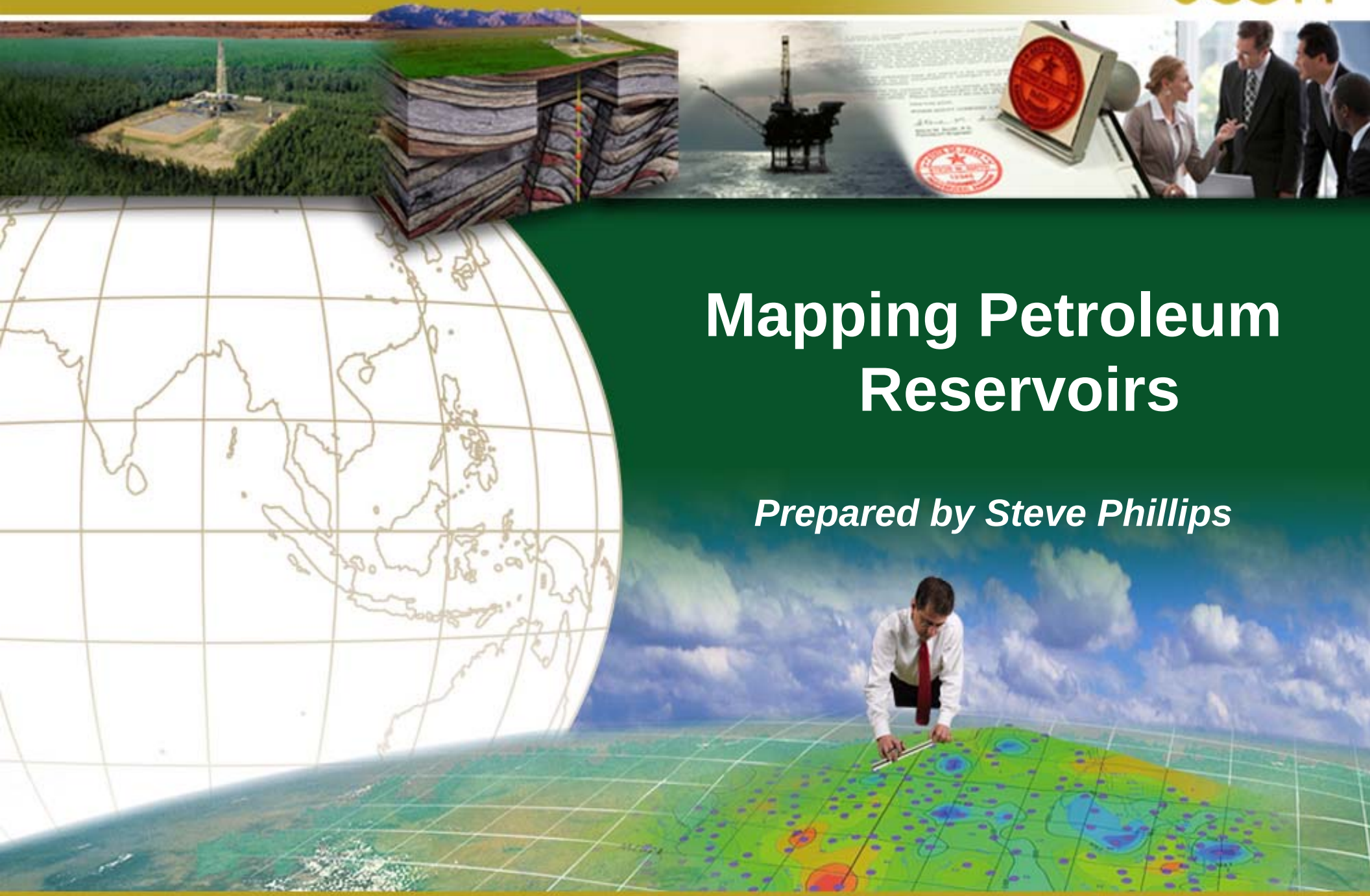
Houston • Denver • Calgary

RYDER SCOTT



Mapping Petroleum Reservoirs

Prepared by Steve Phillips

The following presentation has been revised to represent a more concise view of the subject matter. Certain slides, therefore, have been removed and/or edited.

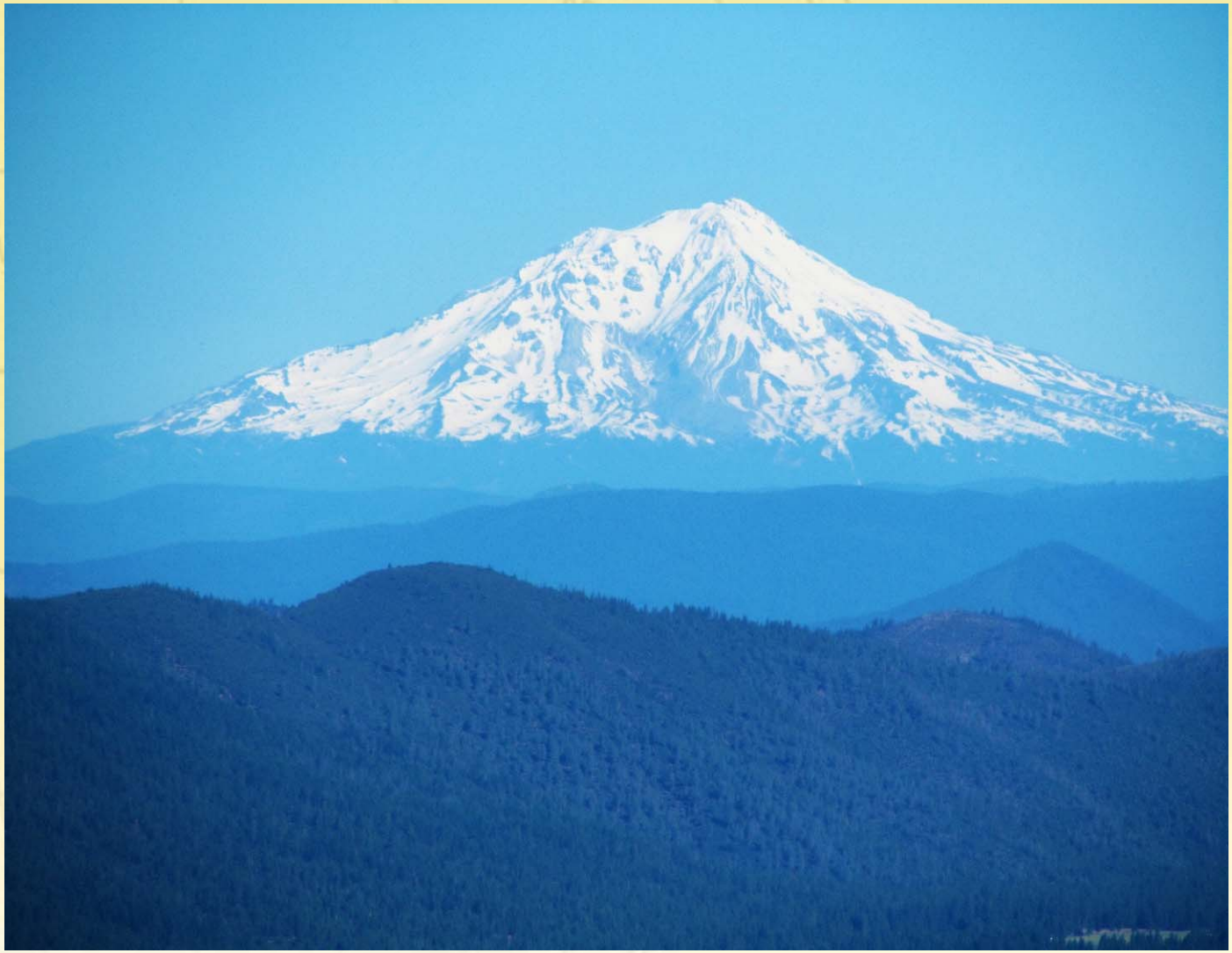
In the original presentation given at the conference, some slides suggested that there may have been errors on the map presented. In the interest of accuracy, it should be noted that any errors or differences of interpretation indicated on those slides that were part of the interim work product were resolved in the final map included in the presentation. To avoid further confusion, and recognizing that the maps presented are not meaningful without the associated dialogue from the presenter, those slides have been removed.

Mapping petroleum reservoirs:

RYDER SCOTT

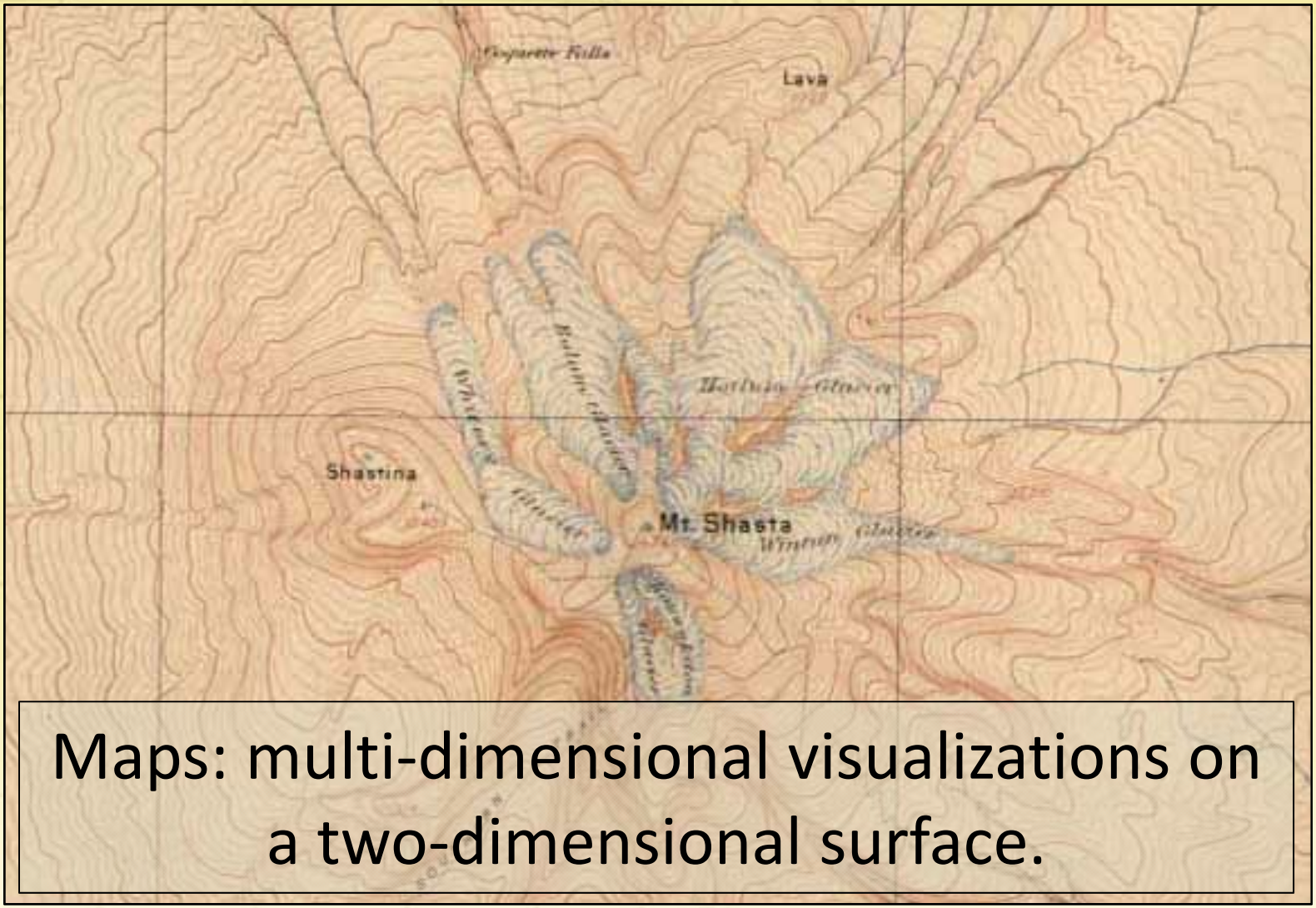
Who's in charge, minds or machines?

