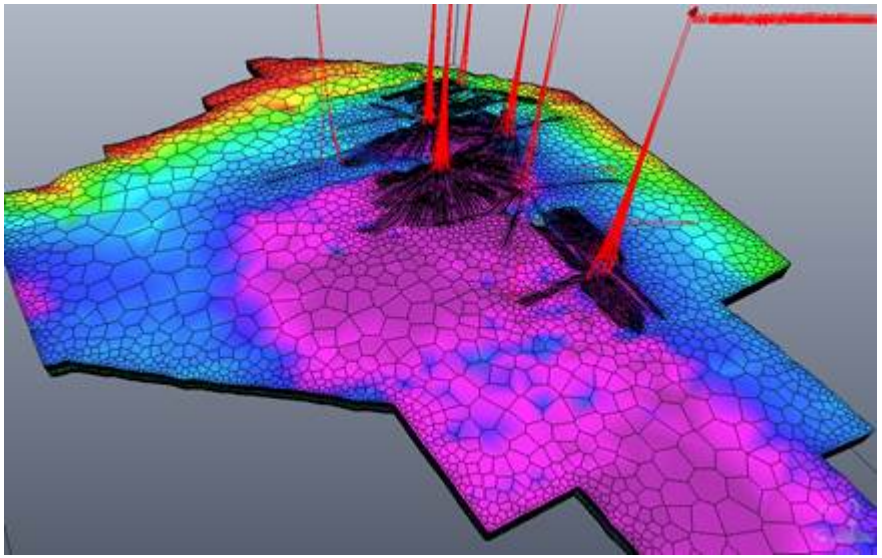
Reservoir Engineering and Simulation

Unconventional

Session in Progress

SIMULATION OF A FULL FIELD GIANT RESERVOIR WITH LONG HORIZONTAL WELLS USING PEBI GRID METHOD AND INTERSECT™



SIS Global Forum

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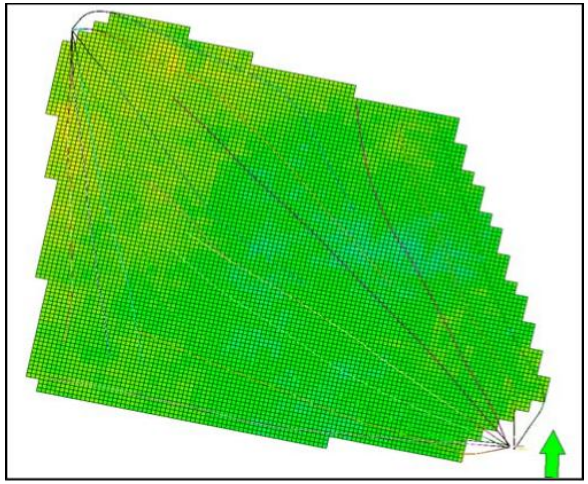
SUMMARY

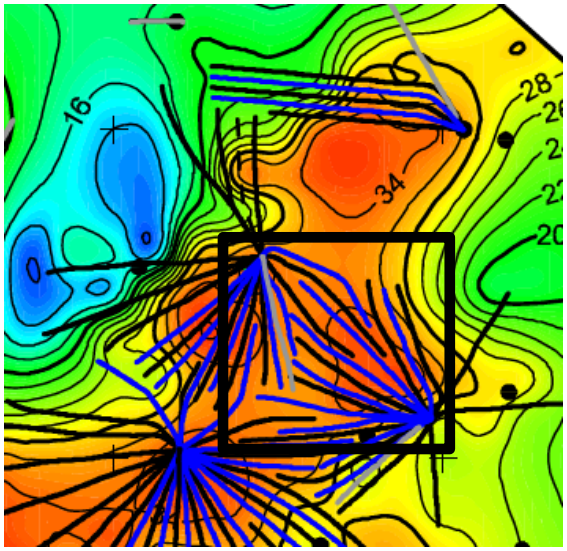
- Voronoi grid and unstructured grid generation
- Structured grid versus unstructured grid IX simulation model
- Intersect™ workflow
- First results and conclusion

INTRODUCTION

- Modeling very long horizontal well (10km) in a large field poses a challenge to find a manageable grid
- The classical option is to use a structured grid with LGR refinement at wells but it leads to huge grid
- Another option addressed by an older paper IPTC 2007 – Vestergaard et al, Maersk Oil is to use a Voronoi grid
- In 2007 Maersk uses Eclipse™ and Flogrid™ but the PEBI grid simulation finally was abandoned (solver convergence, complex grid updating)
- We try again using Intersect™ and an internal gridder/geomodeller software

