3-D Grid Types in Geomodeling and Simulation – How the Choice of the Model Container Determines Modeling Results*

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Abstract

Requirements for subsurface modeling have changed substantially over the past years: the perception that limits of hydrocarbon availability are in sight has moved attention in exploration and development to more complex reservoirs; more data has become available for predicting and monitoring performance that now need to be integrated in subsurface models. Targets for (re)development have become more sophisticated and depend more critically on accurate models of geometry and actual properties. This paper attempts to analyze the requirements of 'static' modeling at reservoir to basin scales and simulation of dynamic subsurface behavior, covering fluid flow as well as geomechanical response to man-made changes in the subsurface.

A quick look back into methods for describing subsurface reservoirs tells us that over the past 15 years using 2-D maps as carrier of geometry and property information have been gradually replaced by 3-D reservoir models, usually built for single reservoir intervals. Maps are still an important means of documentation for securing funding and getting well plans certified, but in general are a derivative of 3-D reservoir models. The latter are now the main mechanism by which a thorough understanding of subsurface processes and their impact on hydrocarbon availability is created. As understanding of processes grew, it has become apparent that 'static reservoir properties' are not static but time-variant, being influenced by phenomena at scales greatly different from that of reservoirs. Production is affected by mechanical processes at foot scale as well as by full-field compaction responding to underburden and overburden up to surface. Large-scale models are also required when using 4D seismic data as a constraint in reservoir modeling and simulation. Effectively the phenomena to be considered for a balanced solution occur at 5 orders of magnitude. Complex or just

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very mature assets cannot be optimized based on single reservoir models. What is required are multi-scale, 3-D consistent representations of the subsurface - in other words, we still need Shared Earth Models even though the term has become less fashionable.

Another learning has been that production data are often not accurate enough for optimizing mature fields, shifting the focus from detailed history matching to real-time measurements of the current performance and using this information for continuous optimization of asset performance. To do so one needs an evergreen model. Therefore, our subsurface models should not only be comprehensive but also easily updatable.

Current reality is different though and practice in maturation teams is frequently pitched at lower levels of sophistication and integration. Sometimes for a good reason - there are indeed cases where re-development can be done well on the basis of decline curve analysis and where models or tools are of secondary importance to experience and skill. However, simple assets can become complex when aging and the number of experienced engineers capable of running a field by decline curves is getting smaller. While integration is required, practice often shows workflows where optimization occurs in single expertise areas. So what is causing this underperformance of all past integration attempts? In our opinion a significant blocker to integration has so far been overlooked; it is actually the ‘heart’ of all modeling packages, the so-called ‘3-D gridder’ that determines how comprehensive models can be and how easily they can be updated.

Reference

Mallet, J-L., 2008, Numerical Earth Models, *in* Education Tour series 3: EAGE, 147 p.

3D Grid Types in Geomodeling and Simulation

How the Choice of the Model Container Determines Modeling Results

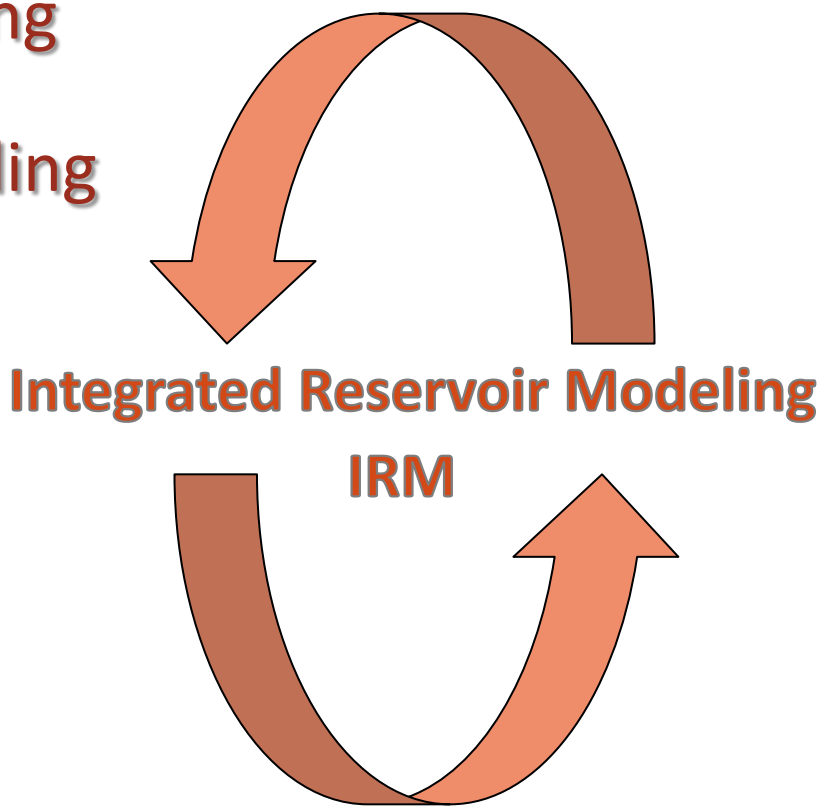
Jim Thom & Christian Höcker, JOA Oil & Gas

Reservoir Development Trends

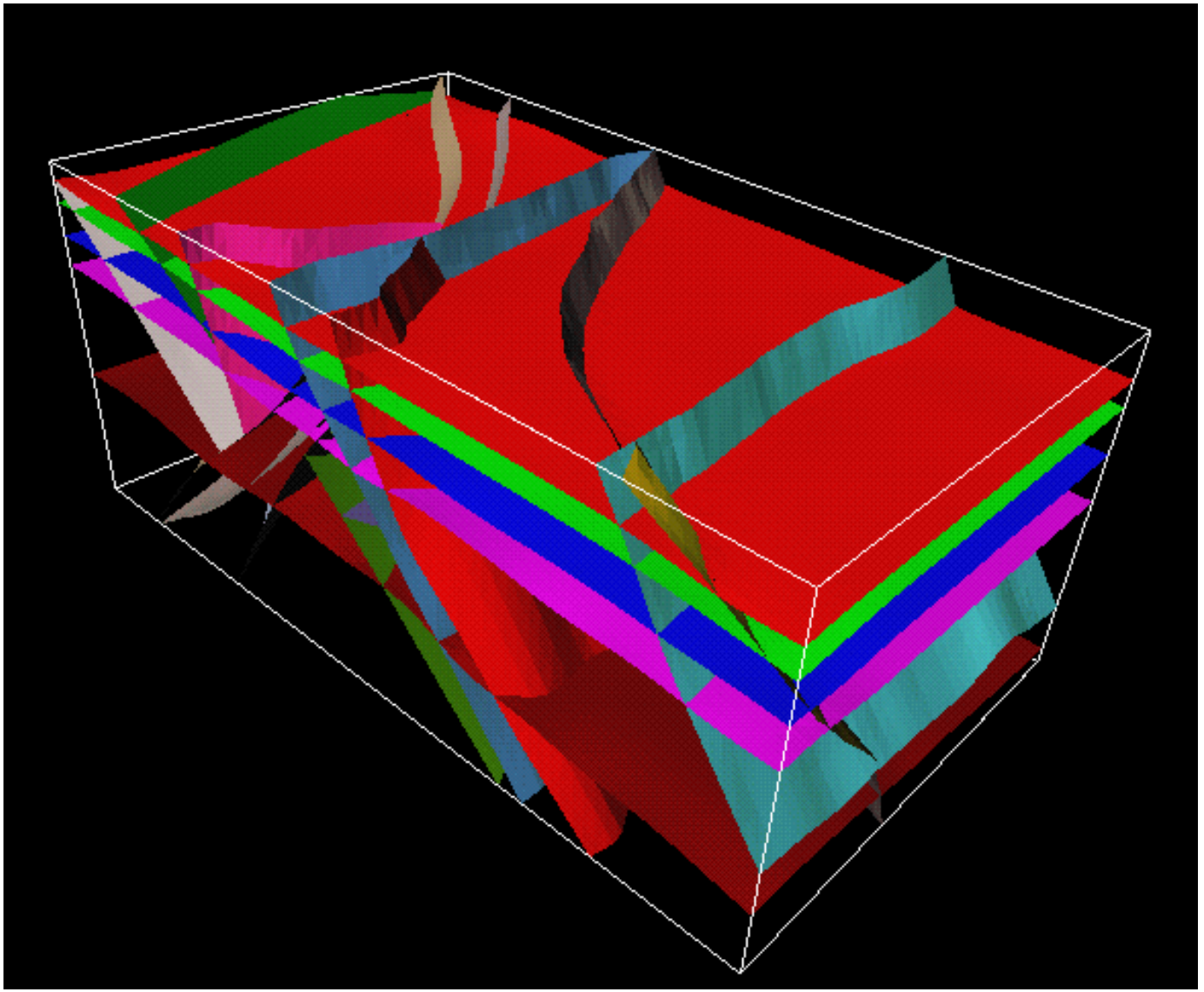
- Clear Industry trend:
  - from 2D Grids/Maps and Decline Curves
  - to 3D Reservoir Models and 3D Dynamic Simulations
- Drivers:
  - Even simple reservoirs get complex when maturing
  - Assets currently under development are more complex than those developed 10 years ago
  - Requirements by banks and regulatory bodies get more stringent
- But:
  - Maps are still important documentation means

Oil Field Management based on Integrated Reservoir Modeling: Generic Workflow

- Structural Framework Modeling
- 3D-Gridding with Layer Modeling
- Property Modeling
- Upscaling
- Numerical Simulation

