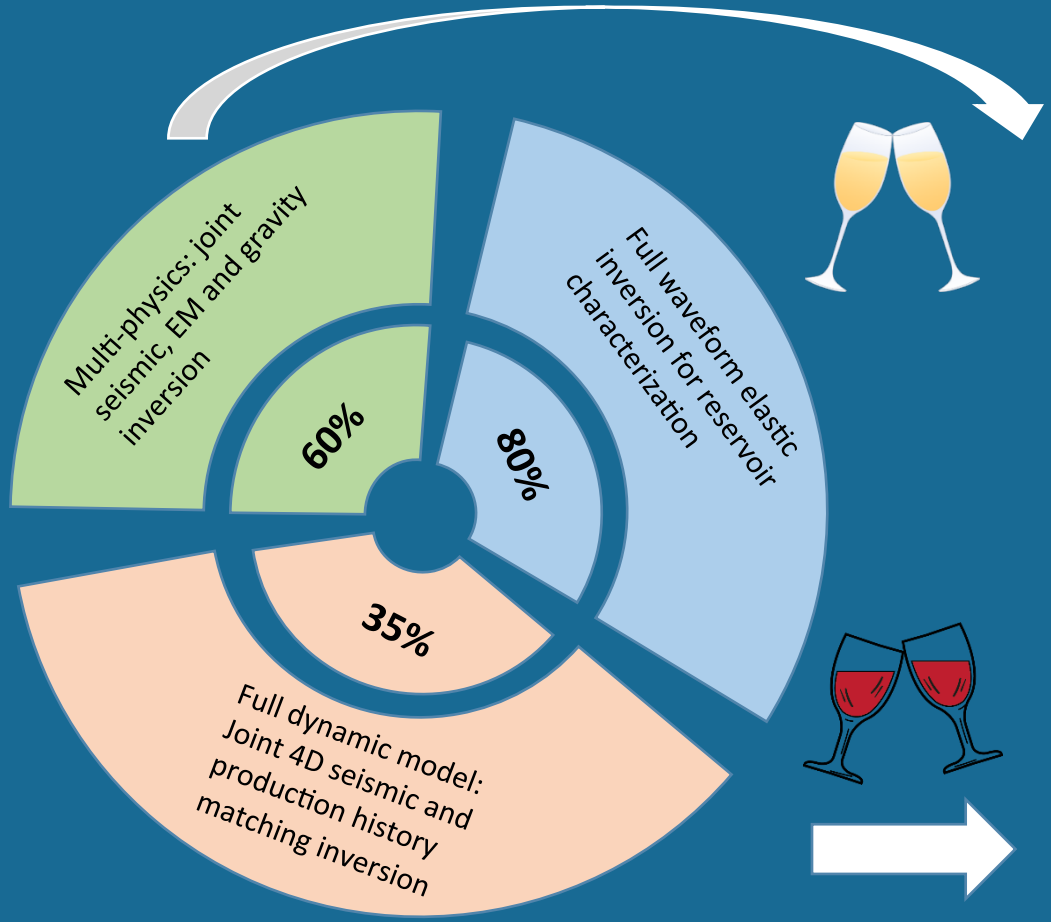
6 months for elaborating a reservoir quantitative model



- Faster availability
- Improved precision
- Uncertainty description
- Automatic update

- Smaller number of experts
- Joint procedures
- User over intelligent phones, workstations and 3D viewers
- Work assisted by the specialized cloud software

FULLY INTEGRATED RESERVOIR:



Prototype complete development and true scale tests

Time/resources

- 12 months
- 2 – 3 professionals
- 80 - 90% station + 20-10% cluster
- Target investment of **2 M USD**