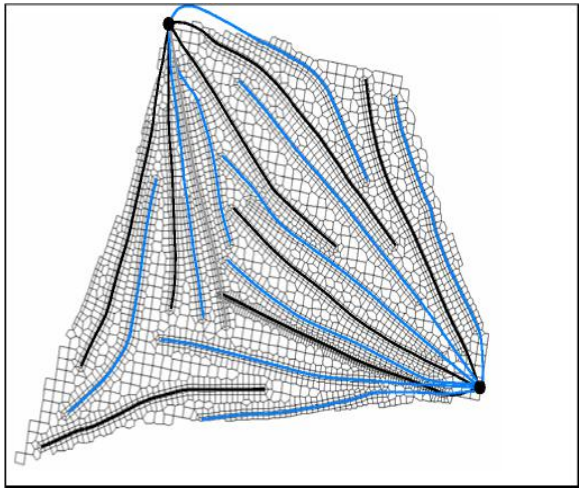
CPG grid with LGR





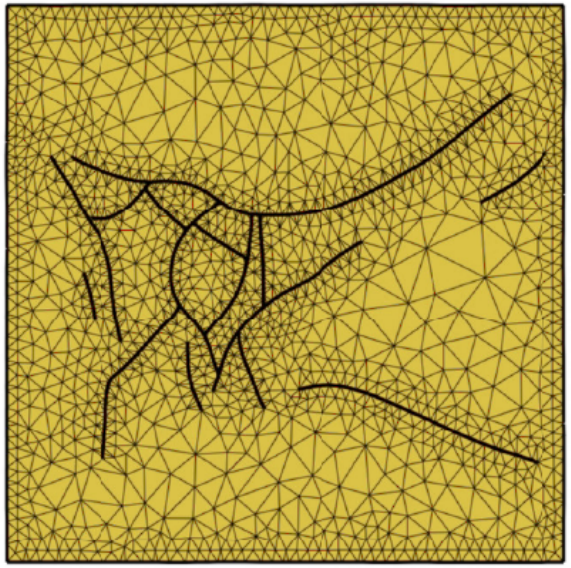
Areal map of wells

Voronoi grid – PEBI method

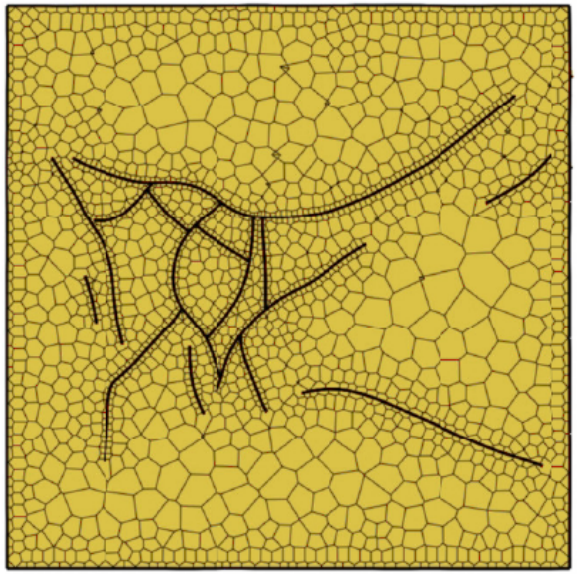


VORONOI GRIDS AND PEBI METHOD

- How to build an unstructured and orthogonal grid ?
  - Start from a « primal » grid where each polygon is inside a circumscribed circle, the « dual » grid obtained in connecting all circles centers is **by construction** perpendicular bisector (PEBI), and therefore **orthogonal**.



Primal grid

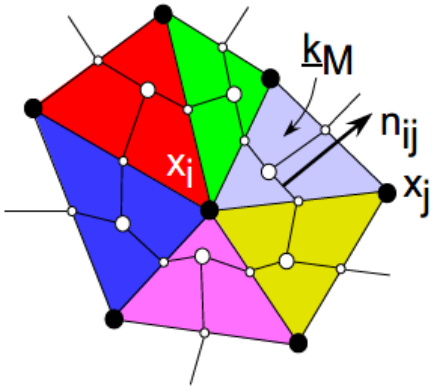


Dual grid

VORONOI GRID AND PEBI METHOD

- Grids for flow simulation must obey to some geometrical constraints
  - Intervene for discretizing the flow equations.
- **Two point flux approximation** (TPFA):
  - Preferred to M(ulti)PFA due to better stability and higher performance
  - Anisotropic permeabilities:
    - Faces of control volumes should be **k-orthogonal** to lines joining their centers:

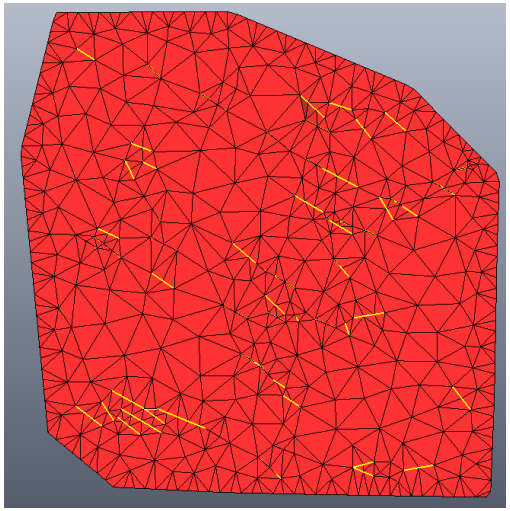
$$\underline{k}_{\mathcal{M}}.\mathbf{n}_{\mathcal{M}}^{ij} \parallel (\mathbf{x}_j - \mathbf{x}_i)$$



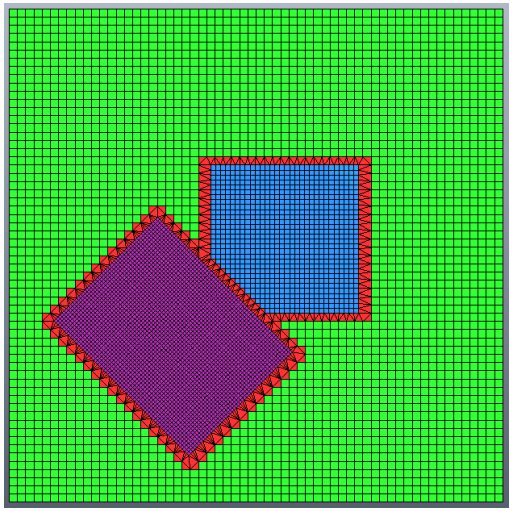
  - In our study PermX=PermY

UNSTRUCTURED GRID GENERATION USING A MODULAR APPROACH

- The 3D reservoir grid is obtained by **extrusion** of a 2D p**olygonal reference mesh**.
- The 2D polygonal mesh is build iteratively from a sequence of boolean **operations on « modules »**:
  - Structural module (fault + AOI)
  - Cartesian module (structured background)
  - Well modules

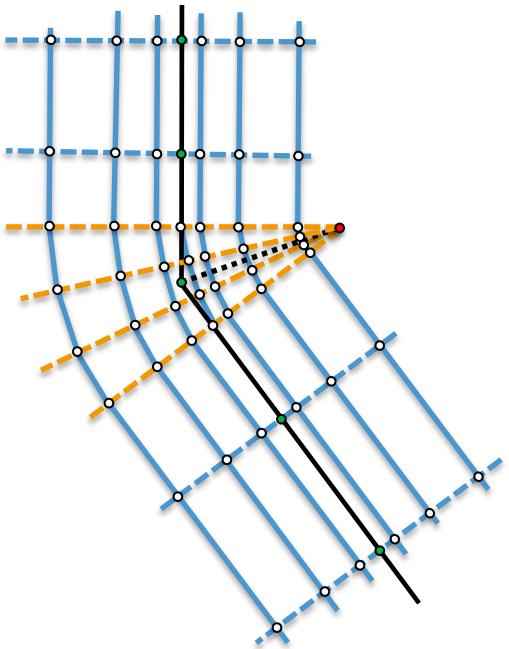


2D polygonal mesh (Delaunay)



