

3D Geological Modeling and Performance Simulation of a Leveed-Channel Outcrop with Application to Deepwater Leveed-Channel Reservoirs*

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Search and Discovery Article #50728 (2012)**

Posted October 8, 2012

*Adapted from oral presentation at AAPG Annual Convention and Exhibition, Long Beach, California, April 22-25, 2012

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Abstract

An outcrop of the Cretaceous Dad Sandstone member of the Lewis Shale---termed Rattlesnake Ridge---is an analog to deepwater leveed-channel deposits. It consists of four stacked channel-fill sandstones which are flanked by thin-bedded levees. A 3D geologic-petrophysical model was constructed using PetrelTM. Input data included: (a) numerous measured stratigraphic sections, (b) a 3D ground penetrating radar survey, and (c) petrophysical and reservoir data from a nearby cored and logged research well through similar strata, as well as from Tahoe Field in the Gulf of Mexico. Flow simulation using EclipseTM was completed specifically to evaluate the effect of muddy channel-drape slumps on production and compartmentalization between channel sandstones and adjacent thin beds.

Five depletion simulations and fifteen waterflood simulations were generated, each with different permeability of the slumps and injector well locations. Results showed that low-permeability (<1 md) slumps prevented water coning from below, while higher-permeability (up to 40 md) slumps allowed coning.

Channel-drape slumps are common in leveed-channel reservoirs and can cause compartmentalization, yet they are likely to be deleted during the upscaling process for reservoir simulation. Our simulations over a 10 year period resulted in a 44% higher oil production and an additional 4 year field life between the low permeability and high permeability slumps. We conclude that deleting such small-scale features in an upscaled model can lead to erroneous simulation of reservoir performance.

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Outline

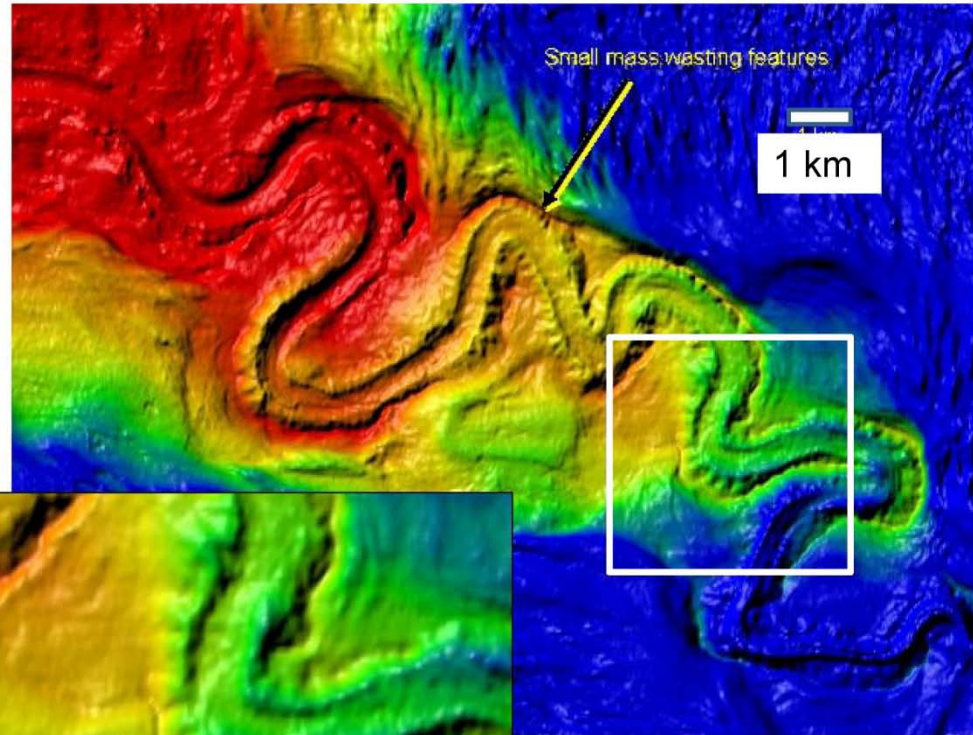
- *Concepts*
- *Objective*
- *Area of Study and Regional Geology*
- *Geological Model*
- *Flow Simulation*
- *Recommendations*
- *Conclusions*

Outline

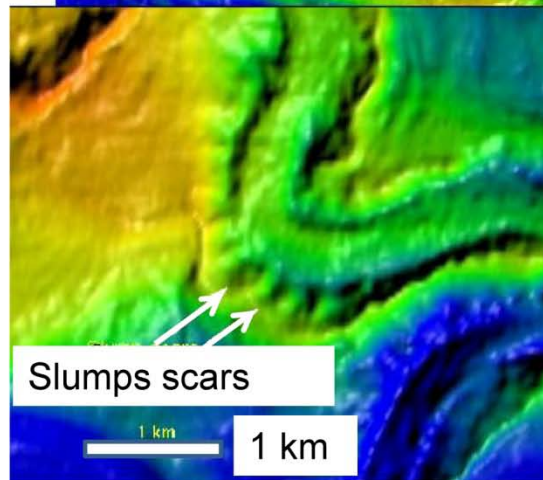
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Concepts

- *Slumps*



Modified from
H. Posamentier
(VSA - 2010)

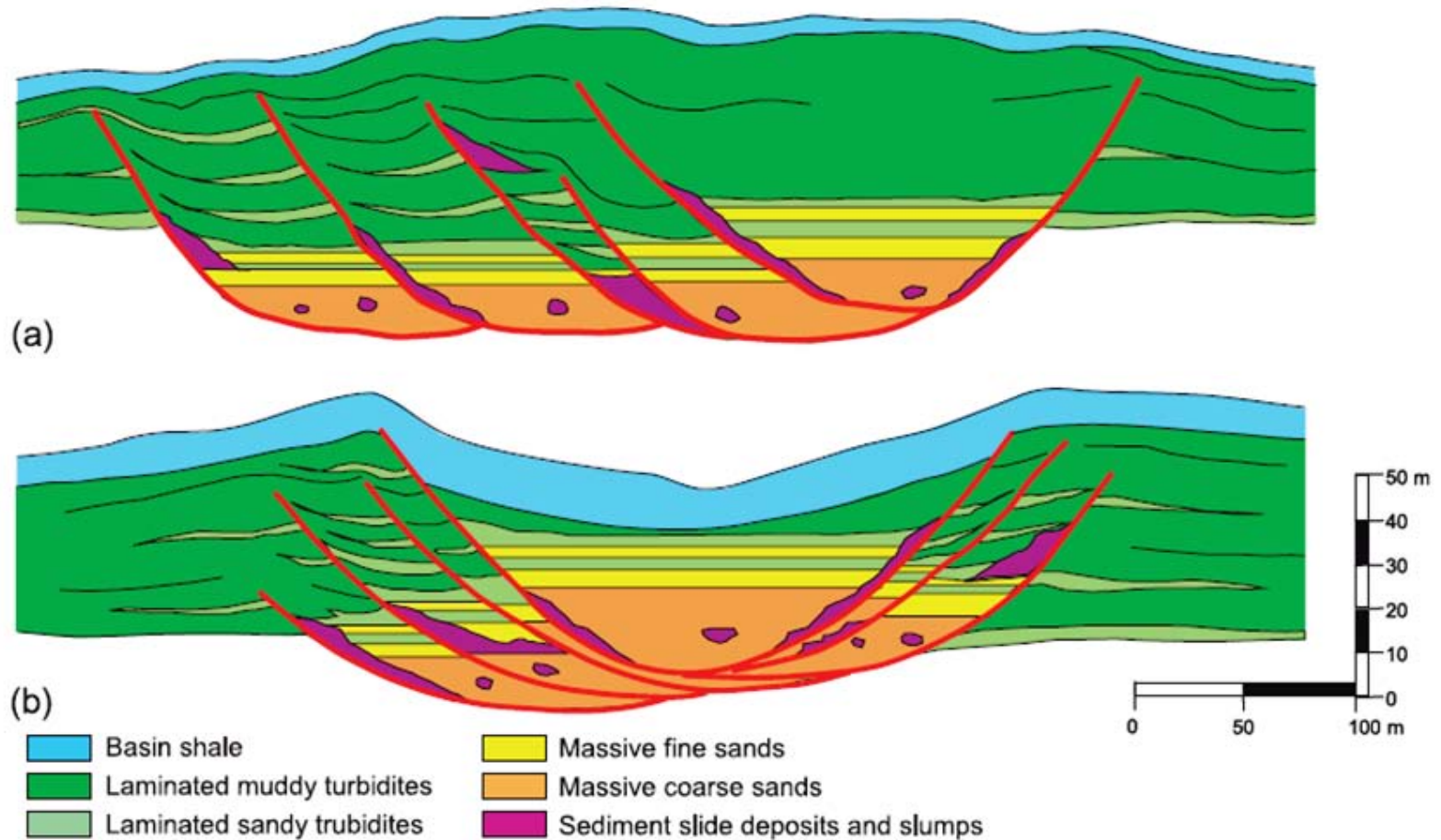


Pleistocene deep-water channel in
approximately 2000 m of water in the
northeastern Gulf of Mexico.

Presenter's Notes: Plan view of small arcuate slump scars that characterize the inner face of levees bounding a Pleistocene deep-water channel in approximately 2000 m of water in the northeastern Gulf of Mexico. This channel lies approximately 80 m below the sea floor and was characterized by flows from right to left. Colors indicate time structure, with warm colors representing bathymetric highs and cool colors representing bathymetric lows. Note that channel fill is characterized by positive relief associated with post-depositional differential compaction. The volume of materials excavated in association with these slumps likely was less than 100 m³ (after Posamentier, H.W., 2003, Depositional elements associated with a basin floor channel-levee system: case study from the Gulf of Mexico: *Marine and Petroleum Geology*, v. 20, p. 677-690). Image presented at the "Frontiers of Seismic Geomorphology" showcase held at the Geological Society, London, June, 2010.

Concepts

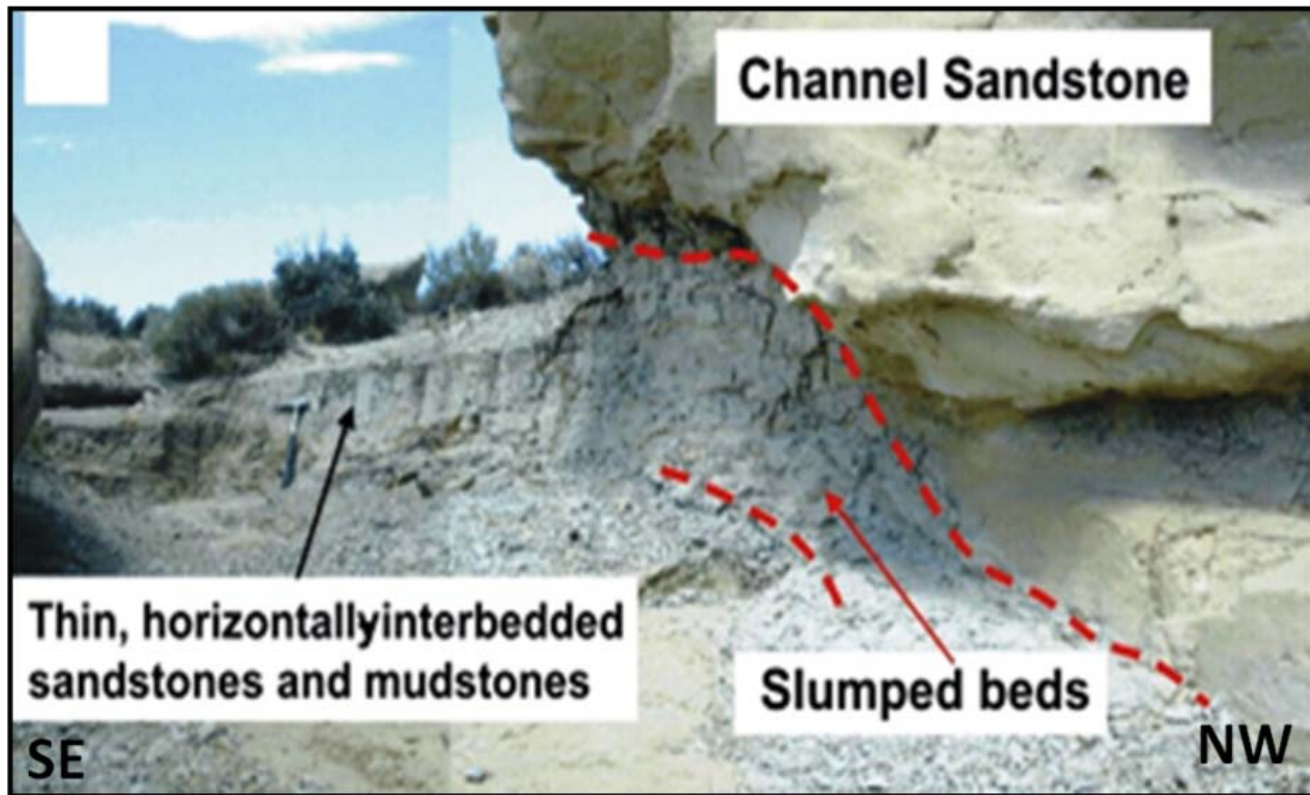
- *Slumps*



Conceptual Sedimentological Model from West Africa Channels
R. Labourdette et al. 2006

Concepts

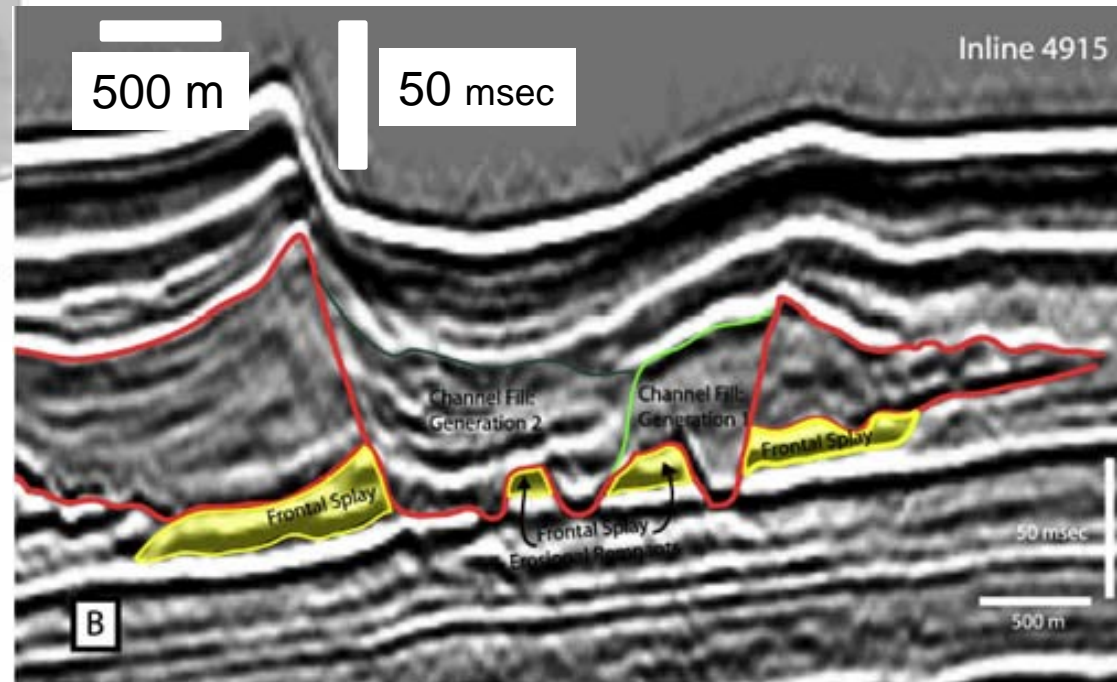
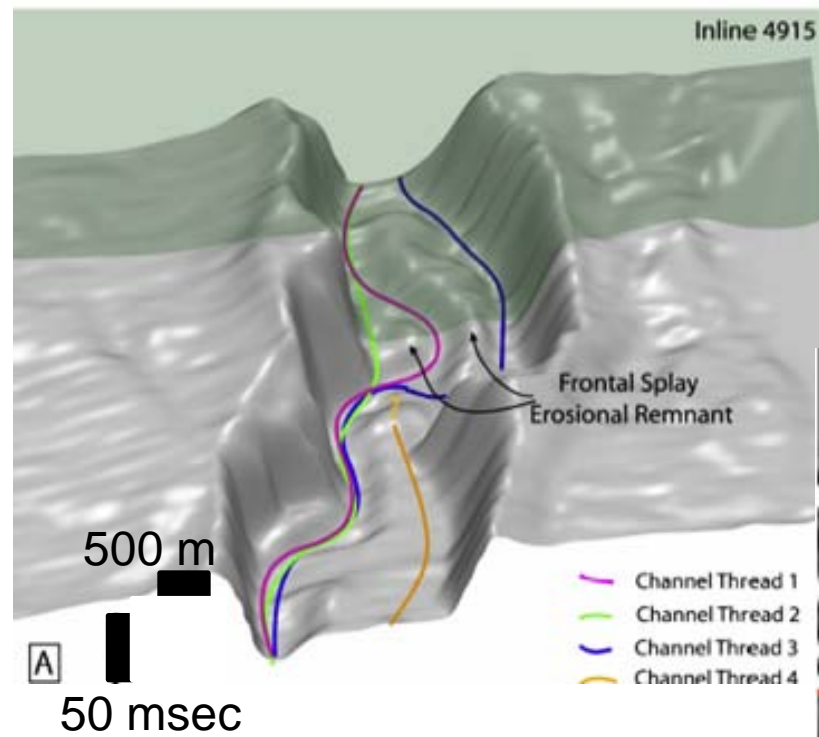
- *Slumps*



Slumped beds beneath a Channel - Outcrop

Concepts

- Erosional Remnants*



Modified from Minken et al., 2004

Outline

- *Concepts*
- **Objective**
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Objective

The objective of this study was to build a geological model for flow simulation of leveed-channel deposits, displayed in outcrop, for comparison with analog reservoirs to evaluate production problems.