Time/resources

- 12 months
- 4 – 5 professionals
- 50% station + 50% cluster
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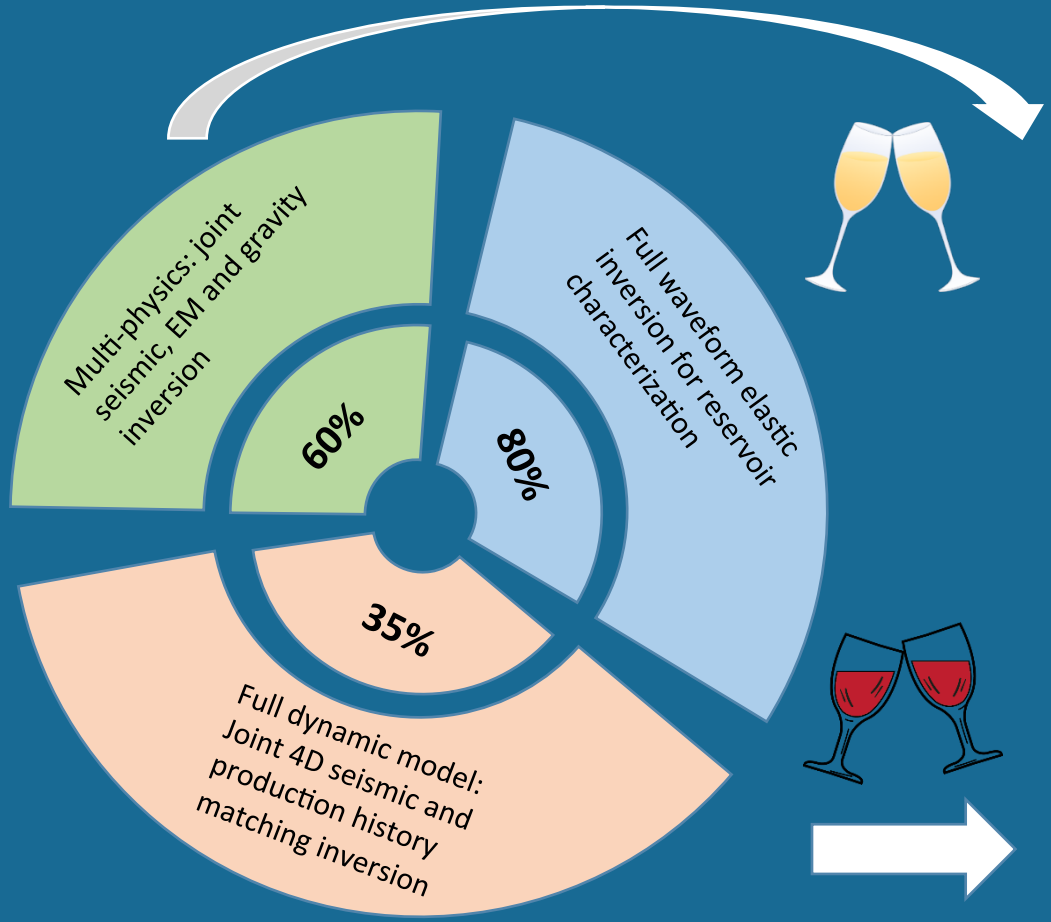
FULLY INTEGRATED RESERVOIR:



Prototype complete development and true scale tests

Funding models:

- Investment
- Consortium
- Association
- Assimilation
- Target investment of **2 M USD**

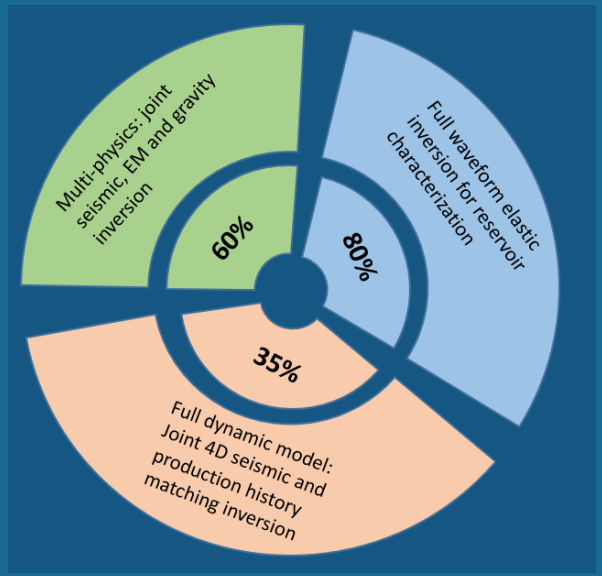
Funding models:

- Investment
- Consortium
- Association
- Assimilation
- Targeted investment of **3 M USD**

FULLY INTEGRATED RESERVOIR:

1 year

- Full development of the reservoir knowledge network codes
- True size reservoir validations



insertion

- Insertion in inhouse or commercial setting
- Development of user interfaces
- Development of graphic interfaces
- Claud and distributed computations

Fast reservoir model elaboration and update !!!

Smaller number of experts
Joint procedures
User over intelligent phones, workstations and 3D viewers !!!

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ecopetrol

suelopetrol

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Bosch M., Inference networks in Earth models with multiple components and data, in Integrated Imaging of the Earth, AGU monographs, John Wyley & Sons, 2016