Cartesian modules

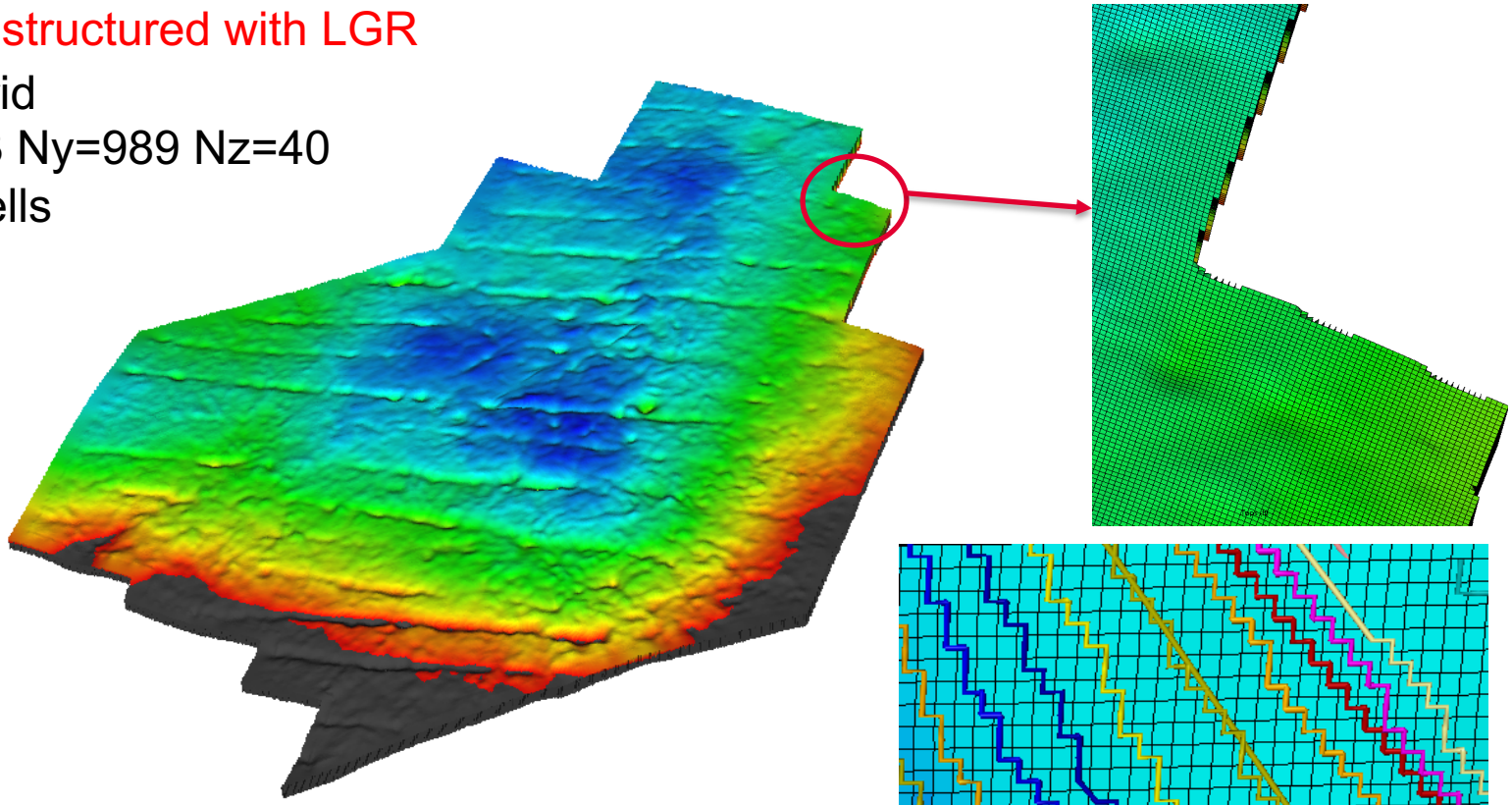
Well module



FULL FIELD GIANT RESERVOIR WITH LONG HORIZONTAL AND DEVIATED WELLS – STRUCTURED IX MODEL

Option 1 : structured with LGR

Pillar grid
Nx=733 Ny=989 Nz=40
28 M cells



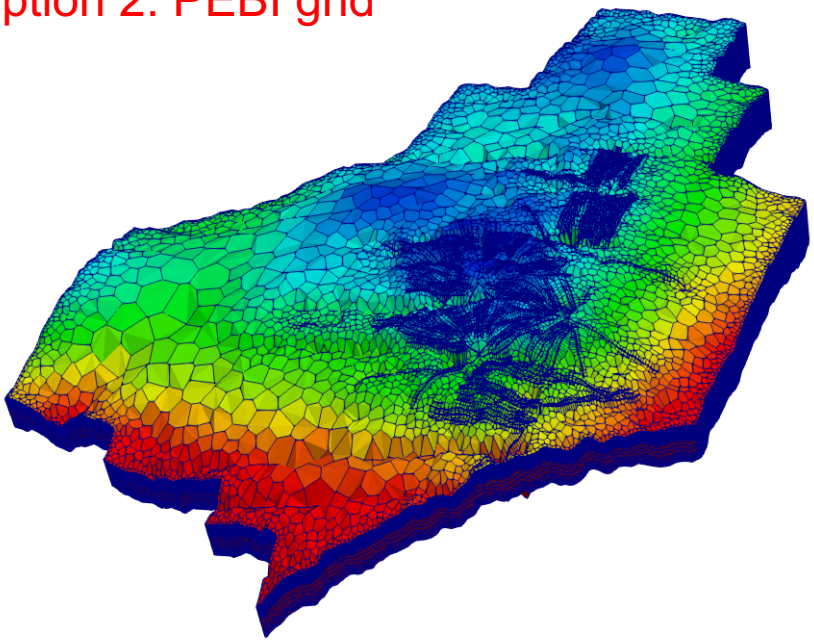
40-layer, 15M active cells, 223 wells

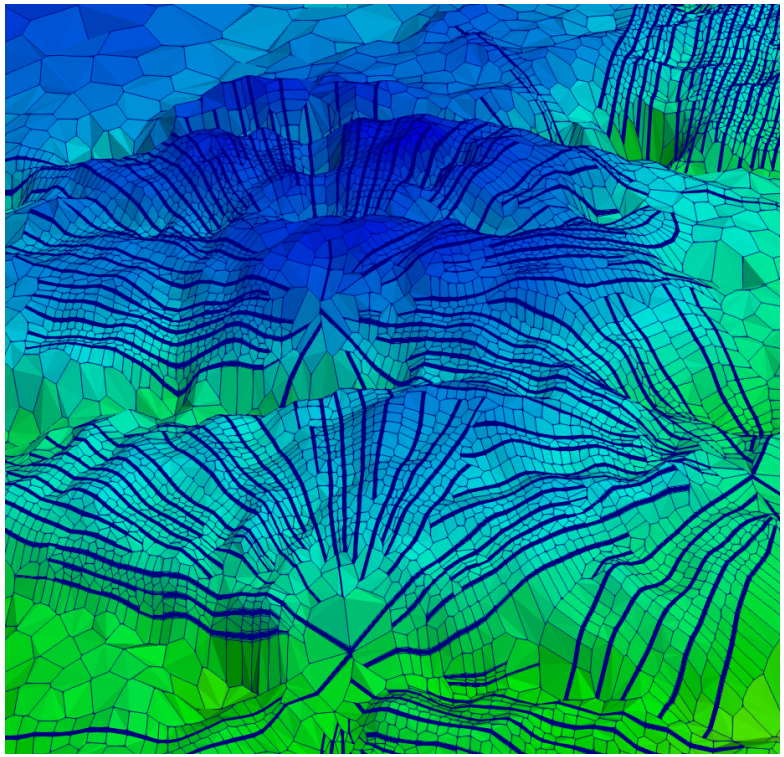
dx, dy about 75m without LGR