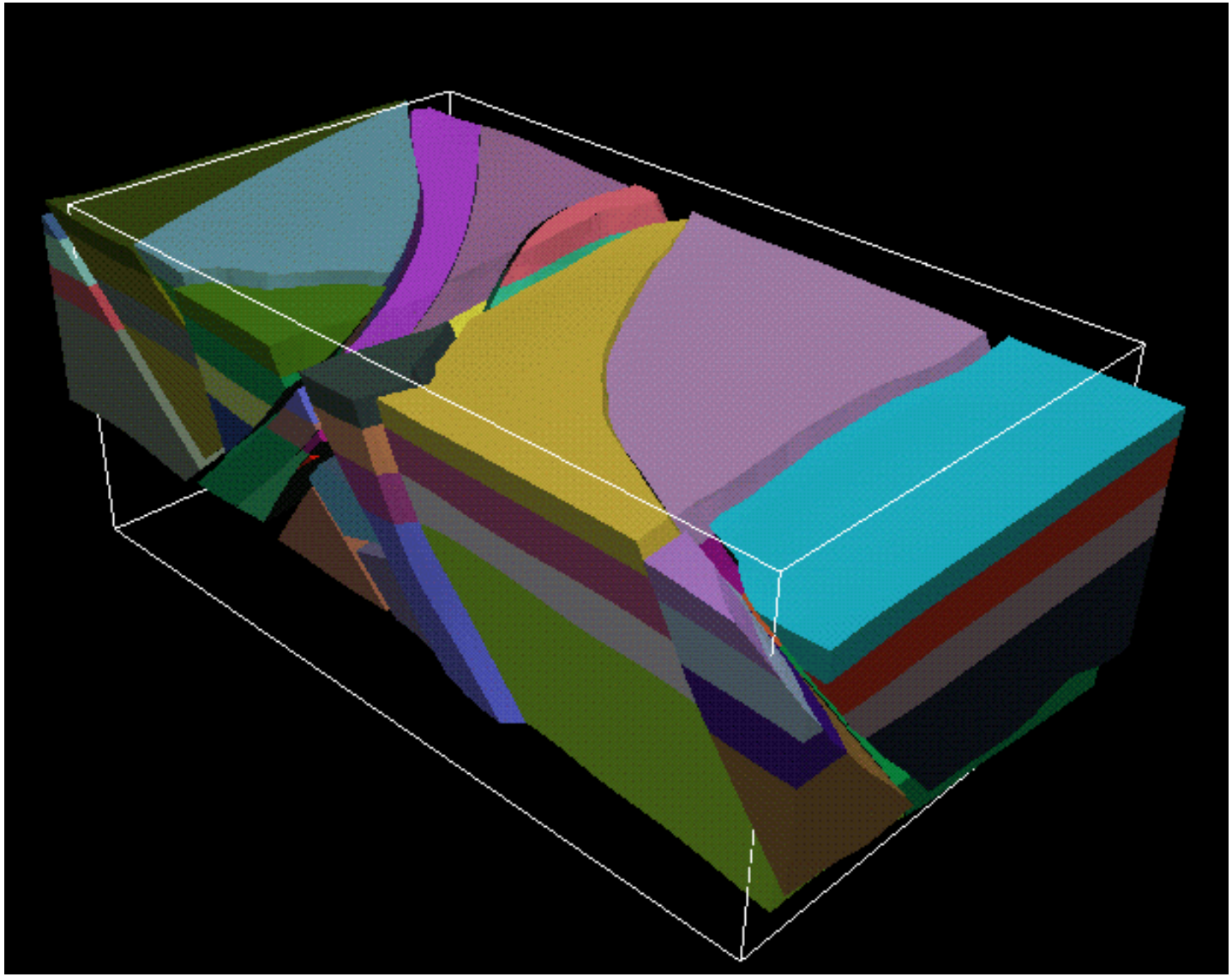


Fault-Horizon Structural Framework Model



from Schlumberger

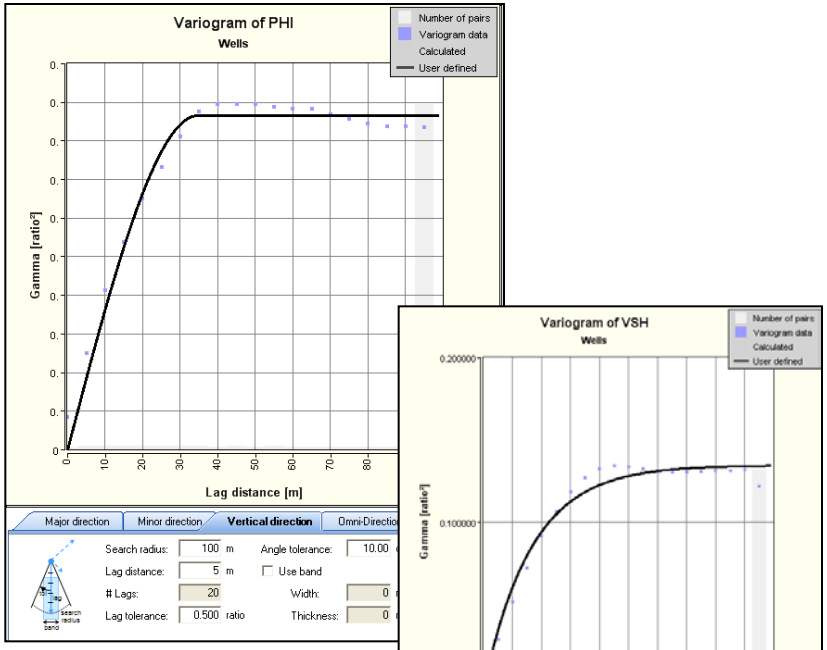
‘Exploded’ Layer Model

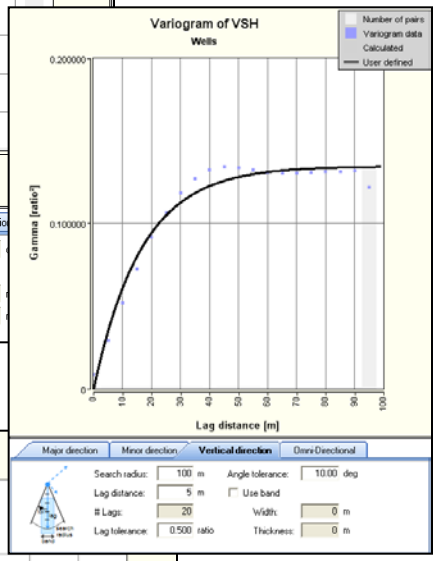


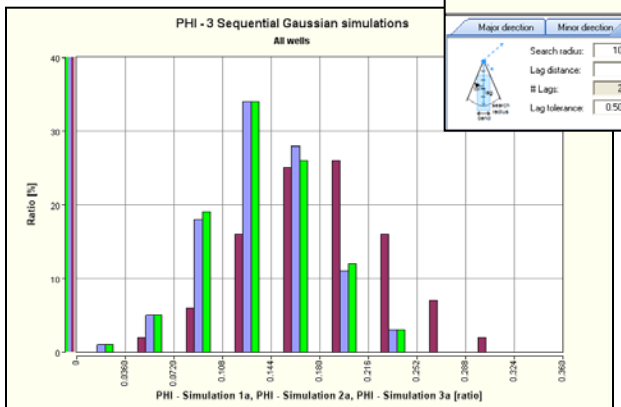
from Schlumberger

Geocellular Property modeling

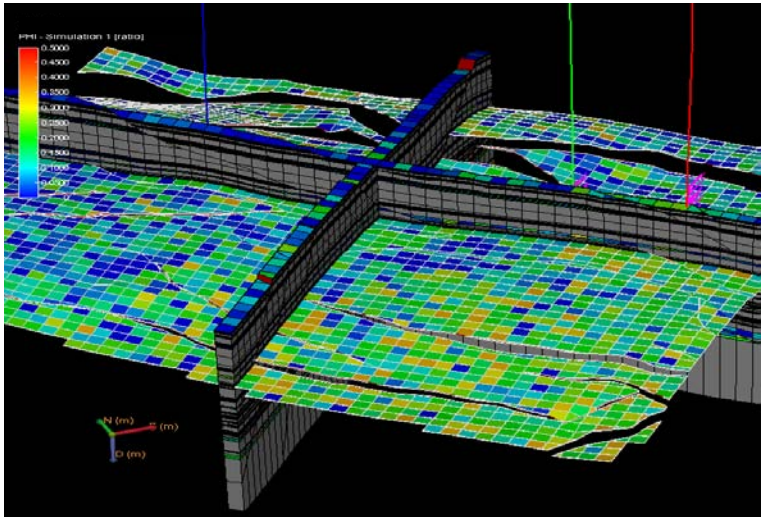
Data analysis

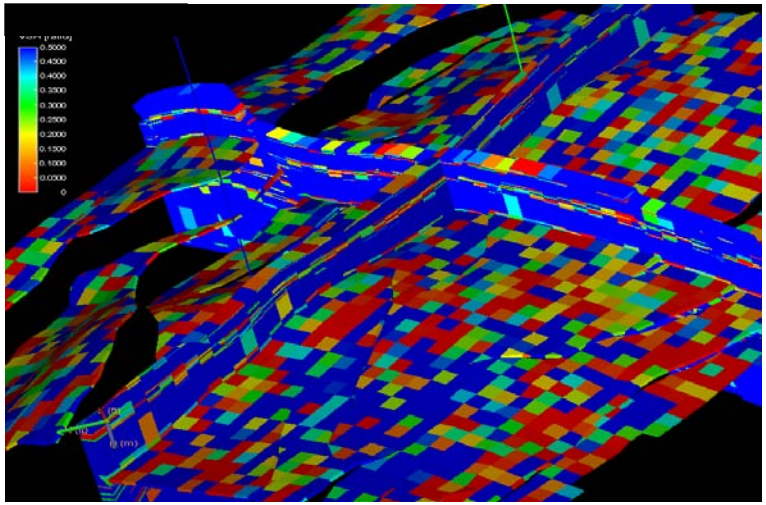




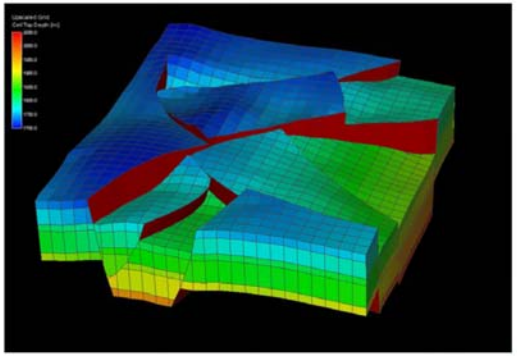


Simulation





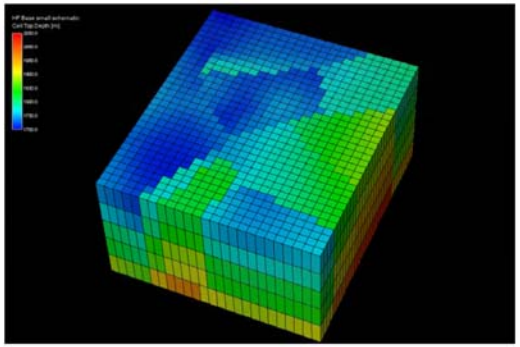
How does it work?
Geological Model versus Simulation Matrix



