Reservoir Evaluation and Simulation of CO_2 Enhanced Oil Recovery

Sand Dunes Field
Muddy Formation
Wyoming, USA

SENIOR DESIGN – PETE 4735

Senior Design II
Group G

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Objectives

1. Geology
2. Problem statement and plan
3. Data collection and analysis
4. Static modeling
5. Dynamic modeling
6. Economic evaluation
7. Conclusions
8. References

Geology

PART I

Field Criteria

CRITERIA NEEDED

- Discovered post 1974
- More than 5 wells, less than 35
- Continuous sandstone
  with few fractures
- EORI CO_2 Screened
- Close proximity to potential CO_2 source

SAND DUNES FIELD

- Discovered 1981
- Total 27 wells
- Continuous shaly sandstone
  with few fractures
- EORI CO_2 Screened
- Close proximity to Denbury CO_2 pipeline

Sand Dunes Field

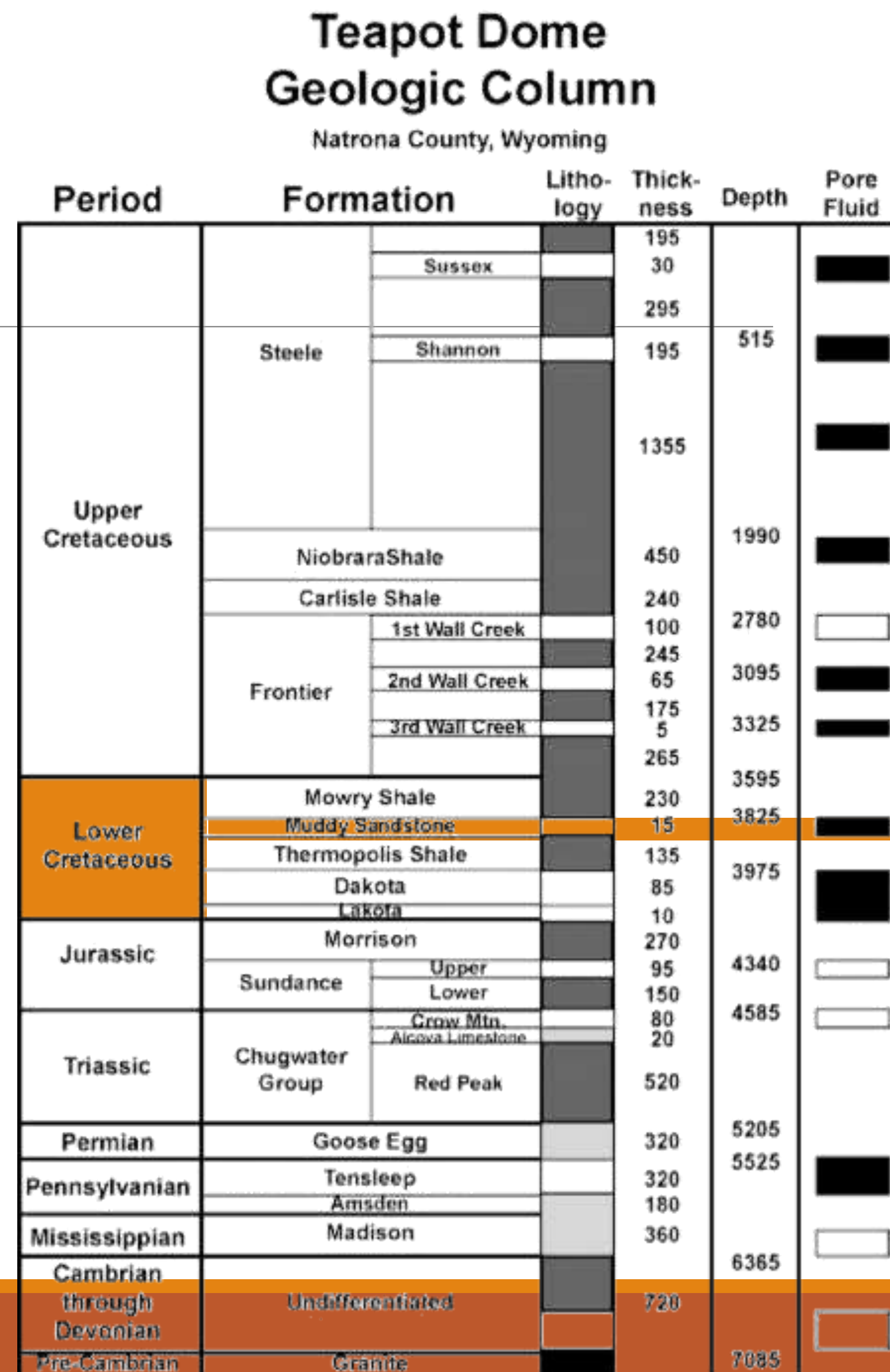
Lithology

Lower Cretaceous

- Muddy Sandstone
- Depth: 3,825 ft – 13,100 ft
- Thickness: 15 ft

Deltaic Deposition

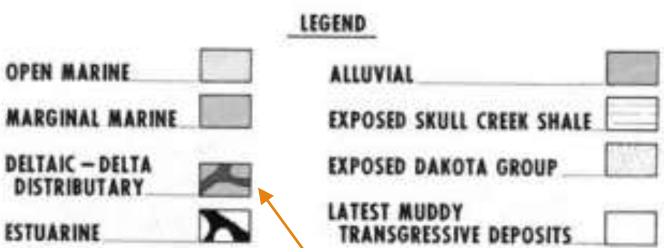
- Incised valley systems



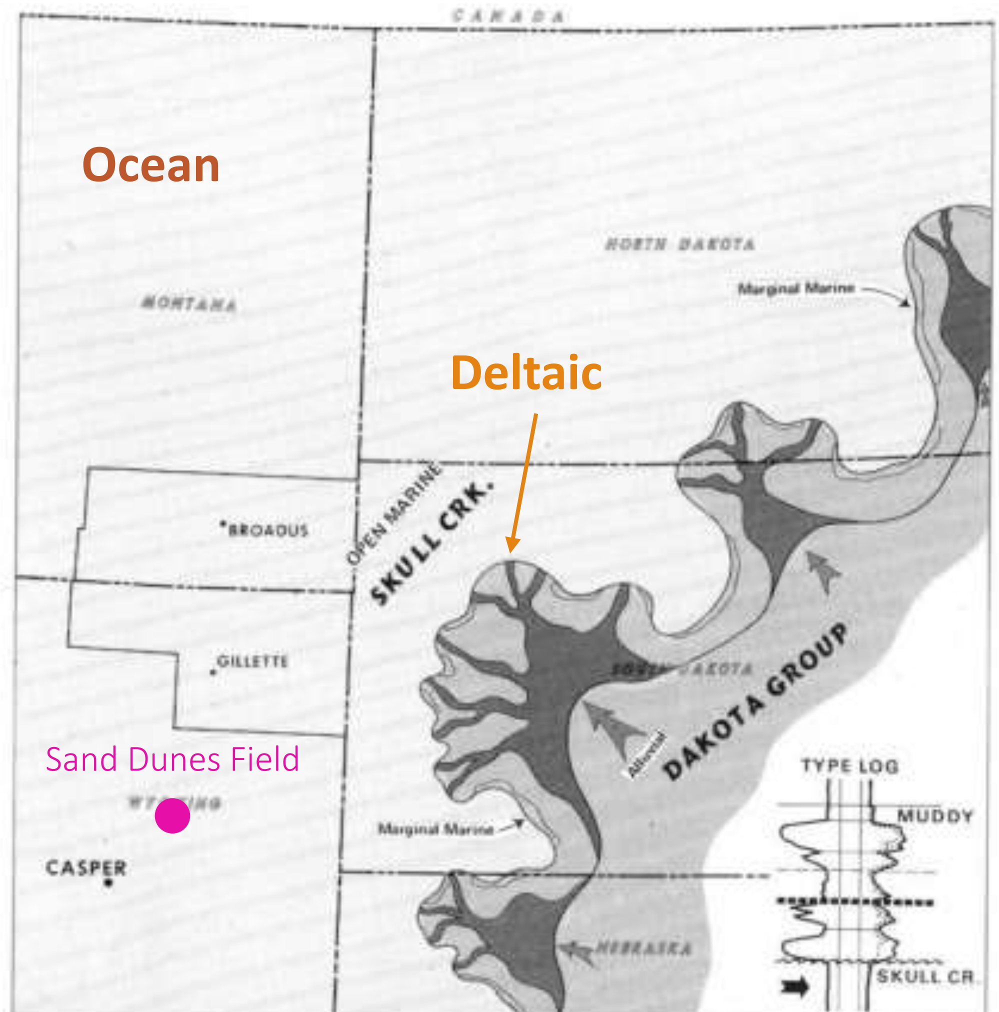
Formation

High sea levels

- Deep water
- Skull Creek shale deposition



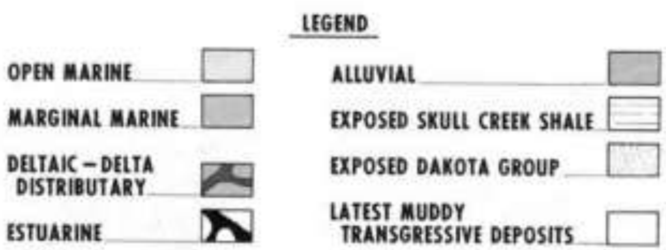
Deltaic Deposition

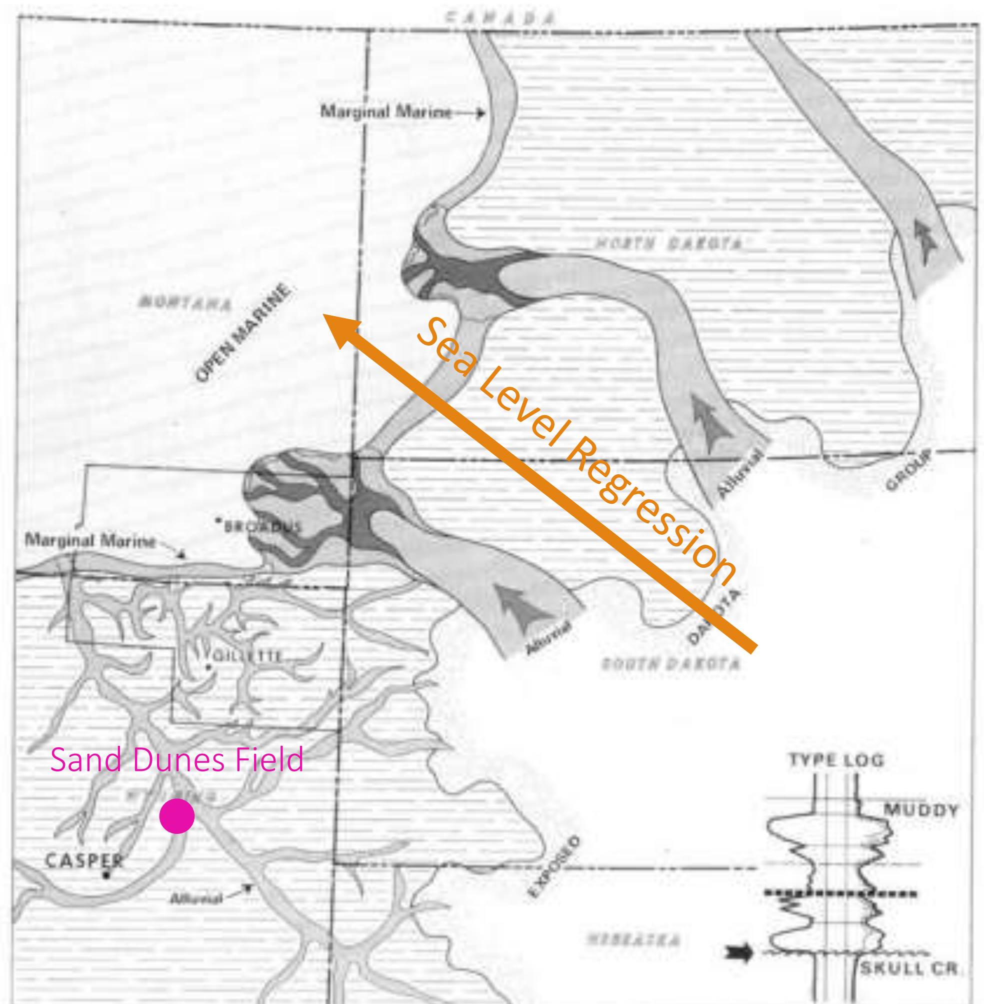


Formation (cont'd)