HORIZONTAL WELL RESOLUTION

FULL FIELD GIANT RESERVOIR MODEL

Option 2: PEBI grid



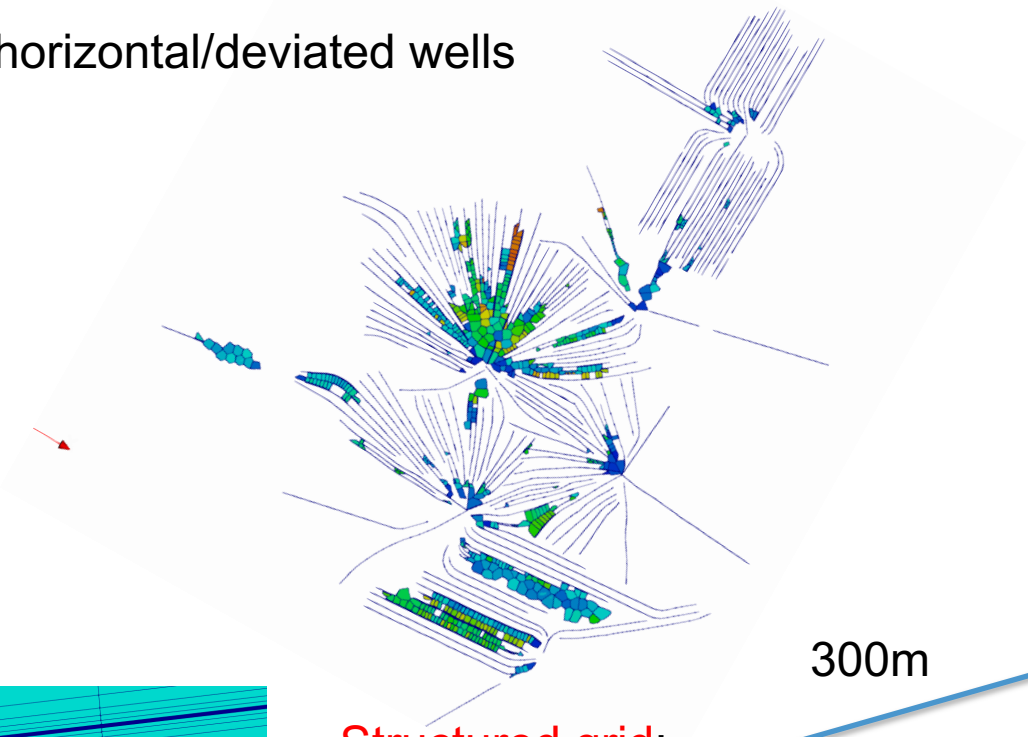


40-layer - 1,8M active cells - 223 wells

OBJECTIVE: Reduced size and Better representation of horizontal wells
(with sufficient resolution between neighbor perforated well blocks and also grid is aligned with the well paths, thereby avoiding grid non orthogonality issues)

