Bharathidasan University

Tiruchirappalli – 620 023, Tamil Nadu

6 Yr. Int. M.Tech. Geological Technology and Geoinformatics

Course Code : MTIGT1003 4 Credits

GIS BASED 3D VISUALIZATION IN GEOLOGICAL TECHNOLOGY

Unit-4: 3D Visualization of Subsurface Lithology

Dr. K.PALANIVEL

Professor, Department of Remote Sensing

Course Objectives

- To learn the fundamentals of 3D visualization in GIS
- To study the possible methods of visualizing various Geological data
- To understand the ways and means of representing topographic relief in a 3 dimensional pattern
- To learn the methods of generating 3D images and interpretation of important geological structures using Geophysical data
- To learn the application of Geoinformatics in natural disaster mitigation.

MTIGT1003: GIS BASED 3D VISUALIZATION IN GEOLOGICAL TECHNOLOGY 4 Credits

Unit-1: Principles of 3D Visualization: Data Input (x, y, z) – Monoscopic and Stereoscopic 3D visualization; TIN – Vertical Exaggeration – DEM based visualization – Concepts of Shaded Relief mapping. **12 Hrs.**

Unit-2: 3D Visualisation of Topographic Data: Generation of x, y, z data – 3D visualization of topography – DEM based topographic analysis – shaded relief – applications. **12 Hrs.**

Unit-3: 3D Visualisation of Geophysical Data: X, Y, Z data from different sources – Generation of DEM, Different processed outputs of DEM, Shaded relief maps of Gravity, Magnetic and Resistivity data – Its applications. **16 Hrs.**

Unit-4: 3D Visualisation of Subsurface Lithology: Collection of borehole data – working out lithology and lithotop of various horizons – DEM of shaded relief of thickness of various formations, Depth of various formations and litho top of various formation – their interpretations. **12 Hrs.**

Unit-5: 3D Visualisation of Groundwater: Collection of water level and other aquifer variables (Transmissivity, Permeability, Storage co-efficient, etc.) – Generation of x, y, z – Generation of DEM and shaded relief of groundwater systems and interpretation. **12 Hrs.**

Unit-6: Current Contours: (Not for Final Exam only for Discussion): Step-by-step procedures for generation of high resolution DEM using CARTOSAT Stereo data; Derivation DEM products like Anaglyph and 3D Fence Diagram. Use of DEM for automated mapping of Geological Structures in GIS.

References

- Burrough, PA., Principles of Geographical Information Systems, Oxford University Press, 1997.
- DeMers, Michael N, Fundamentals of Geographic Information Systems, John Wiley and Sons, 1999.
- David J., Bringing Geographical Information Systems into Business, Second Edition Grimshaw, John Wiley and Sons, 1999.
- Christian, Serving Maps on the Internet: Geographic Information on the World Wide Web Harder, ESRI Press, 1998.
- Graeme F. Bonham-Carter, Geographic Information Systems for Geoscientists: Modelling with GIS, Pergamon Publications, 1994.
- Sabins, F.F.Jr., Remote Sensing Principles and Interpretation, Freeman, Sanfrancisco. 1978.
- Lillisand, T.M. and P.W. Kiefer, Remote Sensing and Image Interpretation, John Wiley & Sons, New York, 1986.

Unit-4: 3D Visualisation of Subsurface Lithology

Unit-4: 3D Visualisation of Subsurface Lithology: Collection of borehole data – working out lithology and lithotop of various horizons – DEM of shaded relief of thickness of various formations, Depth of various formations and litho top of various formation – their interpretations. **12 Hrs.**

Unit:4 - 3D Visualization of Subsurface Lithology

Depiction of Litholog / Bore hole data

- 2D / 3D monoscopic / stereoscopic Vertical cross section of bore holes
- 3D monoscopic / stereoscopic Vertical profiles
- 3D Fence Diagram
- 3D Perspective view of distinct Layer
- 3D Layered Stacking in Combination with proper Layer Separation / offsetting options.

Monoscopic methods of Depth Perception

Distances to objects, or depth can be perceived monoscopically on the basis of

- **Relative sizes of objects**
- **Hidden objects**
- **Shadows and**
- **Differences in focusing of the eye for viewing objects at varying distances.**

Concepts of Shaded Relief mapping

Initially, to create shaded Relief map, slope and aspect are to be calculated based on the plane defined for each triangle.

Slope can be written in degrees by specifying degree and Aspect is always reported in degrees. Zero is north, and values increase clockwise like a compass. Flat triangles will be assigned an aspect value of -1.

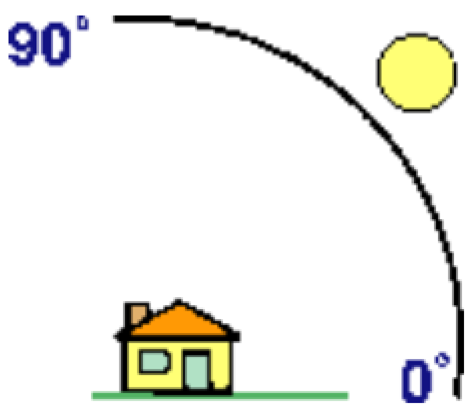
Optionally, a hillshade field can be written containing a brightness value for each triangle. Values range from zero to 255.

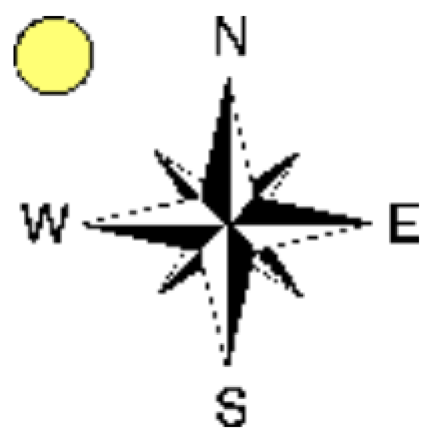
The brightness value is based on the relation between the plane defined by each triangle and a **light source**. The position of the light source defaults to the northwest, with an azimuth of 315 degrees (compass-based with 0 north, positive clockwise) and an altitude of 45.

For Hill shade, it is necessary to obtain the hypothetical illumination of a surface by determining illumination values for each cell in a raster.

It should be done by setting a position for a hypothetical light source and calculating the illumination values of each cell in relation to neighboring cells.

It can greatly enhance the visualization of a surface for analysis or graphical display, especially when using transparency.





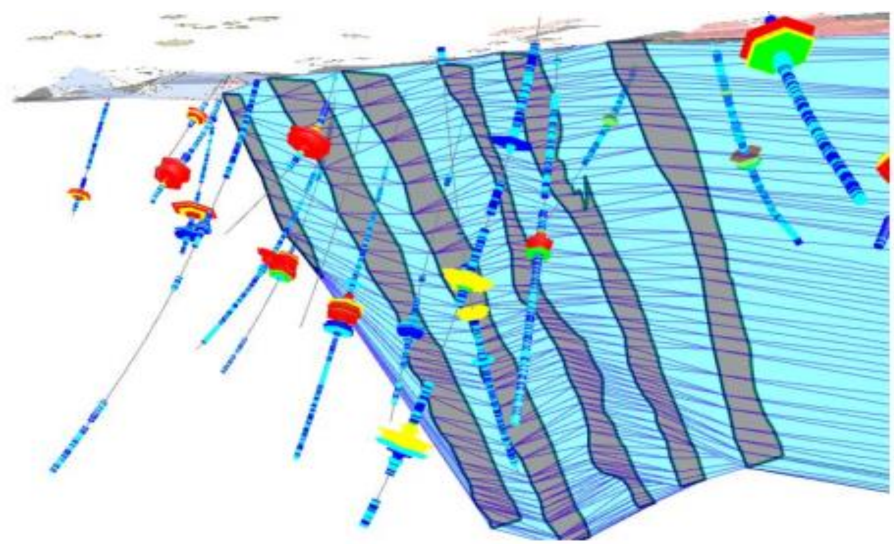
Voxels

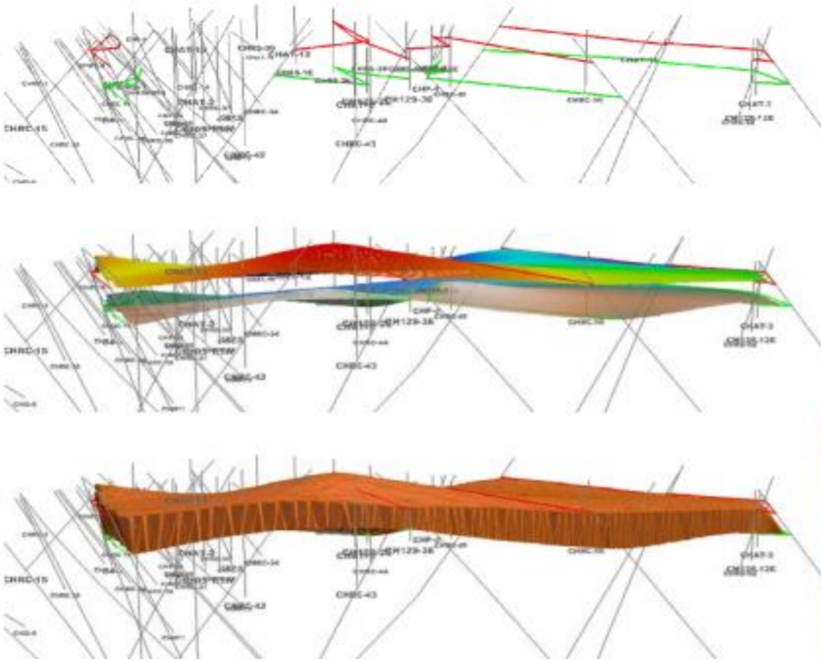
- **Voxels** are 3D / **Vo**lumetric Pi**xels**
- Useful for depicting objects of any type esp., Geological features of surface and subsurface
- Volume estimation with voxels becomes very easy
- Several objects and their spatial distribution in the surroundings can be depicted properly with proper dimensions
- Easy to depict as 3D Layer staked images with **offsets**
- Easy to derive several products such as Fence diagrams, 3D vertical profiles, etc.
- Can derive **isosurface**, i.e., displaying each individual thresholded cell
- It is a surface where a single data value specified to combine the cells to form a surface (called an isosurface).

