

**PS Cerro Fortunoso Field: Static-Dynamic Modelling of a Complex Faulted and Thrusted Reservoir (Malargüe Fold and Thrust Belt, Argentina)\***

**Griselda Vocaturo<sup>1</sup>, Vanesa Consoli<sup>1</sup>, Abel Garriz<sup>1</sup>, Pablo Giampaoli<sup>1</sup>, Gastón Manestar<sup>1</sup>, Anthony Thompson<sup>1</sup>, and José Luis Massaferro<sup>1</sup>**

Search and Discovery Article #20223 (2013)\*\*

Posted November 21, 2013

\*Adapted from a poster presentation given at AAPG International Conference and Exhibition, Cartagena, Colombia, September 8-11, 2013

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### **Abstract**

The Cerro Fortunoso field is an east-verging anticline located in the Malargüe fold and thrust belt (central-west Argentina). The anticline geometry varies along strike, affected by low and high angle east-verging inverse faults generating a sub-vertical flank (up to 80°) dissected by igneous intrusions. The reservoir consists of 500m thick Upper Cretaceous siliciclastic continental sediments (Neuquén group). This includes prograding alluvial fan deposits (Rio Limay Formation) and aggrading-prograding channel and flood-plain deposits (Rio Neuquén and Rio Colorado Formations) separated by a 1st order maximum flooding surface. Stratigraphically these units could be separated into higher order cycles correlatable across the field. A 3D static model representing the structural complexity and the high order cycle correlation was needed to justify the expansion of the current 15 well secondary recovery pilot to a 200 well full field development. RFT data demonstrated that flow in the reservoir was controlled by multiple thin sandstones (~ 2m) that are isolated from each other. To determine the secondary recovery potential of the field it was critical to understand the areal extent and connectivity of these highly heterogeneous bodies. This was challenging, as these sandstones, due to their heterogeneity, do not show consistent log responses between wells. Additionally the very high angle of dip meant that a sandstone body could plausibly connect with a number of different sandstones on a neighboring well. To determine which ones correlated to each other, multiple correlation scenarios were constructed and subsequently evaluated by dynamic testing against production and pressure data. To capture the vertical distribution of the sandstones, modelling had to be completed on a fine scale in a reservoir with a thickness of 500 meters; therefore cell size needed to be optimized and sector models used to ensure realistic simulation times.

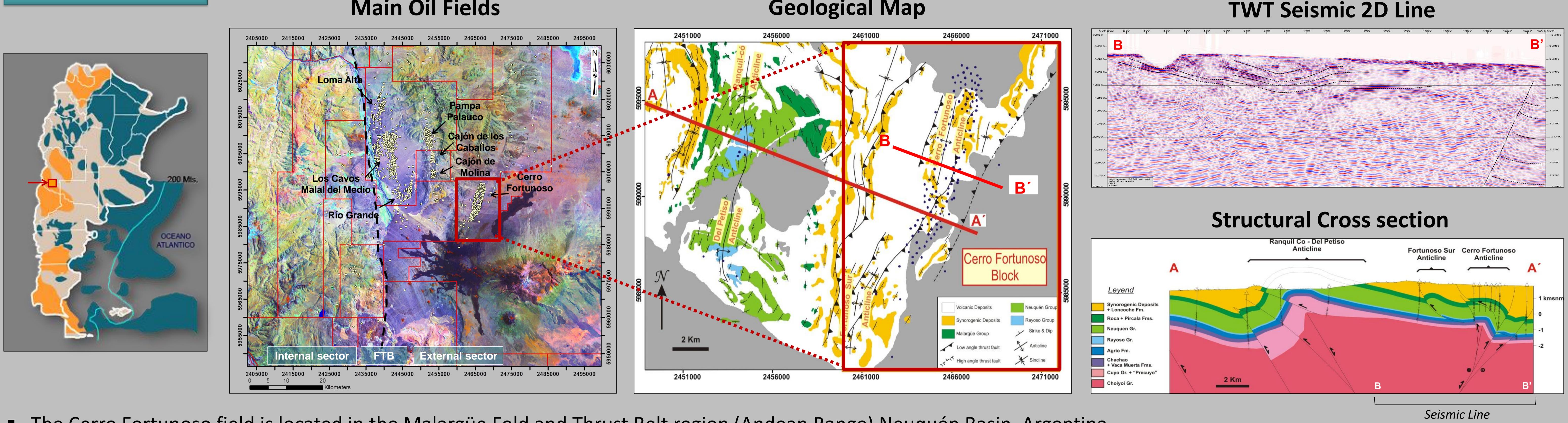
The geological understanding developed showed that sandstone throughout the field had similar connectivity and petrophysical characteristics to those in the waterflood pilot area. It was also seen that if the sandstones were to be more discontinuous or to have a lower net-to-gross than modeled (potential risks to waterflooding), historical production could not be matched in dynamic simulation. This methodology has demonstrated the potential to recover significant incremental hydrocarbons by waterflooding the whole field.

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## LOCATION



- The Cerro Fortunoso field is located in the Malargüe Fold and Thrust Belt region (Andean Range) Neuquén Basin, Argentina

## FIELD SUMMARY

### STRATIGRAPHY

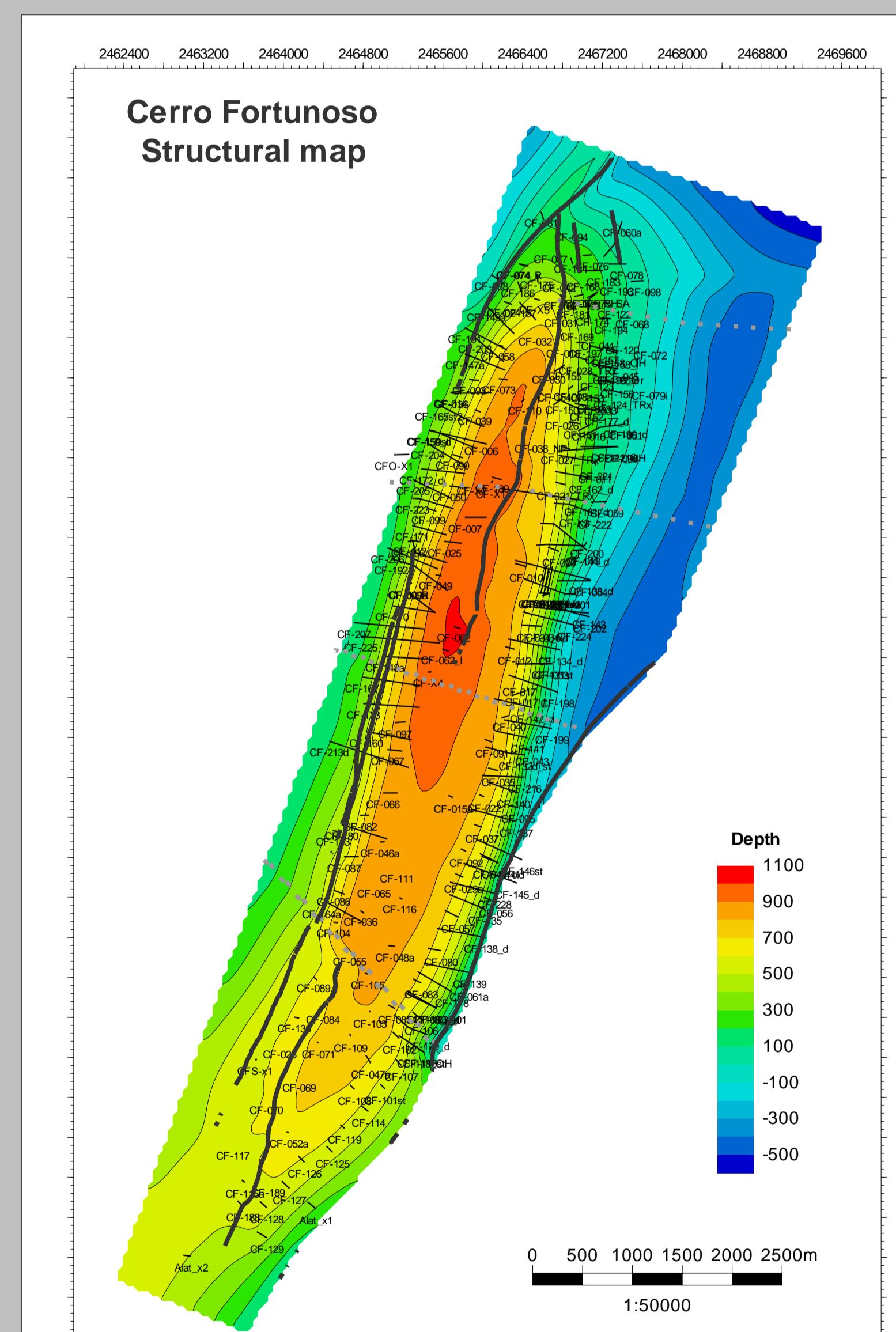
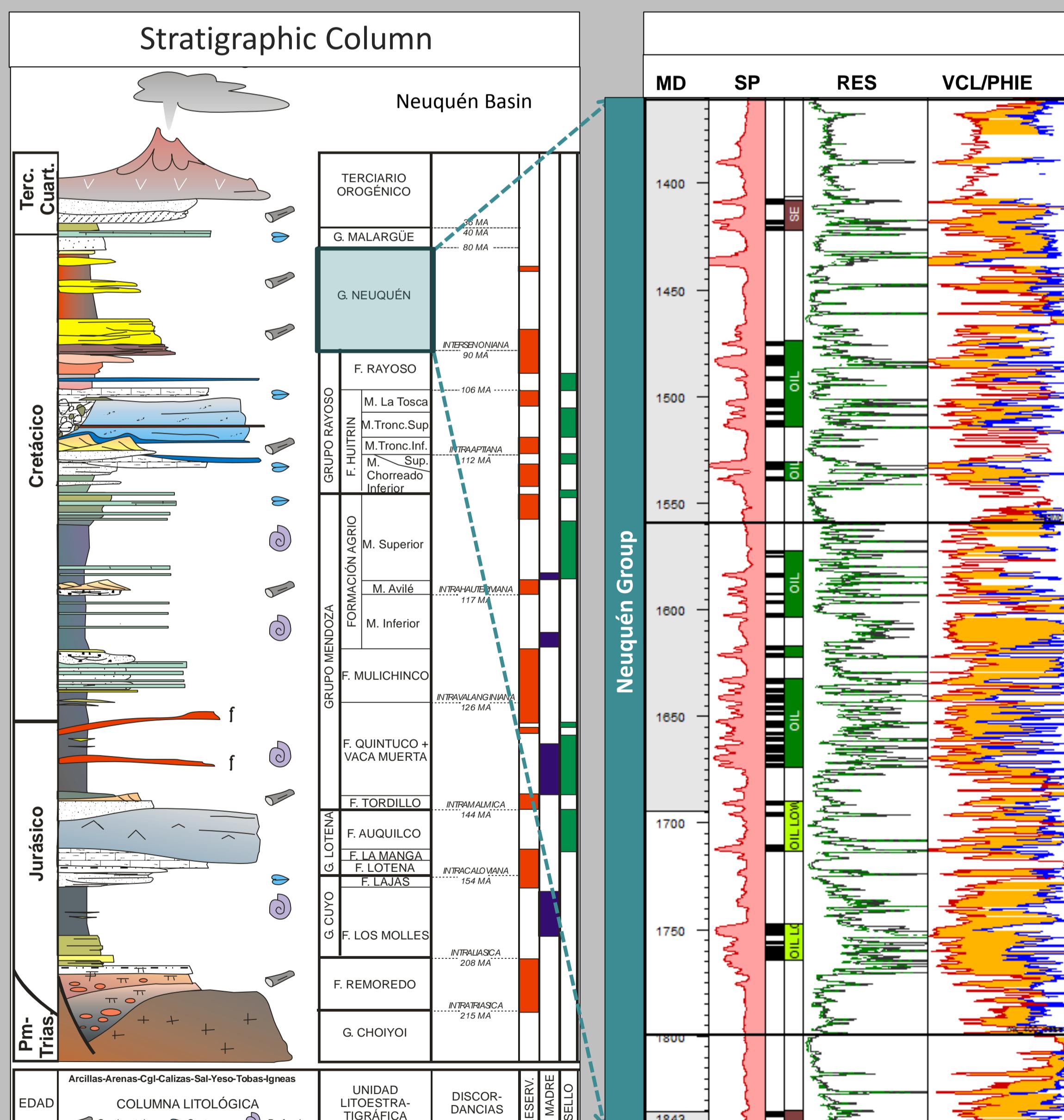
- Neuquén Group (Upper & Middle section)
- Thickness ~ 500 m
- Trap Type: four-dip closure anticline
- Seal: shales (top Neuquén Group & Loncoche Fm)