The real world



Mount Shasta, STP 2013

Representation of the real world

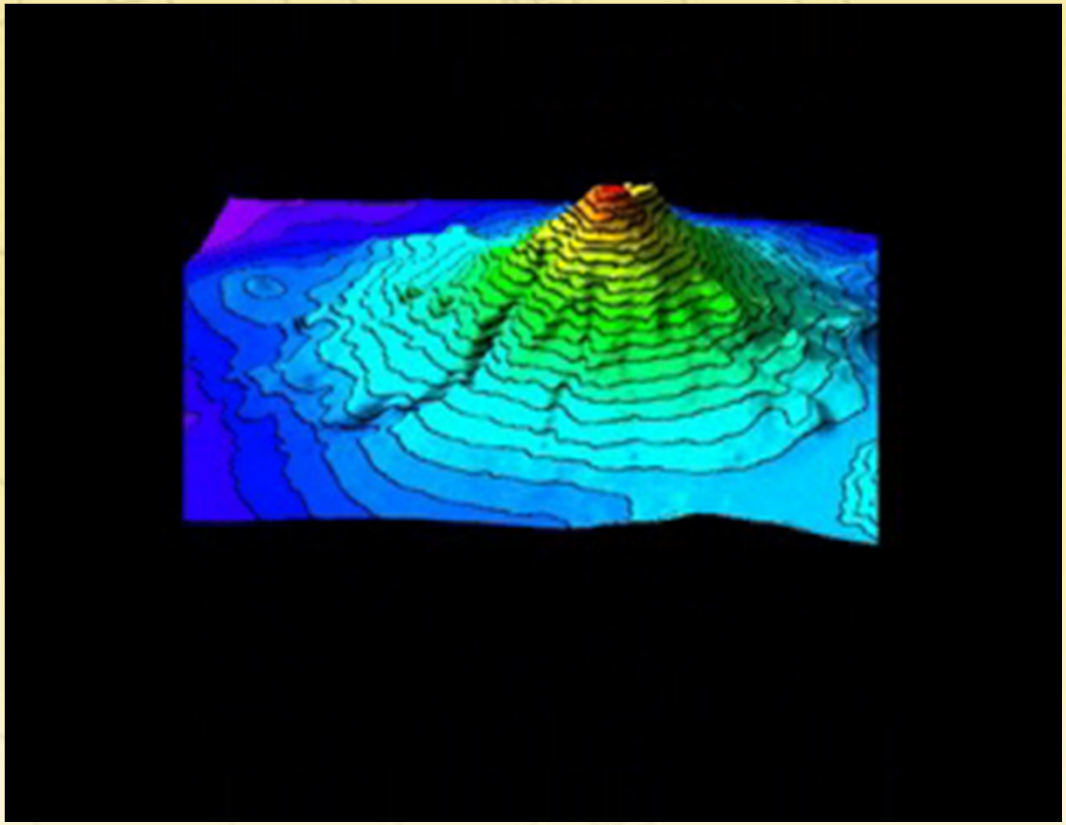


Maps: multi-dimensional visualizations on a two-dimensional surface.

Topographic map of Mount Shasta, 1884, USGS

3D visualization now

Also a projection onto a 2D surface.
Is there more information here than the paper map?



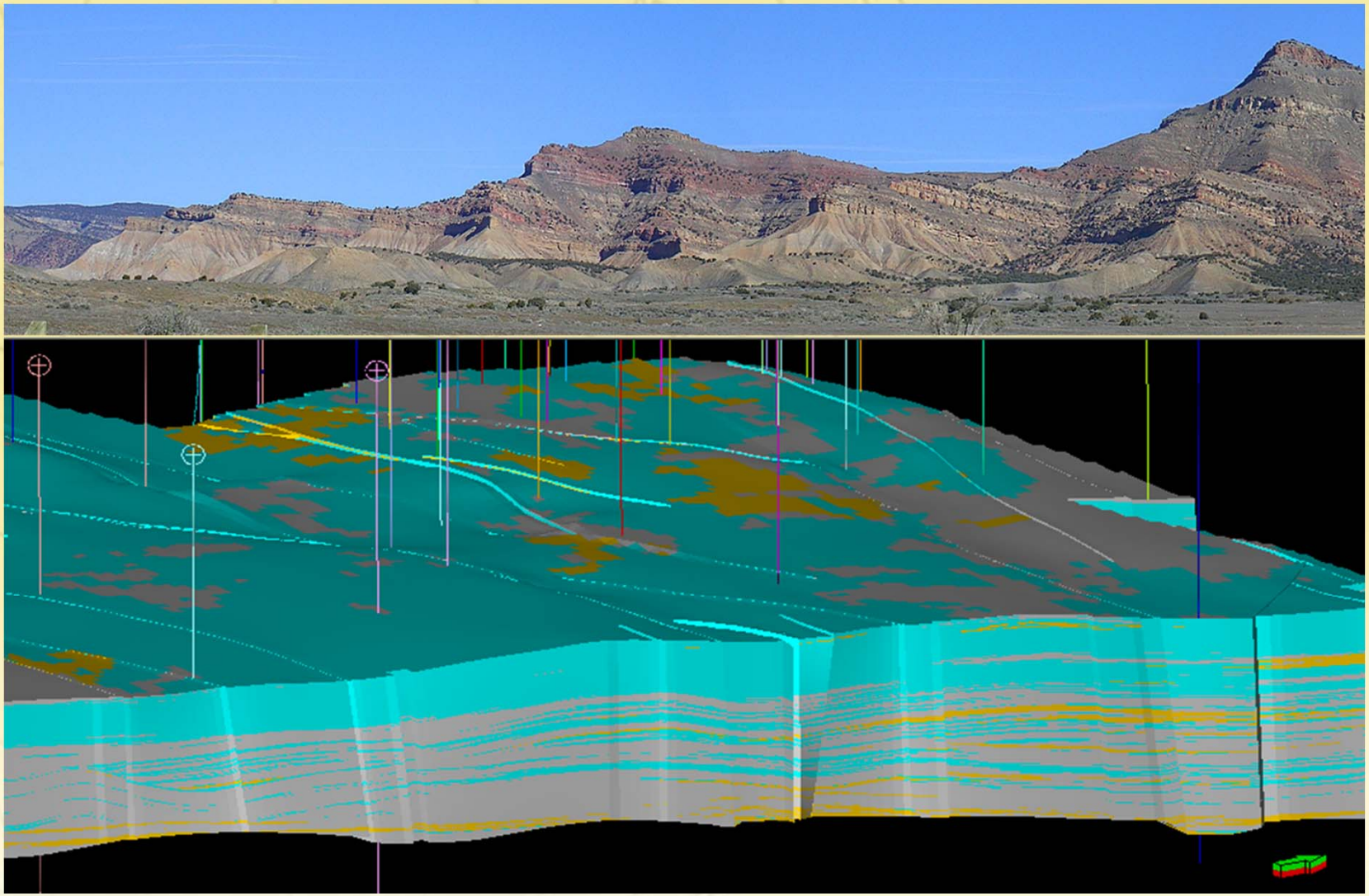
http://www.honolulu.hawaii.edu/instruct/natsci/geology/brill2/topomov.html

True 3D

http://learnerwithin.blogspot.com/2012/02/topography.html

Real world…

…always more complex than our ability to describe it.



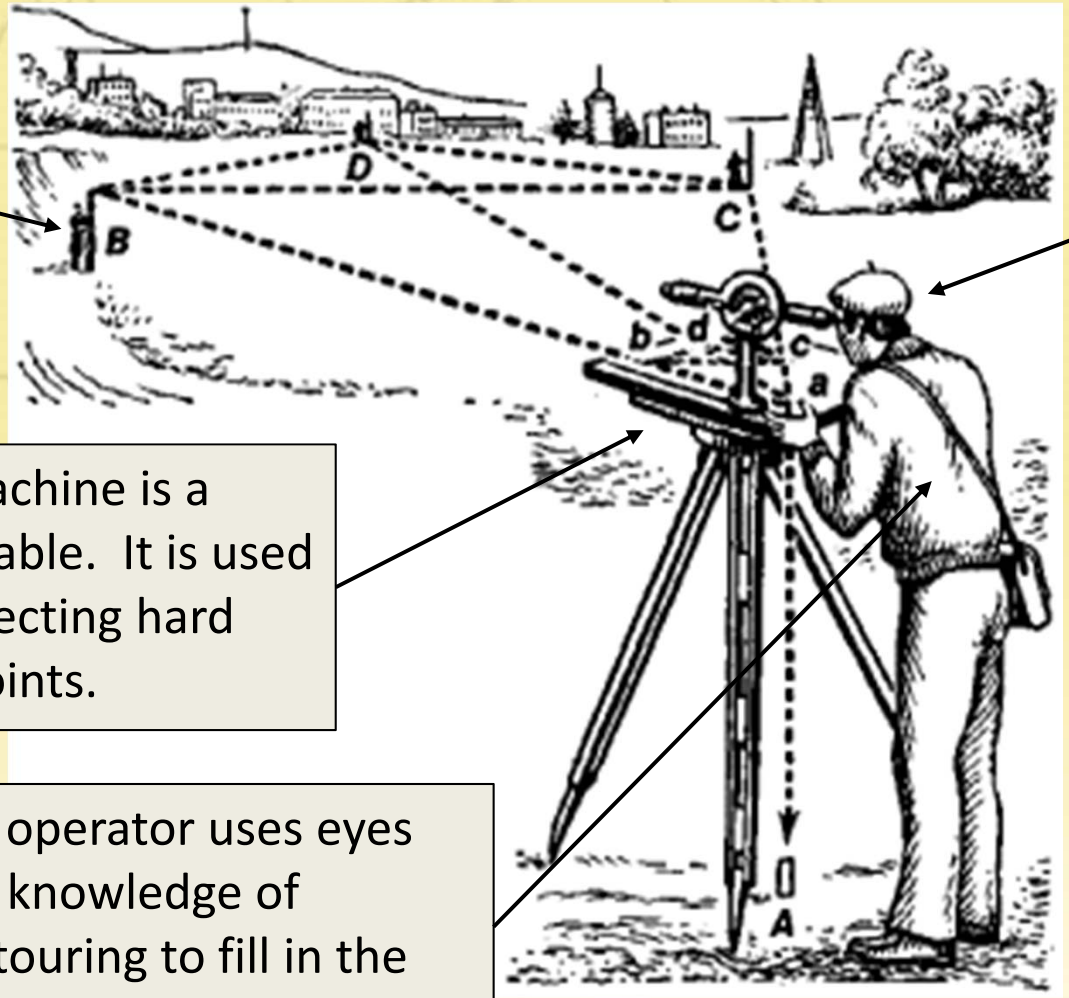
Imperfect information

Sebastian Münster, 1540

www.learnnc.org

Improving the information

This guy uses eyes to watch out for snakes.



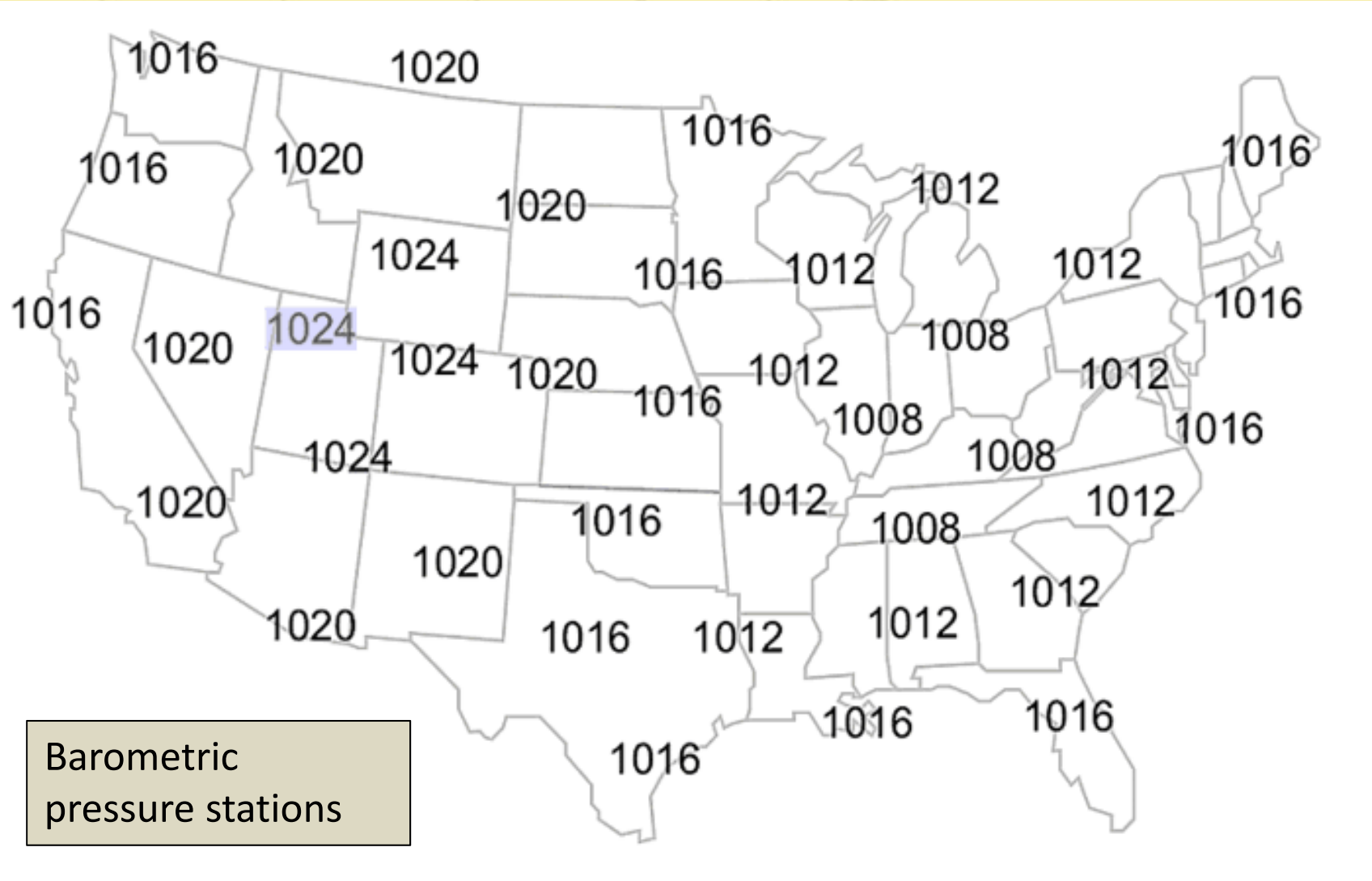
Not typical field attire.

This machine is a plane table. It is used for collecting hard data points.

