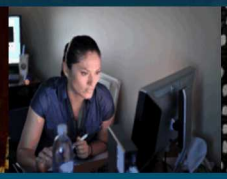
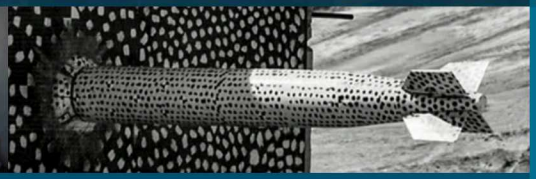
SAND2020-10951PE

West Hackberry Salt Dome Mapping Refinement





Gulf Coast Cavern Operators Committee Meeting

Barry L. Roberts - Sandia National Labs

Anna Lord - Sandia National Labs

Drew Evens – Geostock Sandia

Sandia National Laboratories is a multimission laboratory managed and operated by National Technology & Engineering Solutions of Sandia, LLC, a wholly owned subsidiary of Honeywell International Inc., for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-NA0003525.

Presentation Outline

I. Reason for this work

II. Overview of West Hackberry SPR site
   I. Geology of the salt dome
   II. West Hackberry SPR site

III. Mapping resources and previous mapping activities

IV. Salt dome mapping refinement

V. Proximity Analysis

VI. Summary

Acknowledgements

Anna Lord – Sandia National Laboratories – Albuquerque, NM

Drew Evens – Geostock Sandia – Houston, TX

Fluor Federal Petroleum Operations – New Orleans, LA

Strategic Petroleum Reserve DOE – New Orleans, LA and West Hackberry site

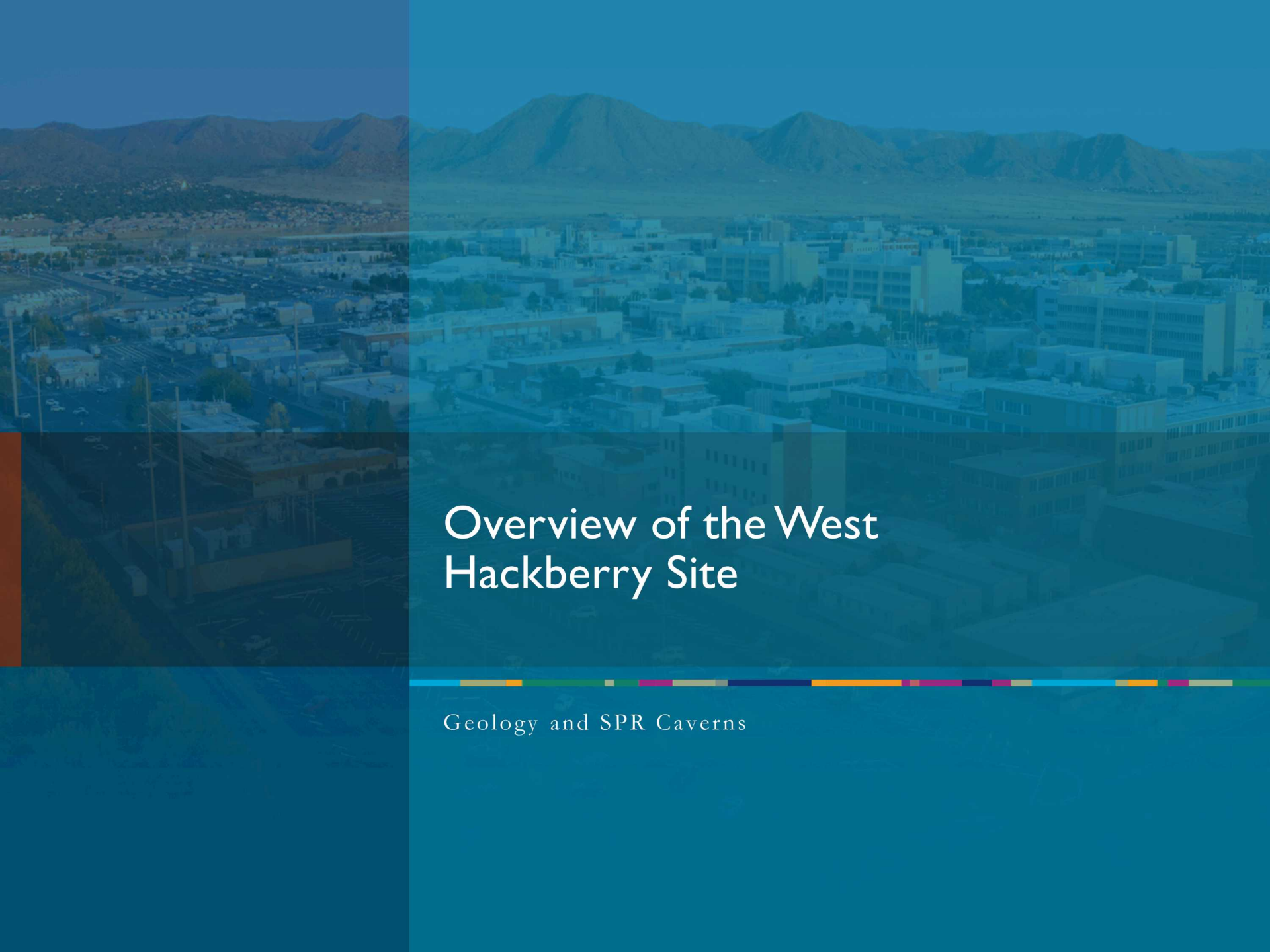
Reason for this work

Louisiana Department of Natural Resources requirements relating to proximity of storage caverns to salt margin.

"*The proximity of all existing and proposed hydrocarbon storage caverns to the periphery of the salt stock and to manmade structures within the salt stock shall be demonstrated to the Office of Conservation…*"

And…

"*An existing solution-mining cavern with less than 300 feet of salt separation at any point between the cavern walls and the periphery of the salt stock shall provide the Office of Conservation with an enhanced monitoring plan…*"