Regression

- Sea level falls
- Bioturbated sand deposited
- Incised river valley system

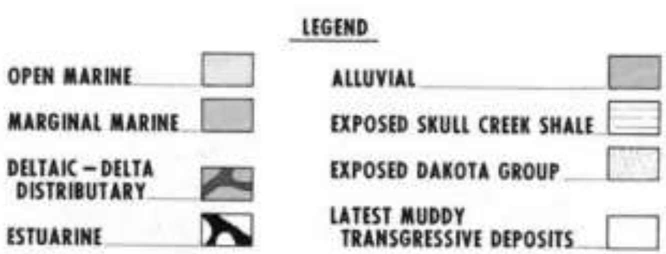


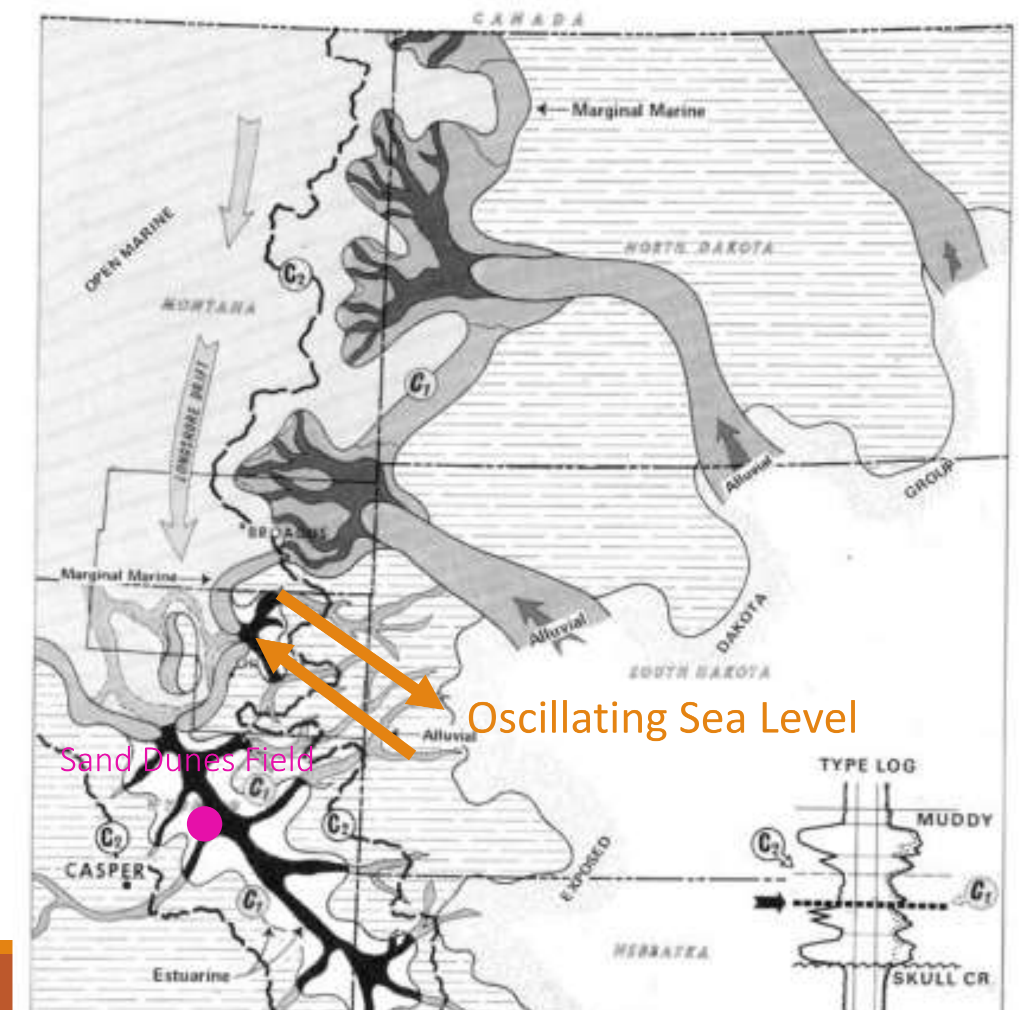


Formation (cont'd)

Maximum Regression

- Valley/river development
- Oscillating sea level
- Muddy deposition
- Topographically low areas



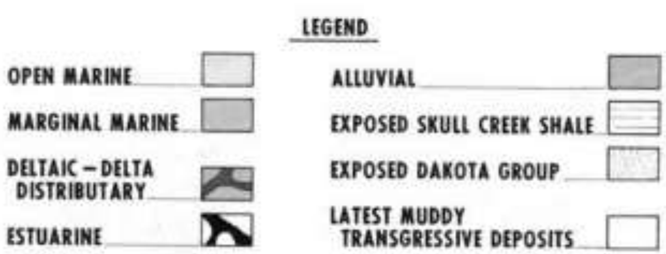


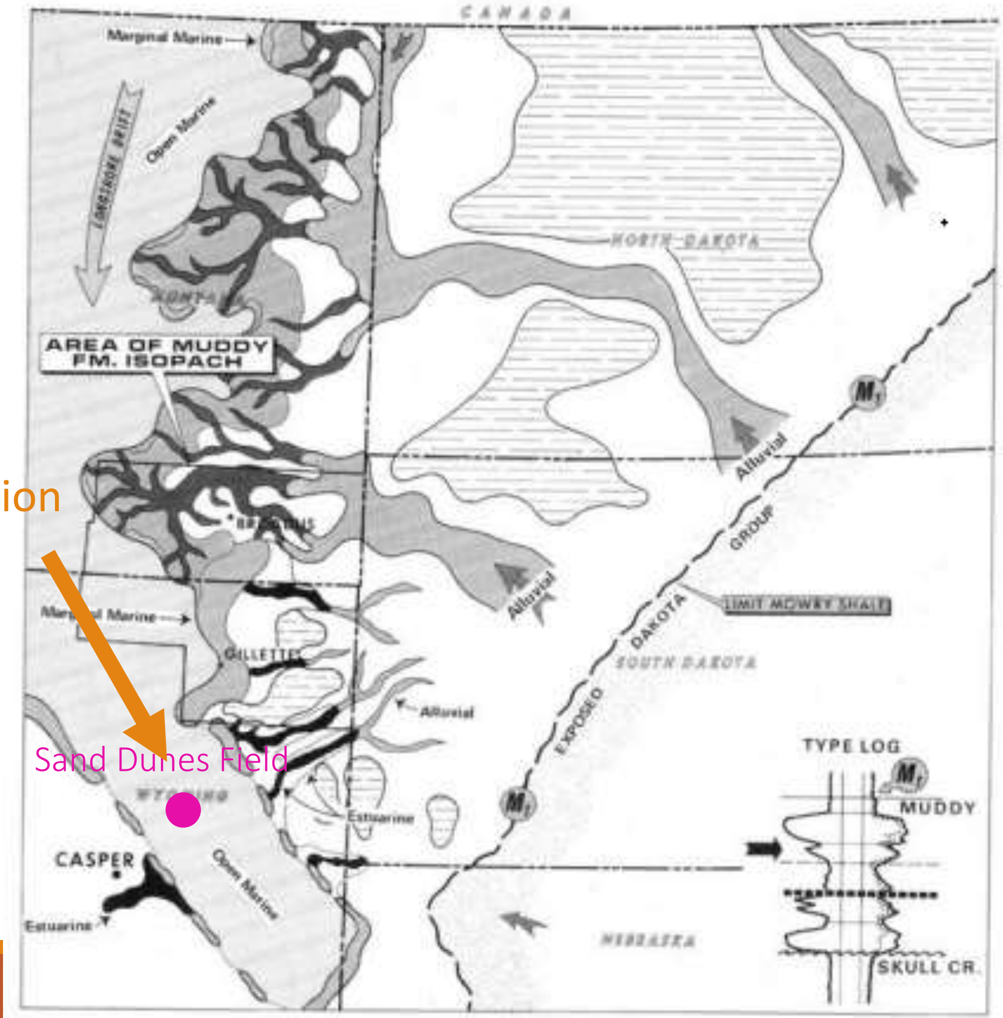
Formation (cont'd)

Transgression

- Sea level rises
- Mowry Shale deposition
- Anoxic (oxygen lacking)

Maximum Transgression



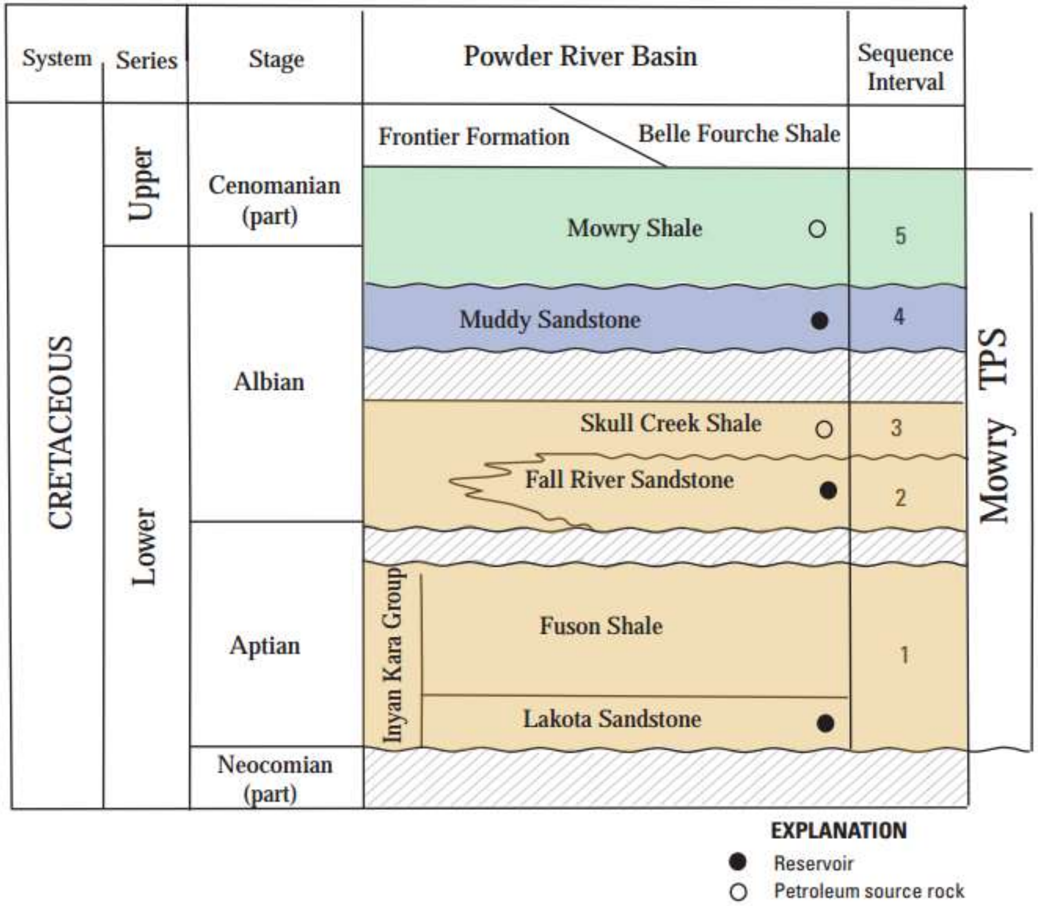


Hydrocarbon Formation and Migration

Mowry TPS

Stratigraphic trap

SW to NE migration



Problem Statement and Plan

PART II

Objective

Analyze CO_2 susceptible field

Build a static 3D reservoir in Petrel

- Determine reservoir characteristics
- History match

Dynamic reservoir simulation

- CO_2 flood on CMG

Incremental oil production estimation

Economic analysis

Data Collection and Analysis

PART III

Collection of Data

Reservoir characteristics

- WOGCC and Wold Energy Partners
- Resistivity, neutron density, porosity logs, and core analysis
- PVT data & well tests