The operator uses eyes and knowledge of contouring to fill in the space between.

thefreedictionary.com

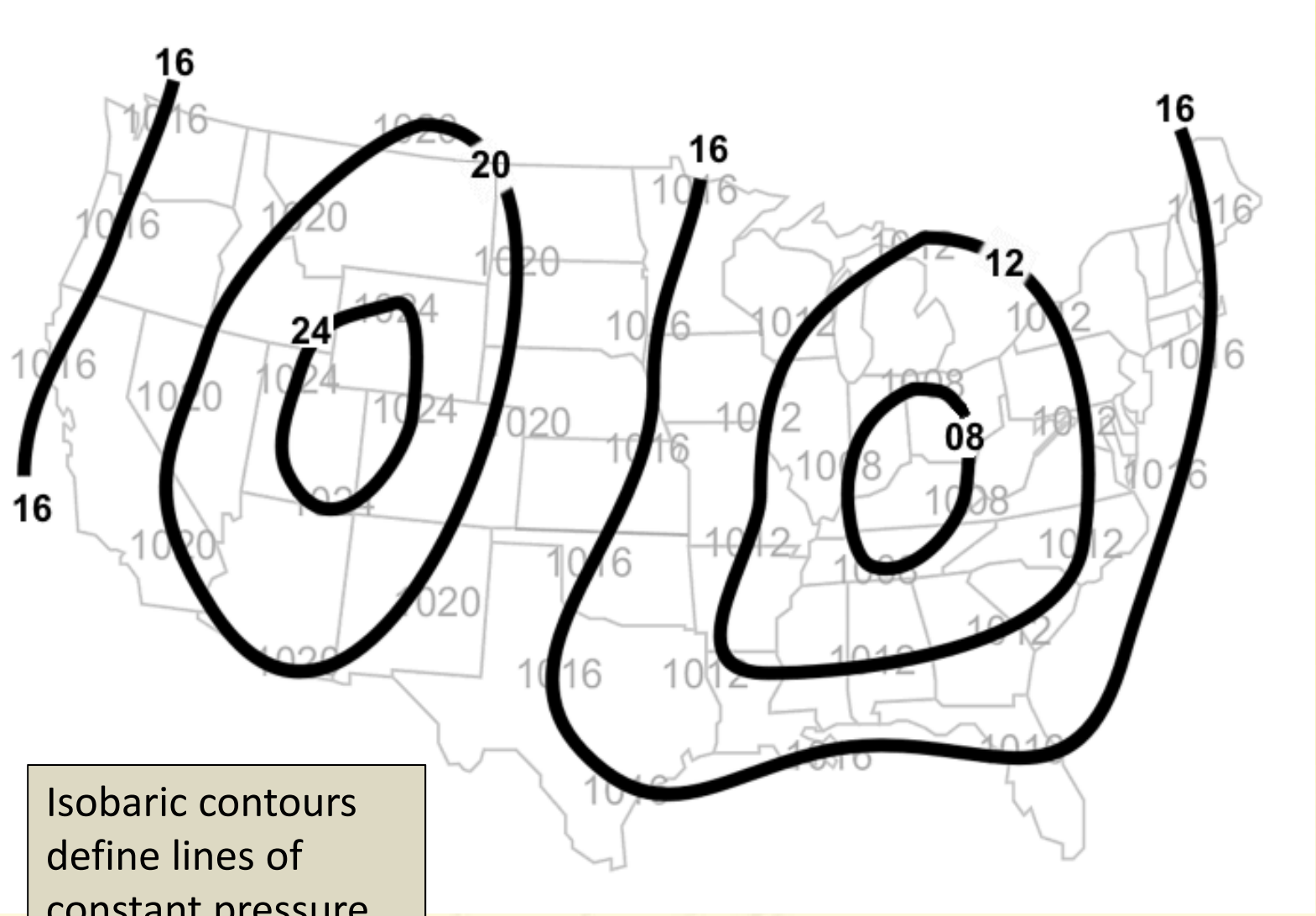
Discrete points of information



Barometric pressure stations

www.srh.noaa.gov

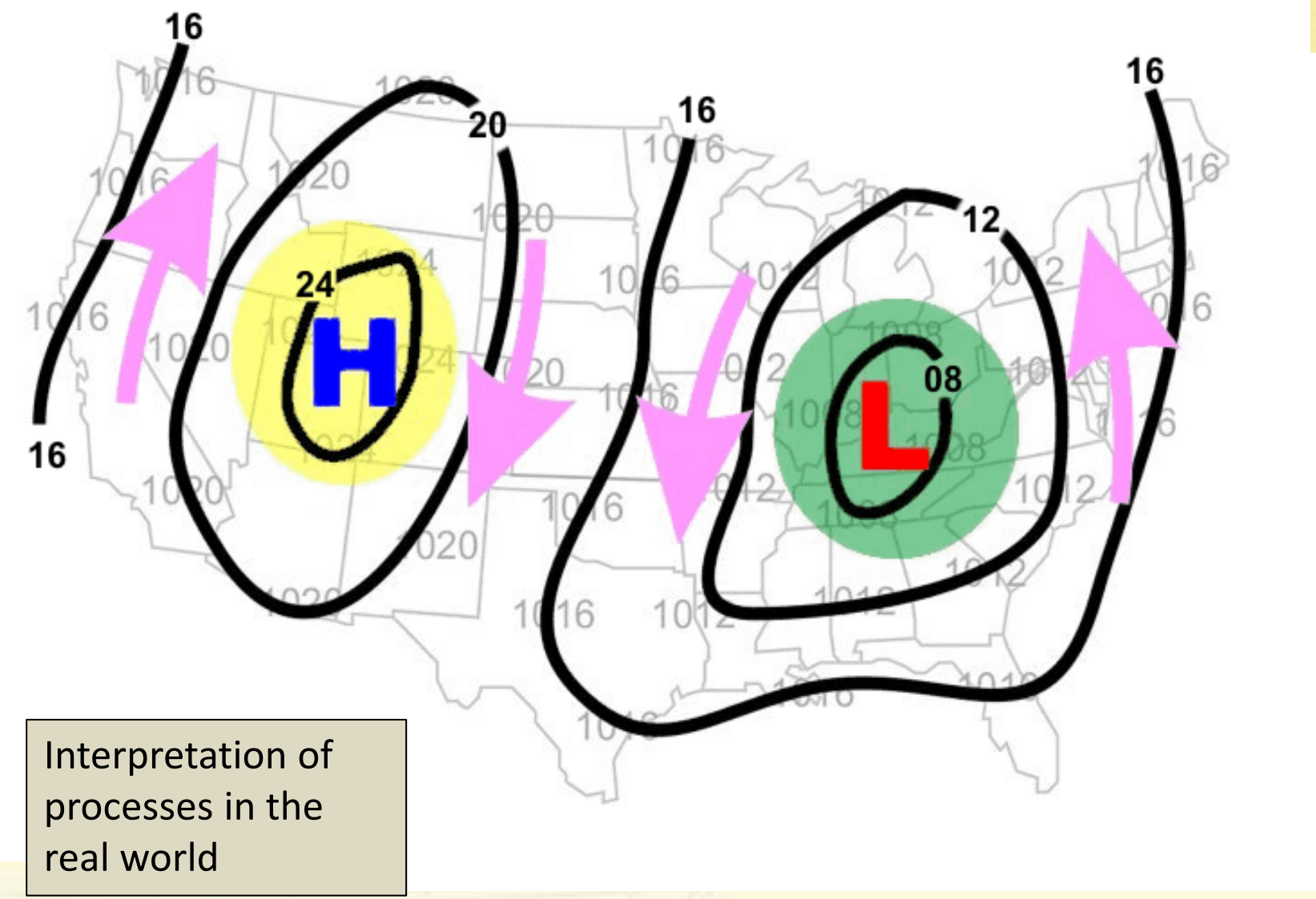
Continuous interpretation



Isobaric contours define lines of constant pressure

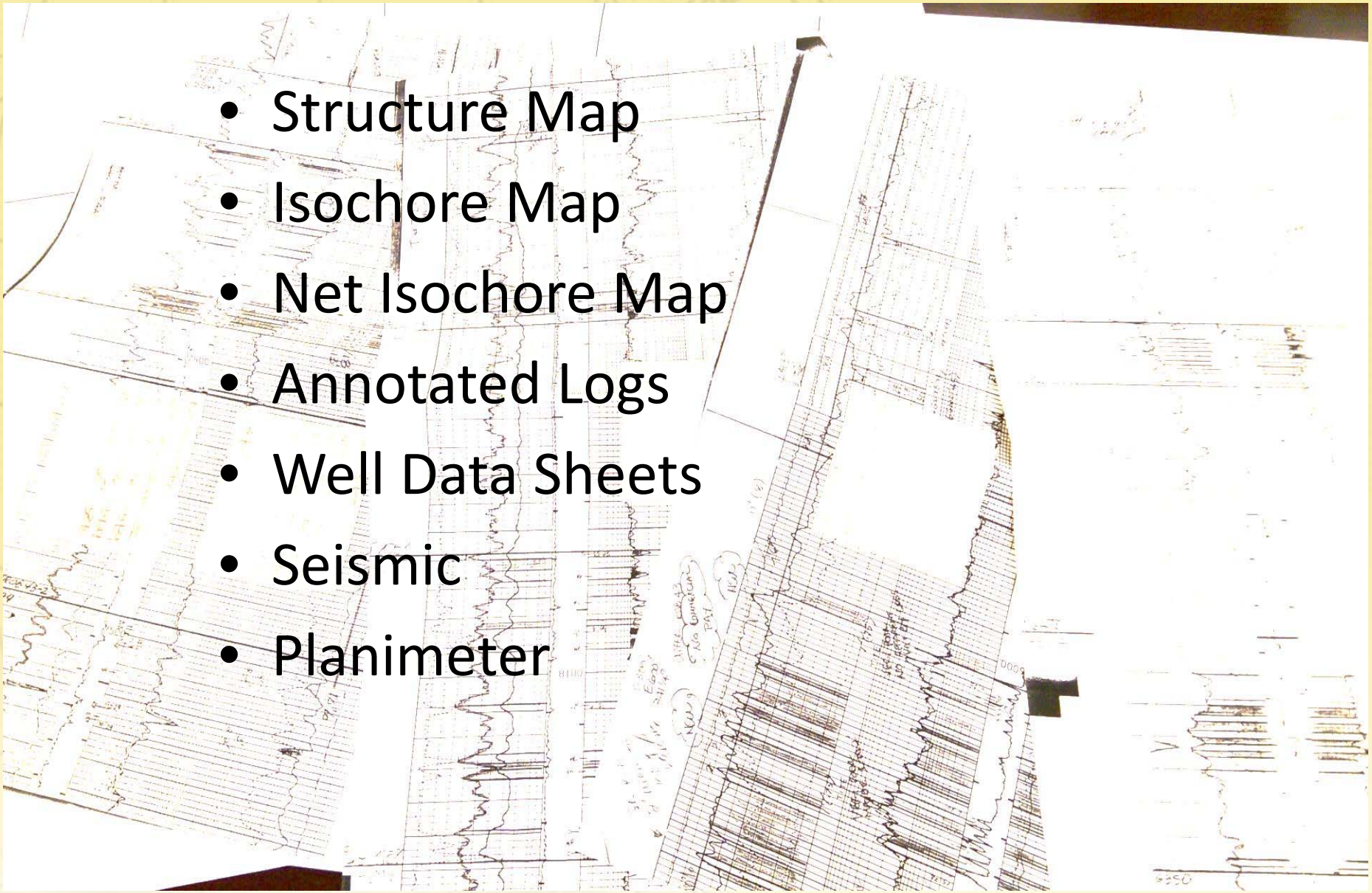
www.srh.noaa.gov

Useful (but imperfect) prediction



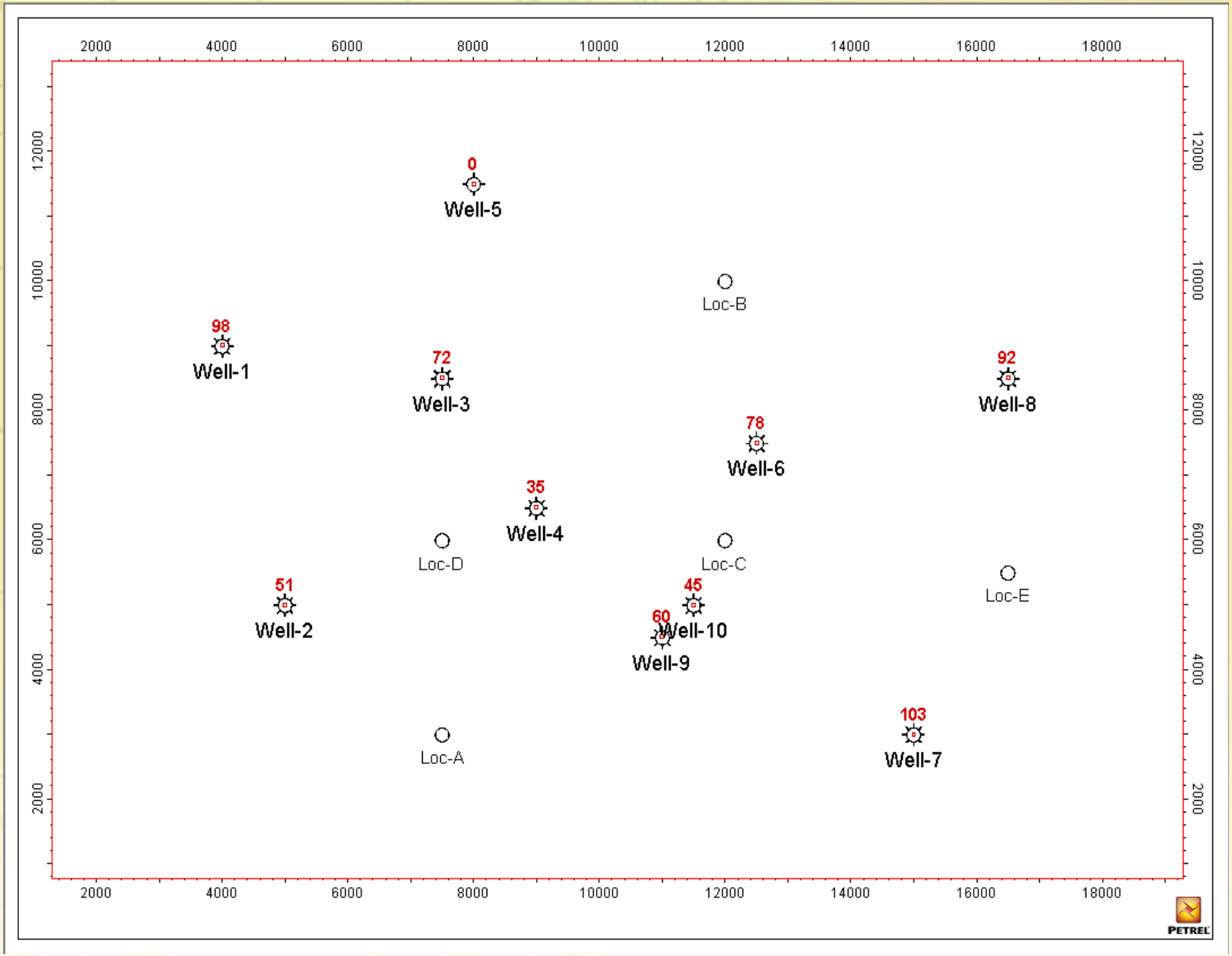
Interpretation of processes in the real world

