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A Three-Dimensional Geometric Model of the Bayou Choctaw Salt Dome, Southern Louisiana, Using 3-D Seismic Data

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NNSA National Nuclear Security Administration

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Topics

- Bayou Choctaw salt dome and SPR site
- The 3-D seismic survey
  - Collection and reprocessing
- Overview of the seismic data
- Modeling approach
  - 2-D interpretation
  - 3-D integration
- Visualization of the new model
  - Comparison to older models
  - Geometric Complexity → Interpretation
- Implications for underground storage

Bayou Choctaw Salt Dome and SPR Site

- The U.S. Department of Energy operates six (6) underground storage caverns for crude oil at the Bayou Choctaw salt dome, southwest of Baton Rouge, La.
- DOE owns 8 other inactive and/or abandoned caverns at the site

- Petrologistics Olefins LLC operates an additional 11 caverns in the same dome

This is a very intensely utilized salt mass

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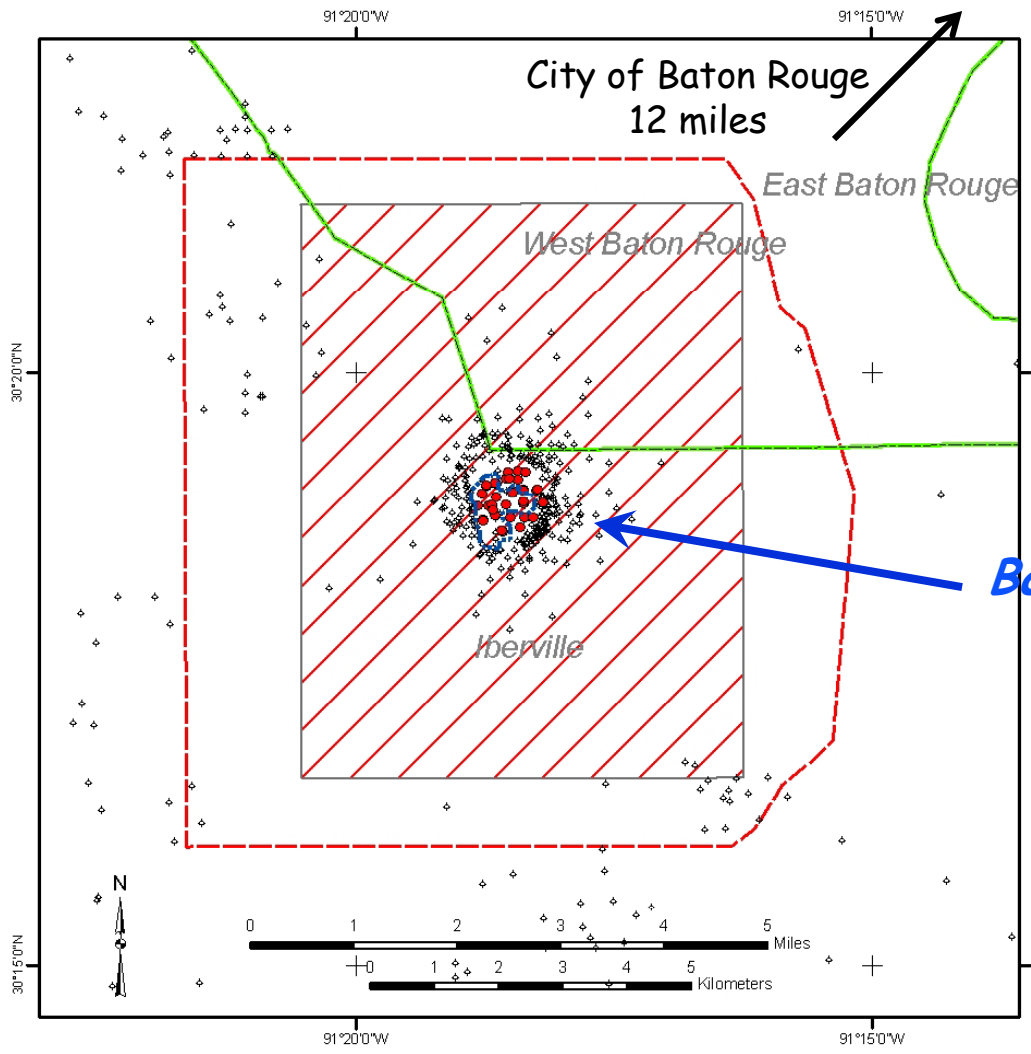
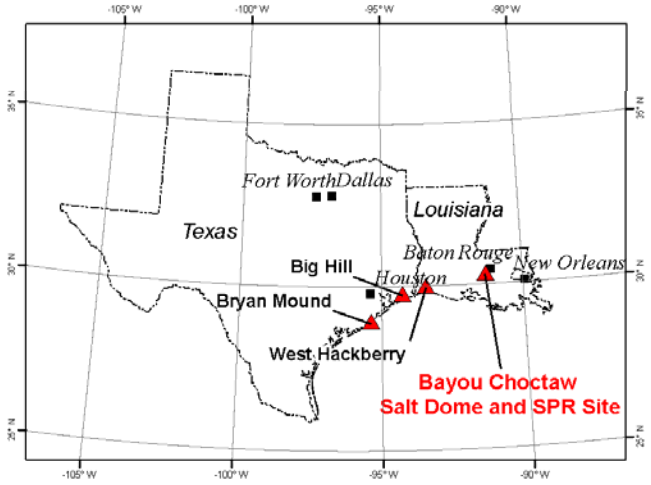
3-D Seismic Data

- **Total survey area: 40.2 sq.mi.**
- **Area licensed by Sandia: 23.7 sq.mi.**
  - **Seitel Data, Ltd.**
- **Shot: 1994, by Quantum Geophysical**
  - **Source: dynamite**
  - **Sample interval: 2 msec**
  - **Bin spacing: 82.5 ft**
  - **Nominal fold: 27**
- **Reprocessed record length: 4000 msec**
  - **Pre-stack time migration with deconvolution**

Seismic Survey at Bayou Choctaw





Bayou Choctaw Salt Dome and SPR Site

Explanation

- Oil or Gas Well
- 3-D Seismic Survey
  - Full Extent
  - Reprocessed by SPR
- Strategic Petroleum Reserve
  - Site Boundary
  - Storage Cavern
  - Parish Boundary

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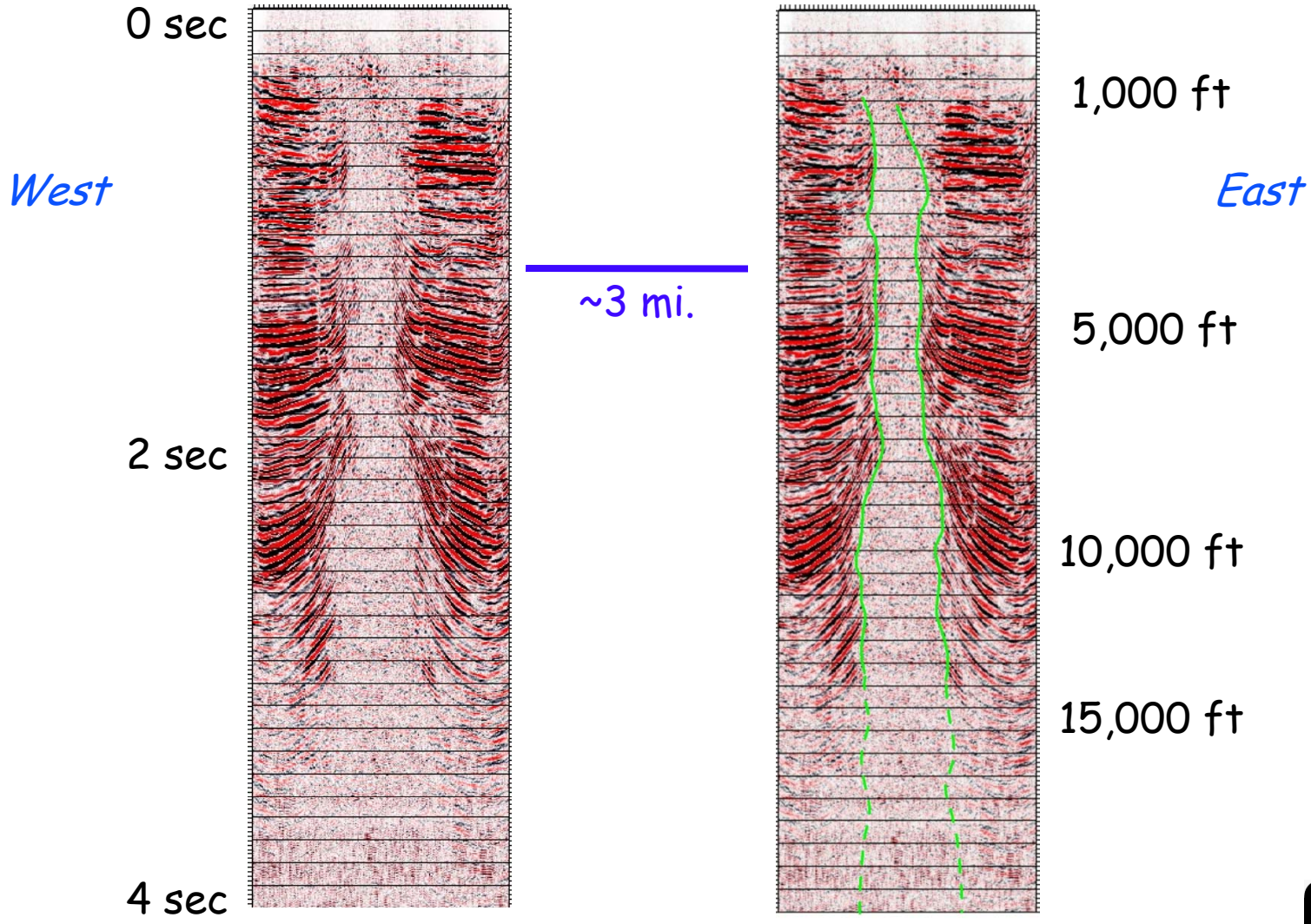
The Seismic Data

West-to-East Compressed Profile



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Impressions …

- **(**The shallow seismic data is very poor**)**
- **Bayou Choctaw salt dome is a narrow, pencil-like diapir**

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- **Salt flanks are *not* straight and smooth**
  - **There is significant variation of width with depth**
  - **Indicates likely older "overhang"**