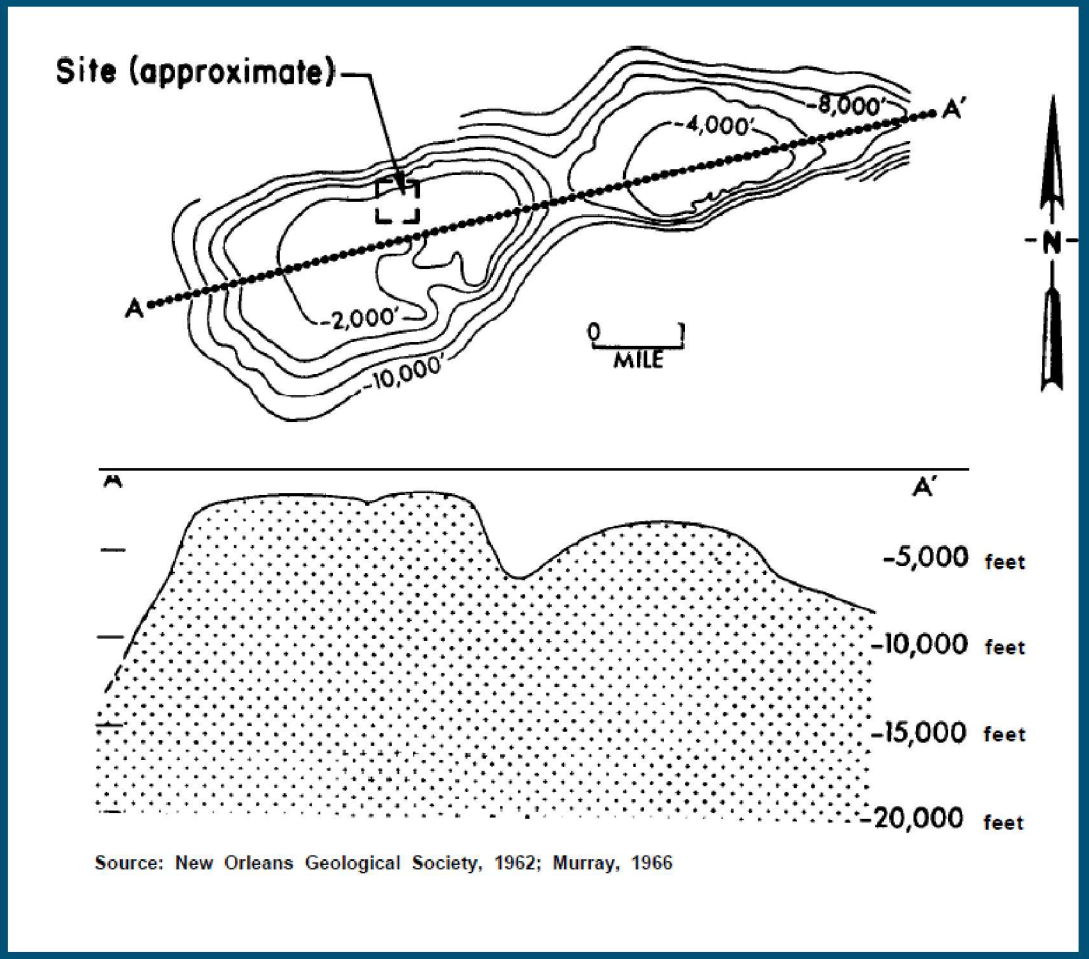


Overview of the West Hackberry Site

Geology and SPR Caverns

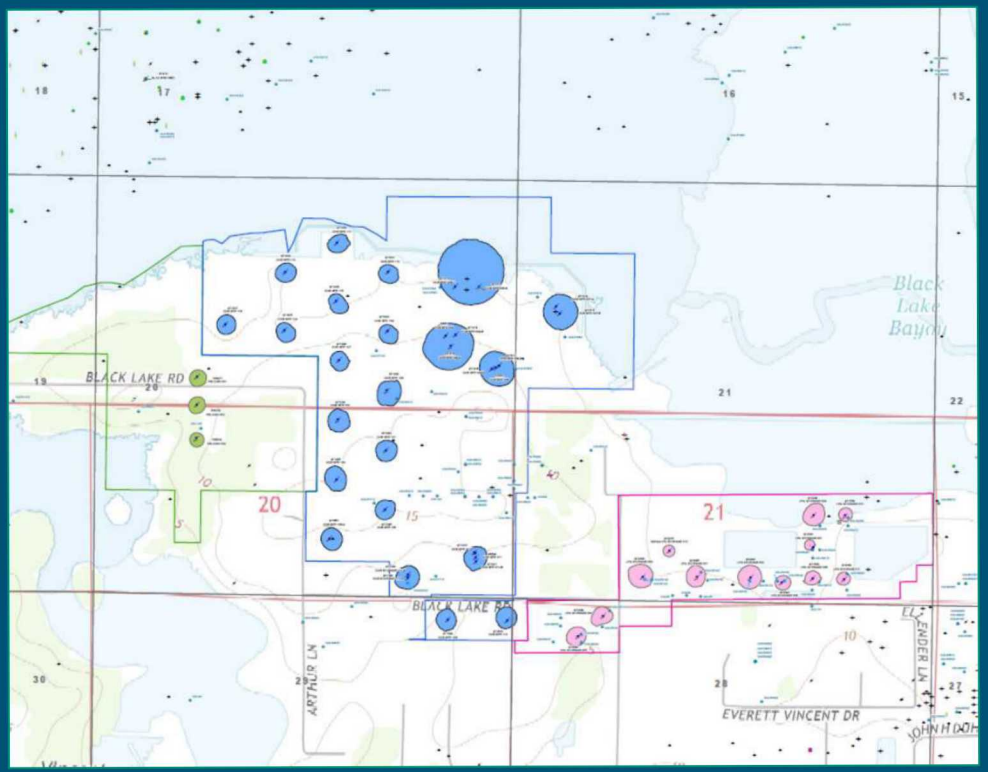
West Hackberry Salt Dome Geology

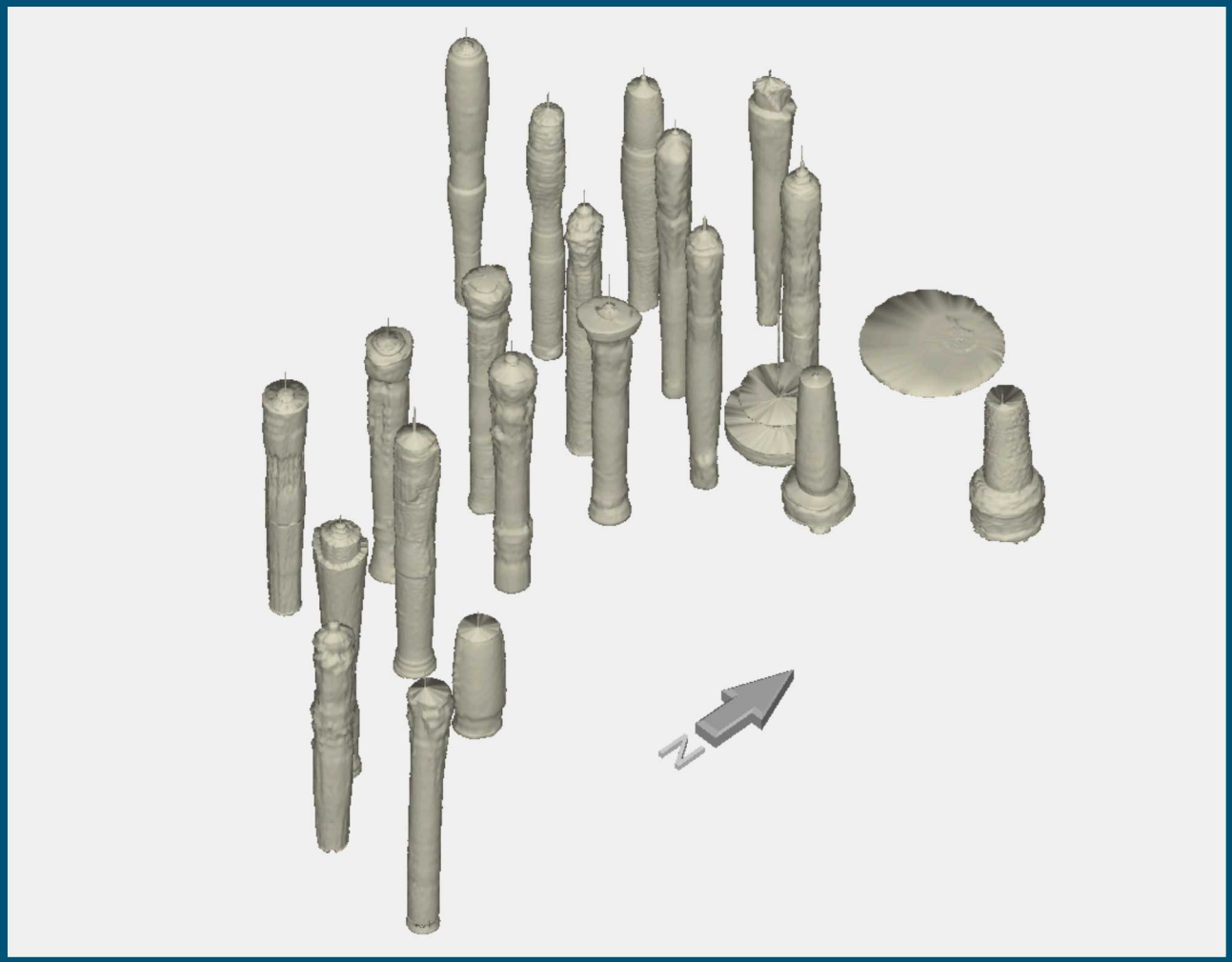
- West Hackberry is a large dome
  - Top of salt at about 2000' depth
  - Salt is fairly homogenous
  - Major growth emplacement in the late Miocene (11 to 15 Ma)
- Caprock
  - Up to 550' thick
  - At a depth of about 1500'
  - Major components are anhydrite and dolomite



West Hackberry SPR Site

- SPR acquired West Hackberry site in 1977 and became operational in 1988
- Has total of 22 SPR caverns
  - 17 caverns created by SPR, 5 inherited with the site
  - 21 are active for storage, authorized for 220 MMB
  - 1 not used for oil storage
- Total of 31 wells including those associated with inactive cavern





SPR Cavern Field

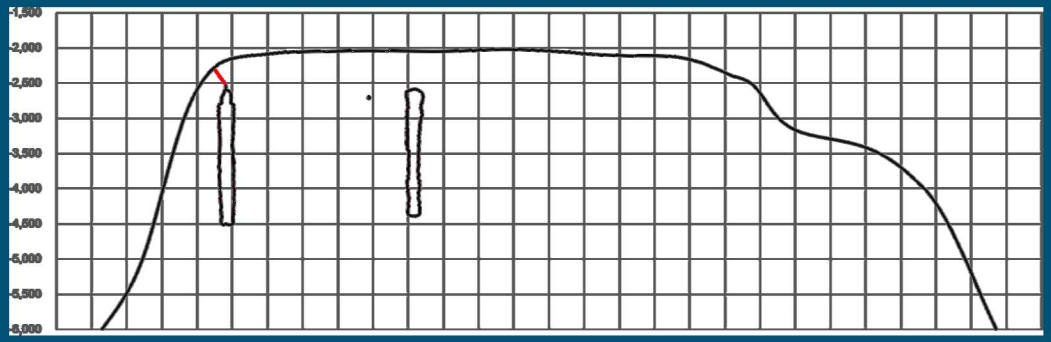
Driver for this Work

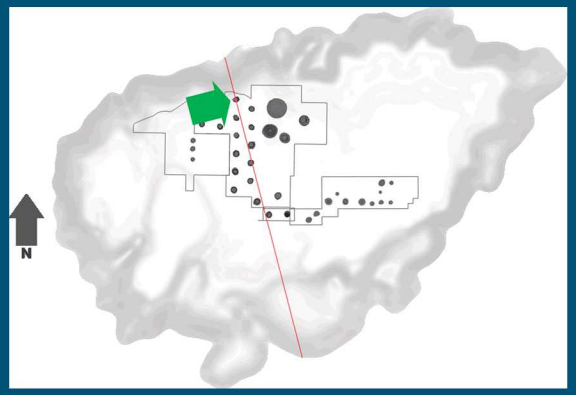
Distance between 2015 salt model and WH-111 was 286 feet. Below threshold requiring enhanced monitoring plan.

Limited control data available - significant uncertainty in our understanding of the northern salt margin location.

Want to improve our understanding of the northern salt margin location since it is the closest approach to SPR caverns.