Outline

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Area of Study and Regional Geology

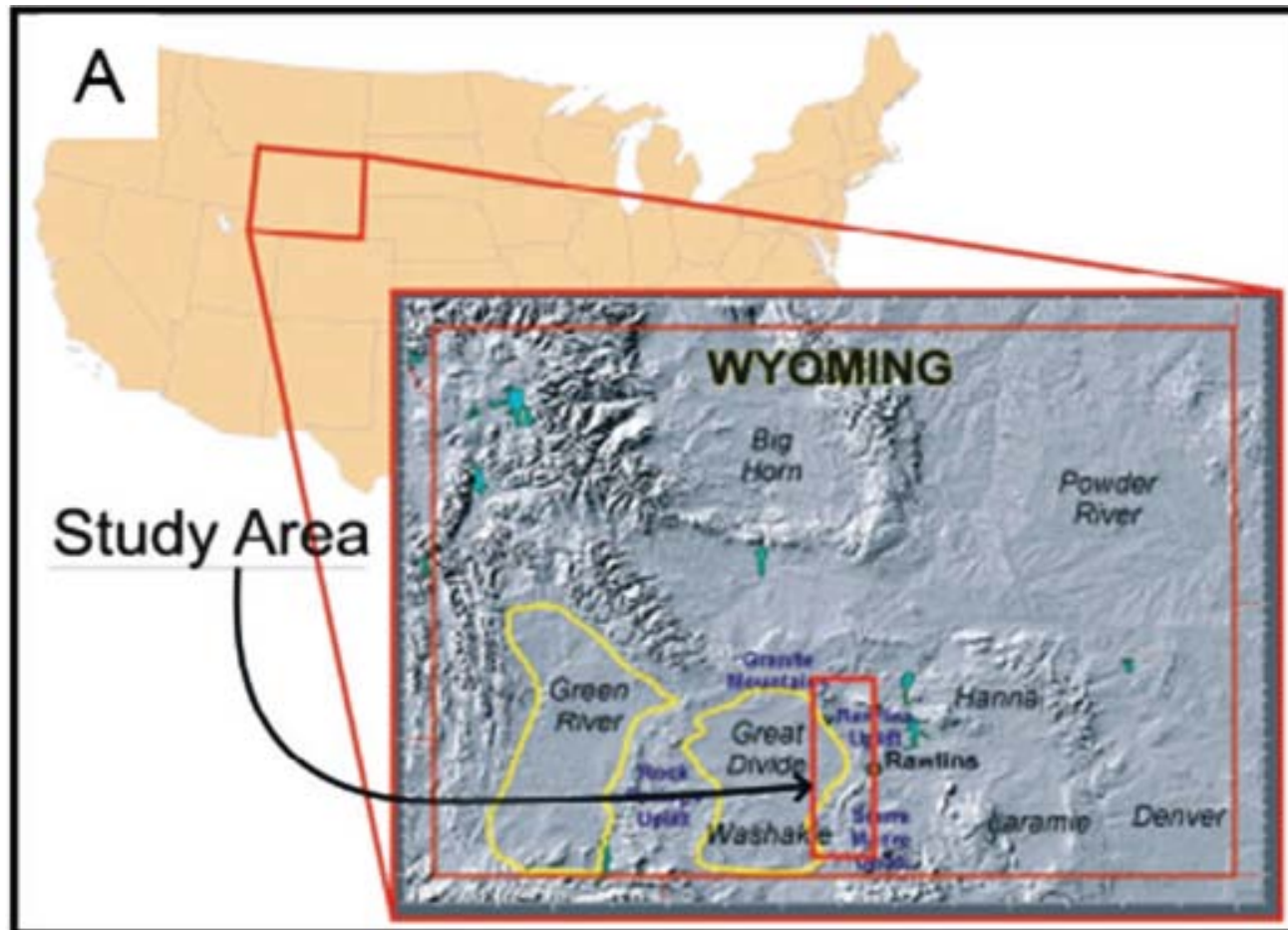


Figure 1. Location of the study area in southern Wyoming on the map of the United States of America (Van Dyke, et al., 2006).

Area of Study and Regional Geology



Figure 2. Map of the United States of America, showing the North American Interior Seaway (75 Ma). The major regression occurred between 71.0 and 69.4 Ma (Blakey, 2006).



Figure 3. Major seaway regression at 65.0 Ma (Blakey, 2006).

Area of Study and Regional Geology

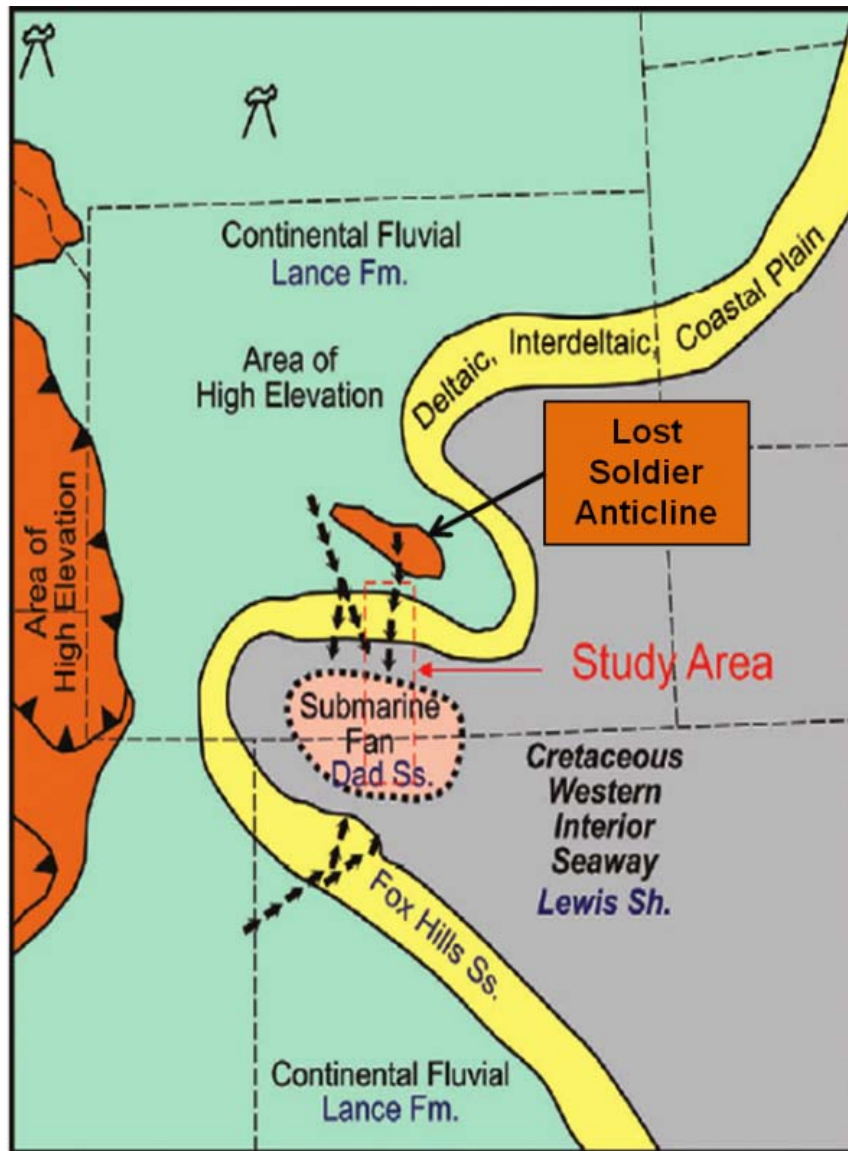


Figure 4. Paleogeographic reconstruction
(modified from Slatt, et al., 2006)

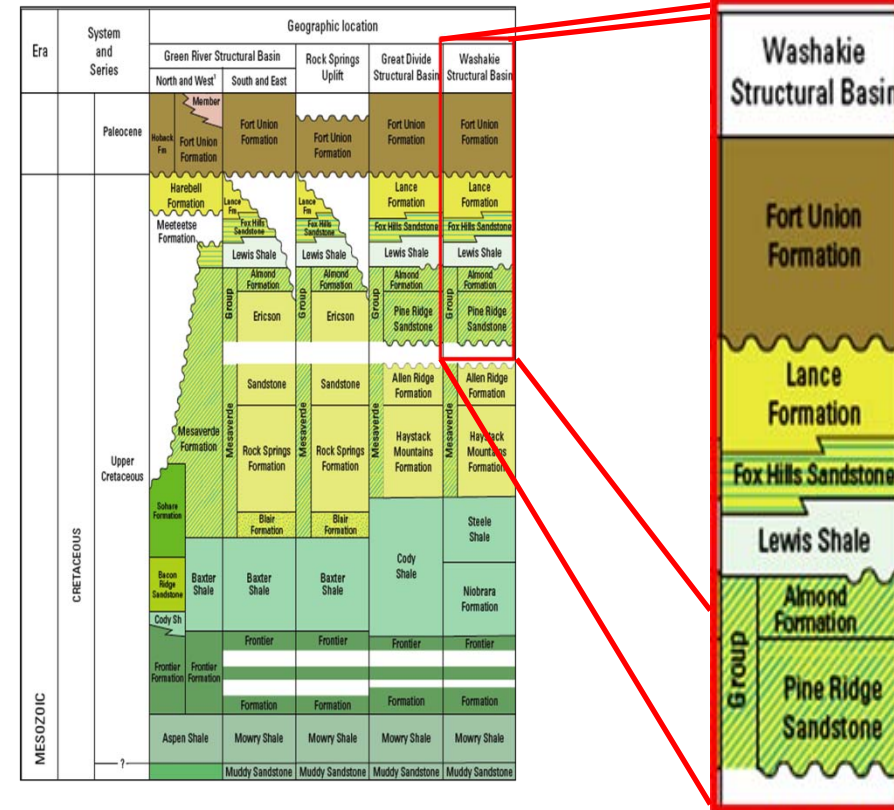


Figure 5. Stratigraphic Column

Area of Study and Regional Geology

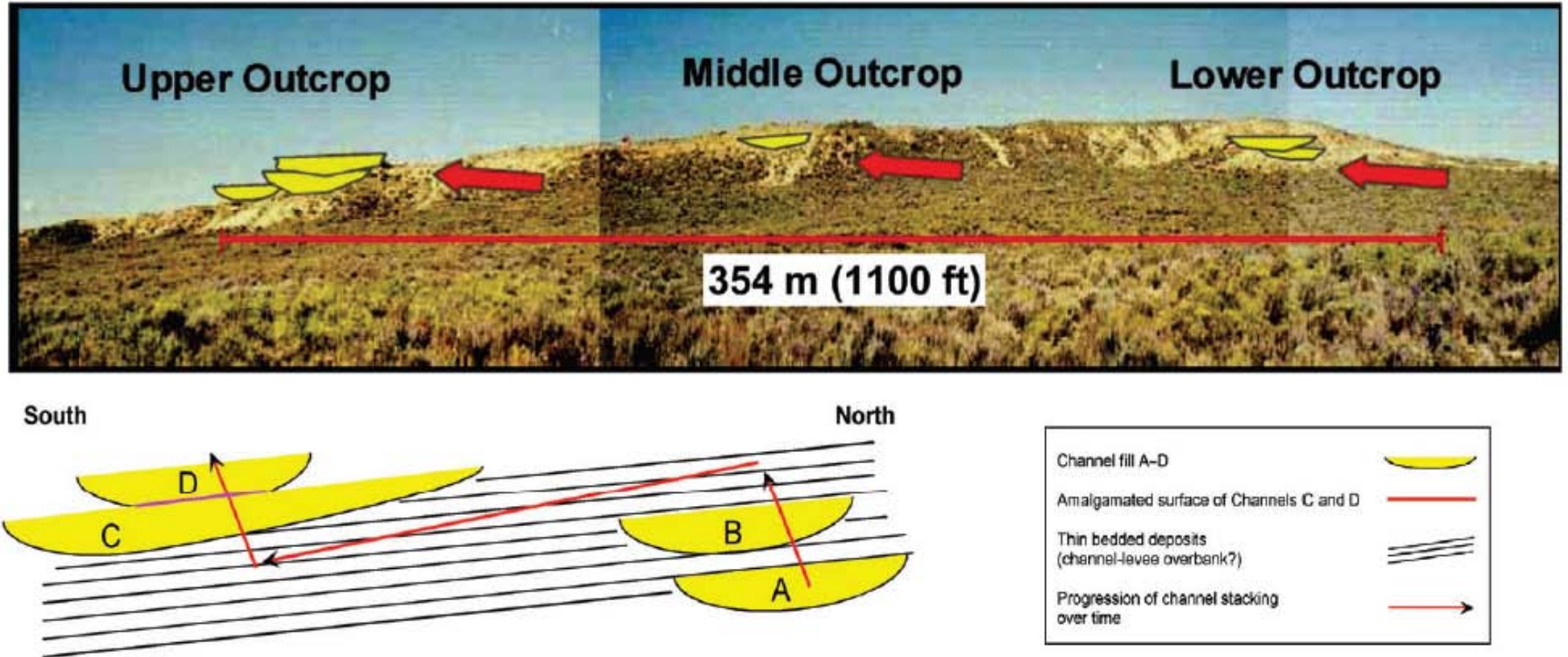


Figure 6. Photomosaic of the outcrop

Area of Study and Regional Geology

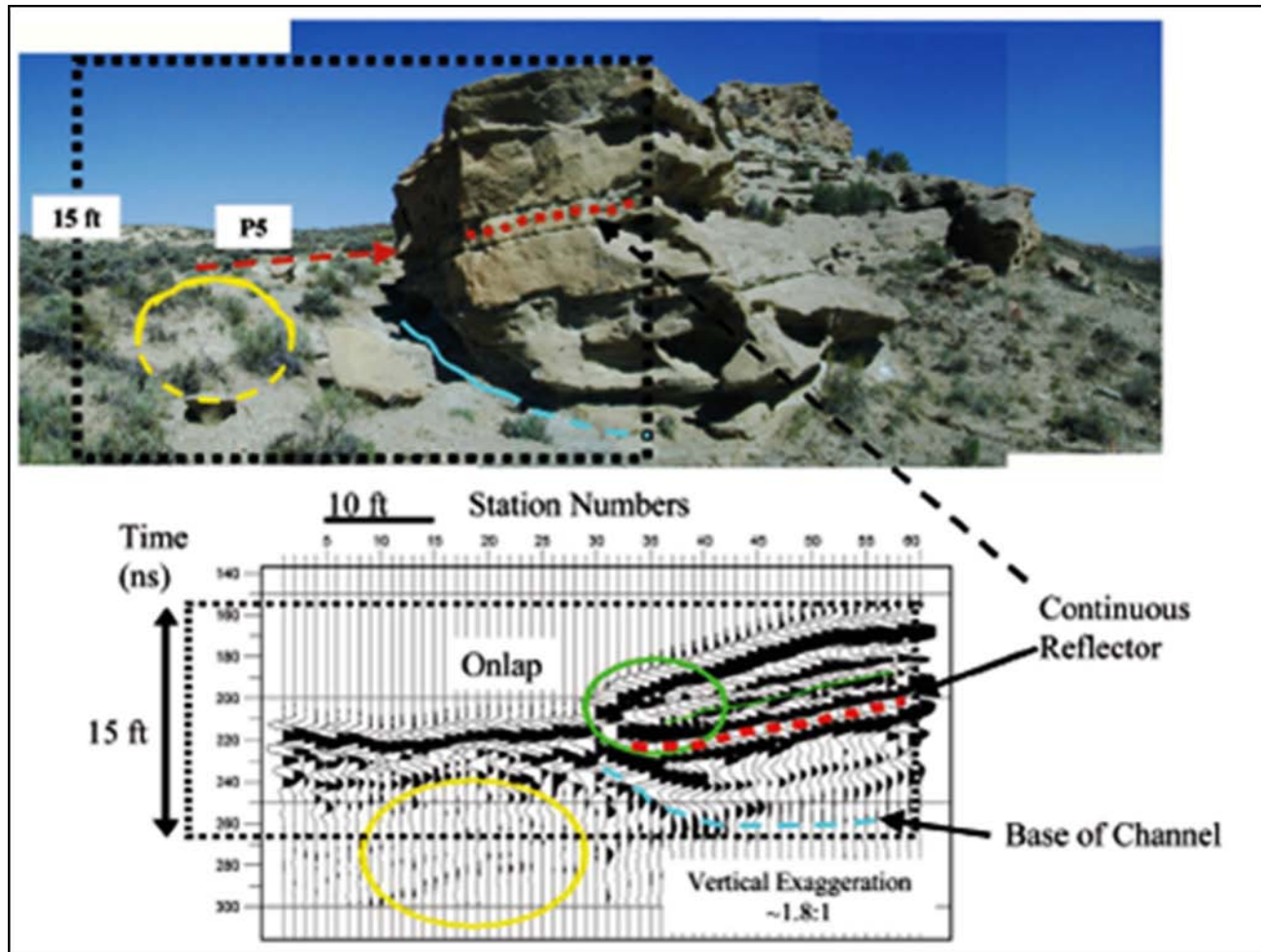


Figure 7. GPR line which identifies the base of the channel (Correa, 2007)

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Geological Model - Imported Data

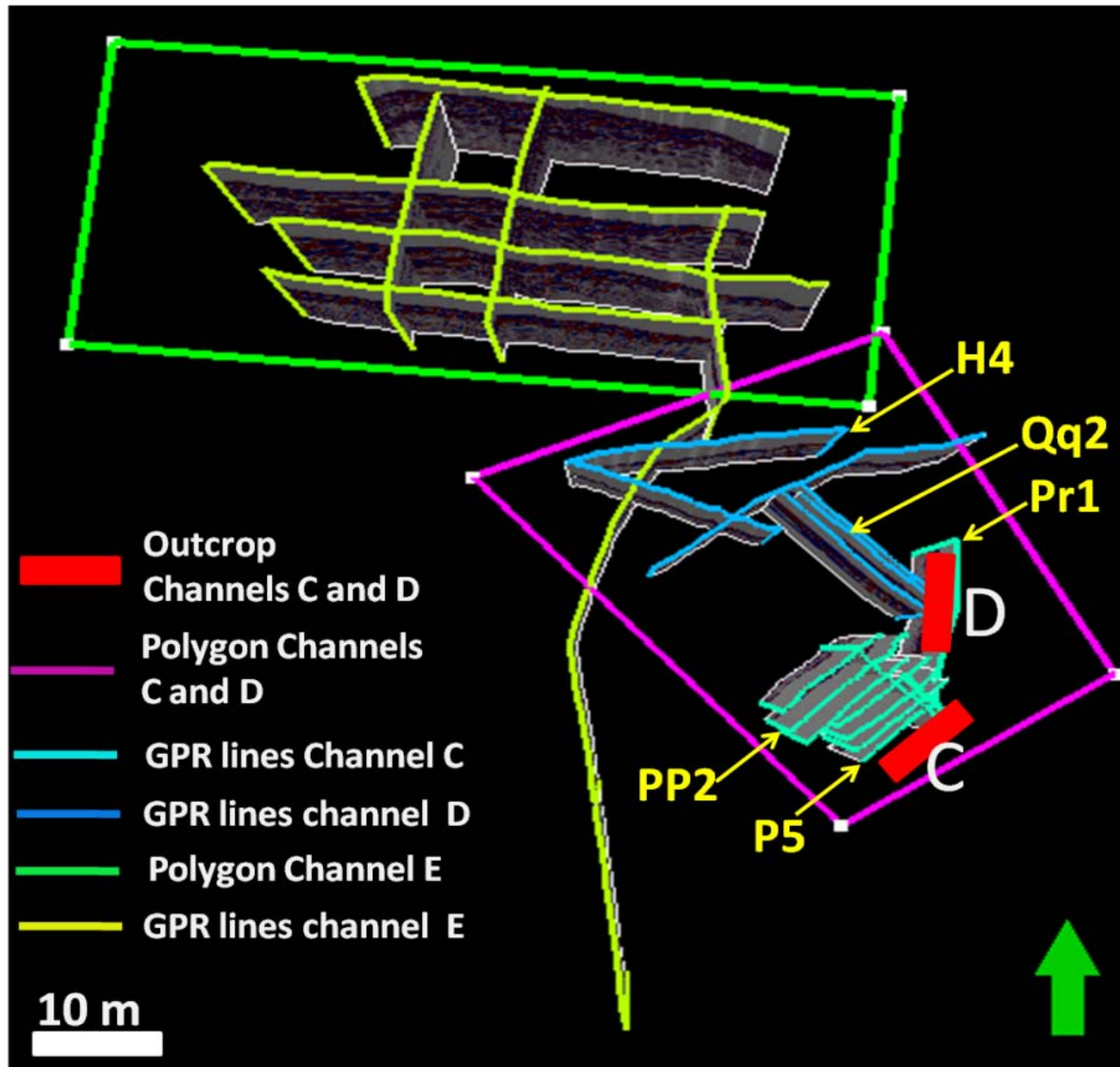


Figure 8. Plan view of the GPR lines, outcrops, and the polygons used to build the geological model.