### STRUCTURE

- East-vergent, slightly asymmetric anticline
- Strike N15°E
- Highly-dipping Eastern flank (central part ~ 80°)
- Complex structure: backthrust, high-angle reverse faults & strike-slip faults

### FIELD HISTORY PRODUCTION

- Discovery 1984 - Oil production 750m<sup>3</sup>/d
- Cumulative production 6.39 Mm<sup>3</sup> (primary)
- Water injection since 1999 - Water cut 50%
- 230 producers + 5 injectors in the NE
- CO<sub>2</sub> gas cap



## CHALLENGES

- Complex structure: Fold & Thrust Belt
- Very poor 2D-Seismic: low signal/noise ratio (basalts on surface)
- High uncertainties within well trajectories
- Highly heterogeneous fluvial system with intrusives
- Viscous oil : low recovery factor
- CO<sub>2</sub> Gas Cap (volcanic activity) and variable WOC

## OPPORTUNITIES

- 8% Recovery Factor (OOIP ~68Mm<sup>3</sup> full field)
- 1.2 Mm<sup>3</sup> by water injection optimization (NE sector)
- 4 Mm<sup>3</sup> by pilot expansion to full field

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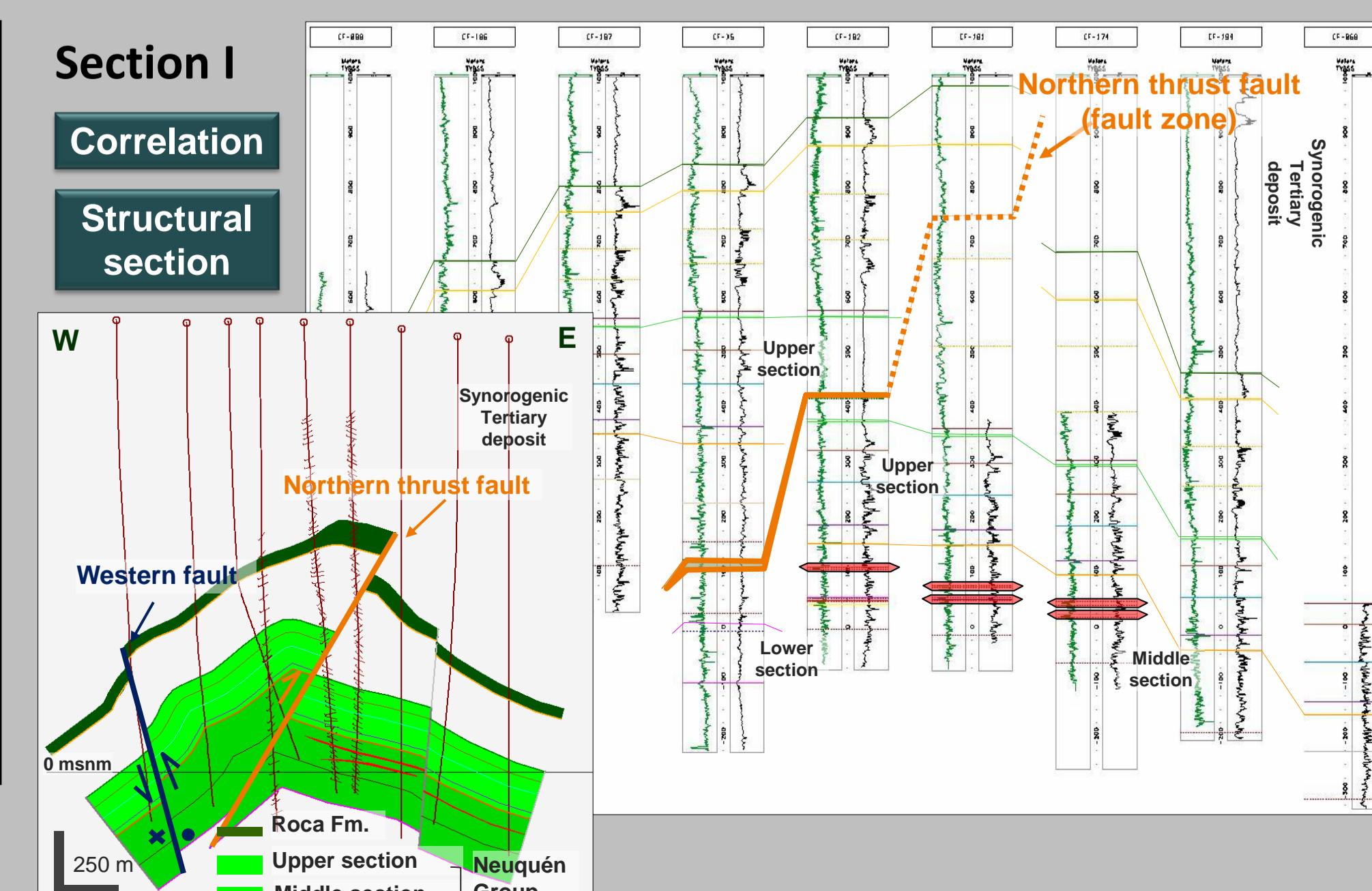