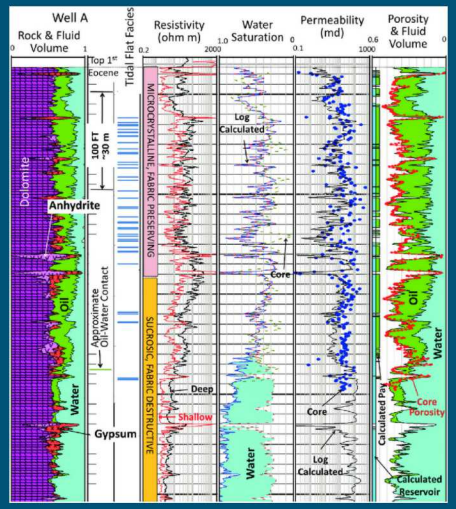
West Hackberry 111

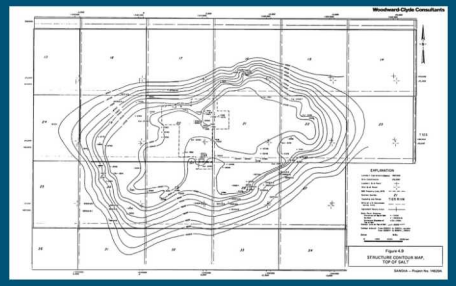


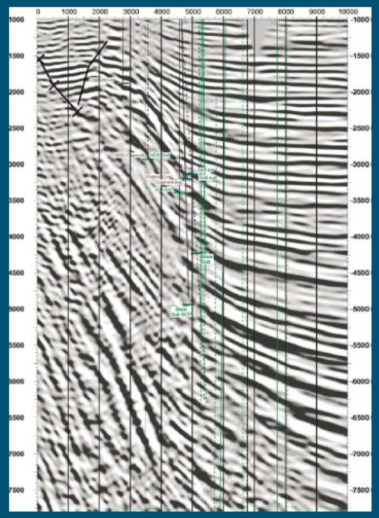


Mapping Resources and Previous Mapping Activities

Available Mapping Resources



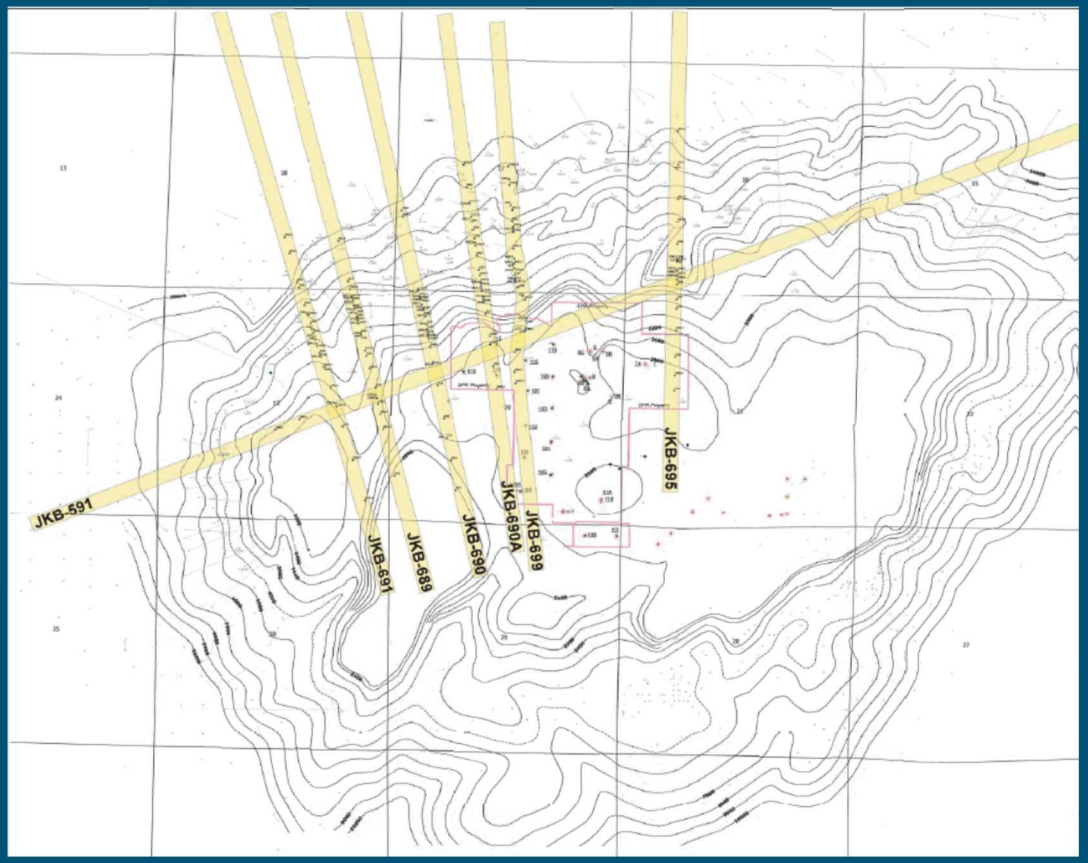




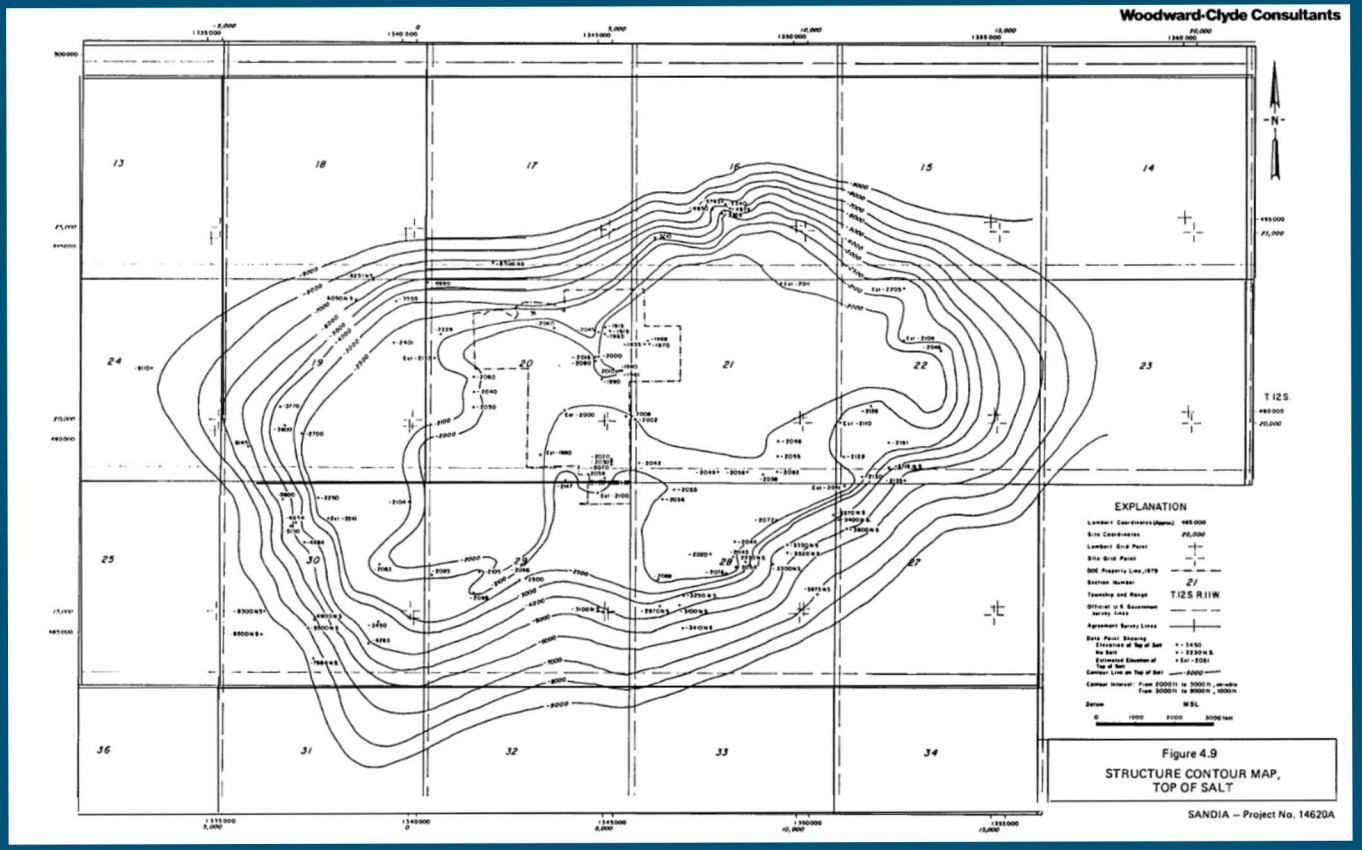
- Well Data
  - Well logs, geologic logging
  - Salt picks
  - Caprock picks
  - Indirect information
- Seismic Data
  - 2D seismic data
  - 7 seismic lines in total
- Previous Mapping

Seismic Data

- Processing supervised by Geostock Sandia
- 2D seismic lines
- 7 seismic lines total
- Reprocessed – depth migrated
- Determination of salt picks with well control

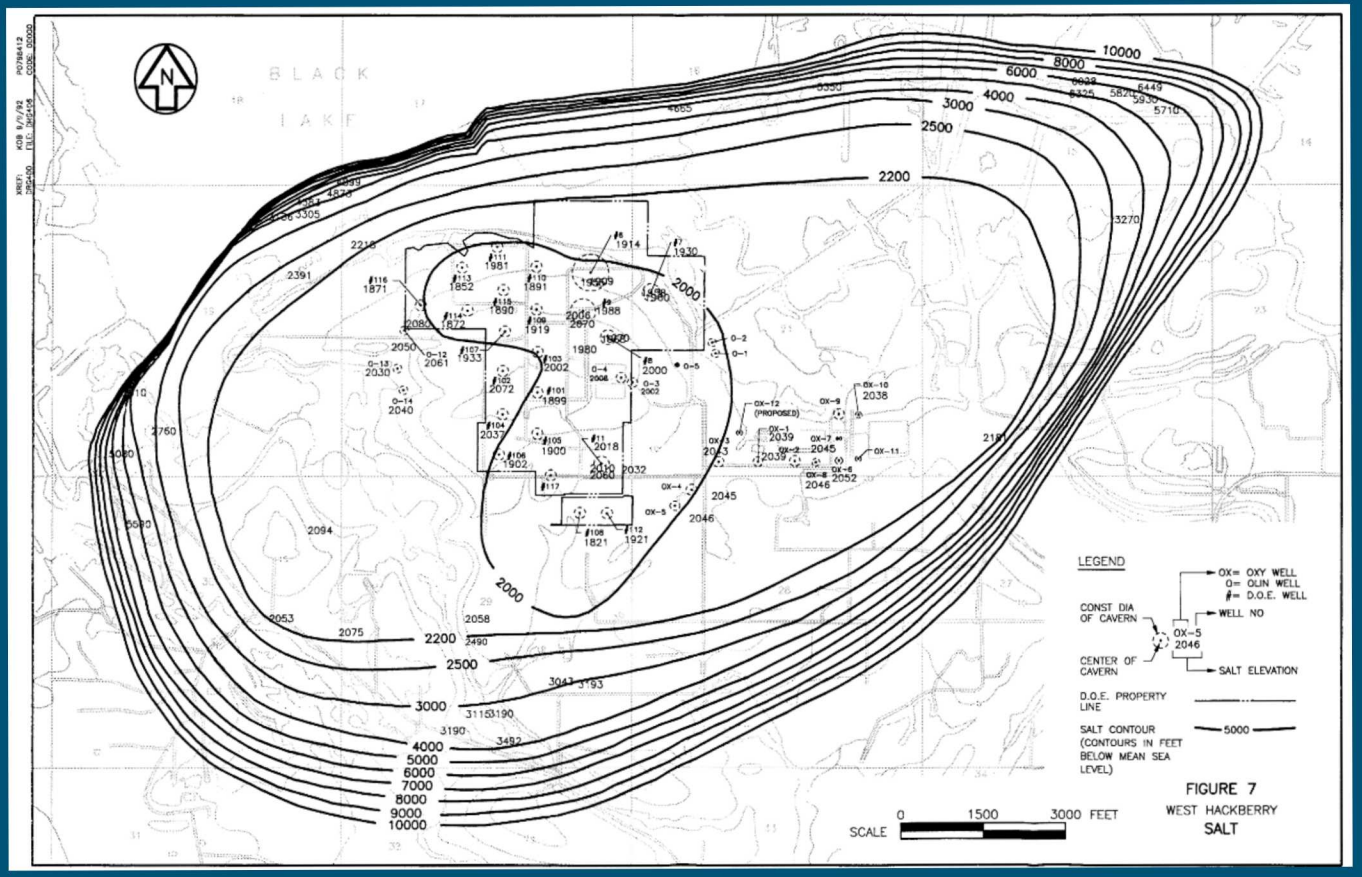


Previous Mapping Products



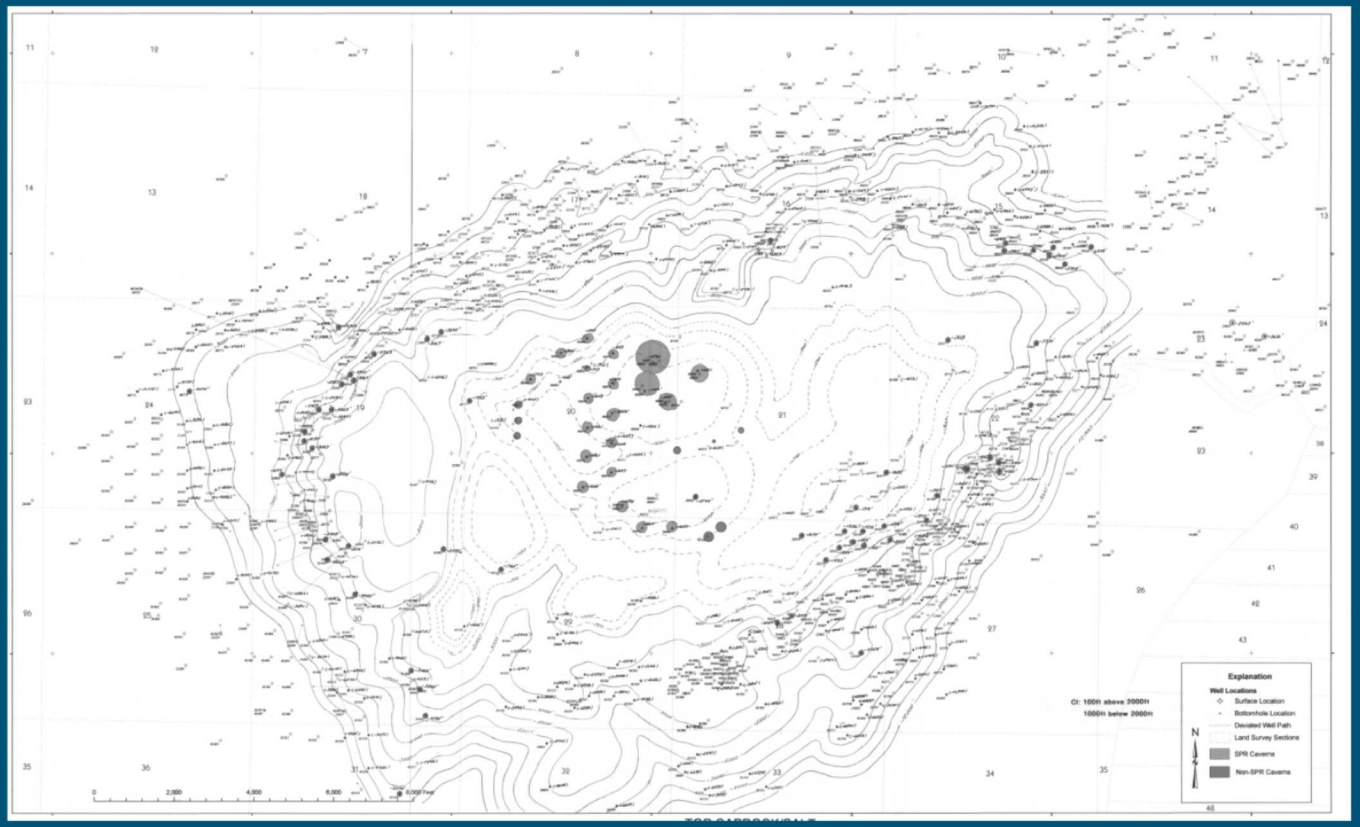
WH top of salt map from GC report – 1981 (SAND80-7131)