Production data

- Lifetime production and injection values
- Oil, gas, and water production

Collection of Data

Location data

- x, y, z coordinates for all wells
- UTM NAD 1927

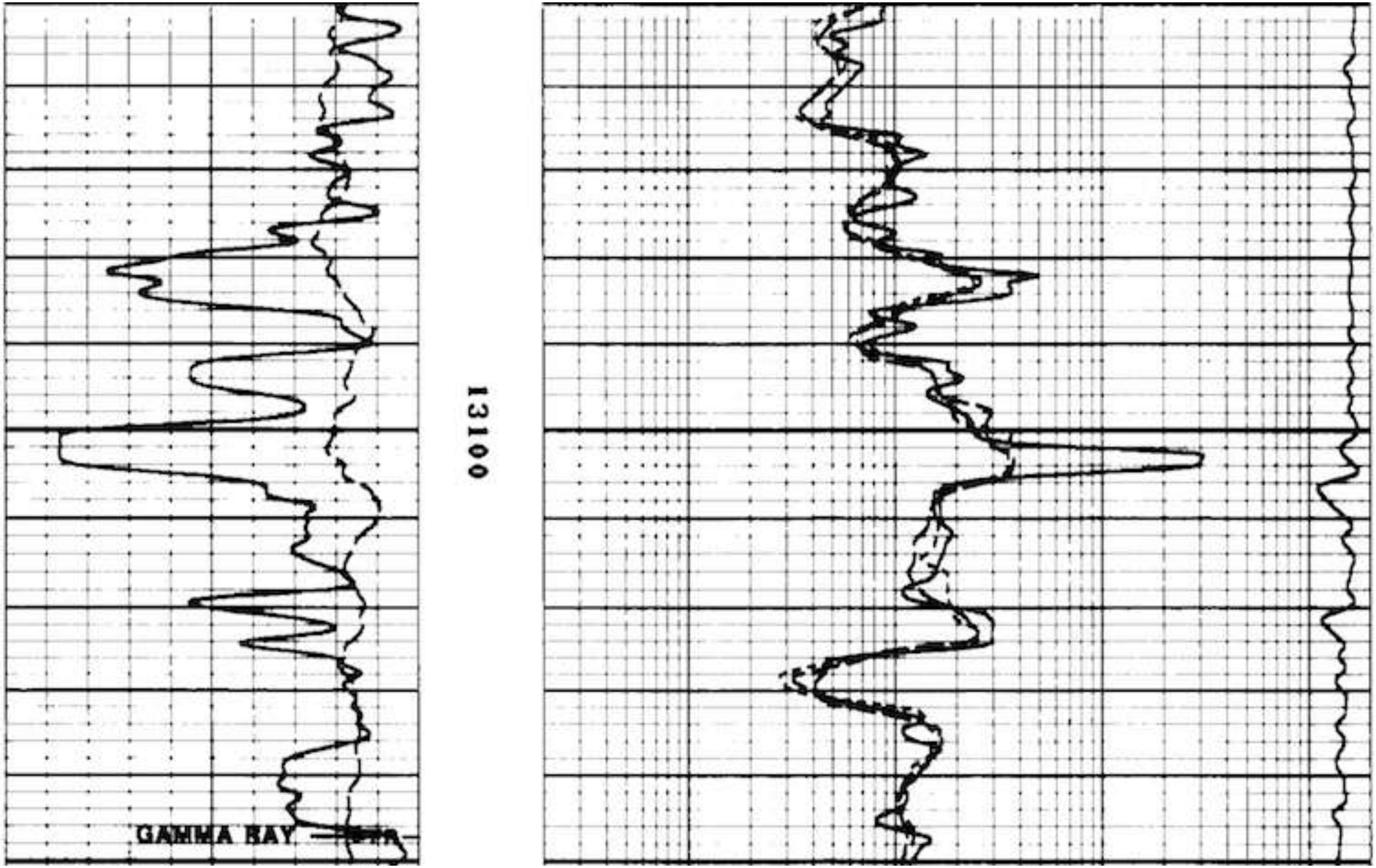
Completion data

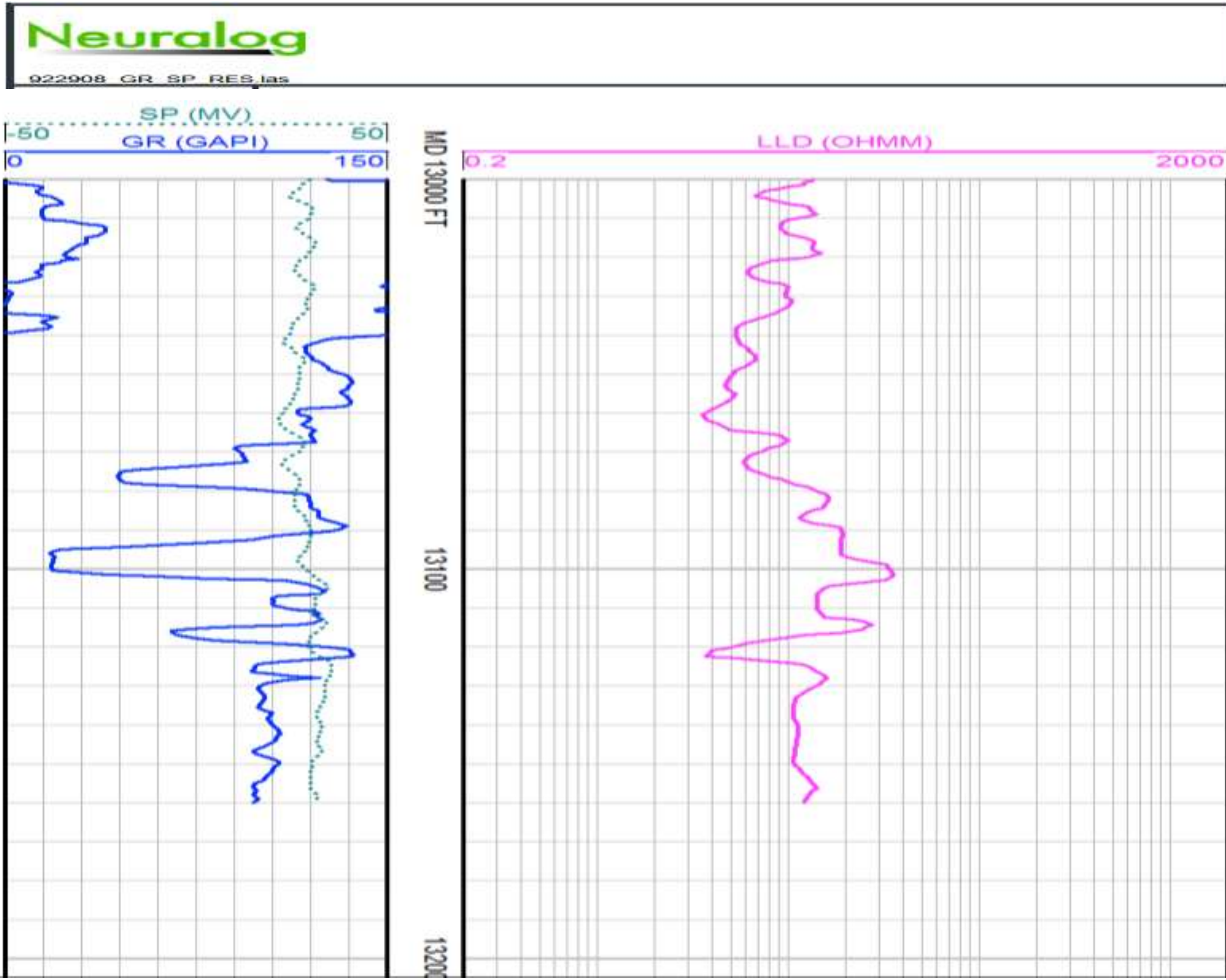
- Perforation specifications, casing sizes, annulus size, and treatments

Constraint:

Production and injection well data, legitimate well logs, completion data, core analysis, and perforation specifications must all be accessible.

Without accurate data to collect, the static reservoir model will be a poor representation of the field of study making the EOR flood simulation inaccurate.


13100
GAMMA RAY


Neuralog
922908_GR_SP_RES.las
SP (MV)
-50
50
GR (GAPI)
0
150
MD 13000 FT
LLD (OHMM)
0.2
2000
13100
1320

Static Modeling

PART IV

Data Entry into Petrel

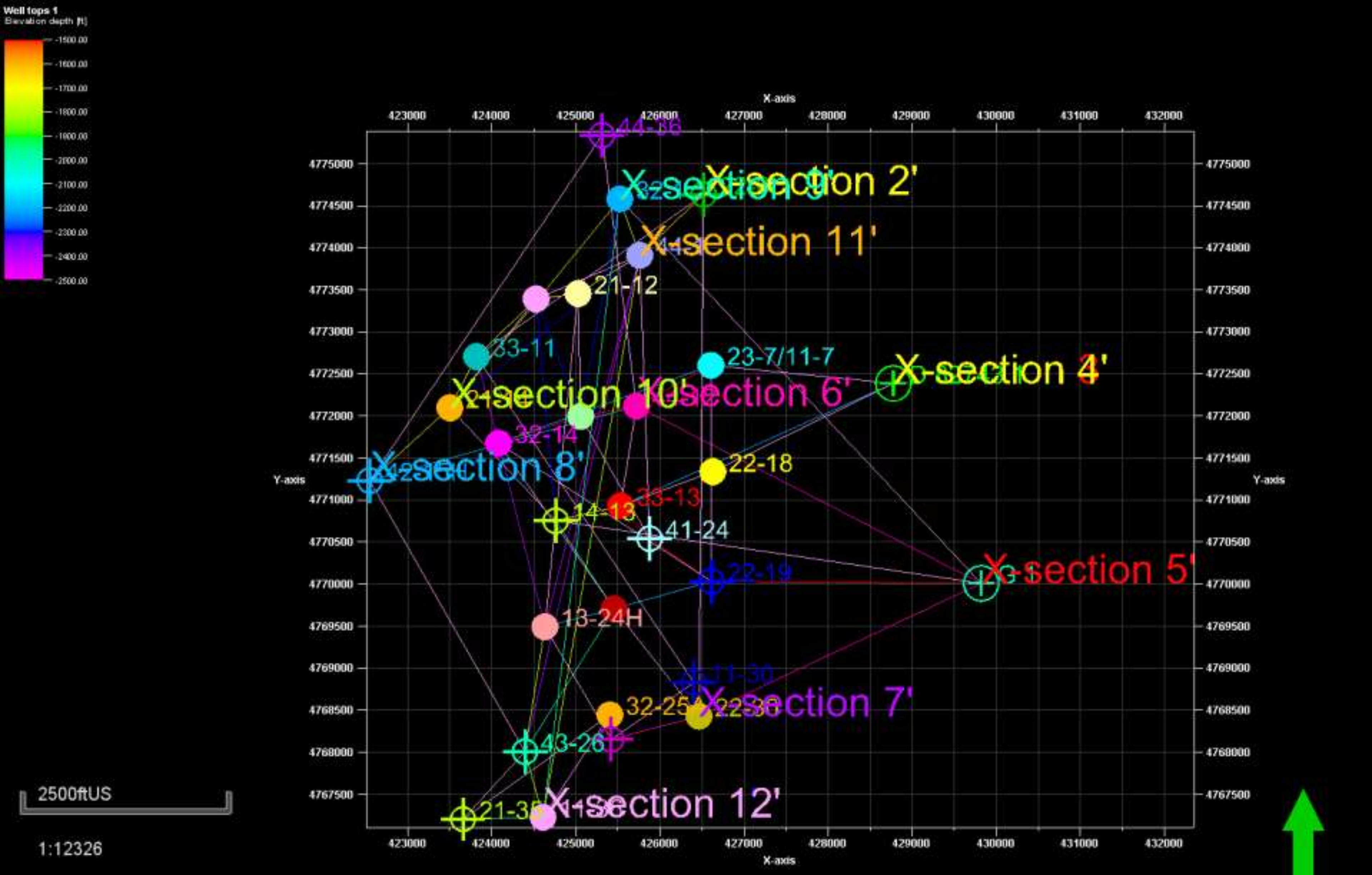
Wells
- Names
- Locations
- Depths

Entering of digitized well log data from NeuraLog

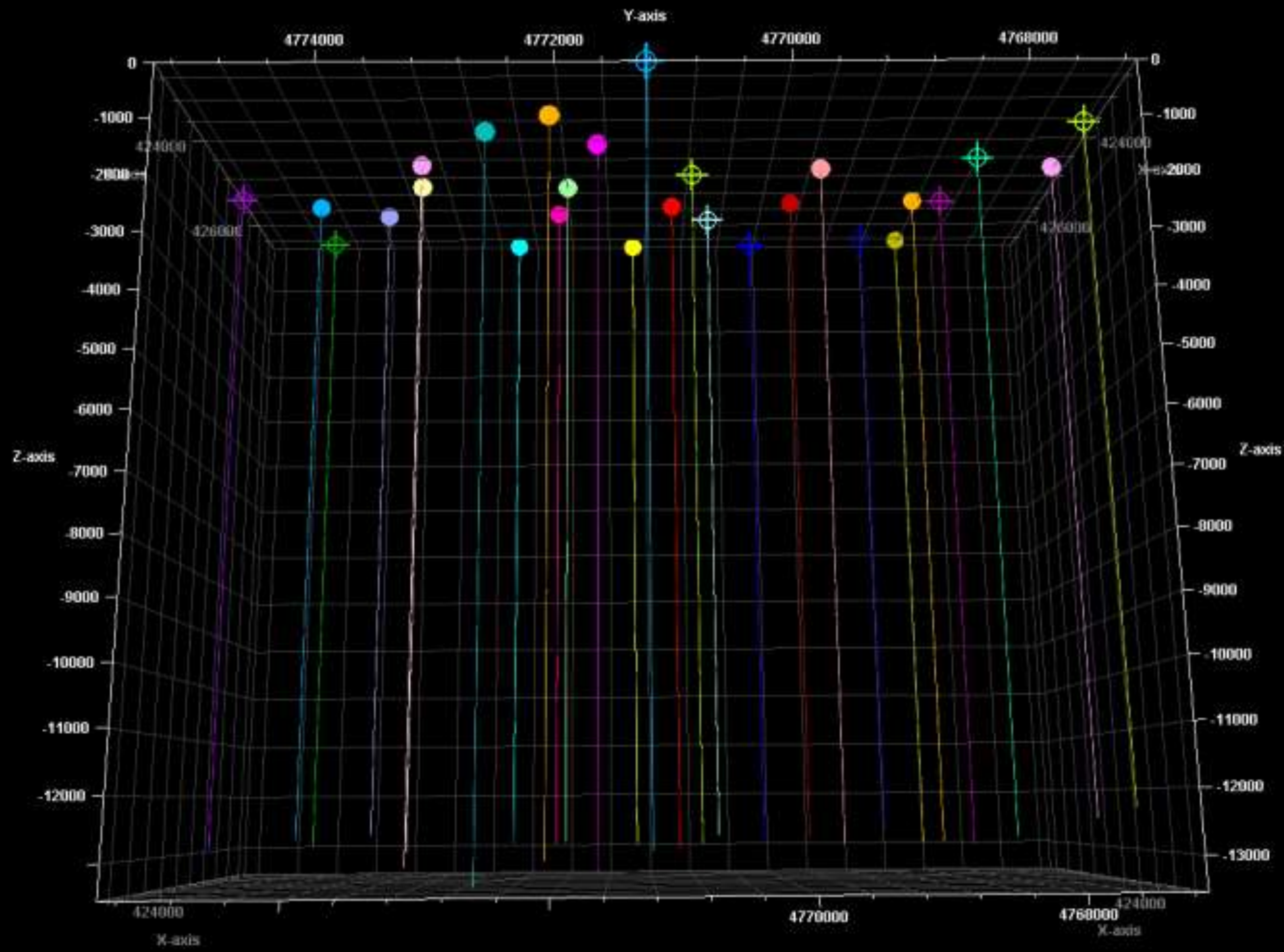
Entering well completion data
- Perforations, tubing, packers