Geological Model - Imported Data

- 21 GPR lines (Staggs et al., 2003)
- 8 Measured Sections (Bracklein, 2000)
- 3 photos combined into a 3D photomosaic, Bracklein, 2000 and Correa, 2007)
- Porosity and Permeability values from Spine 1 (Slatt et al., 2006) and Tahoe field (White et al., 1992)

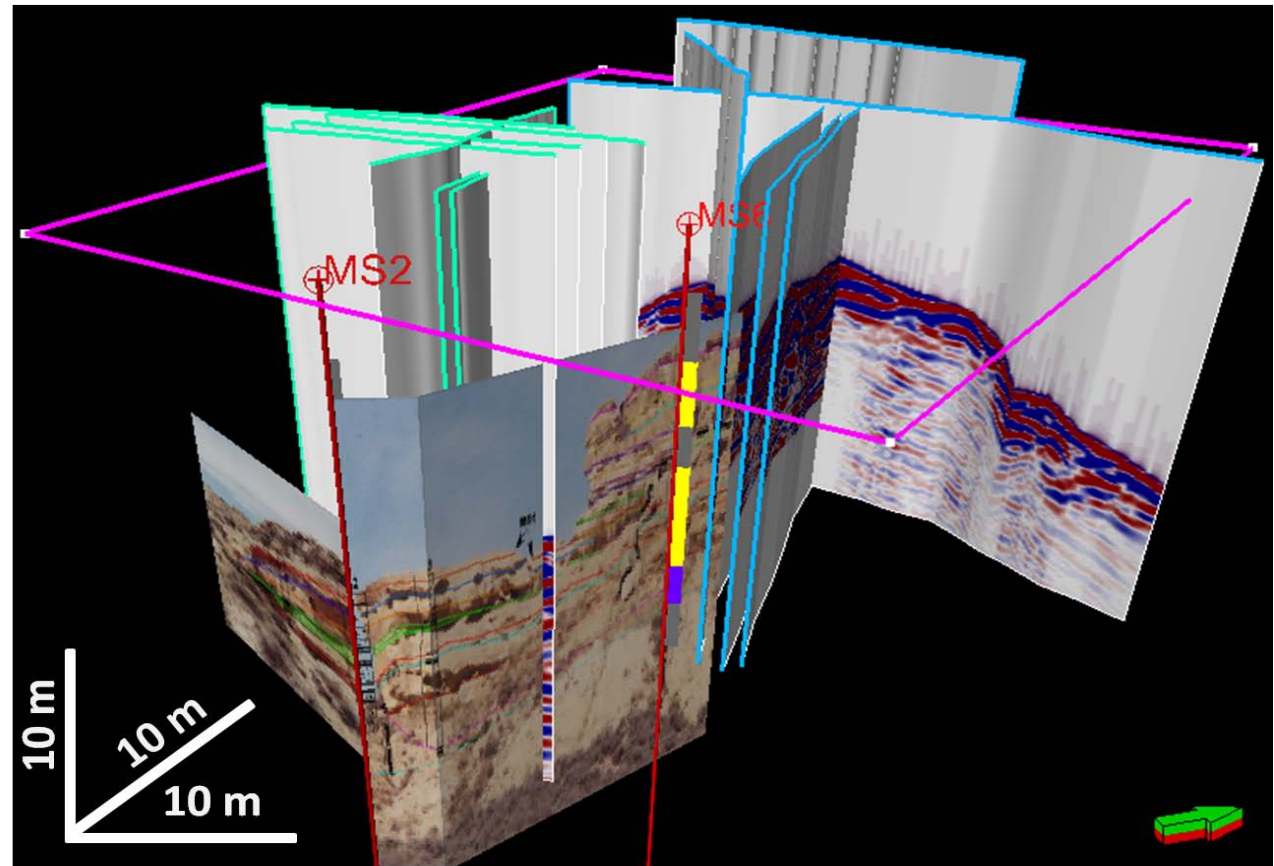
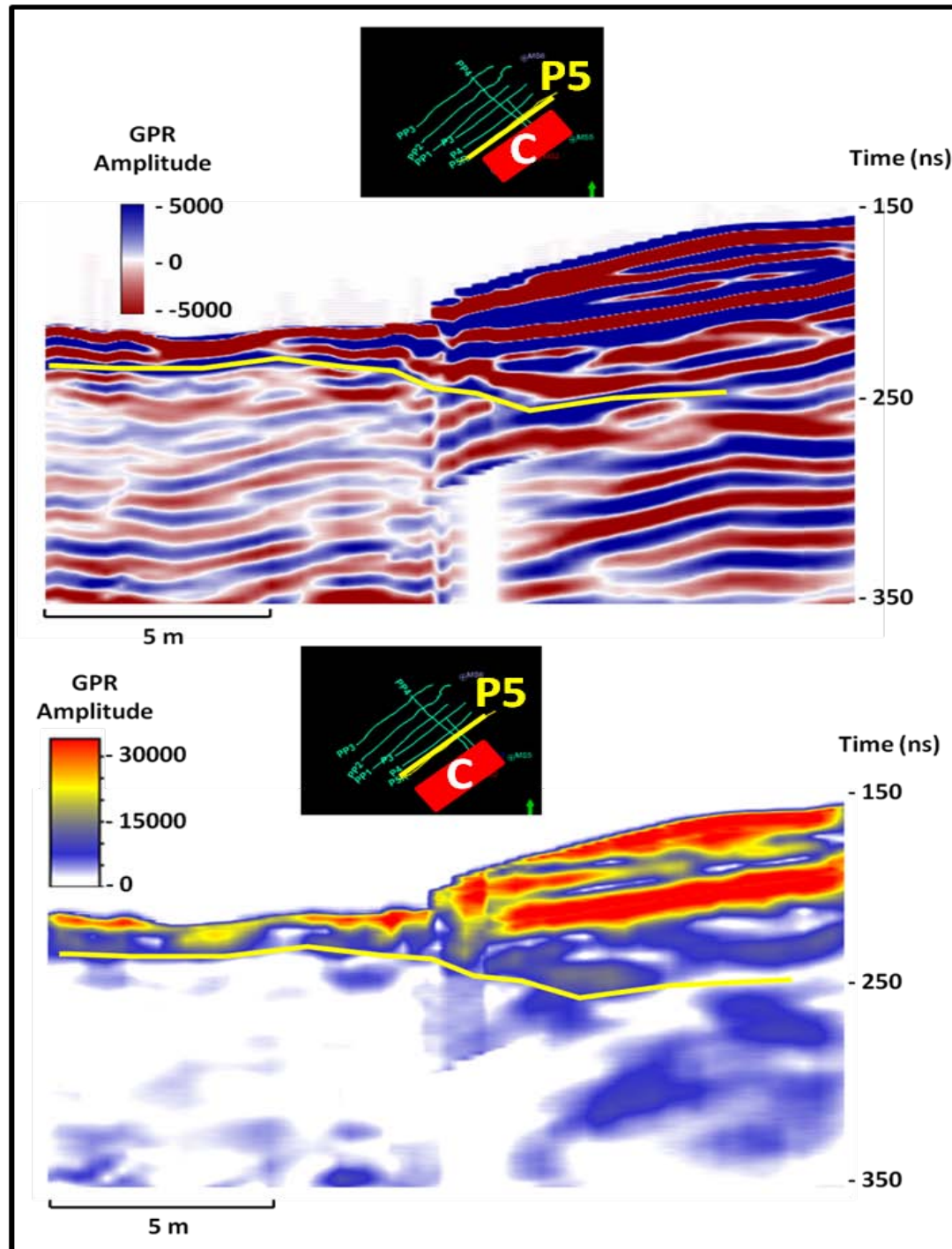
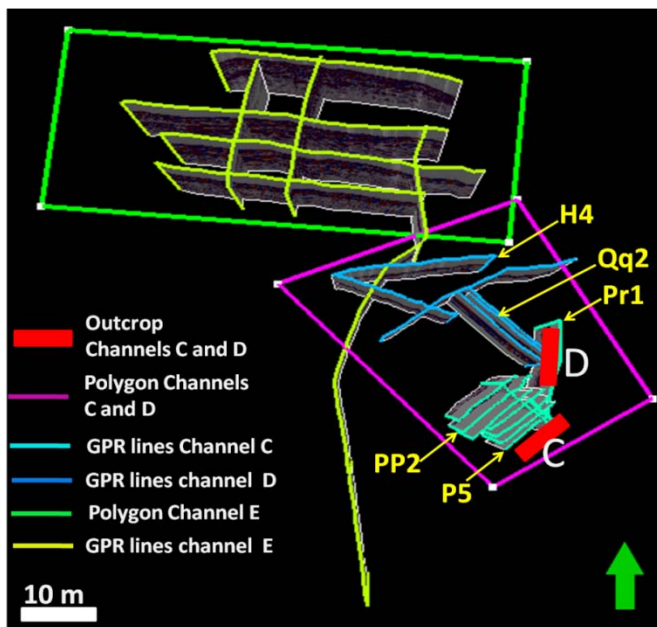


Figure 9. Some of the available data used to model Channels C and D.

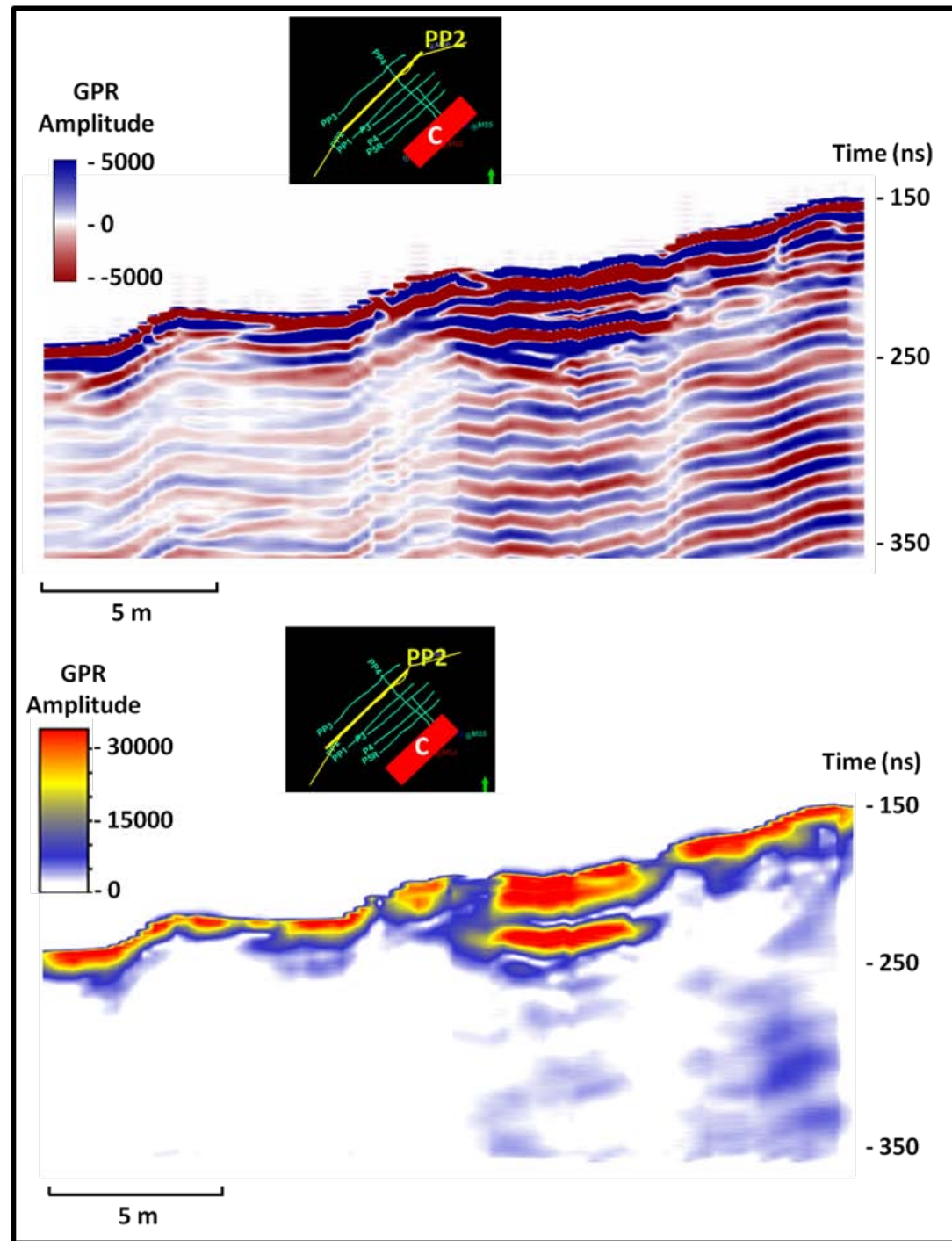
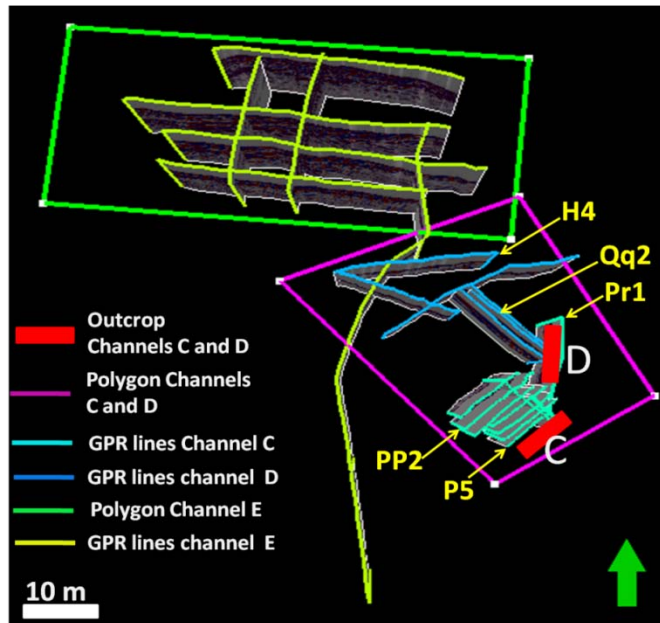
Geological Model

Figure 10. Quality control for Envelop GPR Attribute.



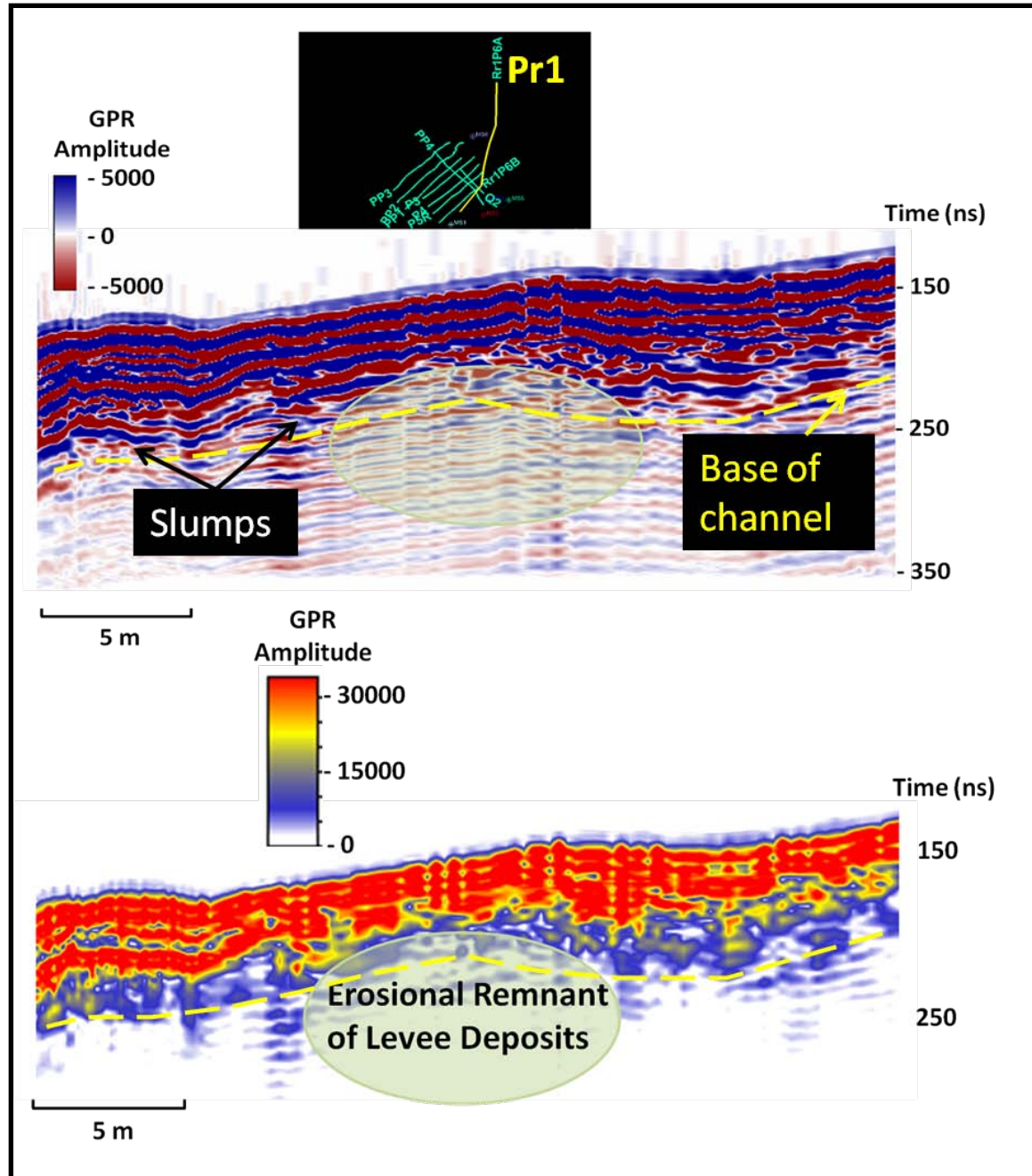
Geological Model

Figure 11. Envelop GPR Attribute highlights the base of the channel C.