Previous Mapping Products



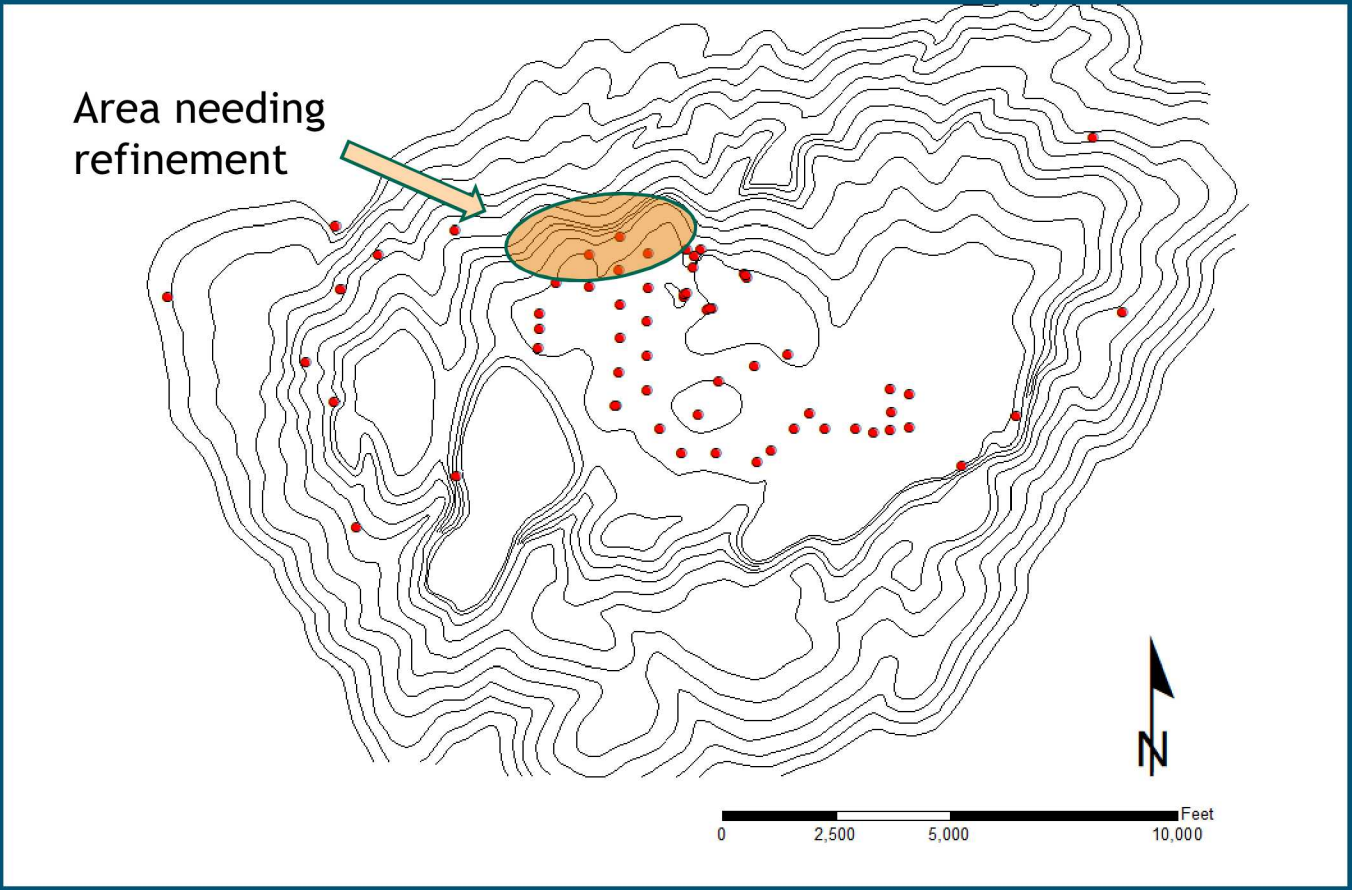
WH top of salt map from GC report – 1991 (SAND90-0224)

Previous Mapping Products



Comprehensive Mapping (salt and caprock) ~2006

Well Top of Salt Data



Distribution of well salt picks

Salt Dome Mapping Refinement

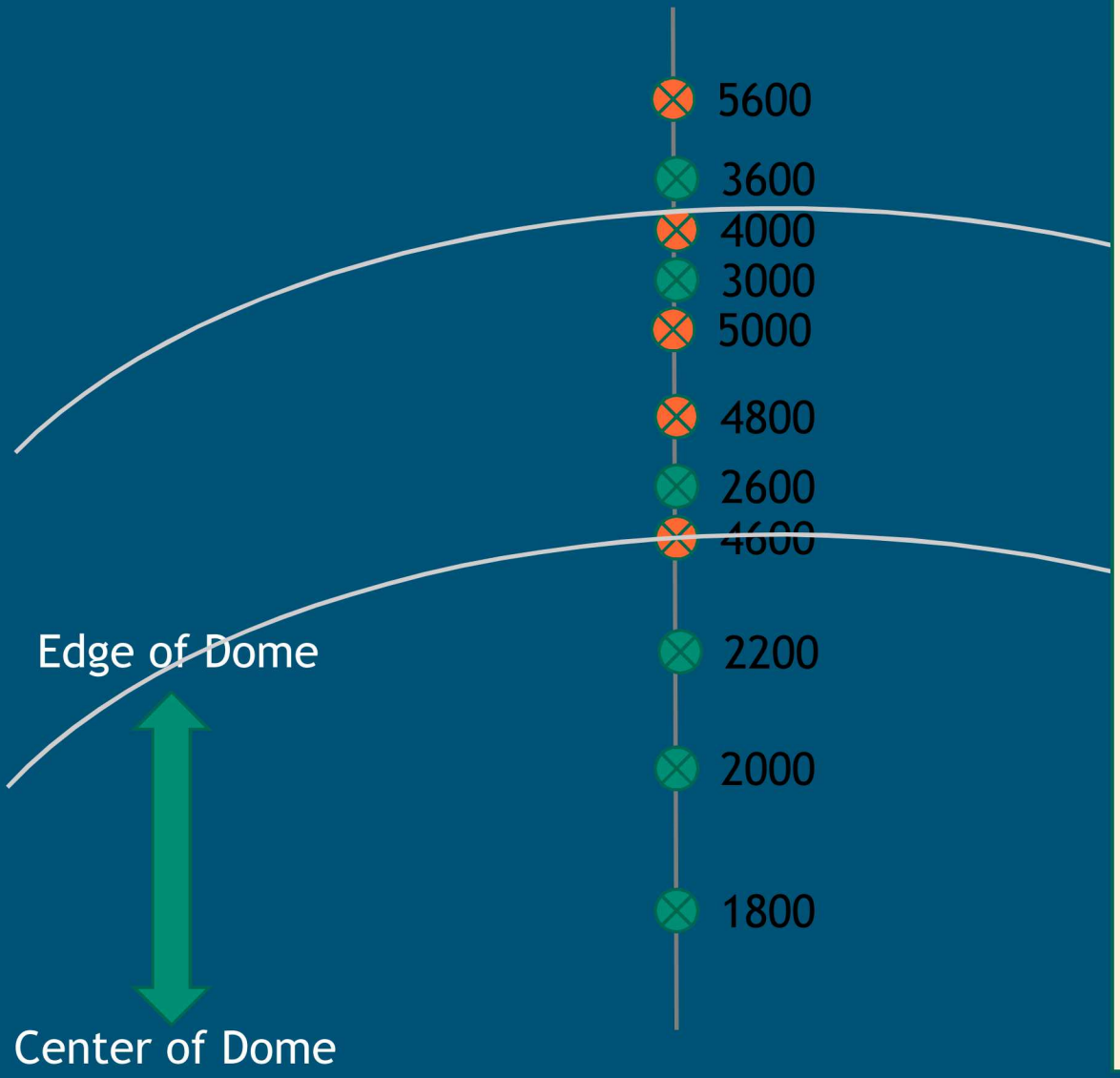
Mapping Workflow

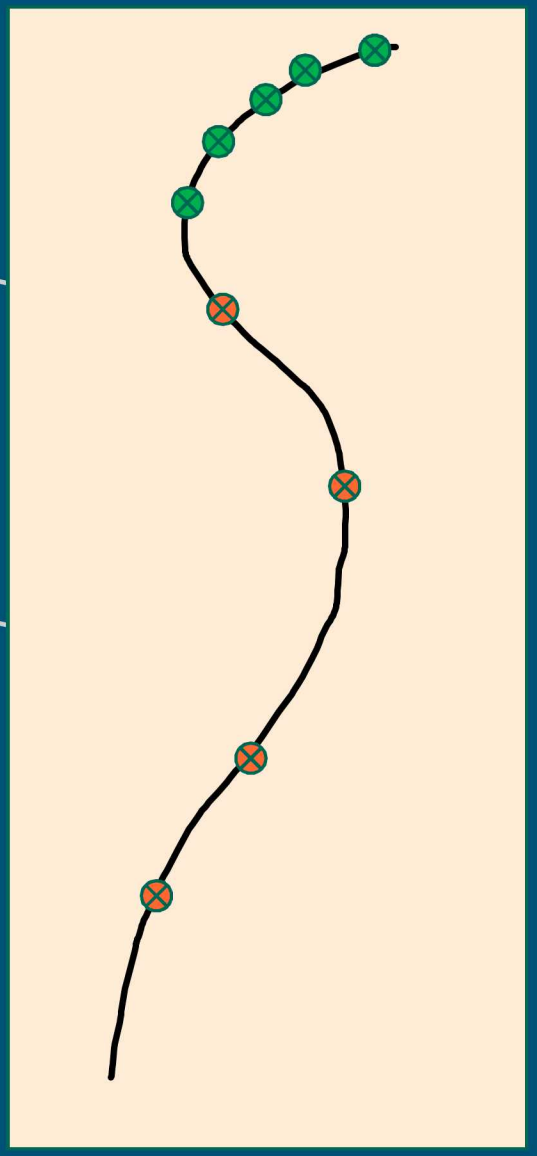
1. Licensing and reprocessing of historic seismic data
2. Manual inspection and determination of salt picks
    1. Seismic reflection data
    2. Well control
    3. Historic mapping
3. Mapping updates using seismic salt picks
    1. 2D contour mapping
    2. 3D QA/QC and interpretation
4. 3D model development
5. Model QA/QC
6. Cavern-to-Dome proximity analysis