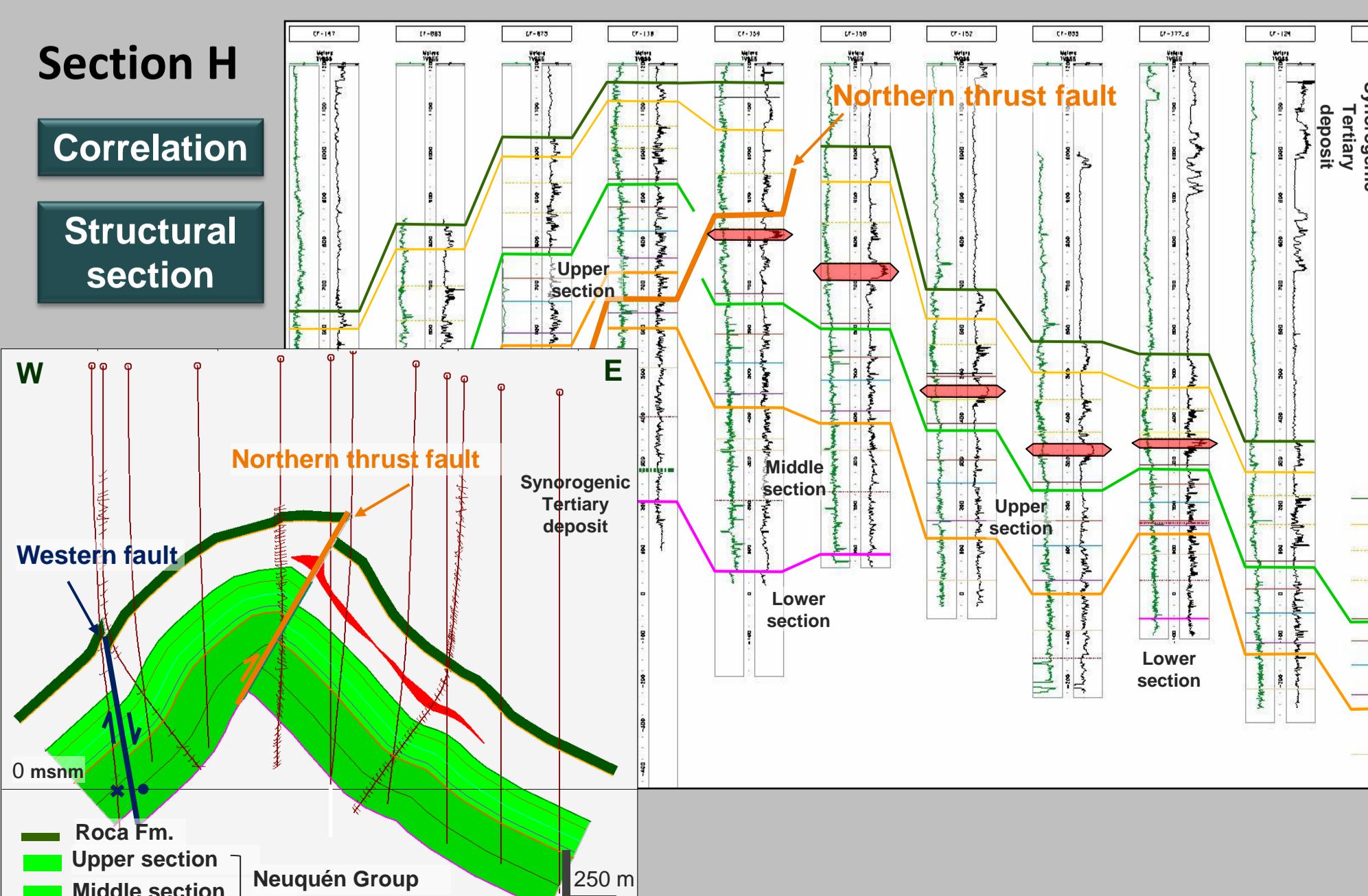
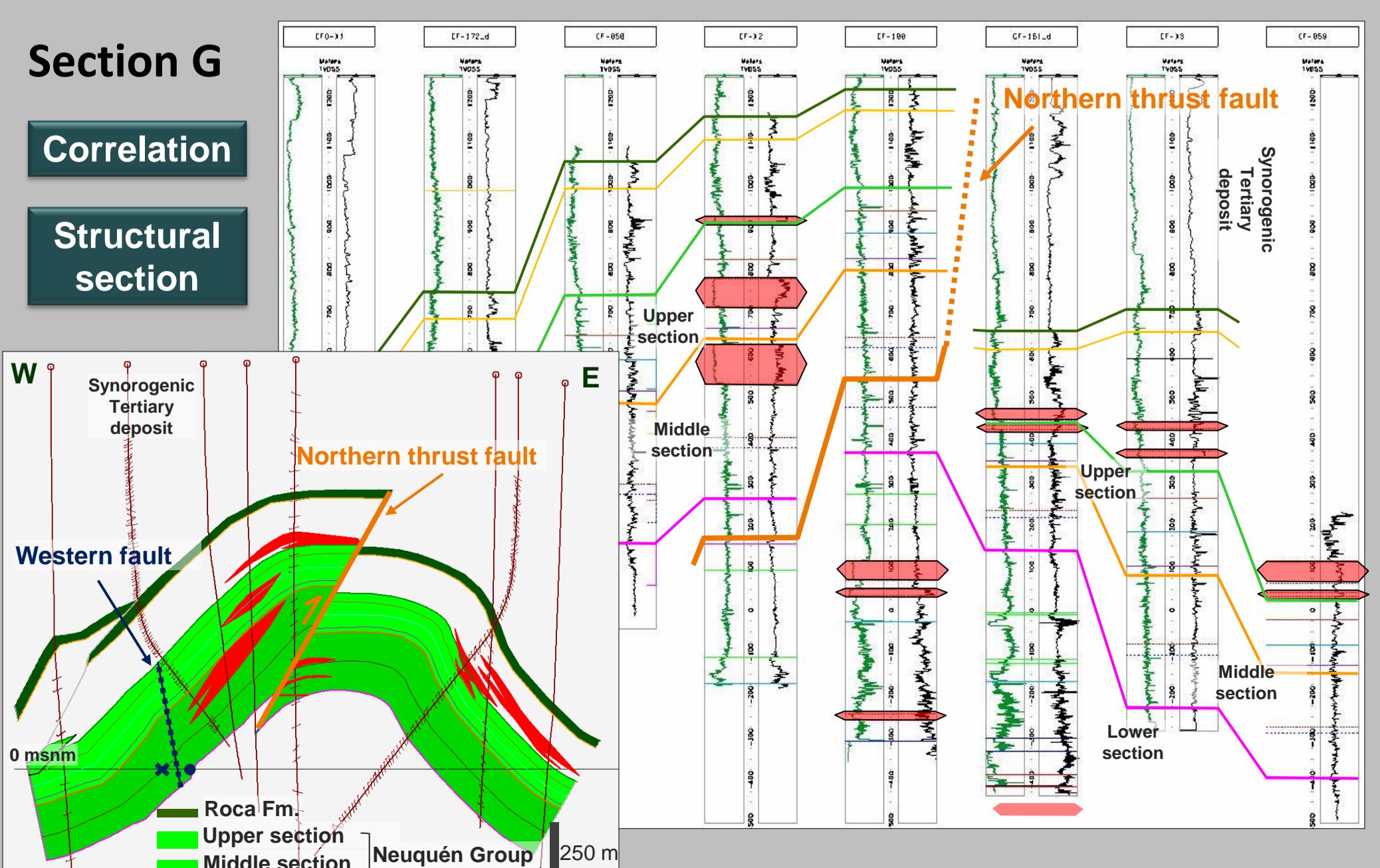
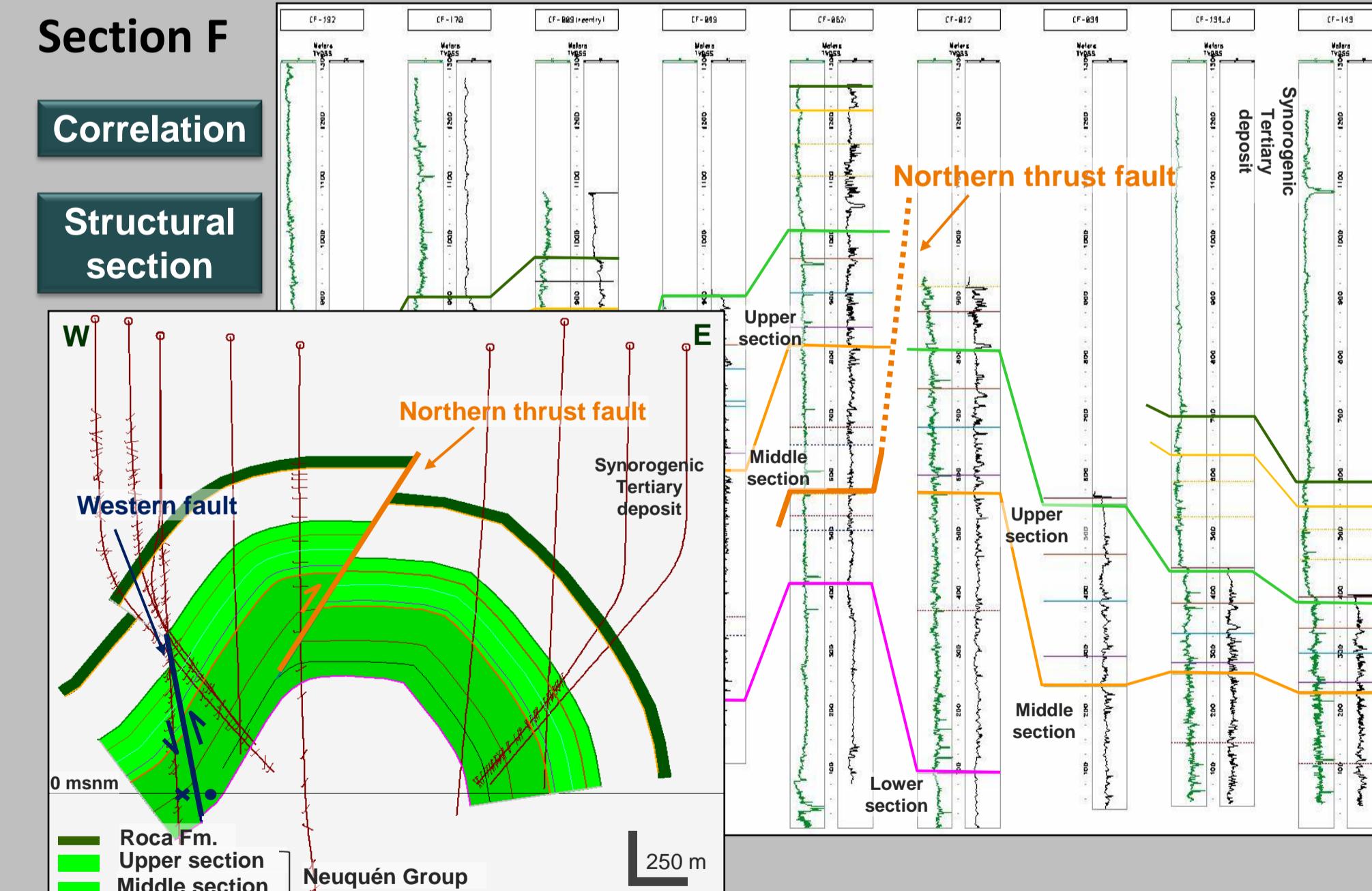
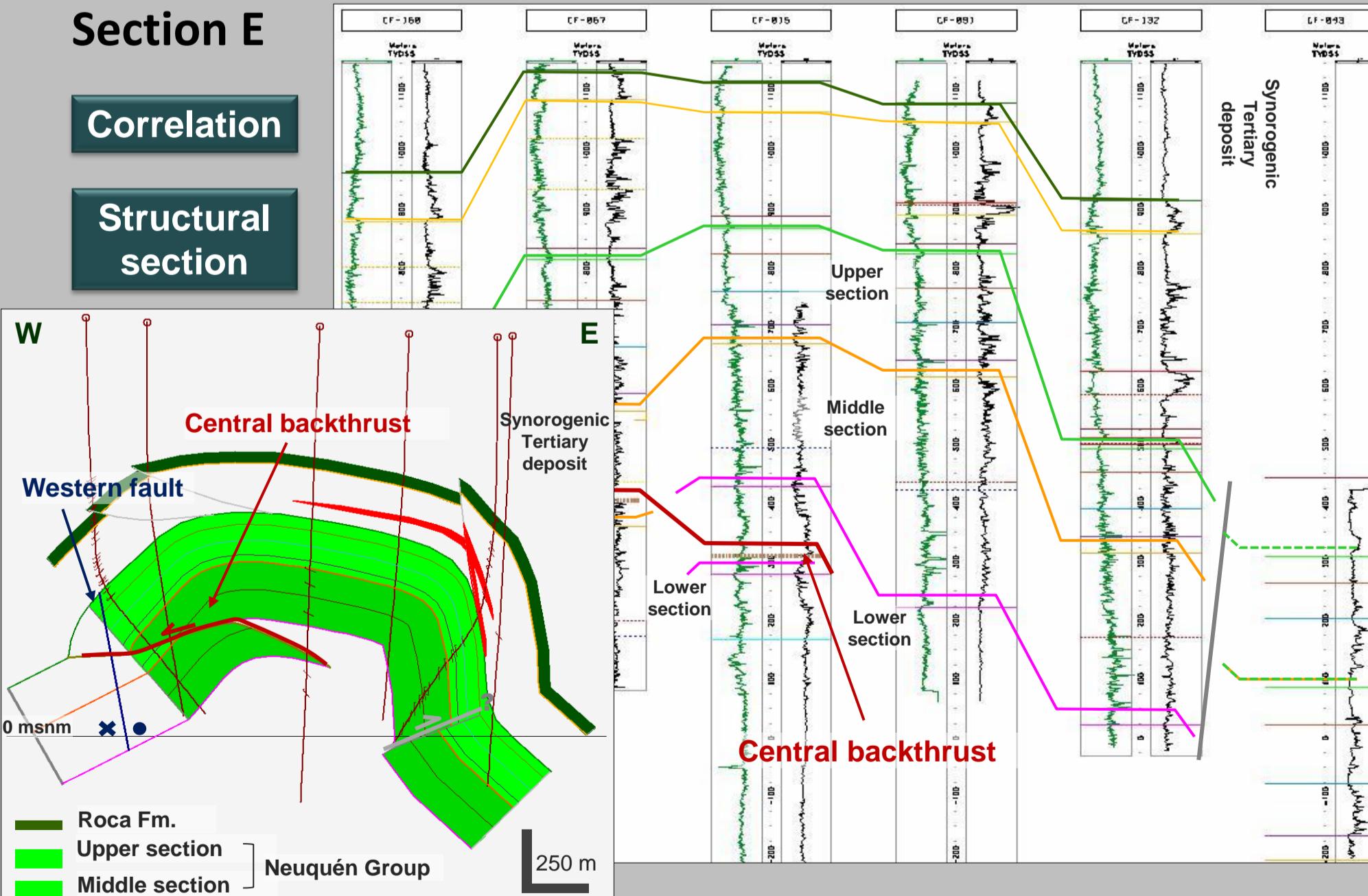
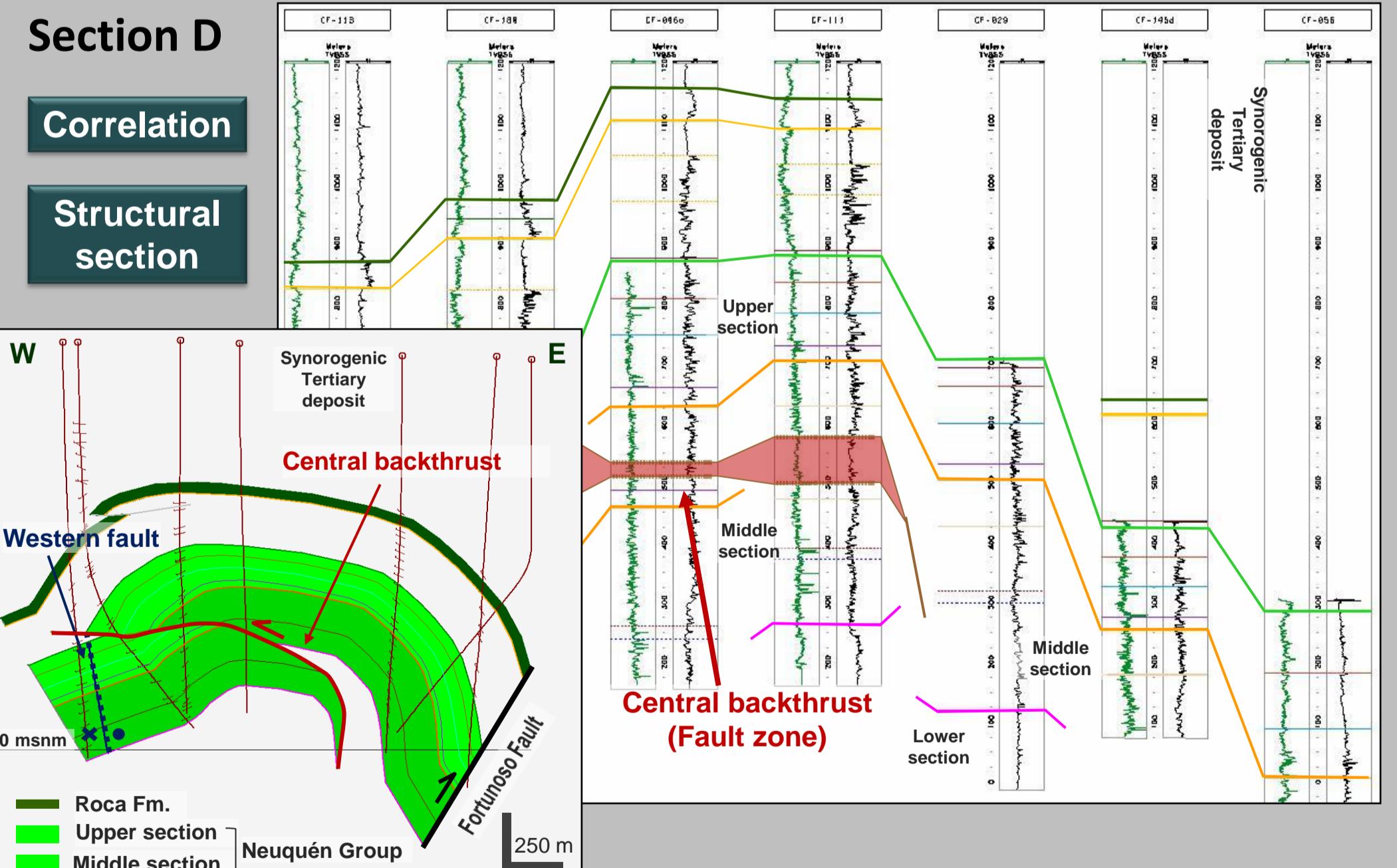
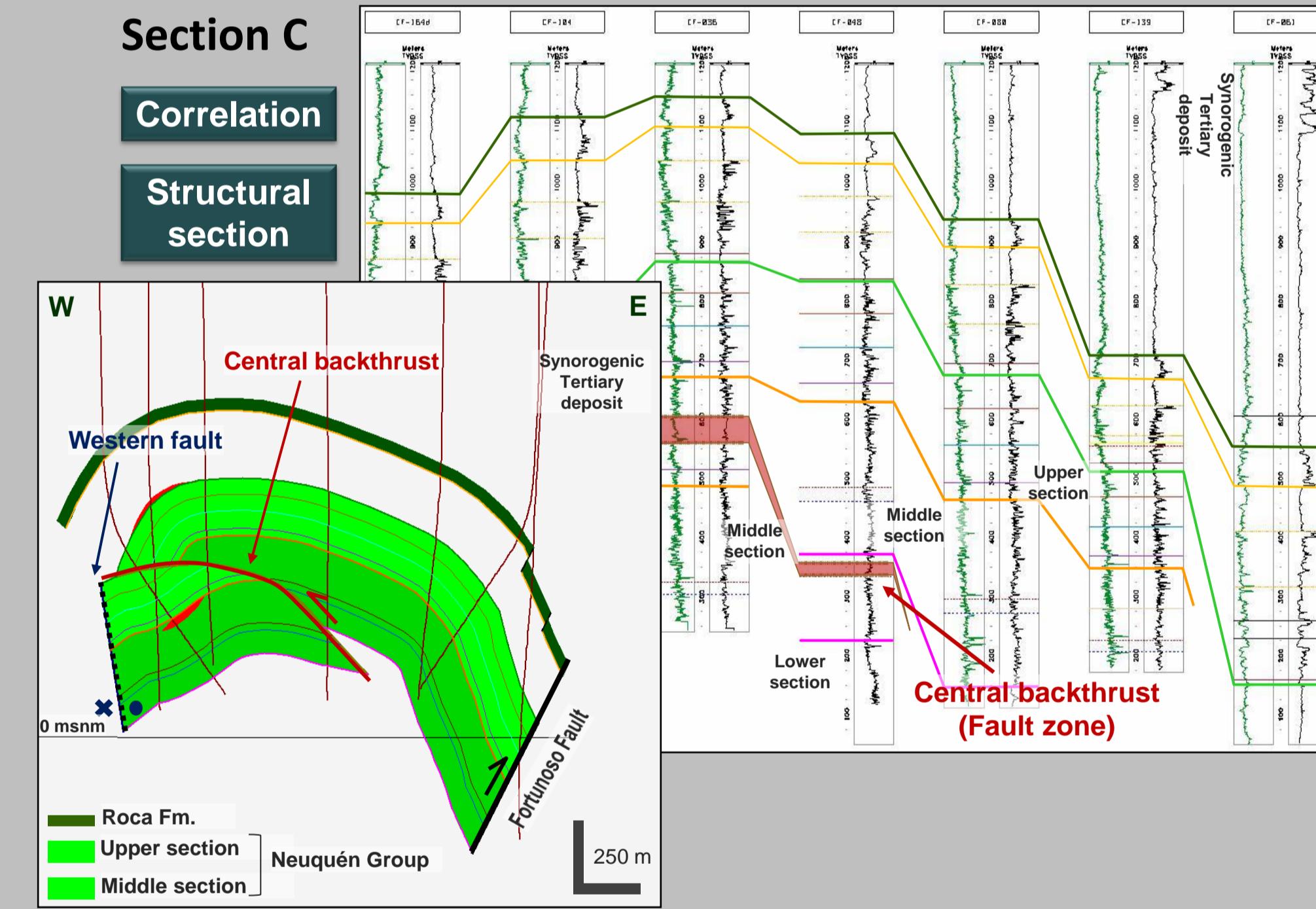
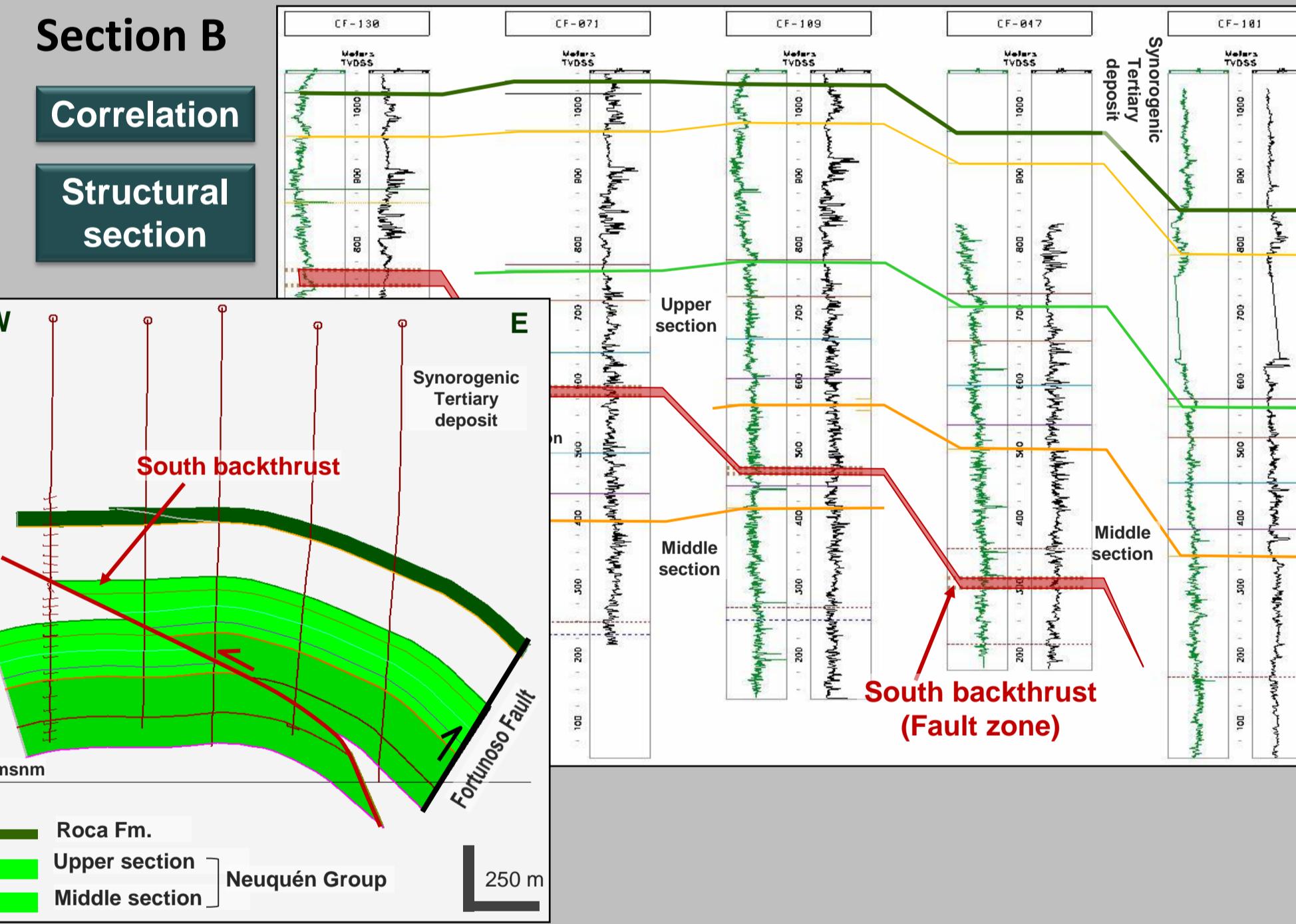
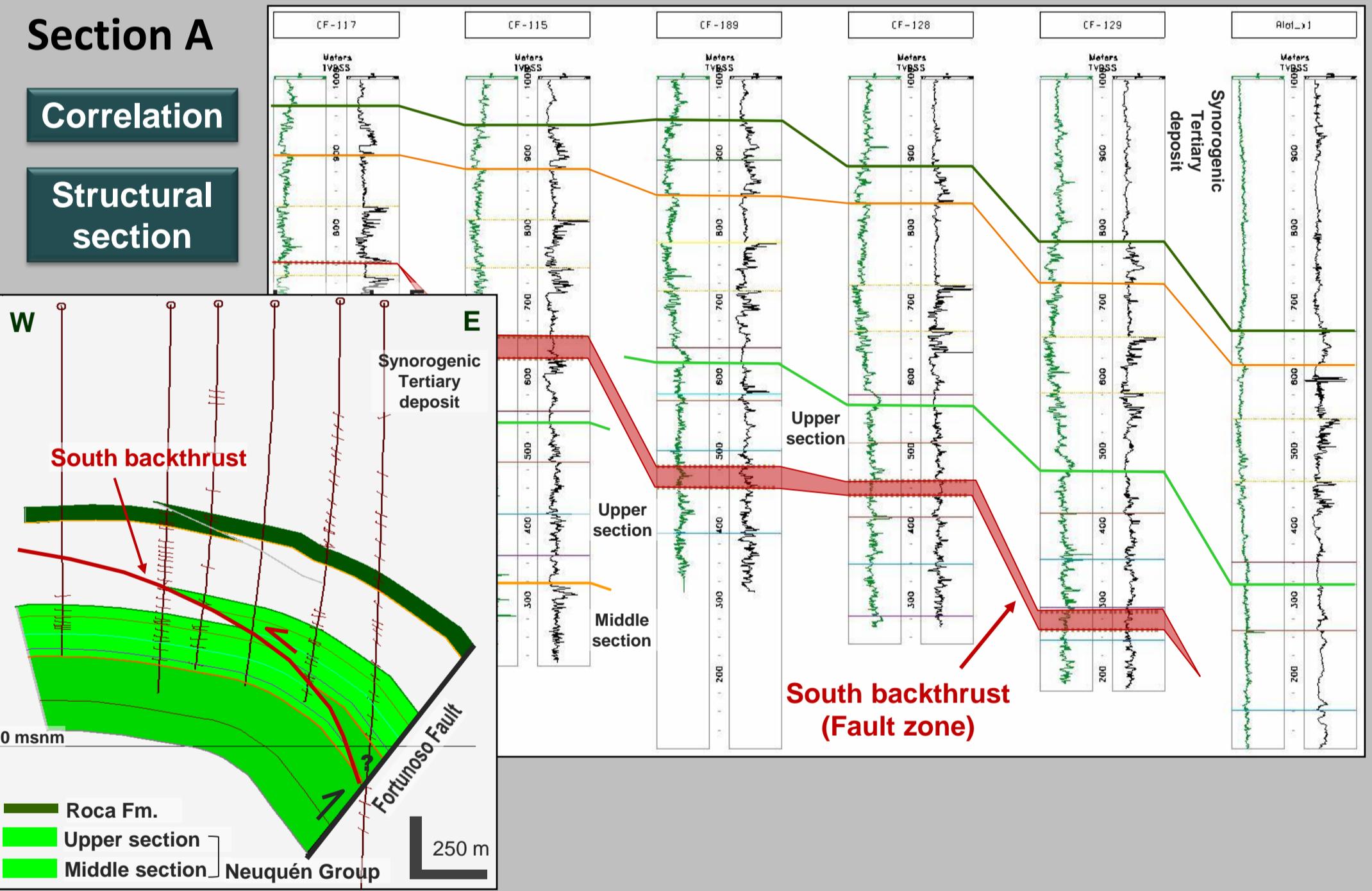
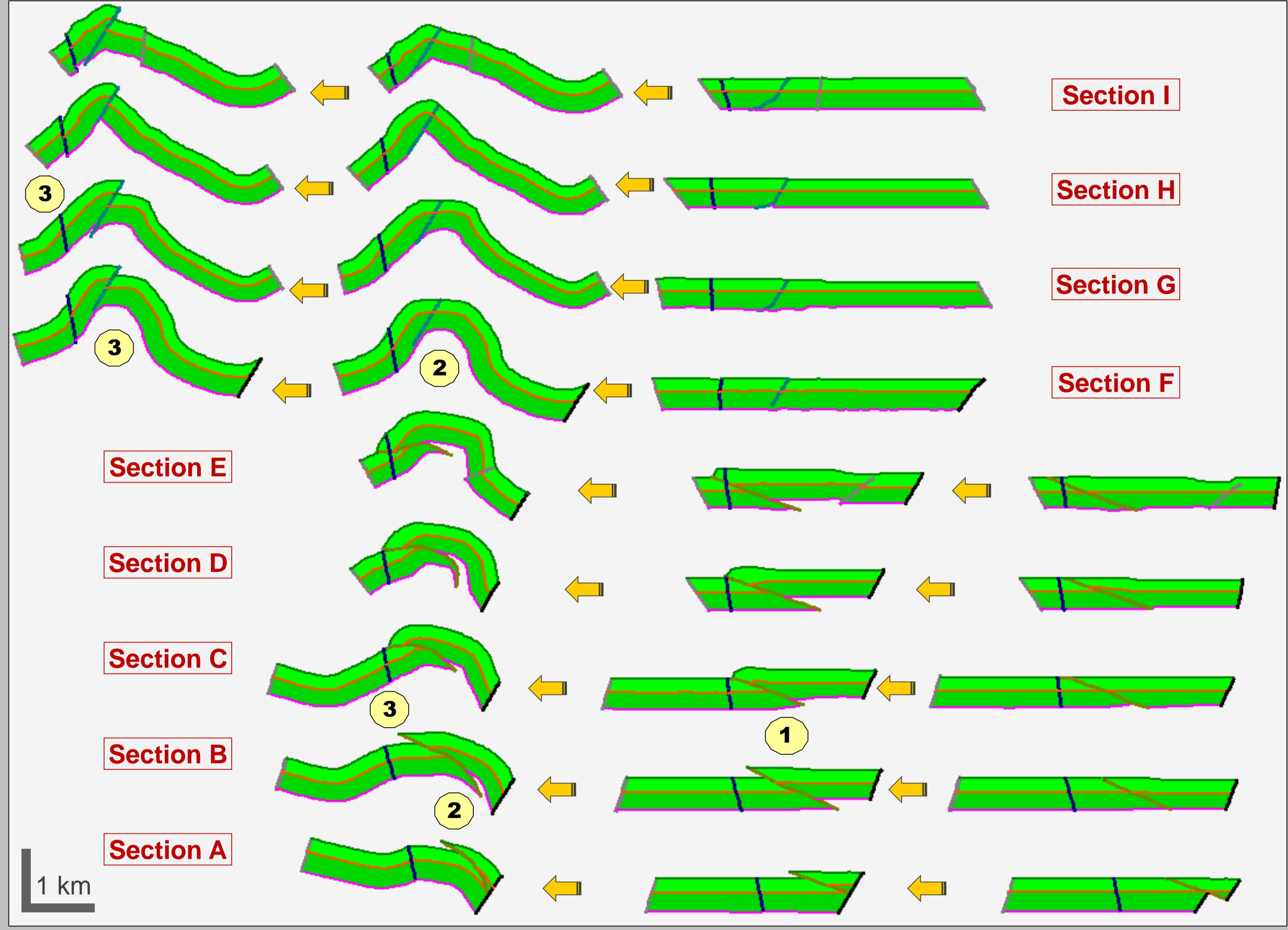
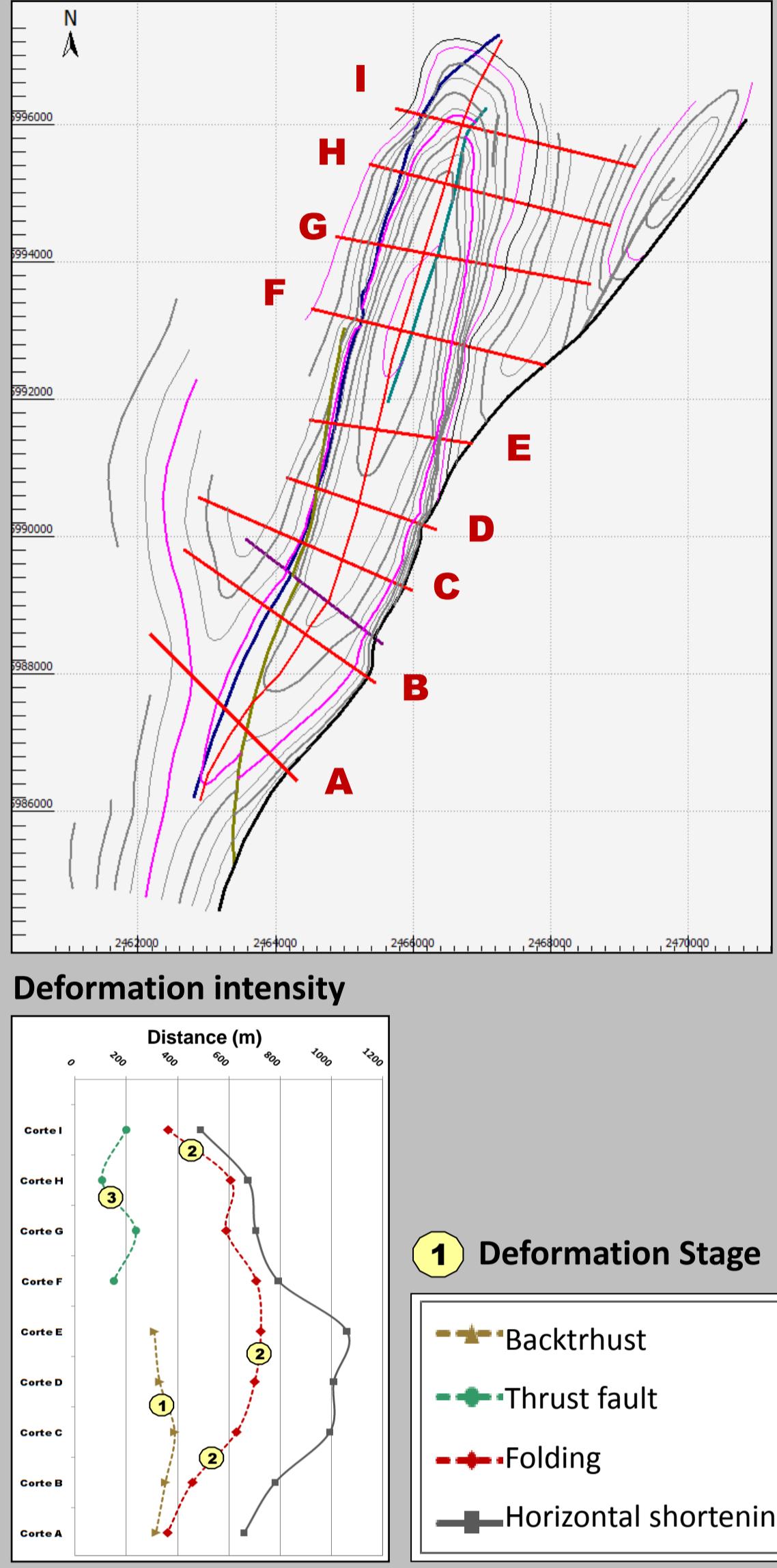
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# STRUCTURAL MODEL BASED ON NINE 2D-BALANCED STRUCTURAL SECTIONS