Geological Model

Figure 12. Erosional remnant of levee deposits identified on Pr1 GPR line



Geological Model

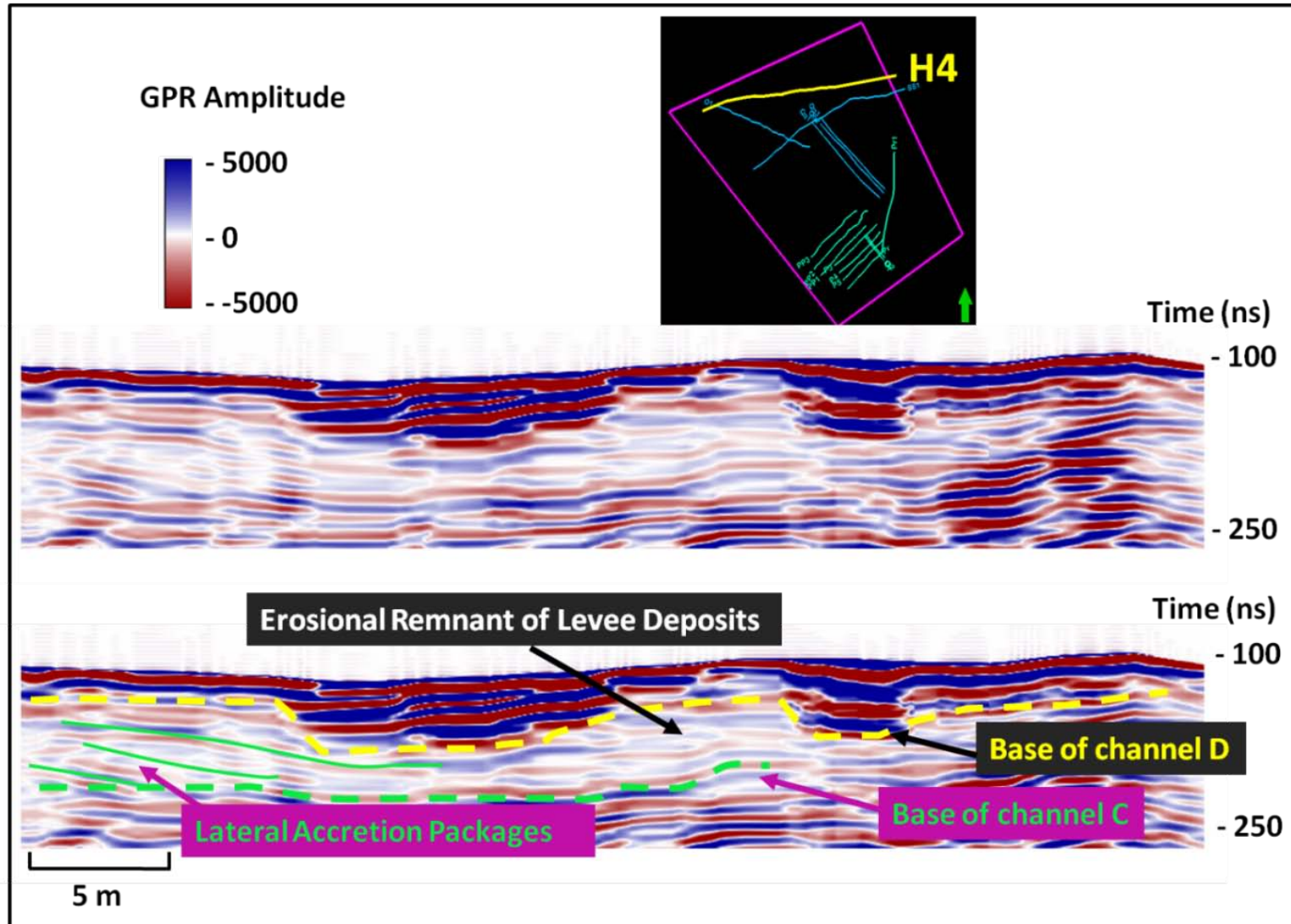


Figure 13. H4 GPR line shows erosional remnant of probable levee deposits. H4 location is shown in the black square.

Geological Model

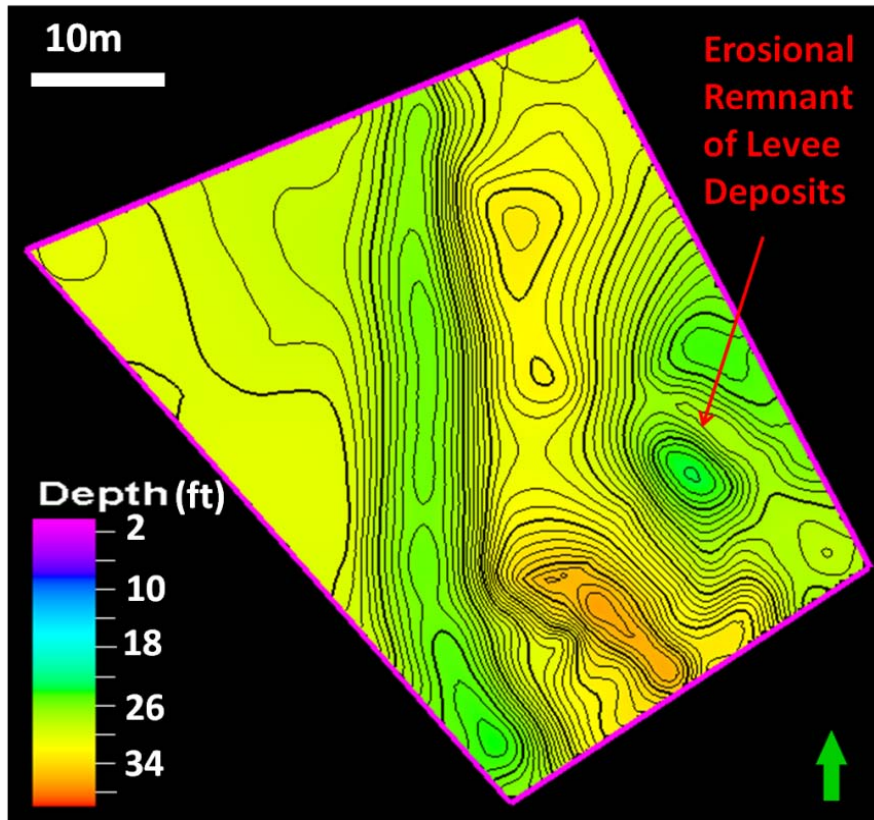


Figure 14. Depth surface of Channel C in a plan view.

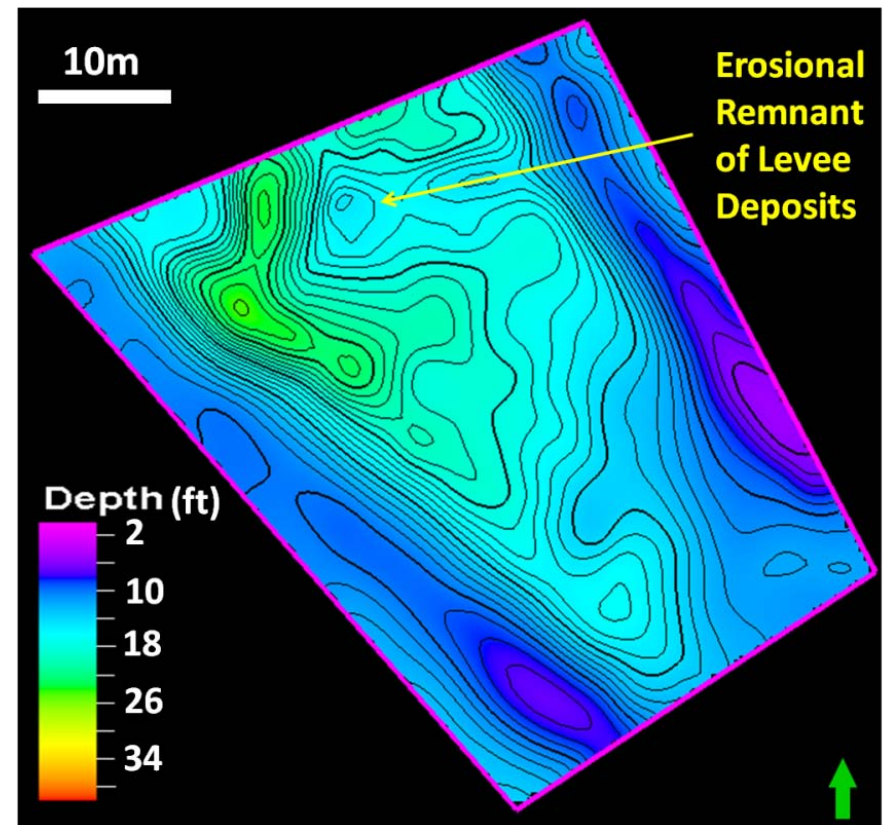


Figure 15. Depth surface of Channel D in a plan view.

Area	Width (m)	Thickness (m)	Dip of reflectors direction
Channel C	32	3.99	SW
Channel D	>30	8.82	SW

Geological Model

Figure 16. Base of Channel C and slumped beds are present beneath it. Modified from Correa (2007)

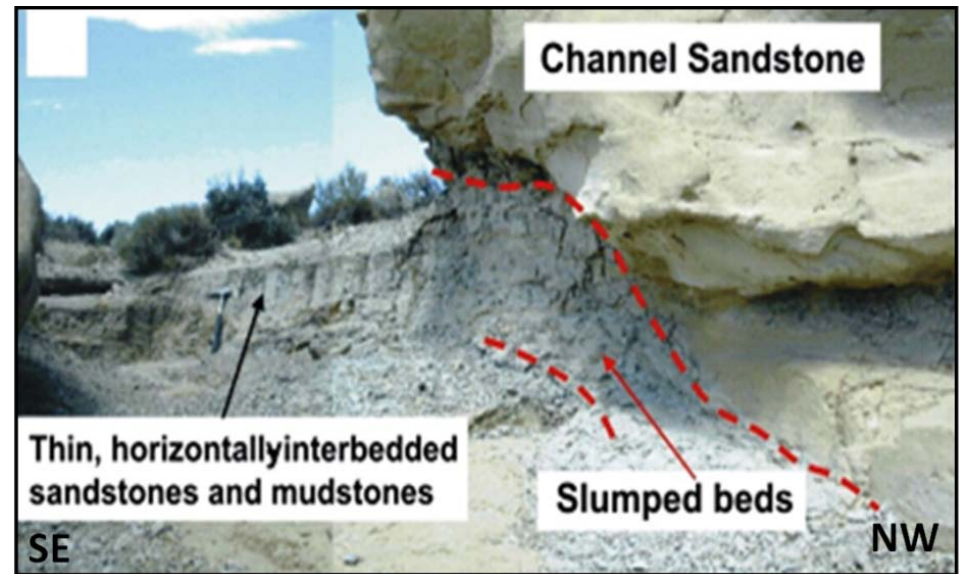
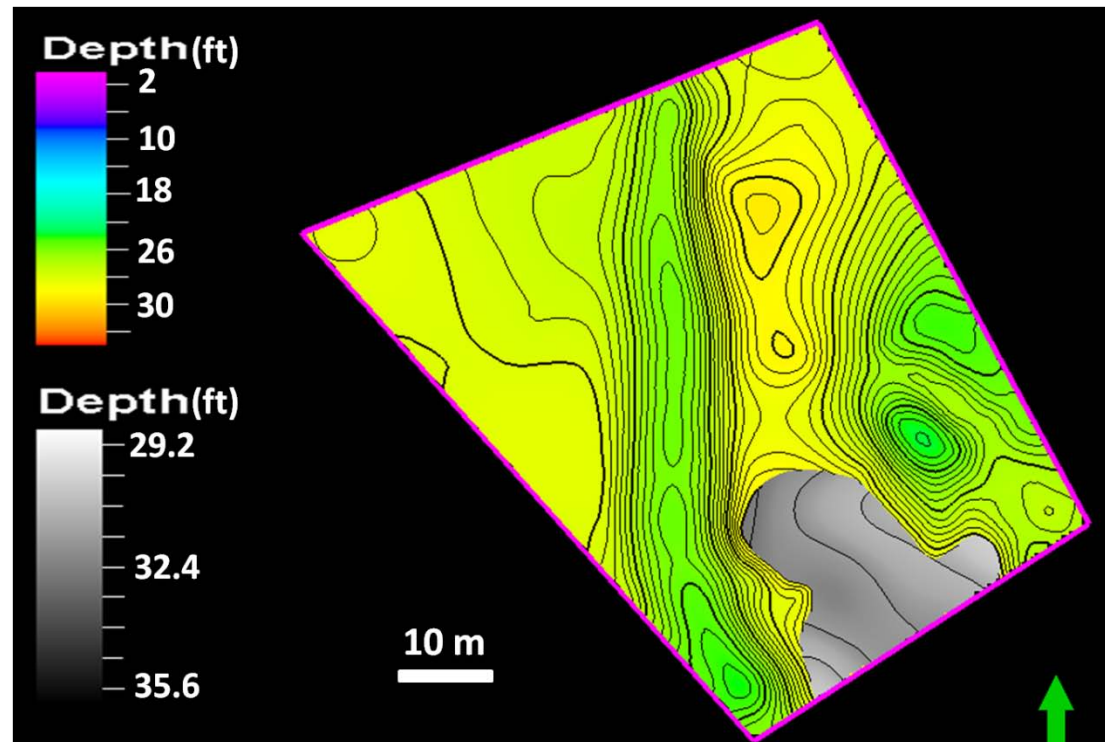


Figure 17. Depth surfaces corresponding to the margin of Channel C (color scale) and slumped beds (gray scale).



Geological Model

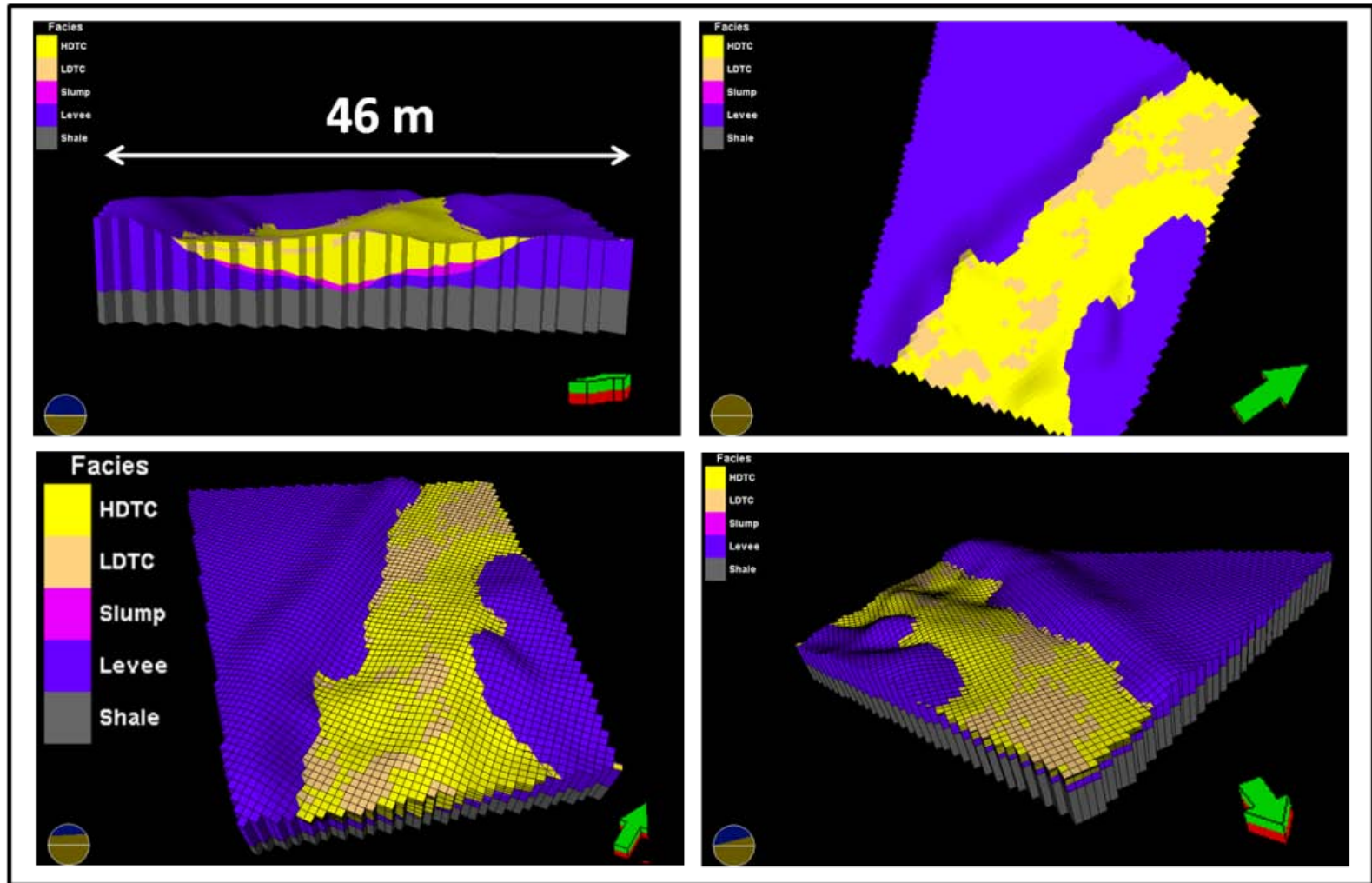


Figure 18. Stochastic model for the combination between LDTC and HDTC in a specific zone in the geological model; there is more uncertainty in the stochastic distribution towards the north, because no data is present there.