Geostock Sandia

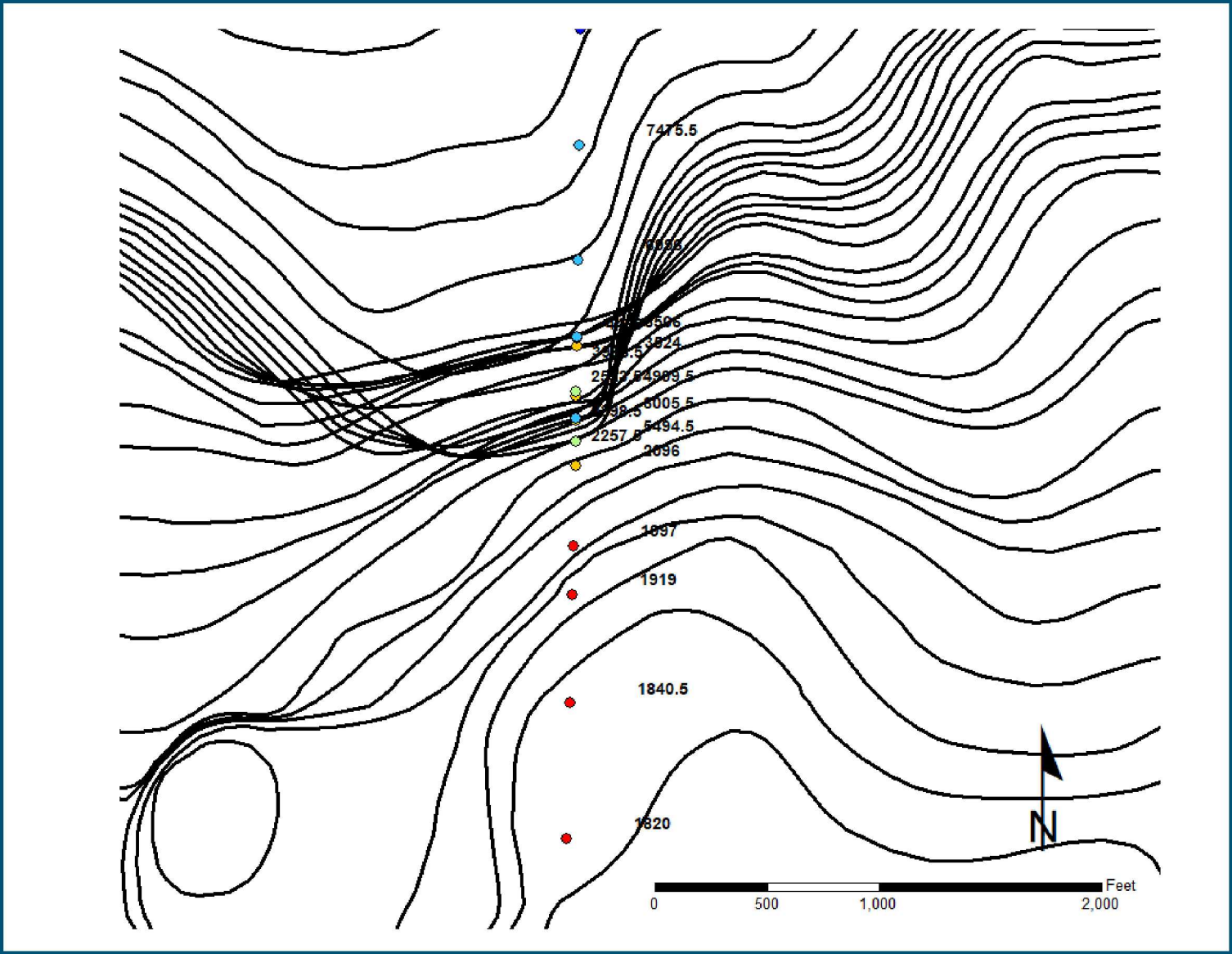
Sandia Nat. Labs

Mapping Seismic Picks – Challenges of 2D Mapping

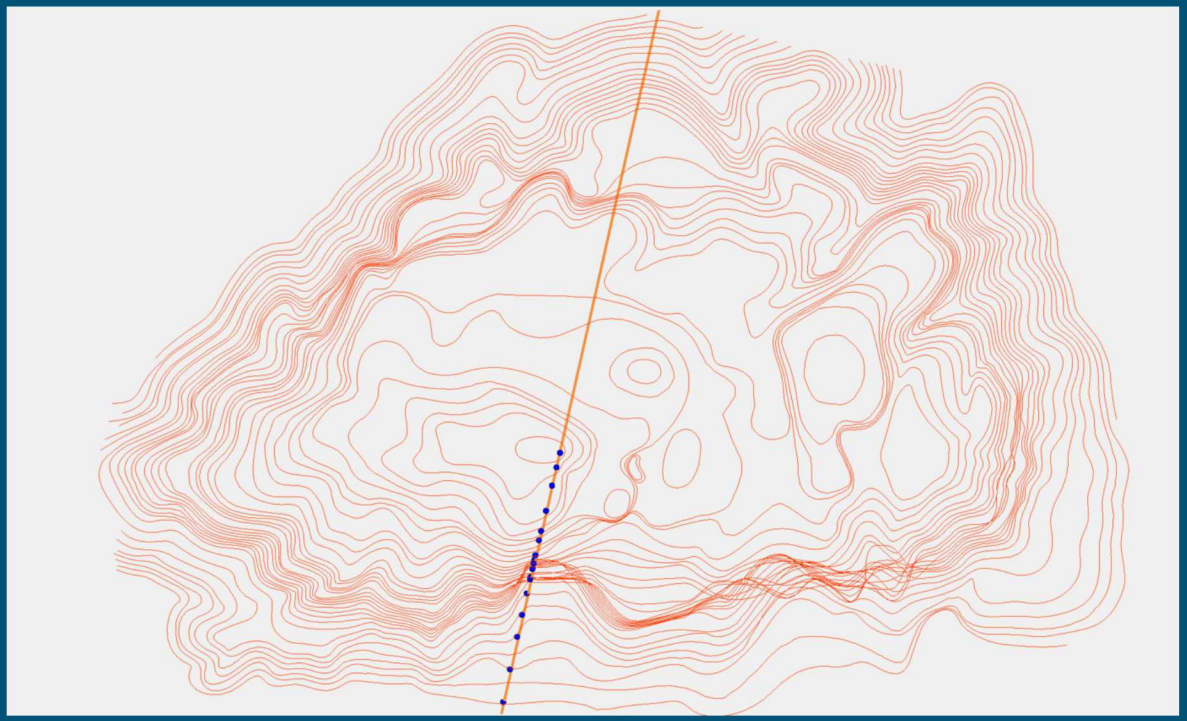




Mapping Seismic Picks – Challenges of 2D Mapping



Mapping Seismic Picks – 3D View



4DIM interactive inspection

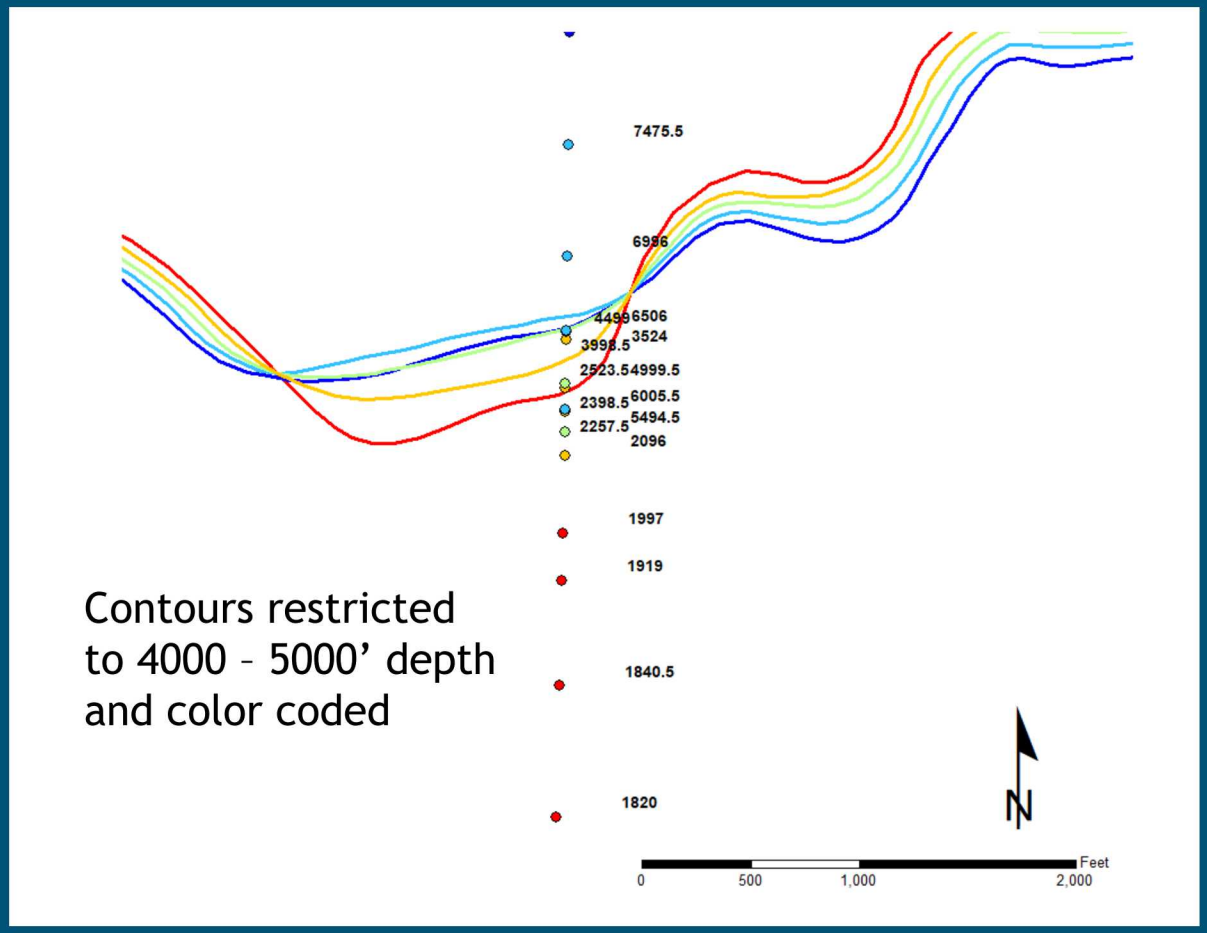
Challenges – Edit in 2D with QC in 3D

- Contour editing is best done in 2D
  - Reflects final map product
  - More intuitive work environment
  - Comprehensive editing tools
- Checking of the contours is best done in 3D
  - Represents true spatial relationships
  - Infinite view points – optimal views of specific relationships