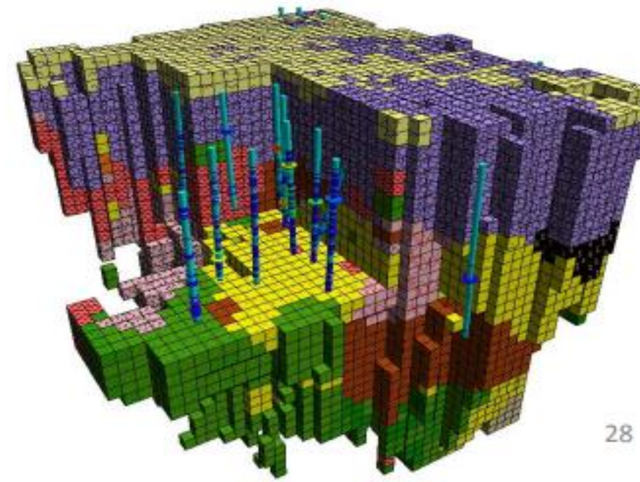
Wireframing

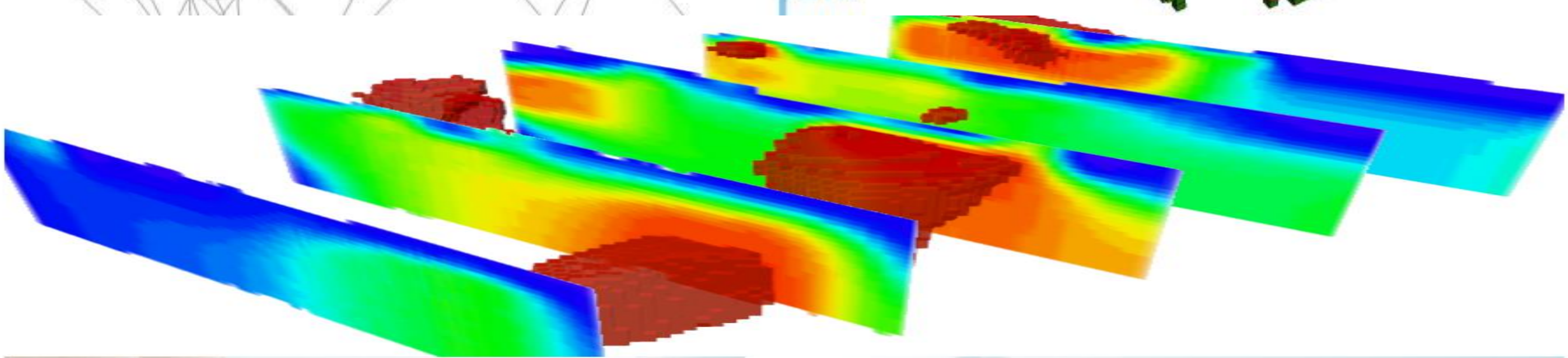
Surface interpolation in 3D

3D Grid/Voxel model Interpolation



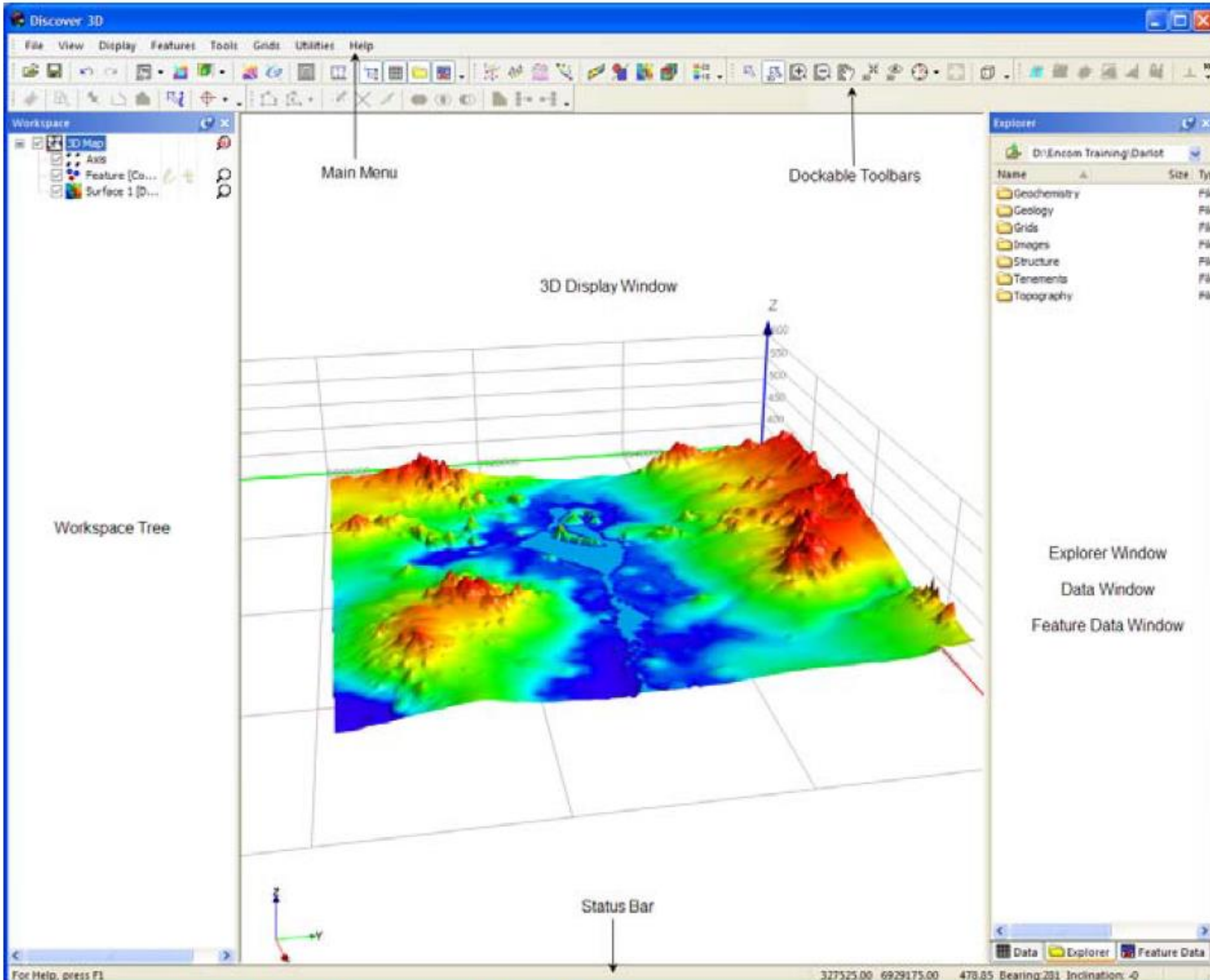




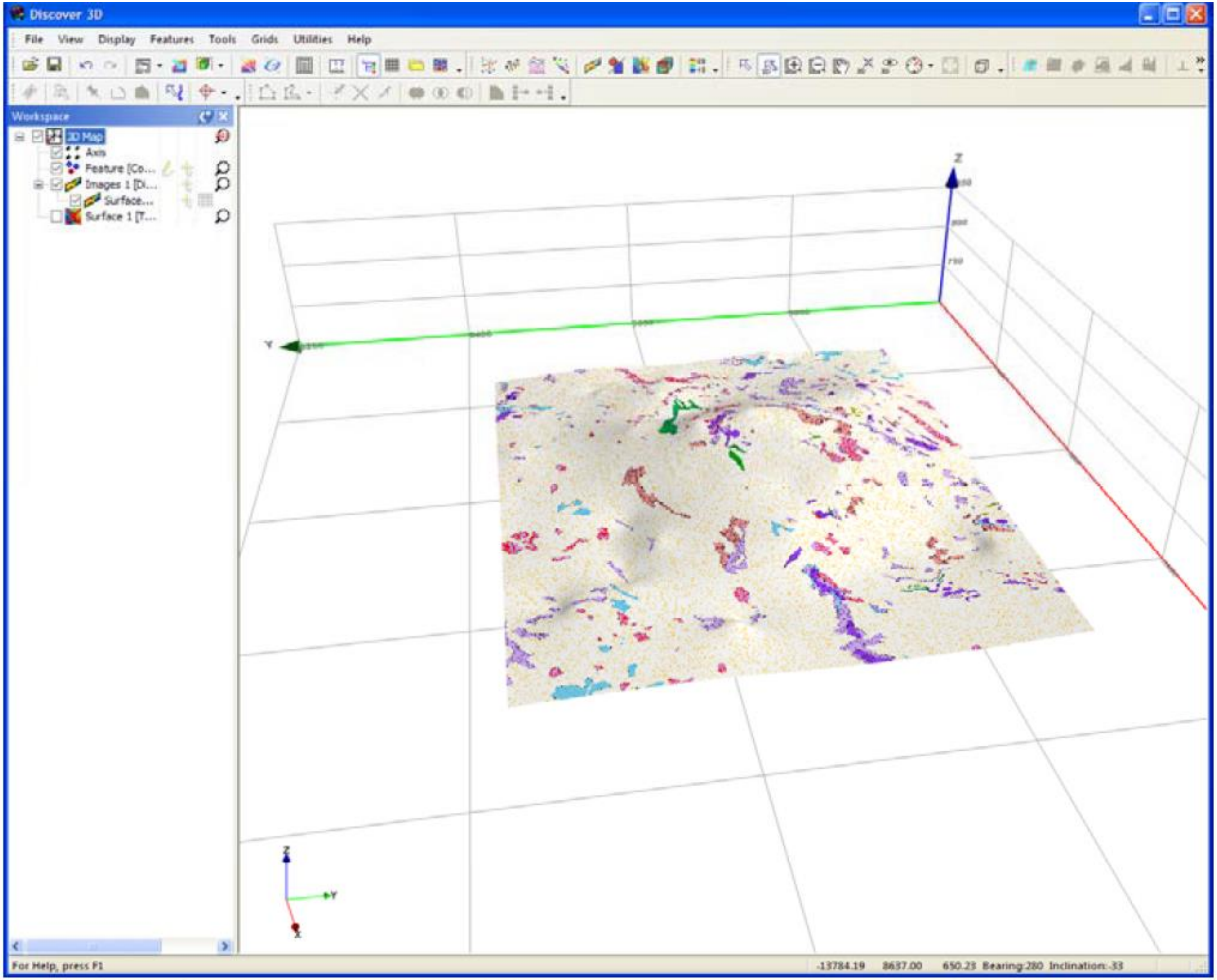


A 3D Visualization Software Product

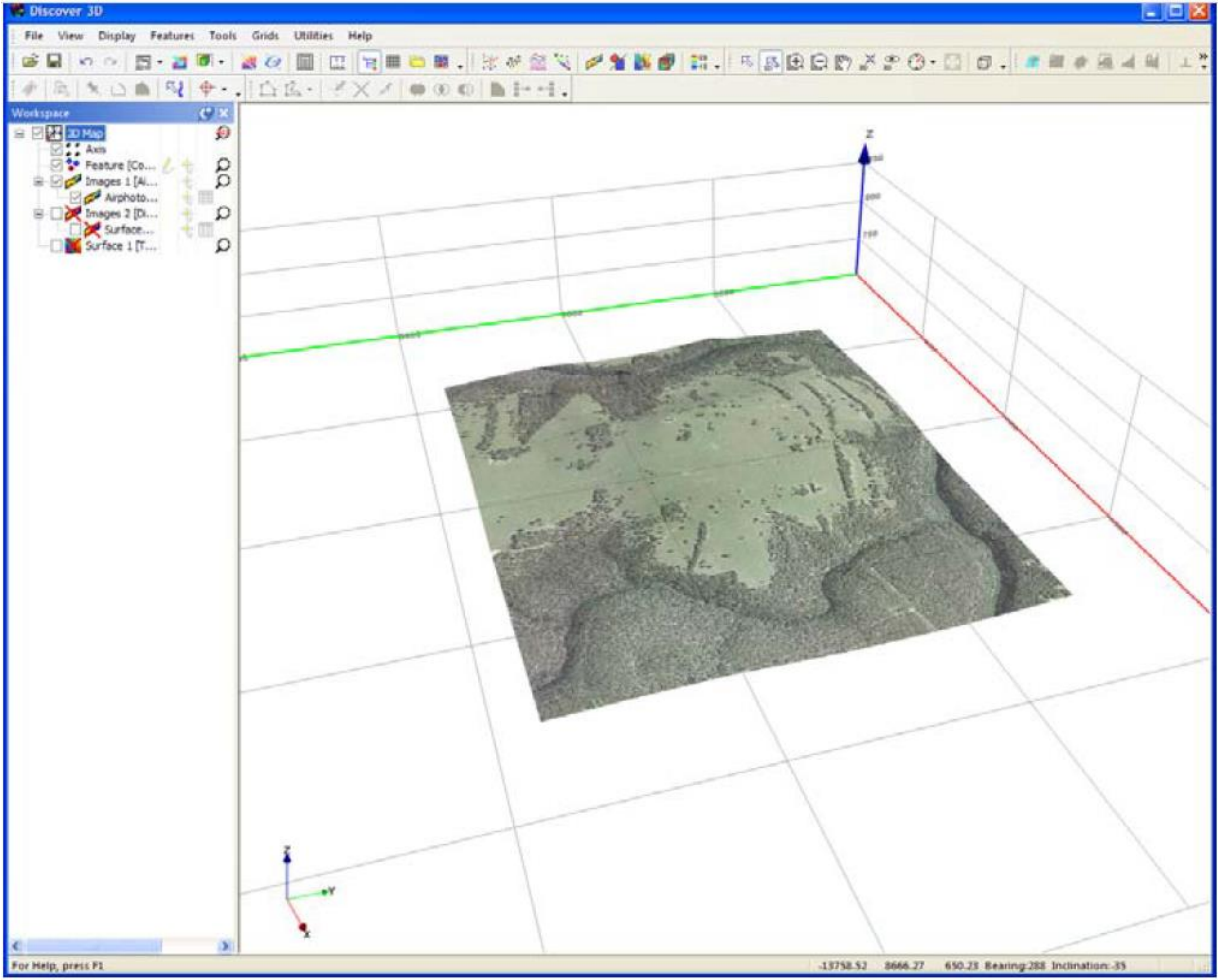
EncomTM
Discover 3DTM
2011



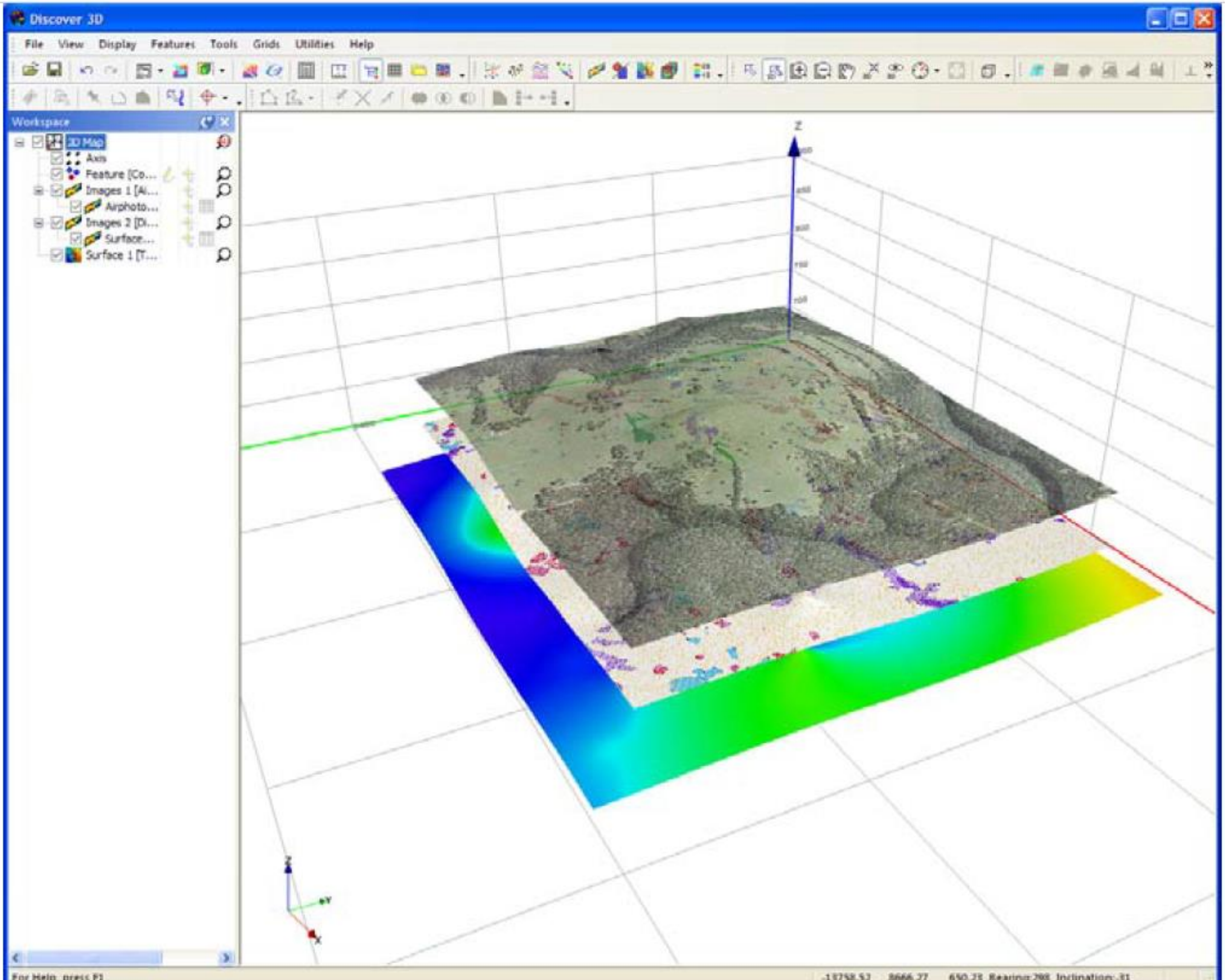
Components of the Discover 3D window.



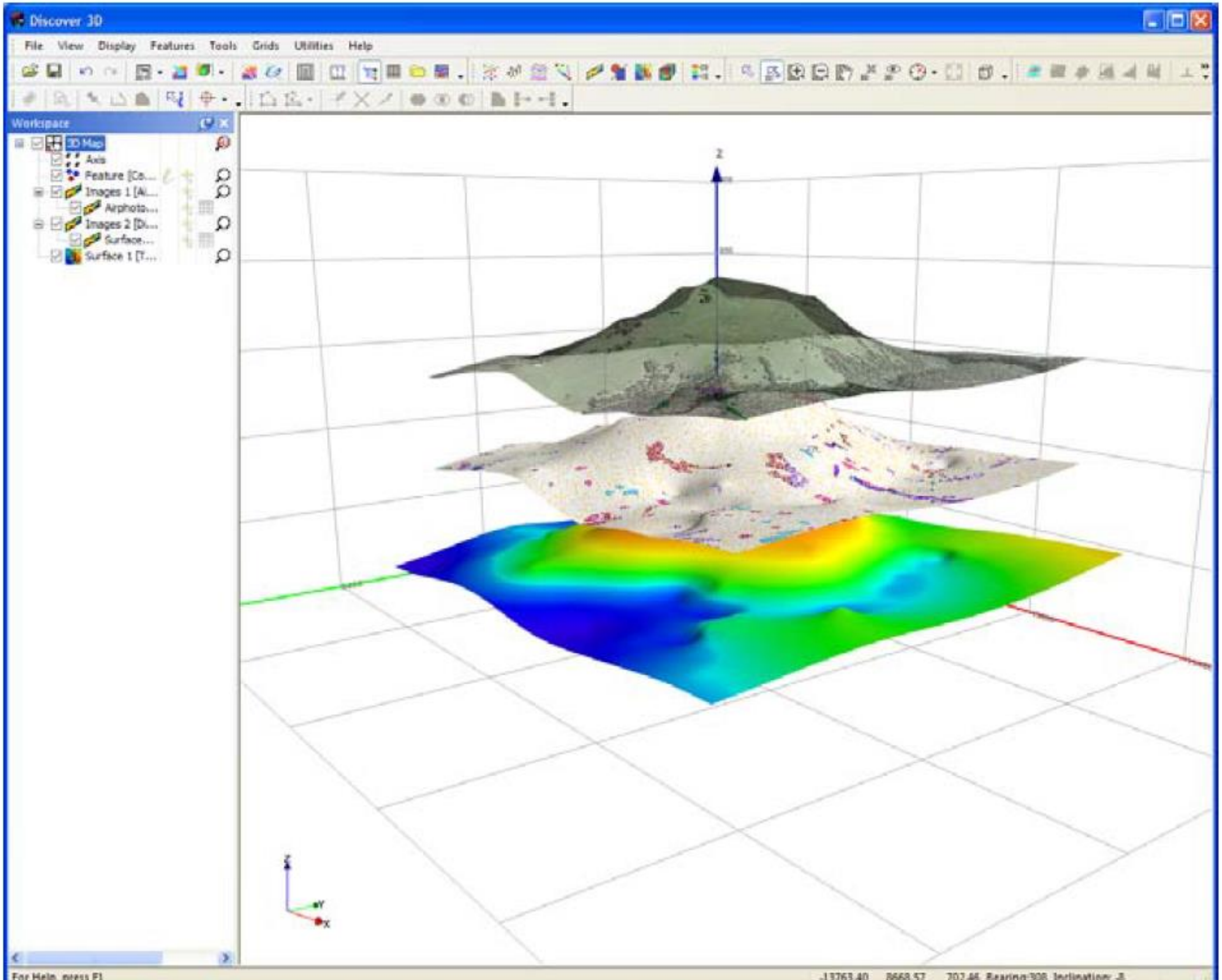
Draped geology layer on surface topography.



Airphoto draped over the surface topography.

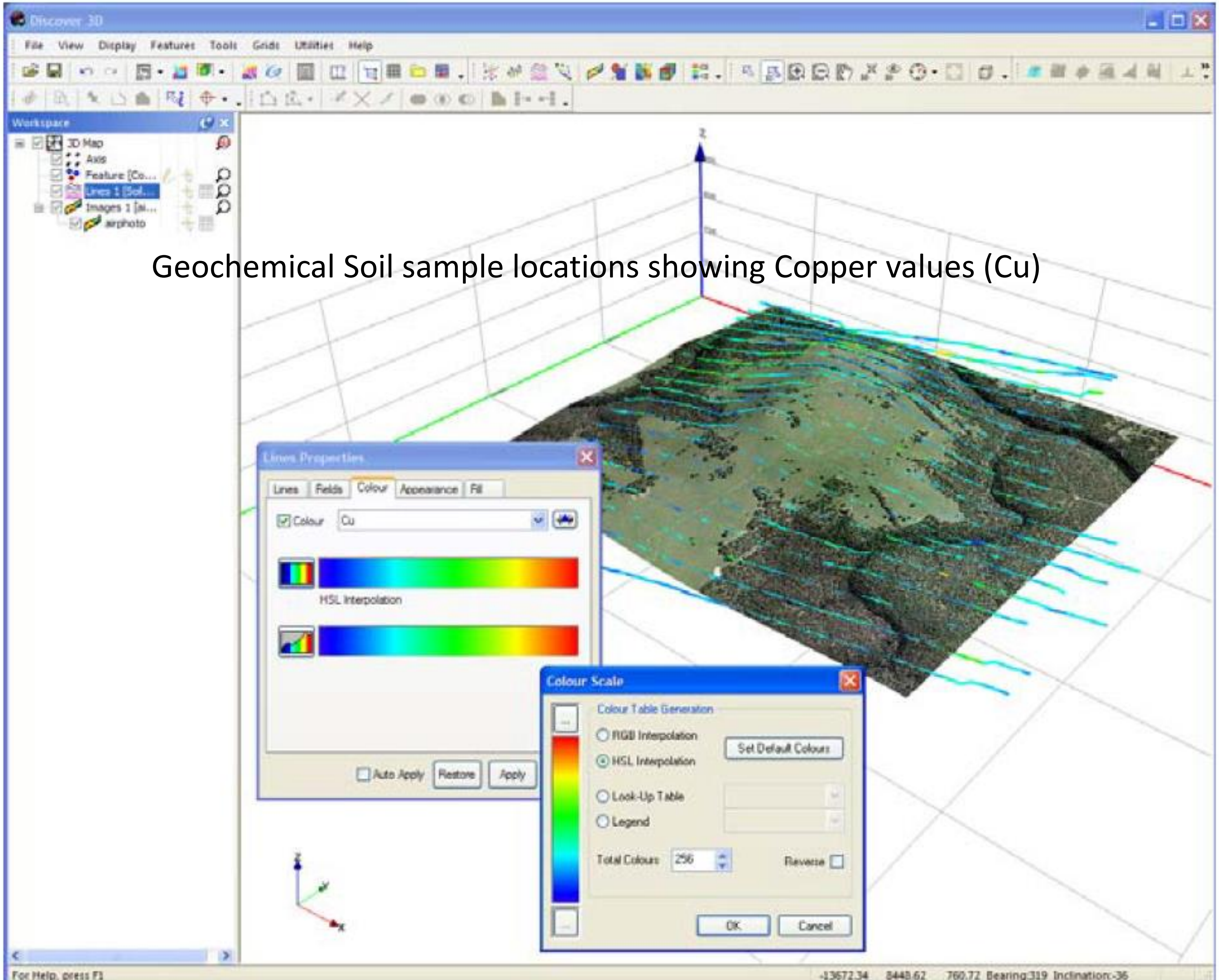


Surface layers offset in 3D.