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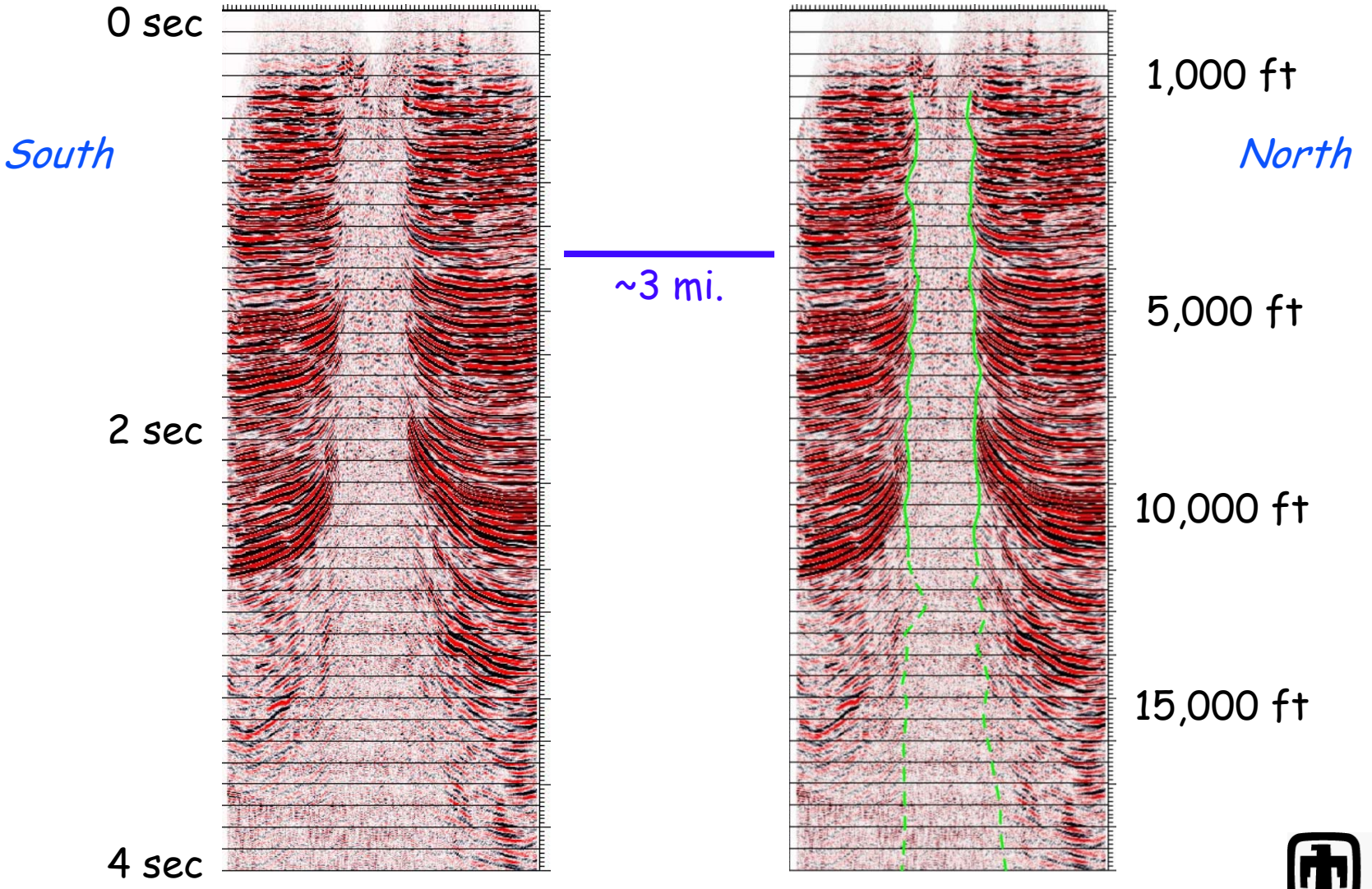
- Movement has been essentially vertical
- Salt flanks are *not* straight and smooth
  - There is significant variation of width with depth
  - Indicates likely older “overhang”
- **There are *numerous unconformities* in the sedimentary section up against the dome**
  - **Suggests topographic expression on the sea floor**
  - **Salt intrusion vs. sedimentary downbuilding**

The Seismic Data

South-to-North Compressed Profile



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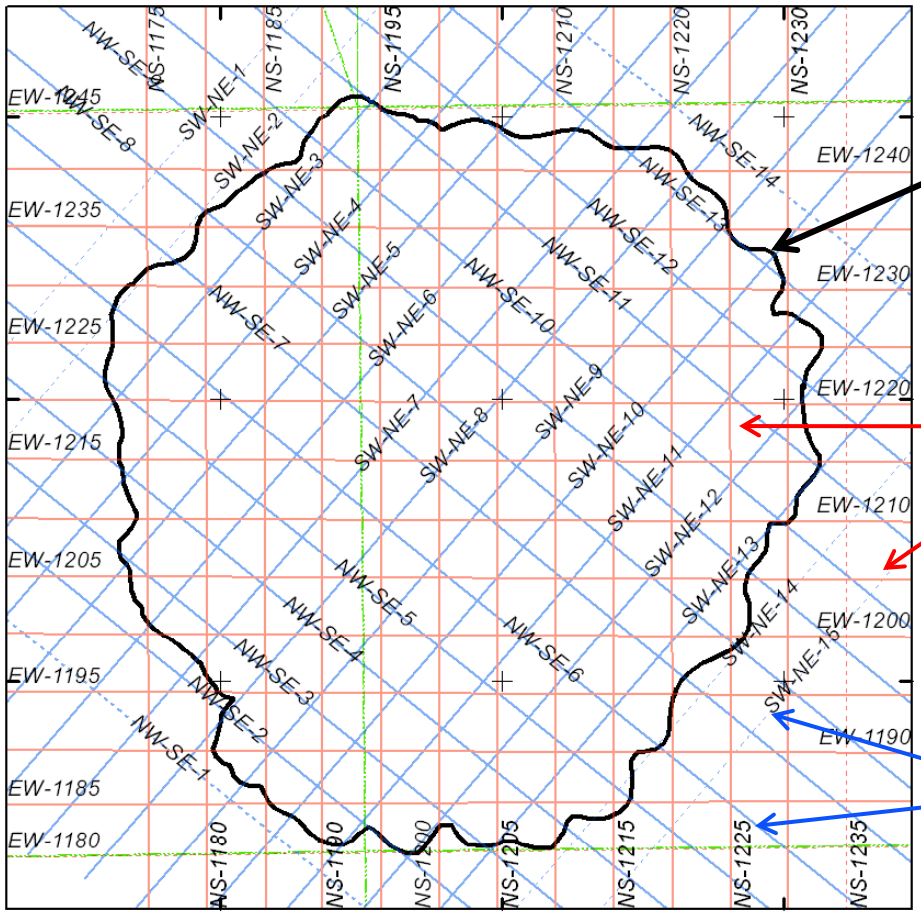
Modeling Approach (1)

- **Use a 2-D / 3-D combined manual / digital approach**
  - **Extract 2-D vertical profiles in four directions**
    - **Inline and cross-line**
    - **45-degree arbitrary lines to above**
  - **Basic interpretation of flanks on vertical profiles**

Modeling Approach:
Interpretation of Numerous 2-D Profiles



Maximum extent of salt

Inlines, Cross Lines (N-S, E-W)

Arbitrary Lines (SW-NE, NE-SW)

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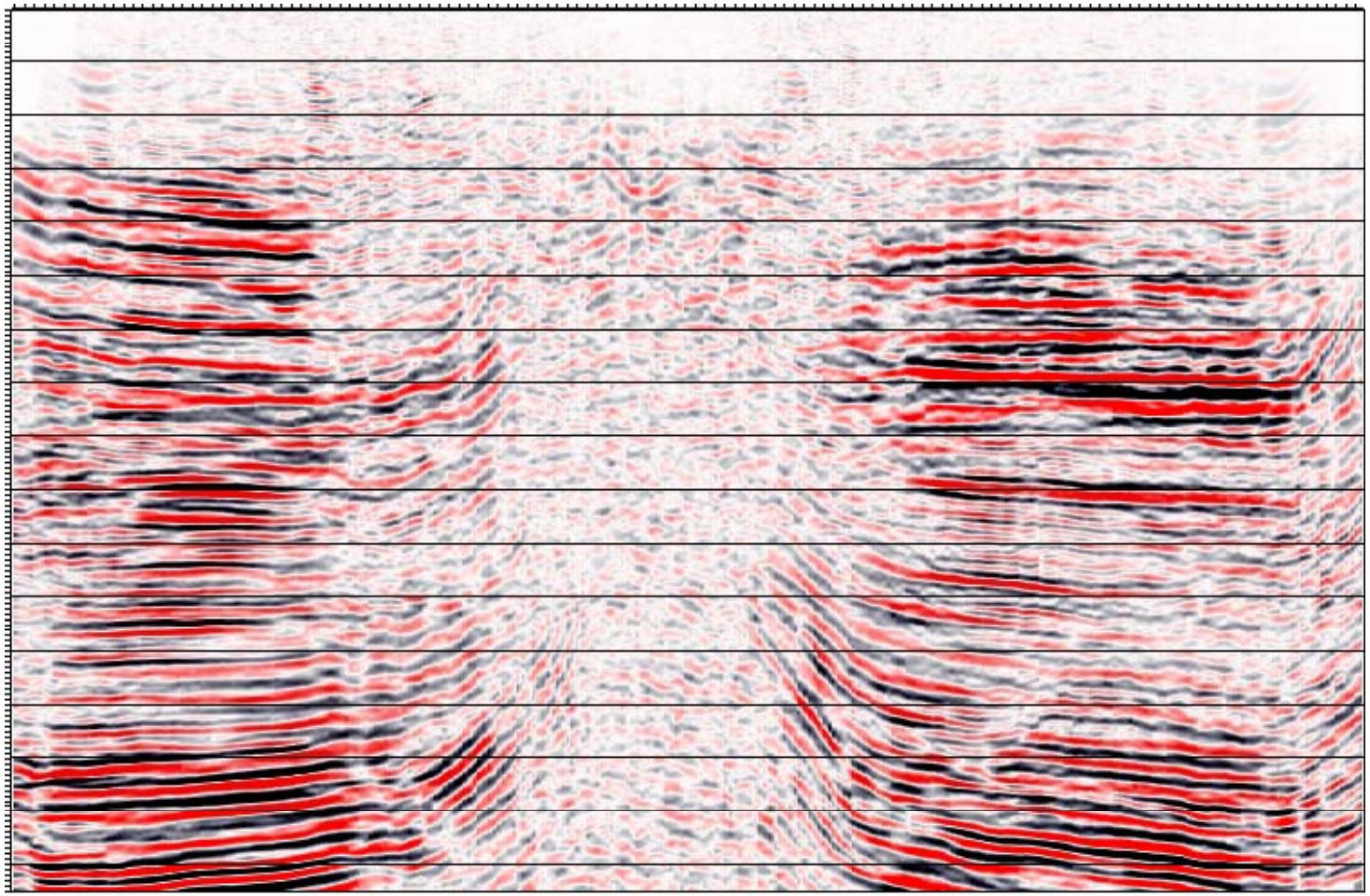
Working Profile:
West-to-East Data



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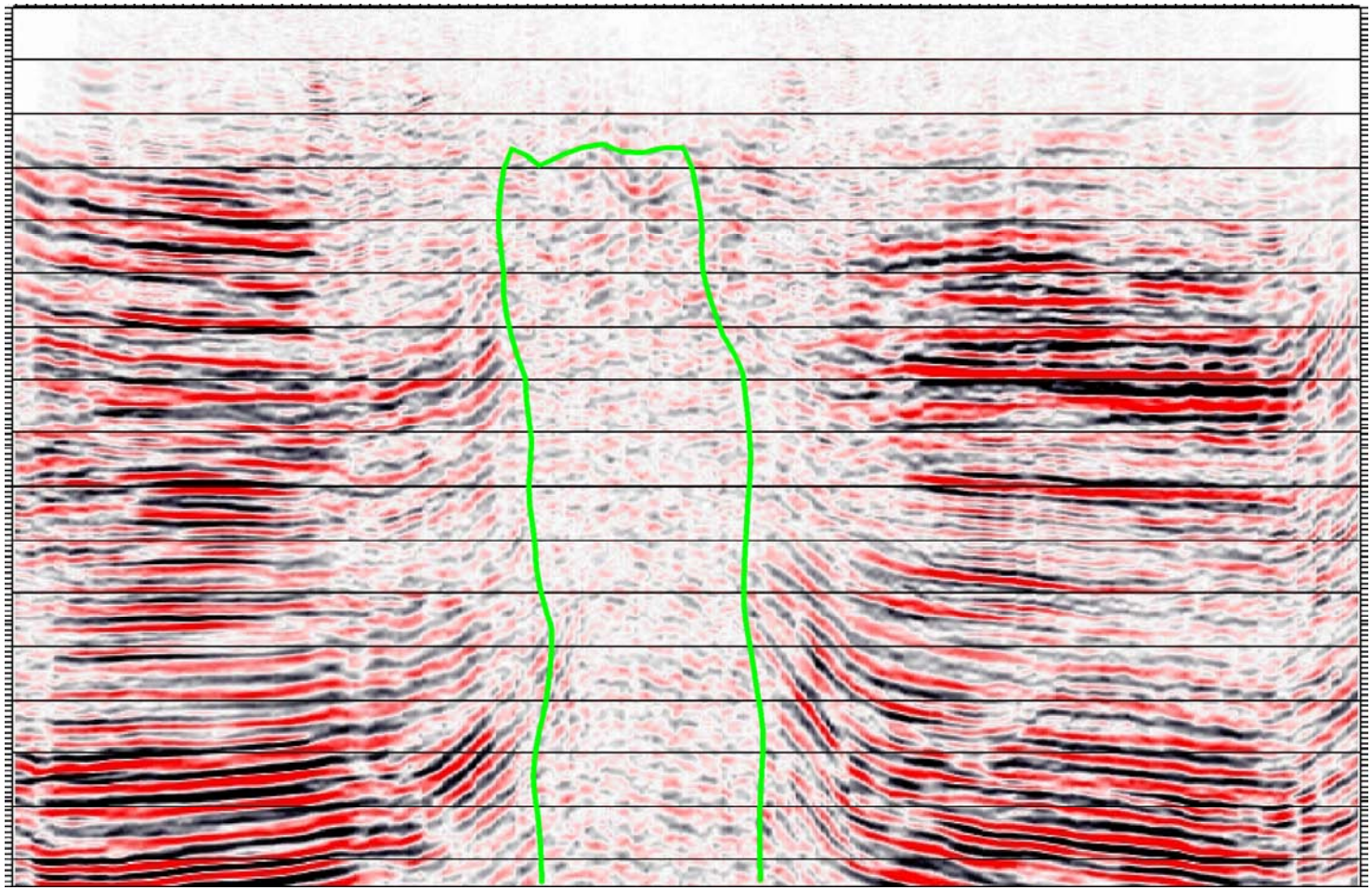
Working Profile:
West-to-East Interpretation