Workflow Guidelines

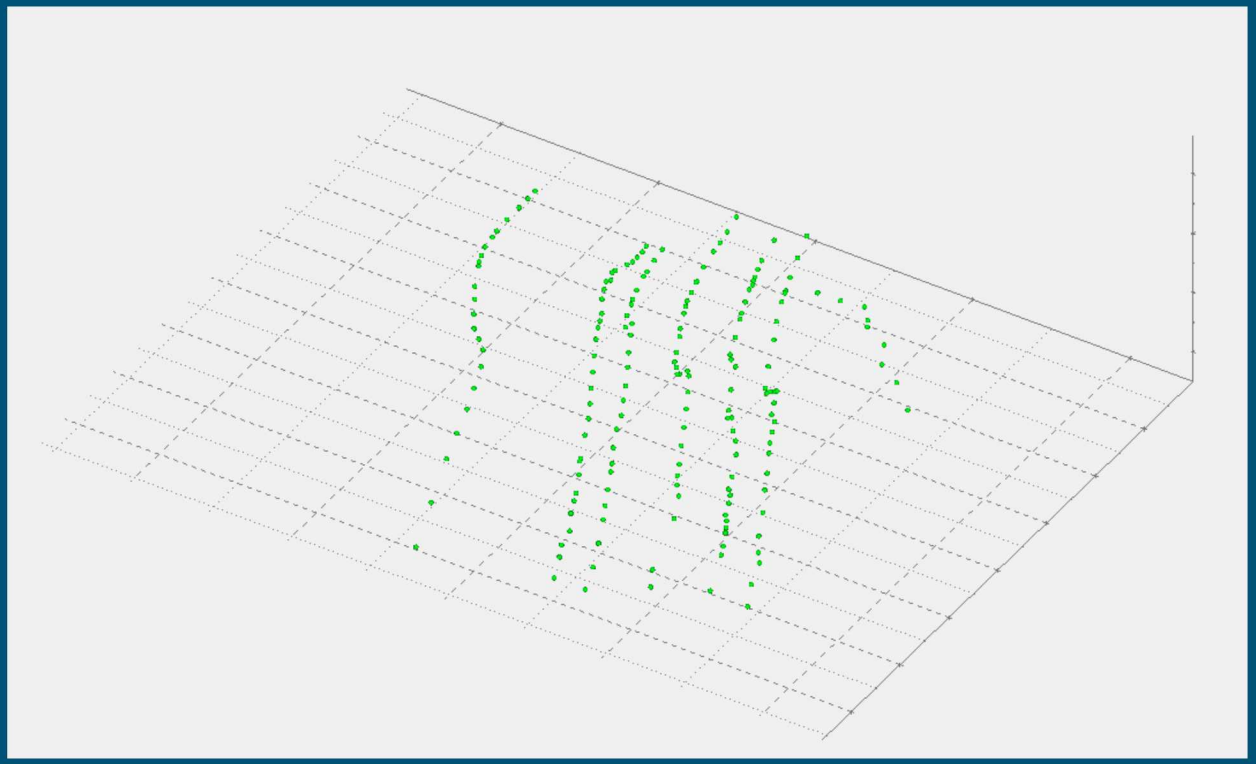
- Work with only a subset of contours
- Color code for additional clarity
- Use tools with a common file format
  - ArcGIS
  - Earth Volumetric Studio
  - Both can use shapefile format
- Combine 2D and 3D work environments as seamlessly as possible

2D Editing Environment



Contours restricted to 4000 – 5000’ depth and color coded

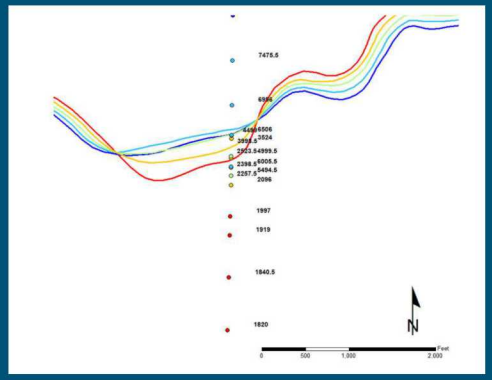
3D Quality Check Environment

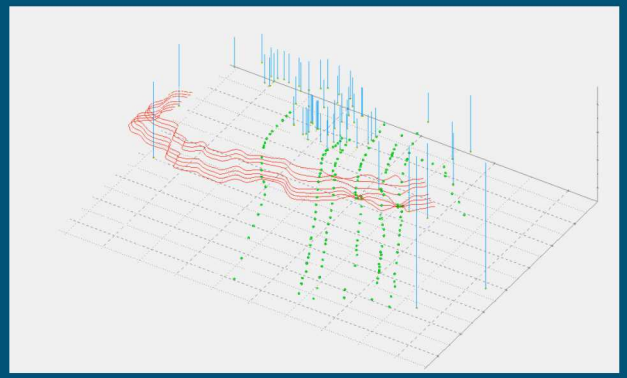


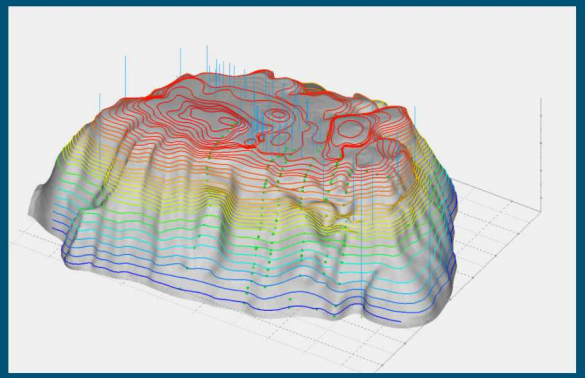
4DIM interactive inspection

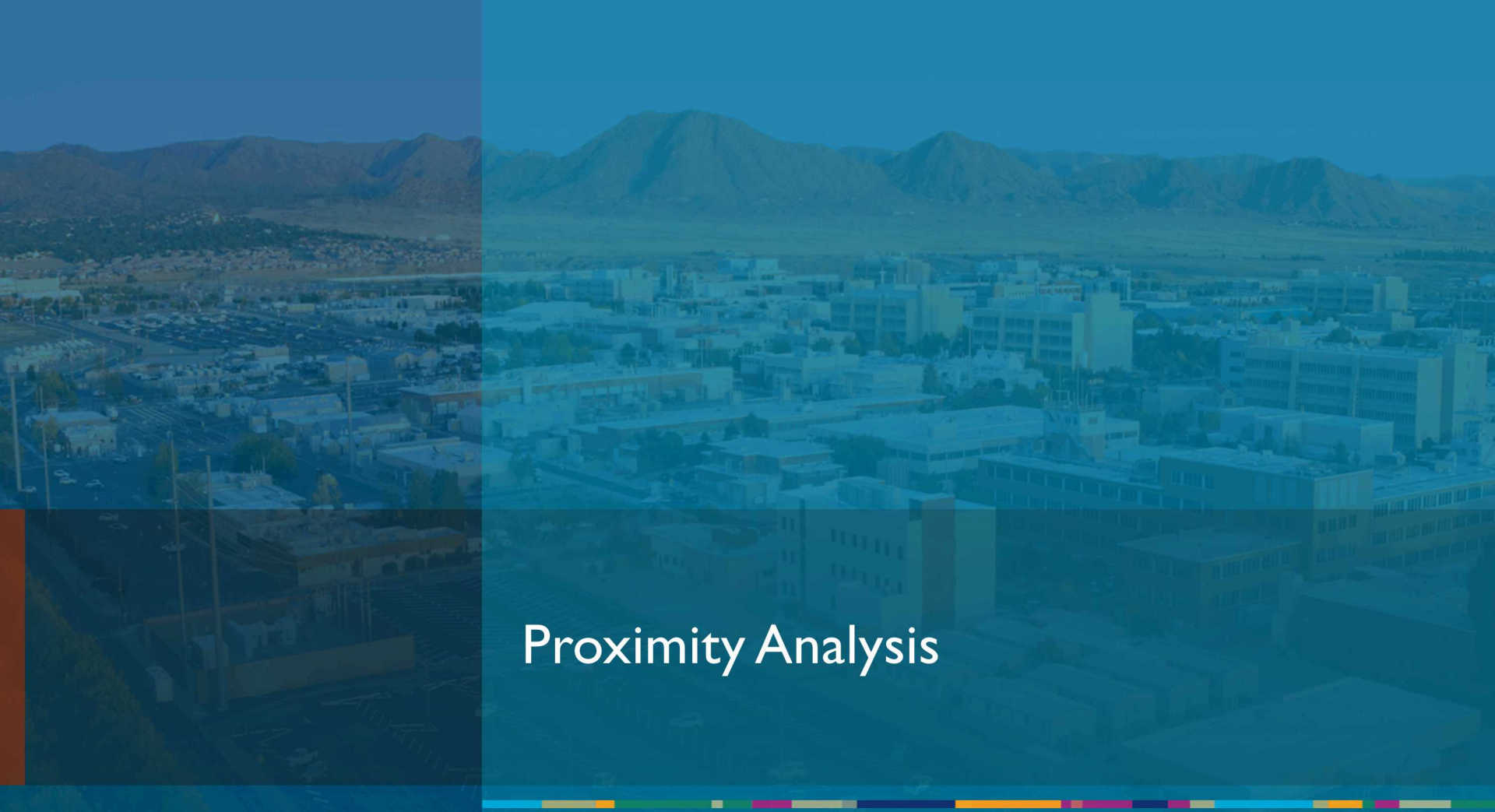
Final Contour Editing Workflow

- Edit contours in 2D to reflect seismic pick data and well control
- Bring contours into 3D review environment to check spatial relationships
- Generate 3D interactive visuals for final review by workgroup
- Use final top of salt contours to generate 3D model for use in proximity analysis