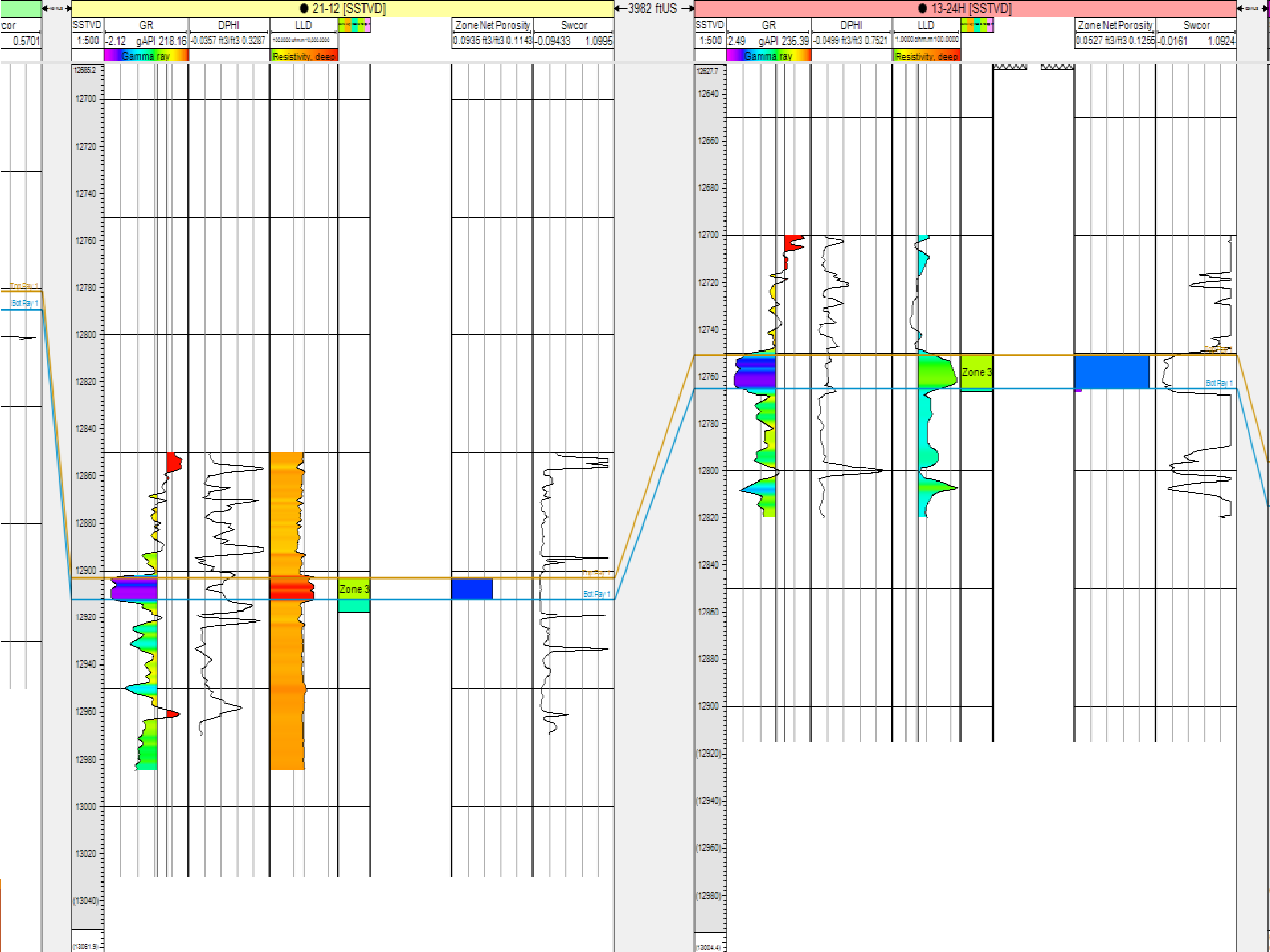
Correlating wells by cross-sectional analysis
- Build horizons and zones

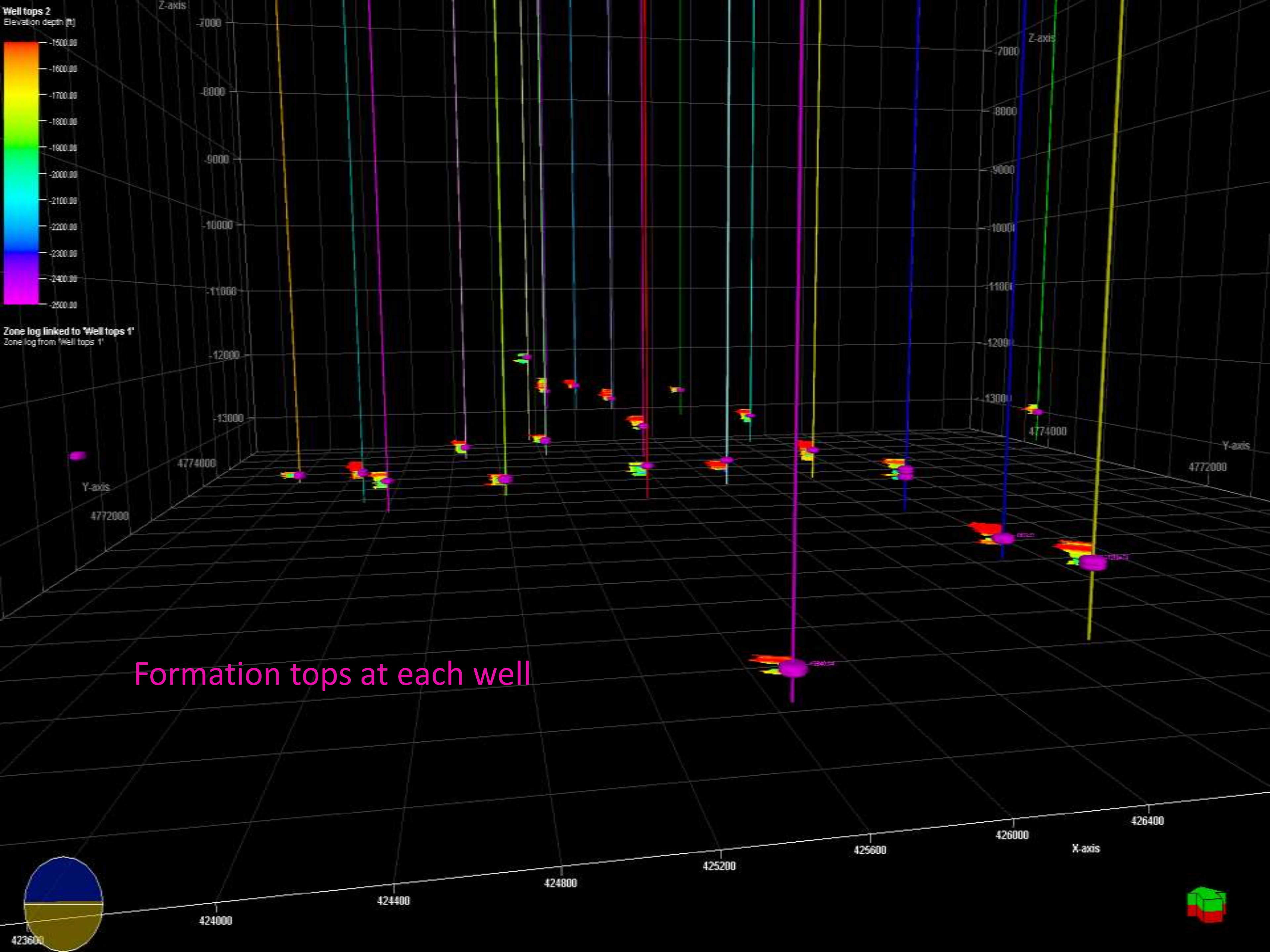
Well locations at surface – areal view



Well bores – cross sectional view

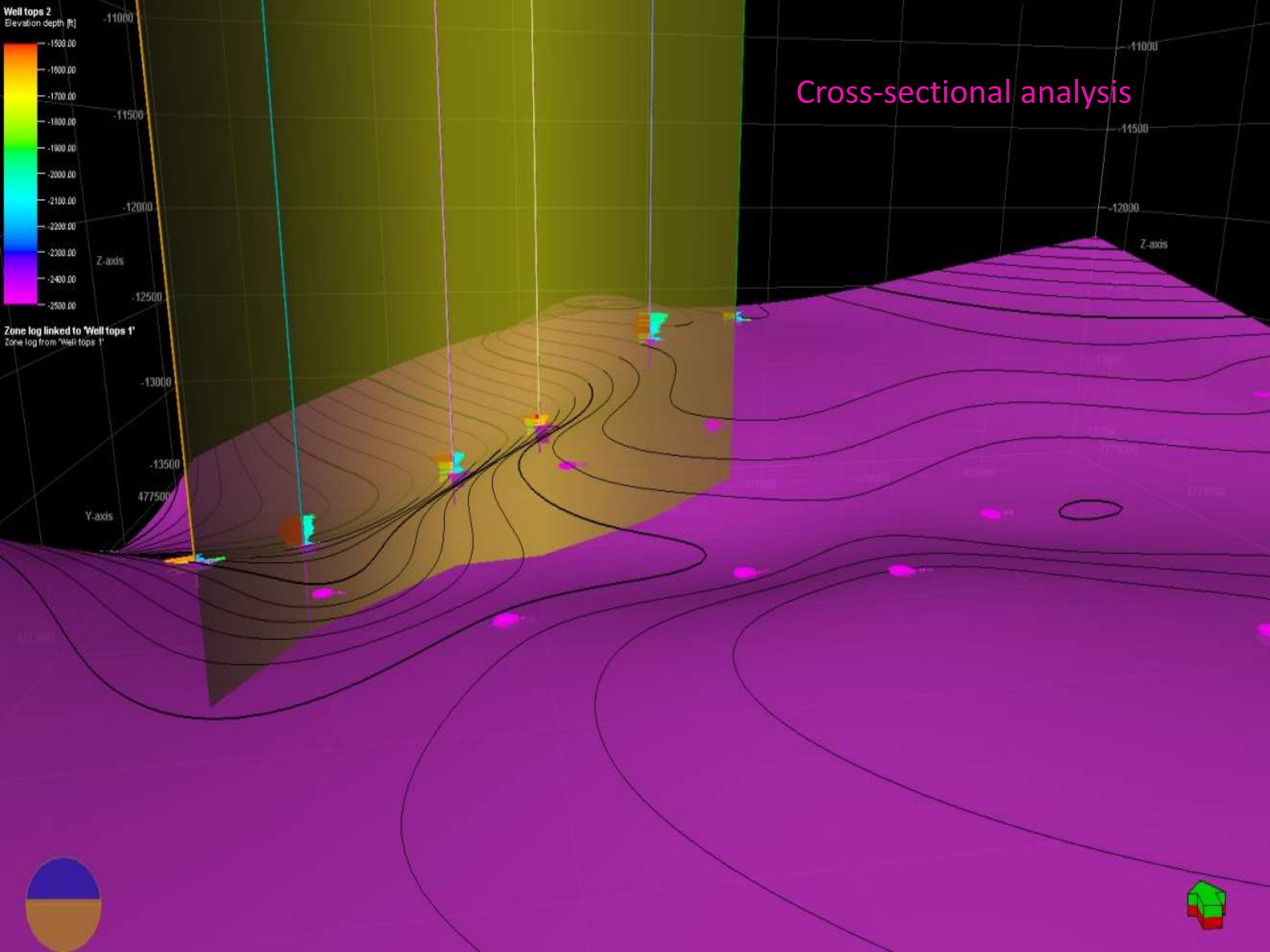



21-12 [SSTVD]
3982 ftUS
13-24H [SSTVD]
SSTVD
GR
DPHI
LLD
Zone Net Porosity
Swcor
1:500
-2.12 gAPI 218.16
-0.0357 ft3/ft3 0.3287
0.0935 ft3/ft3 0.1143
-0.09433 1.0995
2.49 gAPI 235.39
-0.0499 ft3/ft3 0.7521
0.0527 ft3/ft3 0.1256
-0.0161 1.0924
0.5701
Gamma ray
Resistivity, deep
Zone 3
Top Ray 1
Bot Ray 1



Formation tops at each well

Cross-sectional analysis



Model Construction

Entering reservoir characteristics

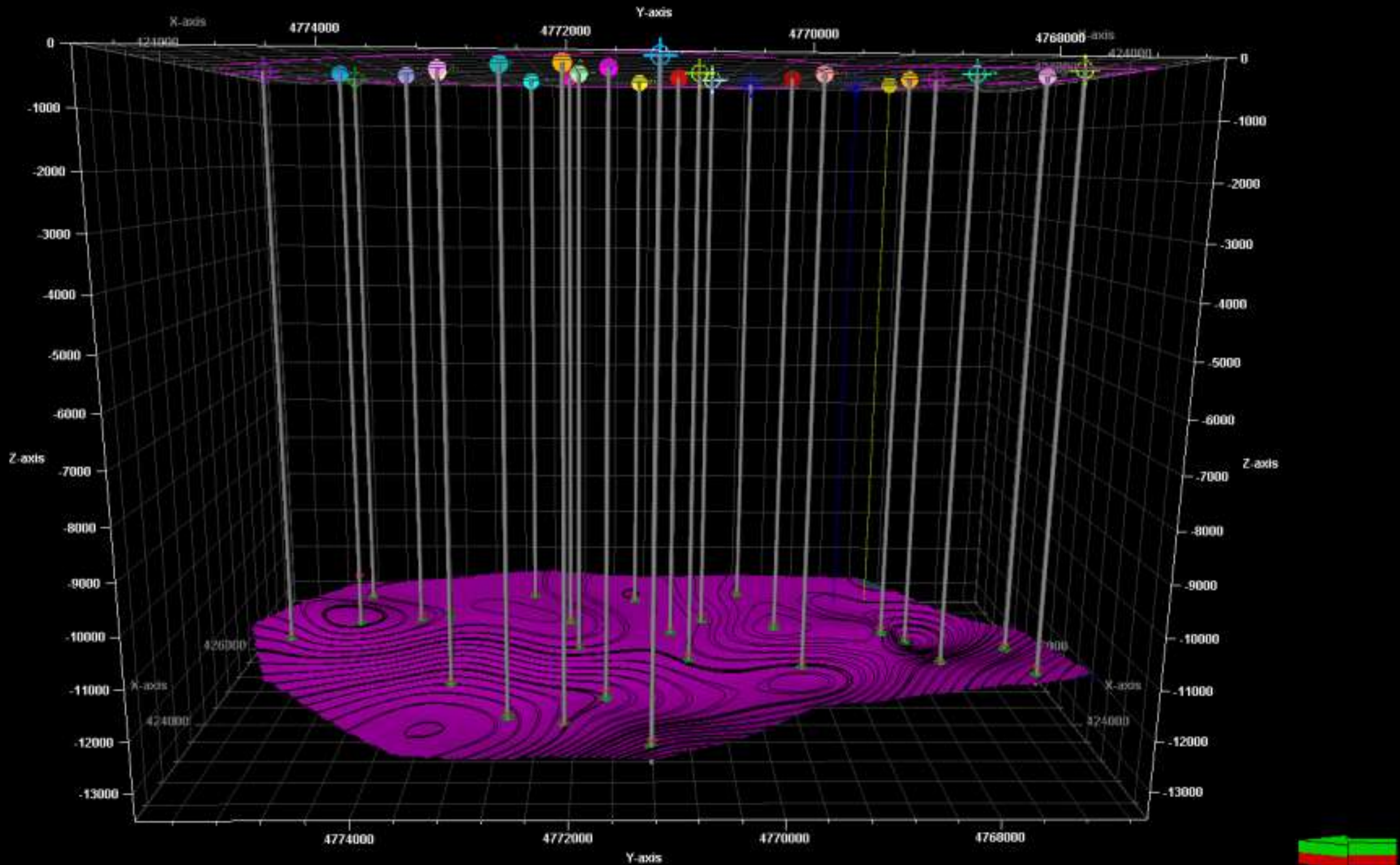
- Porosity, permeability
- Oil, water, and gas saturations