Geological Model

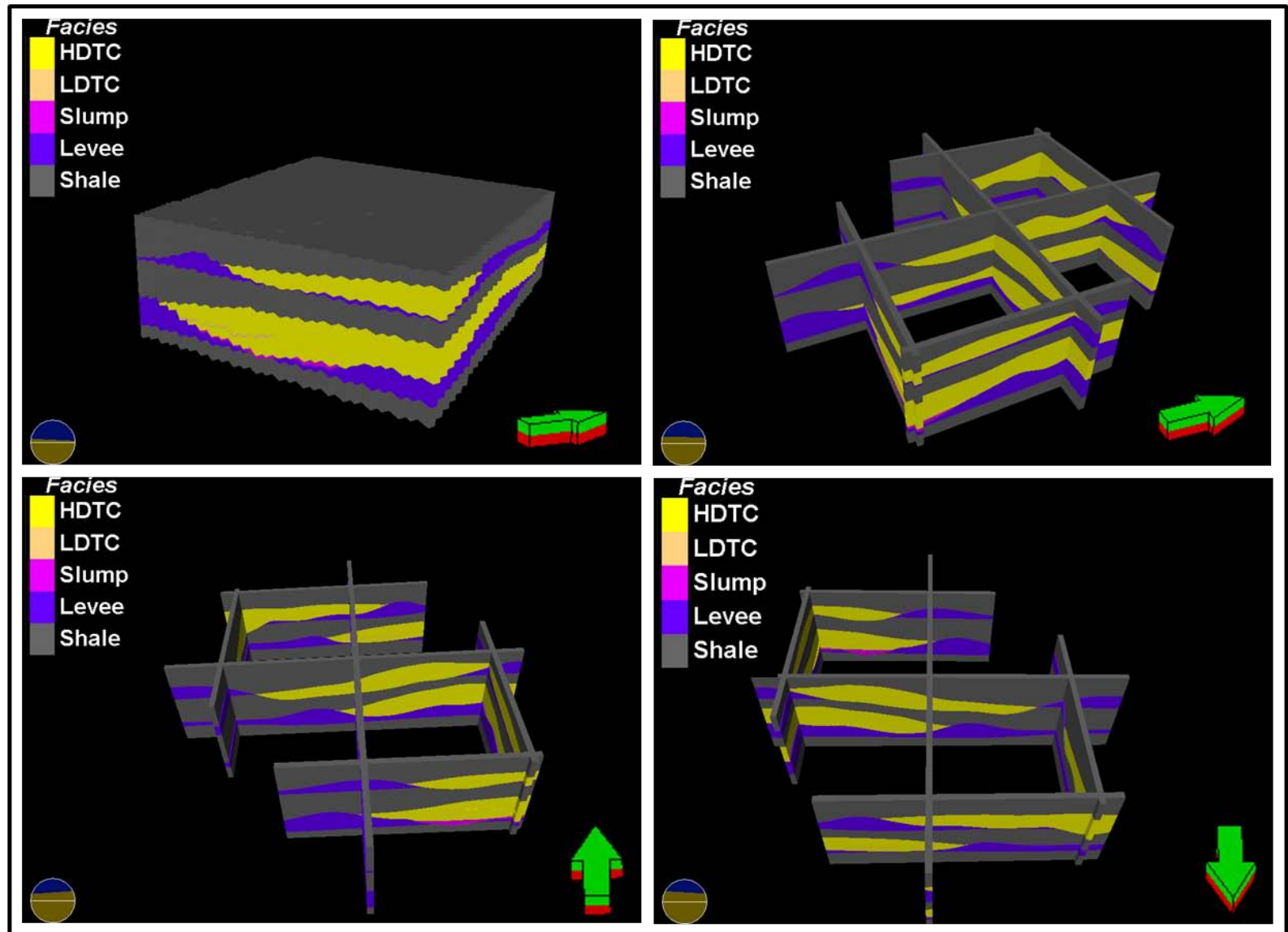


Figure 19. Fence diagram of the facies model.

Geological Model

Facies	Porosity		Permeability	
	Mean (%)	Std. Deviation	Mean (md)	Std. Deviation
HDTC	29.5	1.1	415	293
LDTC	29	2.3	304	301
Shale	14.6	0.7	0.03	0.01
Levee	18.4	2	40	5
Slump	15	5	N/A	N/A

***Table 1. Porosity and permeability values,
Spine 1 facies (White et al., 1992 and Slatt et
al., 2009).***

Geological Model

Figure 20. Petrophysical (permeability) model of a HDTC in Channel D showing that permeability improve basinward.

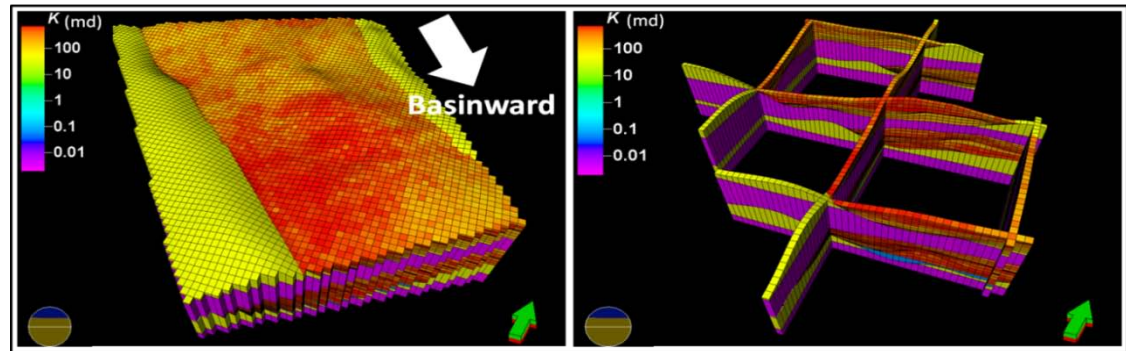
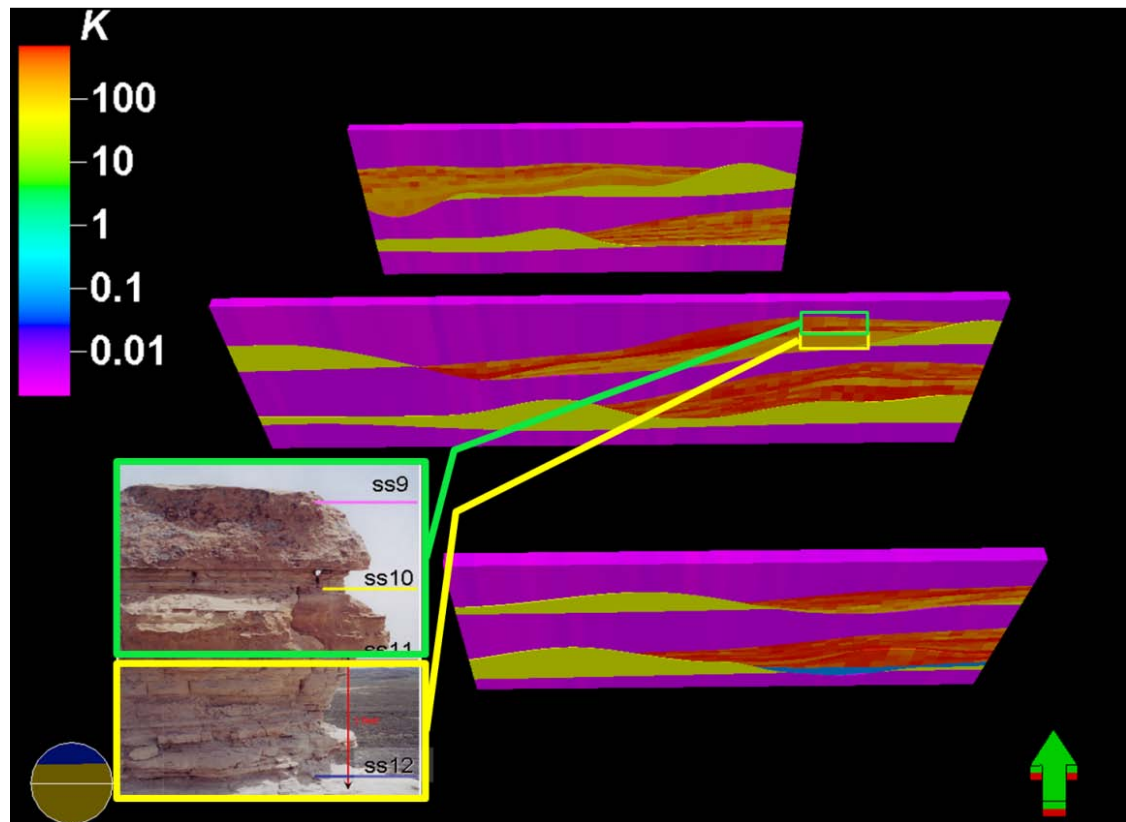


Figure 21. Fence diagram (from north to south) of the petrophysical model shows that permeability improves basinward, and it illustrates vertical variation in the different beds.



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Flow Simulation

Volumetric calculations

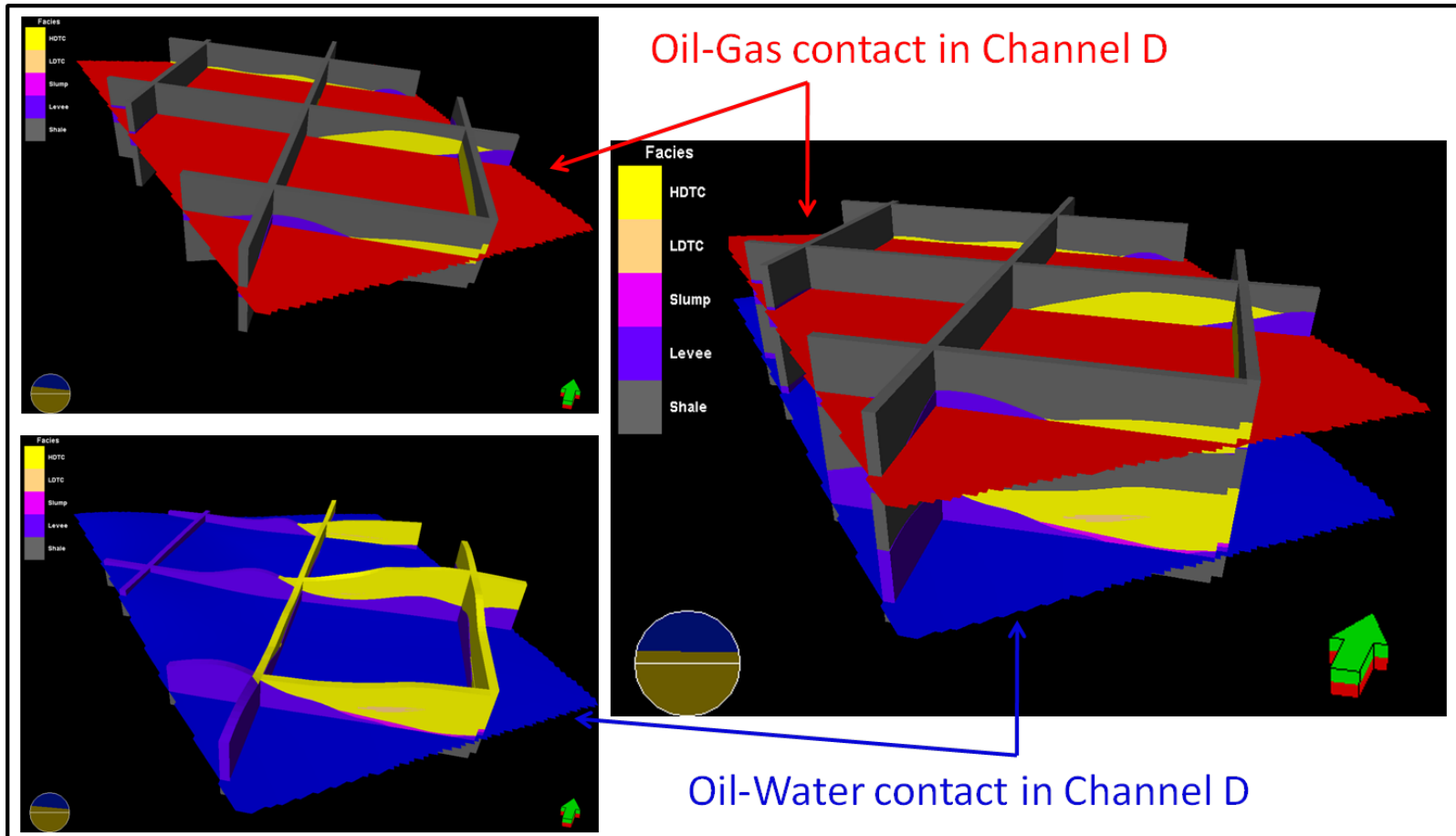
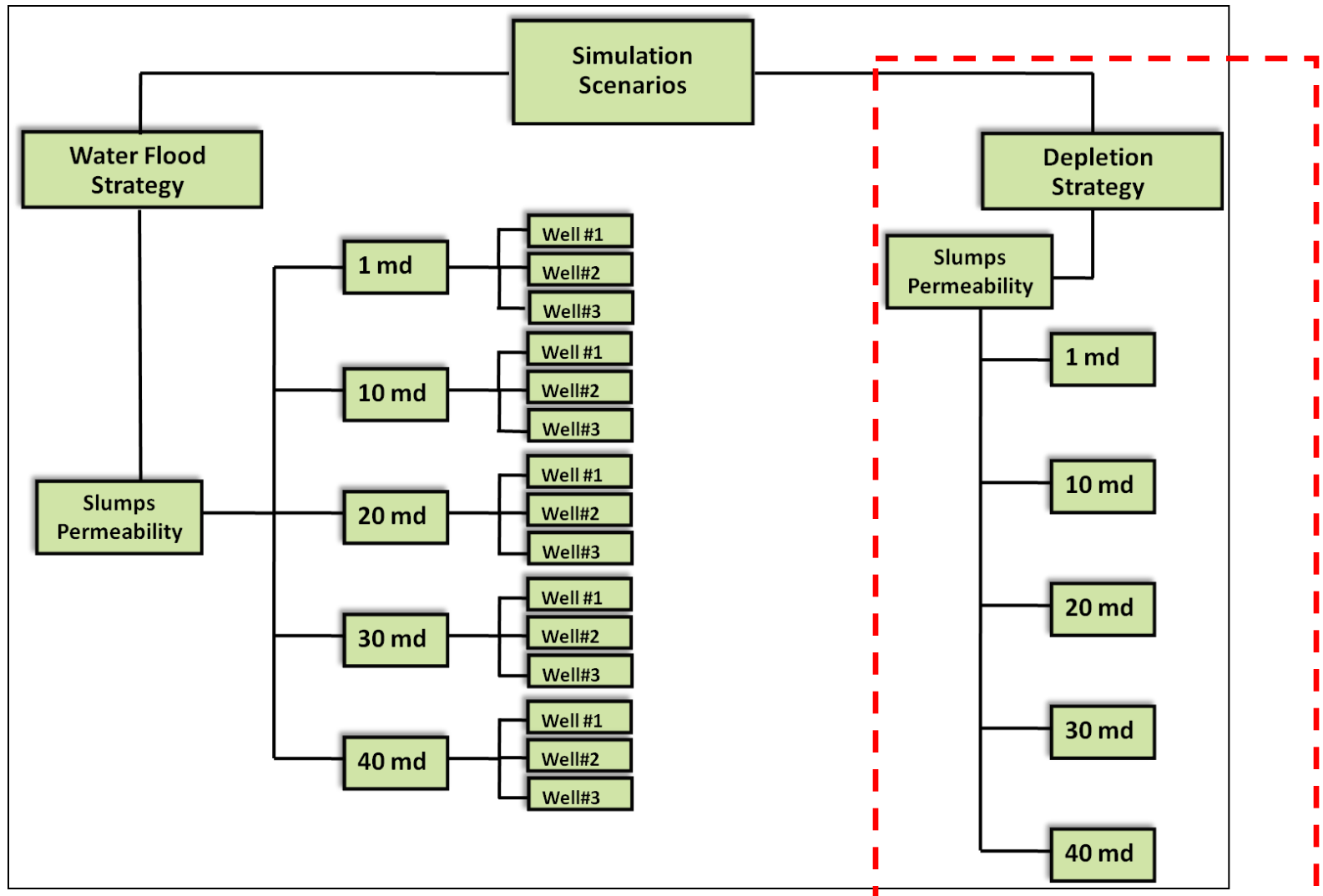


Figure 22. Oil-Water and Oil-Gas contacts in Channel C and Channel D respectively. Blue is water contact and red is gas contact

Flow Simulation

Simulation Scenarios



Flow Simulation

Eclipse flow simulation

Property	Value
Initial Reservoir Pressure (Pi)	350 bar (5080 psia)
Reservoir Temperature	250 (°F)
Bubblepoint Pressure (Pb)	275 bar (3990 psia)
Solution Gas oil ratio (GOR)	205 sm ³ /sm ³ (863 scf/STB)
Oil FVF at Pi (Boi)	1.52 rm ³ /sm ³ (bbl/STB)
Oil Viscosity at Pi (μ_{oi})	0.86 cp
Oil Gravity (API)	35 API
Specific Gas gravity	0.75
Irreducible Water Saturation (Swi)	20%
Irreducible Oil Saturation (Soi)	10%

Table 2. Reservoir properties used in the flow simulations.

Flow Simulation

Eclipse flow simulation

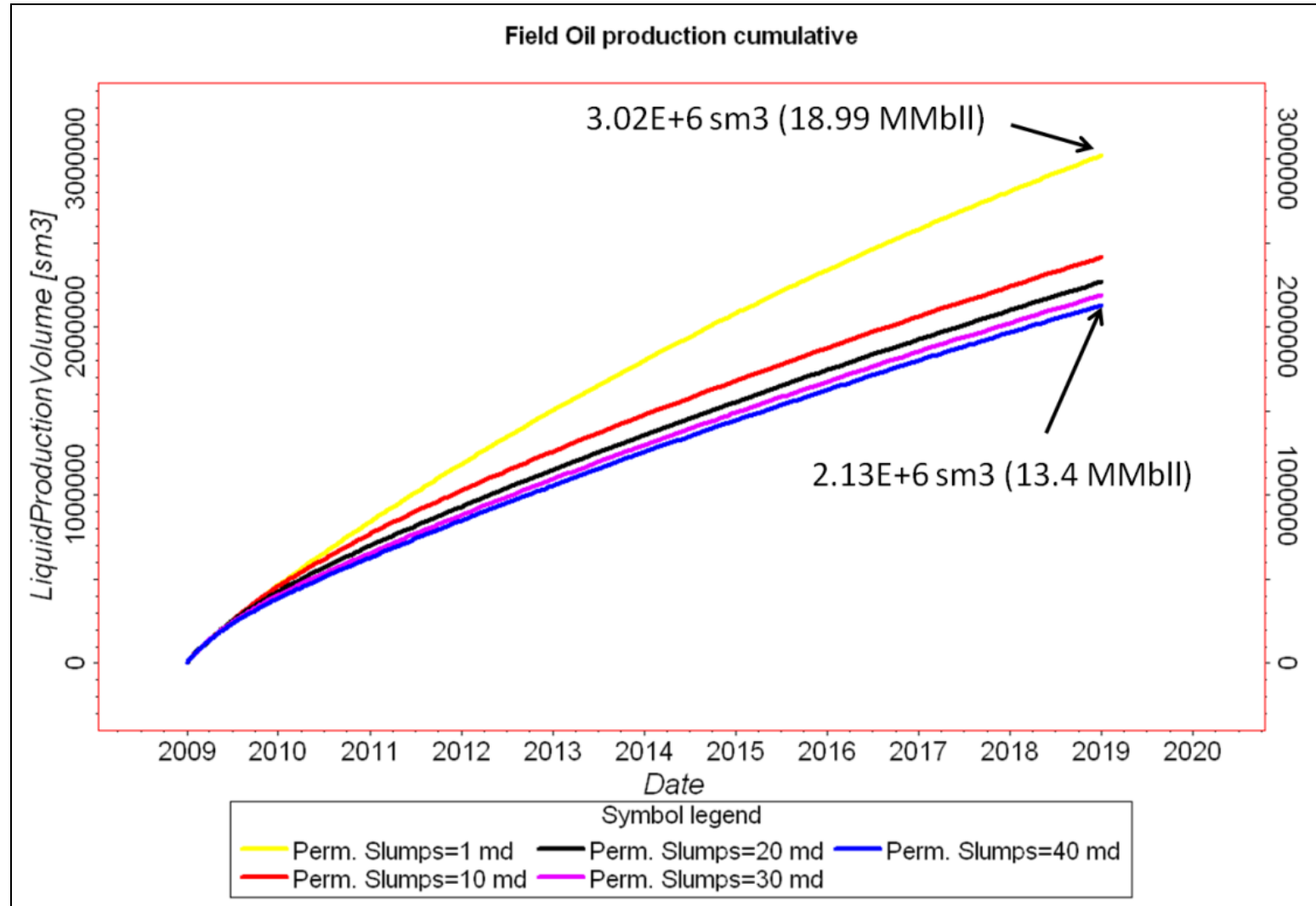


Figure 23. Field oil cumulative production for the different simulation cases.