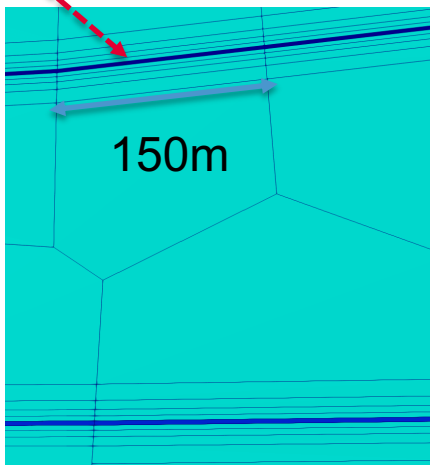
PEBI GRID: HORIZONTAL WELLS PATTERN

Well pattern with 223 horizontal/deviated wells

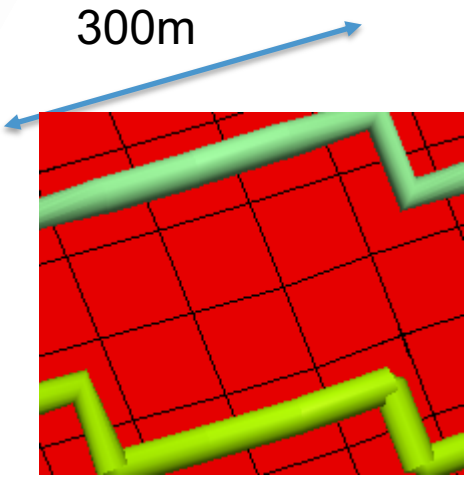


Perforated cells

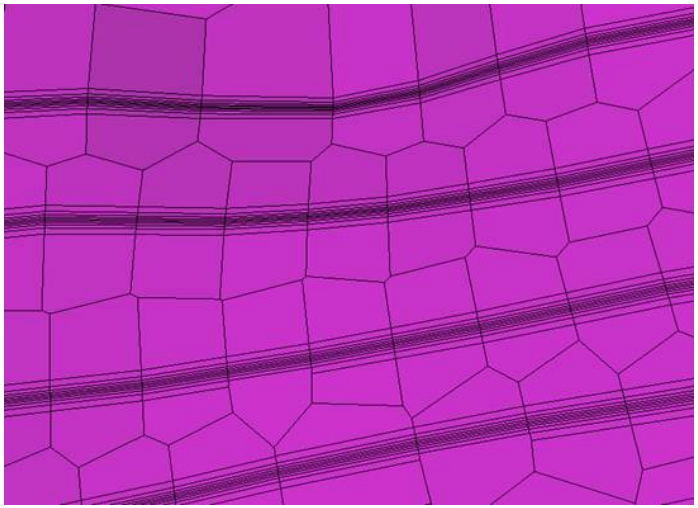
Pebi grid:
typical resolution
L=150m
width = 3m,
more than 10 cells
between 2 wells

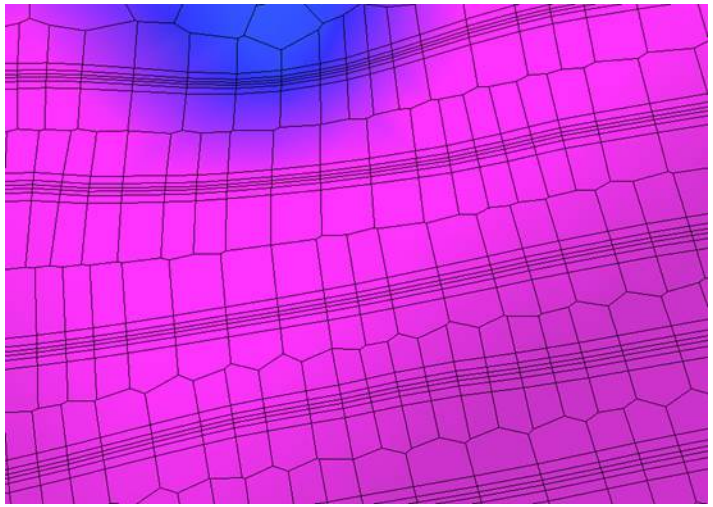


Structured grid:
L = width=75m
one cell
between 2 wells

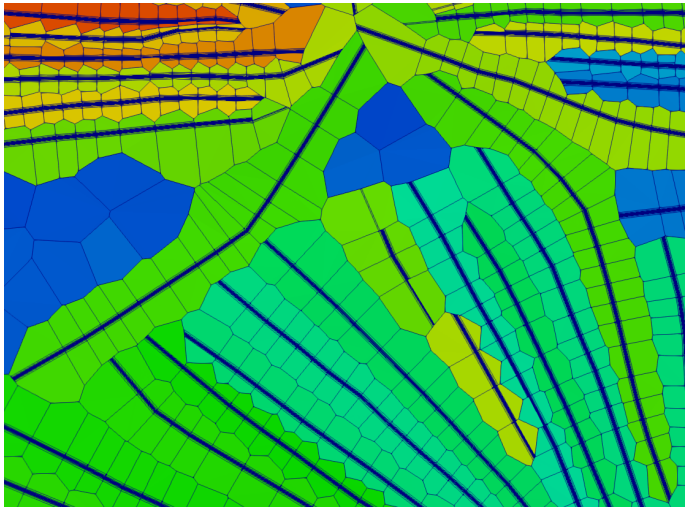


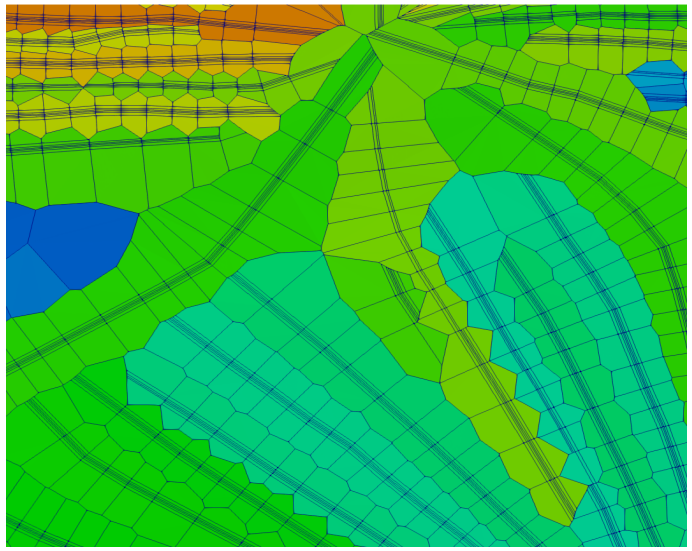
PEBI GRID: TWO TYPES OF WELL DISCRETIZATION ARE TRIED





Pebi grids G1 (width=1m to 3m) and G2 (width=7m)