Upscaled characteristics, trend model, modified petrophysical criteria

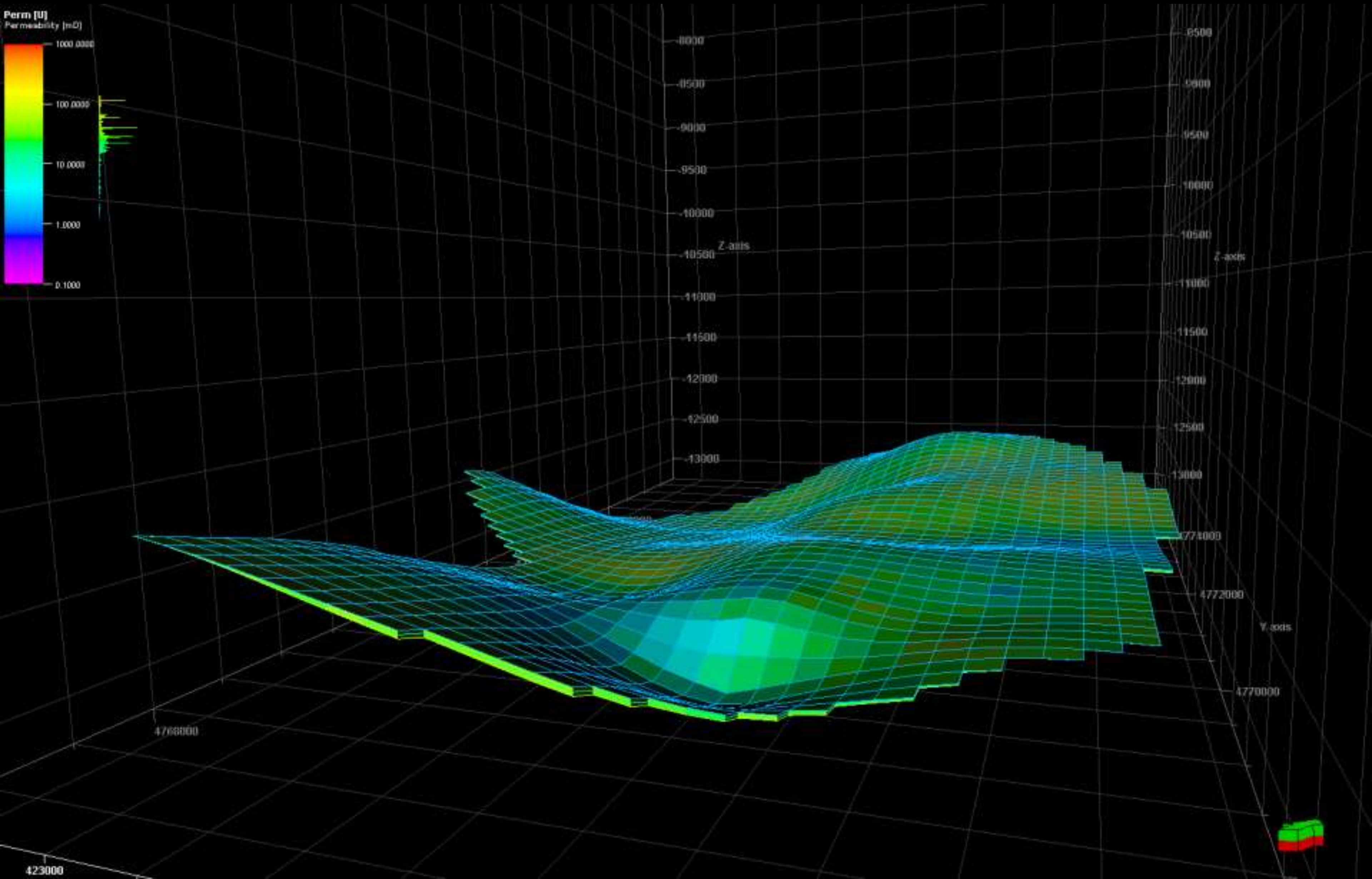
Gaussian random function simulation

Determine grid pattern (150 x 150)

Reservoir model with top layer and wells



Gaussian random function simulation to determine permeability



Model Validation

Constraint:

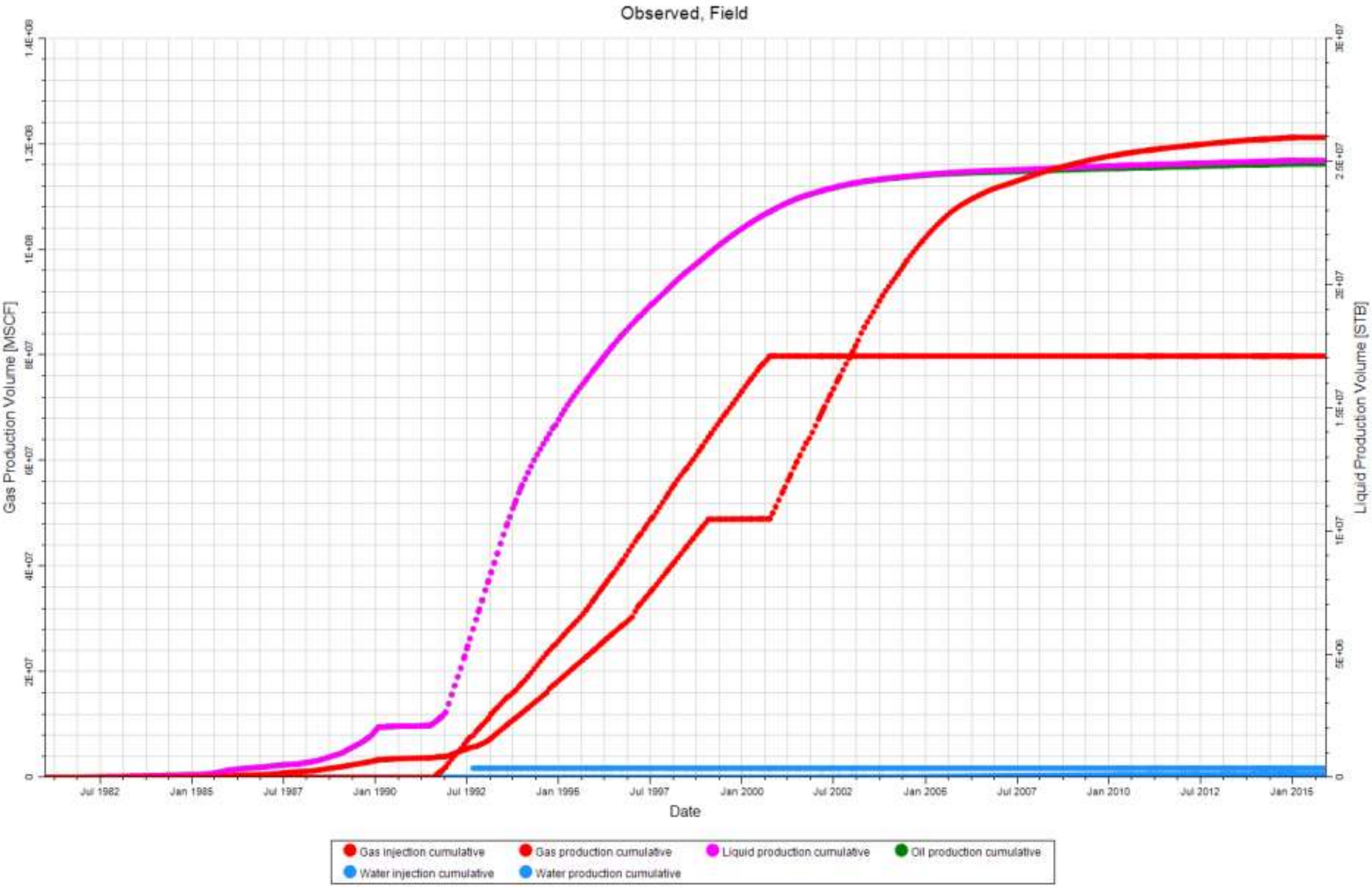
Fluid volumes illustrated in the reservoir must match the measured production and injection values. This will take continuous adjustment of the reservoir characteristics and fluid volumes until the model best matches its actual history.

Entering historical production and injection data

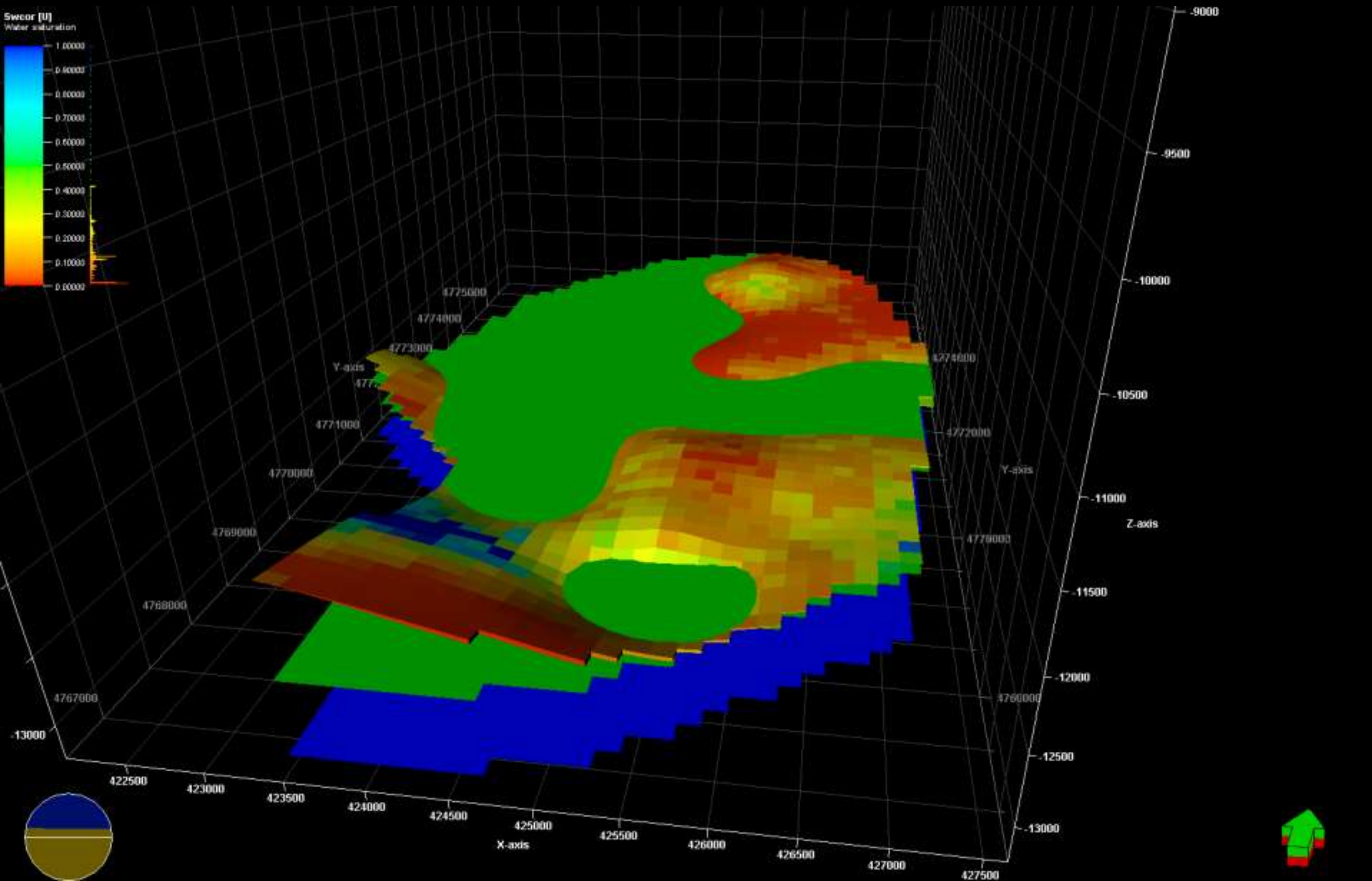
History match
- Determining OOIP, OGIP, and HCPV and matching real life field behavior
- Determining oil-water contact and gas-oil contact

Must be as accurate as possible by following historical data provided from research

Reservoir simulation will not work if the history data does not match the static model data