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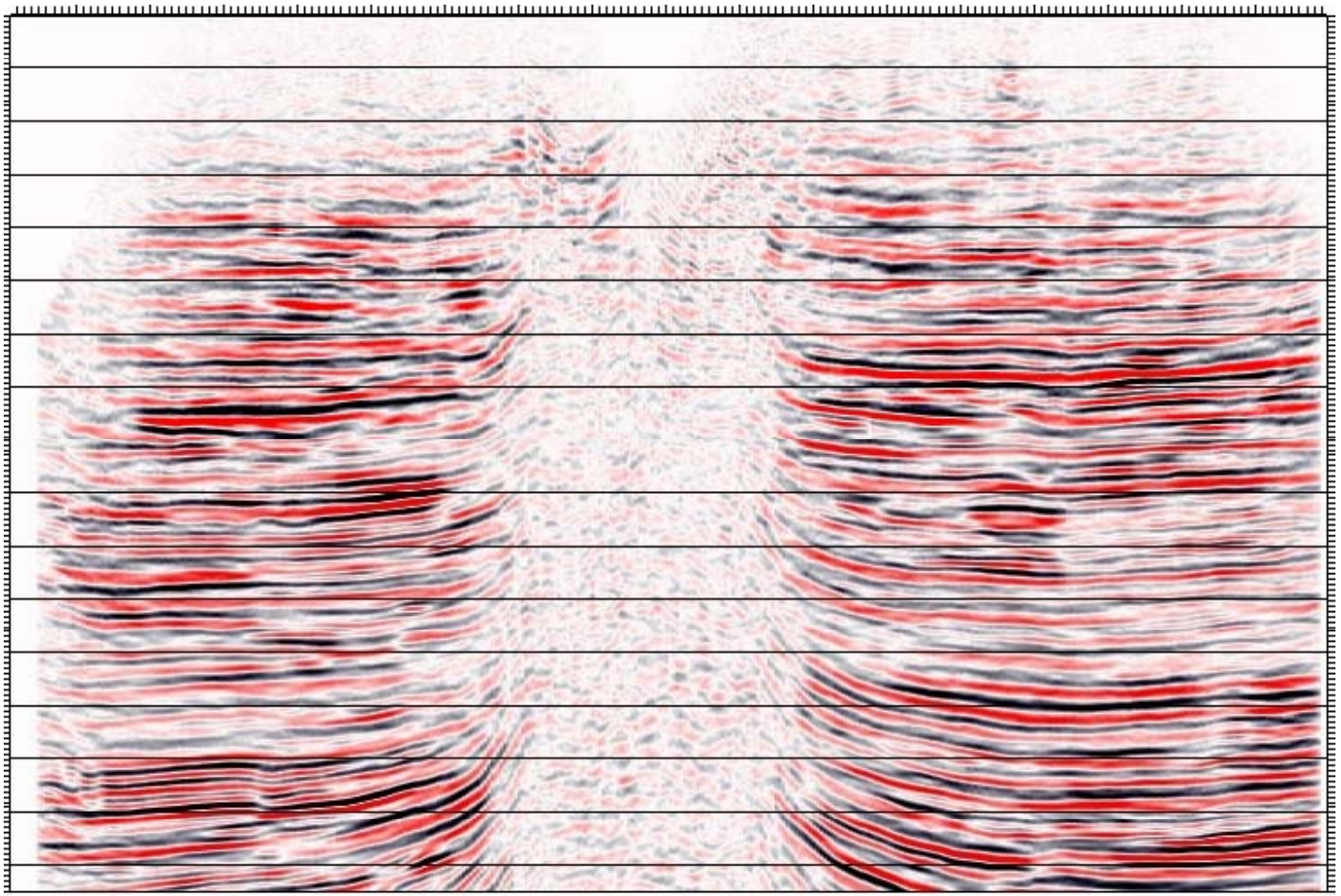
Working Profile:
South-to-North Data



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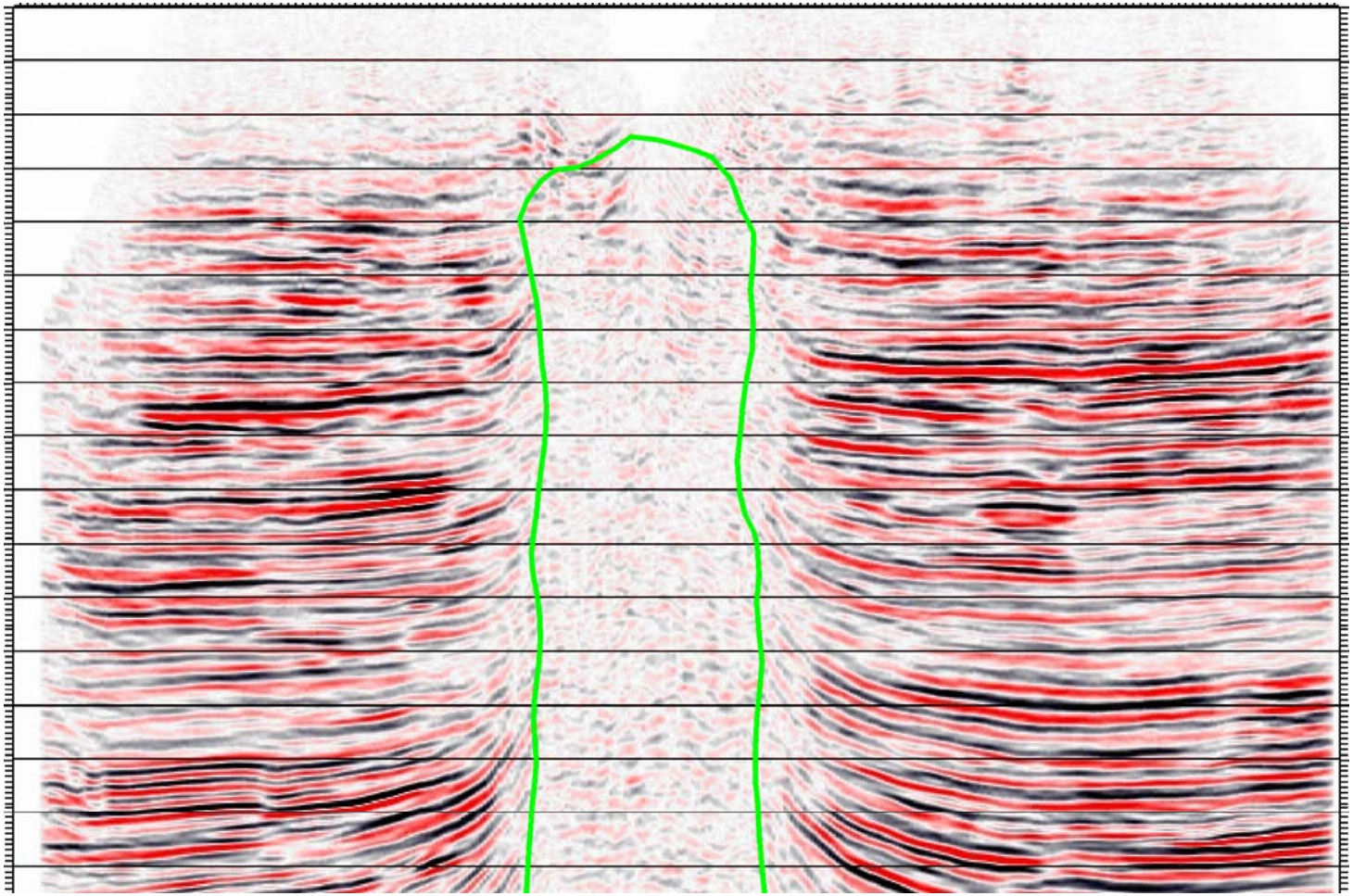

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Interpretive Issues

- **Reflector *termination* is not always obviously the contact with salt**
  - **Strength of reflector may decrease sharply near dome, obscuring actual truncation**
- **Salt flank may be represented better by *roll-over* of one or more reflectors**
  - **More broadly: any break in slope**
- **Salt flank may be represented better by a marked change in the character of a group of reflectors**
- ***Note: Well control tightly constrains the seismic interpretation in some situations***

Modeling Approach (2)

- Use a 2-D / 3-D combined manual / digital approach
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  - **Convert vertical profiles to 2-D map locations at 100-msec time intervals**
  - **Reconcile map locations of flank intercepts from differing directional vertical profiles**

Modeling Approach (3)

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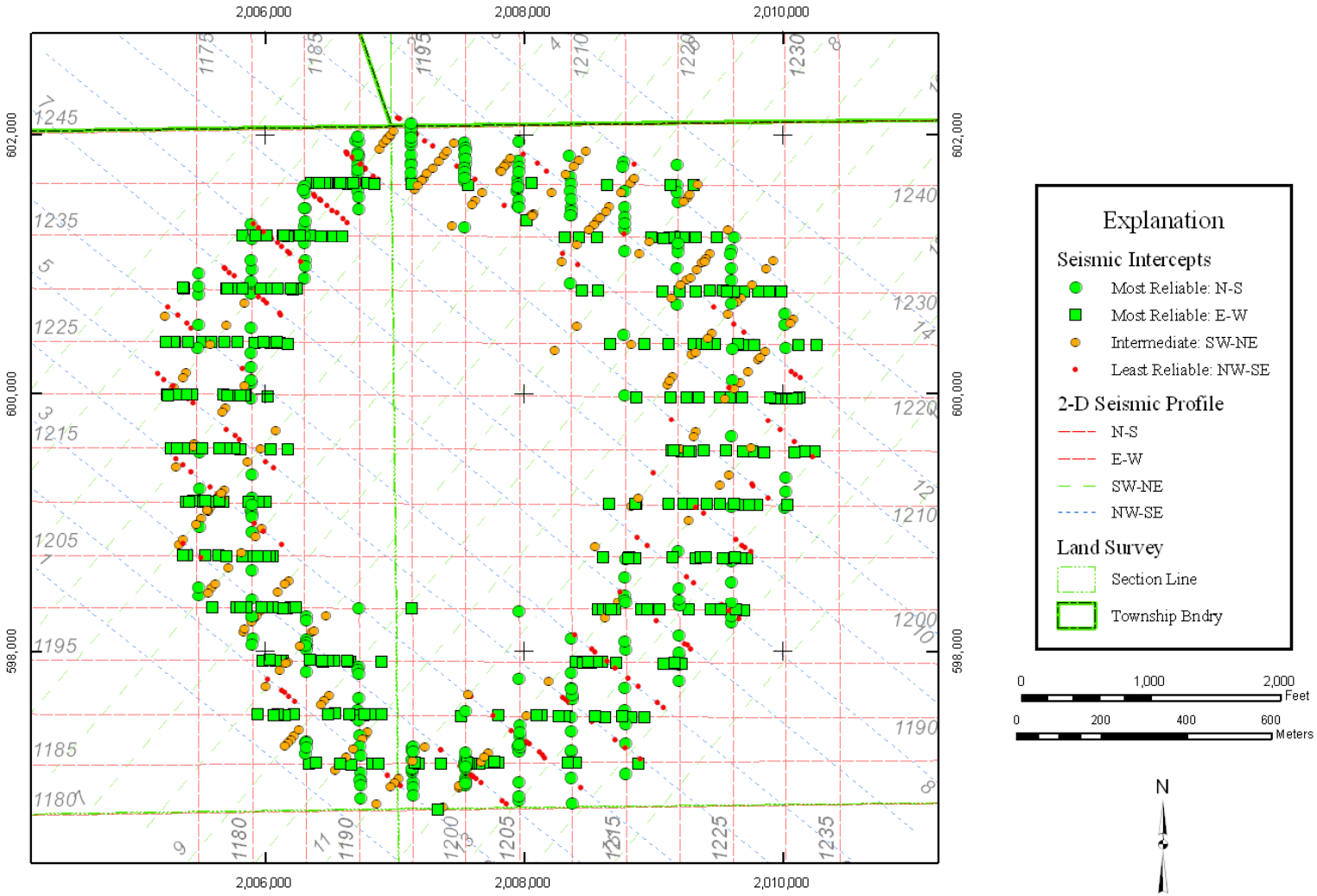
  - Basic interpretation of flanks on vertical profiles
  - Convert vertical profiles to 2-D map locations at 100-msec time intervals
  - **Reconcile map locations of flank intercepts from differing directional vertical profiles**
    - **This involves considerable back-and-forth manual effort to generate a logically consistent set of picks**