Geological Models

- Distinguish between geometrical properties and reservoir properties
- Geometry information defines coordinates of corner points between grid cells and can describe complex shapes
- Faults are explicitly represented

Intermediate stage: **Upscaled Simulation Model**



Simulation Matrix (in commercial simulators)

- Regular 'ijk grid'
- Geometry is represented as cell properties 'depth' and 'volume', and indirectly in transmissibility with neighbor cells
- Faults are not explicit in model but represented as anomalous transmissibility; juxtaposition can be expressed as Non-Neighbor Connections (NNC's)
- Current commercial simulators assume cells to be hexagonal; simulators using complex cell shapes are at prototype stage

Notes by Presenter:

Corner geometry to cell centered geometry from perm transmissibility

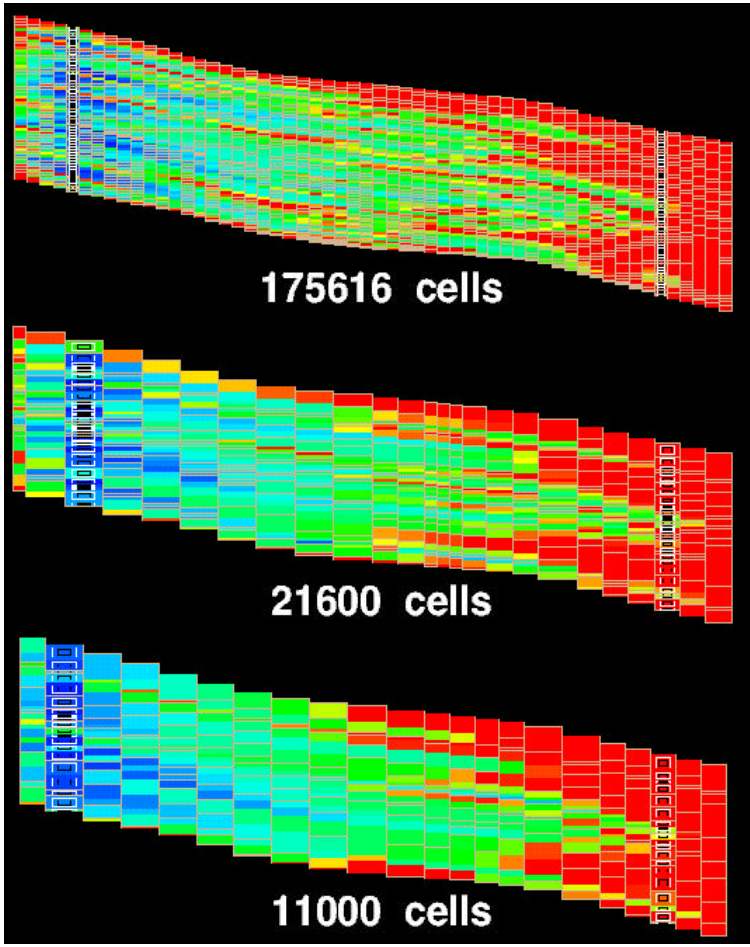
Upscaling Properties from Geological Grid to Simulation Grid

Why Upscaling?

CPU time in simulation grows exponentially with number of cells

An "accurately" upscaled simulation grid has got:

- **Similar breakthrough time of displacement front**
- **Similar shape of displacement front**
- **Similar recovery**



images from Schlumberger

Recent Learnings in Reservoir Management

- 'Static' models do not reflect time-variant reality
  - Static reservoir properties vary under influence of hydrocarbon production
  - Need tighter coupling between static and dynamic models
- Mechanical processes occur at a large range of scales
  - from well neighborhood
  - to entire overburden
- Subsurface models should be holistic 'Full-Field' models
  - not only entire field extent laterally
  - but also including entire overburden and some underburden thickness
  - at adequate variable resolutions for diverse data types

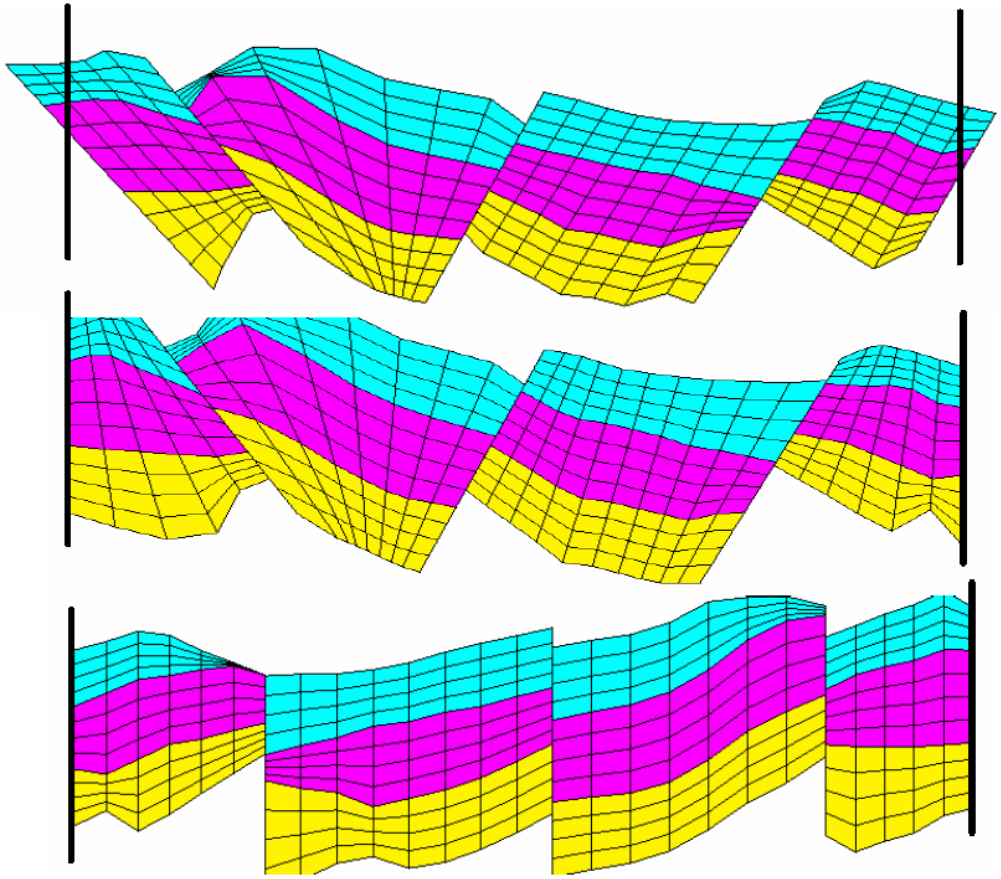
Notes by Presenter:

Stress from well scale 6 inches to seismic 20 ft to gravity and magnetic data hundreds of feet scale of 1:1000

3D Grid Types used in Geological Modeling

- Pillar Grid — by Petrel, gOcad, Irap RMS
- SKUA Grid — by Paradigm
- S-Grid — various applications
- Faulted S-Grid — by JewelSuite

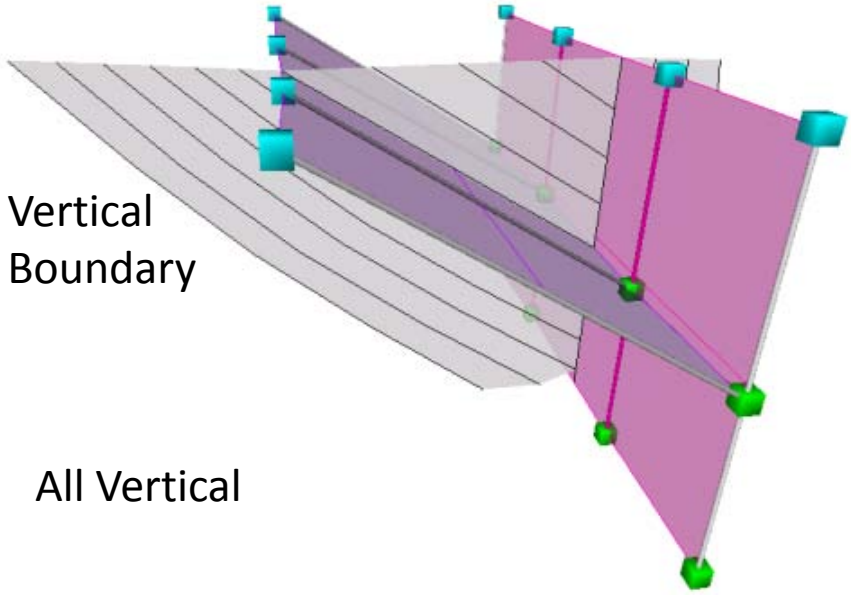
Pillar Grid



All Sloping

Vertical
Boundary

All Vertical



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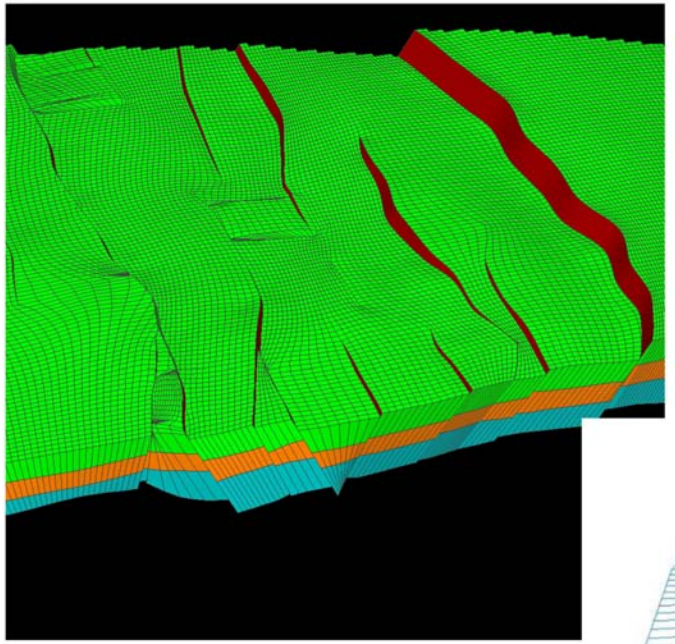
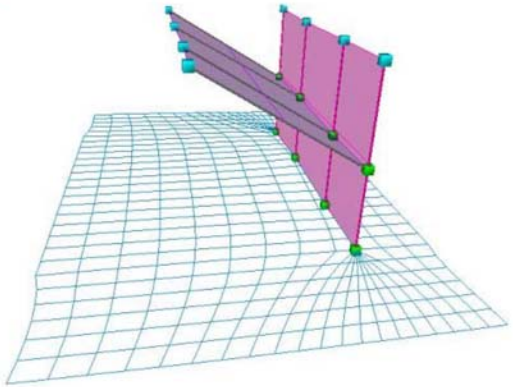
Pillar Grid



features:

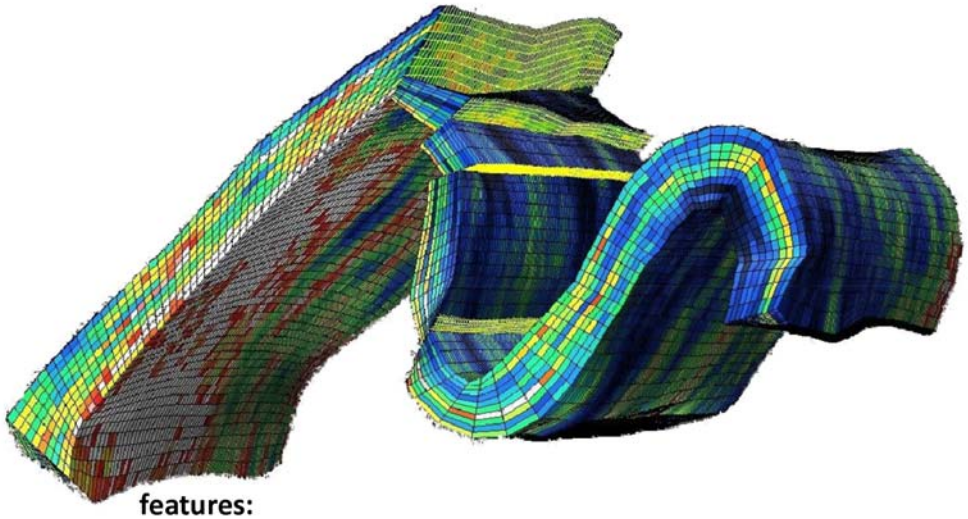
- cell stacks parallel to (simplified) faults
- simple model dimensions:
  fixed number of cells in i, j, k grid
  ⇨ relates well to indexing in simulation grid
- locally very irregular footprint at all levels
- problematic handling of intersecting faults and of lateral changes in fault dip;
  complexities are usually avoided by confining model to relatively thin interval



Notes by Presenter:

Stress strike slip and listric faulting

SKUA grid



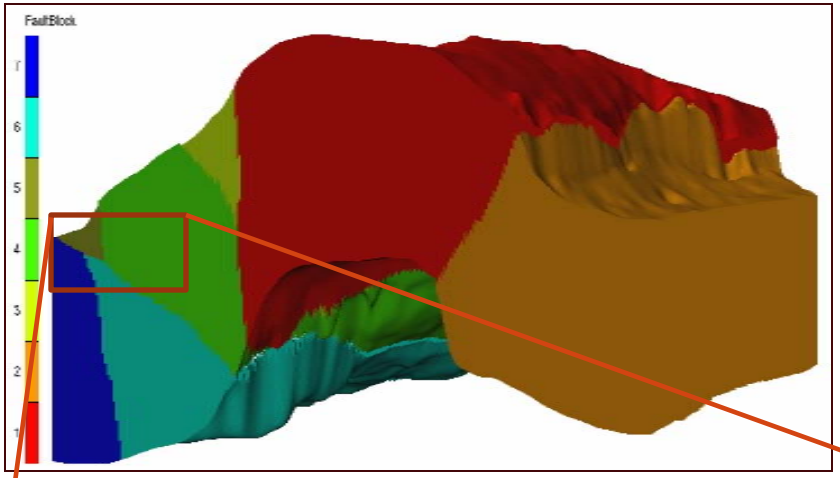
features:

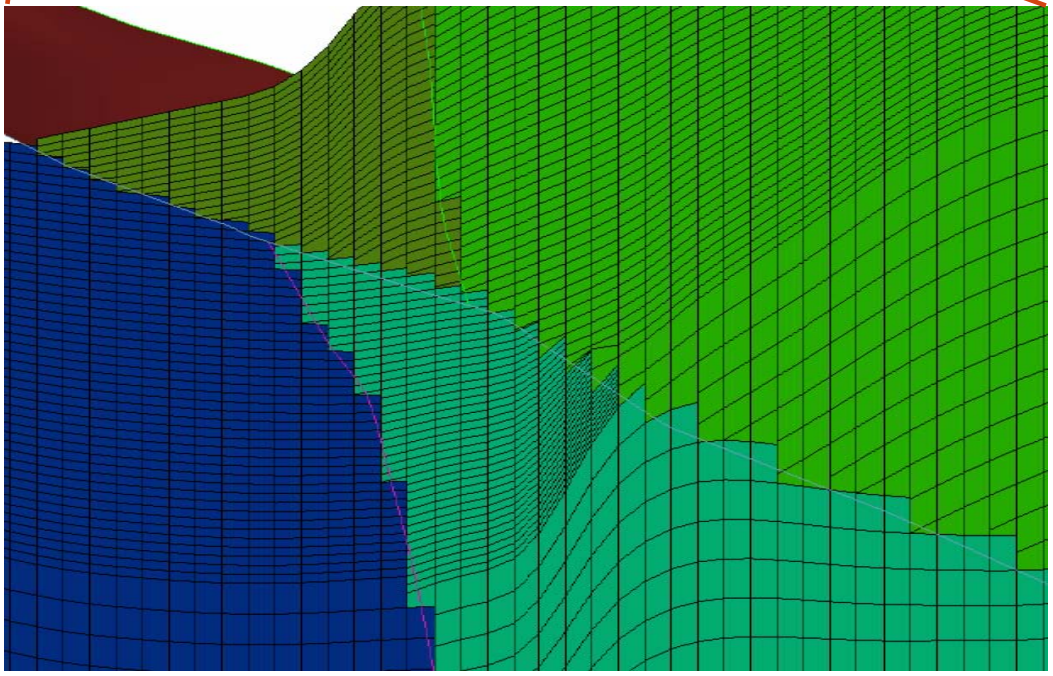
- semi-regular grid at top Modeling interval, stretch-squeeze towards base interval
- cell stacks mostly orthogonal to top interval, at faults either aligned or with faulted cells
- can adopt folded structures as defined at top and base modeling interval
- relatively easy to implement facies and property modeling to be consistent with paleo-domain (with respect to statistics and continuity of bodies across faults)
- can represent structural complexity only in models of limited thickness

Notes by Presenter:

Easier to implement surface consistent geostats, paleo reconstruction… questionable ability to go into simulators (translation) to sugar cube

Conventional S-Grid

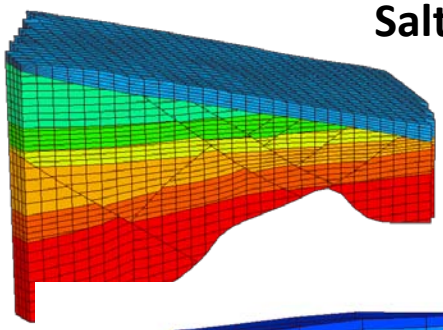




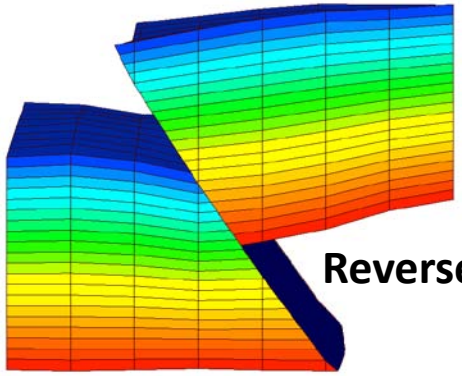
features:

- orthogonal footprint at all levels
- vertical cell stack
- faults are ‘voxellized’ into steps of vertical and horizon-parallel segments
- no restrictions to geometry/topology handling except for granularity; sampling of layers may be poor with dips over 45 degrees

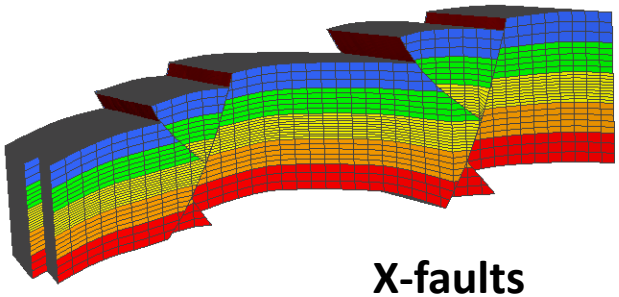
Faulted (orthogonal) S-Grid – Jewel Grid