Observed, Field
Gas Production Volume [MSCF]
Liquid Production Volume [STB]
Date
Jul 1982
Jan 1985
Jul 1987
Jan 1990
Jul 1992
Jan 1995
Jul 1997
Jan 2000
Jul 2002
Jan 2005
Jul 2007
Jan 2010
Jul 2012
Jan 2015
Gas injection cumulative
Gas production cumulative
Liquid production cumulative
Oil production cumulative
Water injection cumulative
Water production cumulative


Swcor [U]
Water saturation
1.00000
0.40000
0.30000
0.20000
0.10000
0.00000
X-axis
Y-axis
Z-axis
422500
423000
423500
424000
424500
425000
425500
426000
426500
427000
427500
-9000
-9500
-10000
-10500
-11000
-11500
-12000
-12500
-13000
4775000
4774000
4773000
4771000
4770000
4769000
4768000
4767000

Dynamic Modeling

PART V

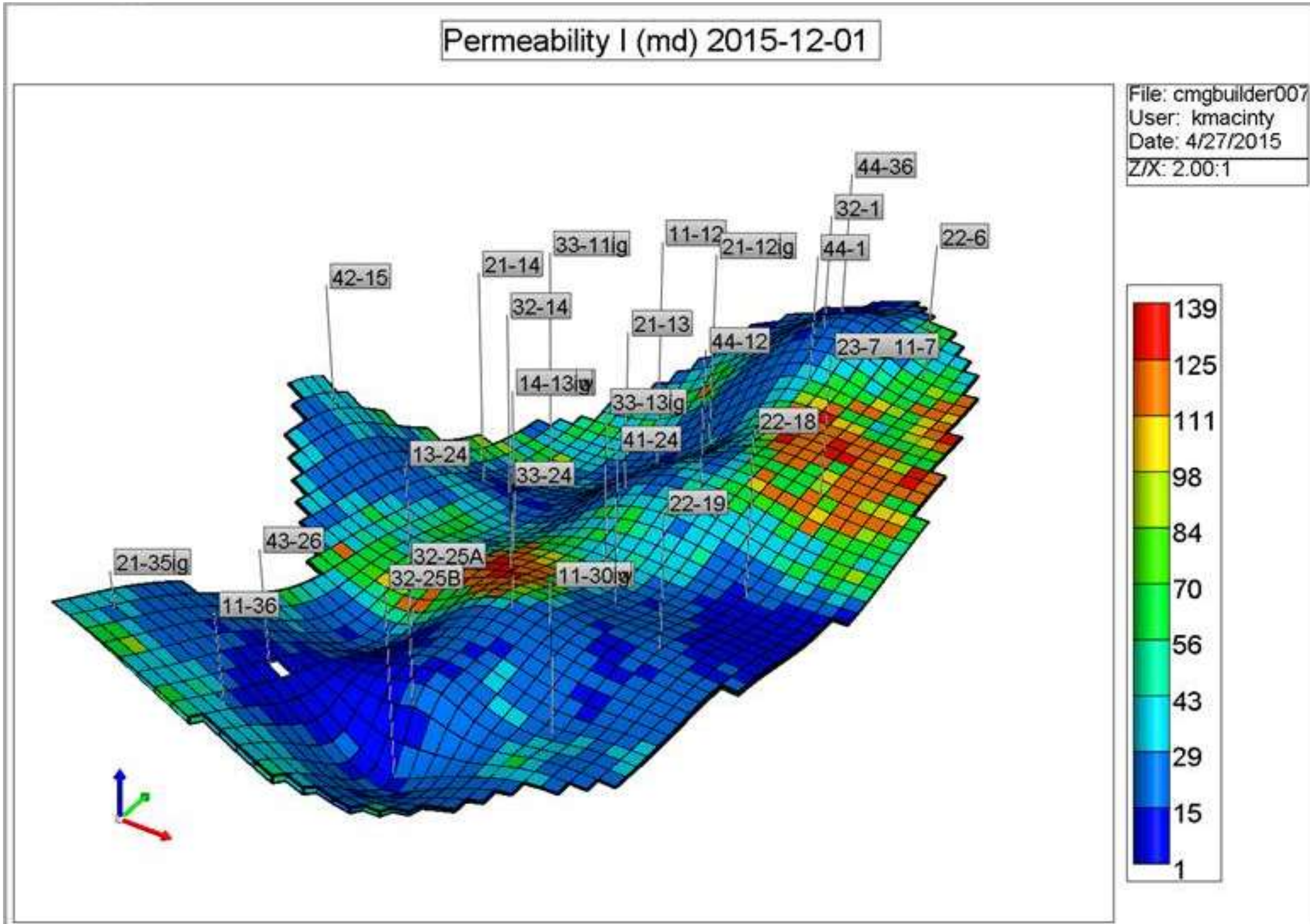
Transition from Petrel to CMG

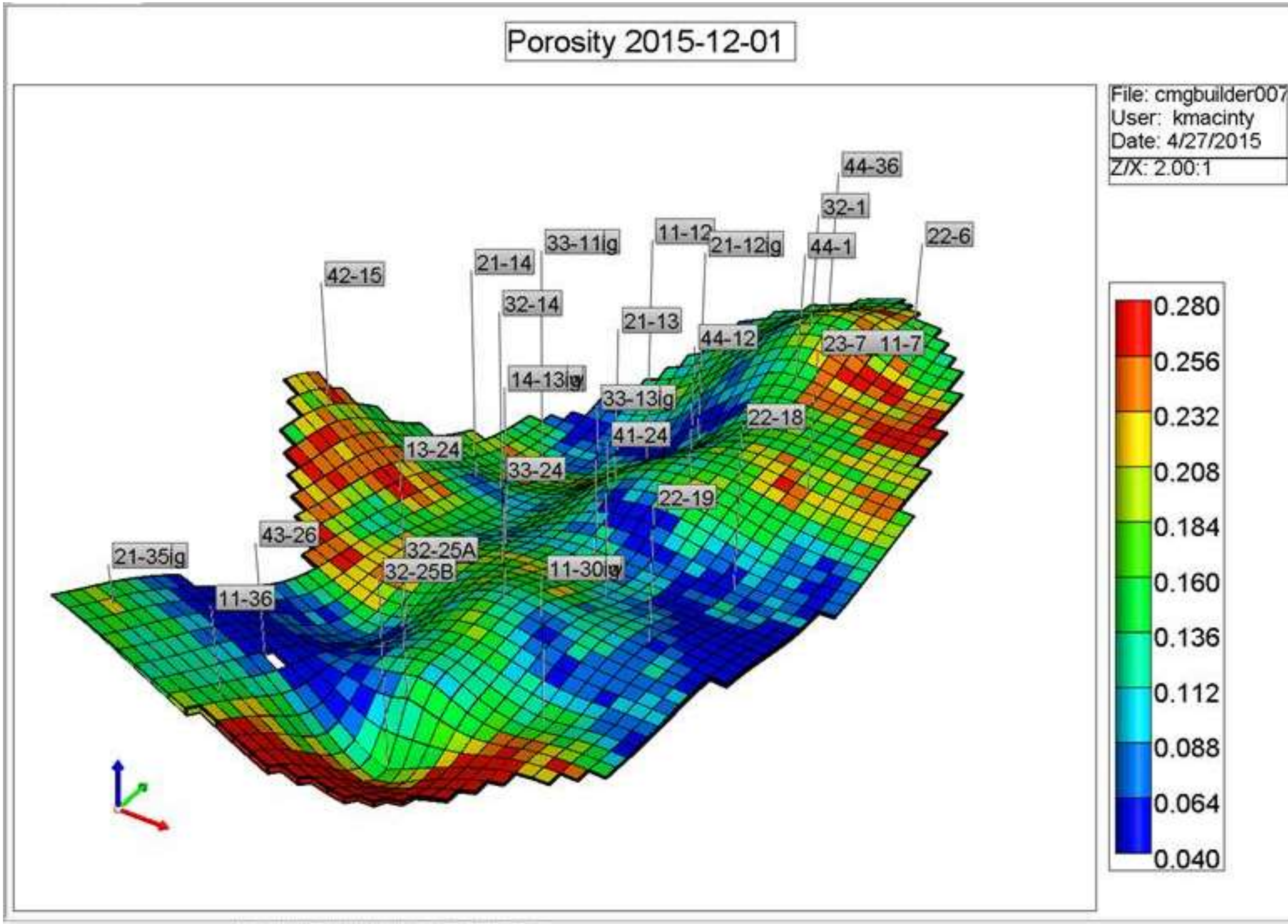
Import directly from Petrel to CMG

Transferred wells and locations

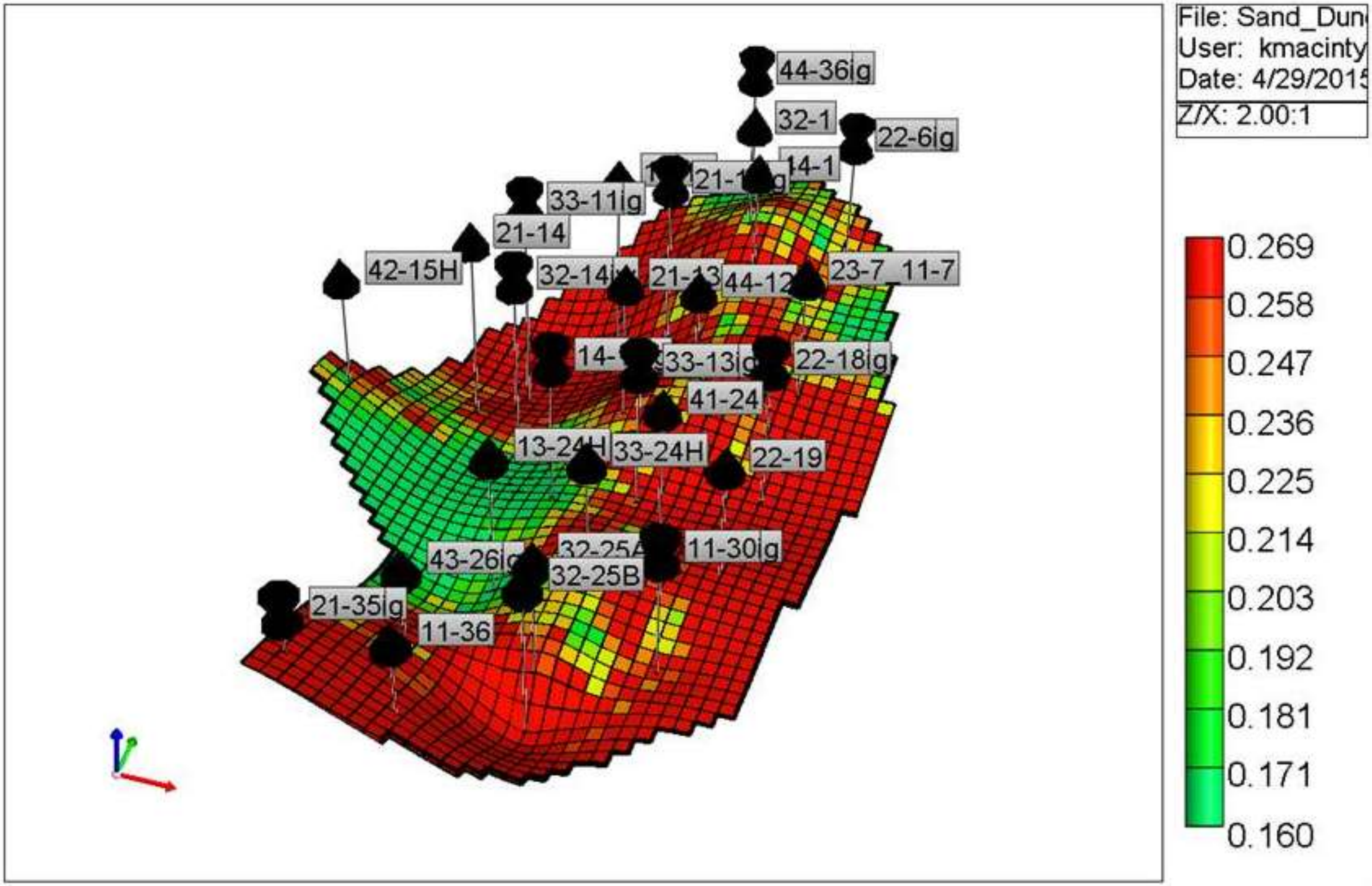
Transferred completion data

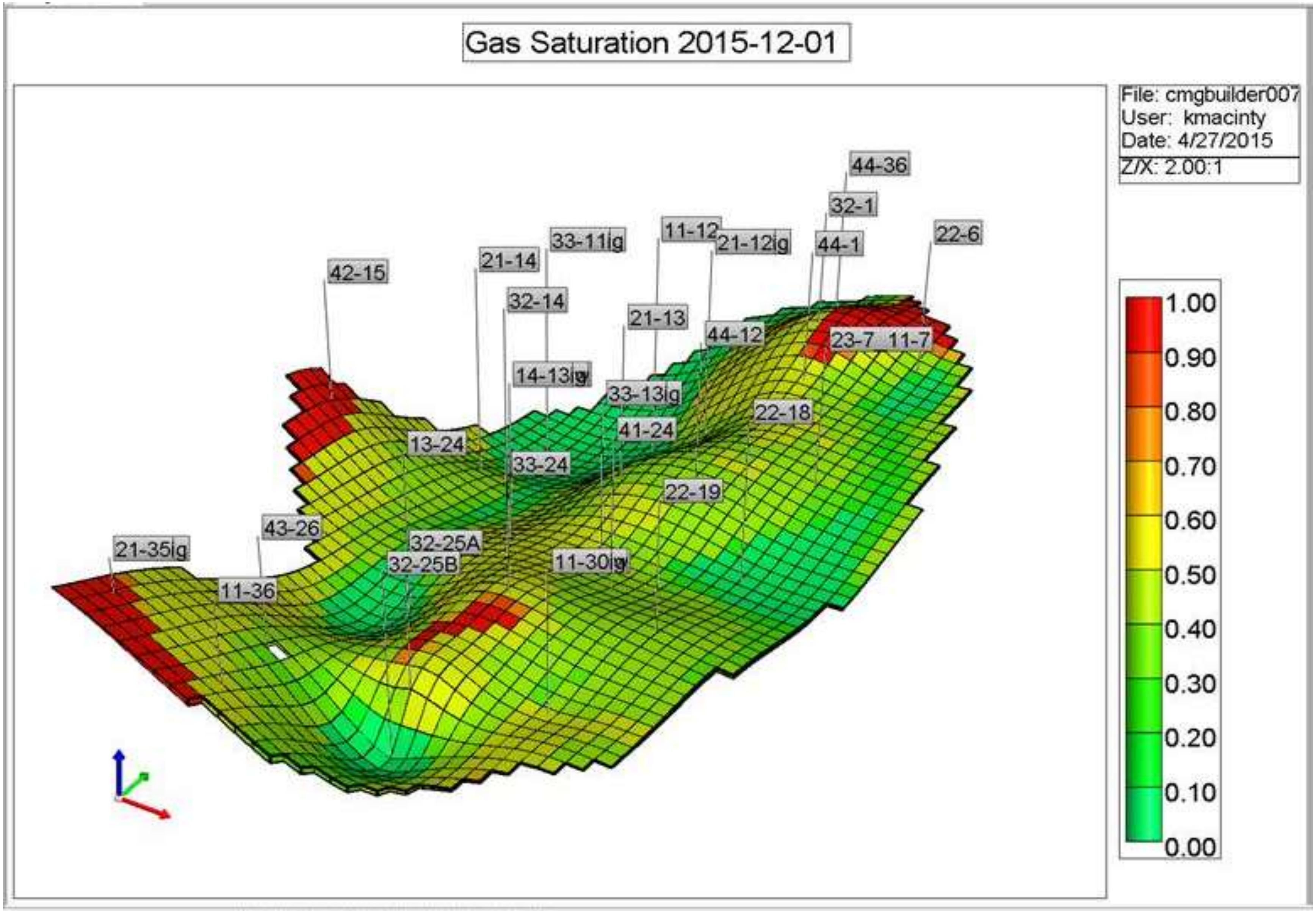
Quality check


Permeability I (md) 2015-12-01
File: cmgbuilder007
User: kmacinty
Date: 4/27/2015
Z/X: 2.00:1
44-36
32-1
22-6
11-12
21-12ig
44-1
33-11ig
21-14
42-15
32-14
21-13
44-12
23-7
11-7
14-13ig
33-13ig
22-18
41-24
13-24
33-24
22-19
43-26
21-35ig
32-25A
32-25B
11-30ig
11-36
139
125
111
98
84
70
56
43
29
15
1


Porosity 2015-12-01
File: cmgbuilder007
User: kmacinty
Date: 4/27/2015
Z/X: 2.00:1
44-36
32-1
11-12
21-12ig
44-1
22-6
33-11ig
21-14
42-15
32-14
21-13
44-12
23-7
11-7
14-13ig
33-13ig
22-18
41-24
13-24
33-24
22-19
43-26
32-25A
21-35ig
32-25B
11-30ig
11-36
0.280
0.256
0.232
0.208
0.184
0.160
0.136
0.112
0.088
0.064
0.040

Oil Saturation 1981-01-01




Gas Saturation 2015-12-01
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Z/X: 2.00:1
44-36
32-1
22-6
11-12
21-12ig
44-1
33-11ig
21-14
42-15
32-14
21-13
44-12
23-7
11-7
14-13ig
33-13ig
22-18
41-24
13-24
33-24
22-19
43-26
21-35ig
32-25A
32-25B
11-30ig
11-36
1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00

CO_2 Complications

Constraint:

Favorable CO_2 injection reservoir characteristics

Unfavorable CO_2 economics

- Workover costs
- Surface facilities
- CO_2 cost

Economic modelling already illustrates negative results

Project with CO_2 not economically feasible

Switched to water and natural gas injection to determine an economical alternative

Natural Gas Simulation

Choose well pattern

- Identify injection and production wells
- Determine rock fluid properties
- Monitor gas and water breakthrough in producing wells

Determine time and volume required for injection

- Ran NG, WAG, and Water floods
- 30-40 Mscf/day/injection well
- 4 year flood

Natural Gas Simulation

Reinjection of produced natural gas

Additional natural gas must be transported to the field

Time and amount of injection fluid dictate feasibility

Constraint:

Aquifer/atmospheric contamination

Public concern

Design for public and professional understanding

Economic Analysis

PART VI

Comparison of Economics

CO_2 FLOODING

- Field not set up with CO_2 source
- Repressurize formation with natural gas before CO_2 flood
- Costs associated with switch between two different sources
- Difficult to recycle due to mix of CO_2 and natural gas

NATURAL GAS FLOODING

- Field already contains natural gas facilities and capabilities
- Repressurize process can be continued into flooding
- No transition fees between CO_2 and natural gas
- Easy recycling of produced natural gas

Economics with Natural Gas