Reservoir Mapping & Supporting Data

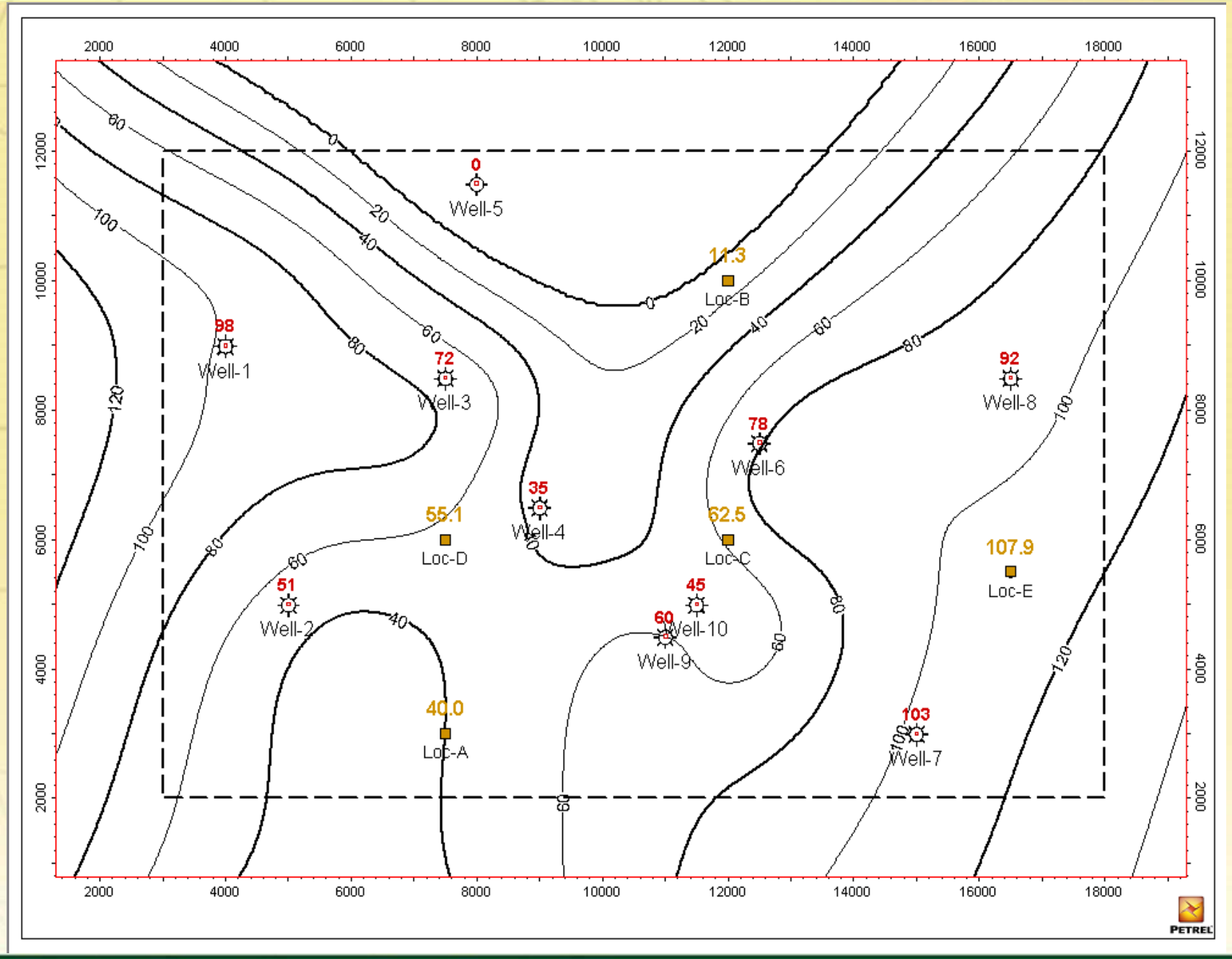


- Structure Map
- Isochore Map
- Net Isochore Map
- Annotated Logs
- Well Data Sheets
- Seismic
- Planimeter

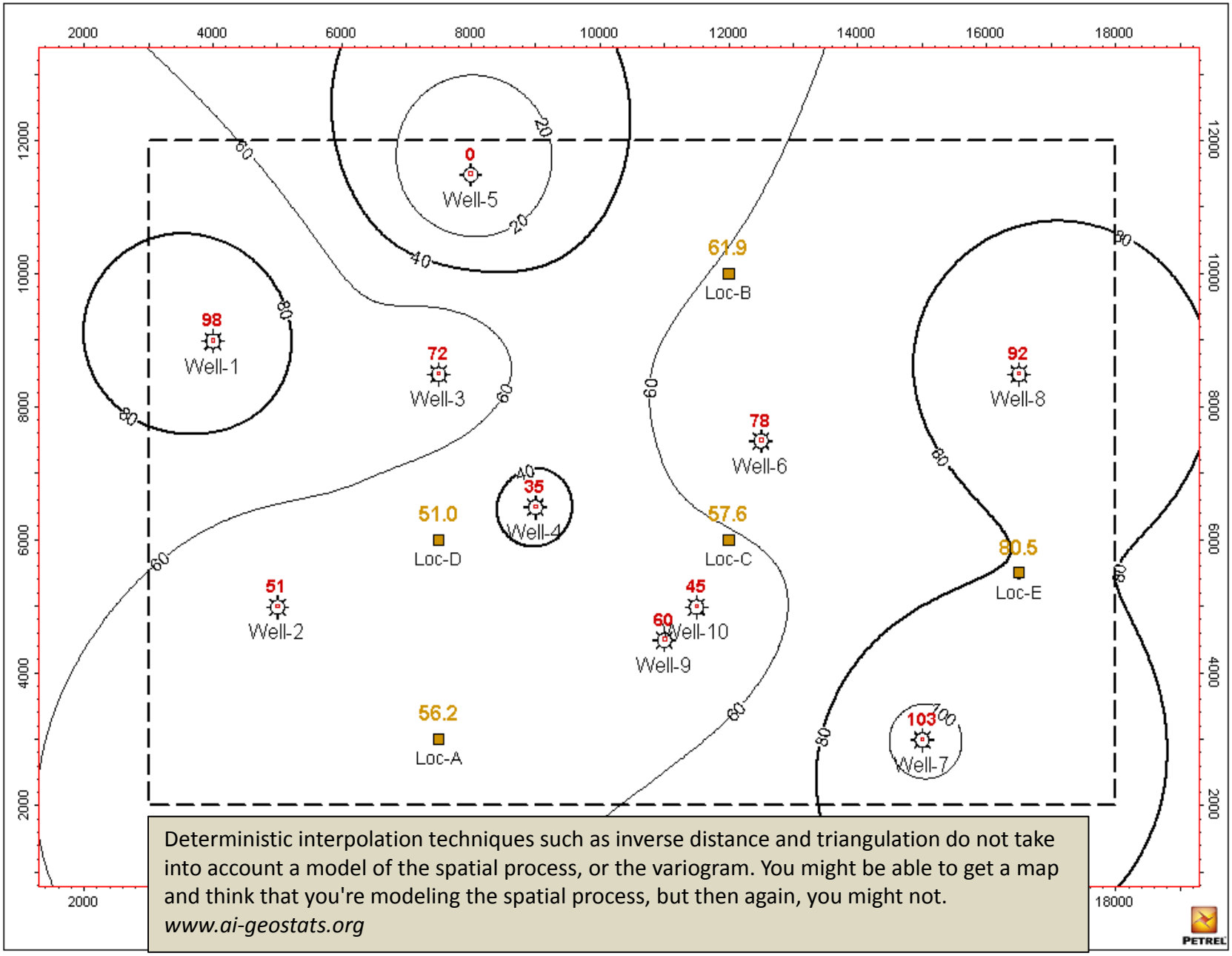
Exercise: Contour the well data, predict values at the undeveloped locations.



Isochore Interpolation (Default Settings)



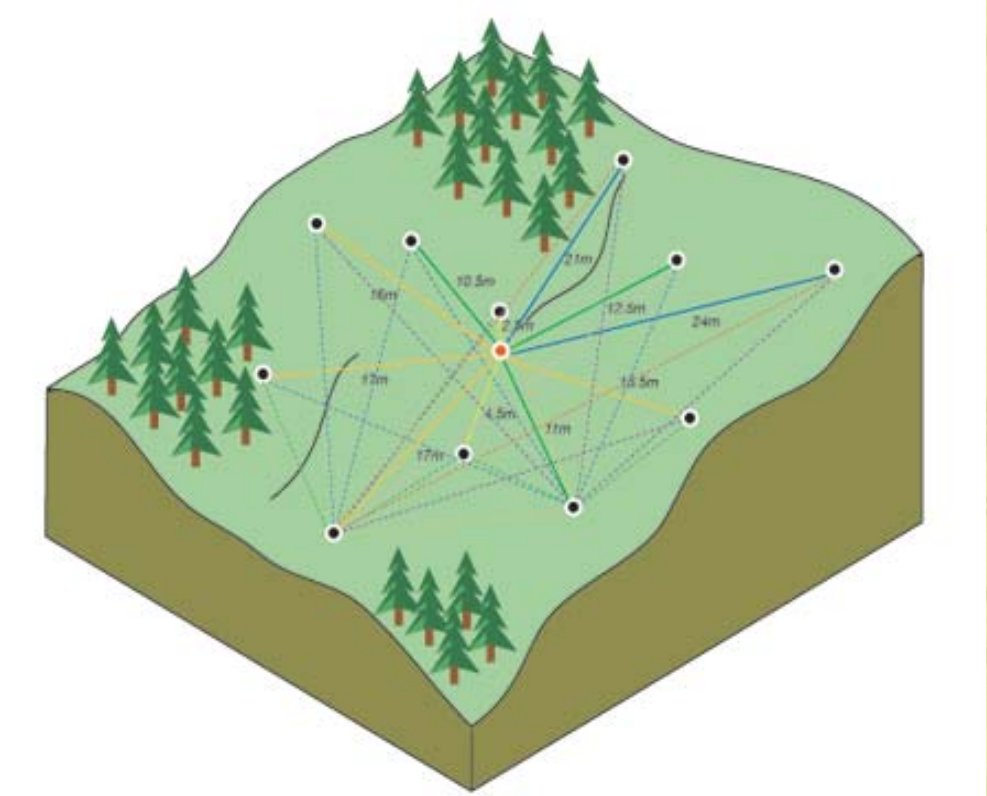
Moving Average (Inverse Distance Squared)



Deterministic interpolation techniques such as inverse distance and triangulation do not take into account a model of the spatial process, or the variogram. You might be able to get a map and think that you're modeling the spatial process, but then again, you might not.
www.ai-geostats.org

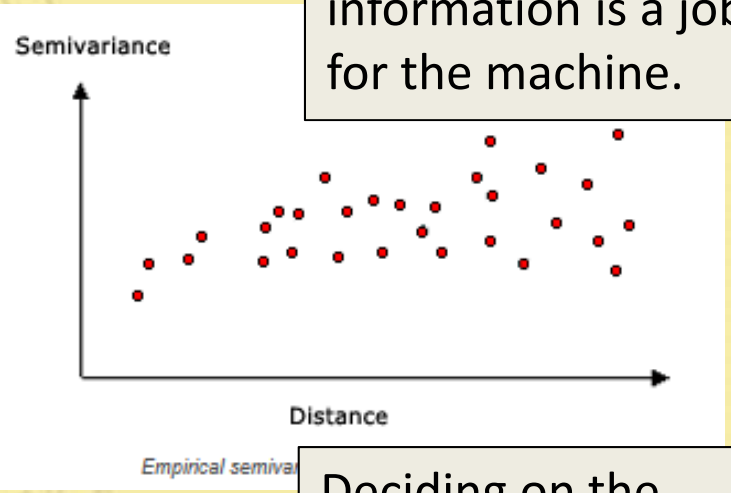
Geostatistical modeling of variability –

Filling in the map based on relationships in the data.