# KINEMATIC EVOLUTION

- Stage 1 → Development of east-dipping low angle faults (backthrust) in the central and southern portions of the structure.
  - Stage 2 → Fault-associated folding of possibly occurring through tectonic inversion. Backthrusts formed in the previous stage are folded together with the sedimentary sequence
  - Stage 3 → Possible halt of folding giving way to high-angle inverse and/or strike-slip faults
  - Stage 4 → Anticline segmentation due to strike-slip faulting

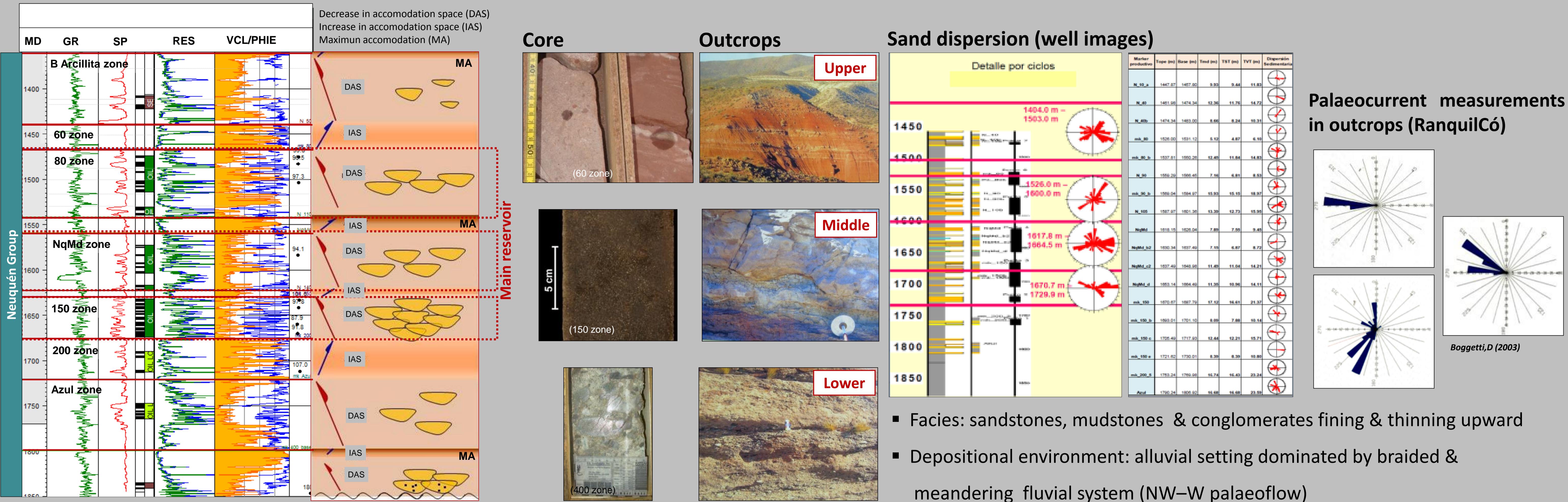


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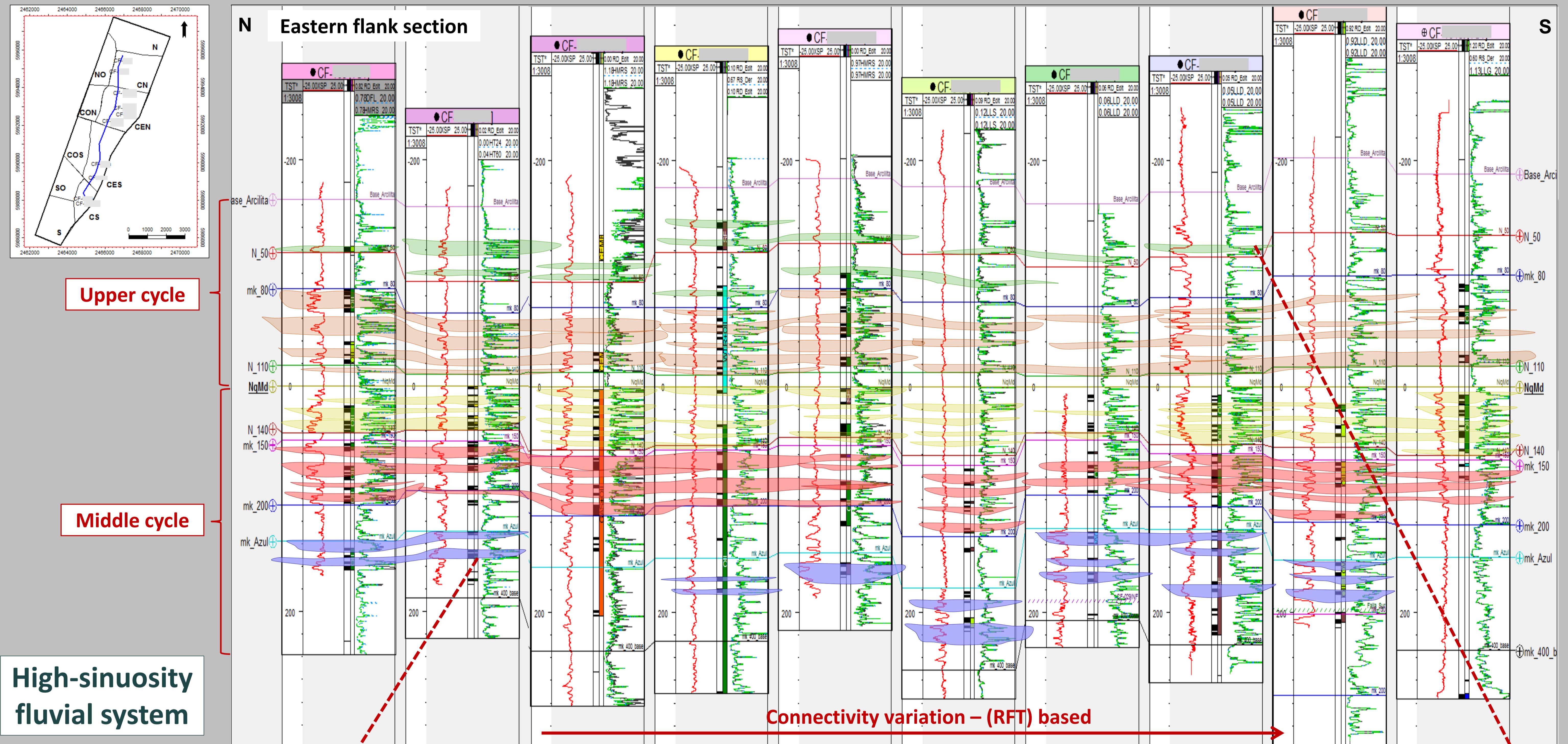
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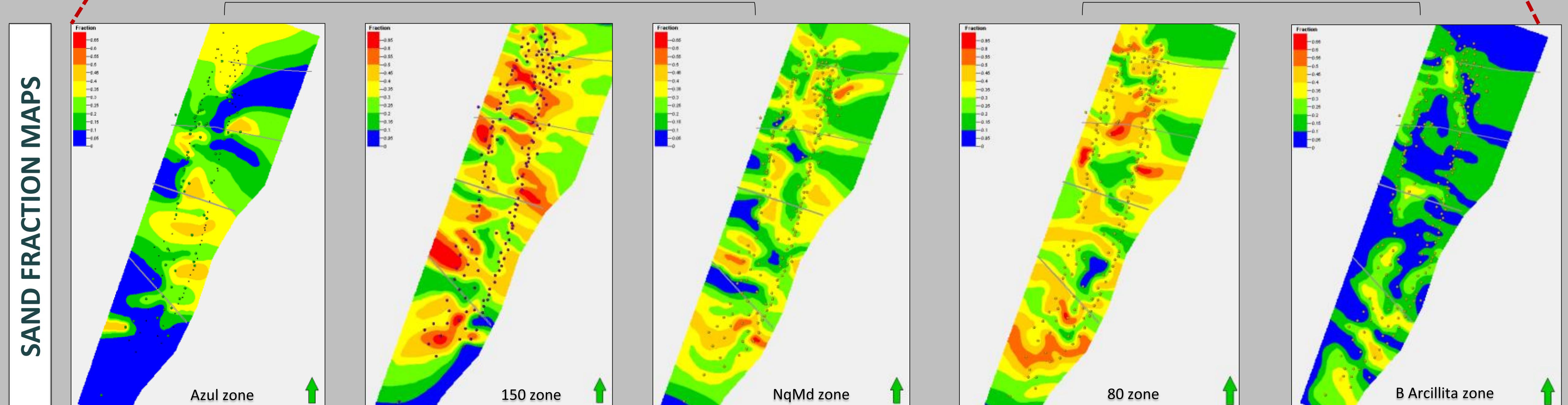
# STRATIGRAPHIC INTERPRETATION



# CORRELATION SCHEME: CONNECTIVITY



- For each zone a series of **sand fraction maps** were generated, later used to guide 3D-property distribution, honoring stratigraphic control on reservoir quality.