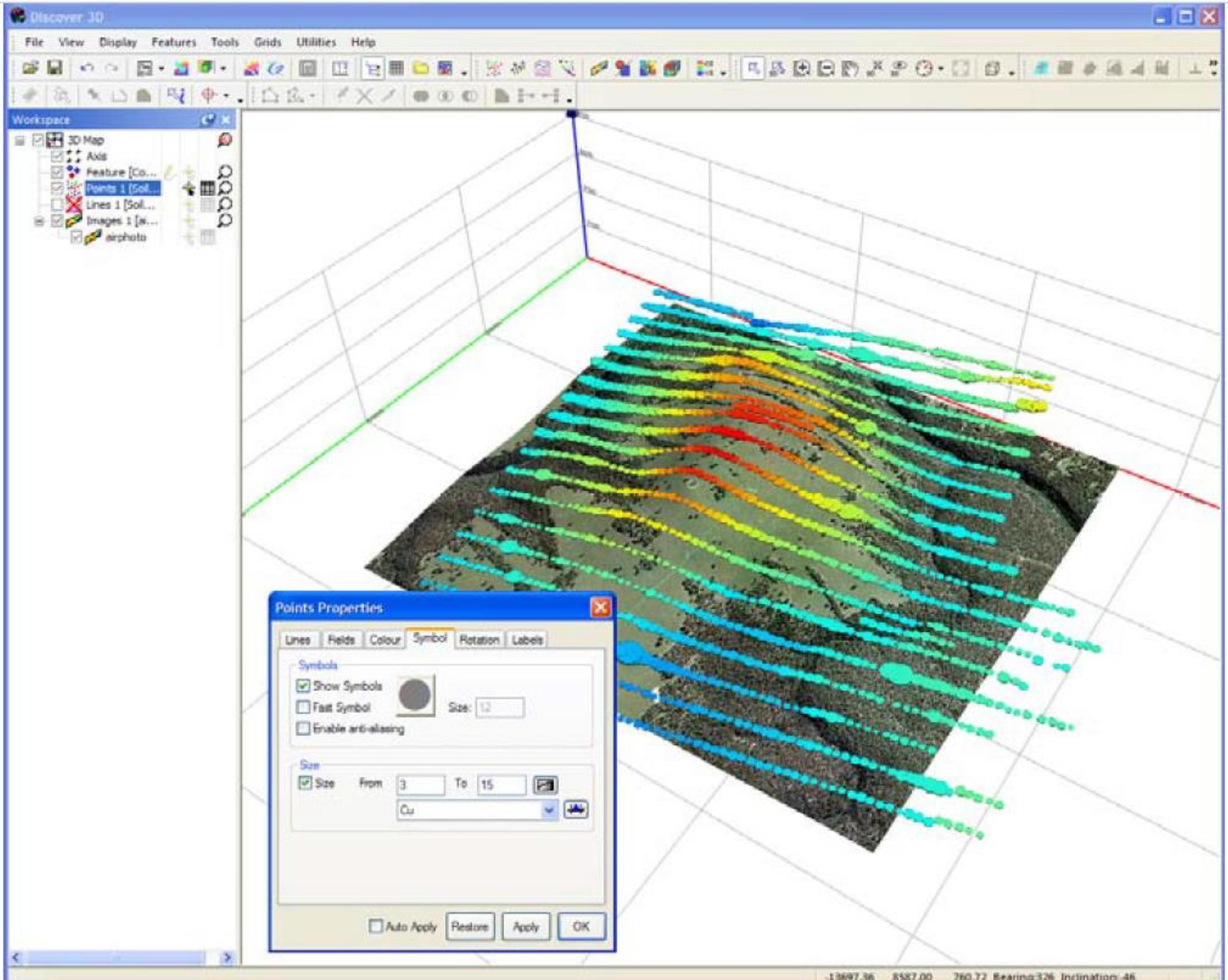


Surface layers offset and rescaled in 3D.

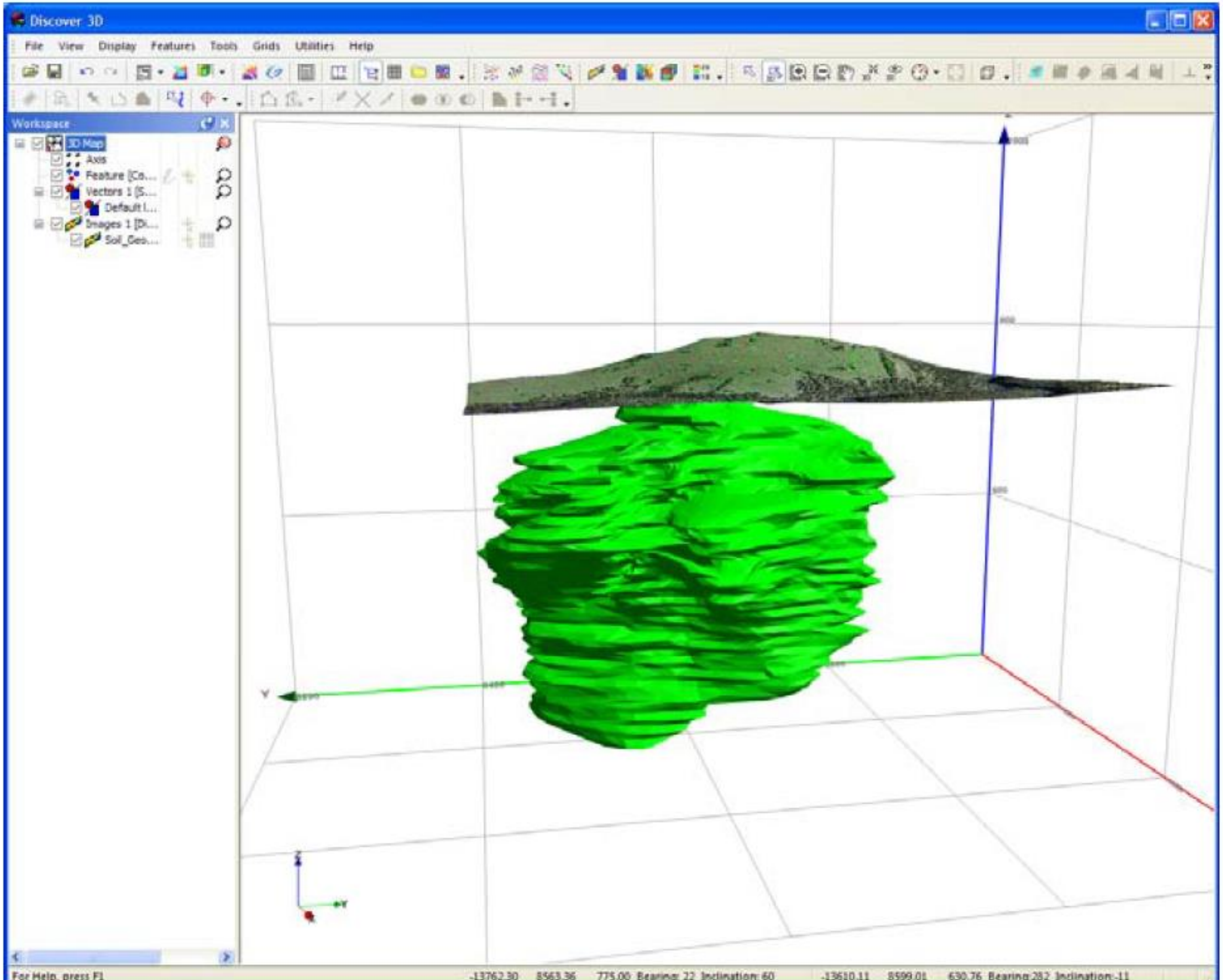
Geochemical Soil sample locations showing Copper values (Cu)



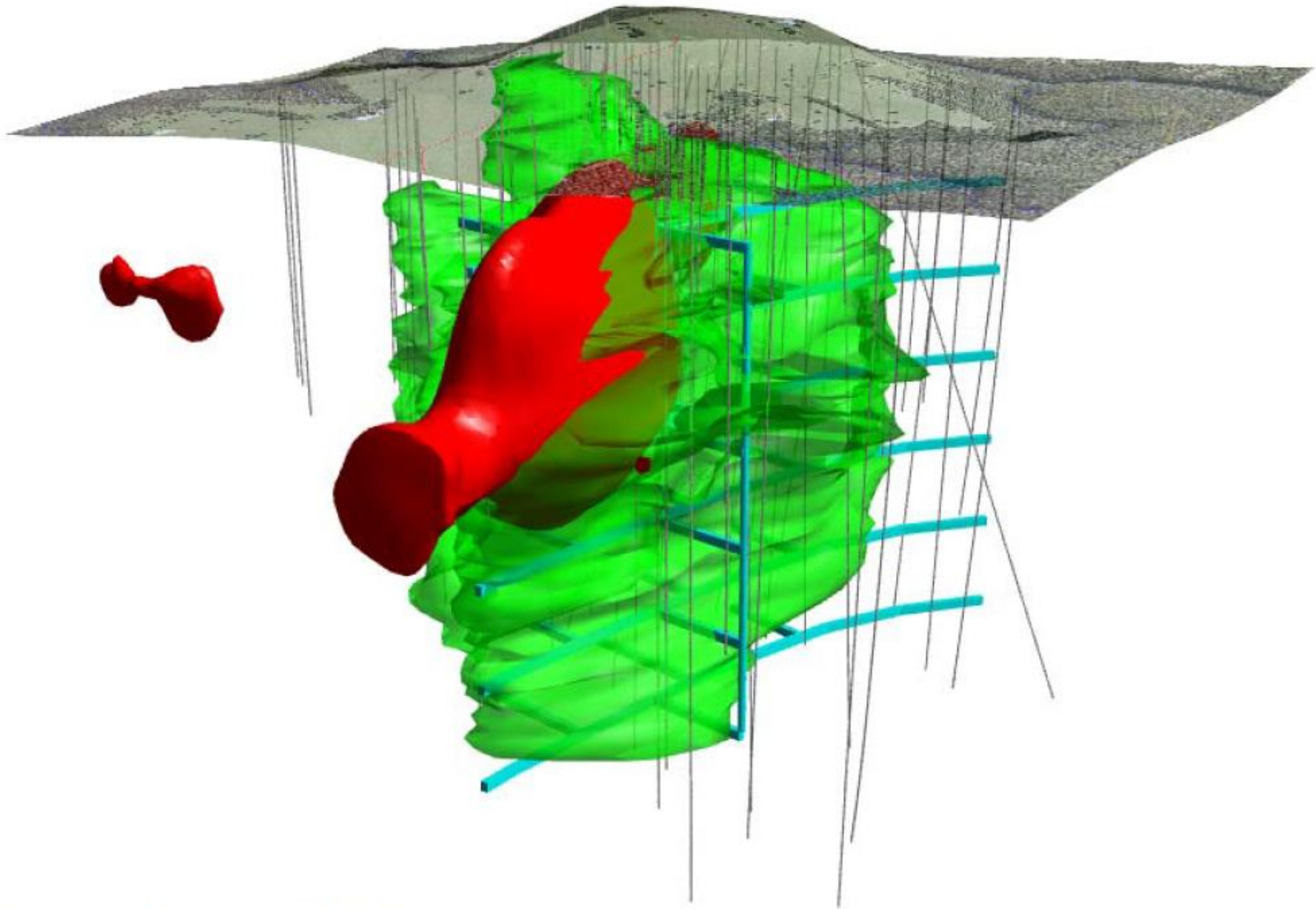
Modulate line colour based on Cu values.



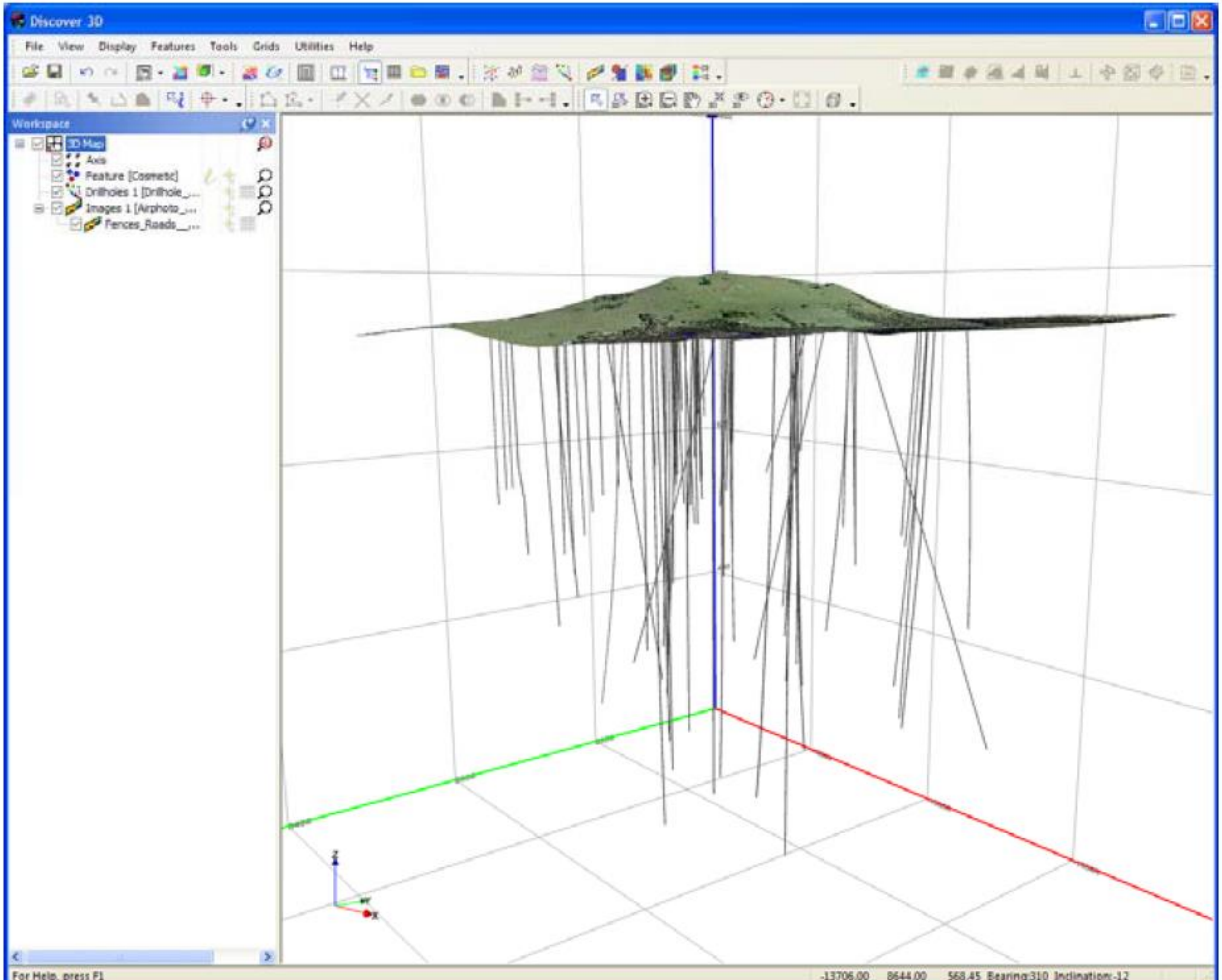
Modulate point size by Cu value.