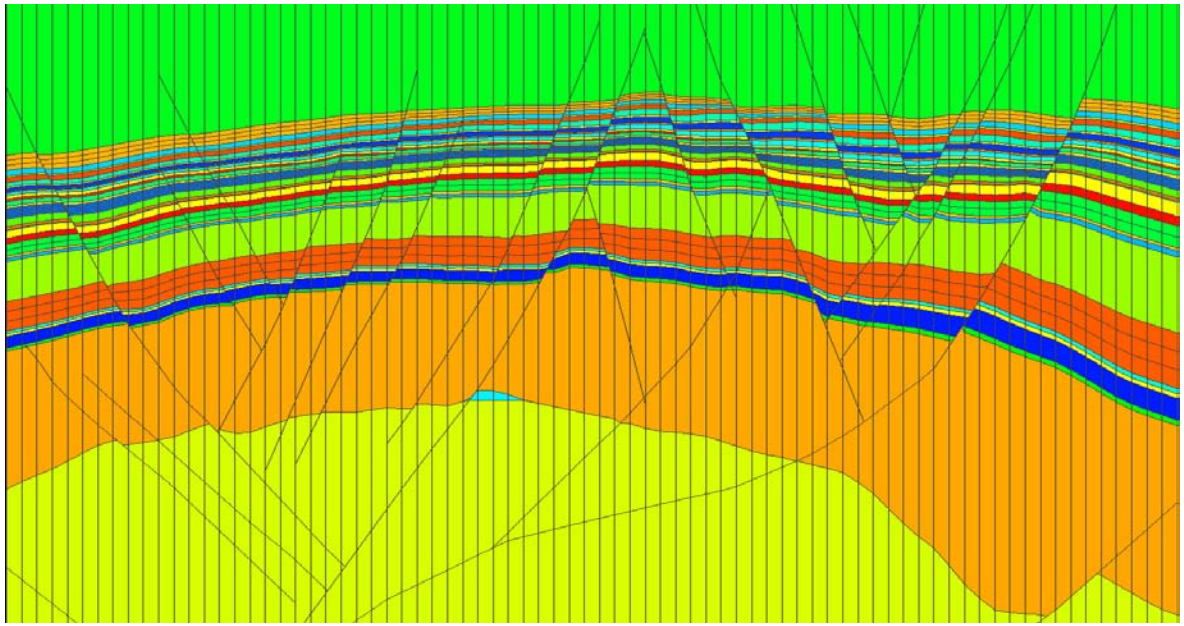
Salt cushion



Reverse faults



X-faults



features:

- orthogonal footprint at all levels
- vertical cell stack
- cells are split exactly where intersected by faults as interpreted
- no restrictions to geometry/topology handling but sampling of layers may be poor with dips over 45 degrees

Grid Ranking Criteria – imposed by Reservoir Geology

- Can complex fault-to-fault geometries be represented?
- Can fault-horizon geometry and topology be handled?
- Can full-field models be built?
- Can stratigraphic architecture geometry be represented?
- Is the 3D grid design flexible enough for models to be updated and extended?

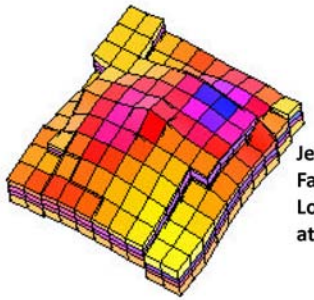
Notes by Presenter:

Range of uncertainty changes as field gets developed …. Dynamic modeling changes entire concept like flank structures and connectivity (new models need to be tried) many times oil water contacts pressures etc new oil types

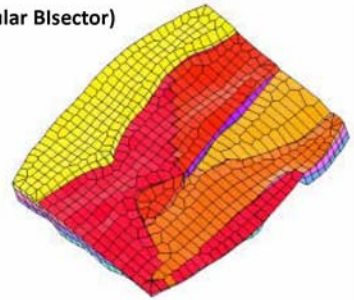
Simulation Grids

Simulation Grid Types

Structured
Rectangular Grid;
"stair-step grid"

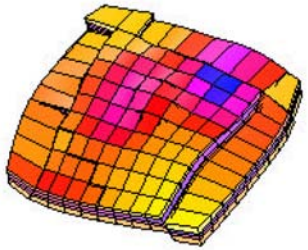


Unstructured
PEBI (PErpendicular BIsector)
or Voronoi Grid

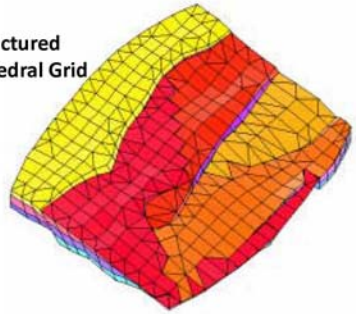


Jewel Grid = hybrid:
Faulted S-Grid
Locally Unstructured
at Faults

Structured
Corner Point
or "Pillar" Grid



Unstructured
Tetrahedral Grid



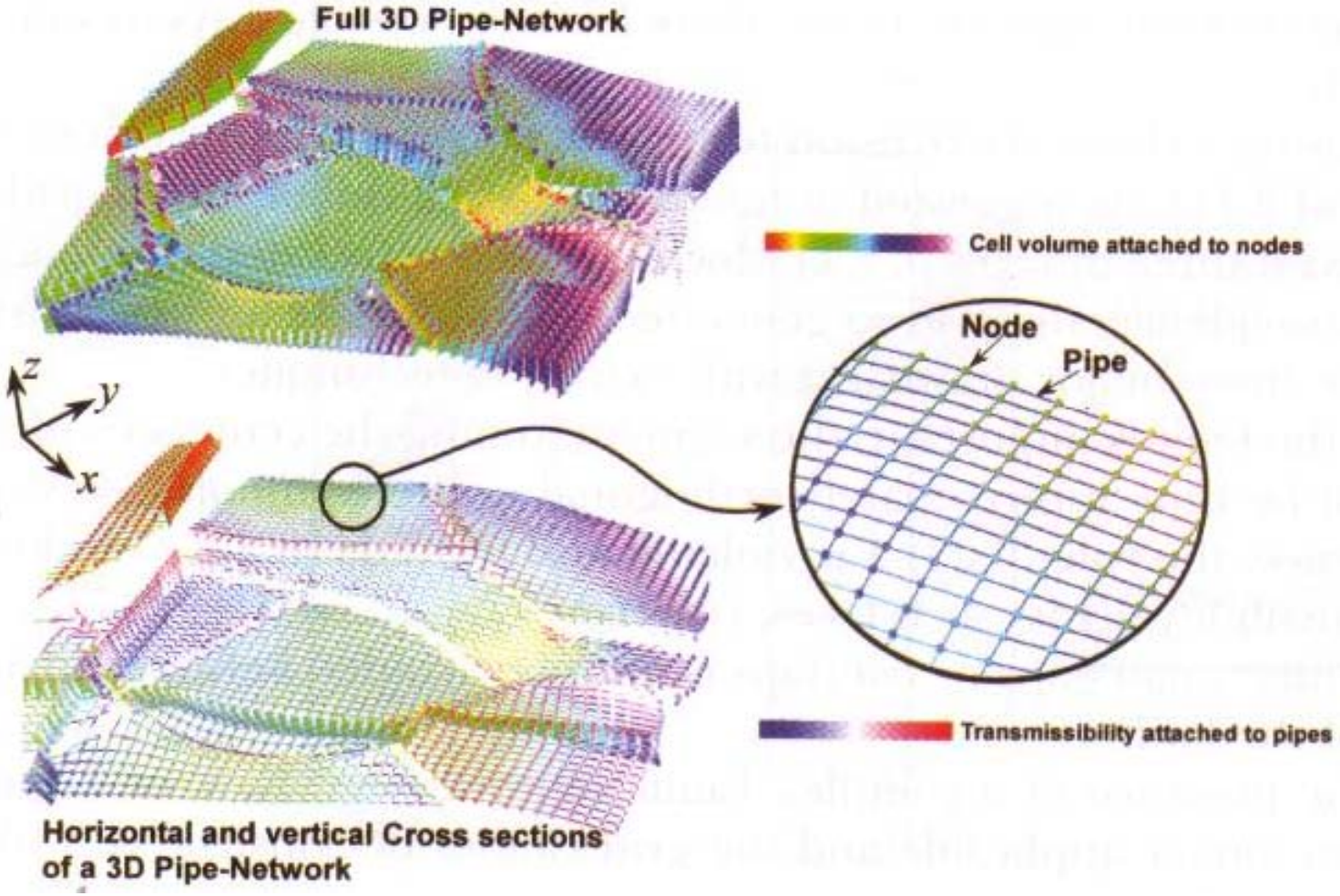
rephrased from Schlumberger

Notes by Presenter:

Simulation grids built from 3D geological models
Grid should follow most of the geologically important features
Maintain orthogonality and smoothness
Maintain vertical cell stacks for gravity and drainage\

Flow Simulators do not know about cells …

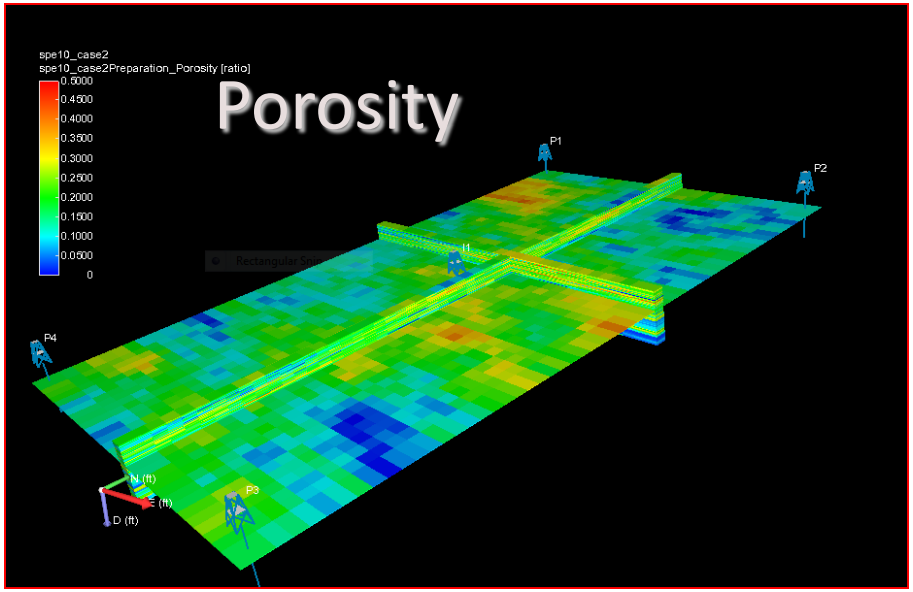
… they only understand 'nodes' with volumes and 'pipes' with transmissibility