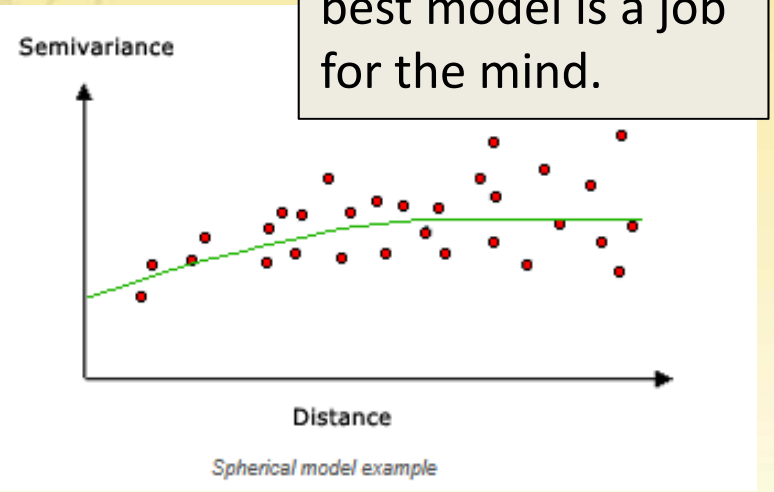
Calculating the difference squared between the paired locations

Accumulating this information is a job for the machine.



Empirical semivar

Deciding on the best model is a job for the mind.



Spherical model example

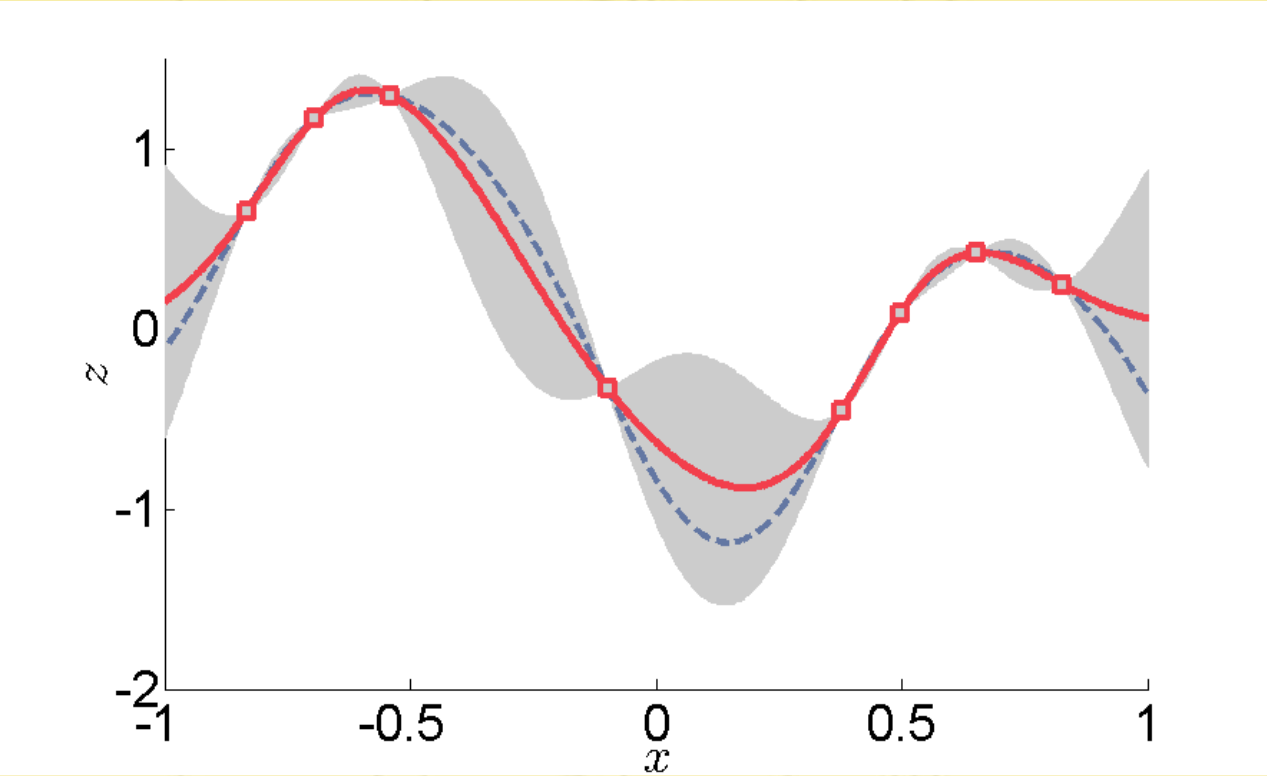
Fitting a model, or spatial modeling, is also known as structural analysis, or variography. In spatial modeling of the structure of the measured points, you begin with a graph of the empirical semivariogram, computed with the following equation for all pairs of locations separated by distance h:

Semivariogram(distance$_h$) = 0.5 * average((value$_i$ – value$_j$)^2)

http://resources.arcgis.com

Kriging -

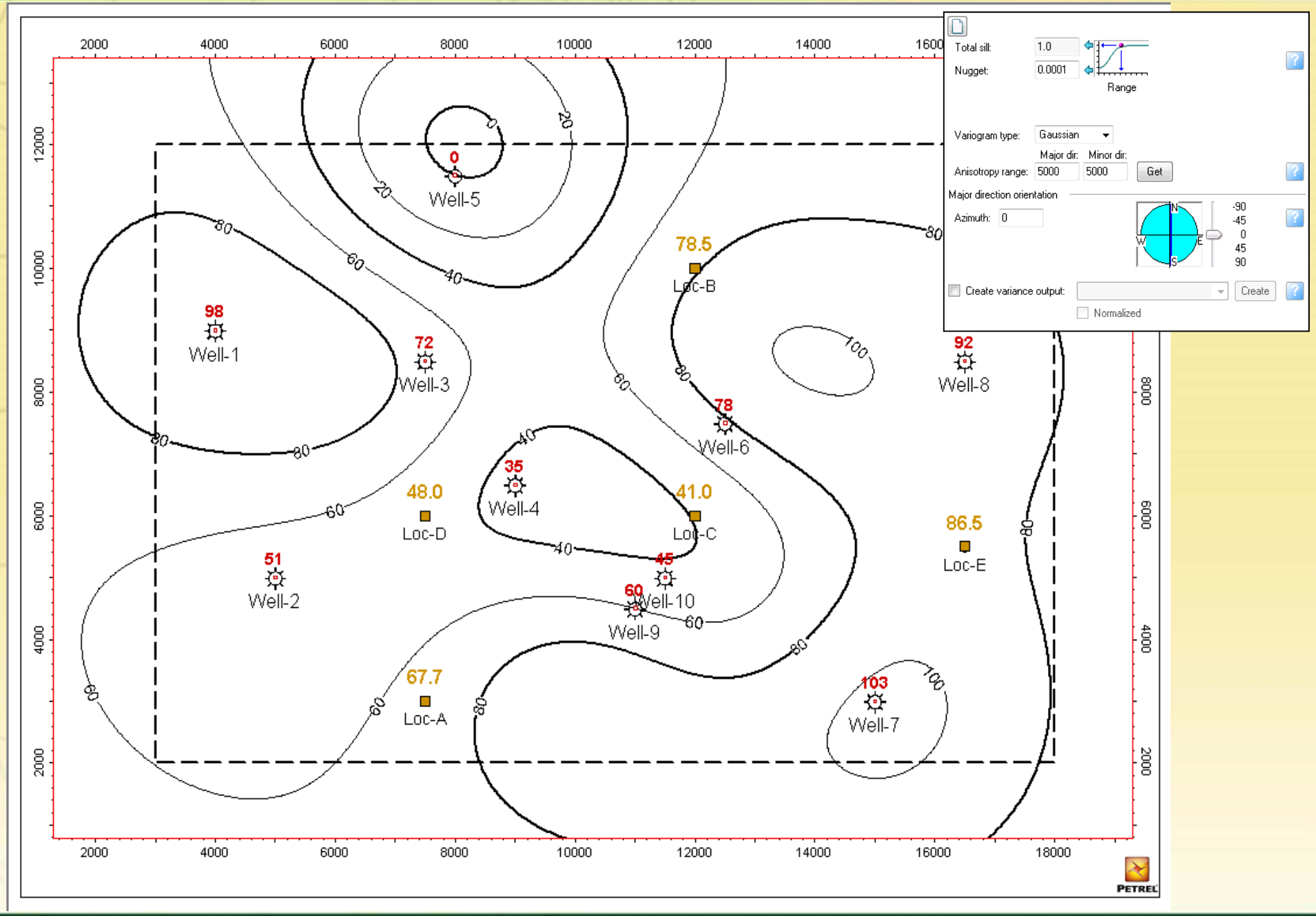
Prediction of values between known data points based on the mean of normally distributed ranges of possible results.



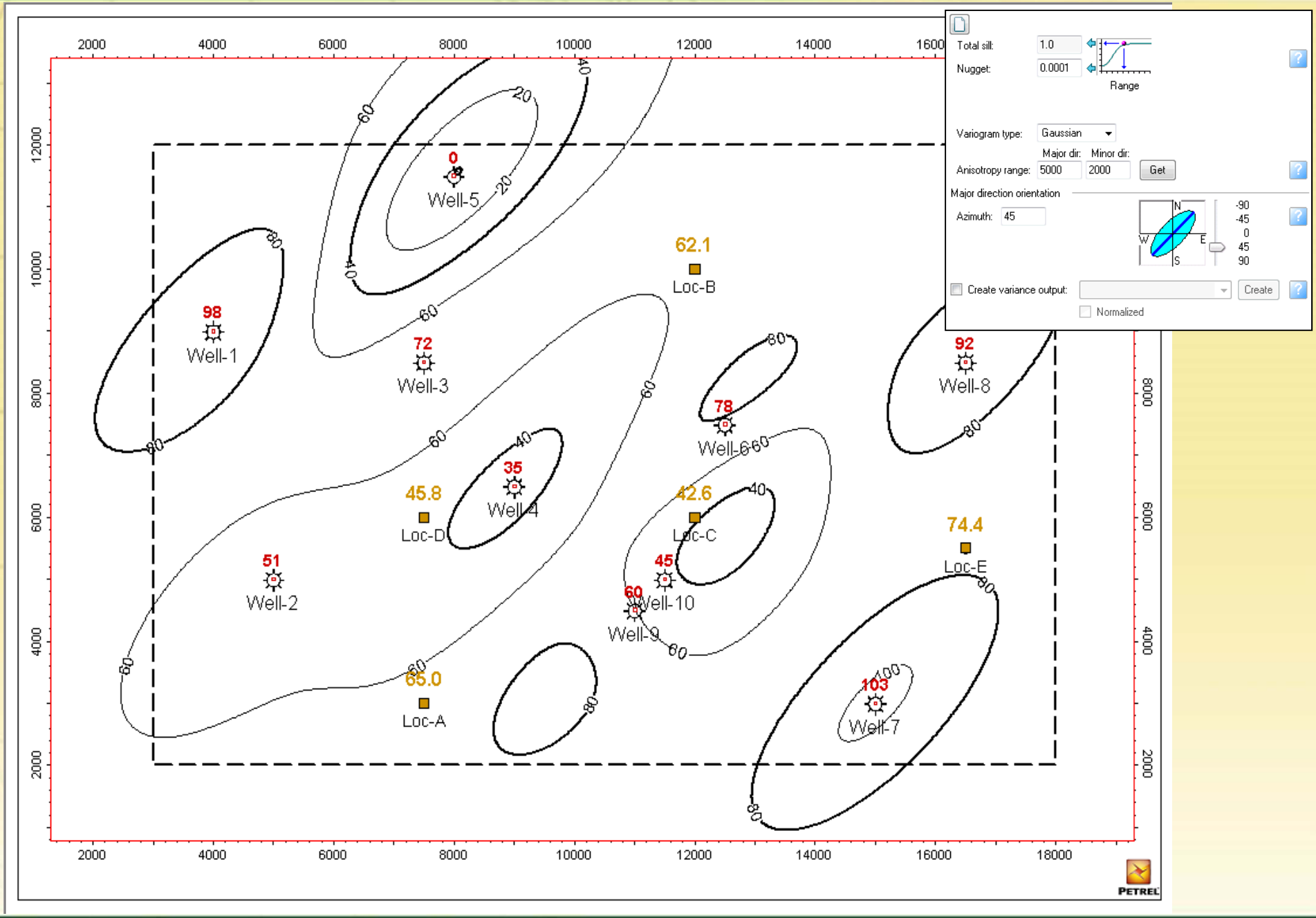
https://en.wikipedia.org/wiki/File:Example_of_kriging_interpolation_in_1D.png

Kriging is a geostatistical estimation technique. It uses a linear combination of surrounding sampled values to make such predictions. To make such predictions, we need to know the weights applied to each surrounding sampled data. Kriging attempts to: (a) minimize the error variance; and (b) systematically set the mean of the prediction errors to zero, so that there are no over- or under-estimates.
www.ai-geostats.org