Interpreted Contacts on Flank of Salt



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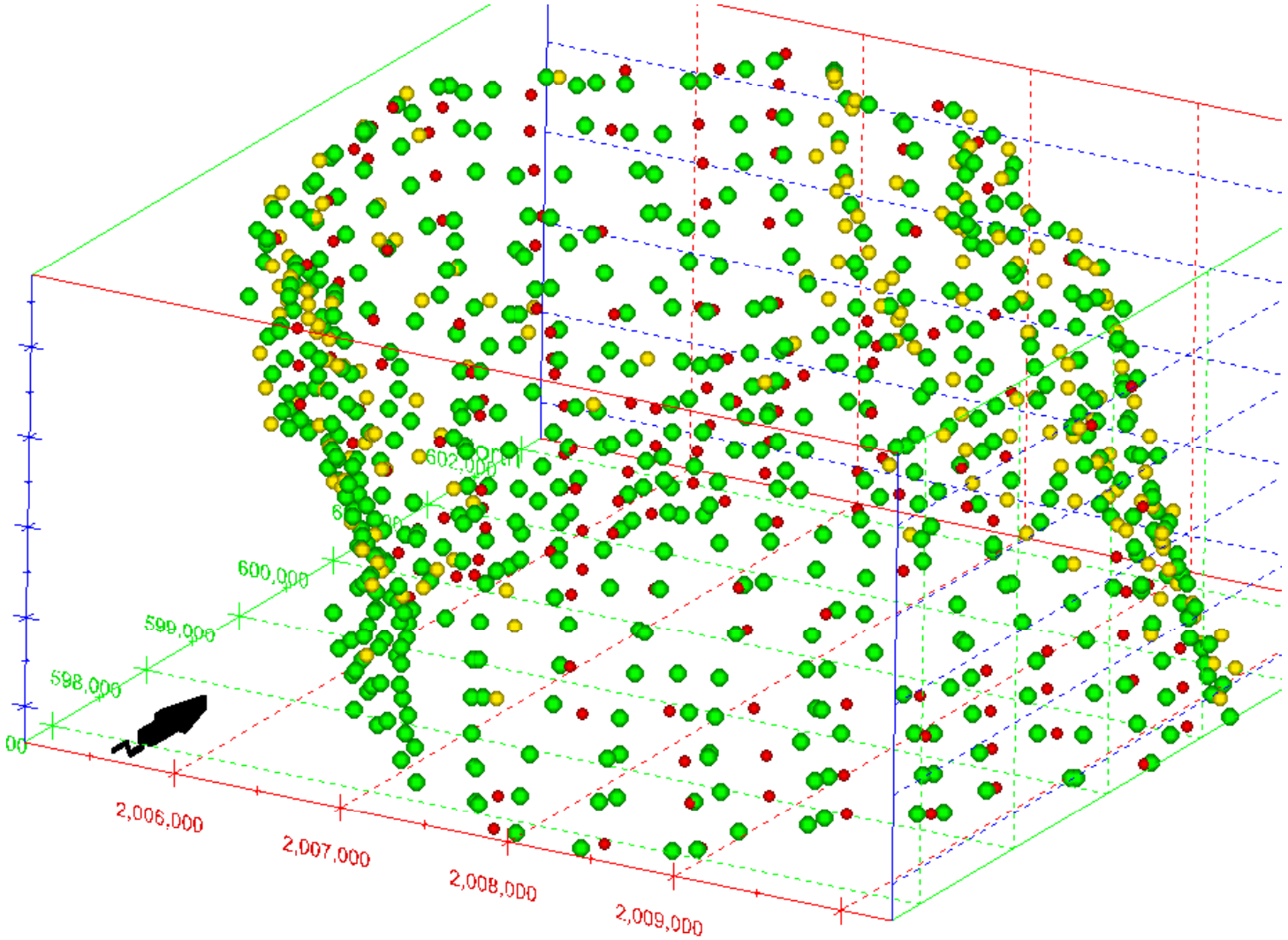
Seismic Intercepts in 3-D



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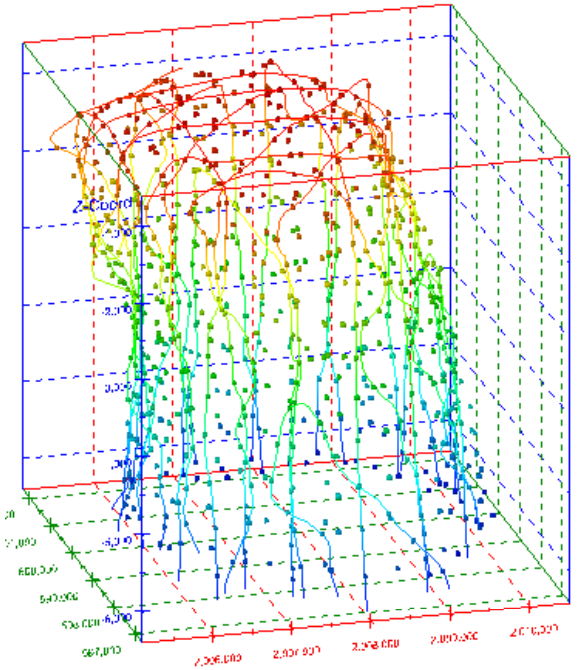
Modeling Approach (4)

Then, we:

- **Construct a set of "rays", which pass through each interpreted point *on the salt margin*, and which are "generally" *normal* to that margin**
- **Generate a set of points along each ray at varying distances from the salt margin**
- **Assign these as x-y-z-Distance tuples**
  - **Distances are negative inside salt dome**
  - **Distances are positive outside salt dome**

Conversion of 3-D Seismic Intercepts to a Thee-Dimensional Geometric Model

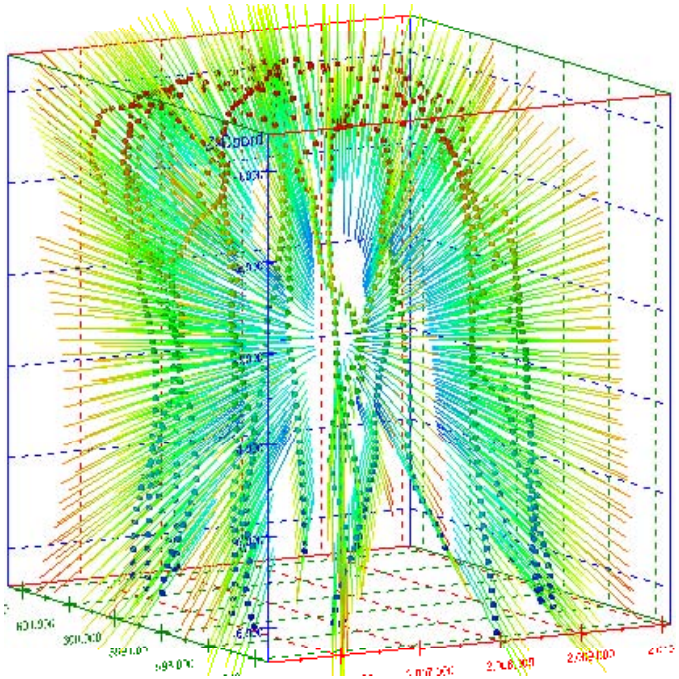


Picked contacts are mapped into 3-D space
(here, a subset of picked contacts)

Additional points are generated along *rays* computed approximately normal to the generalized salt flank

Time values have been converted to depth

(only rays shown here)



These additional points are assigned *positive* distance values *outward* from the salt contact and *negative* values inward

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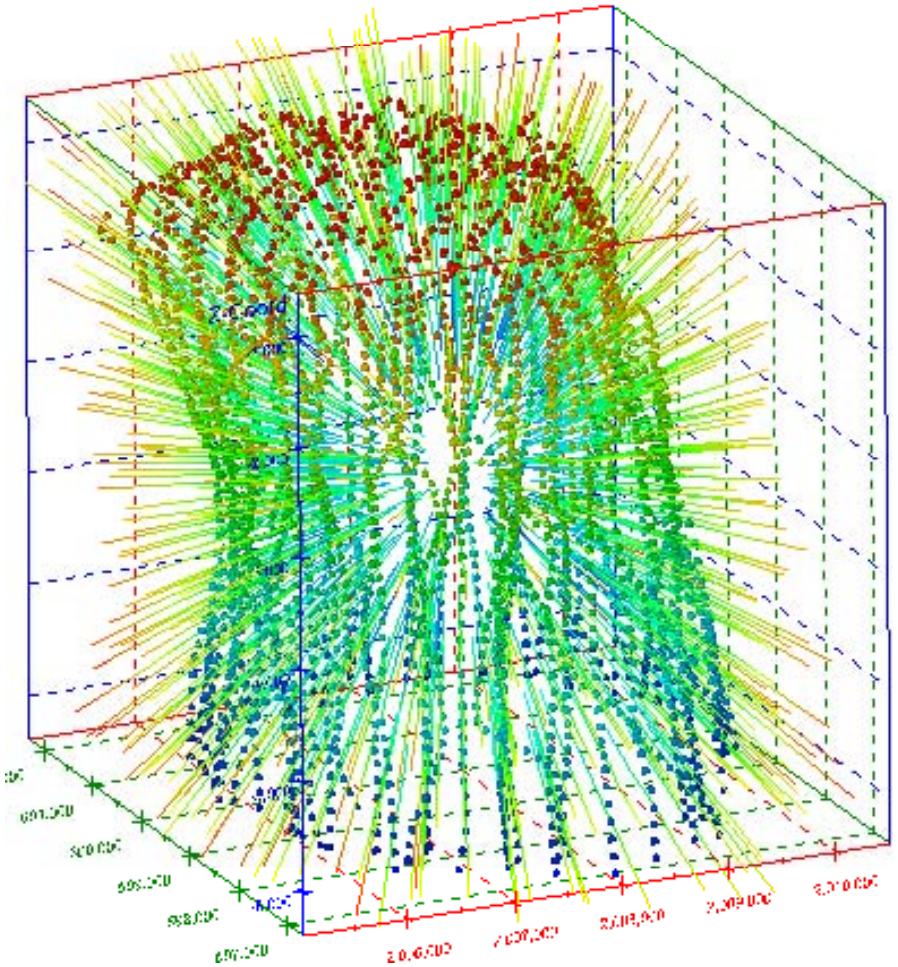
43,000 3-D Modeling Points!