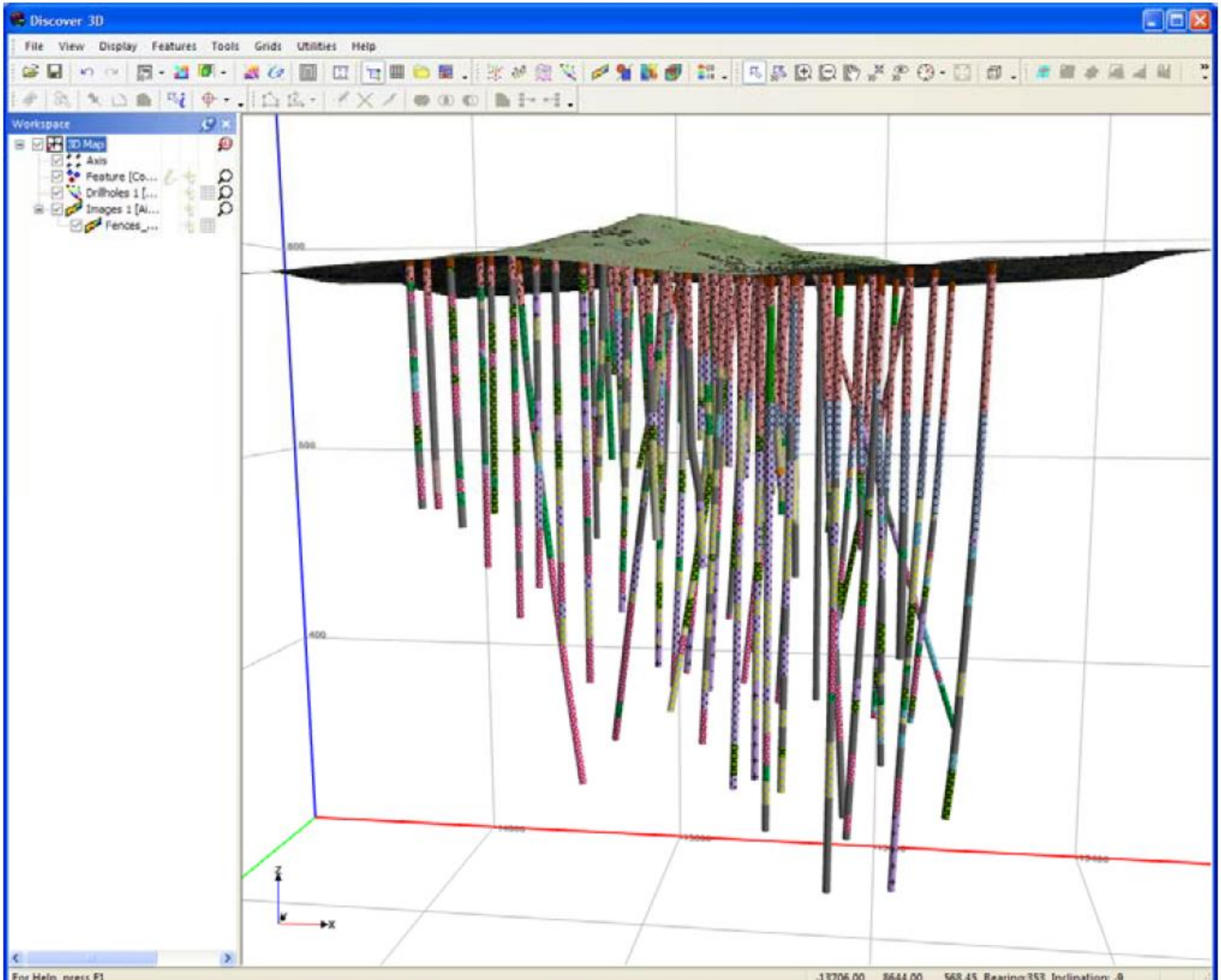
Skarn orebody displayed in 3D.



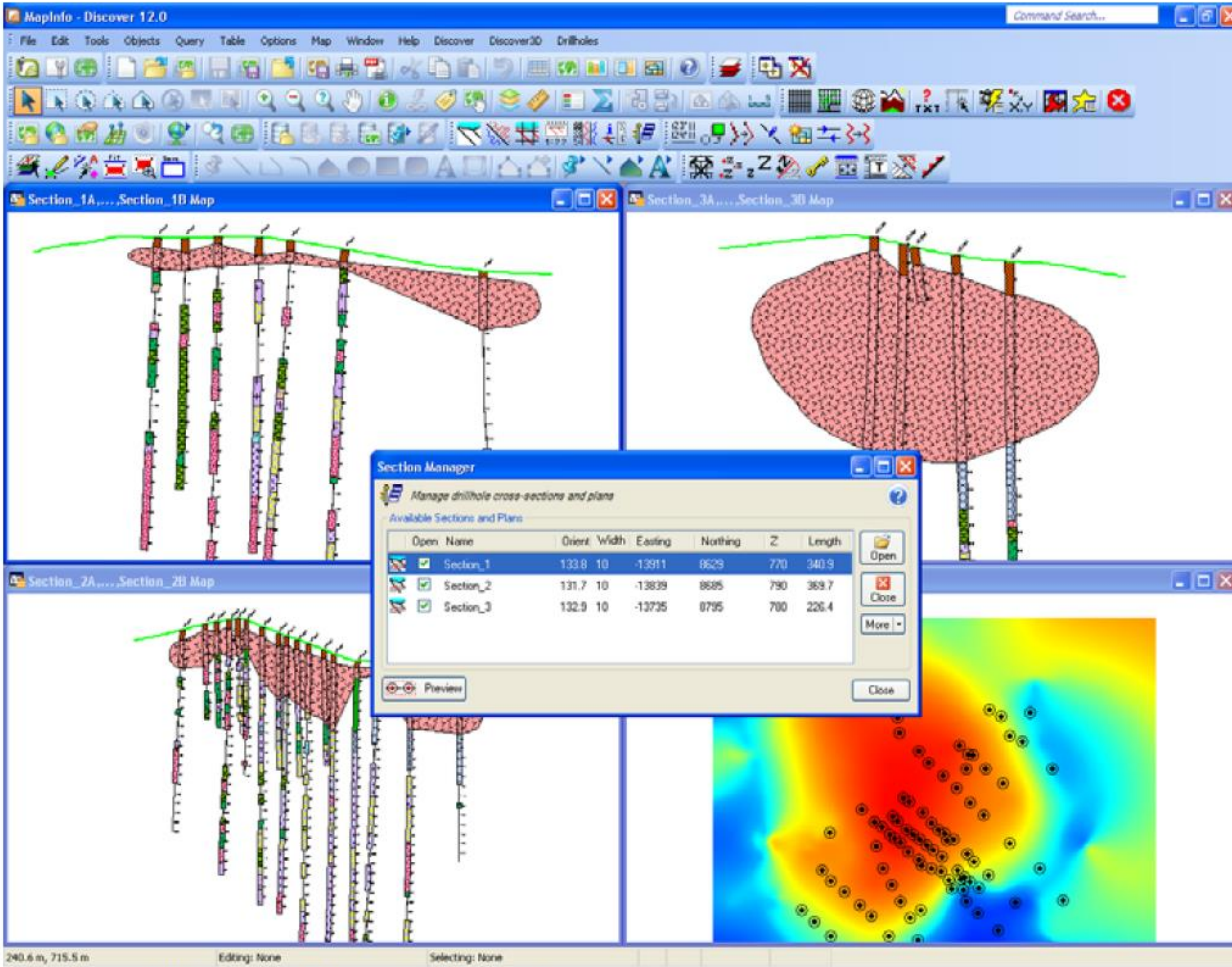
Example Discover 3D display.



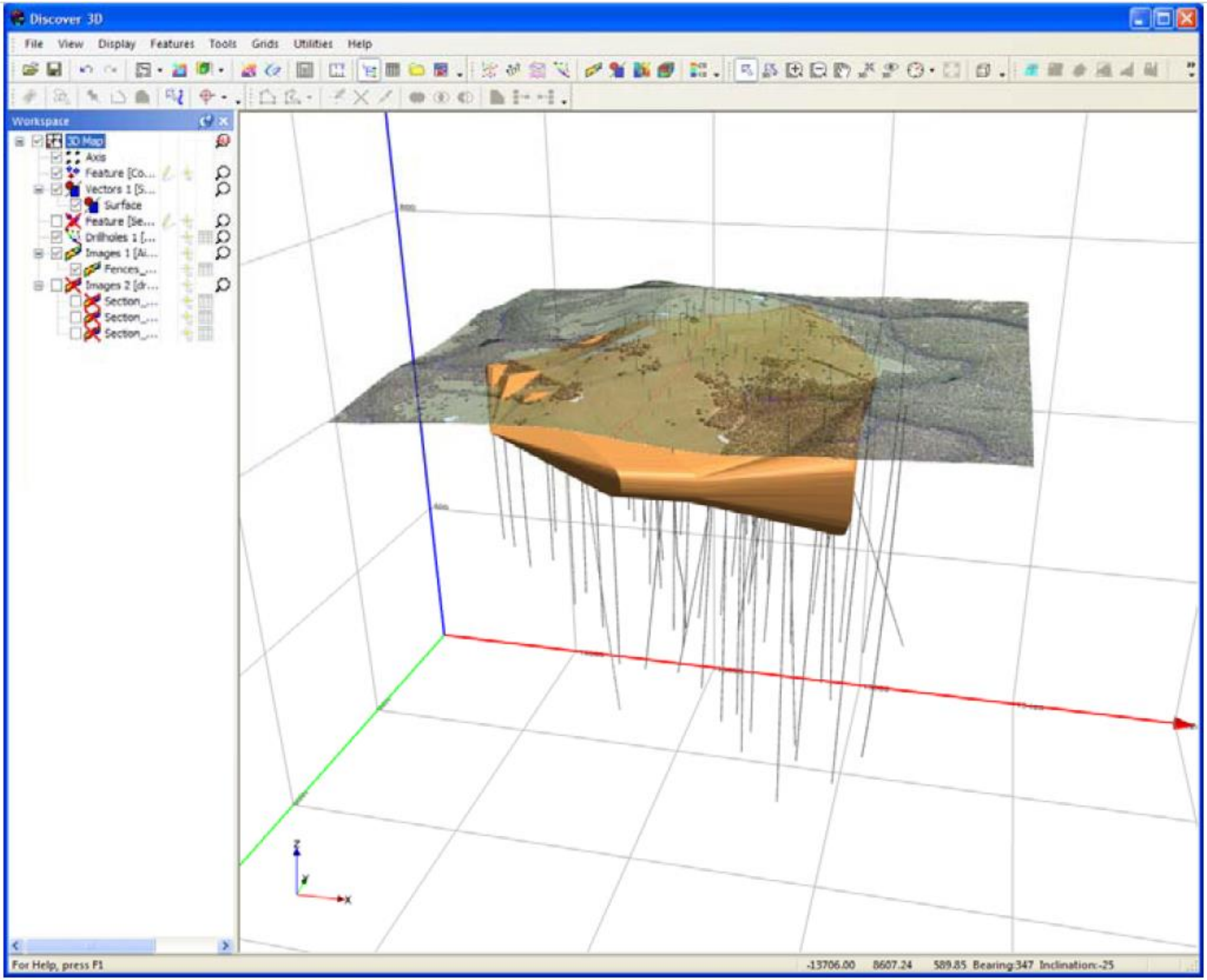
Drillhole traces displayed in Discover 3D.



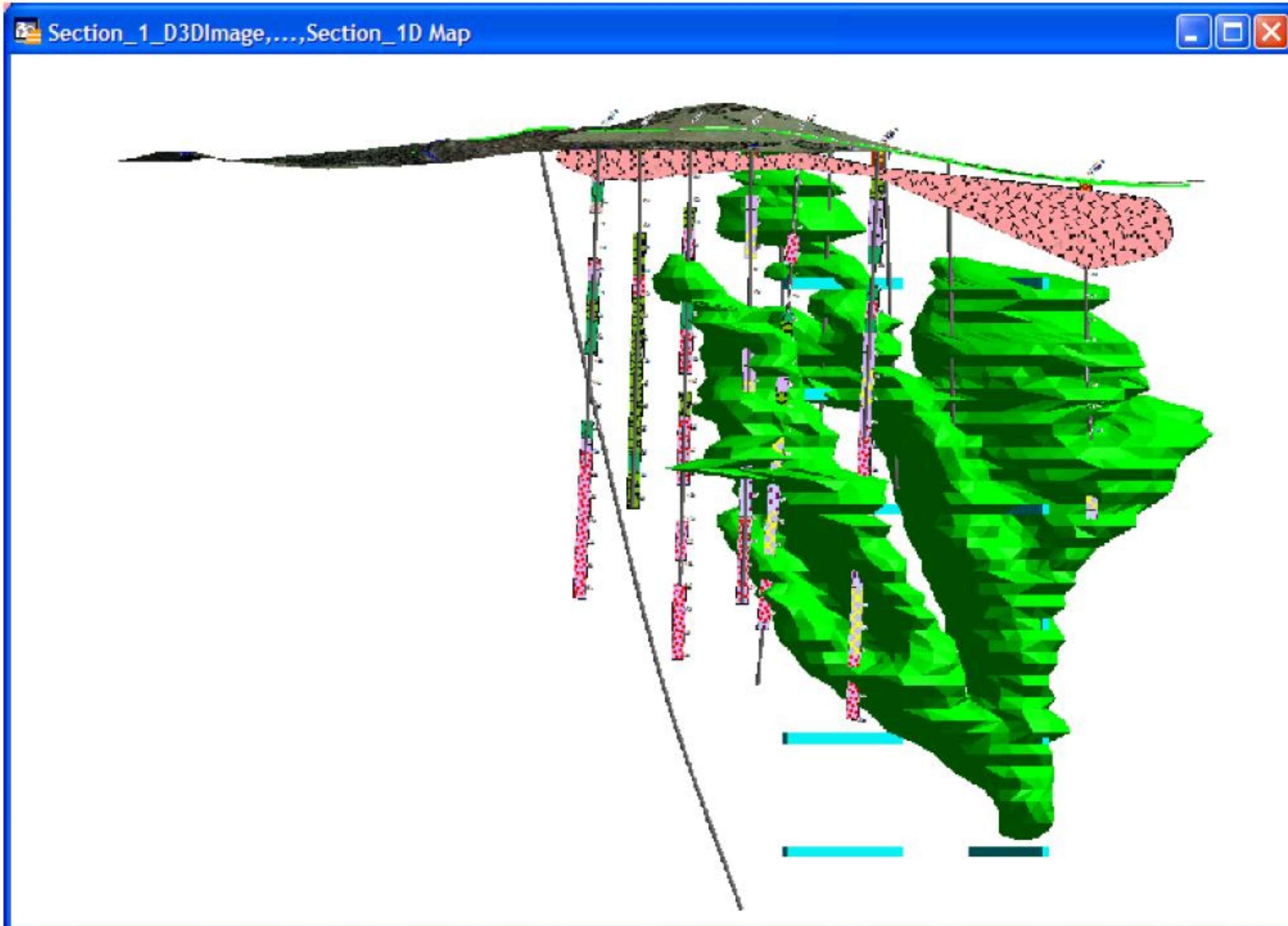
Drill trace modulated by lithology.



Display drillhole sections in MapInfo.

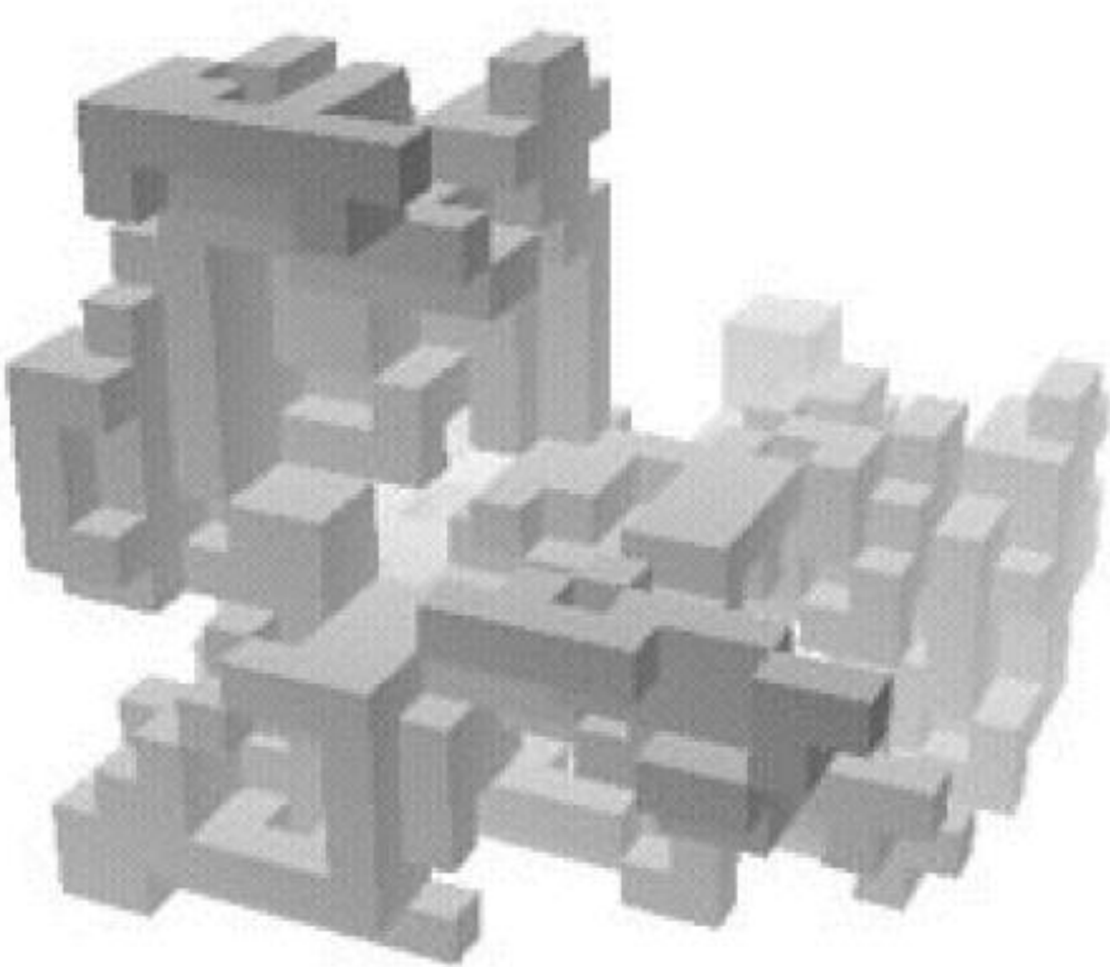


3D solid created with the 3D Solid Generator.