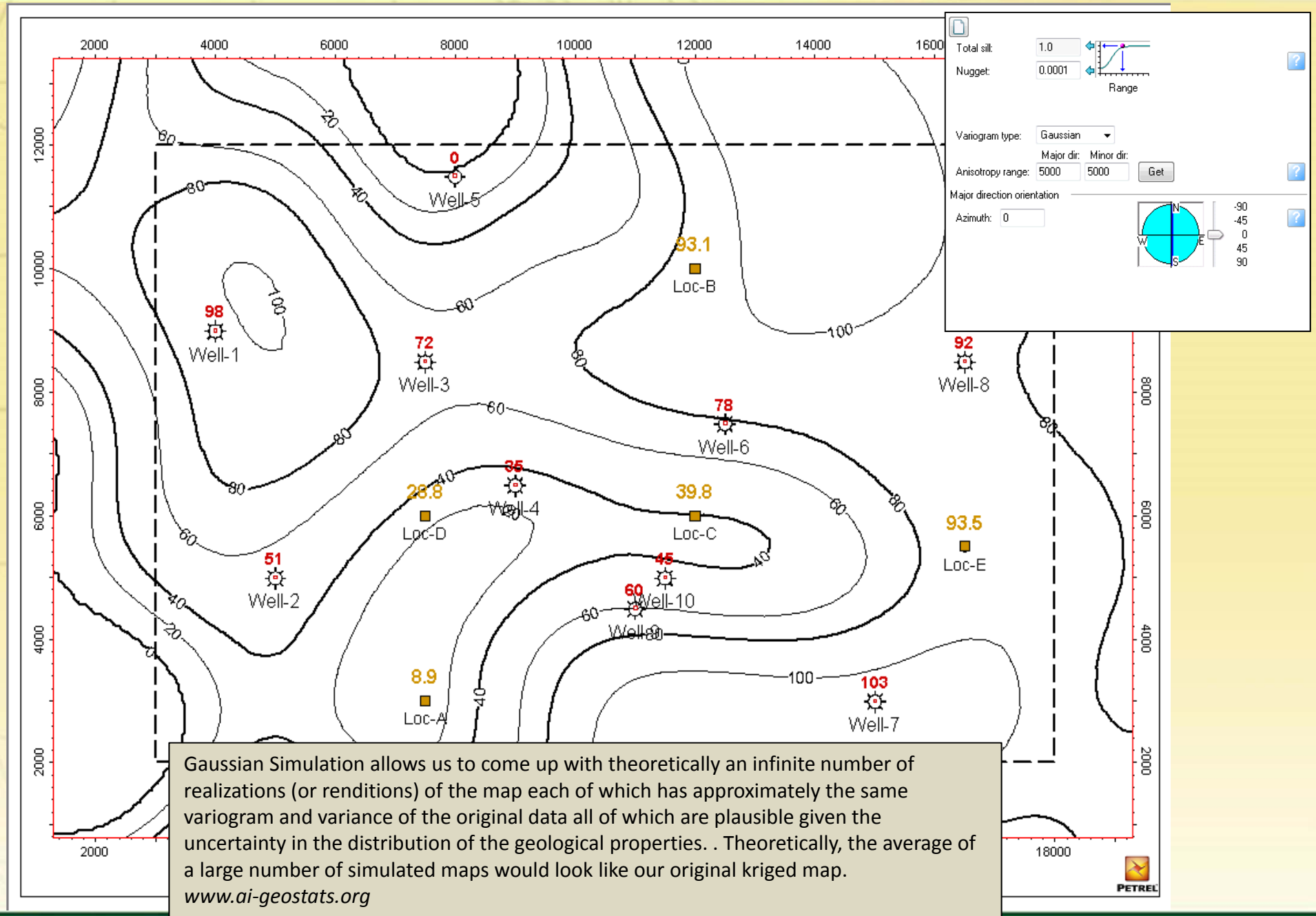
Kriging1


Total sill: 1.0
Nugget: 0.0001
Range
Variogram type: Gaussian
Major dir: Minor dir:
Anisotropy range: 5000 5000 Get
Major direction orientation
Azimuth: 0
-90
-45
0
45
90
Create variance output: Create
Normalized
Well-1 98
Well-2 51
Well-3 72
Well-4 35
Well-5 0
Well-6 78
Well-7 103
Well-8 92
Well-9 60
Well-10 45
Loc-A 67.7
Loc-B 78.5
Loc-C 41.0
Loc-D 48.0
Loc-E 86.5
PETREL

Kriging2

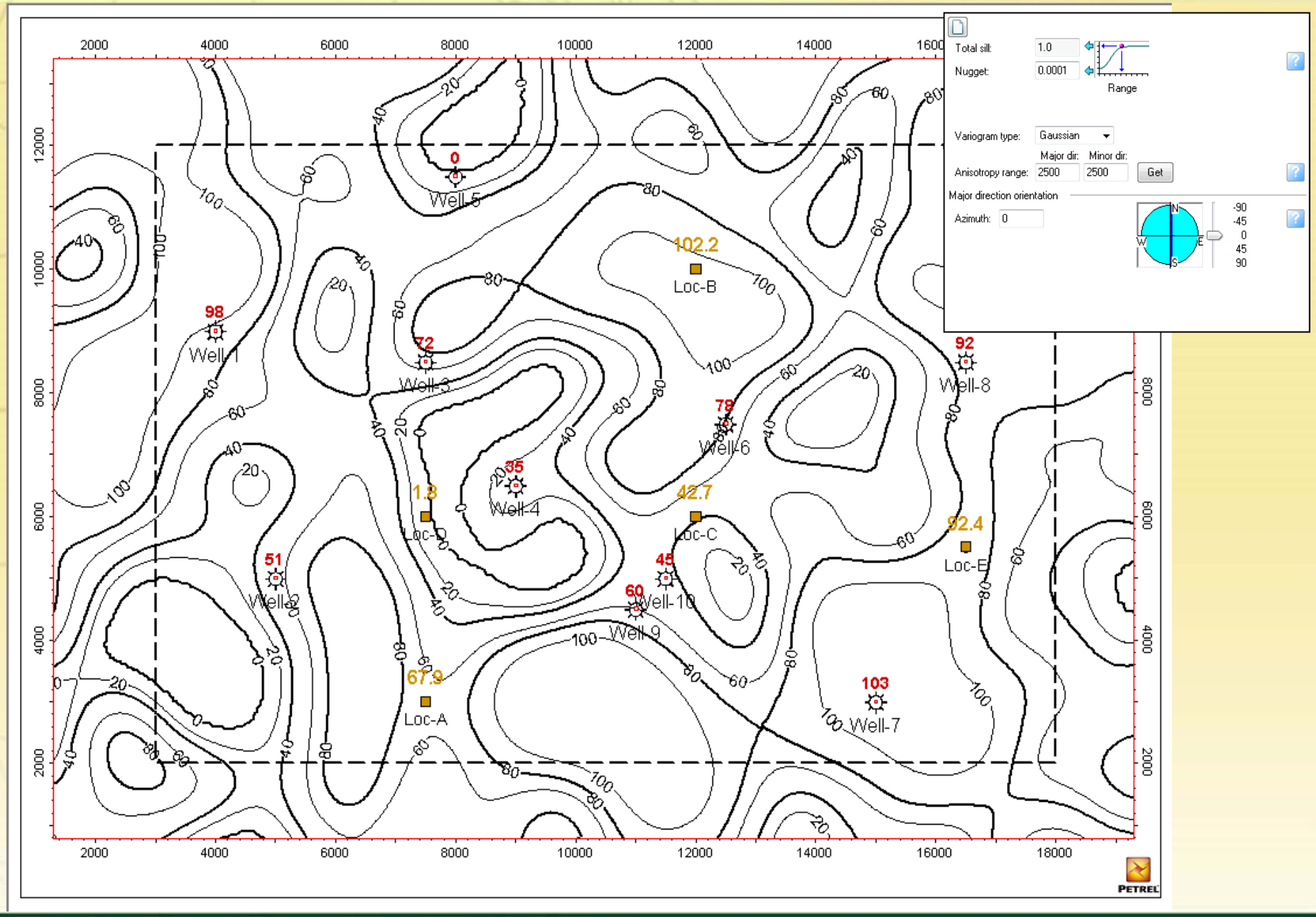

Total sill: 1.0
Nugget: 0.0001
Range
Variogram type: Gaussian
Major dir: Minor dir:
Anisotropy range: 5000 2000 Get
Major direction orientation
Azimuth: 45
N
E
S
W
-90
-45
0
45
90
Create variance output:
Create
Normalized
Well-1 98
Well-2 51
Well-3 72
Well-4 35
Well-5 0
Well-6 78
Well-7 103
Well-8 92
Well-9 60
Well-10 45
Loc-A 65.0
Loc-B 62.1
Loc-C 42.6
Loc-D 45.8
Loc-E 74.4
PETREL

Gaussian1

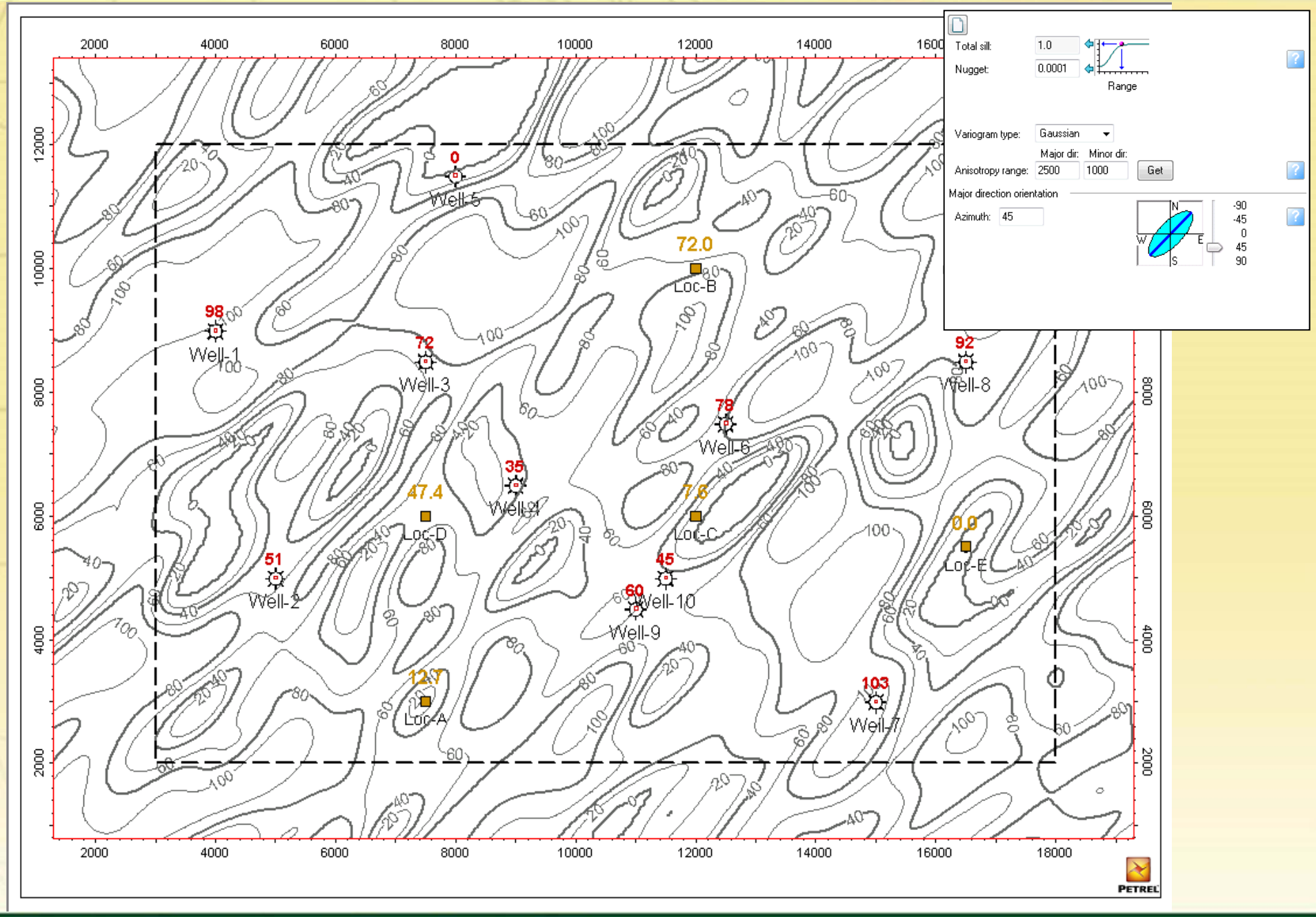


Gaussian Simulation allows us to come up with theoretically an infinite number of realizations (or renditions) of the map each of which has approximately the same variogram and variance of the original data all of which are plausible given the uncertainty in the distribution of the geological properties. . Theoretically, the average of a large number of simulated maps would look like our original kriged map.
www.ai-geostats.org