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Modeling Approach (5)

Now, to generate the actual digital model, we:

- **Create a 3-D numerical grid encompassing the entire set of points → volume elements**
- **Use an interpolation algorithm, known as *kriging*, to estimate the "distance" variable at each grid node conditioned by our set of x-y-z-Distance tuplets**
  - ***Estimated distances "invariably" will be positive outside the salt margin and negative within*, because the estimation process uses the "nearest" points, weighted essentially by proximity**

Modeling Approach (6)

Now, we:

- **Subset the discretized volume at Distance = zero**
- **Discard all non-zero grid nodes**
- **Connect the Distance = zero nodes to form a surface mesh representing the salt margin**

This surface mesh can be used for a variety of engineering purposes

Discussion

Why this approach? **(vs. commercial software)**

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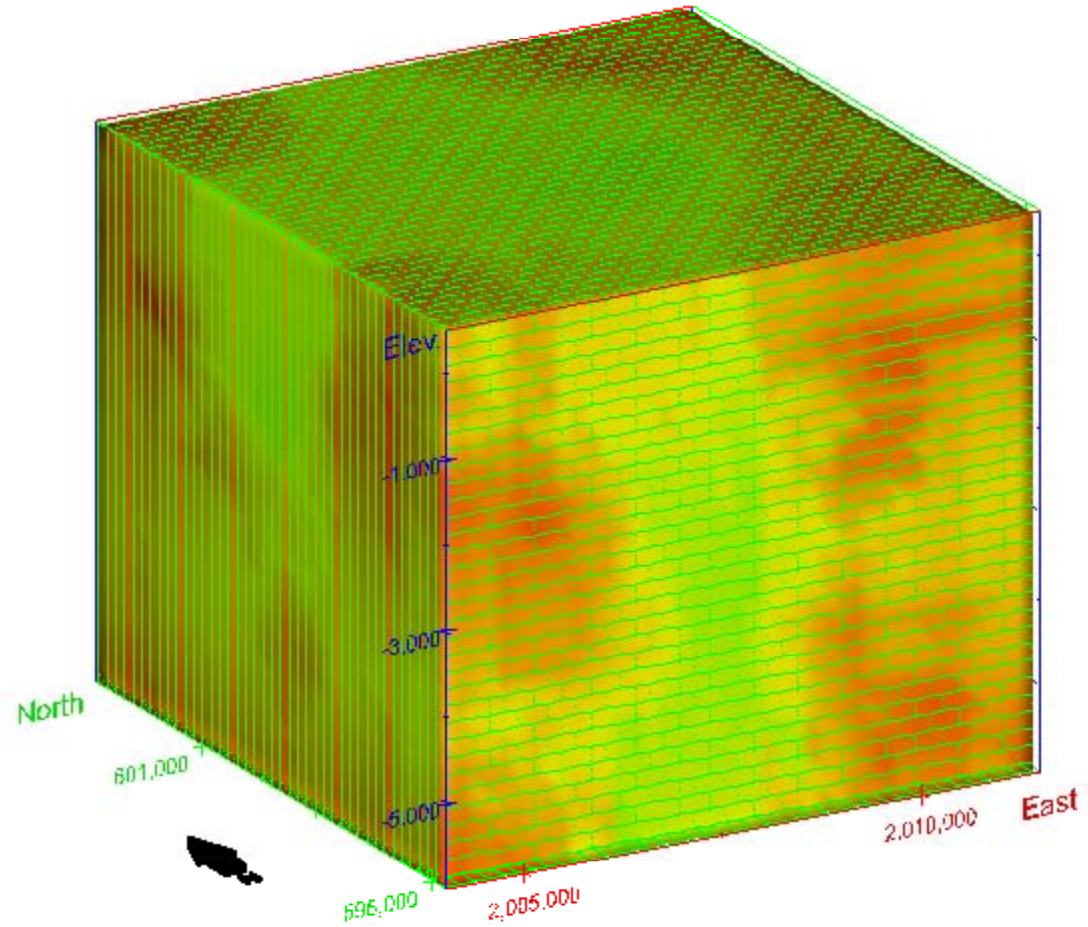
- Salt domes, in general, and the Bayou Choctaw dome, in specific, exhibit significant salt overhang
- ***Conventional "surface" modeling algorithms cannot deal with overhang***
  - **Invariable attempt to interpolate elevation of the bounding surface directly**
  - **Mathematically impossible to interpolate two different elevation values at the same x-y spatial position**

Discussion

Why this approach? (vs. commercial software)

- Salt domes, in general, and the Bayou Choctaw dome, in specific, exhibit significant salt overhang
- *Conventional "surface" modeling algorithms cannot deal with overhang*
  - Invariable attempt to interpolate elevation of the bounding surface directly
  - Mathematically impossible to interpolate two different elevation values at the same x-y spatial position
- ***Interpolating the "distance-from-salt" as an attribute independently from the elevation-based "boundary" consideration removes this limitation***

The Discretized Distance Model



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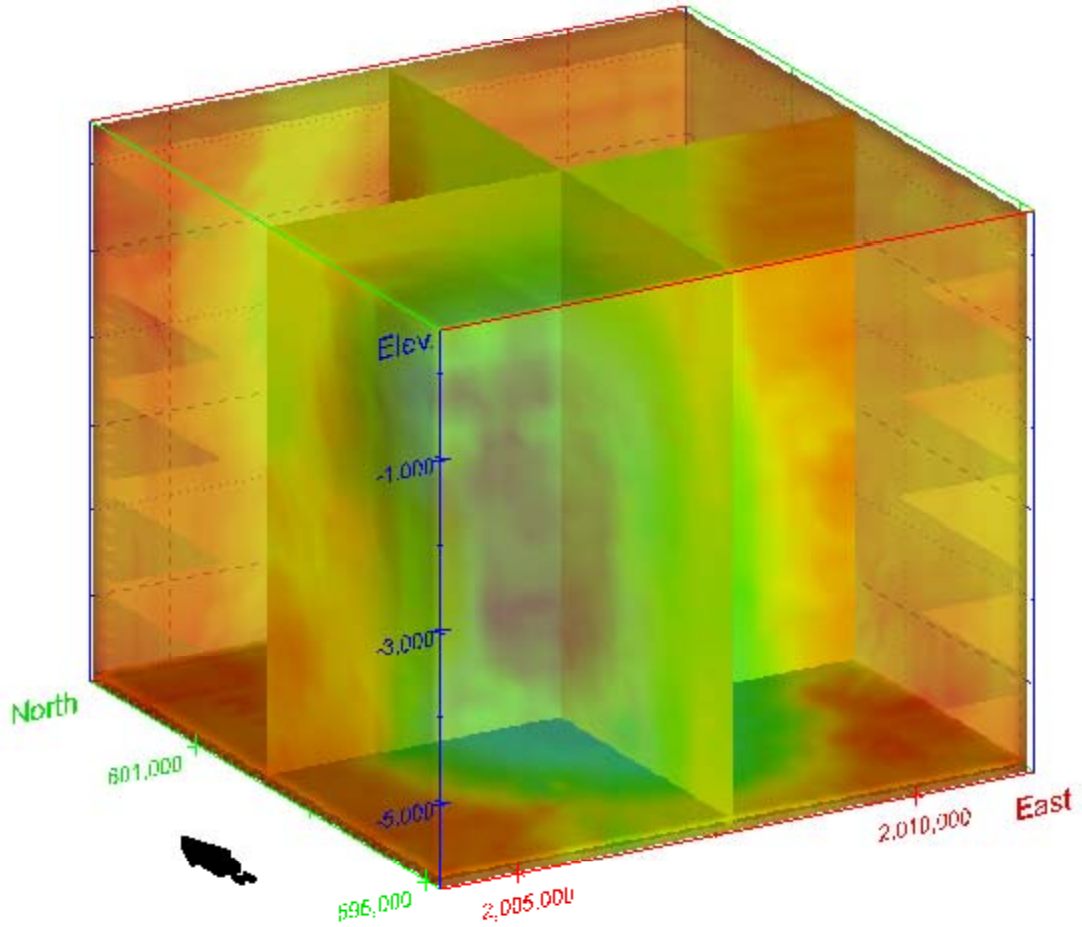

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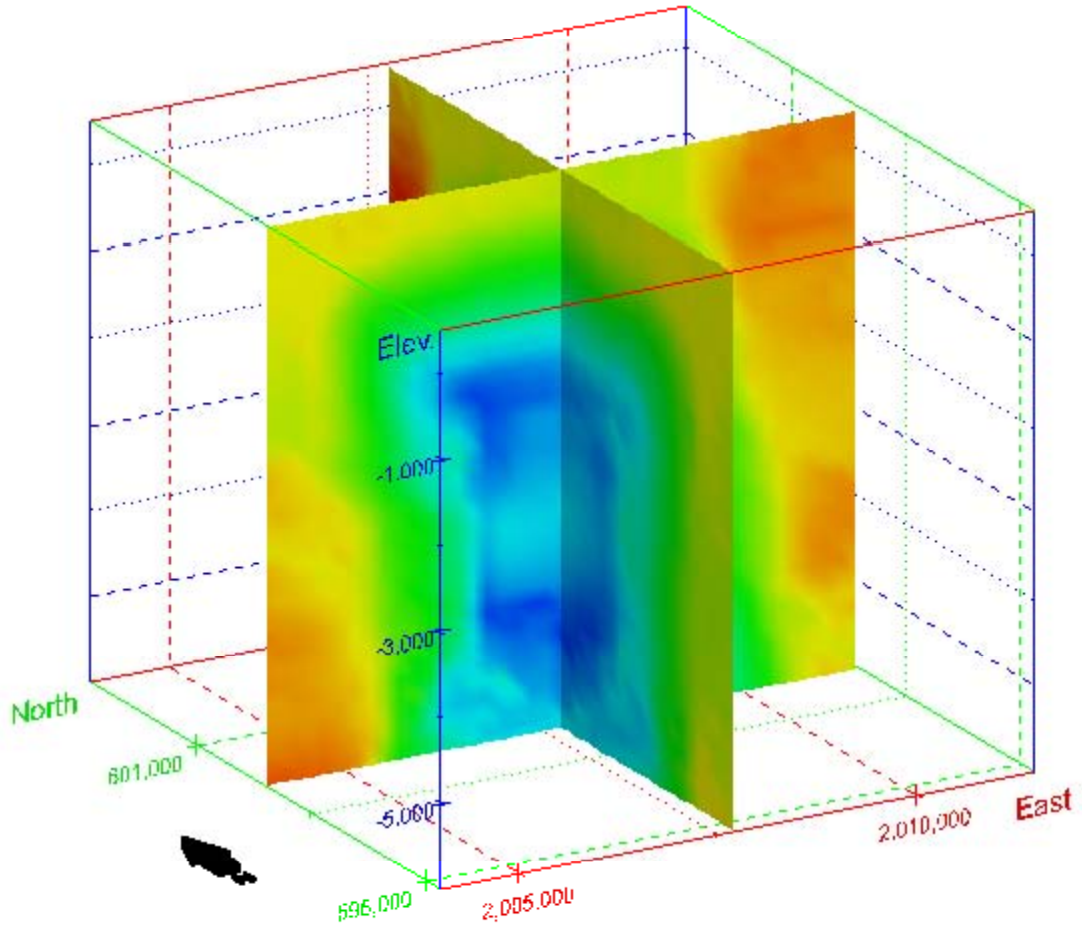