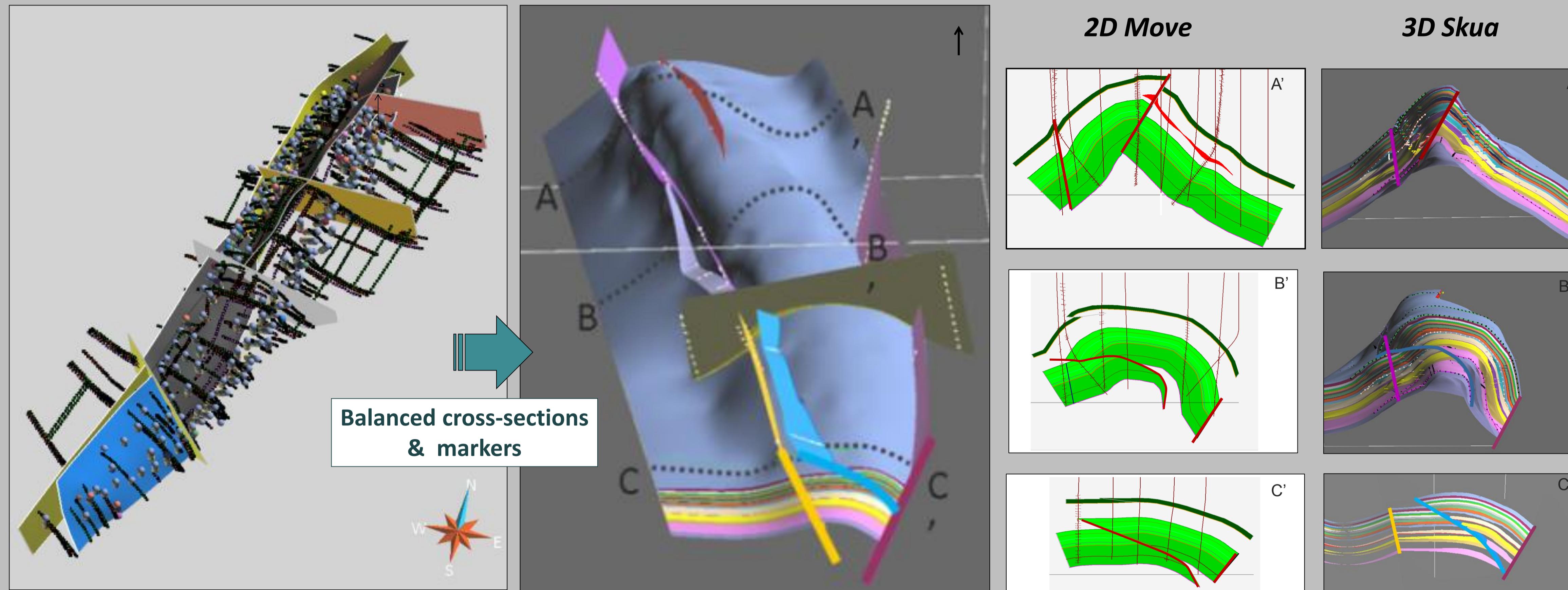


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## 3D STRUCTURAL MODEL



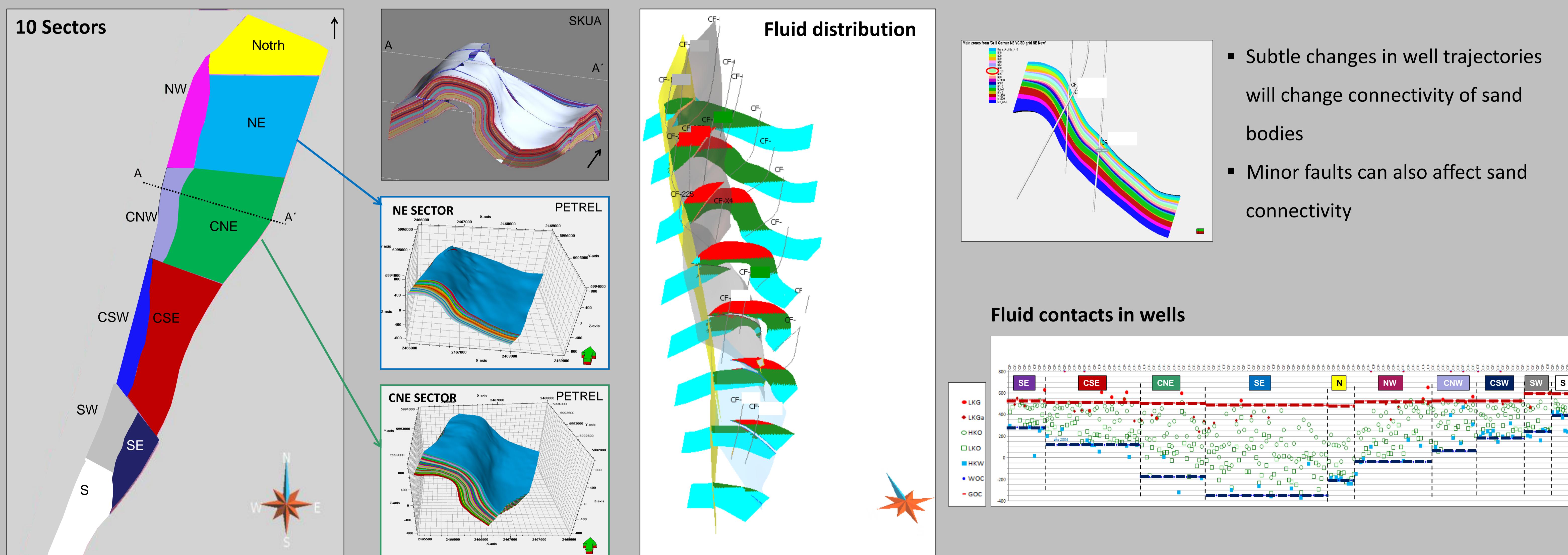
## Complex Structure captured in Static Model

- Thickness preservation within correlated cycles
- Complex thrust faults & stratigraphic repetitions
- High dipping flanks (15 to 80°)
- Variable OW contacts along fault system

The 2011-2012 drilling campaign

(8 wells) validated the proposed model

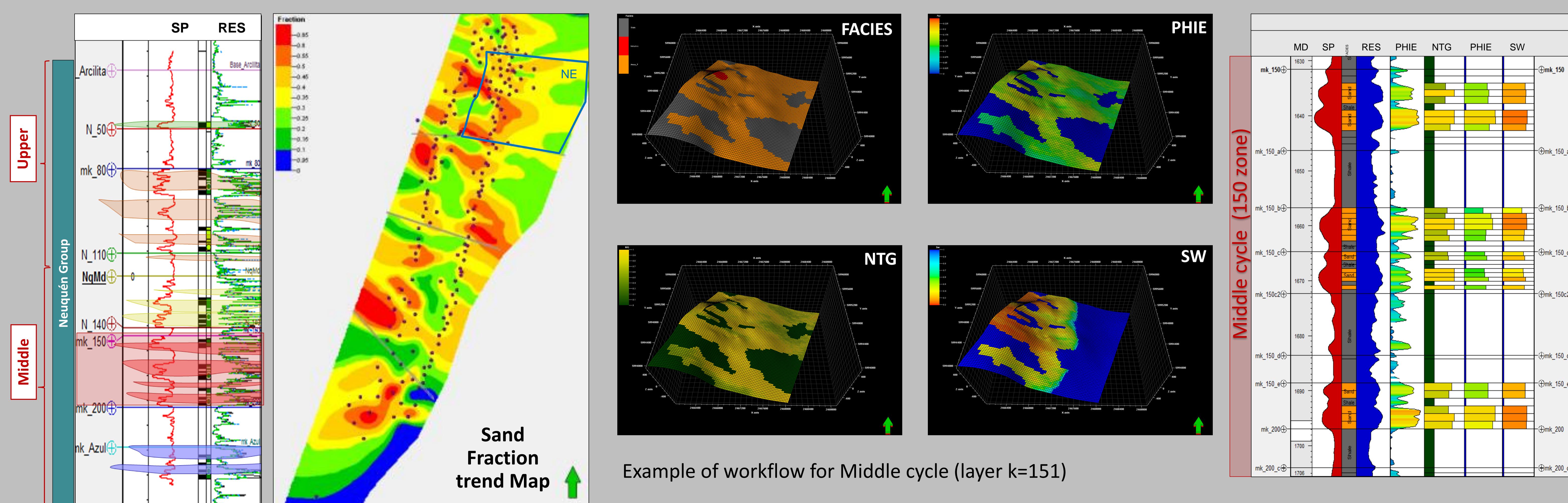
## SECTOR MODELS



- Subtle changes in well trajectories will change connectivity of sand bodies
- Minor faults can also affect sand connectivity

## Fluid contacts in wells

## NE SECTOR PROPERTIES



Example of workflow for Middle cycle (layer k=151)