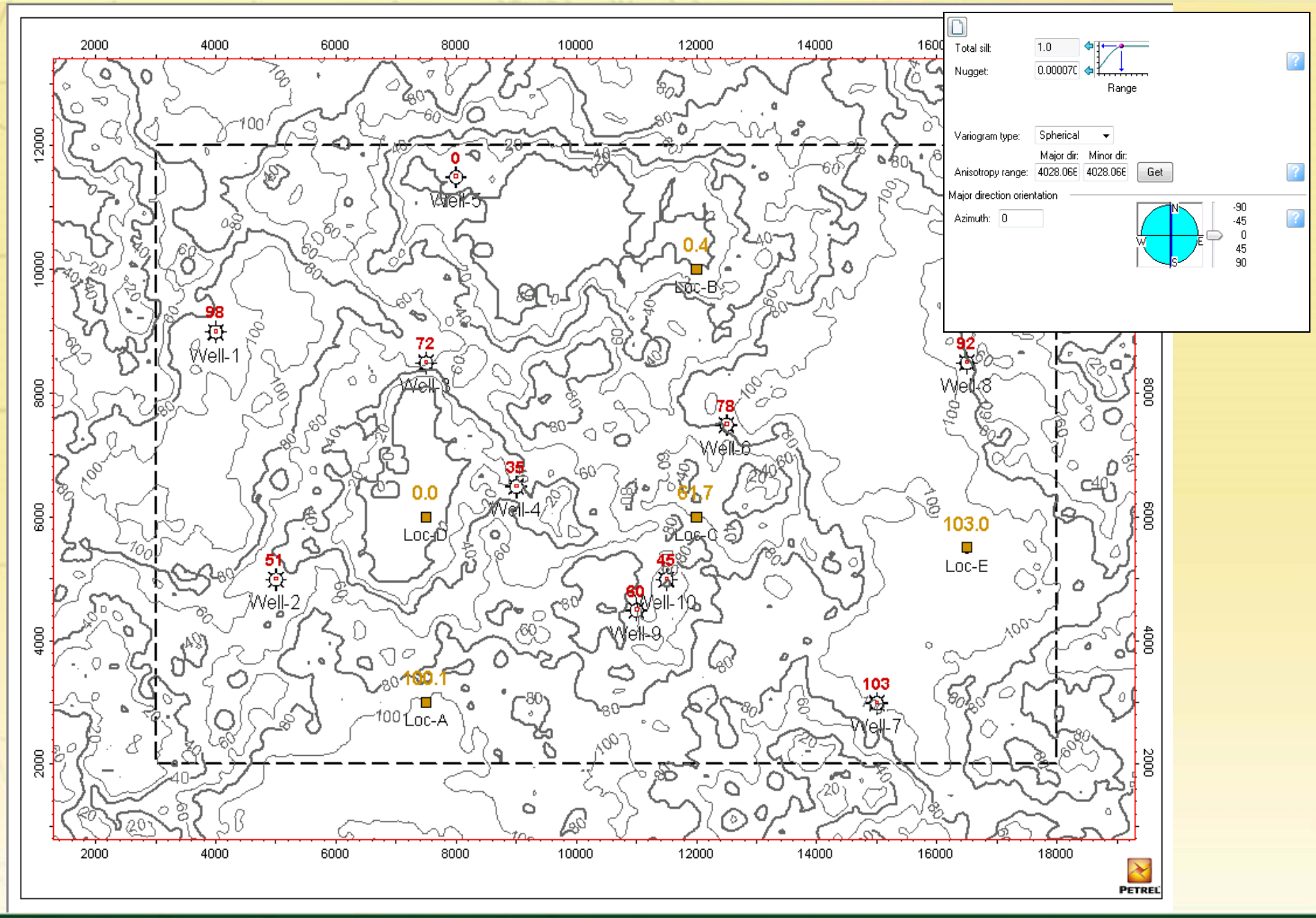
Gaussian2


Total sill: 1.0
Nugget: 0.0001
Range
Variogram type: Gaussian
Major dir: Minor dir:
Anisotropy range: 2500 2500 Get
Major direction orientation
Azimuth: 0
N
E
S
W
-90
-45
0
45
90
Well-1
Well-2
Well-3
Well-4
Well-5
Well-6
Well-7
Well-8
Well-9
Well-10
Loc-A
Loc-B
Loc-C
Loc-D
Loc-E
98
51
72
35
0
78
92
60
45
103
67.9
102.2
42.7
1.8
92.4
PETREL

Gaussian3


Total sill: 1.0
Nugget: 0.0001
Range
Variogram type: Gaussian
Major dir: Minor dir:
Anisotropy range: 2500 1000 Get
Major direction orientation
Azimuth: 45
N
W
E
S
-90
-45
0
45
90
Well-1
Well-2
Well-3
Well-4
Well-5
Well-6
Well-7
Well-8
Well-9
Well-10
Loc-A
Loc-B
Loc-C
Loc-D
Loc-E
98
51
72
35
0
78
92
60
45
103
12.7
47.4
7.6
72.0
0.0
PETREL

Gaussian4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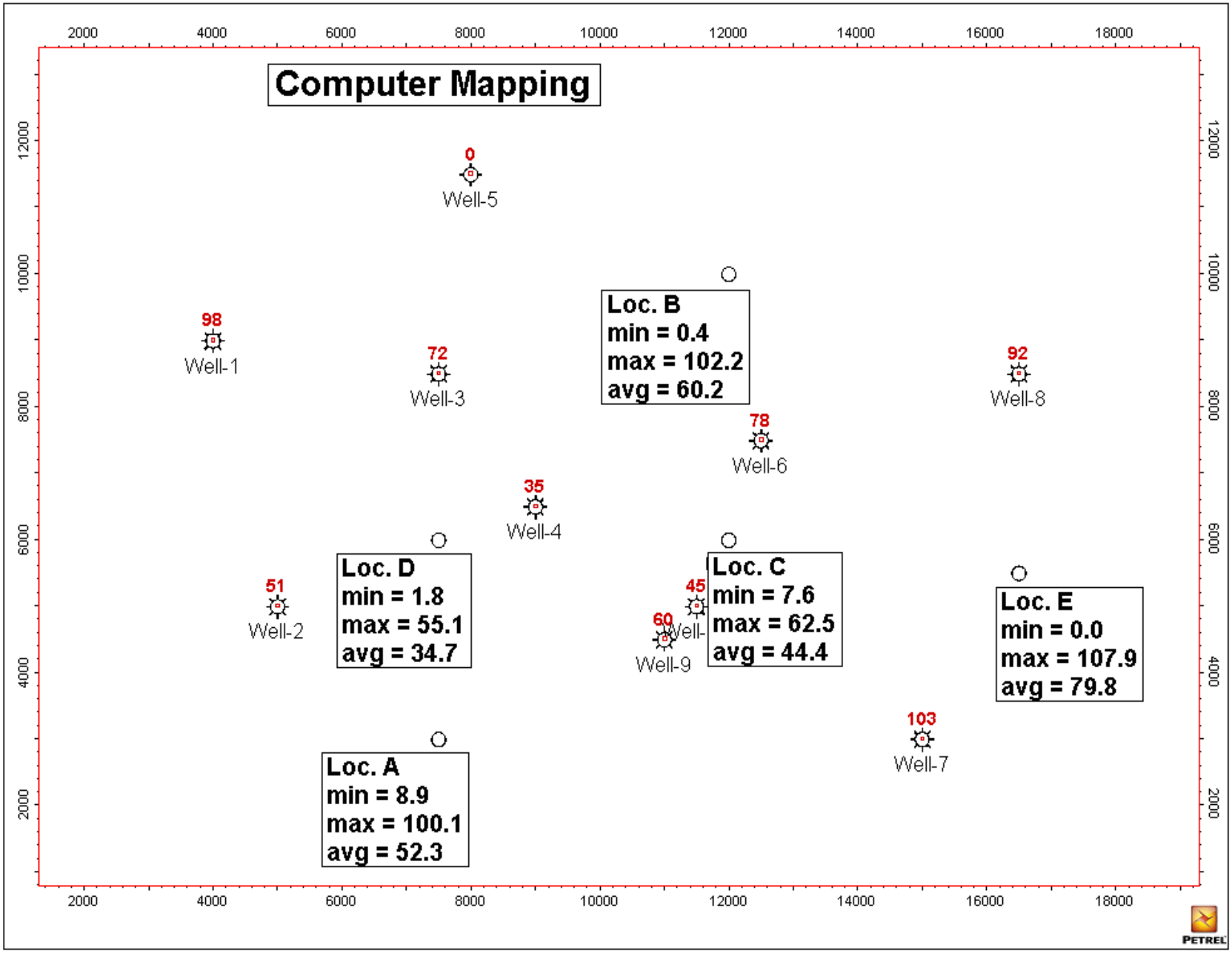
Nugget: 0.00007
Range
Variogram type: Spherical
Major dir: Minor dir:
Anisotropy range: 4028.06 4028.06 Get
Major direction orientation
Azimuth: 0
N
W
E
S
-90
-45
0
45
90
Well-1
Well-2
Well-3
Well-4
Well-5
Well-6
Well-7
Well-8
Well-9
Well-10
Loc-A
Loc-B
Loc-C
Loc-D
Loc-E
PETREL

Comparison of Computer Algorithms

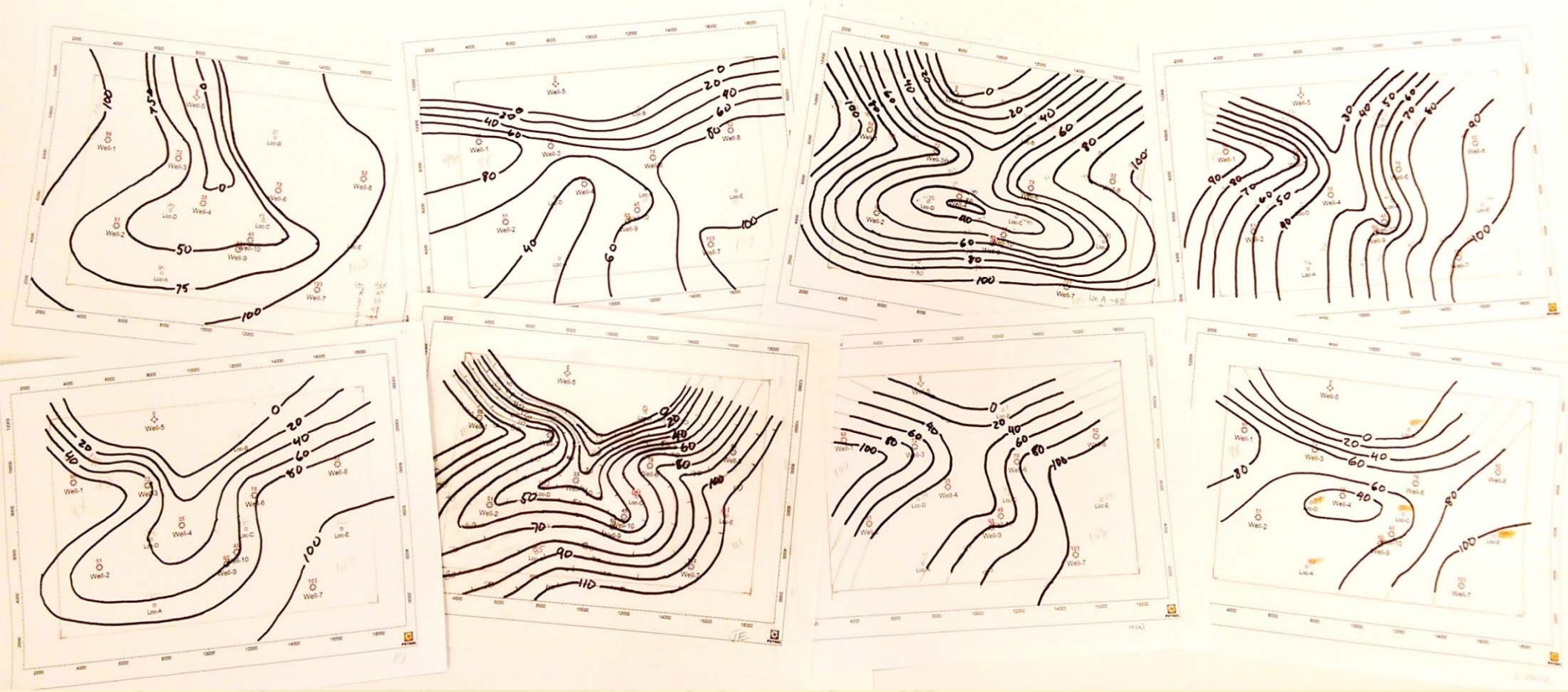


Comparison of computer algorithms

Loc Name	Isochore	Moving Avg	Kriging1	Kriging2	Gaussian1	Gaussian2	Gaussian3	Gaussian4	AVG	Delta
Loc-A	40.0	56.2	67.7	65.0	8.9	67.9	12.7	100.1	52.3	91.2
Loc-B	11.3	61.9	78.5	62.1	93.1	102.2	72.0	0.4	60.2	101.8
Loc-C	62.5	57.6	41.0	42.6	39.8	42.7	7.6	61.7	44.4	54.9
Loc-D	55.1	51.0	48.0	45.8	28.8	1.8	47.4	0.0	34.7	53.3
Loc-E	107.9	80.5	86.5	74.4	93.5	92.4	0.0	103.0	79.8	107.9
SUM	276.8	307.2	321.7	289.9	264.1	307.0	139.7	265.2		
AVG	55.4	61.4	64.3	58.0	52.8	61.4	27.9	53.0		
VOL in AOI (mm M3)	9,404.6	9,747.6	10,420.7	9,716.0	10,537.5	9,597.0	9,497.7	9,969.0	**9861.2**	
Percent of AVG	95%	99%	106%	99%	107%	97%	96%	101%		