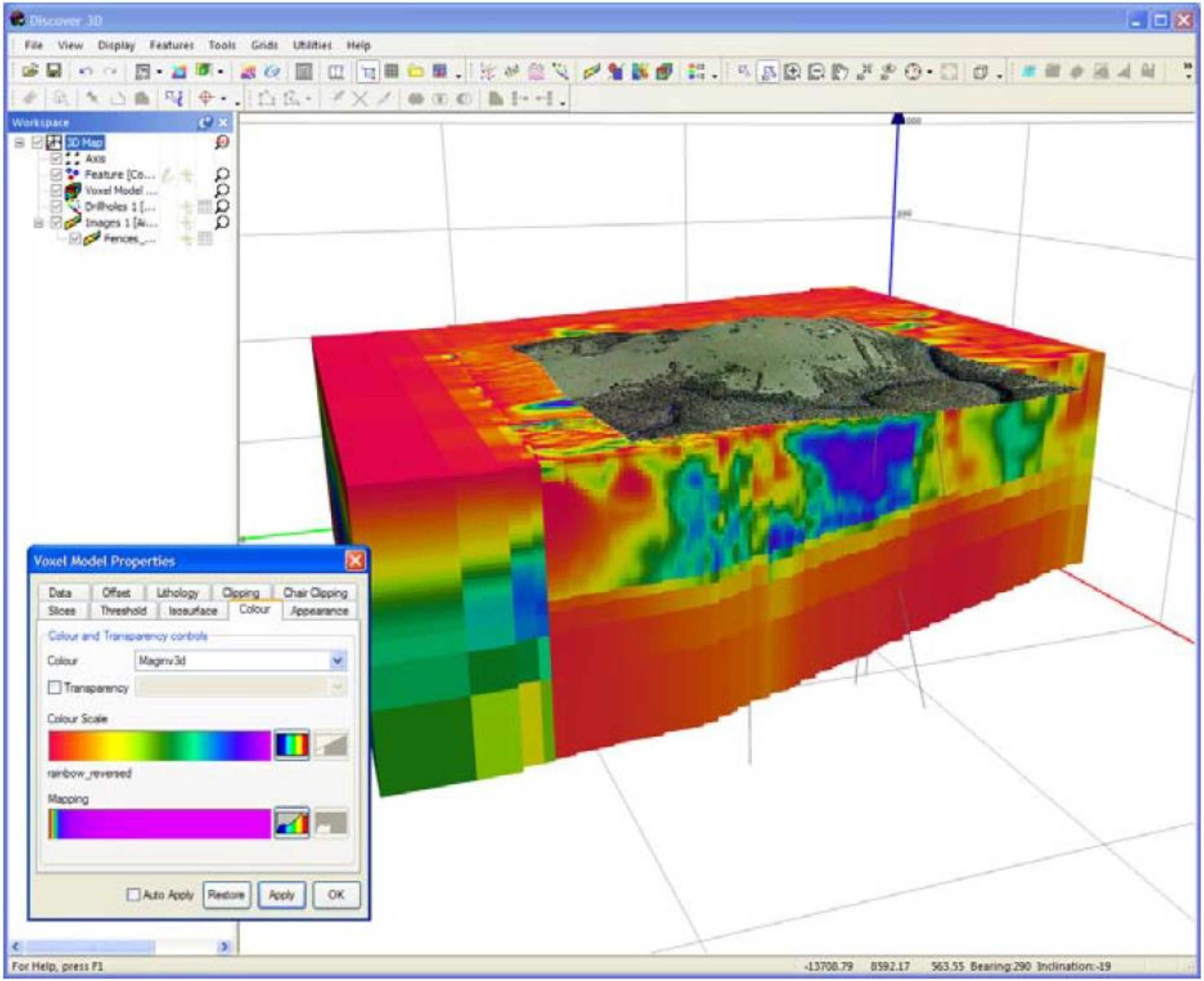


Discover cross section with georeferenced Image of a Skarn orebody and aerial image exported from the Discover 3D window.

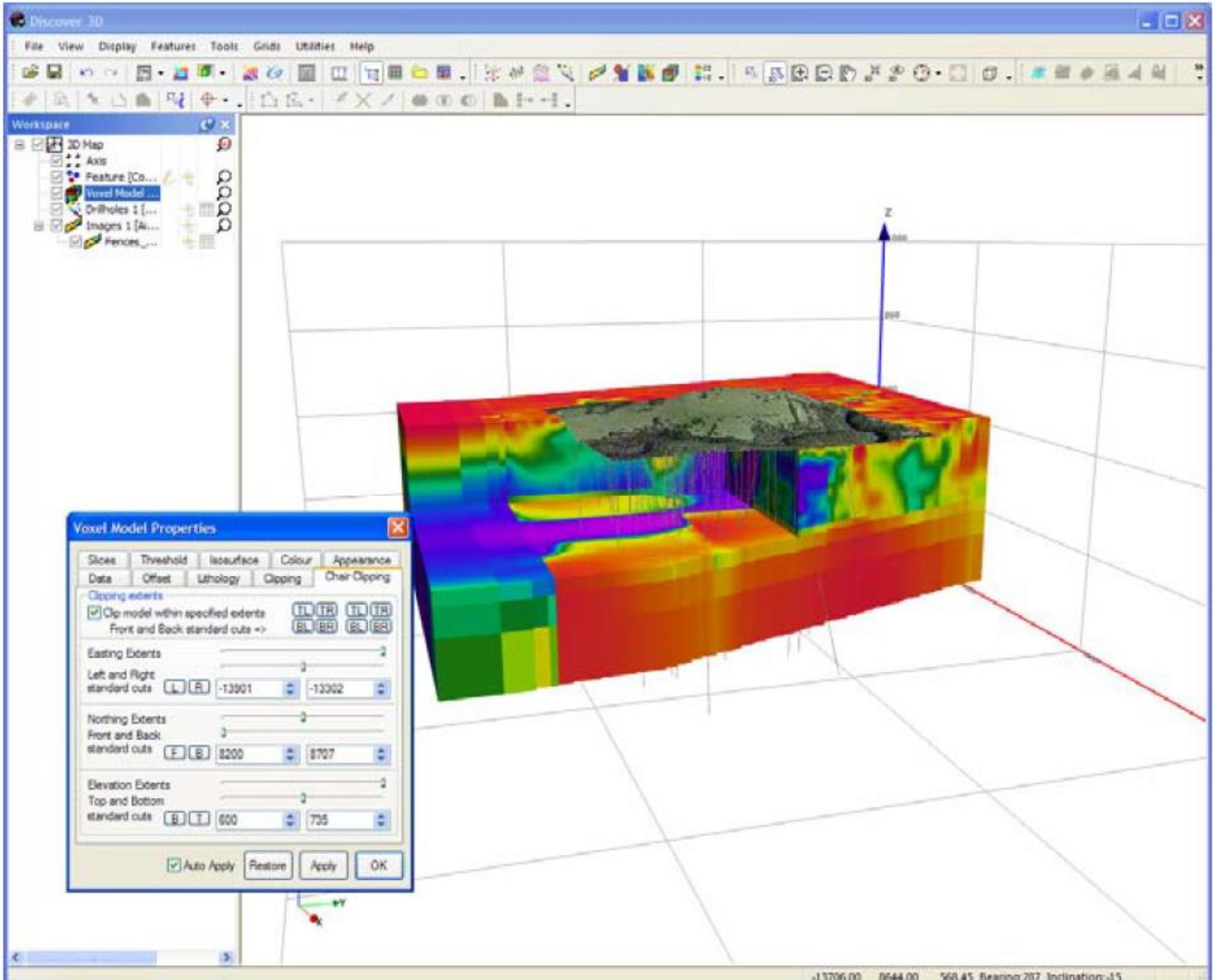
- Use bore hole geological data
- Geophysical survey data
- Integrate any number of geological data or various sources
- Interpolate and generate DEM / DTM
- Derive 3D products to visualize
- Size of the economic ore deposit
- Grade of the ore deposit
- Spatial distribution of ore deposits based on its various grades
- Slicing of different layers based on depth and their grades
- Planning to exploit / mine, access to the ore
- Mode of pickingout / mining, bring to the surface and transportation



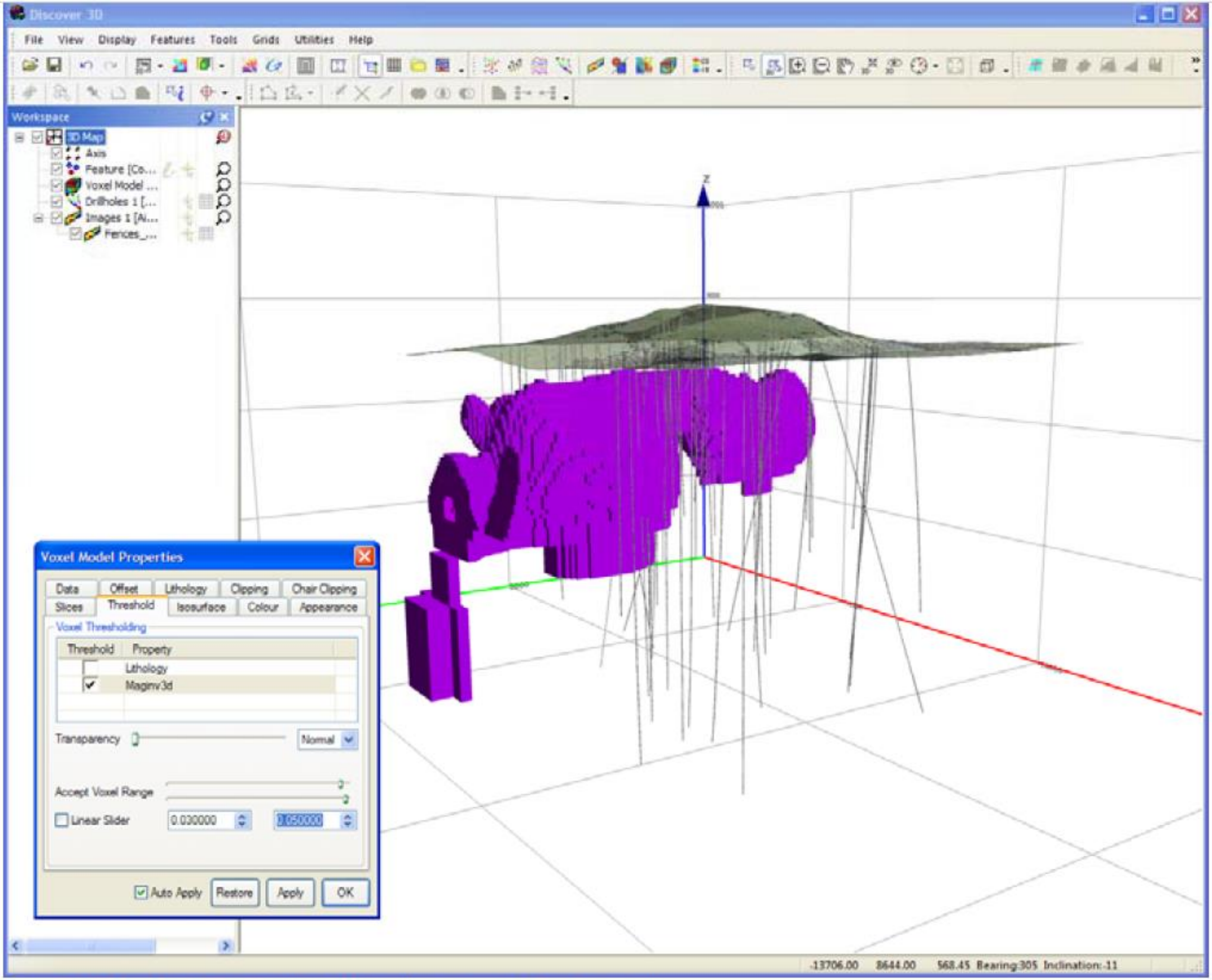
Example Voxel model.



Colour Voxel model by LUT.



Chair Clipping the Voxel Model to reveal internal structure.



Voxel Model Thresholded to reveal anomaly.

Case Study-1

GIS BASED 3D VISUALIZATION OF SUBSURFACE GEOLOGY AND MAPPING OF PROBABLE HYDROCARBON LOCALES, PART OF CAUVERY BASIN, INDIA

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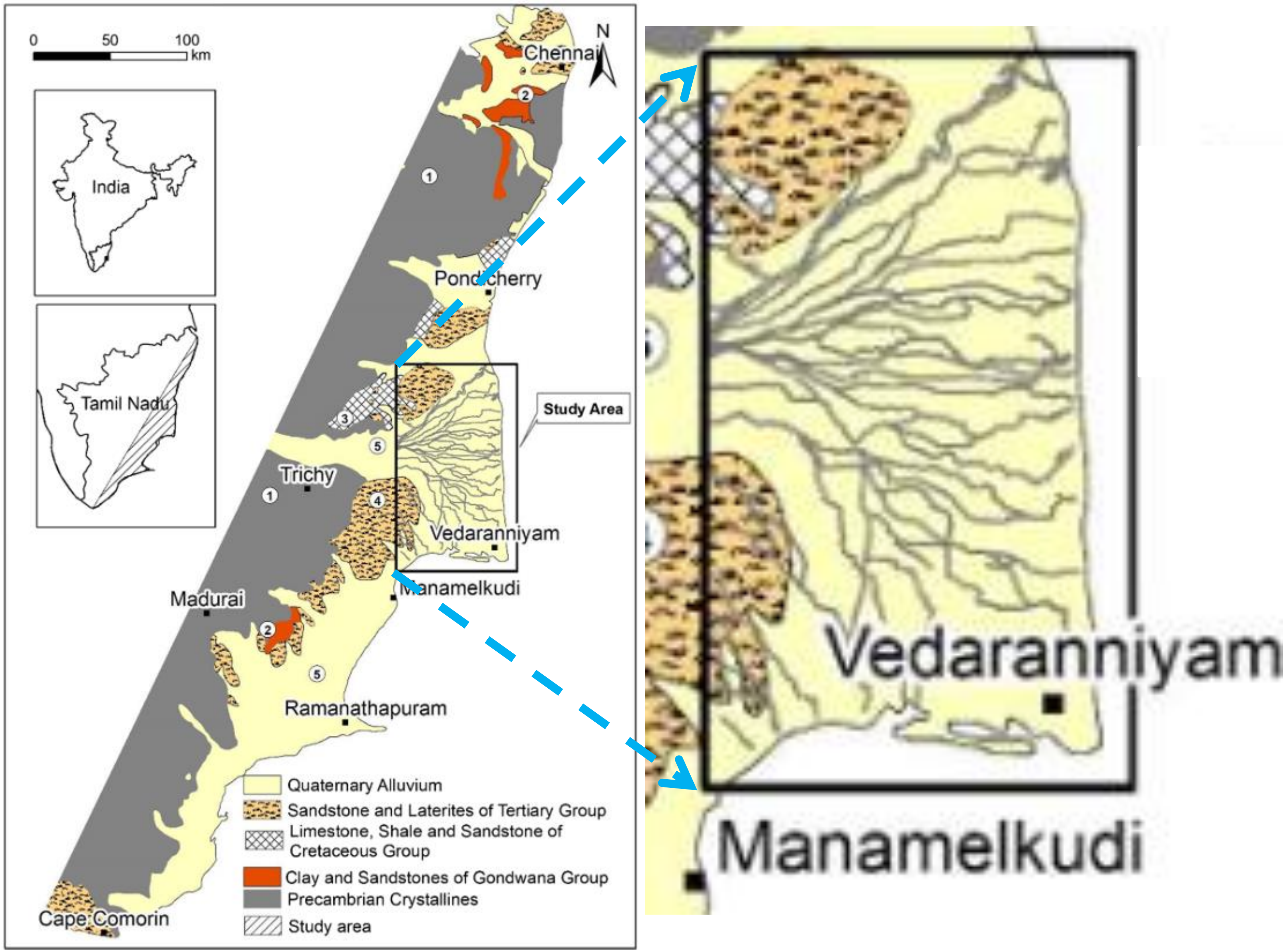
J. Earth Syst. Sci. (2020) 129:36 Ó Indian Academy of Sciences
https://doi.org/10.1007/s12040-019-1307-2

https://www.researchgate.net/publication/338089247_GIS_based_3D_visualization_of_subsurface_geology_and_mapping_of_probable_hydrocarbon_locales_part_of_Cauvery_Basin_India

- 3D visualization of geological – geophysical and geochemical data of Cauvery basin
- Delineate surface structures using SRM and other 3D products
- 3D visualization of gravity subsurface features
- 3D visualization of subsurface lithological features using borehole data
- 3D visualization of subsurface resistivity features using geophysical resistivity survey data
- Integration of surface structures, existing oil & gas well locations
- layer stacking of all surface and subsurface geological features
- Identify connectivity with surface structures with subsurface structures
- Locate favourable zones for hydrocarbon exploration.