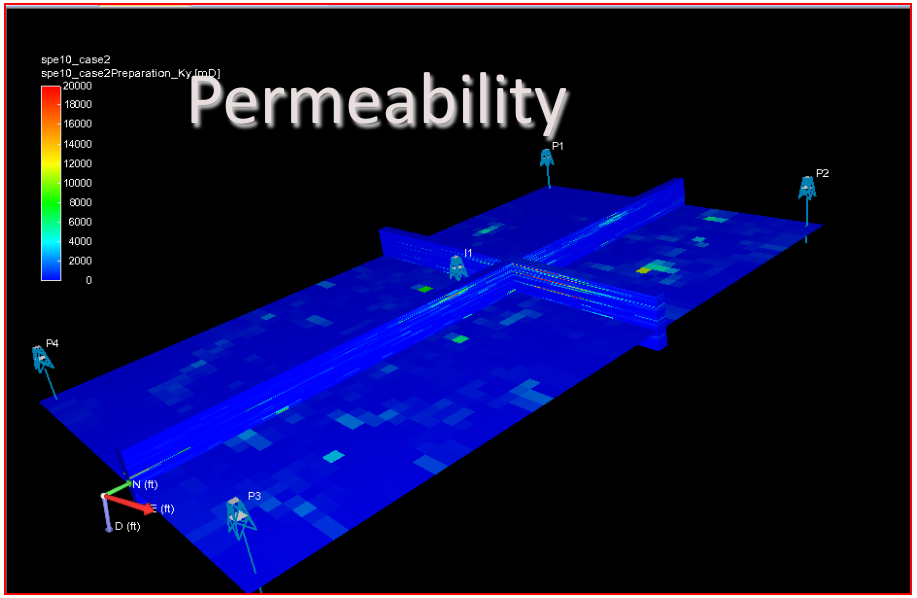


from Mallet 2008

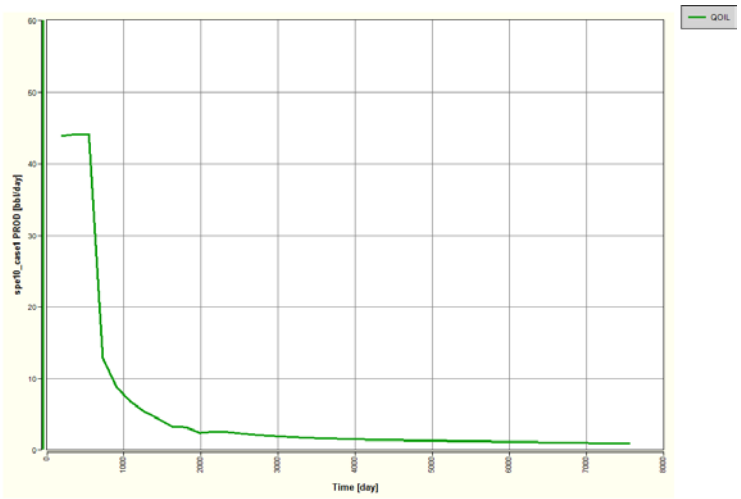
SPE10 Benchmark – Sensor + CMG IMEX

- Black Oil Model
  - Heterogeneous permeability's + porosity
  - Little - no structure – no faults
  - 5 spot pattern – water injection

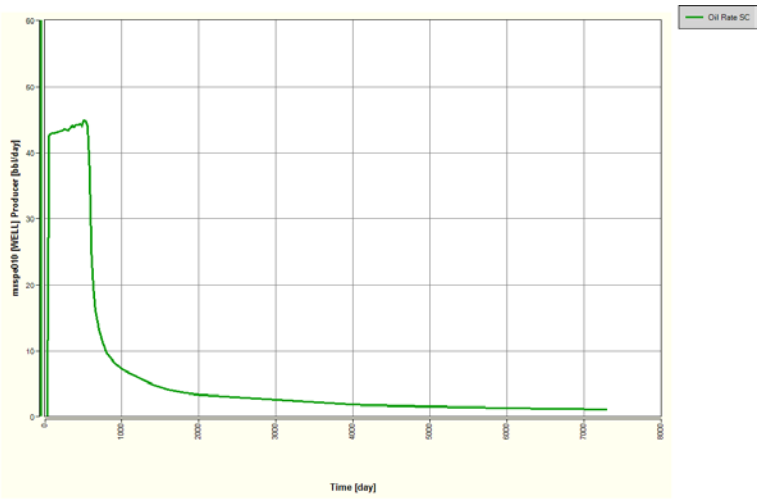




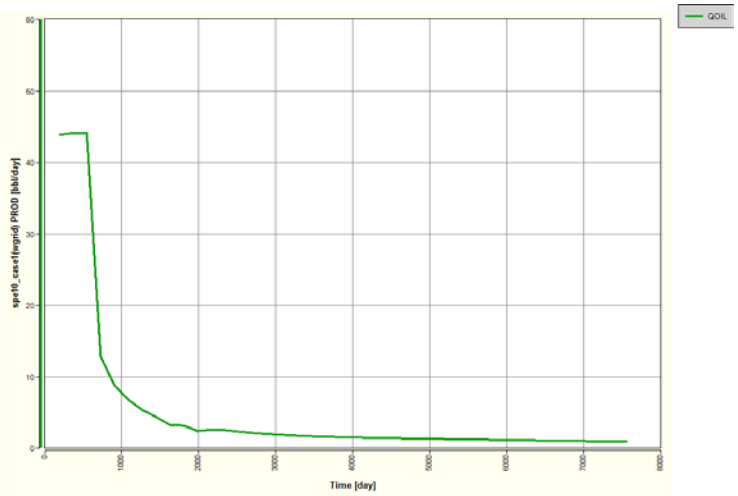
SPE10 Benchmark – S-Grid versus Faulted S-Grid: Oil Production Rate



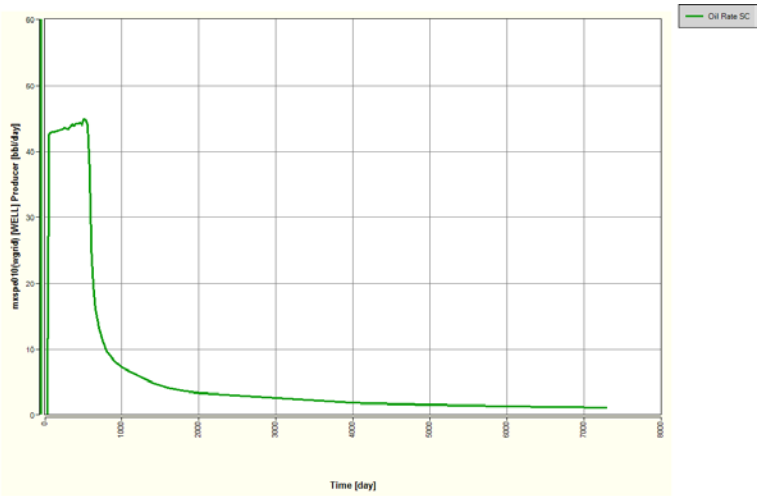
Spe10 run in Sensor : Oil production rate



Spe10 run in IMEX : Oil production rate

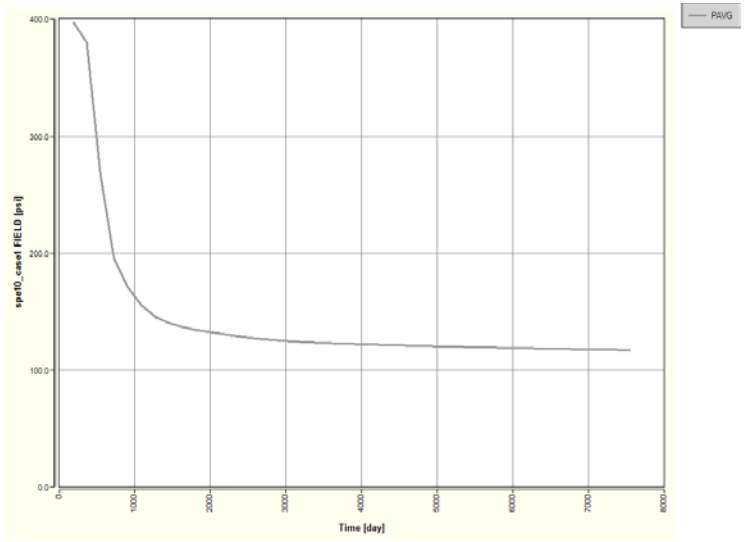


Spe10 run in SENSOR coupled with S-grid: Oil production rate

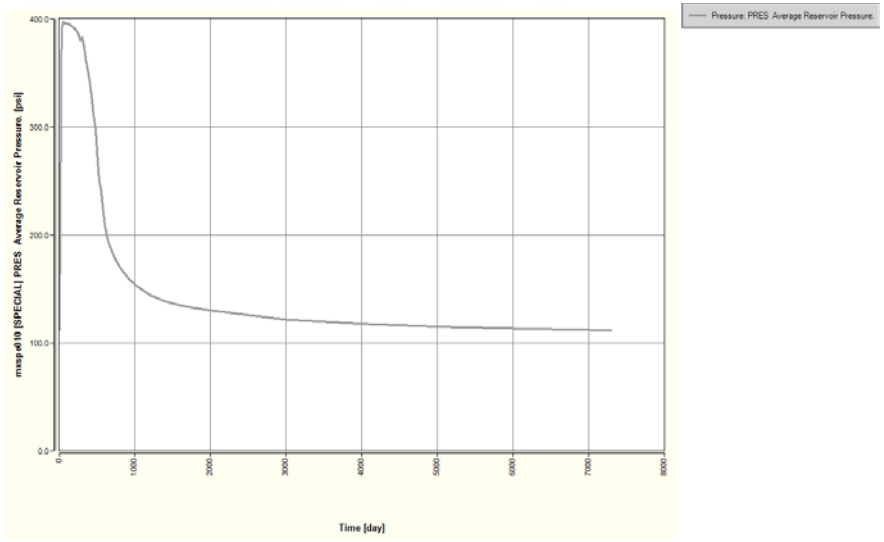


Spe10 run in IMEX coupled with S-grid: Oil production rate

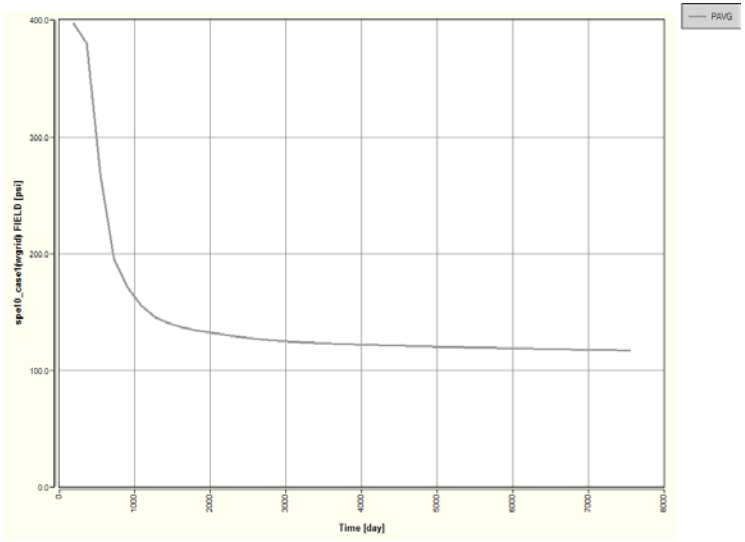
SPE10 Benchmark – S-Grid versus Faulted S-Grid: Average Reservoir Pressure