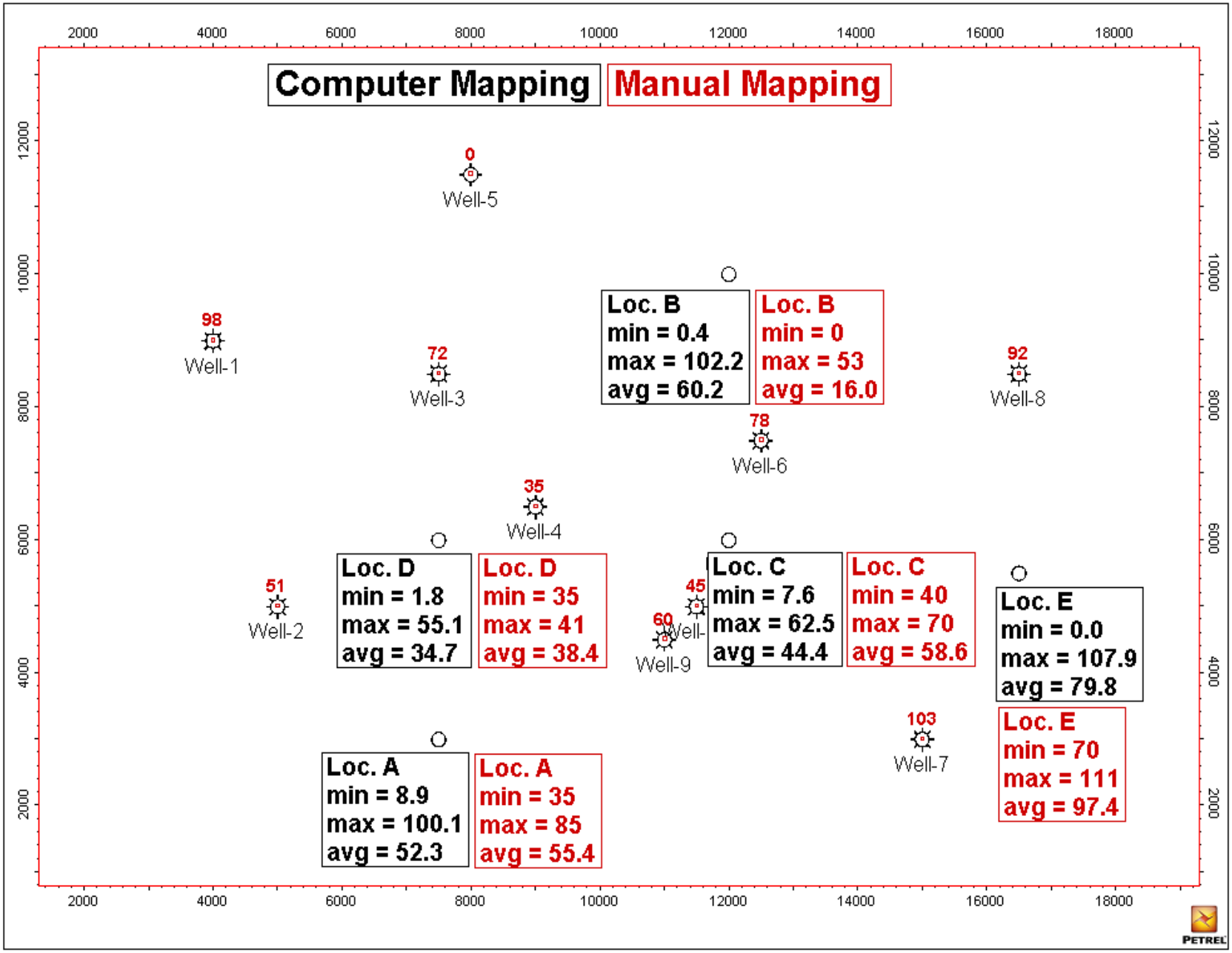
Predictions at specific locations ***do not*** correlate with overall volumetric outcome in this example. Weird.

Eight geologists walk into a bar….



With no other geological, regional, seismic, or other information to constrain the interpretation

Comparison: Computer vs. Manual



Comparison of geologist-drawn maps

Loc Name	Geo1	Geo2	Geo3	Geo4	Geo5	Geo6	Geo7	Geo8	AVG	Delta
Loc-A	80.0	36.0	37.0	50.0	65.0	85.0	35.0	60.0	56.0	50.0
Loc-B	50.0	53.0	9.0	0.0	0.0	0.0	0.0	80.0	24.0	53.0
Loc-C	40.0	59.0	58.0	54.0	70.0	69.0	60.0	48.0	57.3	30.0
Loc-D	35.0	41.0	38.0	35.0	39.0	40.0	41.0	40.0	38.6	6.0
Loc-E	70.0	94.0	105.0	101.0	103.0	111.0	98.0	100.0	97.8	41.0
SUM	275.0	283.0	247.0	240.0	277.0	305.0	234.0	328.0		
AVG	55.0	56.6	49.4	48.0	55.4	61.0	46.8	65.6		
VOL in AOI (mm M3)	9,625.0	9,304.9	8,537.5	8,292.0	8,444.0	8,956.5	7,707.0	10,443.4	8913.8	
Percent of AVG	108%	104%	96%	93%	95%	100%	86%	117%		

Predictions at specific locations ***do*** correlate with overall volumetric outcome in this example. Hmmm.

Comparison of geologist-drawn maps

Loc Name	Algorithms		Geologists	
	AVG	Delta	AVG	Delta
Loc-A	52.3	91.2	56.0	50.0
Loc-B	60.2	101.8	24.0	53.0
Loc-C	44.4	54.9	57.3	30.0
Loc-D	34.7	53.3	38.6	6.0
Loc-E	79.8	107.9	97.8	41.0
VOL in AOI	9861.2	1132.9	8913.8	2,736.4
Percent of AVG	95% to 107%		86% to 117%	

Geologist's maps are less variable predicting *thickness* at specific locations.

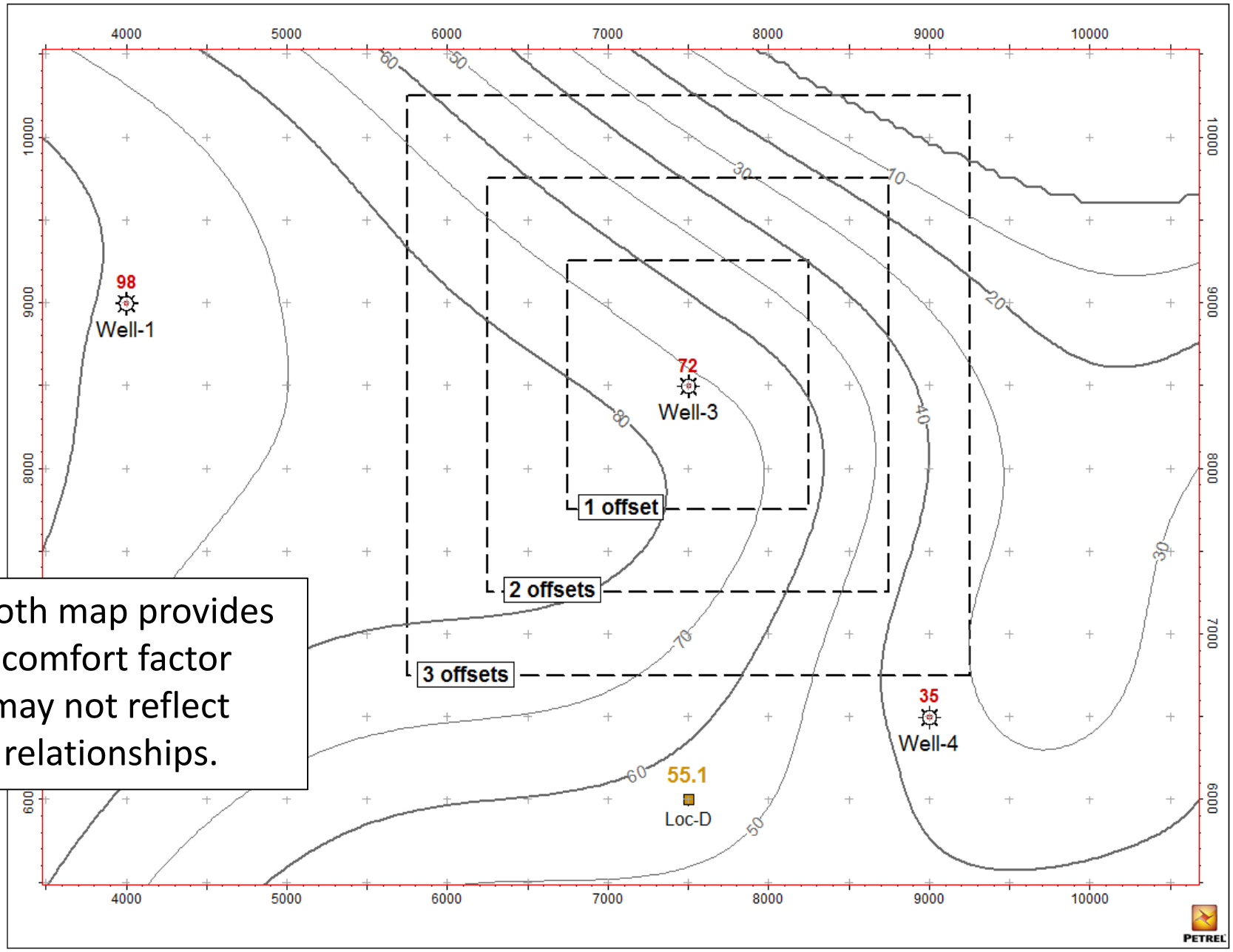
However, computer maps produce narrower range of *volumes* in AOI.

What's going on?

- Human mappers are basically good at *interpolating and extrapolating*. Can be biased by previous experience and other subjective factors. Many times this bias is appropriate.

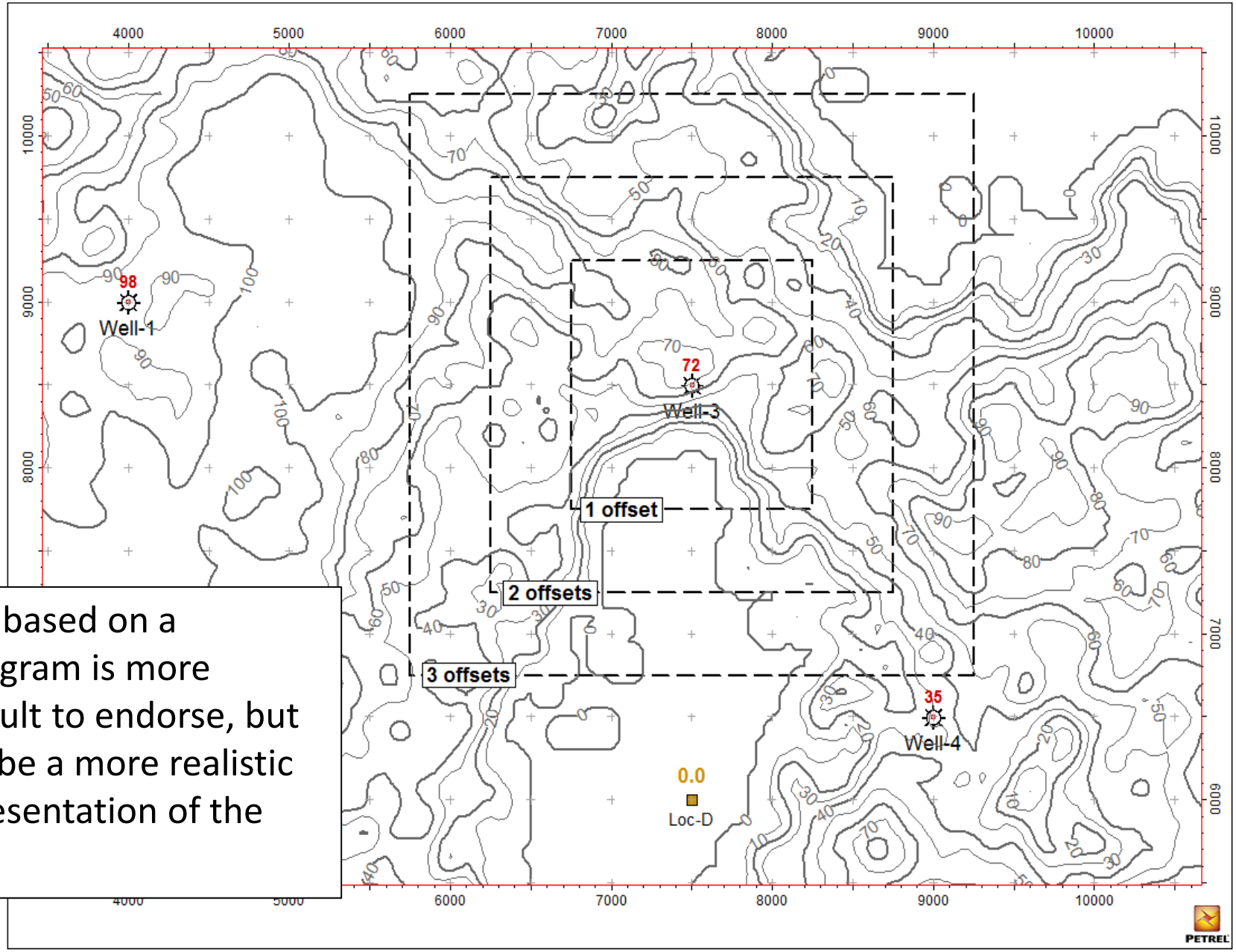
- Computer algorithms *attempt to model data relationships* and maintain these in non-data areas. They follow the rules they are given. No bias – not necessarily good.

Does map support reserves categories?



Smooth map provides high comfort factor but may not reflect data relationships.

Does map support reserves categories?



Map based on a variogram is more difficult to endorse, but may be a more realistic representation of the data.

Why maps are good (products of mind or machine)

- Hardcopy (and pdf) advantages: portable, durable, readable
- Can be self-explanatory
- Quick assessment of quality
- Illustrate degree of extrapolation/interpolation relative to data
- Help you tell your story with confidence

3D models, on the other hand…

- Exist only in the digital realm, requiring a computer with a visualization program to view
- Need considerable methodology documentation
- Quality is not readily evident by looking at it
- Difficult to appreciate how much of a model is composed of computed results vs. data
- Easy to lose your story in the complexity

Recommendations

- Data, data, data
- Location, location, location
- Be aware of the power and limitations of the mind and digital tools
- Remain open to alternative approaches before committing to a final outcome
- Be accountable for the geology

Will minds or machines prevail?

Hopefully, both

Hasta la vista, baby.