0 50 100
km
N
India
Tamil Nadu
Chennai
Pondicherry
Study Area
Trichy
Vedaranniyam
Manamelkudi
Madurai
Ramanathapuram
Cape Comorin
Quaternary Alluvium
Sandstone and Laterites of Tertiary Group
Limestone, Shale and Sandstone of Cretaceous Group
Clay and Sandstones of Gondwana Group
Precambrian Crystallines
Study area
Vedaranniyam
Manamelkudi

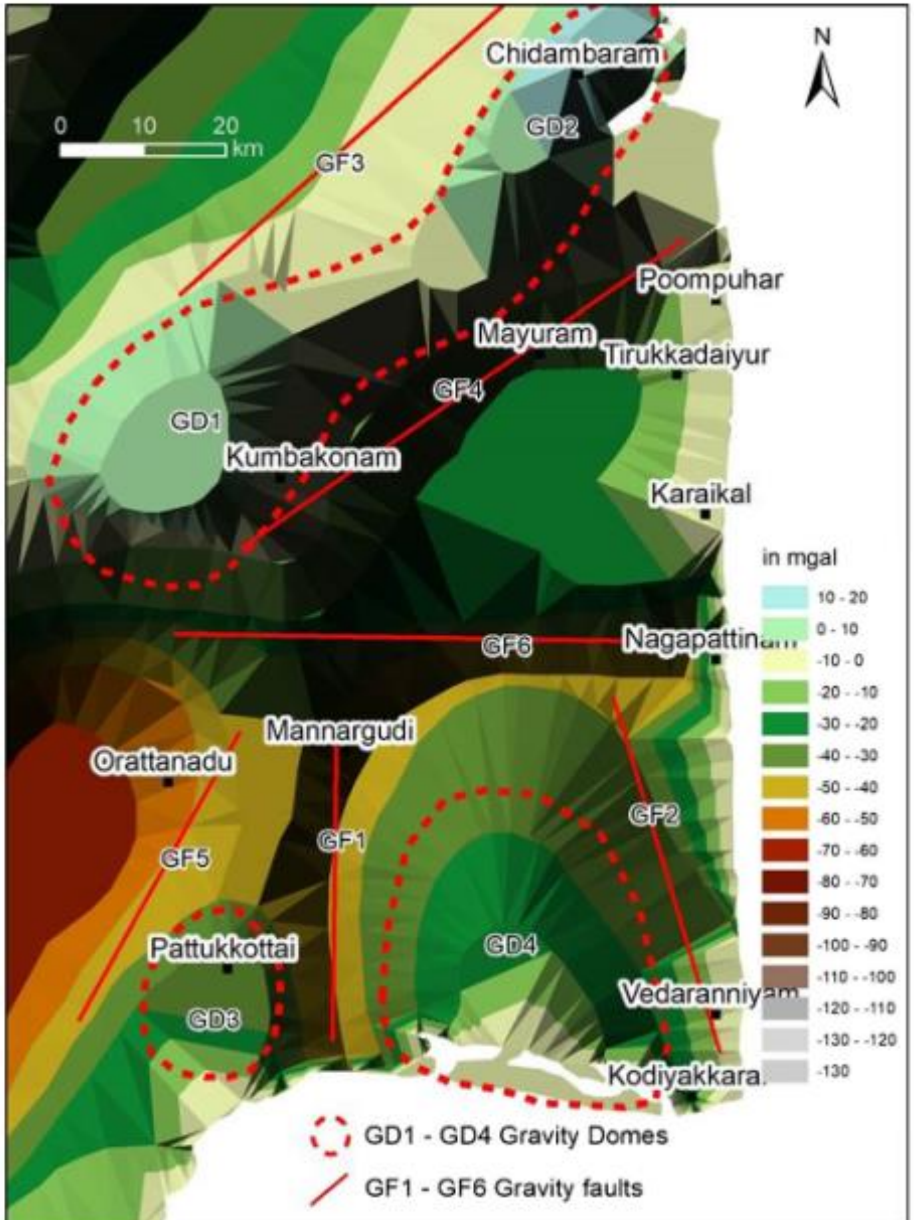


Figure 2. Digital Elevation Model of Bouger gravity data showing the possible domes and faults of the basement crystalline.

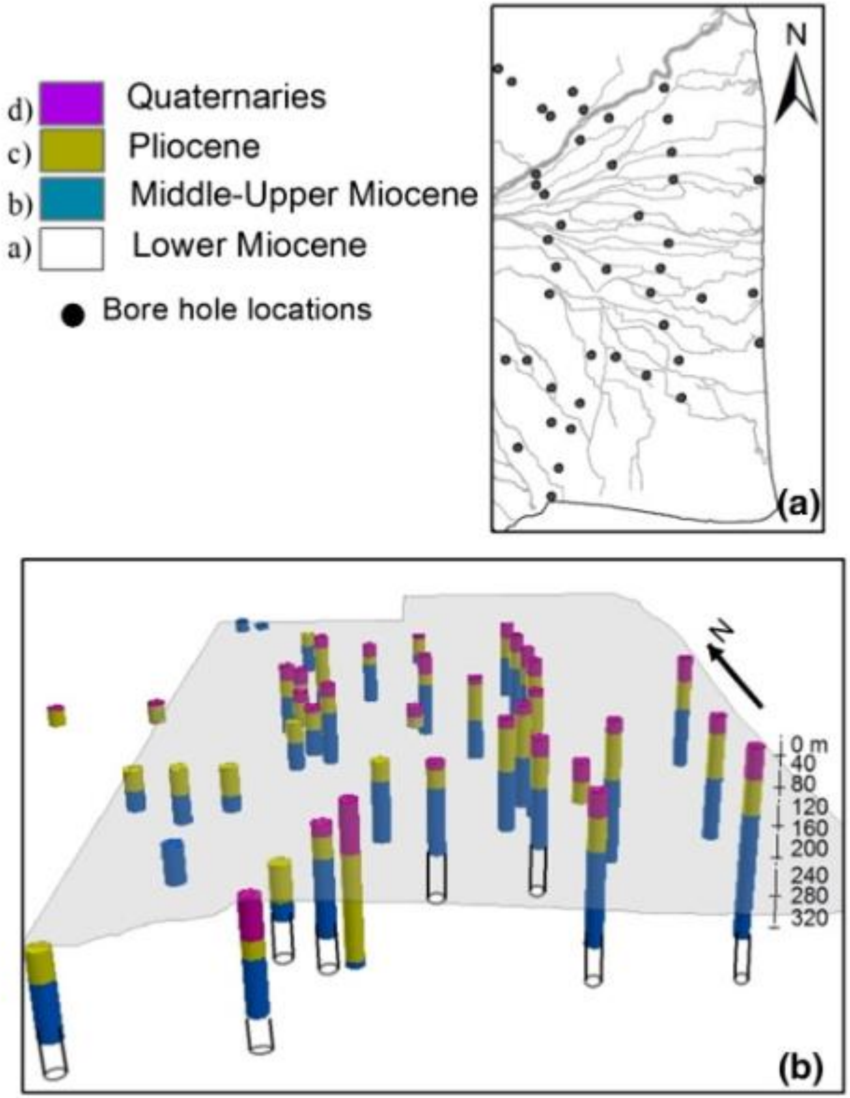


Figure 3. (**a**) Locations of boreholes of the study area; (**b**) (1) Lower Miocene, (2) Middle–Upper Miocene, (3) Pliocene, and (4) Quaternary sediments interpreted from lithologs of the borehole.

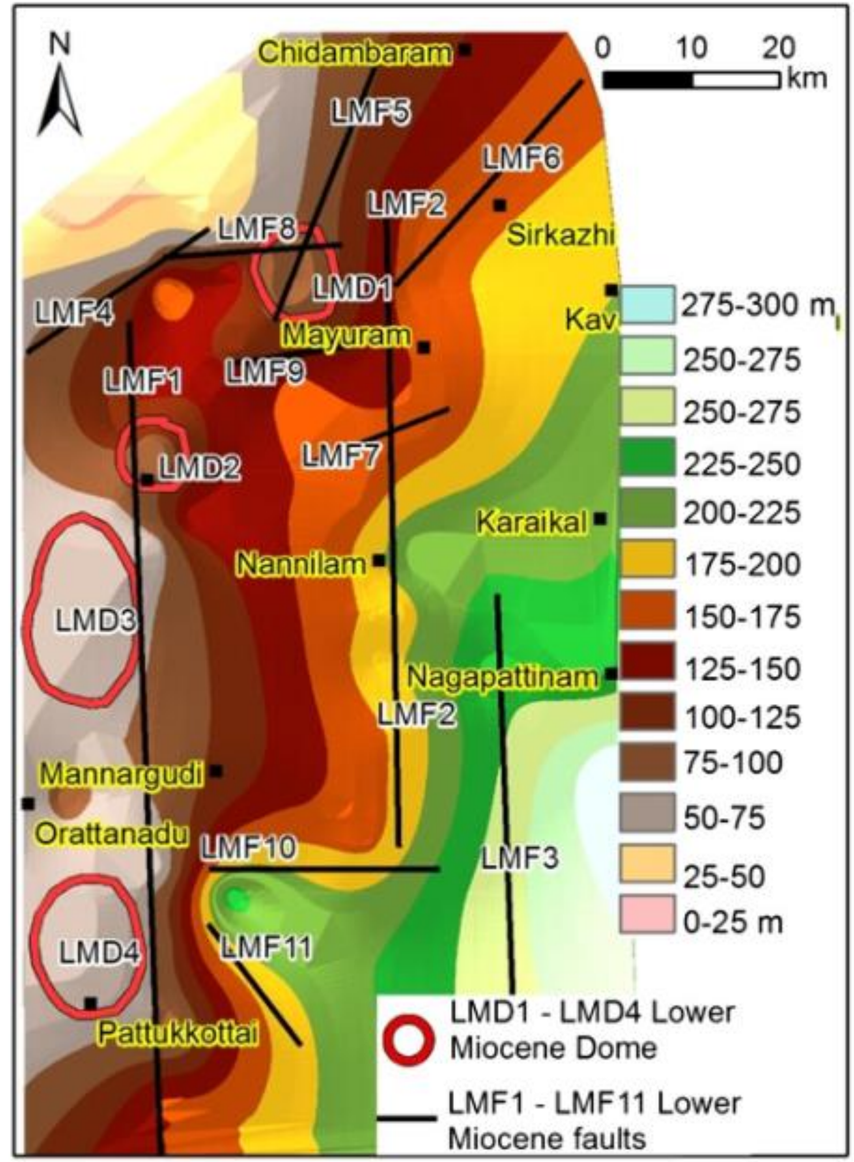


Figure 4. Digital Elevation Model of the top surface (litho top) of Lower Miocene formation and the interpreted domes (LMD1–LMD4) and faults (LMF1–LMF11).

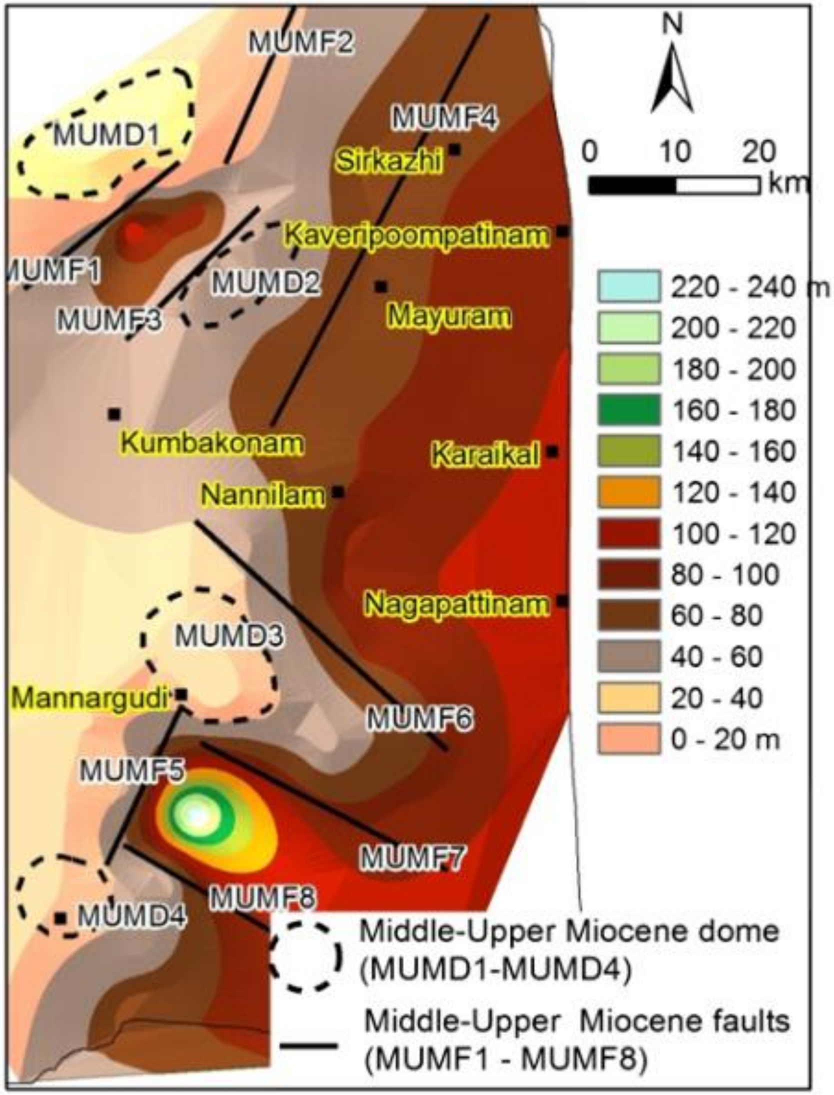


Figure 5. Digital Elevation Model of the top surface (litho top) of Middle–Upper Miocene formation and the interpreted domes (MUMD1–MUMD4) and faults (MUMF1–MUMF8).

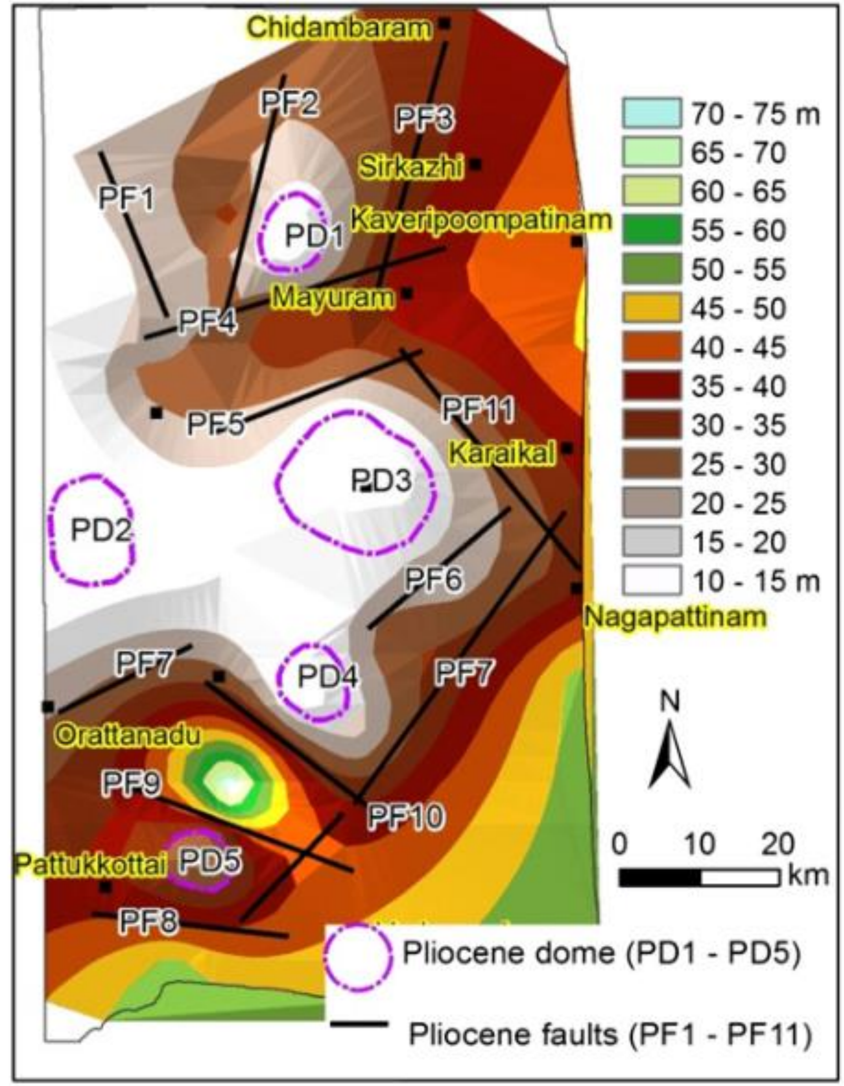


Figure 6. Digital Elevation Model of the top surface (litho top) of Pliocene formation and the interpreted domes (PD1–PD5) and faults (PF1–PF11).