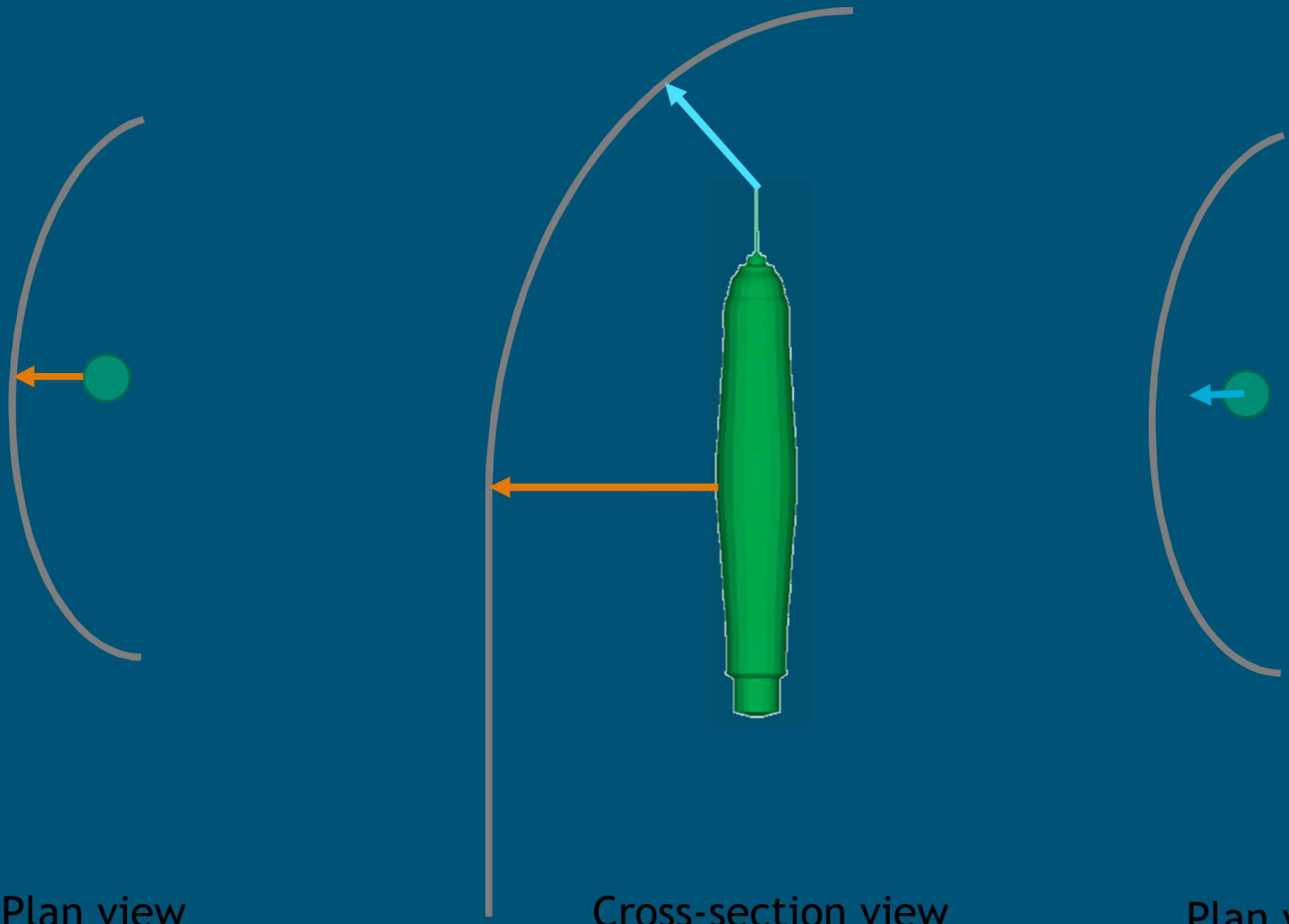






Proximity Analysis

Calculating Distance to Salt Margin

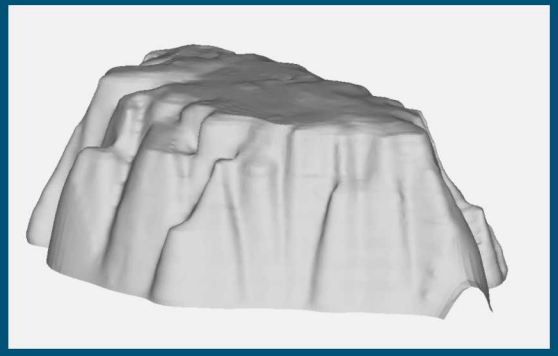


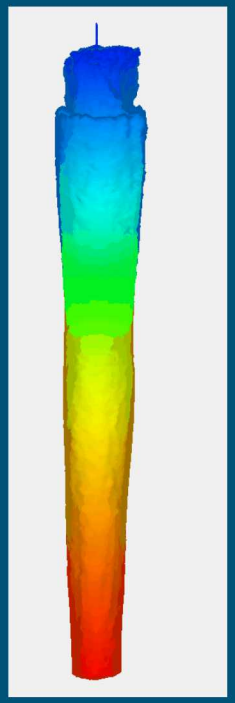
Plan view

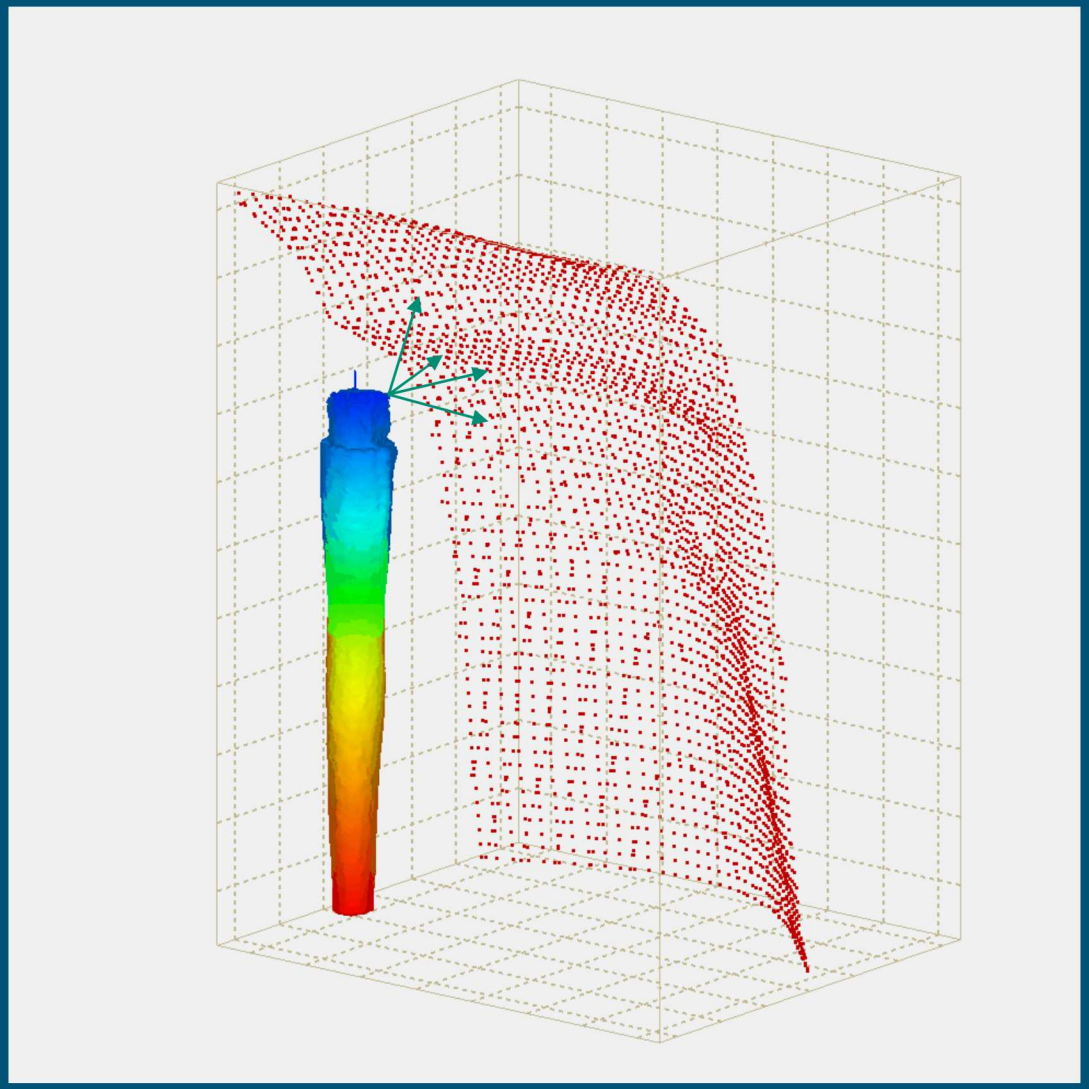
Cross-section view

Plan view

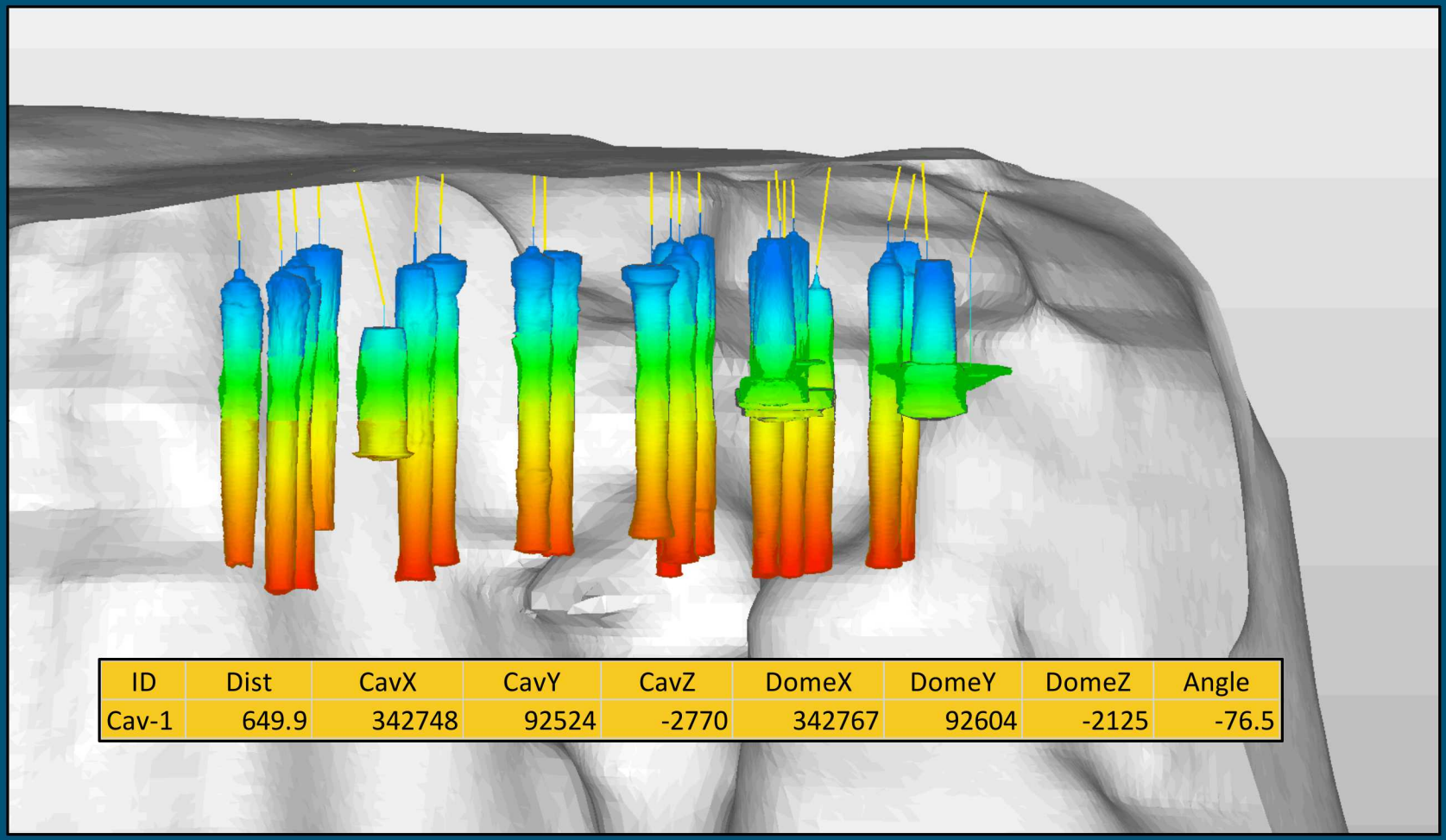
Nearest Neighbors Calculation







Example NN Processing Output



ID	Dist	CavX	CavY	CavZ	DomeX	DomeY	DomeZ	Angle
Cav-1	649.9	342748	92524	-2770	342767	92604	-2125	-76.5

Automated Proximity Computations

Python Code For Nearest Neighbor Calculations

```
dist = dometree.query(cavdata)              # query cavern nodes against domenode KD tree
mindist = min(dist[0])                      # min distance
minindex = numpy.argmin(dist[0])            # index of the min distance in the dist array
mincavnode = cavdata[minindex]              # coords of cavern node with min distance
mindomenode = domedata[dist[1][minindex]] # coords of dome node with min distance

deltax = mindomenode[0] - mincavnode[0]   # get distances between X, Y, Z of the cavern and dome min distance nodes
deltay = mindomenode[1] - mincavnode[1]
deltaz = mindomenode[2] - mincavnode[2]
minvectangle = math.atan(deltax/deltay)       # angle of min distance from north CCW in radians, only considers X and Y, assumes projected to XY plane, Z-
minvectangle = (minvectangle*180.0)/math.pi   # angle from radians to degrees
if minvectangle<0:                            # take care of negative angles
    minvectangle += 180.0
minvectangle -= 90.0                            # MVS has zero degrees as east


nn_out_data.append((thiscav[1], mindist, mincavnode[0], mincavnode[1], mincavnode[2], mindomenode[0], mindomenode[1], mindomenode[2], minvectangle))
cav_end_time = time.perf_counter()
cav_time = cav_end_time - cav_start_time
cav_rate = cav_time/thisfilesize
est_time = (tot_node_file_size * cav_rate)/60
```