Flow Simulation

Eclipse flow simulation

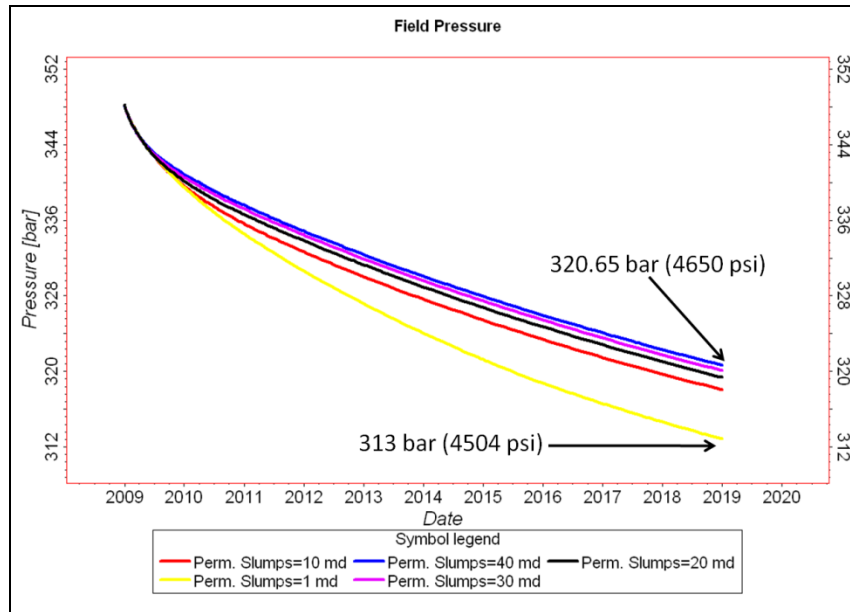


Figure 24. Field pressure for the different simulation cases.

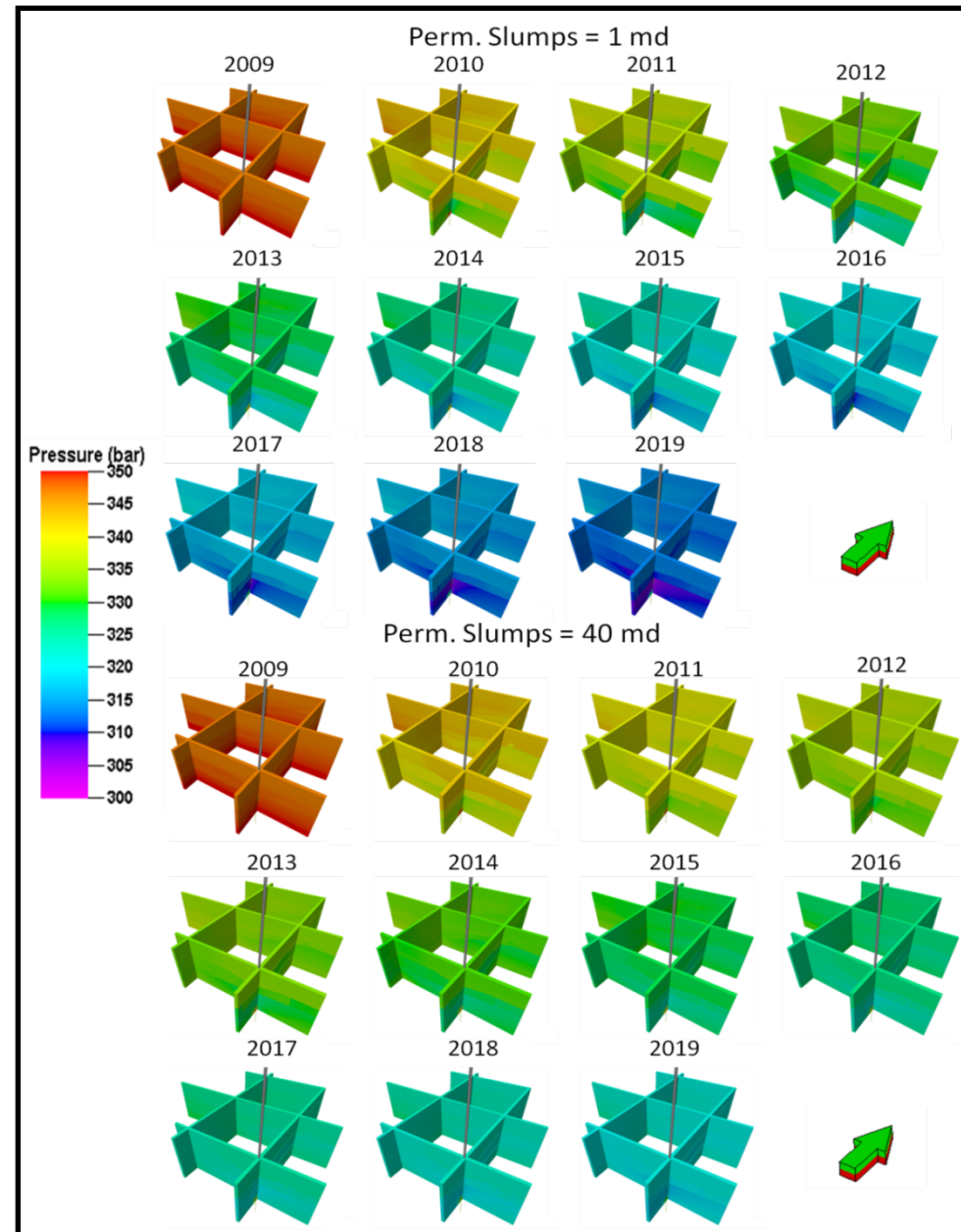


Figure 25. Pressure fence diagrams in the low case (Perm. Slumps = 1 md) and in the high case (Perm. Slumps = 40 md).

Flow Simulation

Eclipse flow simulation

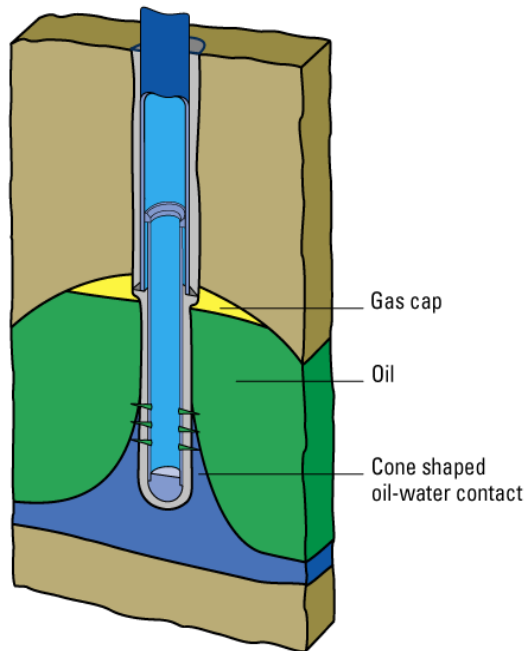


Figure 26. Water coning diagram. SLB, 2006.

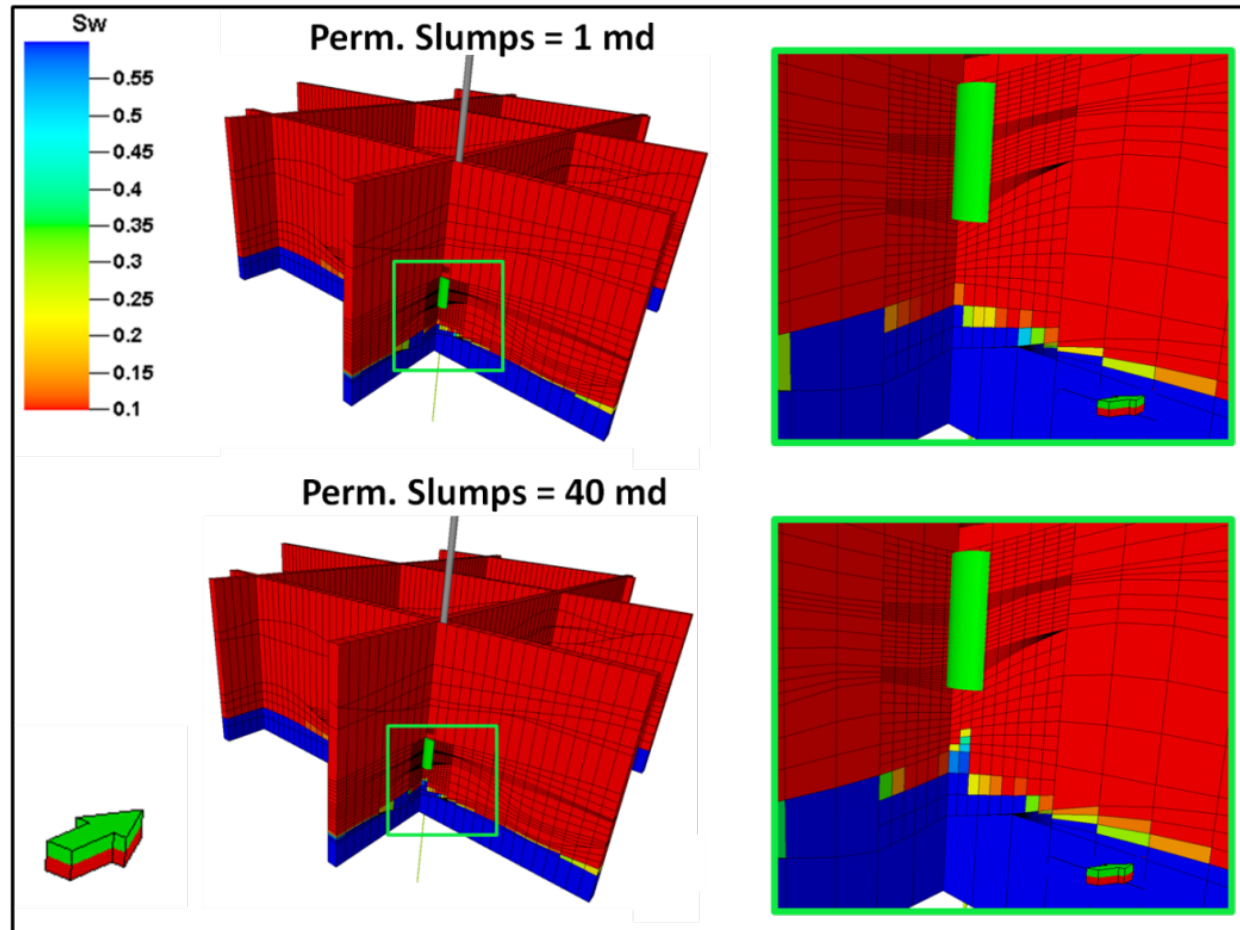
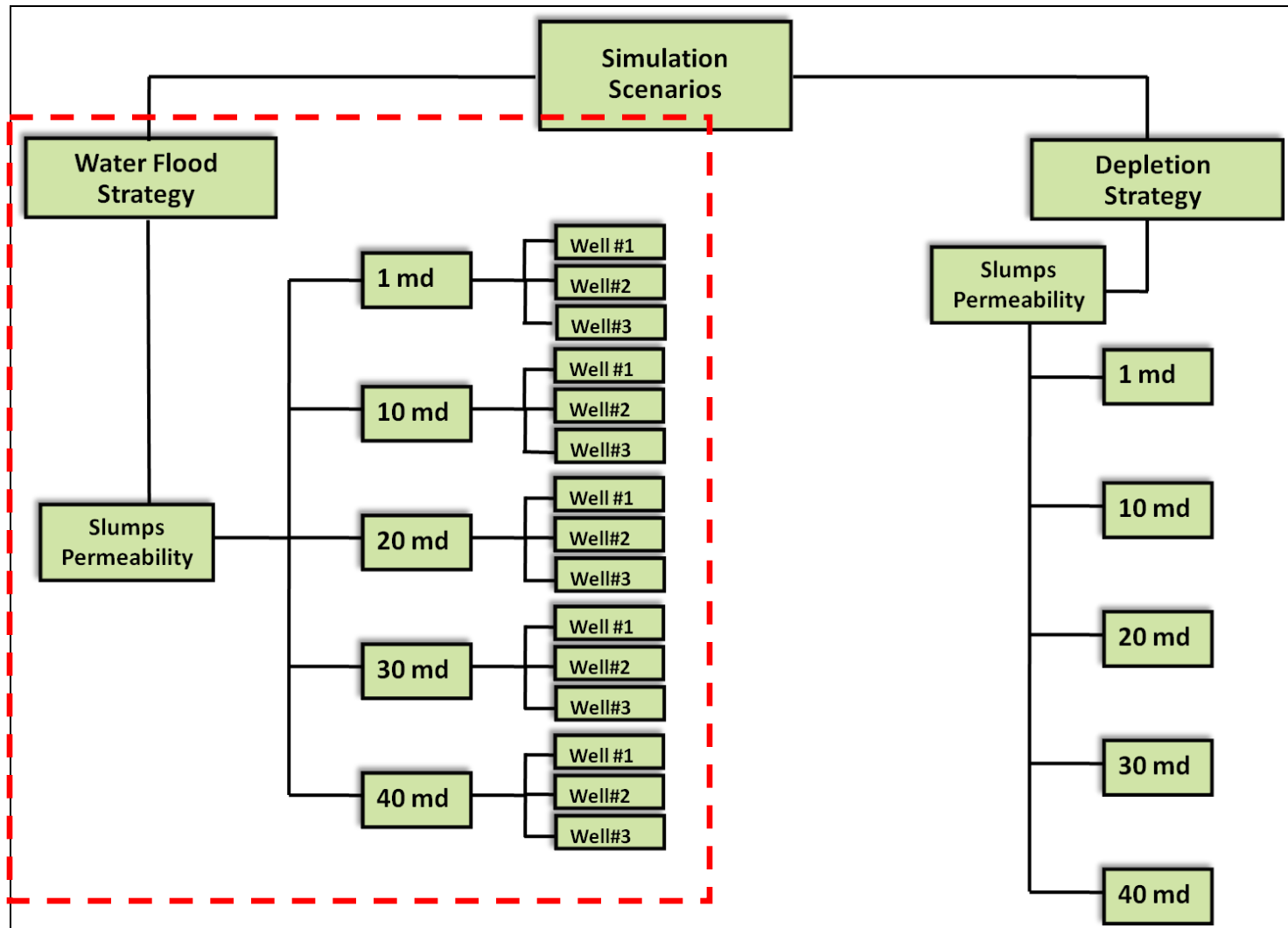


Figure 27. Water coning process in the low and high cases at year 2010.

Flow Simulation

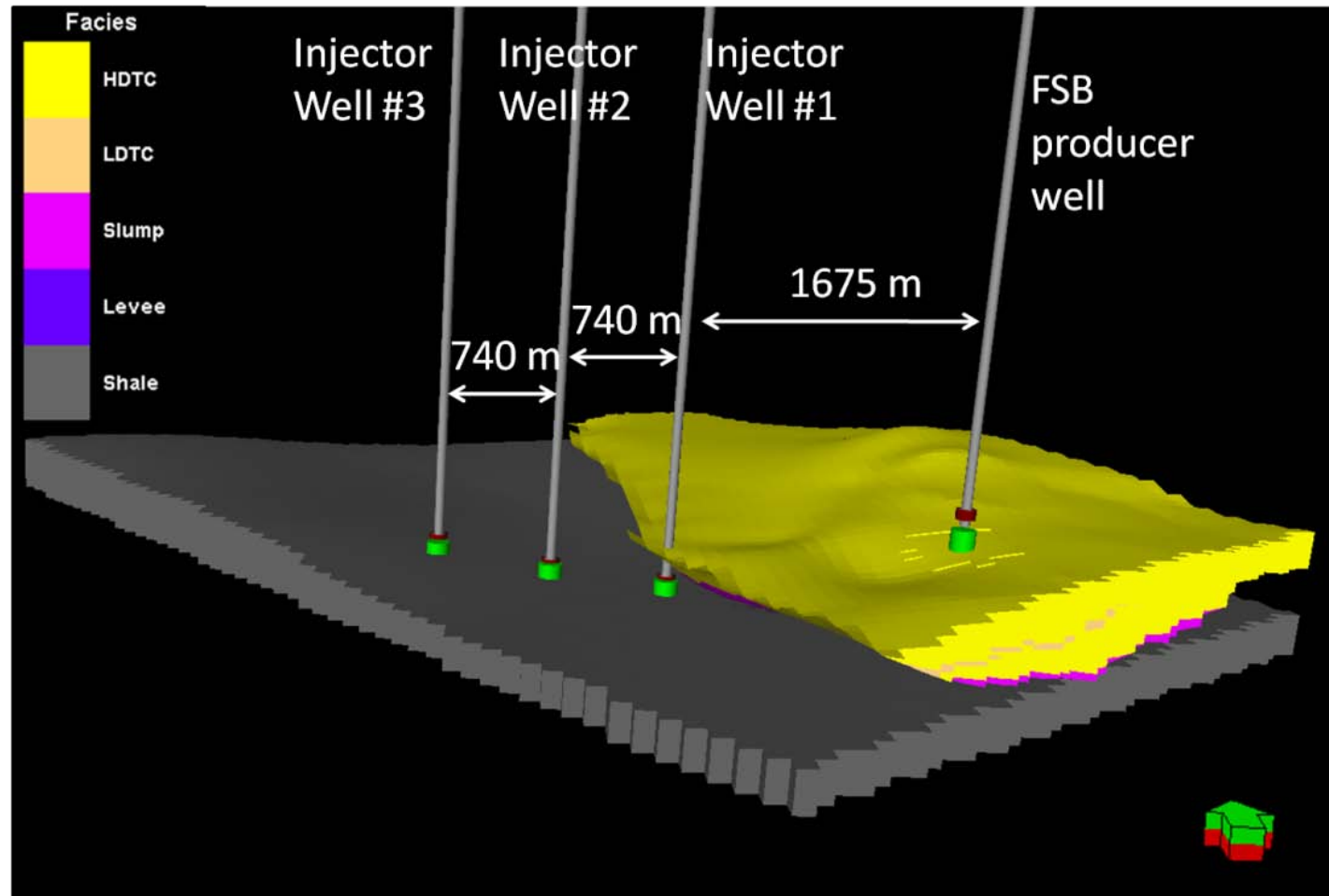
Simulation Scenarios



Flow Simulation

Well Engineering

Figure 28. Location of the 3 injector wells in the levees of Channel C.