Muddy Field has surface facilities to handle natural gas

State and Federal taxes (12.5% and 16.7% respectively)

Well workovers (approx. $250,000 per well)

CAPEX (well workovers, updates to facilities)

OPEX (Royalties, Severance tax, Ad Valorem, Natural Gas purchases)

- Other liquid costs per barrel
- Other well operating costs per well/yr

Profits: Incremental oil*oil price (per barrel)

Net cash flow = Profits - Expenditures

Final Economic Evaluation

Gas Price $/MMScf	2770
Gas Hauling Cost $/MMScf	2000
Water Price $/Mstb	700
Water Haul Price $/MStb	8000
Oil Price $/STB (WTI)	60

NPV			
Year	NG	Water	WAG
2017	$(1,052,010.69)	$(2,899,393.15)	$(2,966,304.06)
2018	$(1,005,898.48)	$(4,488,663.82)	$(3,485,349.61)
2019	$(889,441.39)	$(6,132,861.12)	$(4,005,927.18)
2020	$(739,070.30)	$(7,857,245.05)	$(4,526,355.75)
2027	$235,108.45		

Economic Data

Consider current market values

- Price of oil
- Price of natural gas
- Transportation costs

Constraint:

Price of oil in current market can make EOR projects uneconomical

Consider values needed to make flood economical

- Price of oil
- Price of natural gas
- Transportation costs

Conclusions

PART VII

Conclusions

CO_2 flooding proved uneconomical for this field, due primarily to:

- Building of surface facilities (expensive)
- Building of pipeline, sourcing the gas from Shute Creek (Greencore capacity)
- Incremental oil recovery not as high as expected

Conclusions Cont.

Natural gas injection potentially economically feasible with oil prices around $120/bbl

Surface facilities for natural gas have already been implemented in this field

Incremental oil produced:

- 4 year: 46.32 MStb (through 2019)
- 10 year: 160.69 MStb (through 2026)

NPV in 2027: **$235,108 (at $60.00 per bbl)**

NPV in 2027: **$3,189,079 (at $120 per bbl)**

With current market prices, natural gas injection in this field is not recommended, until oil prices increase and remain steady

References

Lawrence O. Anna, 2009, Geologic assessment of undiscovered oil and gas in the Powder River Basin Province: U.S. Geological Survey Digital Data Series DDS–69–U, 93 p.

Fulco, George, Wayne Roberts, and Connie Hawkins. "Sand Dunes Area (Sand Dunes and Derrick Draw)." *Wyoming Oil and Gas Fields Symposium* (2000): 436-38. *American Association of Petroleum Geologist*. Web. 1 Nov. 2014. <http://archives.datapages.com/data/wga/data/065/065001/436_wga0650436.htm>.

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Dalton, Gordon, and James Fox. "POWDER RIVER BASIN PROVINCE (033)." *United States Geological Survey*. United States Geological Survey. Web. 19 Nov. 2014. <http://certmapper.cr.usgs.gov/data/noga95/prov33/text/prov33.pdf>.

Murrell, Glen. "North American CO2 EOR Supply Status and Developments." SPE Powder River Basin Section. Enhanced Oil Recovery Institute. , Gillette, Wyoming. 8 Jan. 2013. Lecture.

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Khairy, M. (2001). Equations Estimate Relative Permeability of Mixed Wettability Shaly Sands. Oil and Gas Journal, 99 (18), pg 53-58.

Swirchzynski, R. “South Glenrock , Sand Dunes, Derrick Draw Meander Belt, Southwest Powder River Basin, Wyoming.” *AAPG Datapages/Archives*. AAPG, 1997. <http://archives.datapages.com/data/wga/data/061/061001/89_wga0610089.htm>.

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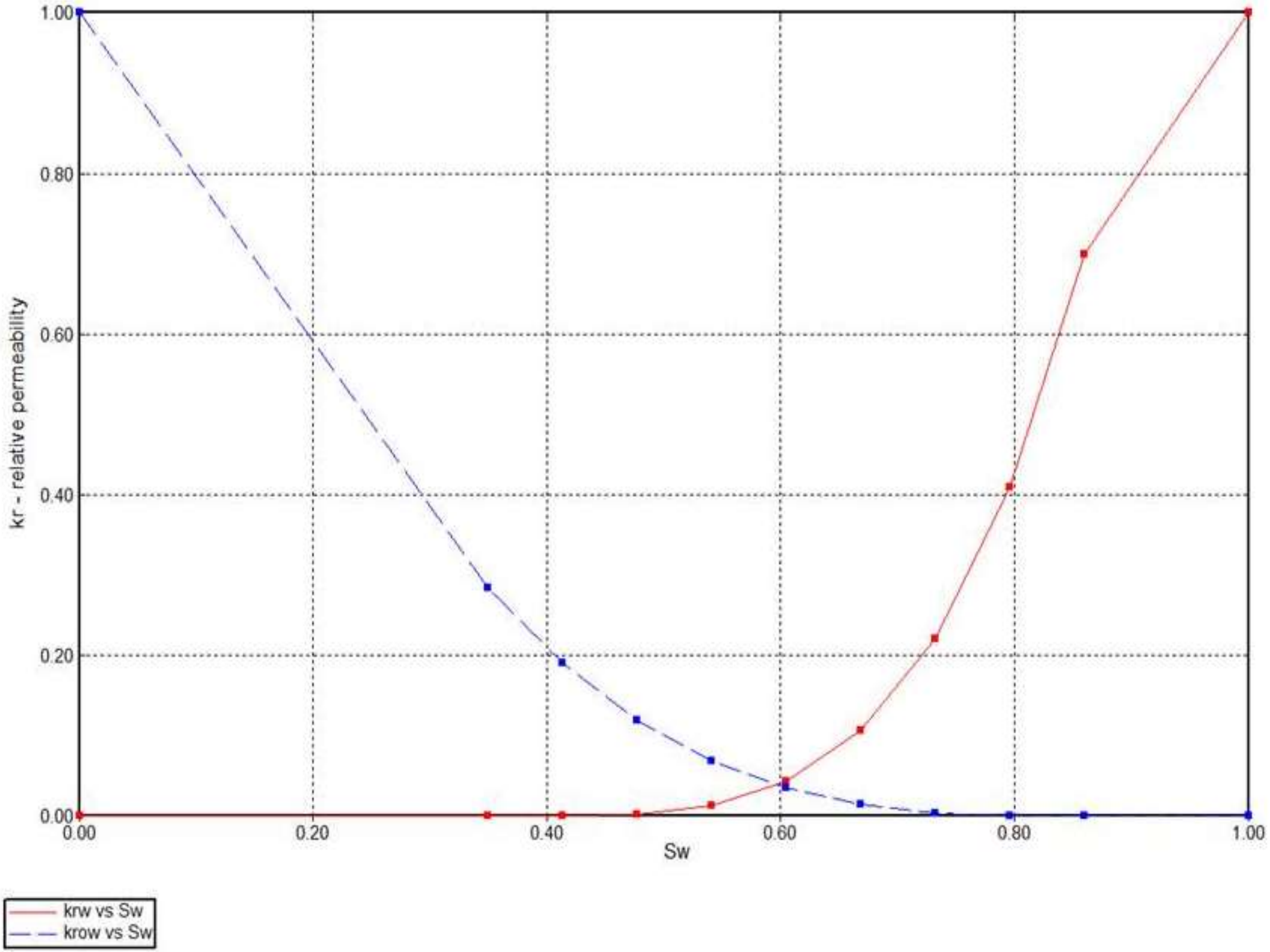
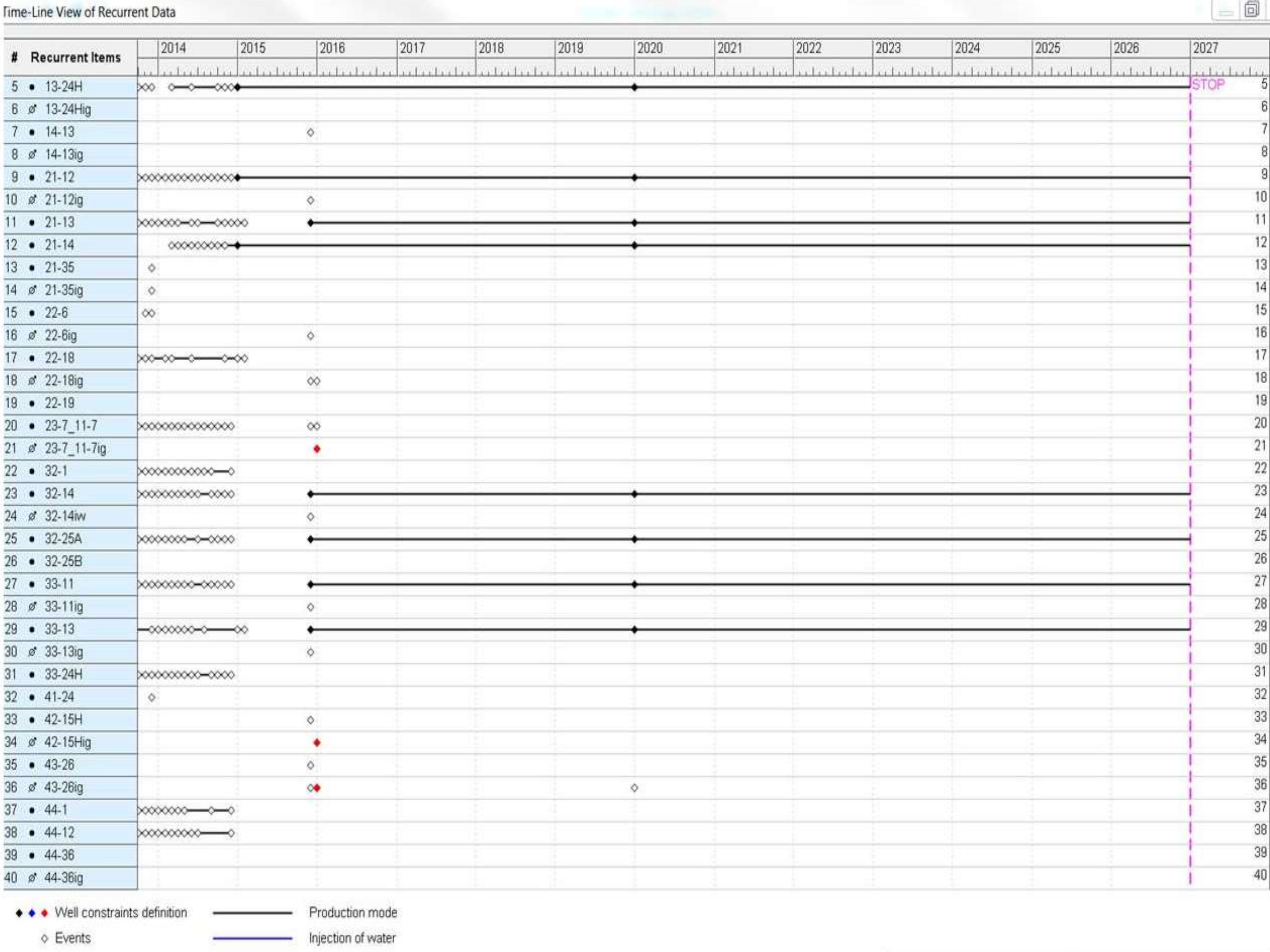
Thank you. Questions?