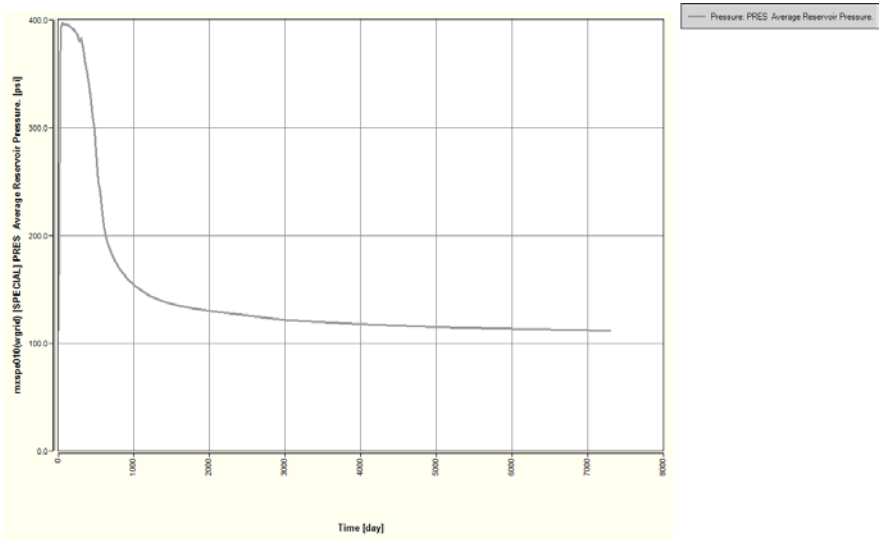
Spe10 run SENSOR Average Reservoir Pressure