PEBI TRANSMISSIBILITIES CALCULATION

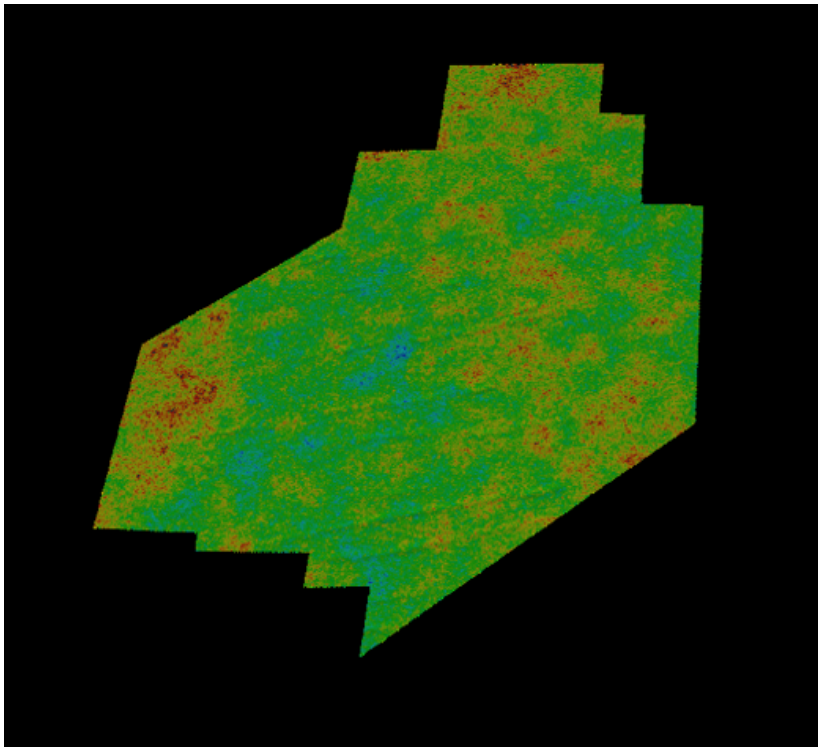
From internal code (academic origin Univ of Bergen / Université de Nice)

- Input: geometry file .msh , permx permy permz, pressure centers
- Output file (connection between cells using IX ConnectionSet format .ixf) in system Nx=1,856 760 Ny=Nz=1

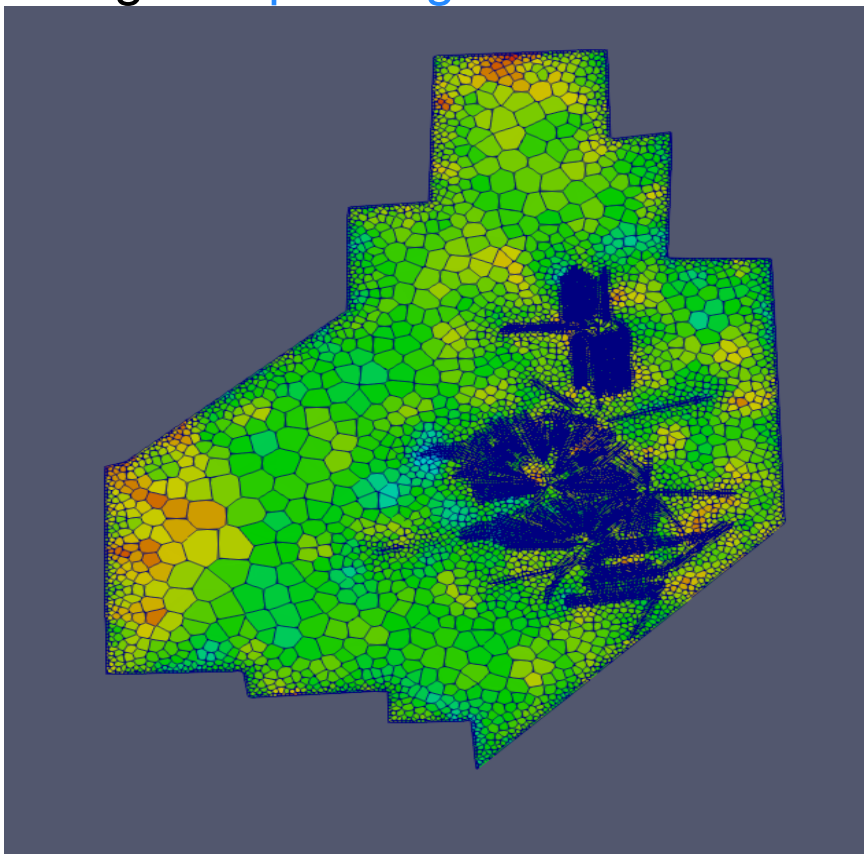
```
ConnectionSet "NNC_1_NON_NEIGHBOUR" [
                Cell1              Cell2        Transmissibility
     (        140 1 1) (       33214 1 1)     0.458359E+01
     (        140 1 1) (        2230 1 1)     0.465659E-02
     (        140 1 1) (         141 1 1)     0.526136E-02
     (        141 1 1) (       33215 1 1)     0.645825E+03
     (        141 1 1) (        2230 1 1)     0.633248E-02
     (        141 1 1) (        2231 1 1)     0.178384E-01
     (        141 1 1) (         142 1 1)     0.185944E-01
     (        142 1 1) (       33216 1 1)     0.110216E+02
     (        142 1 1) (        2231 1 1)     0.794704E-02
     (        142 1 1) (        2232 1 1)     0.762708E-02
     (        142 1 1) (         143 1 1)     0.898420E-02
     (        143 1 1) (       33217 1 1)     0.544557E+01
     (        143 1 1) (        2232 1 1)     0.142594E-01
     (        143 1 1) (         144 1 1)     0.963153E-02
     (        144 1 1) (       33218 1 1)     0.599868E+01
     (        144 1 1) (         145 1 1)     0.659358E-02
     (        144 1 1) (        3127 1 1)     0.784050E-02
     (        144 1 1) (        2232 1 1)     0.160713E-02
```