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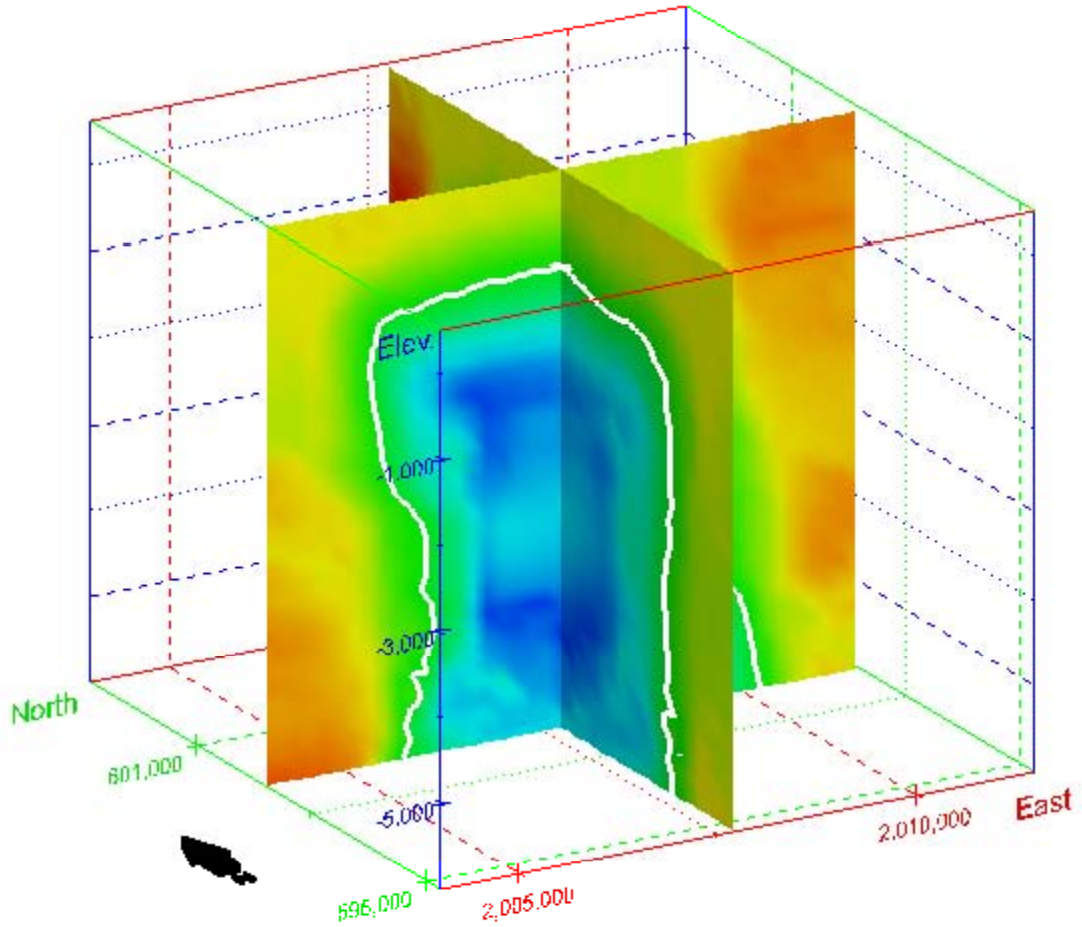

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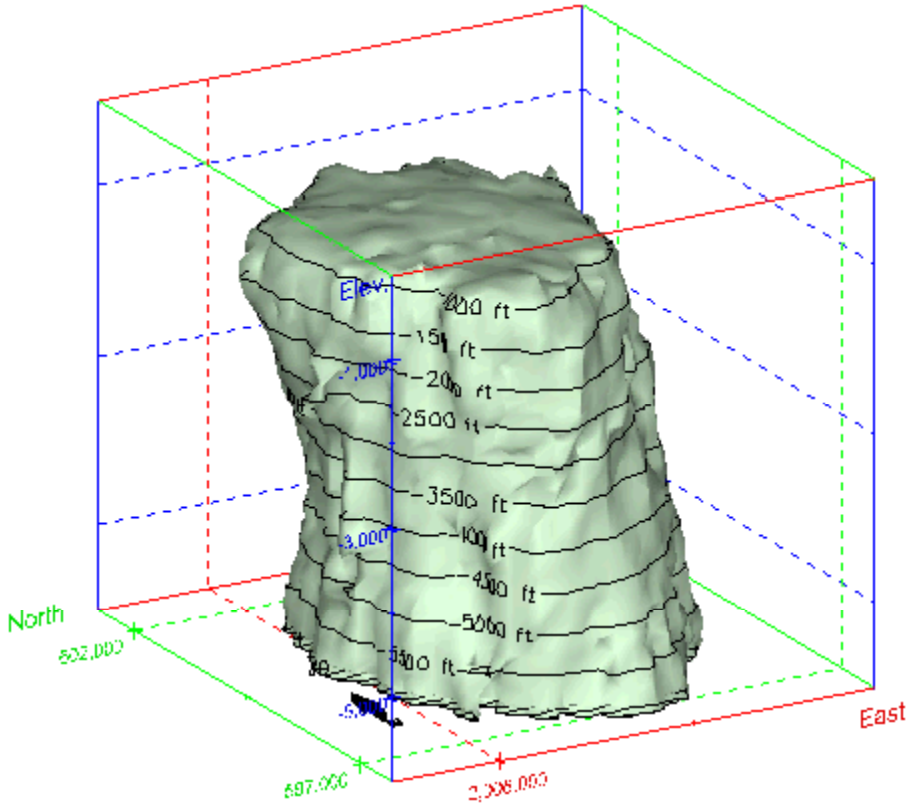
The Kriged Model Subset at Zero Distance



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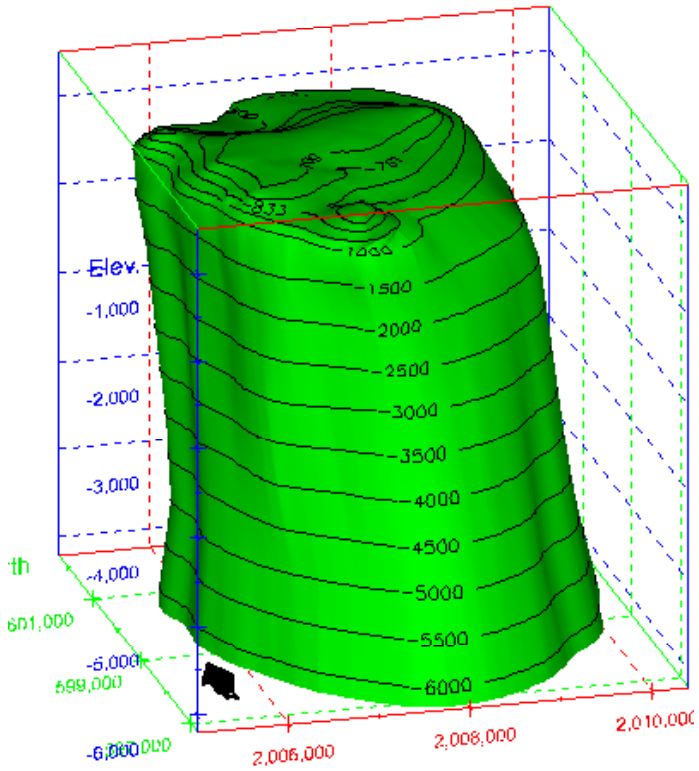
Historical Models of the BC Salt Dome



1980

using only well data and older conceptual model

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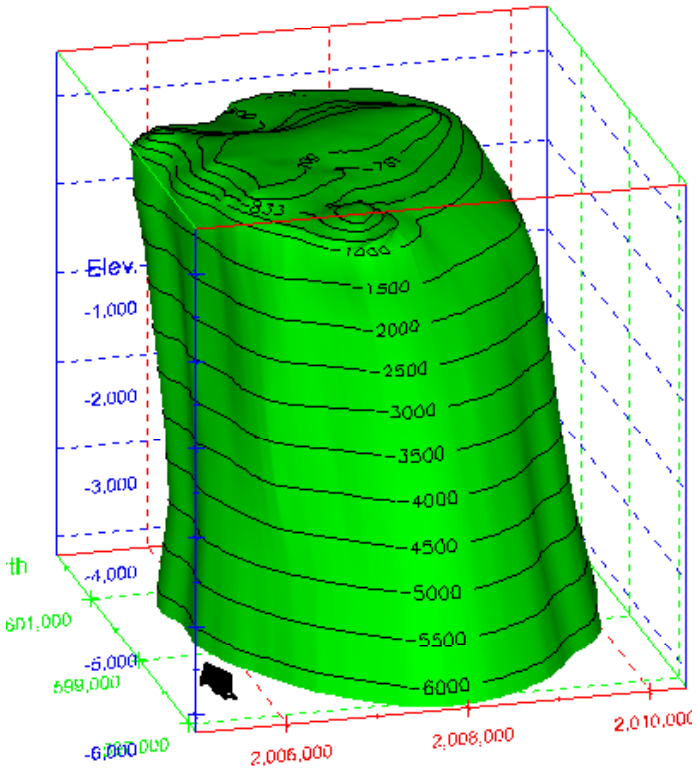

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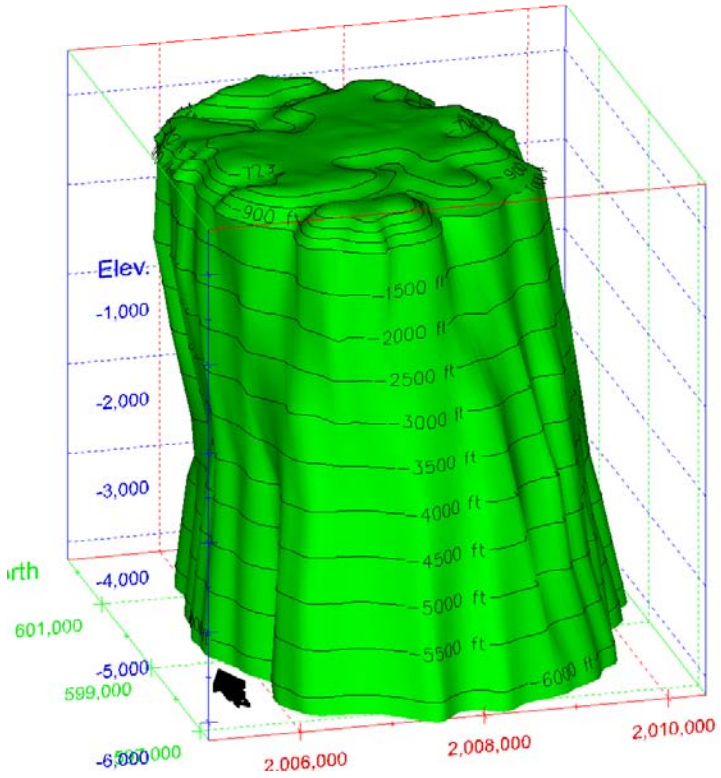

2005

using only well data ***and more recent conceptual model***

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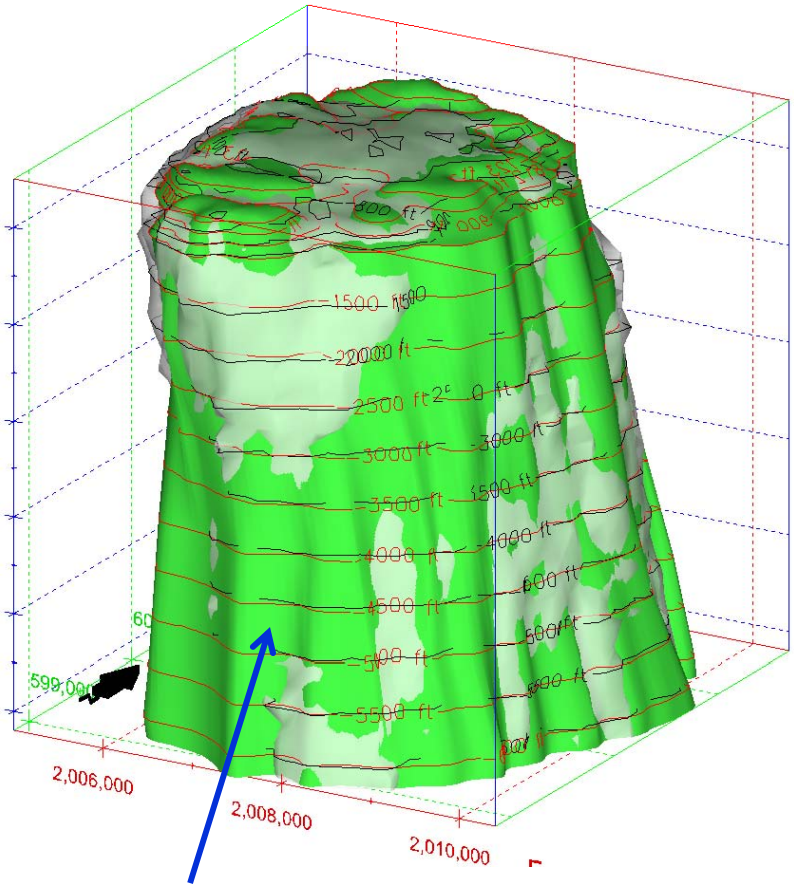
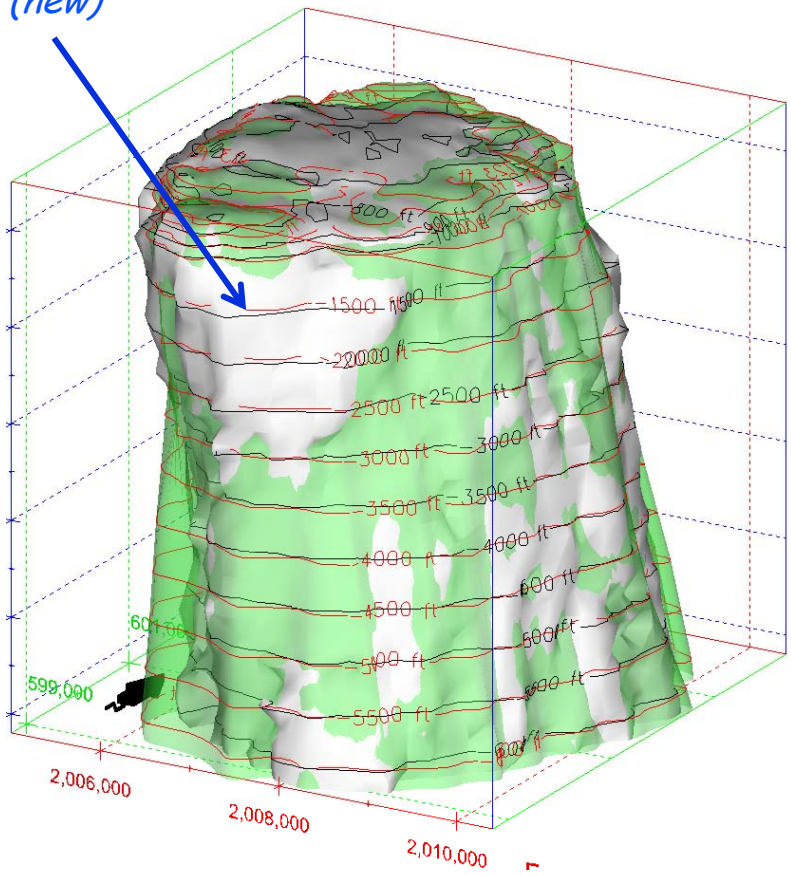
Comparison of Models