Flow Simulation

Streamline flow simulation

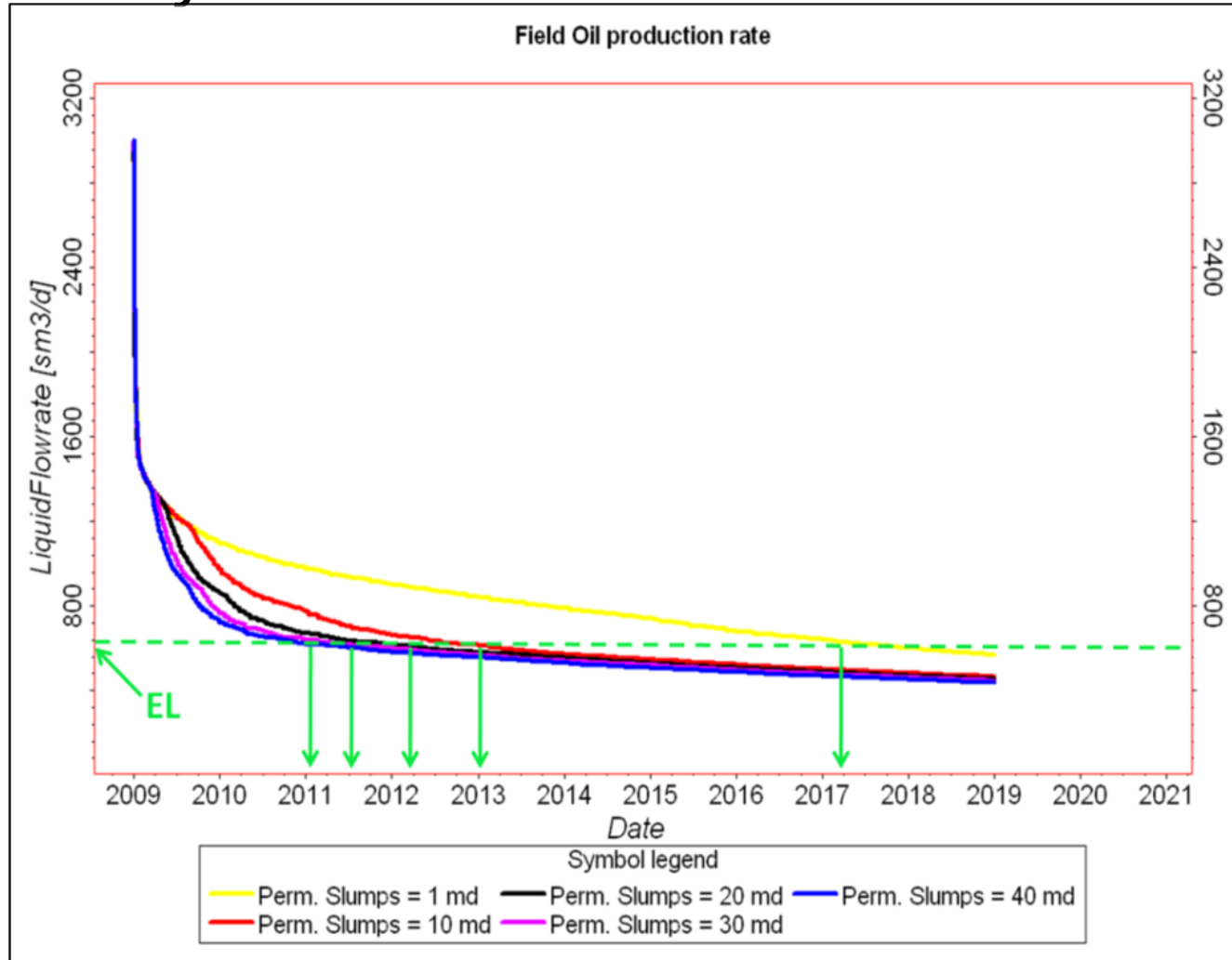
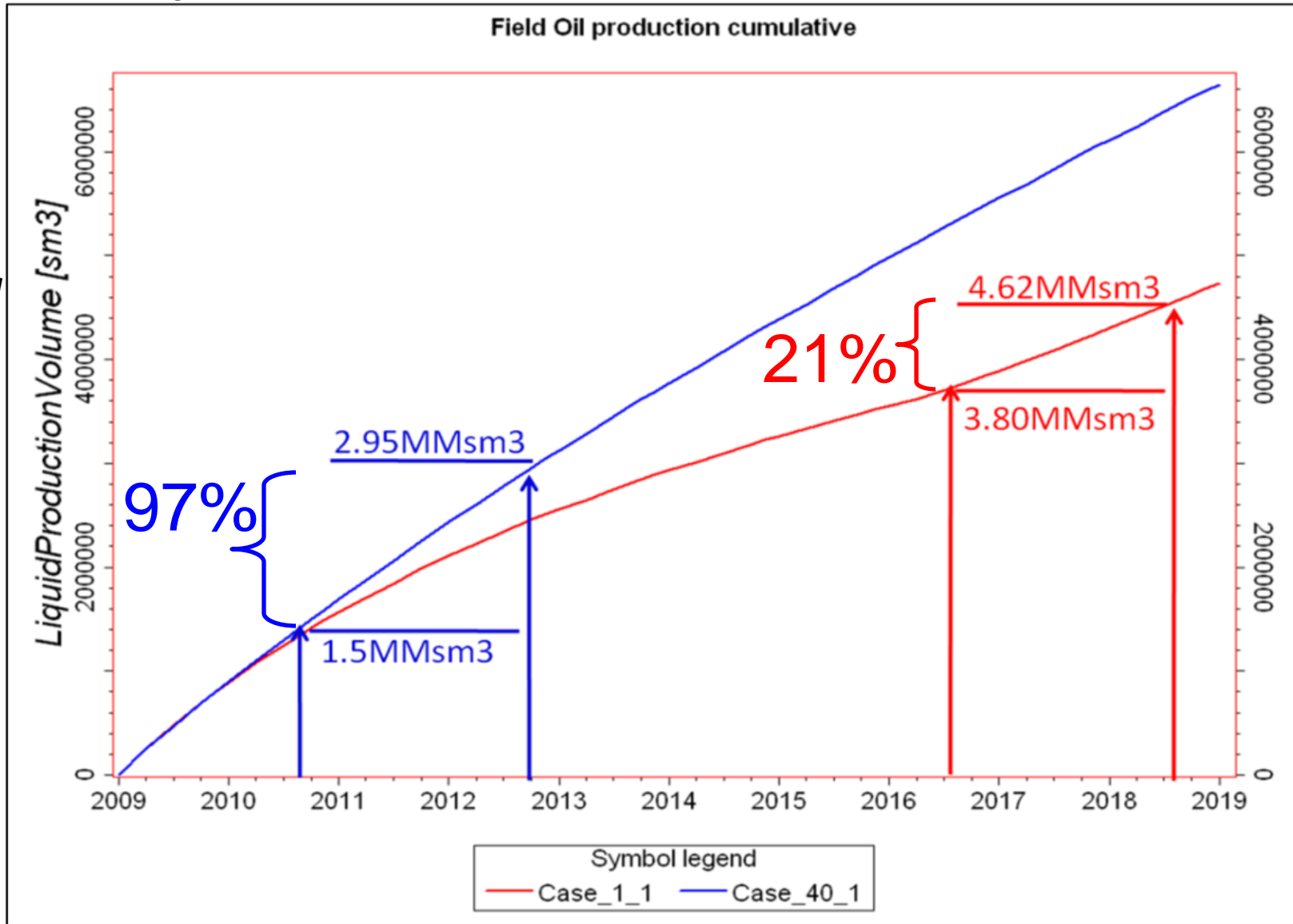


Figure 29. Determination of a date to apply waterflood strategy from the economic limit (EL).

Flow Simulation

Streamline flow simulation

Figure 30. Oil cumulative production curve, which allows to calculate incremental production from water injection.



Flow Simulation

Streamline flow simulation

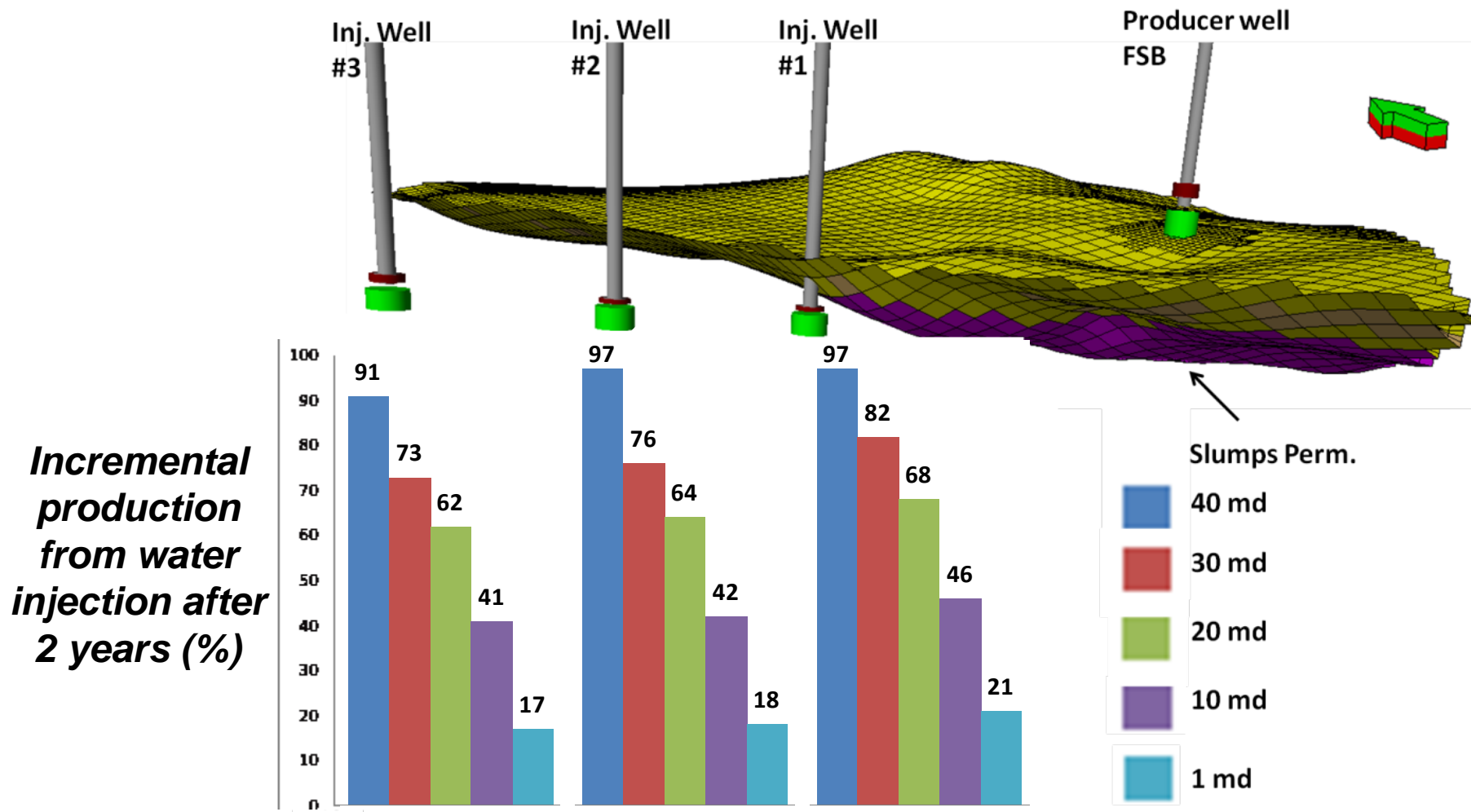
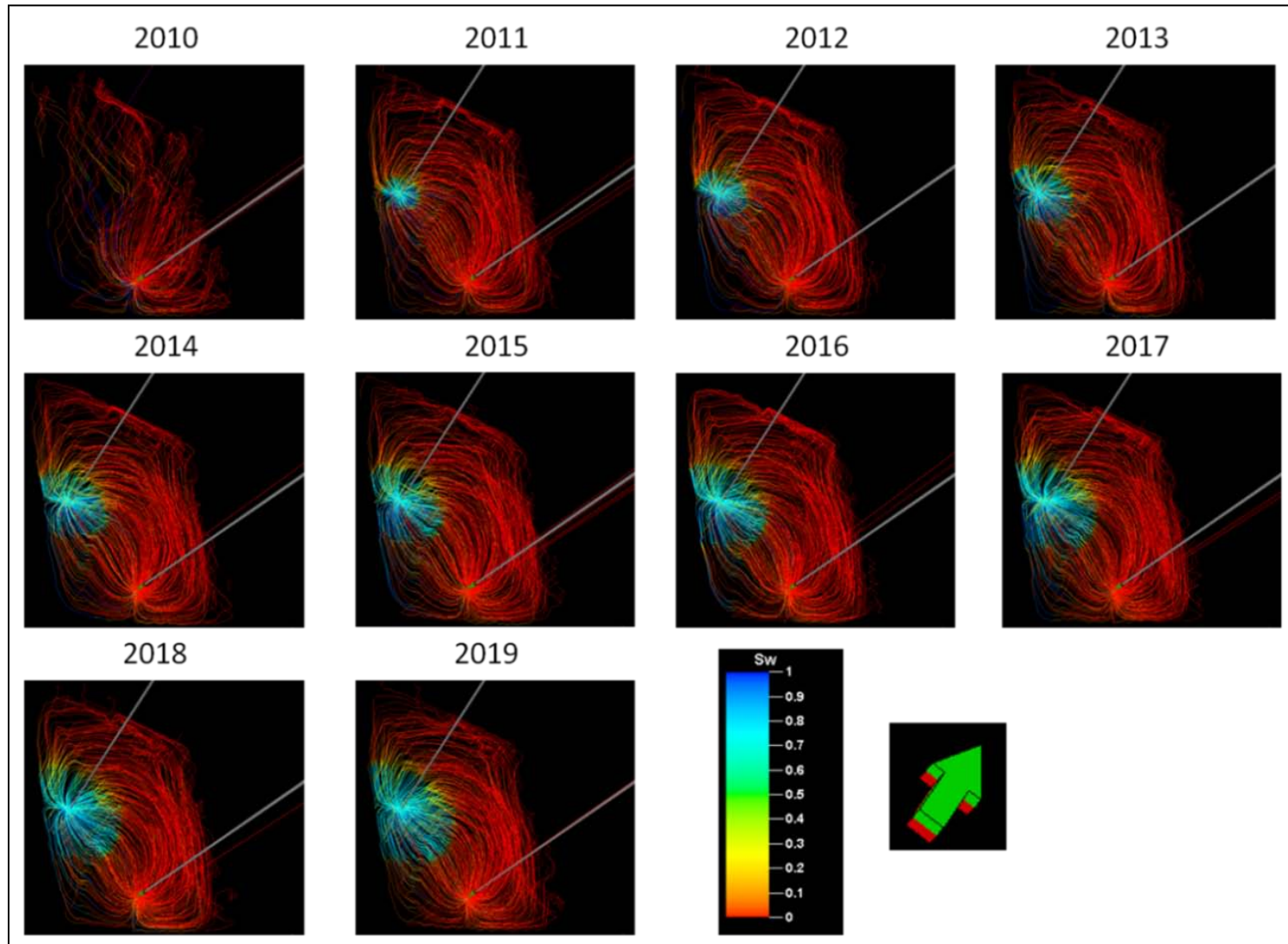


Figure 31. Incremental production from water injection

Flow Simulation

Streamline flow simulation

Figure 32.
Streamline
simulation of
the water
saturation for
case_40_3.



Flow Simulation

Streamline flow simulation

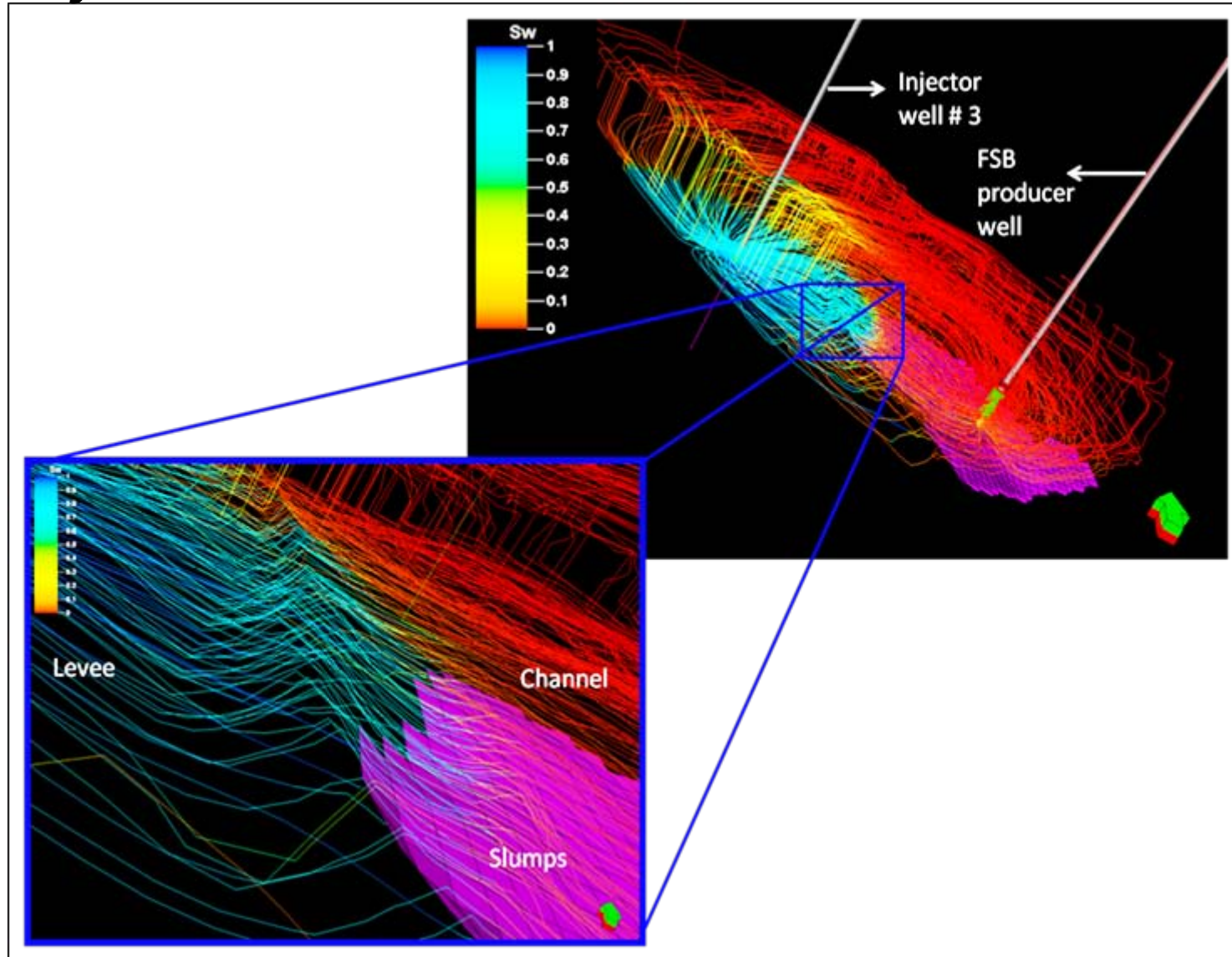


Figure 33. Injected water tries to overlap the slumps.