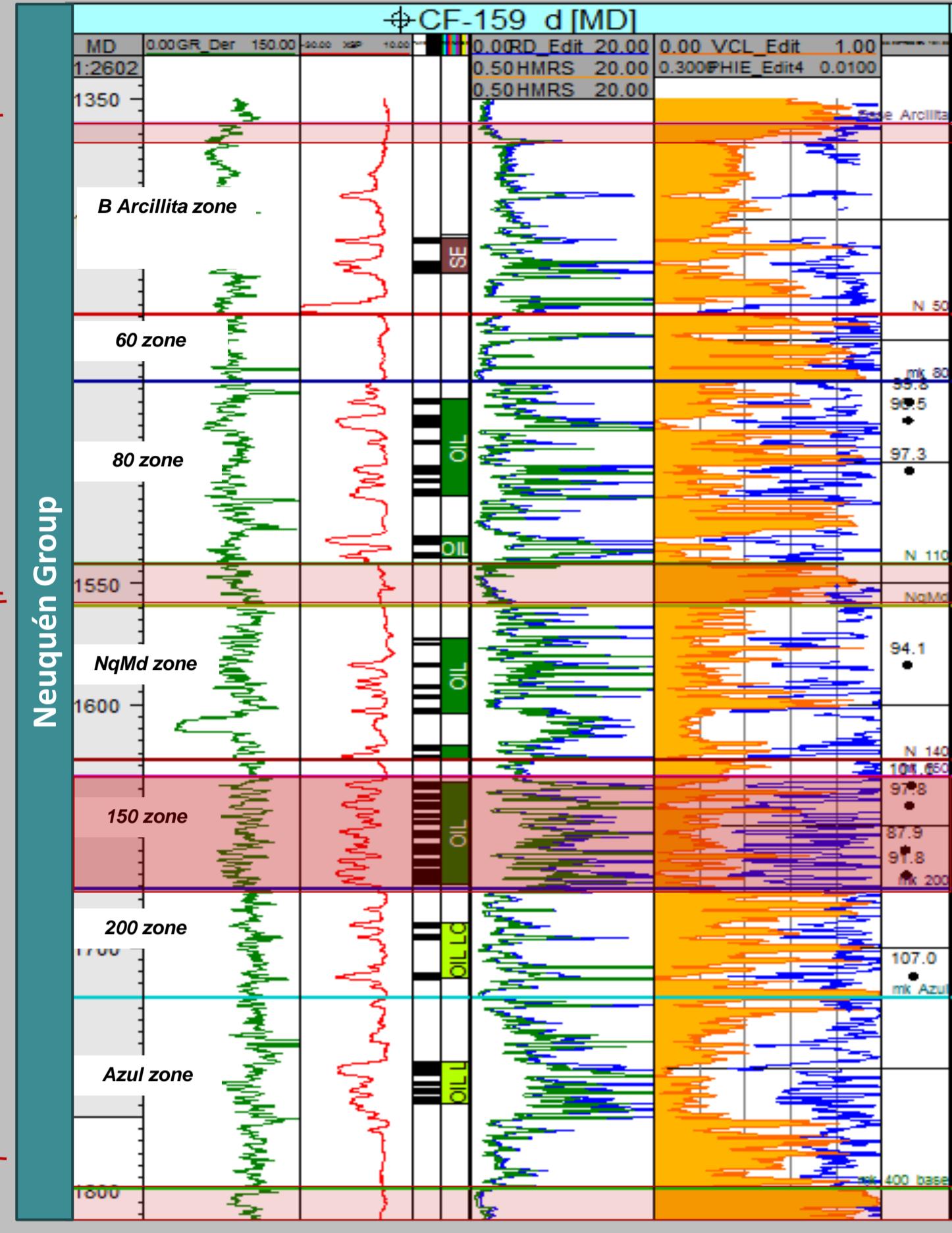
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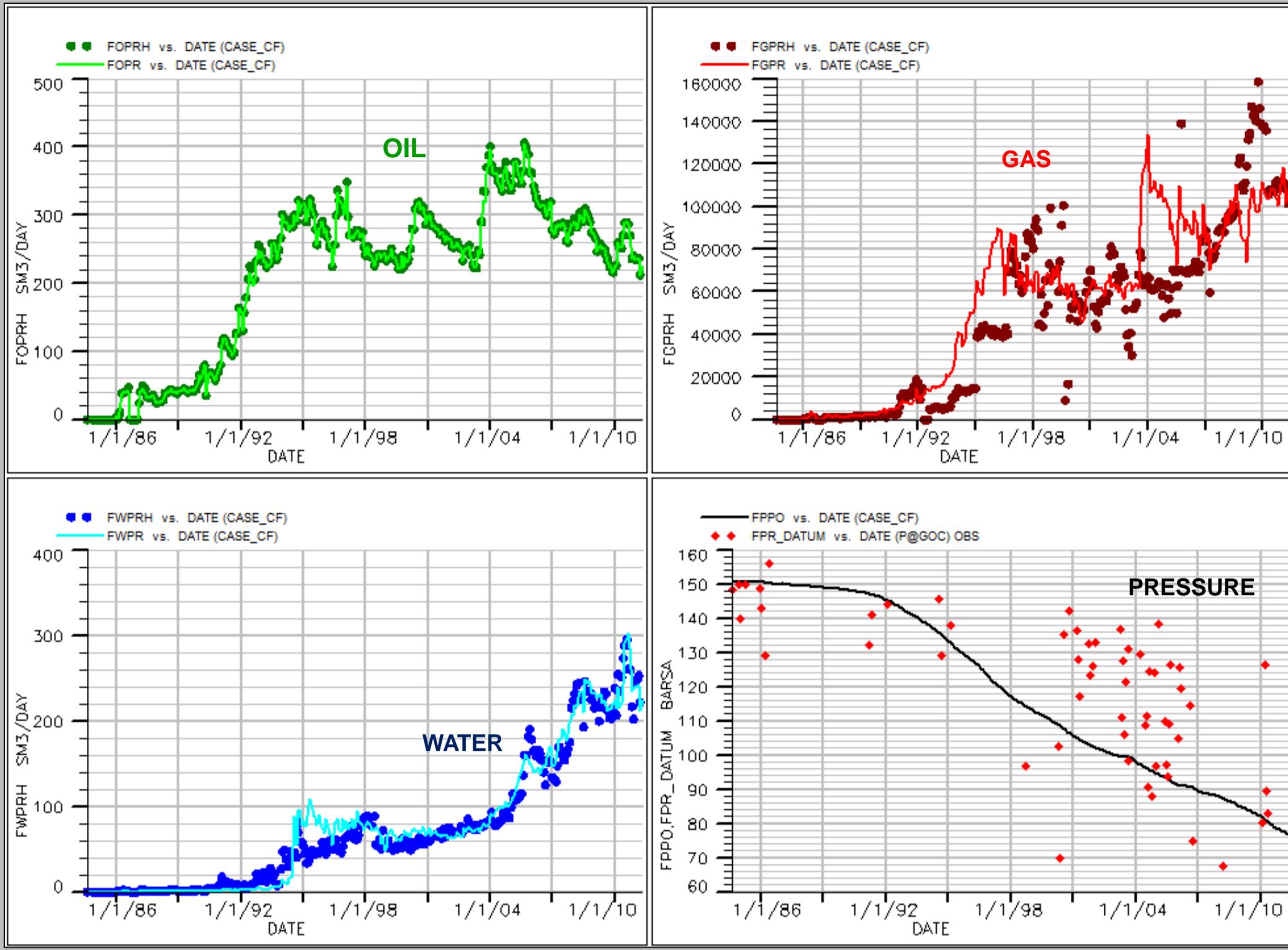