SENIOR DESIGN II – GROUP G

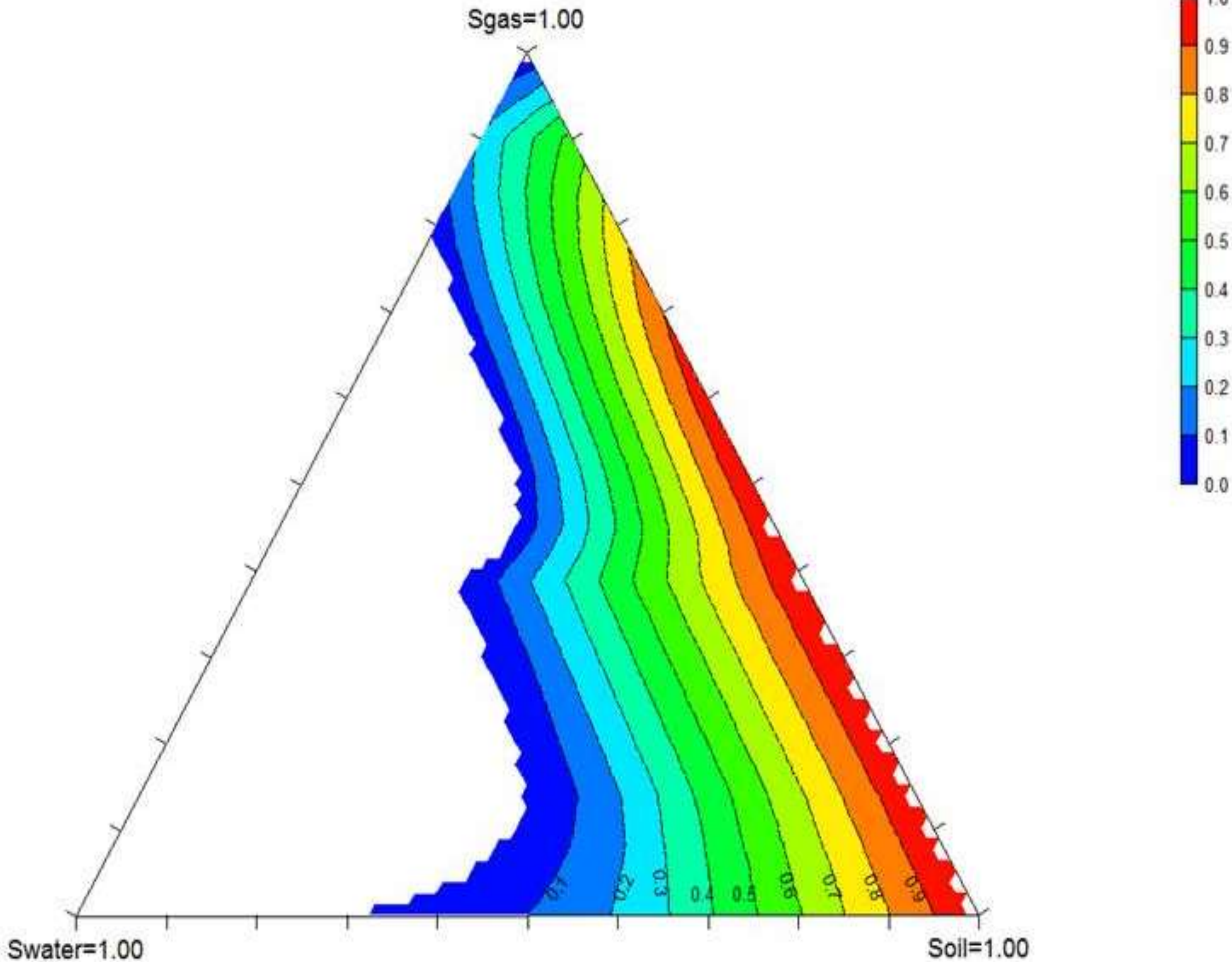


1.00
0.80
0.60
0.40
0.20
0.00
kr - relative permeability
0.00
0.20
0.40
0.60
0.80
1.00
Sw
krw vs Sw
krow vs Sw

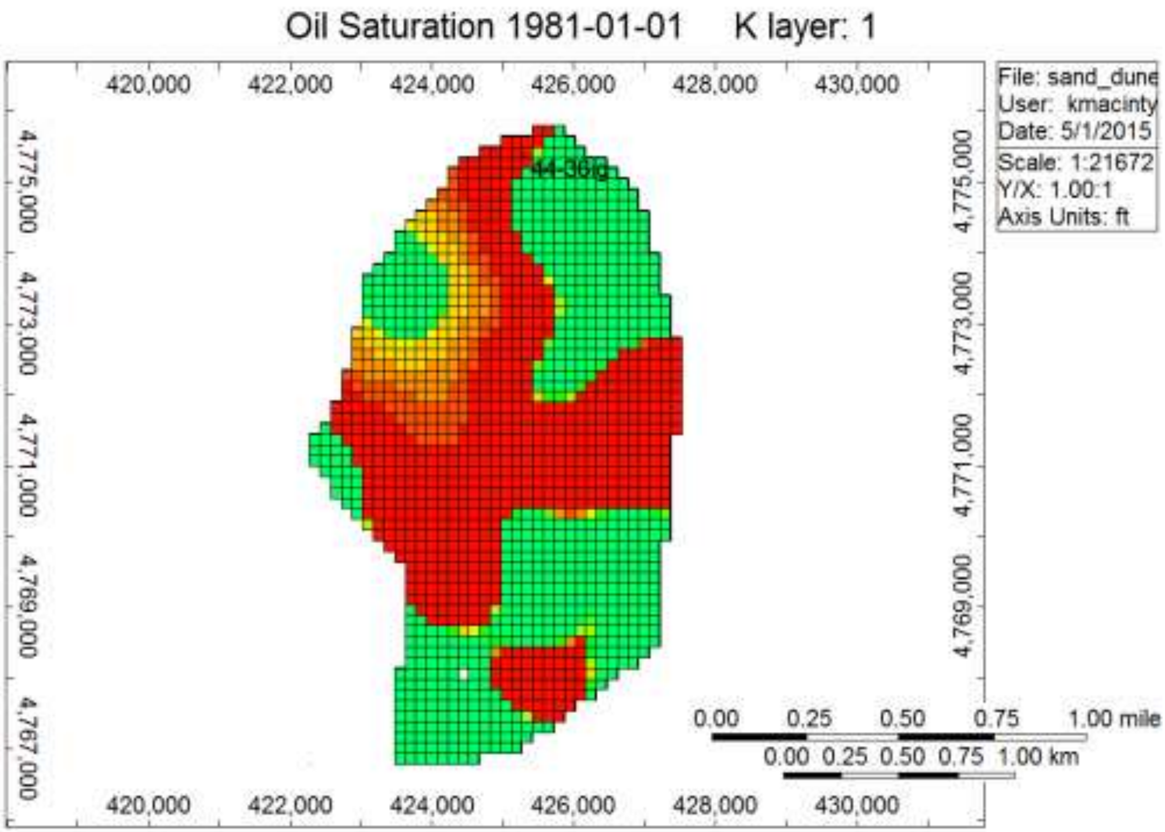


Time-Line View of Recurrent Data
Recurrent Items
2014
2015
2016
2017
2018
2019
2020
2021
2022
2023
2024
2025
2026
2027
STOP
5 13-24H
6 13-24Hig
7 14-13
8 14-13ig
9 21-12
10 21-12ig
11 21-13
12 21-14
13 21-35
14 21-35ig
15 22-6
16 22-6ig
17 22-18
18 22-18ig
19 22-19
20 23-7_11-7
21 23-7_11-7ig
22 32-1
23 32-14
24 32-14iw
25 32-25A
26 32-25B
27 33-11
28 33-11ig
29 33-13
30 33-13ig
31 33-24H
32 41-24
33 42-15H
34 42-15Hig
35 43-26
36 43-26ig
37 44-1
38 44-12
39 44-36
40 44-36ig
Well constraints definition
Events
Production mode
Injection of water

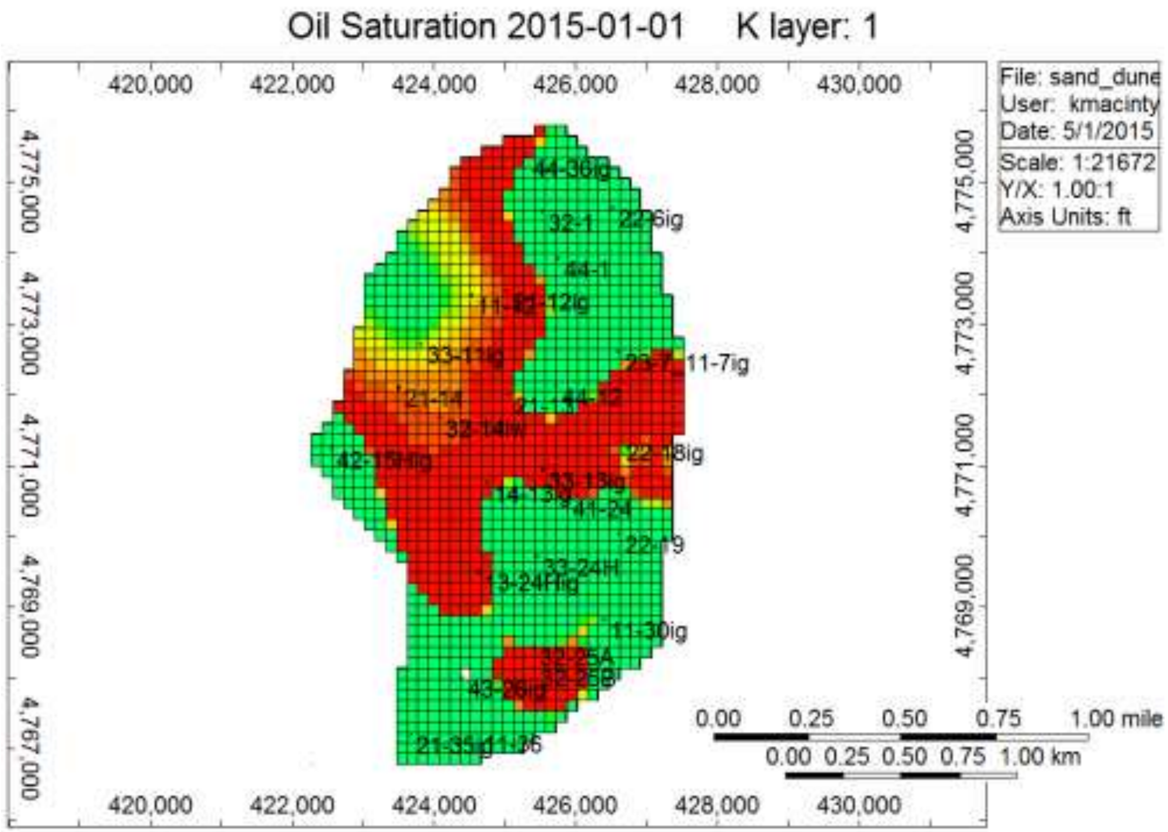
Kro by Stone #2 Model, SWSG



Decline Curve Recovery from 1981 to 2020



Natural Gas Influence from 2015 to 2020



WAG Influence form 2015 to 2020