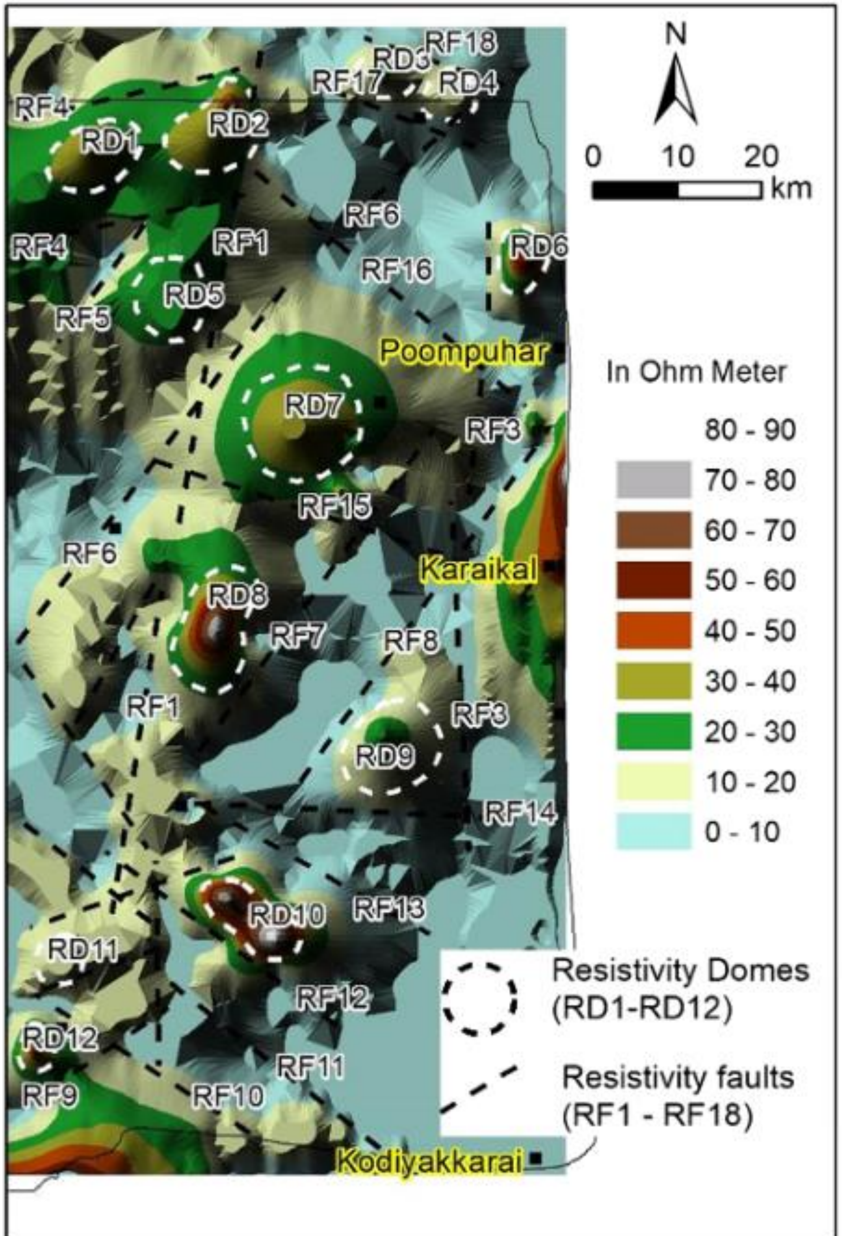


Figure 7. Digital Elevation Model of the geophysical resistivity values of 50 m depth and interpreted resistivity domes (RD1–RD12) and faults (RF1–RF18).

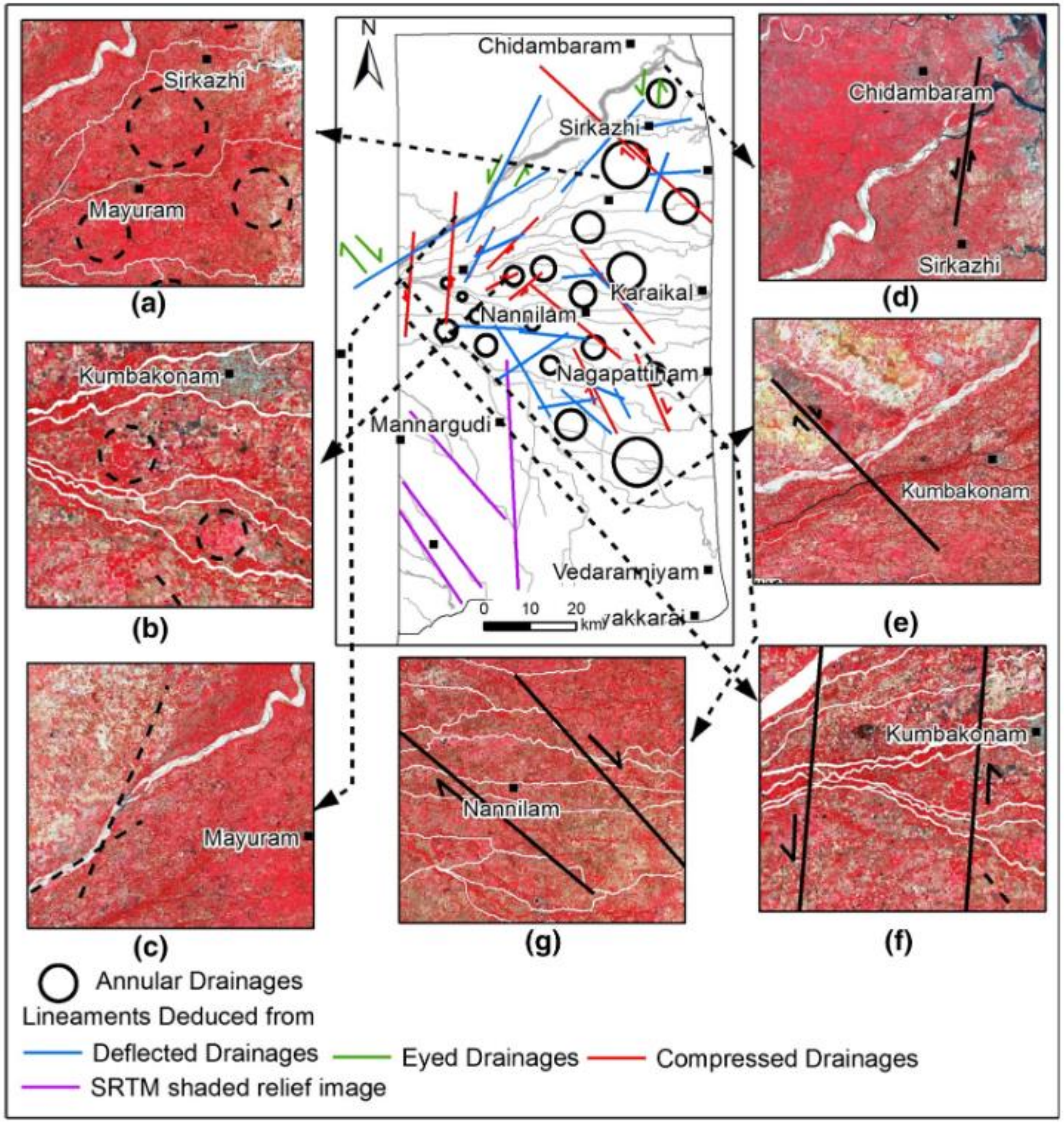


Figure 8. Surface domes and faults, Cauvery delta. IRS satellite FCC images showing annular and curvilinear drainages and circular features (**a**, **b**), deflected Coleroon river and NE–SW/NNE–SSW lineaments (**c**), eyed drainages with 'S' shaped drags and N–S sinistral faults (**d**), eyed drainage with 'Z' shaped drags and NW–SE dextral fault (**e**), 'S' shaped compressed drainages and N–S sinistral faults (**f**), 'Z' shaped compressed drainages and NW–SE dextral faults (**g**).

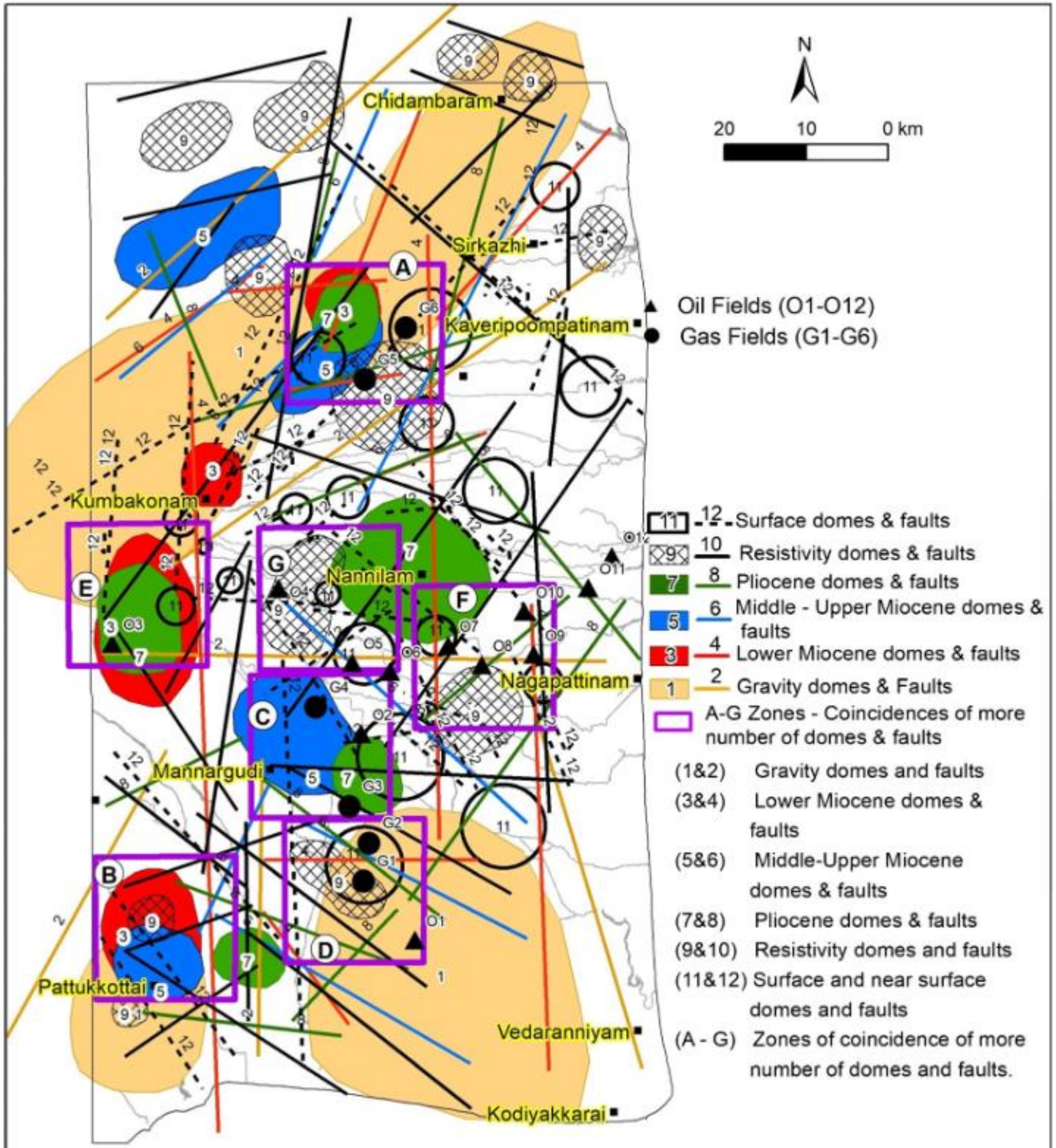


Figure 9. Multi-depth and surface tectonic features.

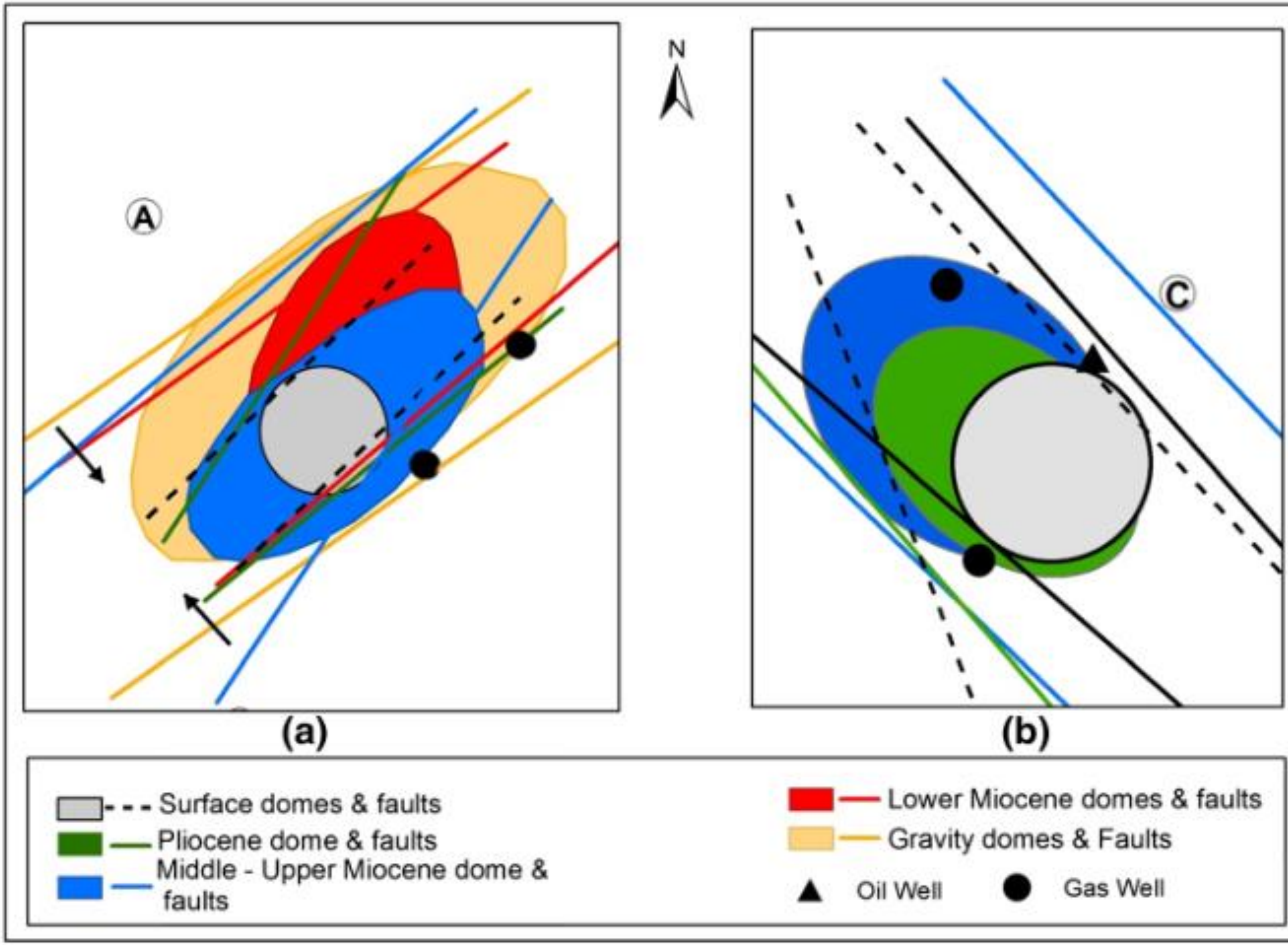


Figure 10. (**a**, **b**) Multi-depth domes and faults in clusters A and C.

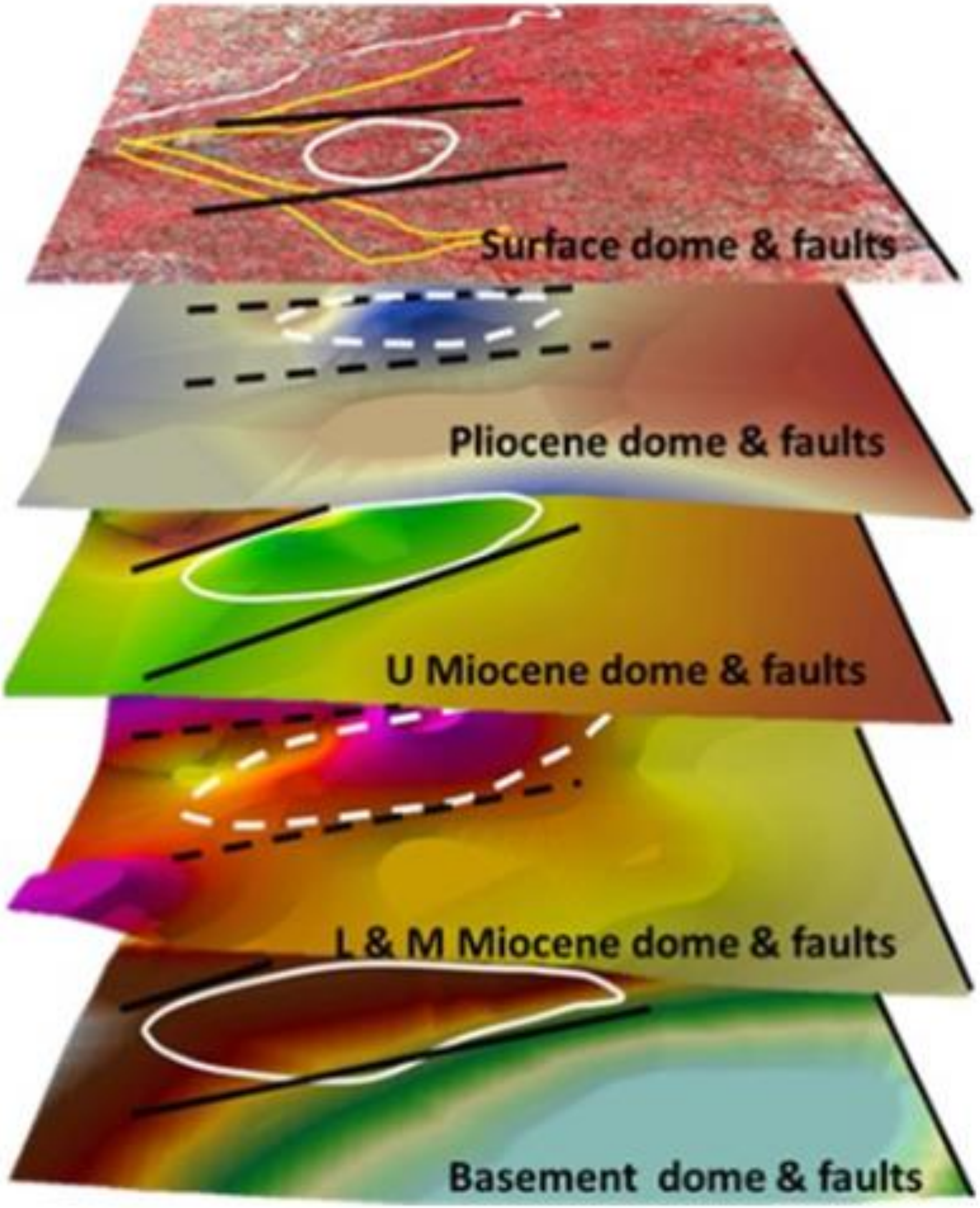


Figure 11. Three dimensionally visualized conceptual model on surface to subsurface domes and faults.