## STATIC - DYNAMIC INTERACTION

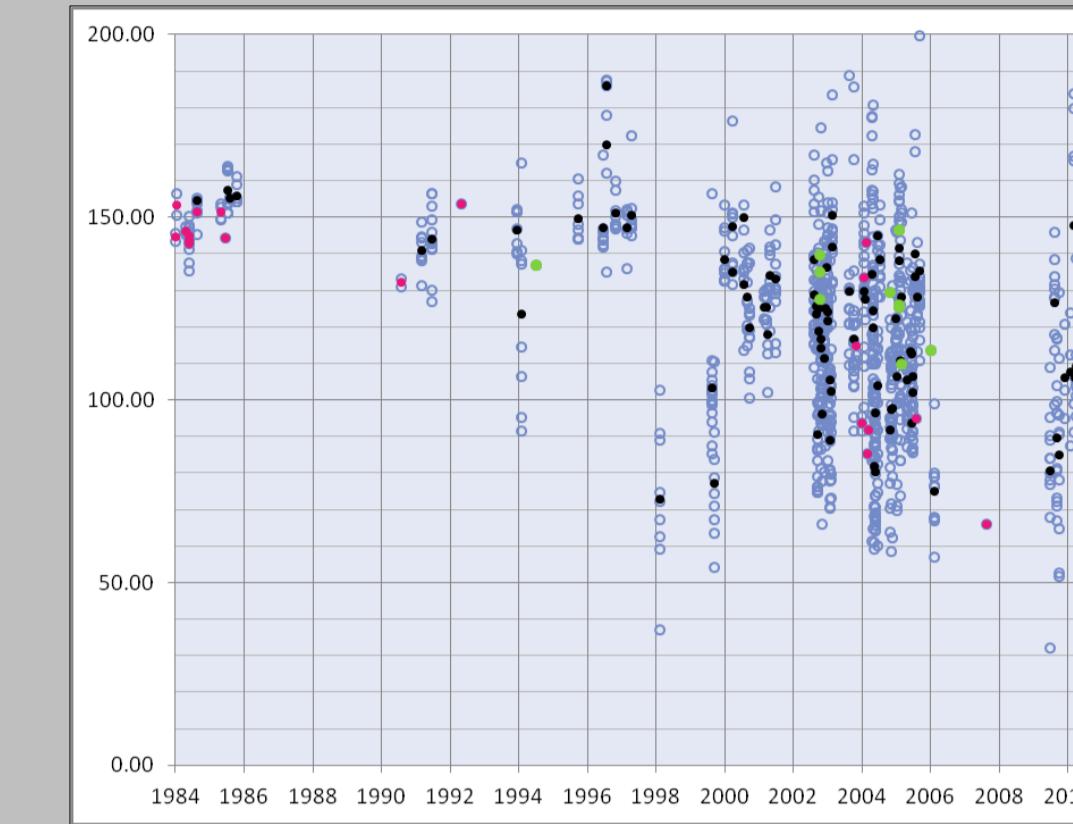
### INITIAL CORRELATION – 17 ZONES



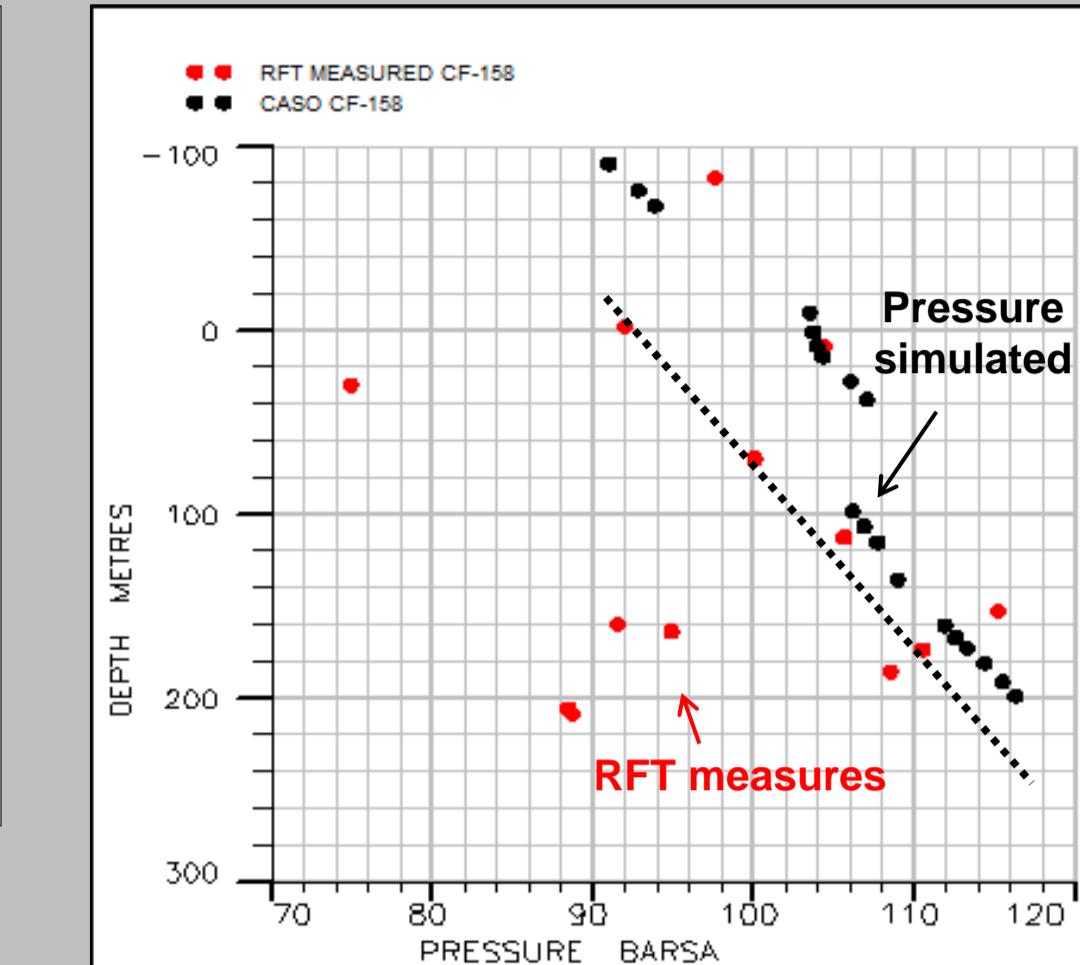
### History match



### Field pressure data



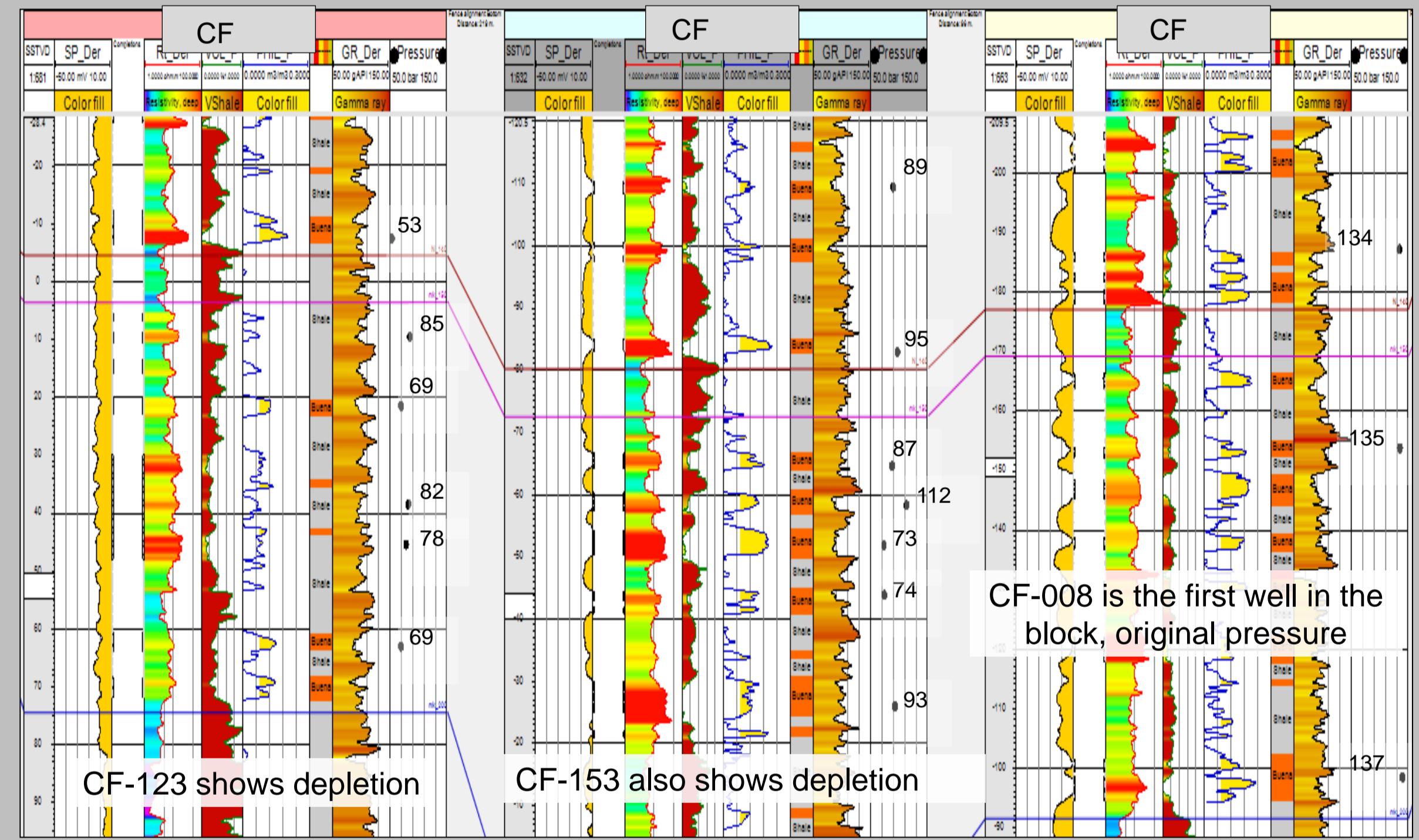
### Pressure mismatch



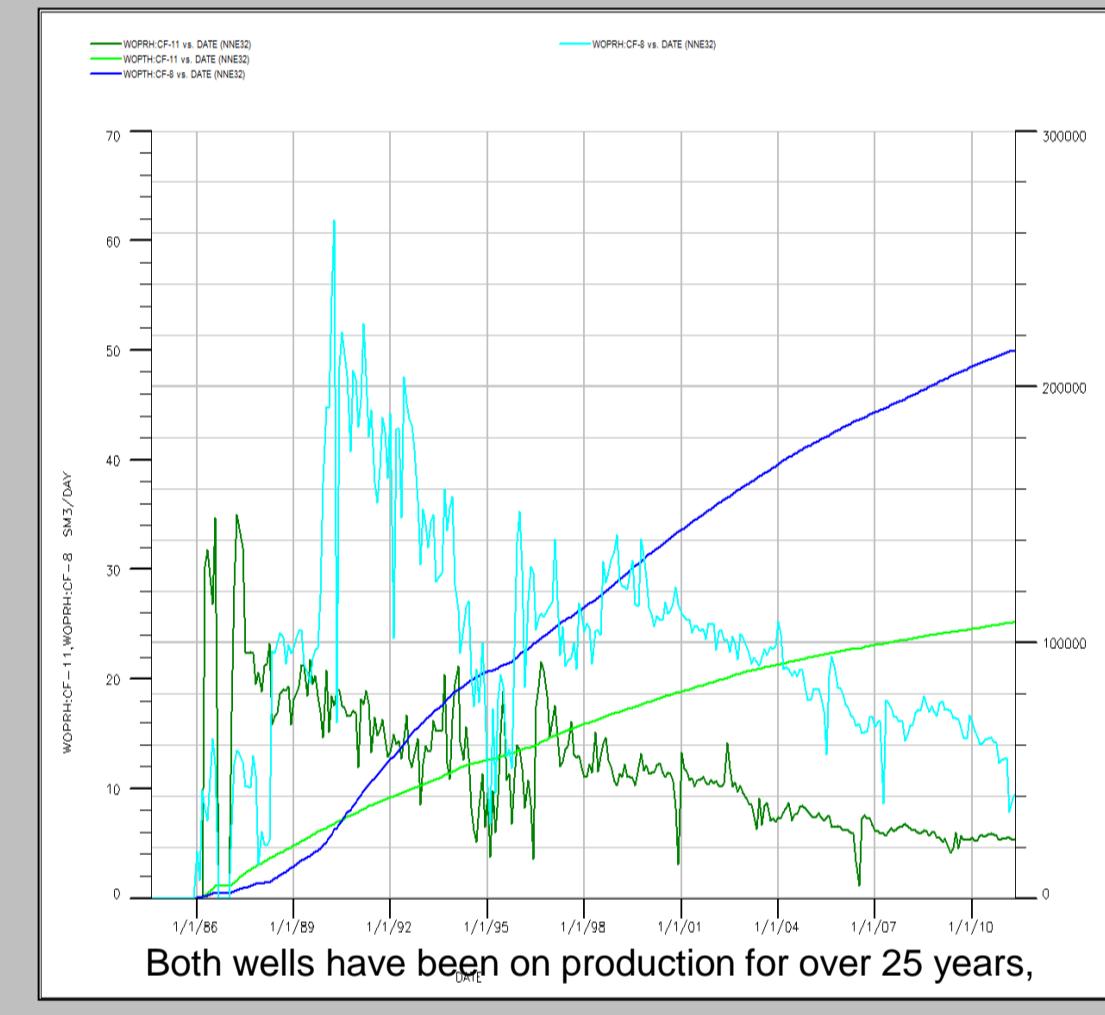
Challenge:  
How to correlate  
these sandstones?

## GEOLOGICAL MODEL CONSTRAINED BY DYNAMIC DATA

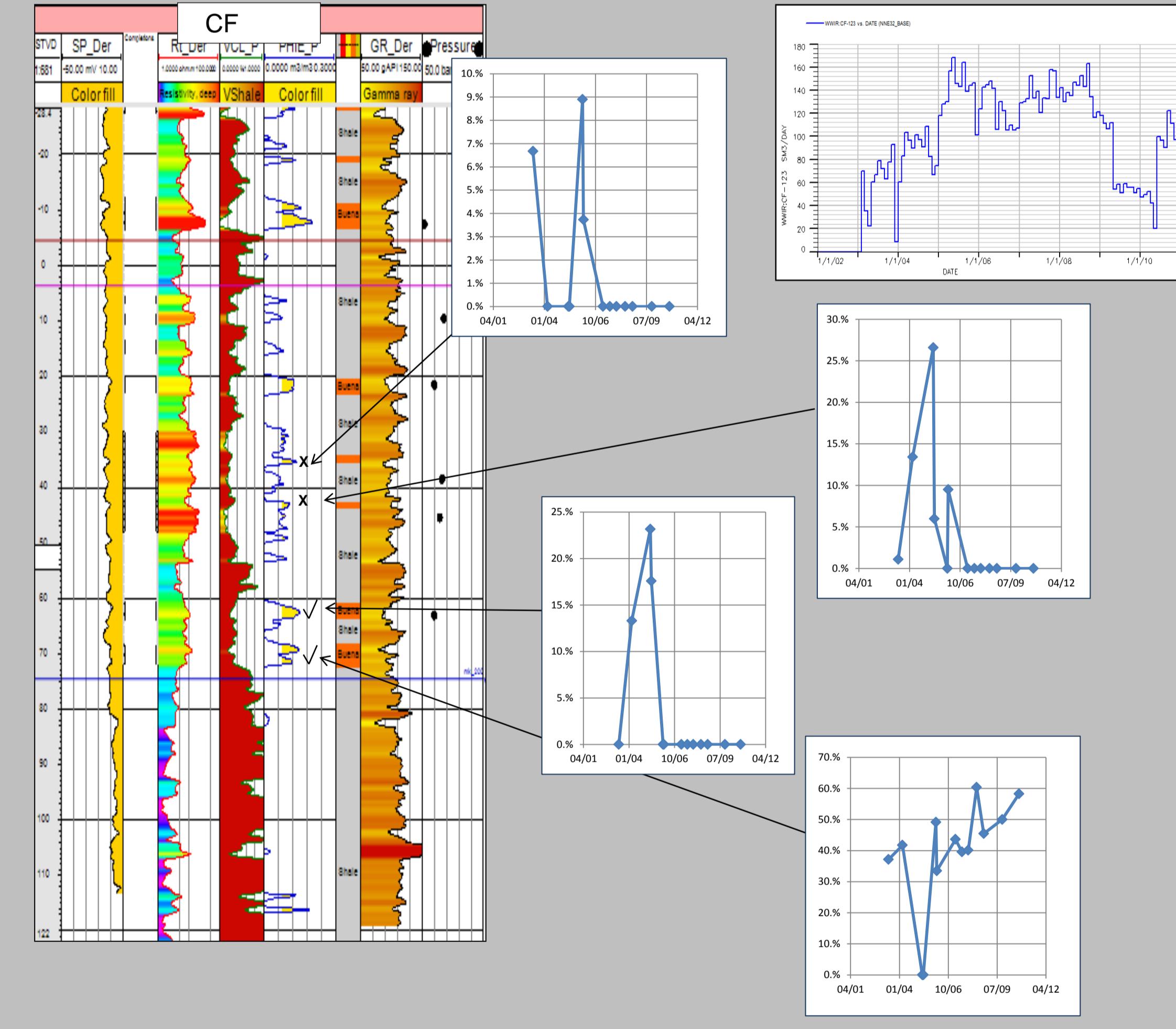
### Static Pressure Data



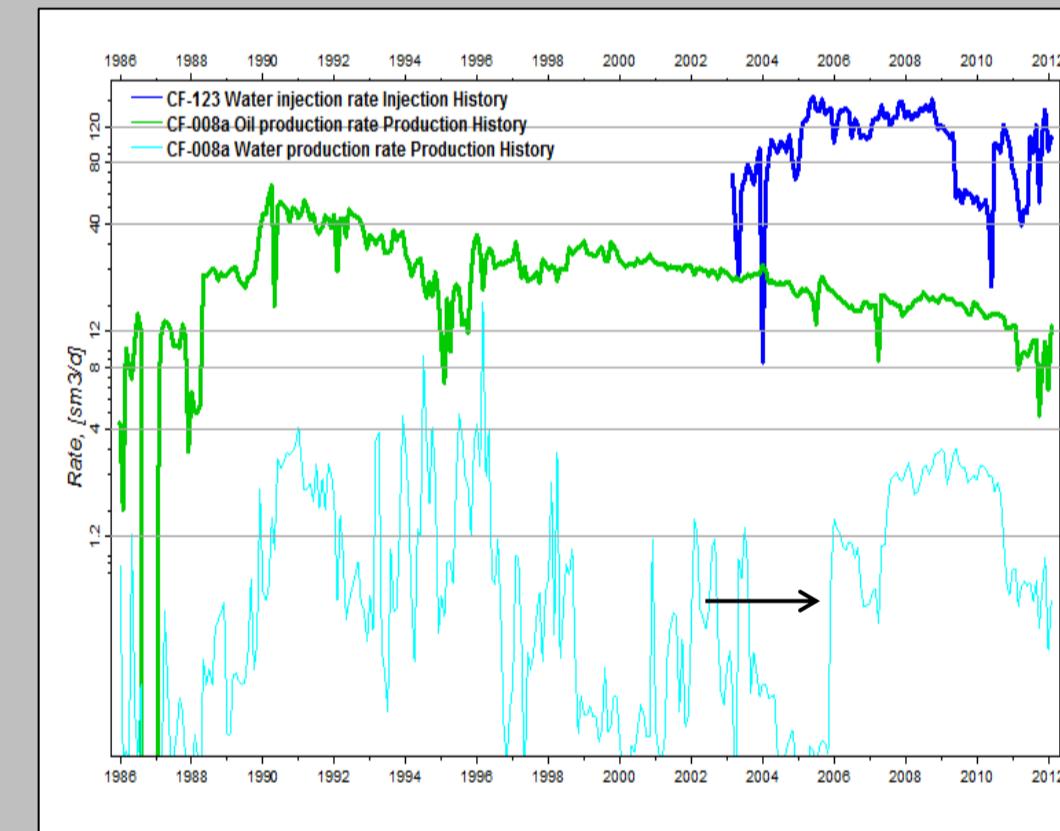
### Cumulative production



### Transit fluid log

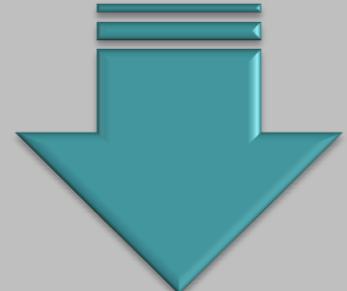


### Production & injection response



## RESULTS & CONCLUSIONS

- NEW ECONOMIC WATERFLOOD SCENARIOS
- FULL-FIELD INCREMENTAL EXPANSION  $\sim 4\text{Mm}^3$



- Static-Dynamic integration
- New stratigraphic correlation at flow units level
- Accurate understanding of the complex structure

### FINAL CORRELATION – 35 ZONES