Spe10 run in IMEX Average Reservoir Pressure

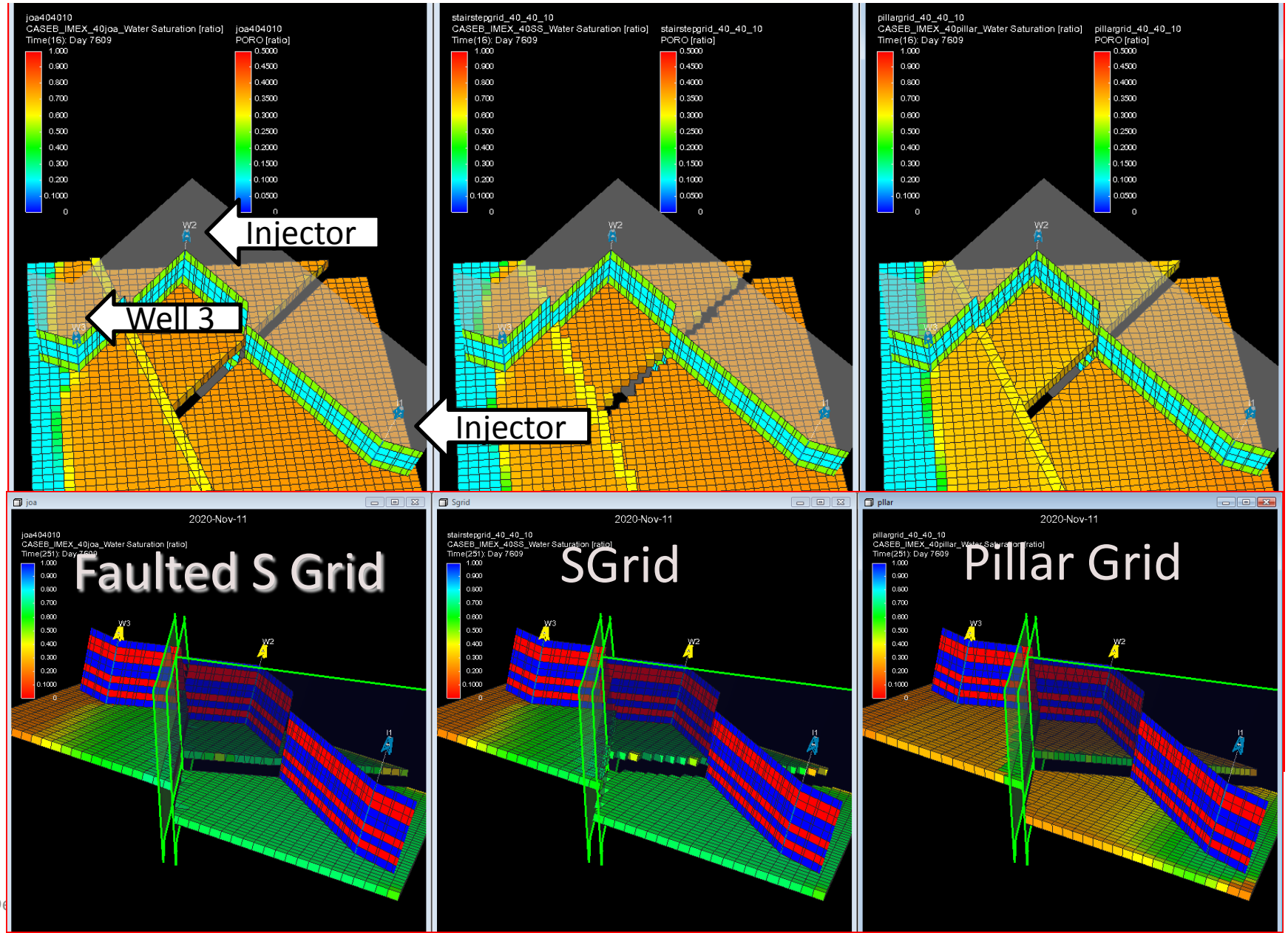


Spe10 run in SENSOR coupled with Faulted S-grid : Average Reservoir Pressure

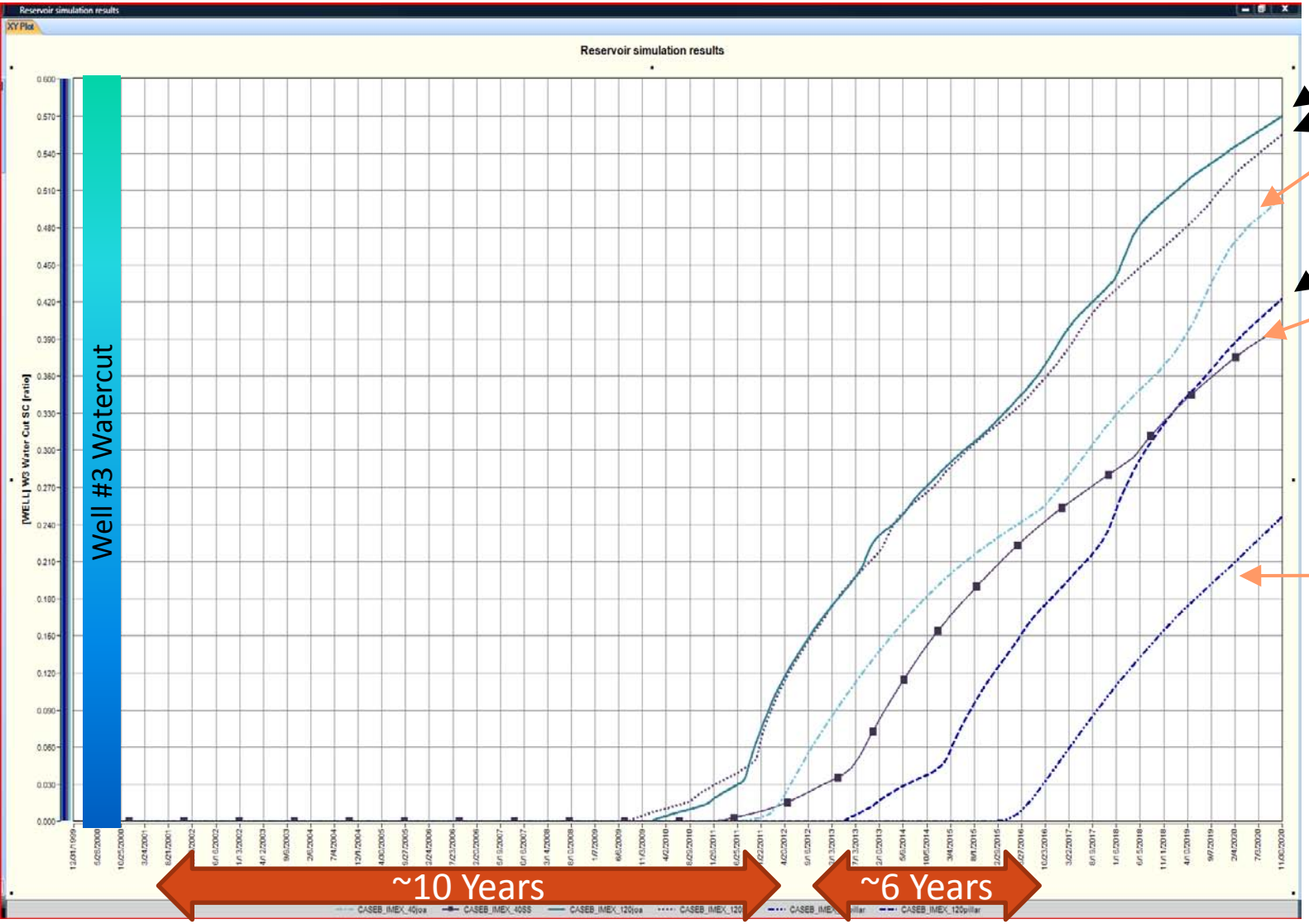


Spe10 run in IMEX coupled with Faulted S-grid : Average Reservoir Pressure

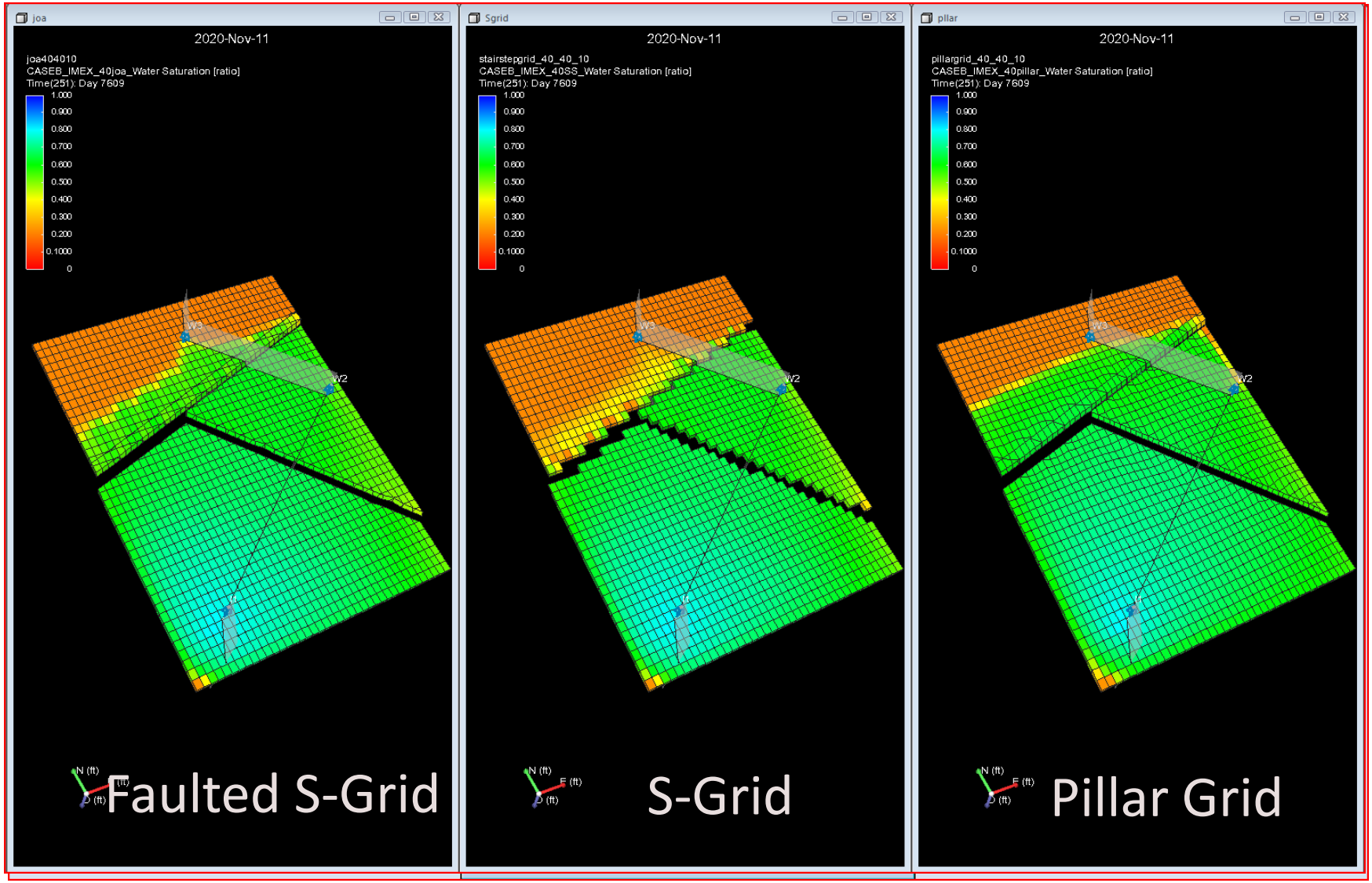
Grid Simulation Comparison – Porosity + Kz



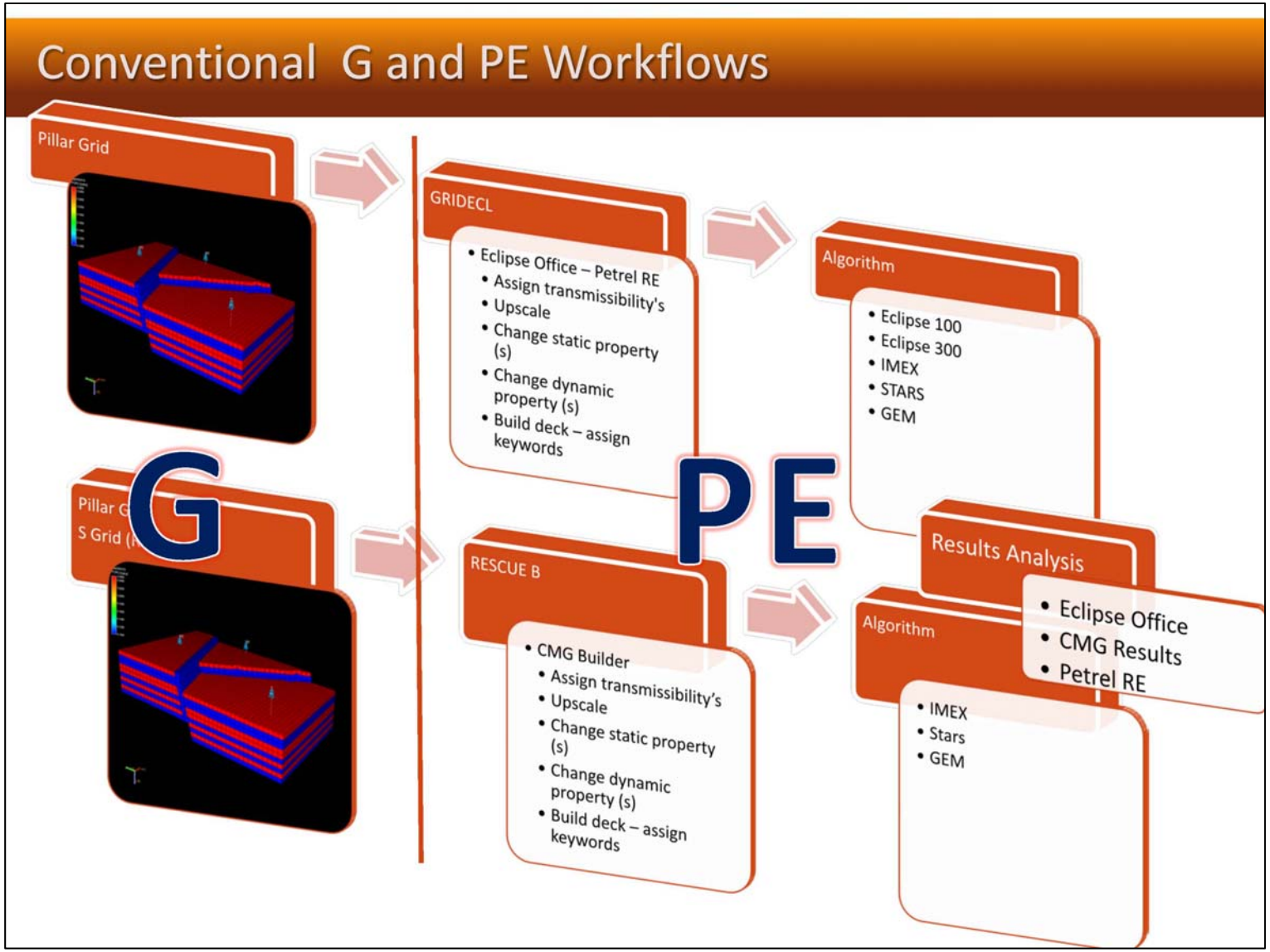
3D Grid Simulation Benchmark Water Production Differencess CMG IMEX



3Dgrid Simulation Benchmark Test – CMG IMEX runs
Distribution of Saturation



Communication between Geological and Simulation Grids

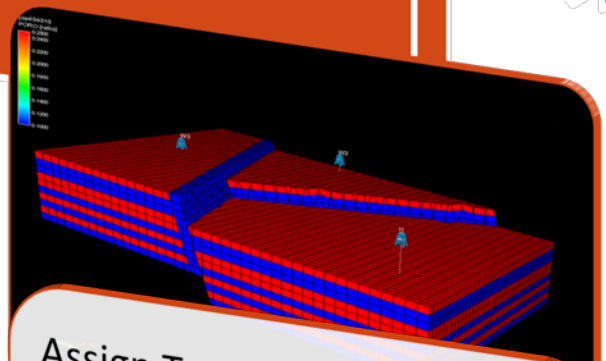


Model on right side develops it's own "personality"…. Organizationally effectiveness

Closed-Loop IRM Workflow

Faulted S Grid
Pillar Grid
S Grid
Results Analysis

G+PE



Assign Transmissibility's
Upscale
Change static property (s)
Change dynamic property (s)
Build deck assign keywords using GUI
Understand static and dynamic model uncertainties using SUNBURST and Microsoft HPC

Algorithm

- Eclipse 100
- Eclipse 300
- IMEX
- STARS
- GEM

Grid Ranking Criteria imposed by Simulation

- Number of cells needed to describe detailed geometries (coming from geology)
  ⇨ to maintain appropriate resolution at critical locations
- Orthogonality of cells
  ⇨ efficiency and numerical accuracy of simulation
- Alignment with meaningful flow measures ($K_{bed\ parallel}$, $K_{bed\ normal}$)
- Alignment with gravity

Conclusions

- FlowGrids should be be (semi-)vertical -gravity
- For low to medium dip reservoirs, geological grids should be be vertical, to serve as a container for geomechanical and geophysical properties; for high-dip, folded and thrusted reservoirs SKUA grids will be a more appropriate container
- Aligning grids with faults is not usually a good idea, even though it is simple to implement when linking geological to simulation models
- The Faulted S Grid approach makes geological and simulation grids most similar, facilitating optimum feed-back from simulation to geological Modeling (e.g. history match process)
- Due to its scale-independent geometry representation, the Faulted S Grid is the ideal Shared Earth model container, supporting property storage at various resolutions and in a grid lay-out that aligns with the geophysical data sources and simulation needs.