INTERSECT™ WORKFLOW FOR PEBI METHOD

- Start from an existing structured IX model
- Petrophysical properties (poro, permxyz), initial composition (zmf), region properties (satnum, pvtnum, eqlnum, ..) are interpolated from the structured model to the unstructured grid - “painting method”



Porosity layer 40 – structured model



Porosity layer 40 – Pebi model

INTERSECT™ WORKFLOW FOR PEBI METHOD (#2)

- Cell number n corresponds to block n,1,1 (1D internal IX model)
- Option 1: create a geometry/properties file (1D geometry + cell properties) using Eclipse™ migrator (GSG format for Intersect™)

```
FIELD
COMPS
  10/
EOS
  PR  /
HWELLS
DIMENS
-- NDIVIX  NDIVIY  NDIVIZ
     1856760     1     1    /
EQUALS
PERMX 0. /
/
INCLUDE
'../PORO_PEBI.grdecl' /
EDIT
INCLUDE
'../PORV_PEBI.grdecl' /
INCLUDE
'../DEPTH_PEBI.grdecl'  /
PROPS
```

```
INCLUDE
'SWOF.PROPS' /
INCLUDE
'SGOF.PROPS' /
INCLUDE
 '../KR_ENDPOINTS_PEBI.inc' /
EQUALS
 KRG 1.0 /
 IKRG 1.0 /
```

```
REGIONS
INCLUDE
'../SATNUM_PEBI.inc' /
INCLUDE
'../IMBNUM_PEBI.inc' /
INCLUDE
'../EQLNUM_PEBI.inc' /
INCLUDE
'../FIPNUM_PEBI.inc' /
NOECHO
SOLUTION
INCLUDE
 'EQUIL.INC' /
INCLUDE
 '../ZMF_PEBI.inc' /
FIELDSEP
```

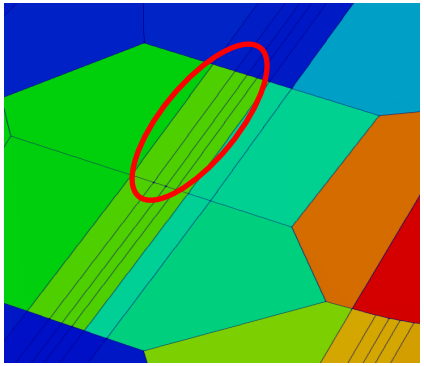
- Option 2: create Resqml files for 1D geometry and 1D properties (will be available soon)

INTERSECT™ WORKFLOW FOR PEBI METHOD (#3)

- Internal code to compute well connections factor WI (Peaceman formula for horizontal wells and parallelipedic elements)

$$T_{wj} = \frac{c\theta Kh}{\ln(r_o / r_w) + S}$$

$$r_o = 0.28 \frac{\left[D_x^2\left(\frac{K_y}{K_x}\right)^{1/2} + D_y^2\left(\frac{K_x}{K_y}\right)^{1/2}\right]^{1/2}}{\left(\frac{K_y}{K_x}\right)^{1/4} + \left(\frac{K_x}{K_y}\right)^{1/4}}$$



```
WellDef "PROD-4" {
 WellToCellConnections  [
   Status  PiMultiplier  Completion     Transmissibility      Cell     SegmentNode   RockRegionName     WellBoreRadius     Skin
     OPEN     1      "COMPLETION_LUMP1"        0.0175 (    103856 1 1)     1             ""              0.354          0
     OPEN     1      "COMPLETION_LUMP1"        2.2594 (    138126 1 1)     1             ""              0.354          0
     OPEN     1      "COMPLETION_LUMP1"        3.6826 (    136908 1 1)     1             ""              0.354          0
     OPEN     1      "COMPLETION_LUMP1"        3.6557 (    203056 1 1)     1             ""              0.354          0
     OPEN     1      "COMPLETION_LUMP2"        0.0118 (    236130 1 1)     1              ""             0.354          0
     OPEN     1      "COMPLETION_LUMP2"        0.0131 (    269204 1 1)     1              ""             0.354          0
     OPEN     1      "COMPLETION_LUMP2"        4.9884 (    203057 1 1)     1              ""             0.354          0
```

INTERSECT™ WORKFLOW FOR PEBI METHOD (#4)

- Simulation file for PEBI model is generated from a copy of the structured model input deck (.afi file format used by Intersect)
- No change in the fm (field management) section
- Update grid, replace well connection factors and add transmissibility file

```
SIMULATION ix "PEBI_2MCELLS" {
  INCLUDE "PEBI_2MCELLS.gsg" { type="gsg" gsg_type="geom_and_props" }
        # 1D grid definition
        INCLUDE "GRID.ixf"
        INCLUDE "Run_Control.ixf"
        INCLUDE "input/include_props/ELQNUM.ixf"
        INCLUDE "input/include_props/PVTNUM.ixf"
        INCLUDE "input/include_props/ROCK.ixf"
        INCLUDE "input/include_props/Rock_Corey_param.ixf"
        # well connection factors
        INCLUDE "PEBI_Wells_IX_ConnectionFactor.ixf"
        # global transmissivity file
        INCLUDE "pebiGrid.ixf" { type="ixf" }
}
SIMULATION fm {
        INCLUDE "input/include_wells/Wells_FM_Completion.ixf"
        INCLUDE "input/observed_data/dates.ixf"
        INCLUDE "Observed_ixf"
        INCLUDE "REPORTING_FM.ixf"
}
```

FIRST RESULTS COMPARISONS

- Evaluation is not yet fully completed
- In place differences between structured grid/Pebi grid (due to “painting” method):

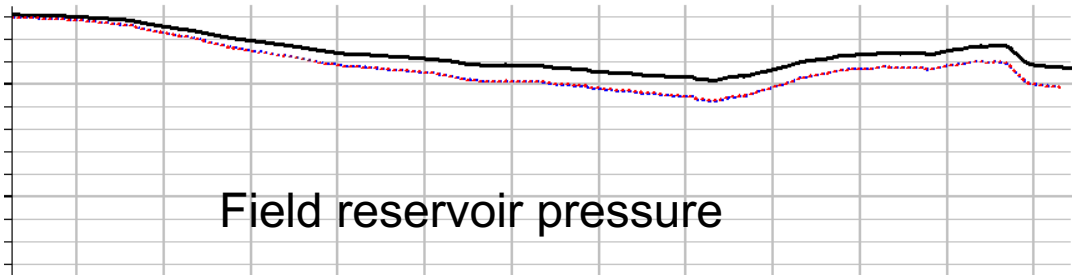
			In place		
	Dyn Pore Volume	Avg Pressure	Surface oil	Surface gas	Surface water
Pebi G1 versus structured	5%	0.40%	0.76%	0.17%	6.33%
PEBI G2 versus structured	5%	0.40%	0.76%	0.13%	6.33%