Outputs for each cavern:

- File of proximity information
  - Distance, vector angle, cavern point, dome point
- 2D vector shapefile for mapping
- 3D vector for review and cross-sections

ID	Dist	CavX	CavY	CavZ	DomeX	DomeY	DomeZ	Angle
Cav-1	649.9	342748	92524	-2770	342767	92604	-2125	-76.5

Automated Cross-Section Generation

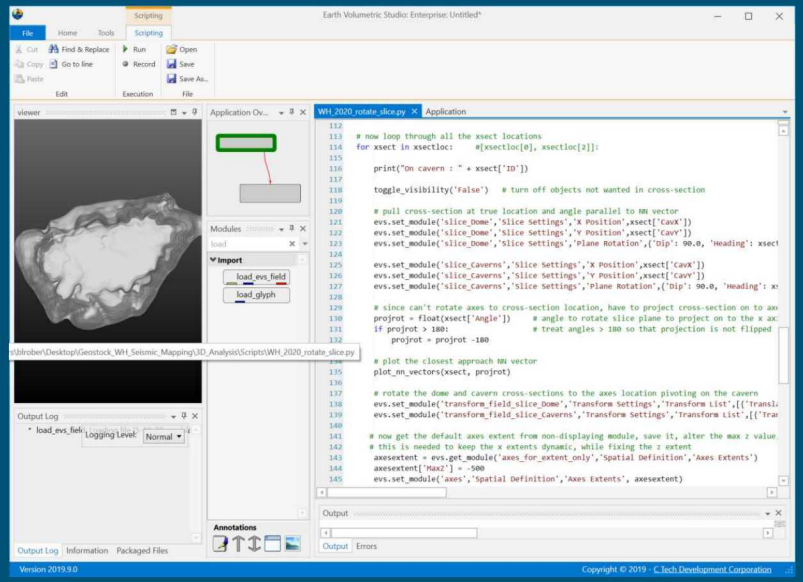
Python code within EVS to generate cross-sections and location maps

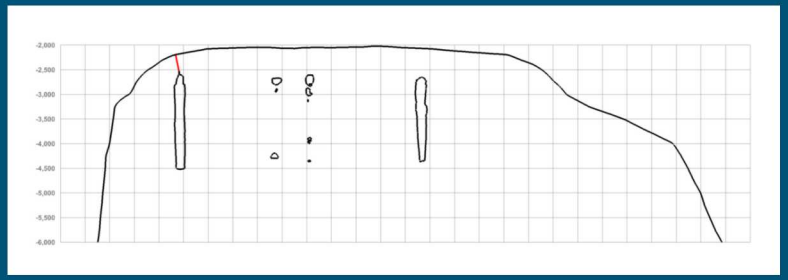
Inputs:

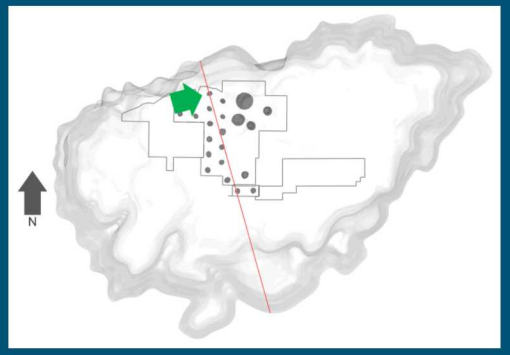
- CSV file from proximity analysis
- Dome 3D model
- Cavern 3D models

Output:

- Cross-sections with proximity vector and cavern and dome outlines
- Location map with section and viewing vector
- 4DIM interactive file



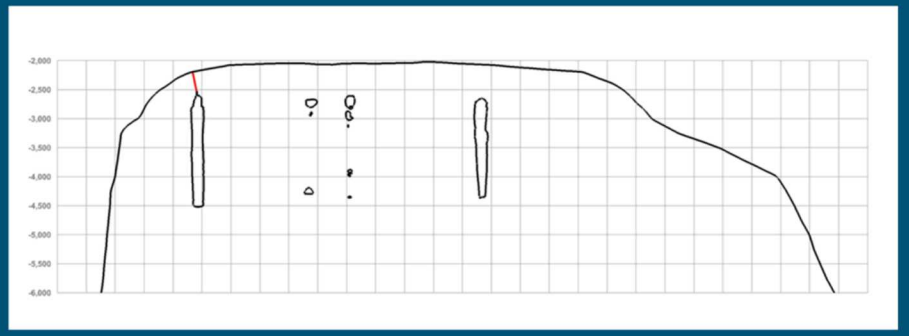




Comparison of 2015 and 2020 Proximity Analysis Results – Cavern WH-111

2020 Results:

- Basically same azimuth
- Vector inclination increased
- Distance increased 57’

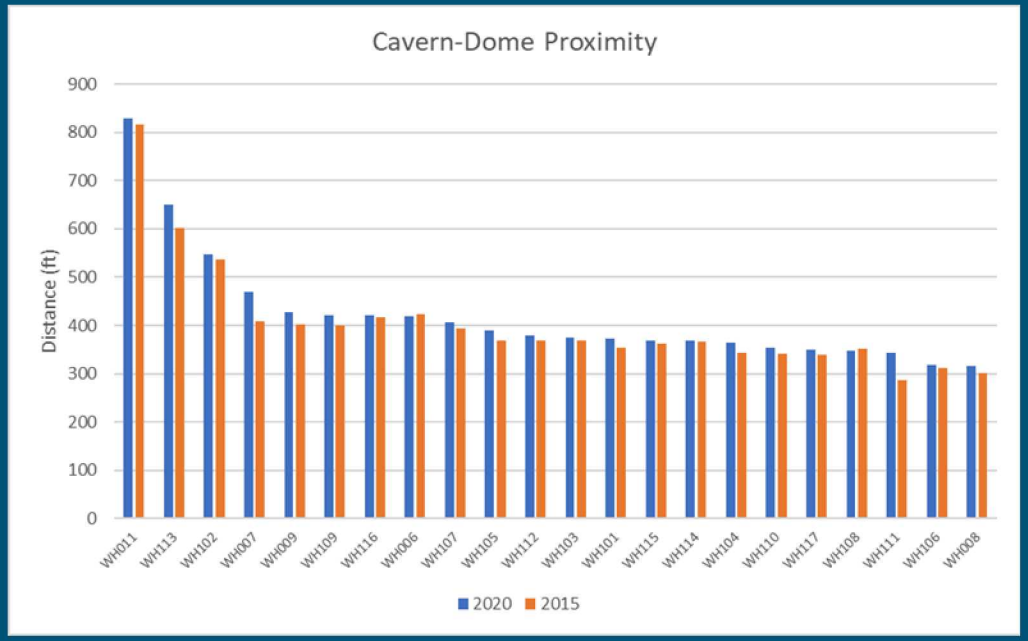


Comparison of 2015 and 2020 proximity analysis results – all caverns

Between 2015 and 2020:

- 2 caverns showed a decrease in distance
- 20 caverns showed an increase in distance
- Average change was 17 feet
- Minimum change was -4 feet
- Maximum change was 60 feet

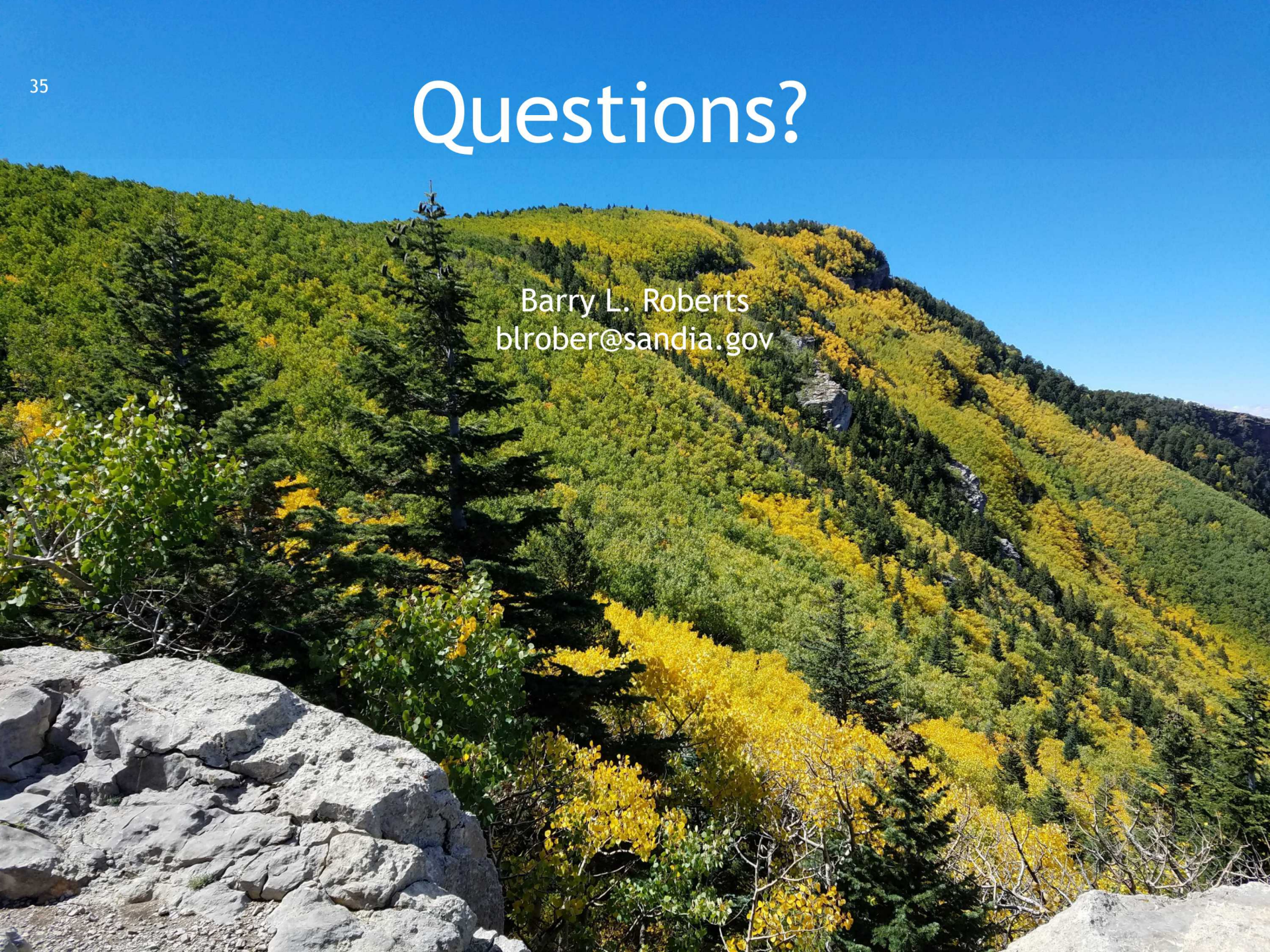
No SPR caverns fall within 300 feet of dome margin



Summary

- Closest approach of West Hackberry salt dome to SPR caverns is along the northern margin
- This area has little well control
- Seismic data are available for this region
- Decision made to refine northern salt dome margin
- Seismic data show northern margin has complex shape with overhanging portions
- Complex, overhanging contour editing requires combination of 2D and 3D edit environments
- Proximity analysis shows seismic refined salt margin is, on average, more distant to SPR caverns than previously modeled
- All SPR caverns are greater than 300 feet from refined salt margin

Questions?



Barry L. Roberts
blrober@sandia.gov