Older Model
(2005)

Seismic Model
(new)



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Increased Geometric Complexity

- **Spatial resolution on the order of the 3-D seismic bin size – *80-100 ft* – reveals a much more complex salt surface than is generally recognized**
  - **Our hope is that this newly revealed geometry will help understand the salt internal to the dome**

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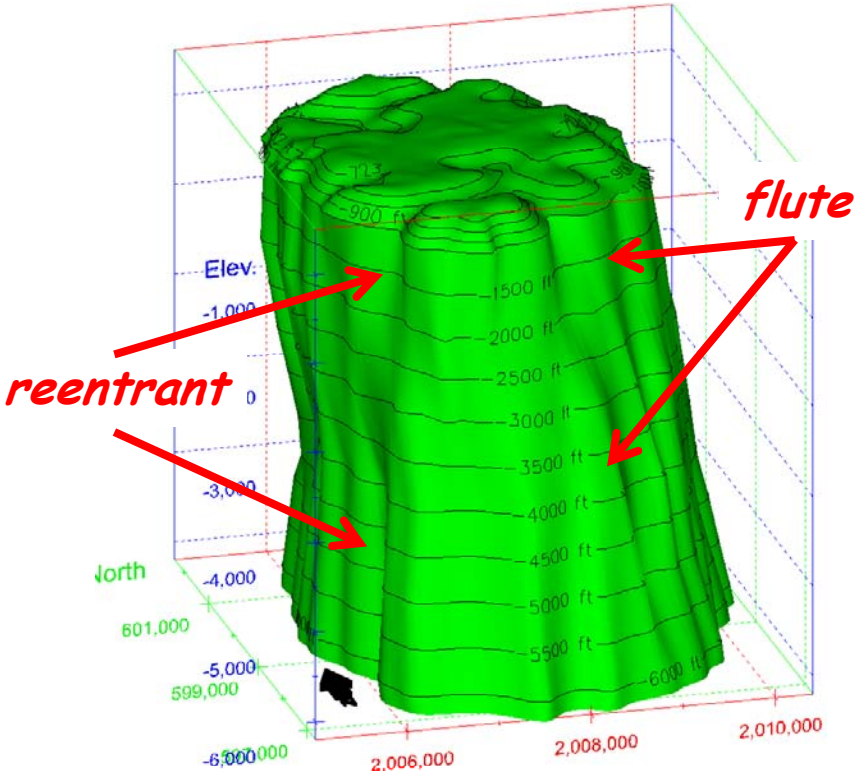
- **Preliminary classification of geometric features:**
  - **Flutes and associated reentrants**
  - **Outward bulges**
  - **Downward-tapering wedges**

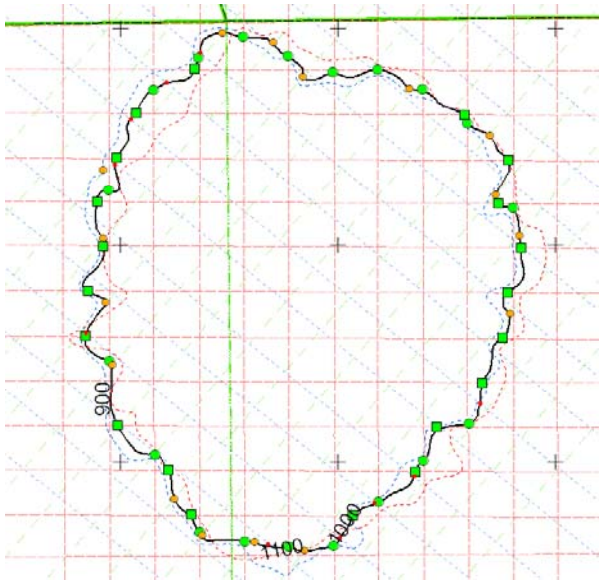
Flutes and Reentrants

These features have been recognizable for some time, even in more simplified domal representations



in 3-D perspective
(older 2005 drill-hole-based model)

in plan view
(seismic picks on salt at 1,000 msec TWTT)



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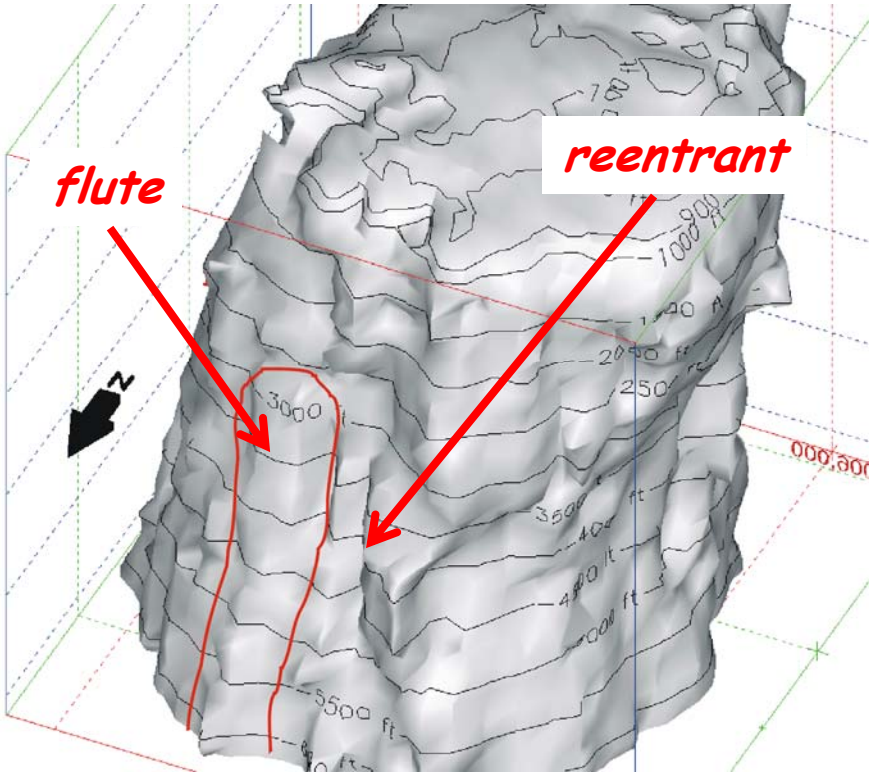
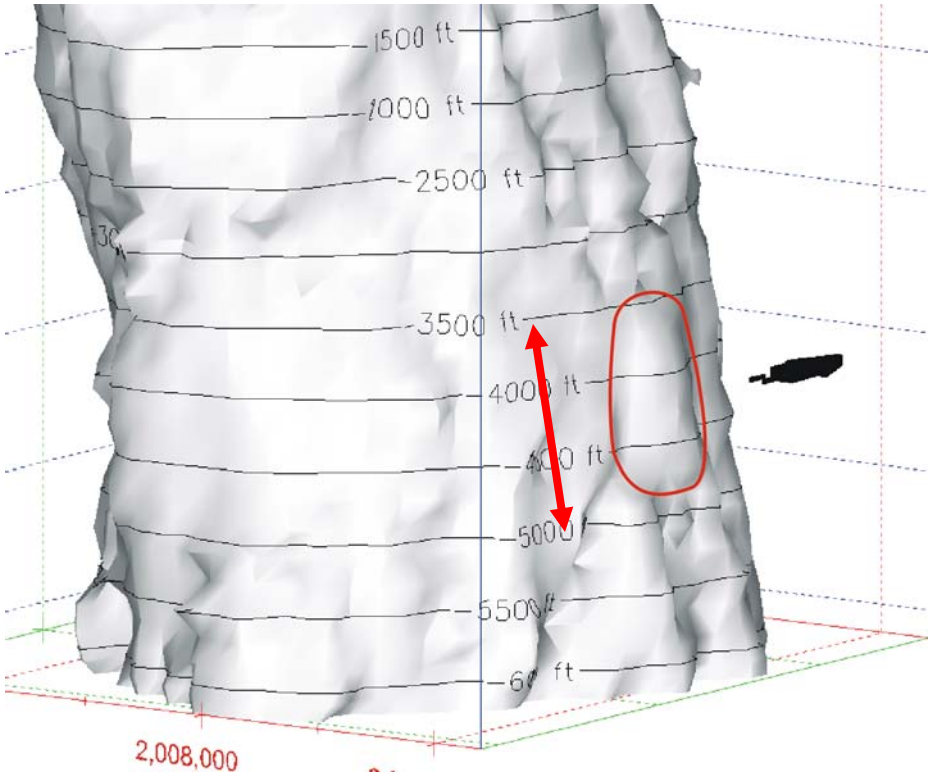
Flutes and Reentrants