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Recommendations

1. Avoid pinch out cells (Irregular cells)

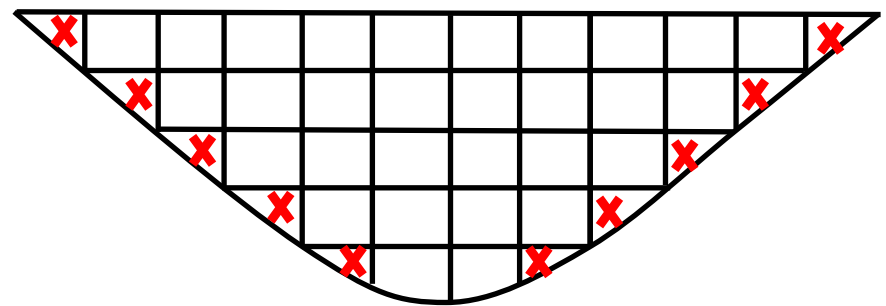
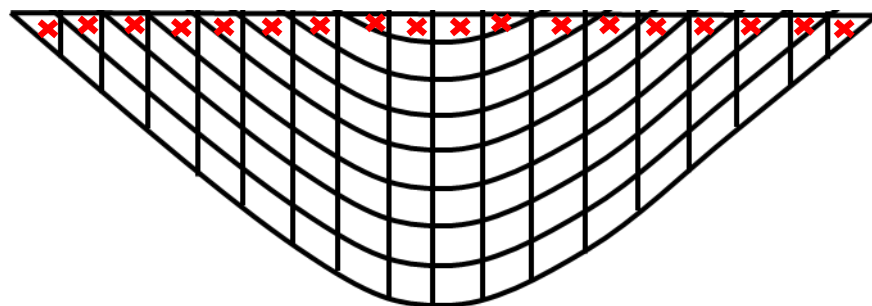
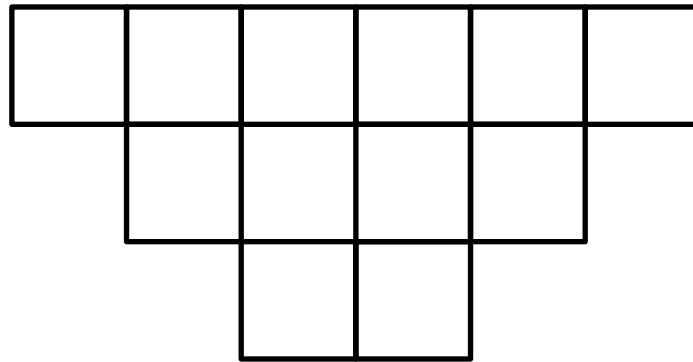


Figure 34. Different grid arrangements in channels.

Recommendations

2. Look for statistics to assign a proper size for slumps. Most of the time slumps are undetected seismically (under seismic resolution) .

Modified from
H. Posamentier
(VSA - 2010)

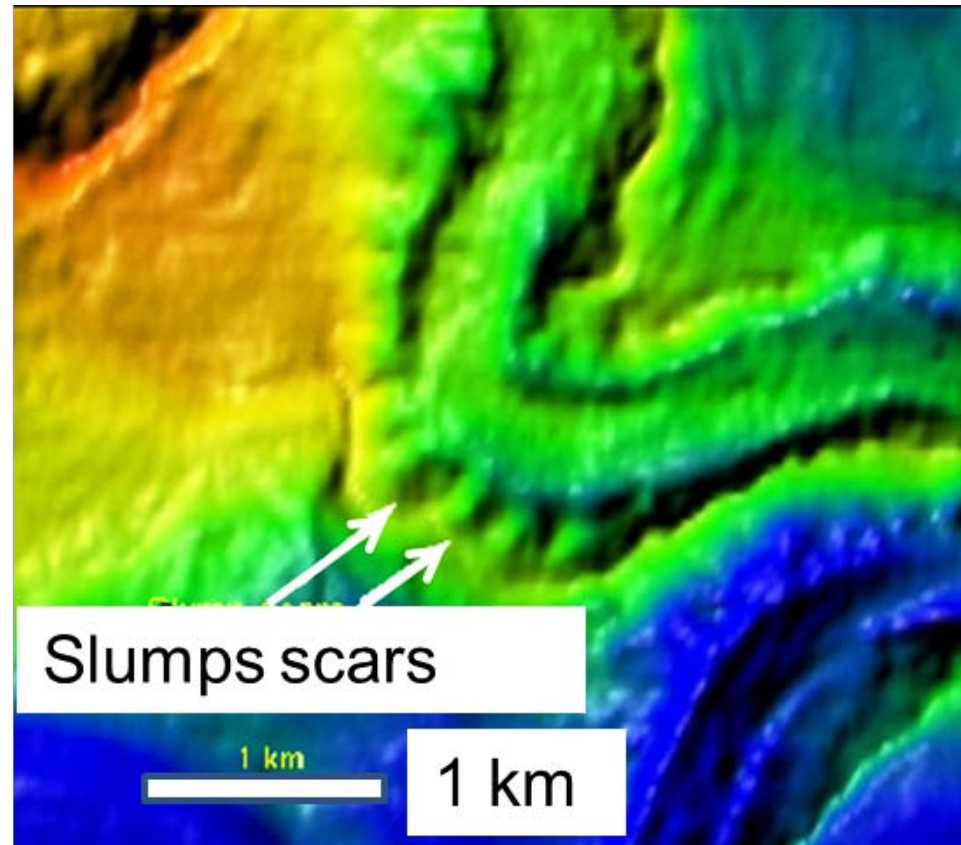


Figure 35. Channel with slumps scars and a representation for different sizes in the slumps inside the channel

Recommendations

2. Look for statistics to assign a proper size for slumps. Most of the time slumps are undetected seismically (under seismic resolution) .

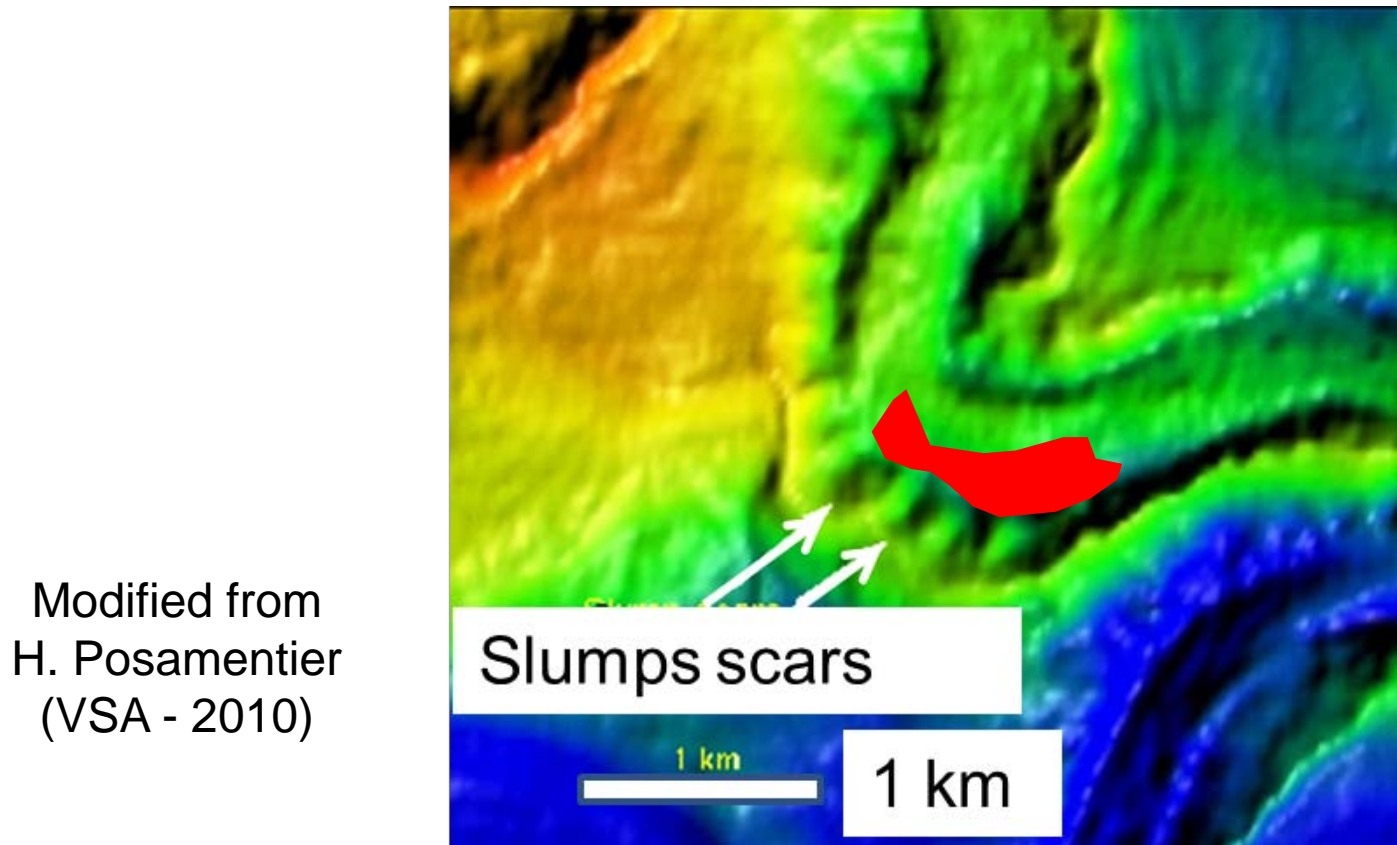


Figure 35. Channel with slumps scars and a representation for different sizes in the slumps inside the channel

Recommendations

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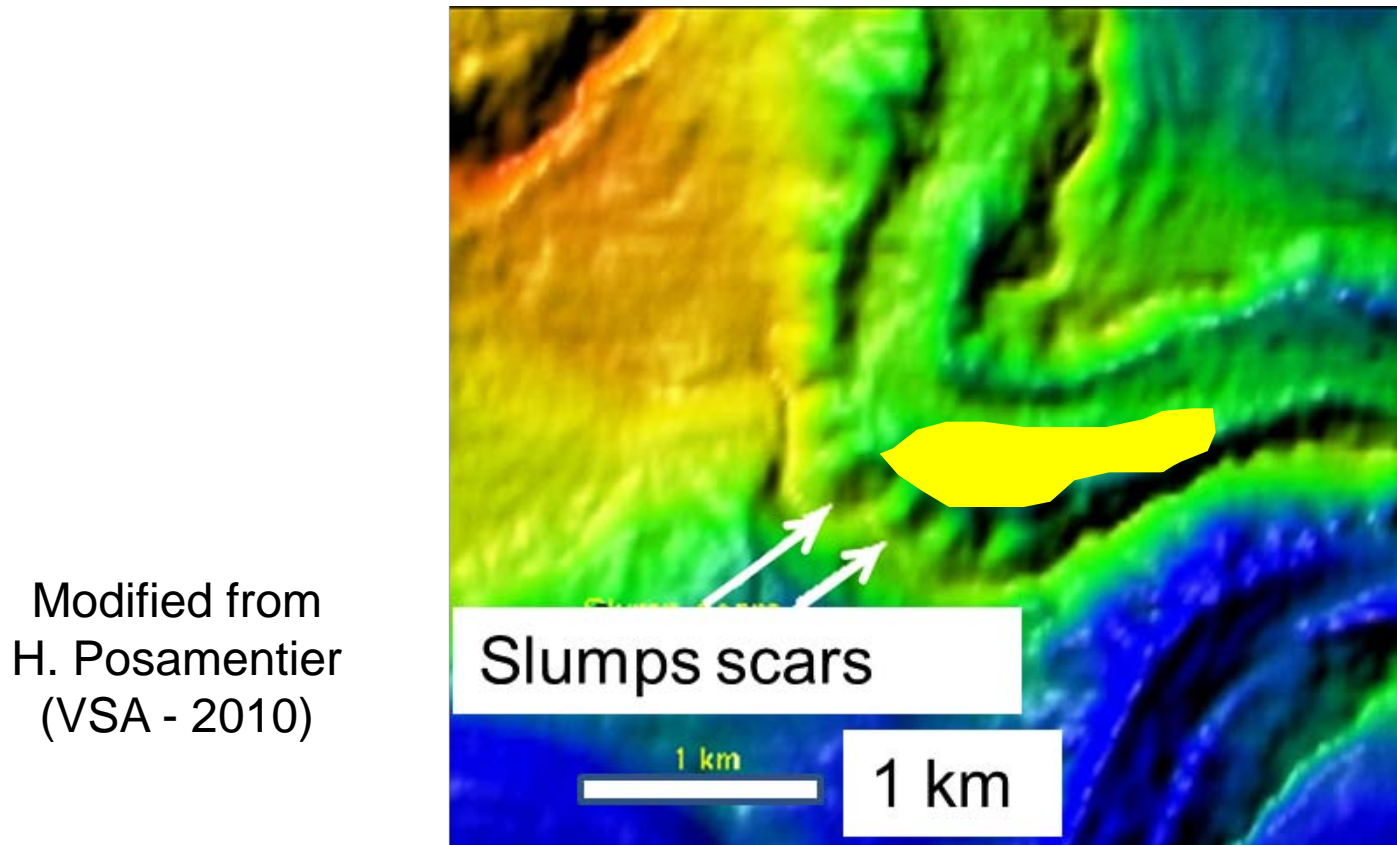


Figure 35. Channel with slumps scars and a representation for different sizes in the slumps inside the channel

Recommendations

3. Petrophysical parameters in slumps are hard to get. Try a probabilistic approach.

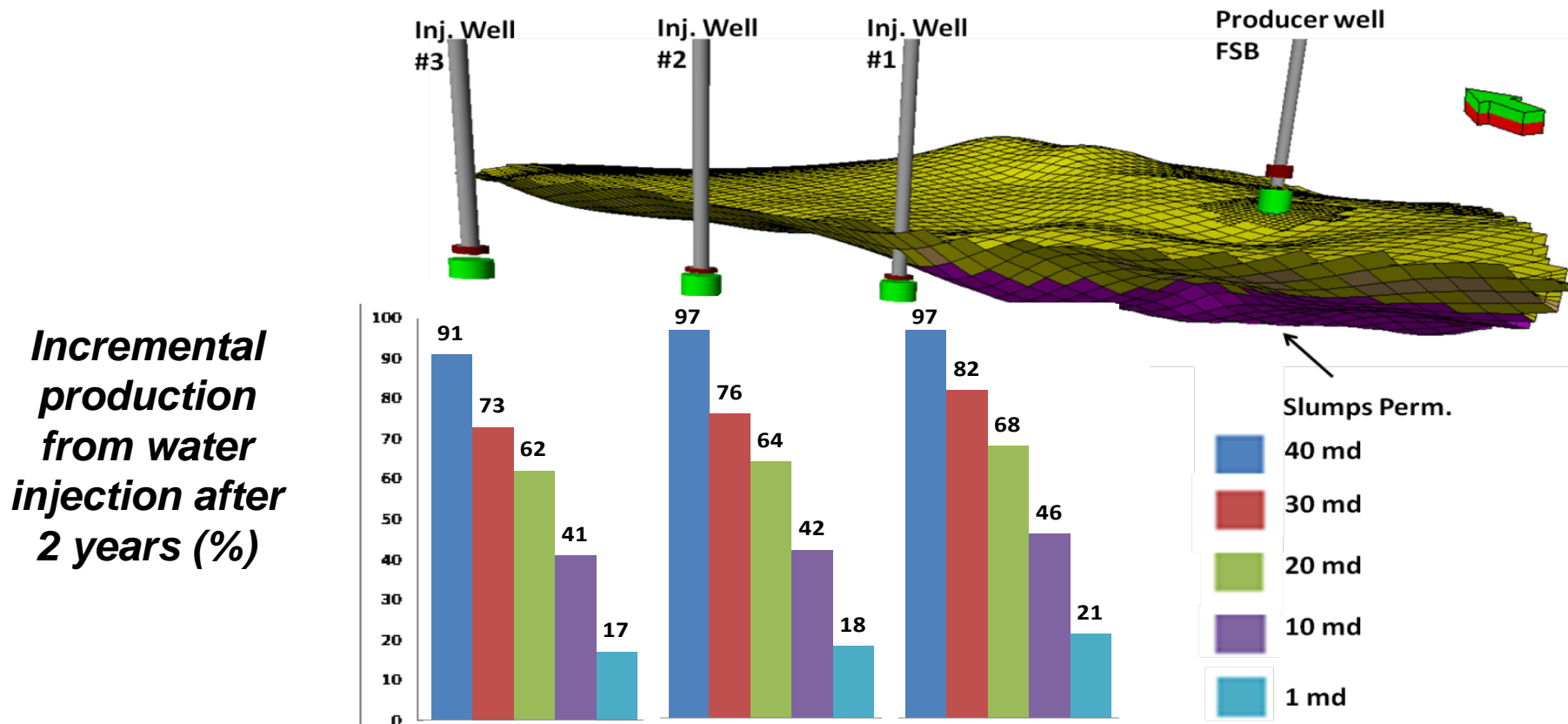


Figure 31. Incremental production from water injection

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- **Conclusions**

Conclusions

1. *A geological model was constructed for Rattlesnake Ridge based on measured sections, GPR data, photomosaics and analog petrophysical data. This geological model contains 2 channels and their respective levees. The lower channel (Channel C) contains erosional remnants, which generate additional slumps due to the steepness of the margin.*
2. *Twenty flow simulation cases were developed based upon varying the production strategy and the permeability of the slumps, with the purpose to analyze production problems related with slumps in leveed-channel deposits.*
3. *In the 5 depletion simulation cases, reduction in the permeability of the slumps helped to maintain the water in the reservoir, thus reducing water coning.*

Conclusions

4. *In the 15 waterflood simulation cases an increase in permeability improved oil production. However, the well location was optimized by analyzing different aspects of the slumps. The water tries to overlap the slumps if they are of low permeability and the water attempts to penetrate the slumps if they are more permeable.*
5. *The continuity, thickness, distribution and petrophysics of the slumps are fundamental for production problems in leveed-channel deposits, which contain these kinds of geological features.*

Acknowledgments

- *Noble Energy Inc.*
- *School of Geology and Geophysics at The University of Oklahoma.*
- *Shell International.*
- *Dr. Yucel Akkutlu and Dr. Kurt Marfurt.- University of Oklahoma*
- *Dr. Roger Young. - University of Oklahoma*
- *Schlumberger: Maria Villalobos, Eva Peza and Bob Davis.*