- History match simulation (reservoir volume rates constraints)
- Global production profiles are quite similar
- Well production profiles are similar for wells aligned with X or Y axis but can differ at some wells aligned 45° with grid axes

- Field reservoir pressure mismatch (less than 1,8%)
- Same for grid G1 and grid G2

--- reference structured
---- pebi grid G1
--- pebi grid G2

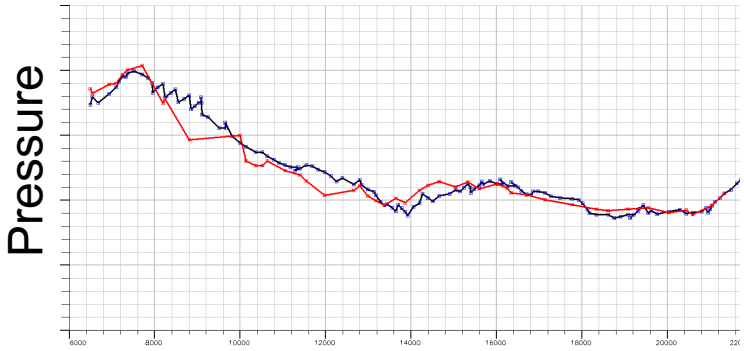
- Typical perforated cell sizes:
  75m x 75m (Structured grid),
  150m x 3 m (Pebi grid G1)
  150m x 7 m (Pebi grid G2)



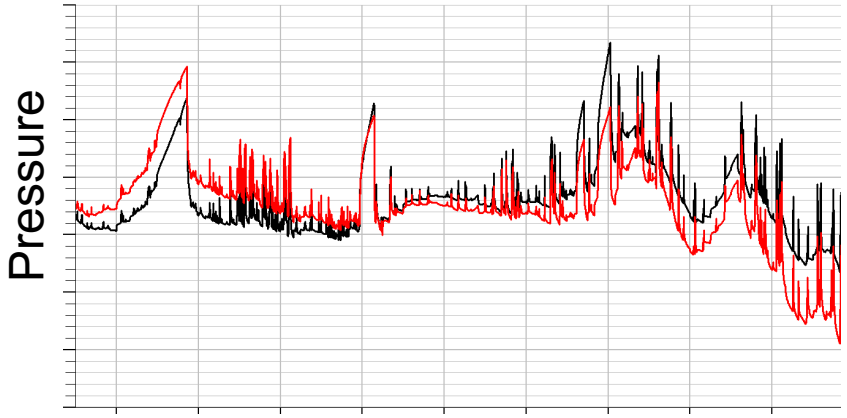
FIRST RESULTS COMPARISONS

--- Structured grid
---- Pebi grid G2

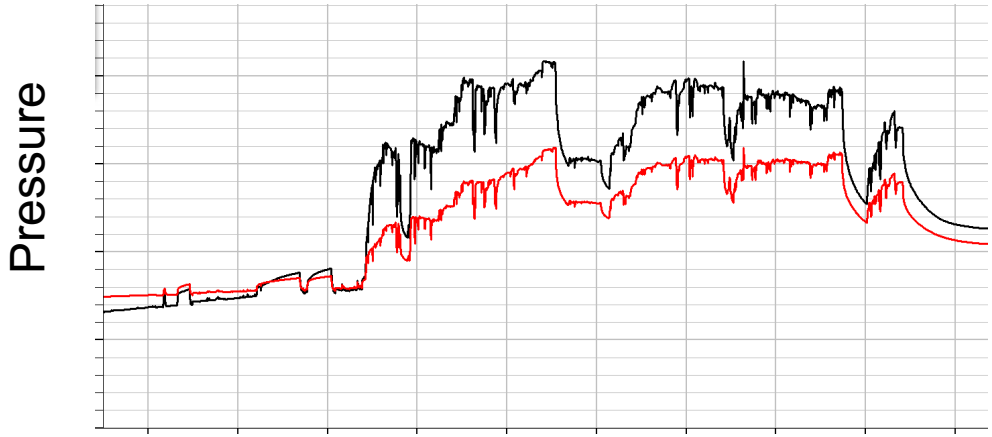
Formation pressure



Well measured depth (ft)



Well BHP – well aligned with X axis



Well BHP – well 45° with X axis

PERFORMANCE COMPARISONS

- CPU times and Newton iterations on HM period

	#procs	Elapsed Time	Timesteps	#Non linears	#Linears
Structured - 14.5 Millions active	192	25h	12627	85865	224141
PEBI- 1.3 Million active	24	12h43	6890	39675	237613
PEBI- 1.3 Million active	48	8h43	6945	40201	257307
PEBI- 1.3 Million active	96	6h54	6876	39677	331088
PEBI- 1.8 Million active	96	12h47	11978	84439	629009

CONCLUSION

- Unstructured Voronoi grids have been constructed and used within Intersect™ using PEBI method
- Interpolation (“painting”) has been used to transfer properties (PERM, PORO, regions (eqlnum, satnum), initial composition, end points, ..) from the structured model to the unstructured model
- A simulation deck workflow has been developed to automatize the input deck generation for each update of the unstructured grid
- Grid refinement proportions are still in progress in order to reduce the simulation time which is sensitive to the perforated cell size
- Grid size is highly reduced (1 million cells versus 28 millions) and global results in terms of production profiles between the structured and the unstructured simulation models remain quite similar
- CPU times are reduced by a factor of 3
- The number of needed cores is reduced by a factor of 4 (48 vs 192)