Flute → Outward bulge with some degree of vertical continuity



terminating upward



bidirectional termination

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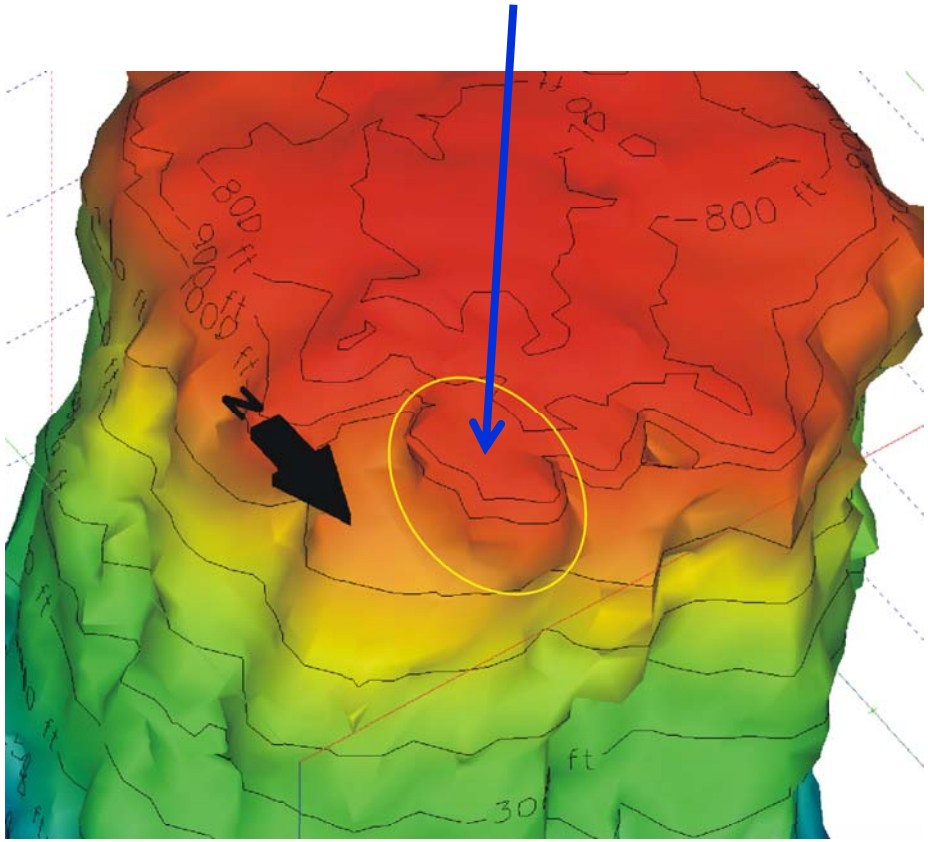
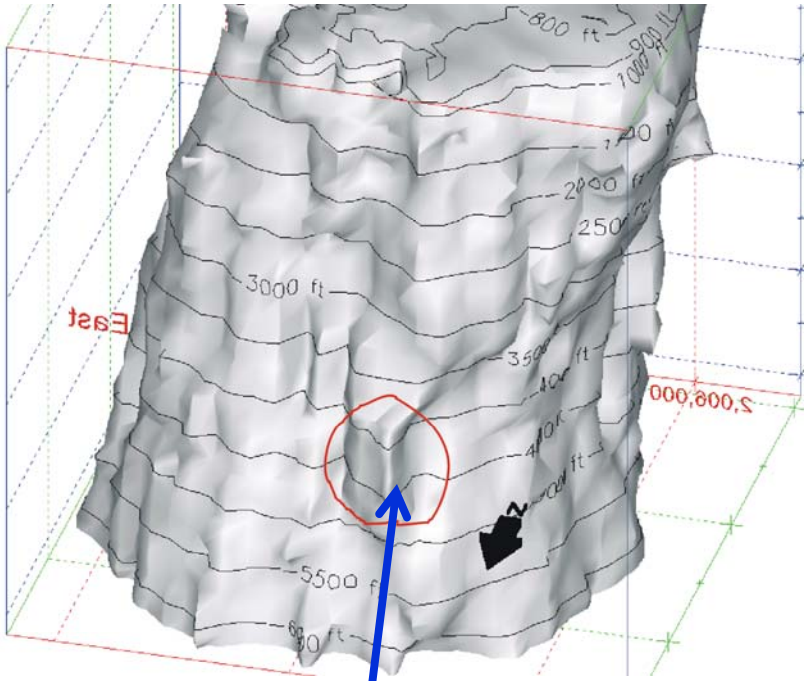
Outward Bulges

at the very crest of the salt stock…





… or buried (?) at depth

(unquestionably a gradational distinction!)

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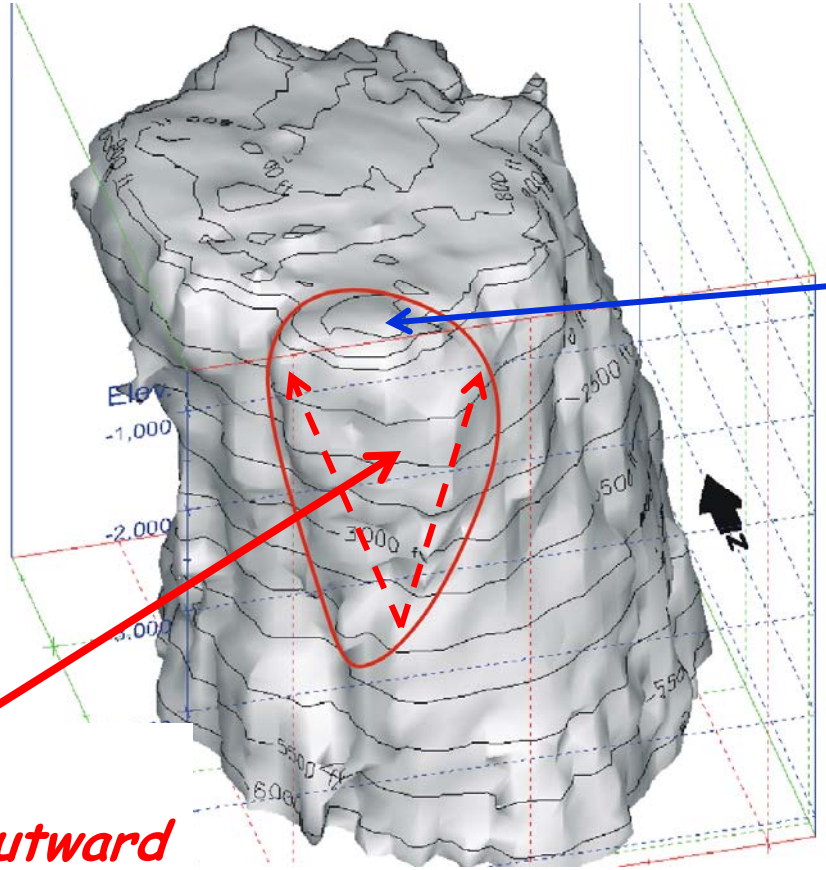
Downward-tapering Wedges



Note that this wedge is also marked by a ***structural culmination*** on the top-of-salt surface

Wedge:
an *upward* and *outward* expansion of the salt margin

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Interpretation of Geometric Complexity

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  - Spine movement may be *other than vertical*
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- **Salt fabric unquestionably is related, in some manner, to salt spines and boundary shear zones**

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  - **Reentrants correspond to boundary shear zones between spines**
- **Outward bulges**
  - **Bulges presumably produced by lateral movement of salt**
- **Downward tapering wedges**
  - **Inferred to represent a spine that was initiated, and which grew upward *and outward* with time and *some degree of horizontal movement***

Implications of Geometric Complexity

- **Surface geometry of a salt dome may give reasonable indications of "off-normal" fabric within the salt mass**
- **Salt fabric can definitely affect leaching and behavior of underground storage caverns**

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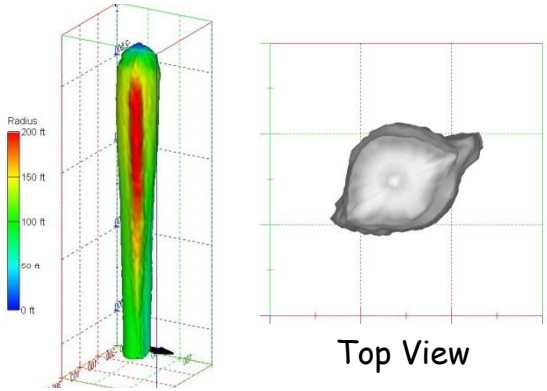
  - ***Example: Big Hill 108*** →



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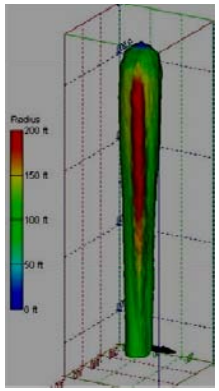

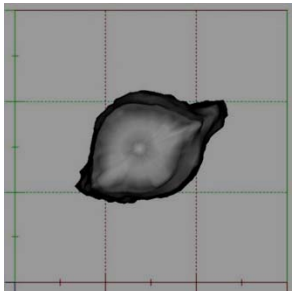

Top View

- **Evaluation of dome geometry may allow better placement of caverns leading to fewer … or at least less severe … operational difficulties**

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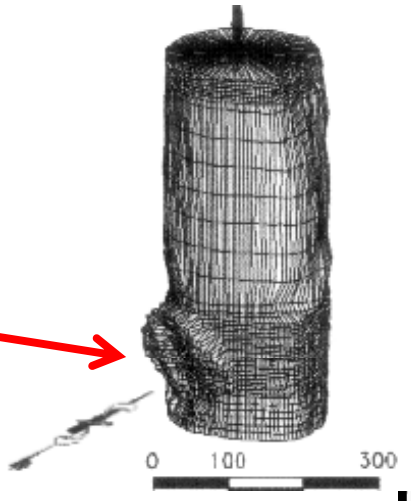

Image from McCauley et al., SMRI 1998 (Rome, Italy)

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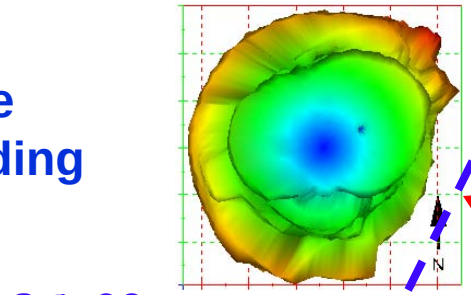

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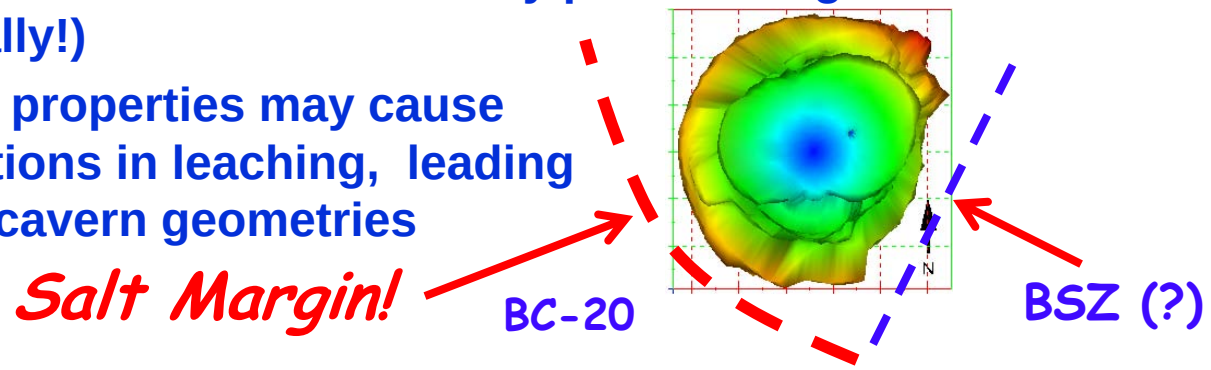

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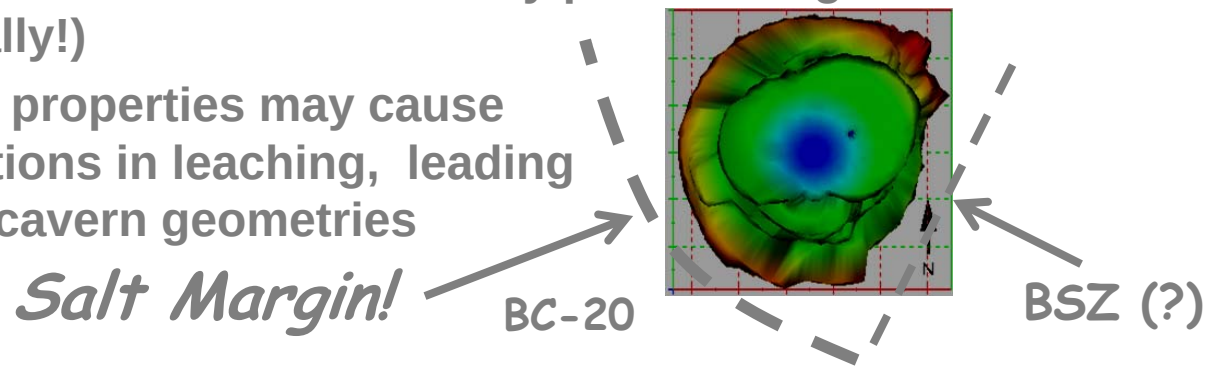

- **Salt overhang – particularly below caprock – suggests (mostly) horizontal movement of salt and likely near-horizontal salt fabric**
  - → **Active horizontal movement may shear casing, causing loss of integrity and stored product**

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Conclusions

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Questions or Discussion?

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