Case Study-2

3D STRUCTURAL-STRATIGRAPHIC MODELLING SUPPORTING MINERAL DISCOVERY IN THE PURCELL BASIN, SOUTHERN BC

Eric de Kemp, Ernst Schetselaar, Mike Hillier, John Lydon, Mike Thomas, Jamel Joseph

MINERALS SOUTH 2012 SPEAKER ABSTRACTS

CHAMBER OF MINES
of Eastern British Columbia

The future of mineral exploration will be in the hands of those who know how to better interpret beyond the head frame and who can reduce risk when drilling deeper geologic targets.

To do this it is necessary to know how to make 3D models with less data, and better use existing, albeit sparse, complimentary data for mutual support.

There is a growing realization in the mining exploration industry that integrated 3D geologic-geophysical model driven targeting is essential to accomplish more efficient and successful deep mineral exploration (> 400 m).

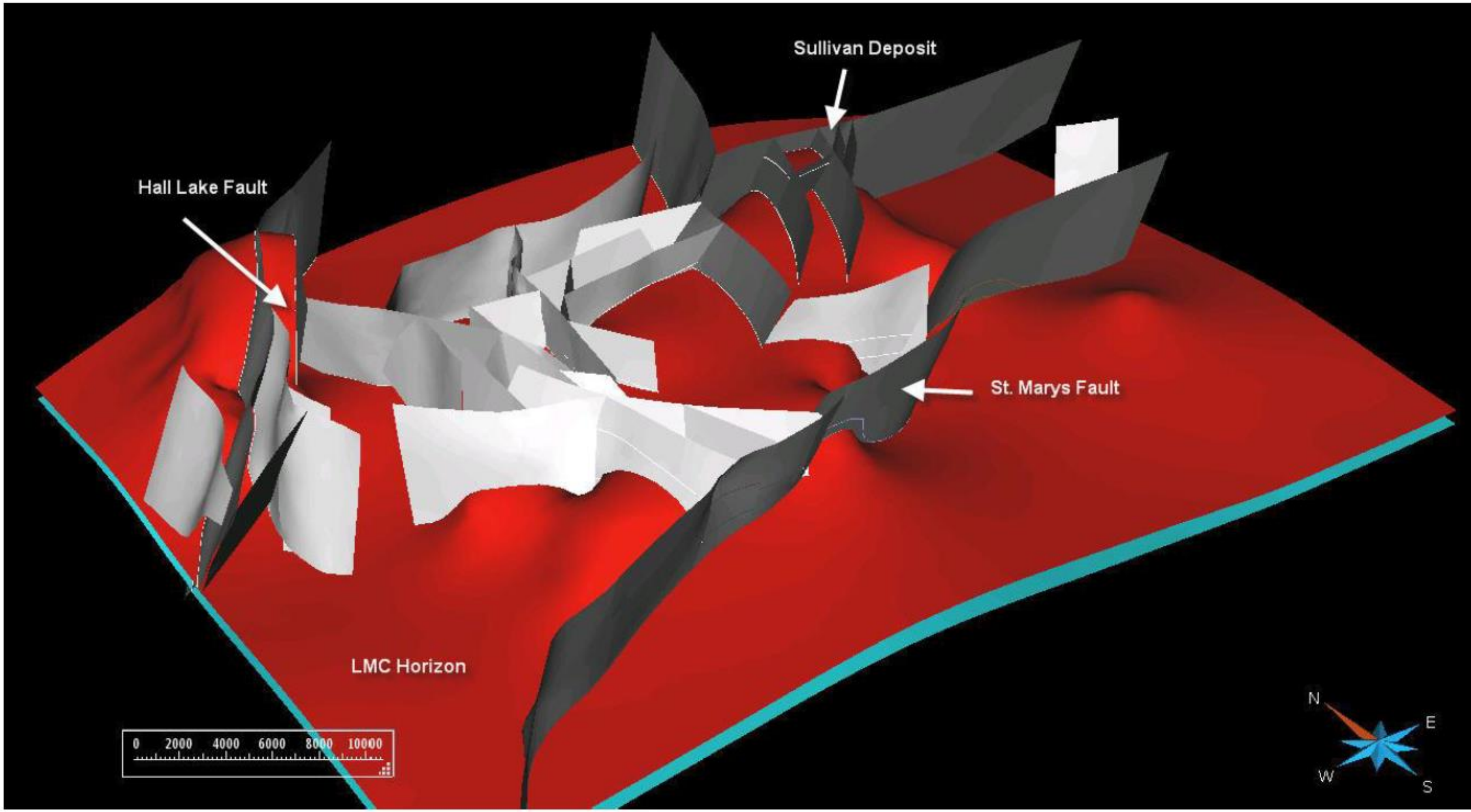


Figure 1 - preliminary model St. Mary's block Lower-Middle Aldridge Contact (LMC) as red surface.

Case Study-3

THREE-DIMENSIONAL PROPERTY MODELLING OF A COMPLEX FLUVIO-DELTAIC ENVIRONMENT: RHINE-MEUSE DELTA, THE NETHERLANDS

Jan Stafleu, Freek S. Busschers, Denise Maljers and Jan L. Gunnink Deltares / TNO – Geological Survey of the Netherlands

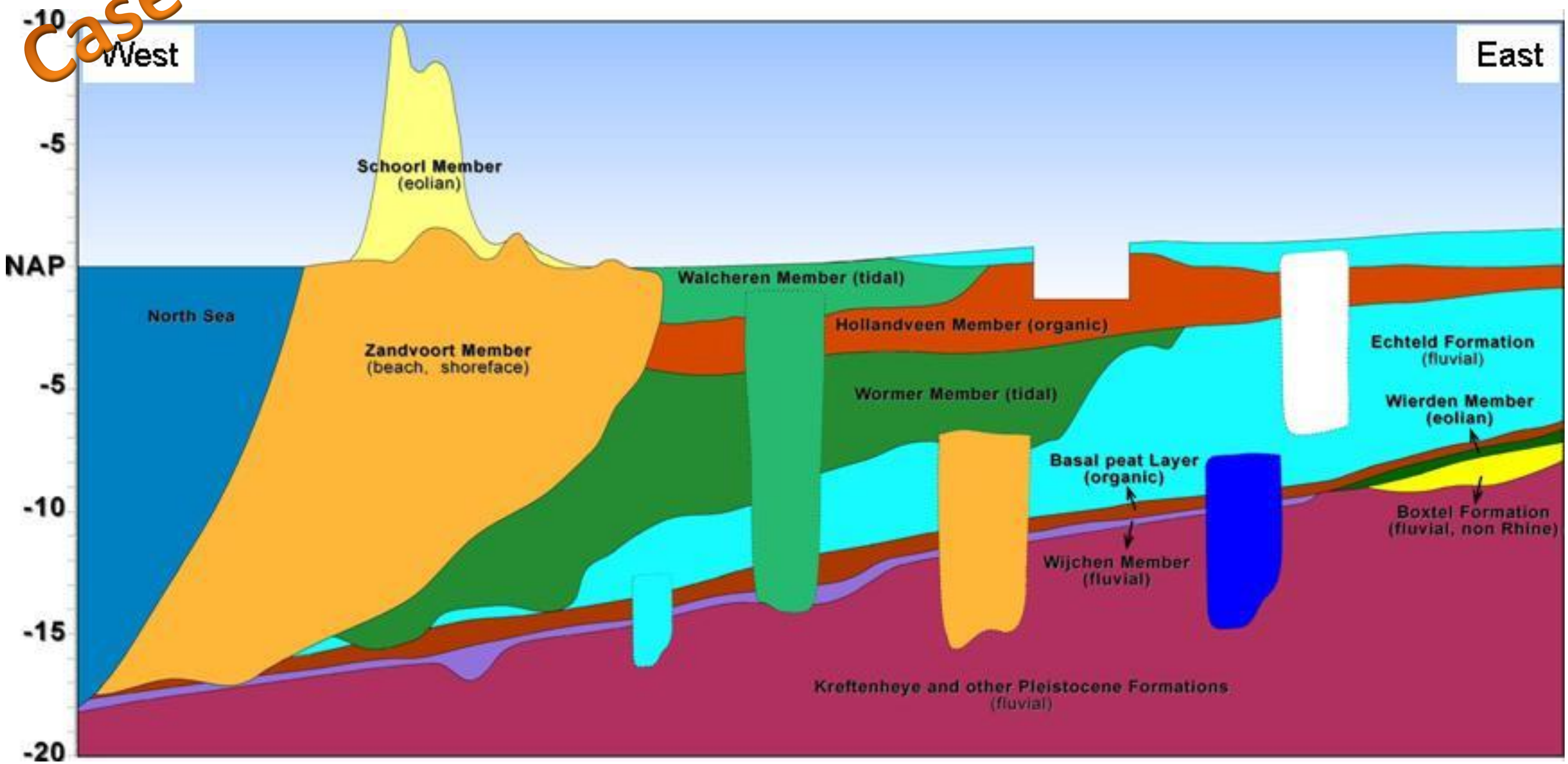


Figure 2. Schematic east-west oriented cross-section through the Holocene deposits in the Province of Zuid-Holland. The horizontal distance is about 70 km, the vertical distance runs down to 20 meters below Dutch Ordnance Datum. See text for discussion of the units.

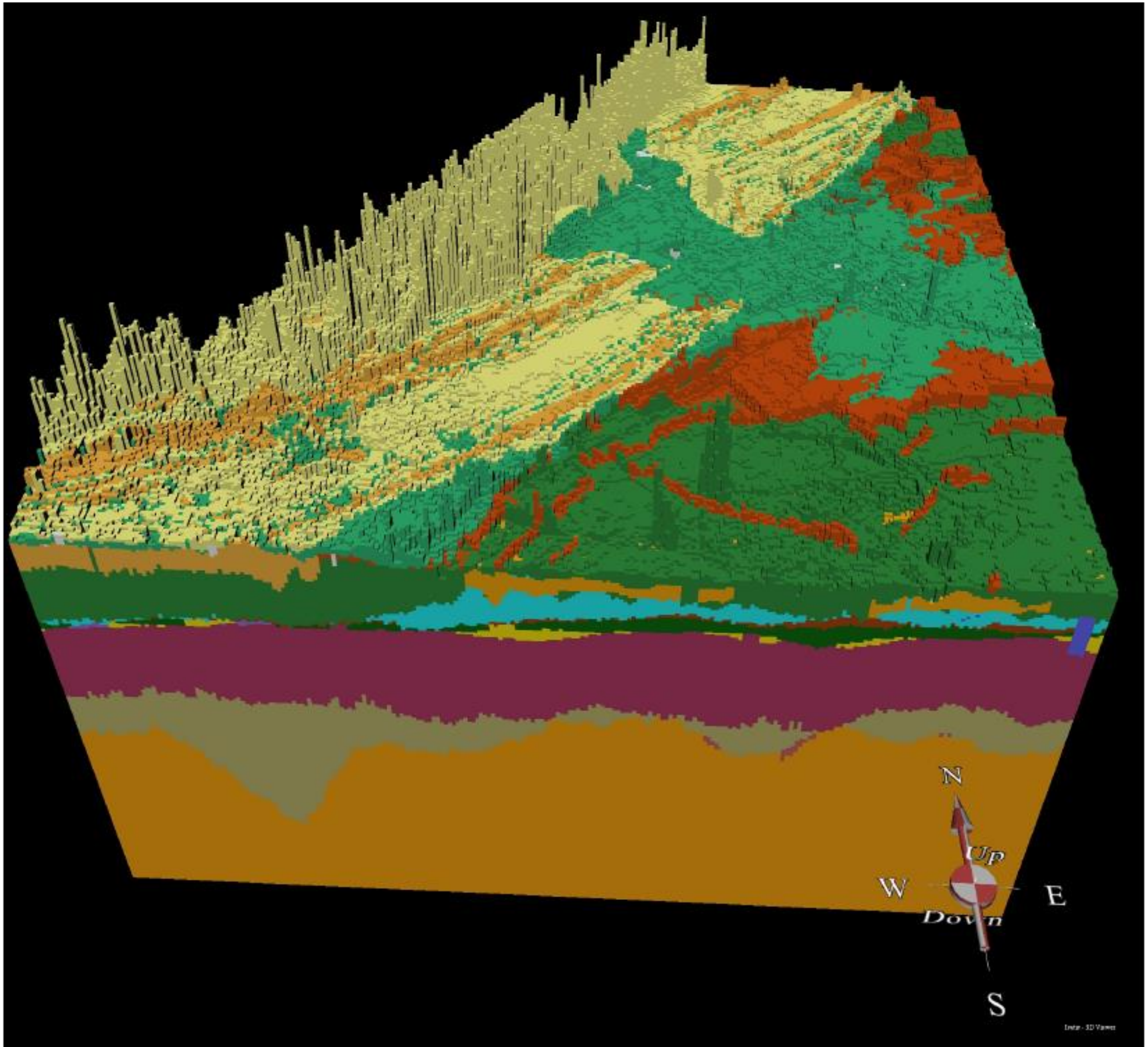
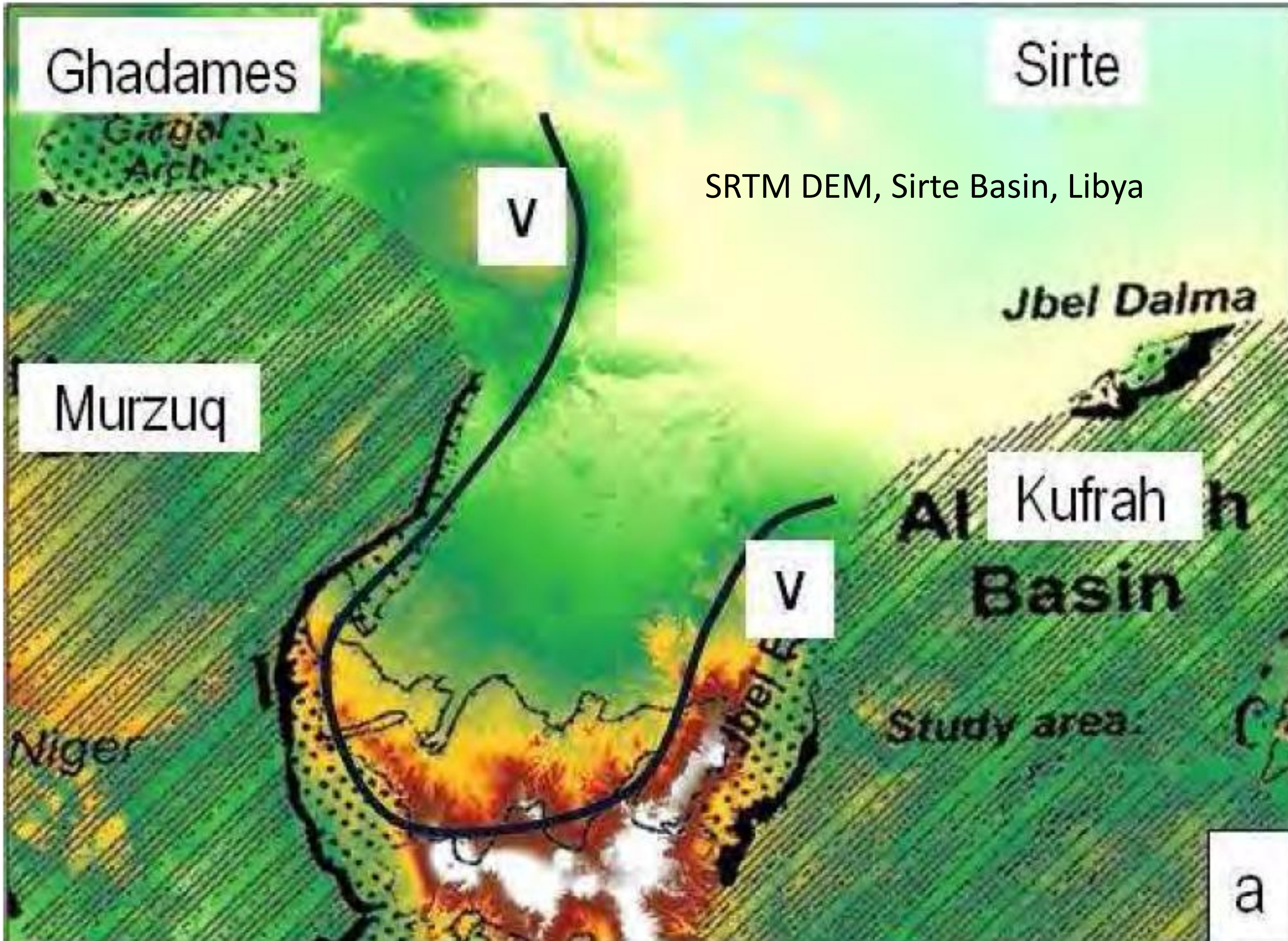
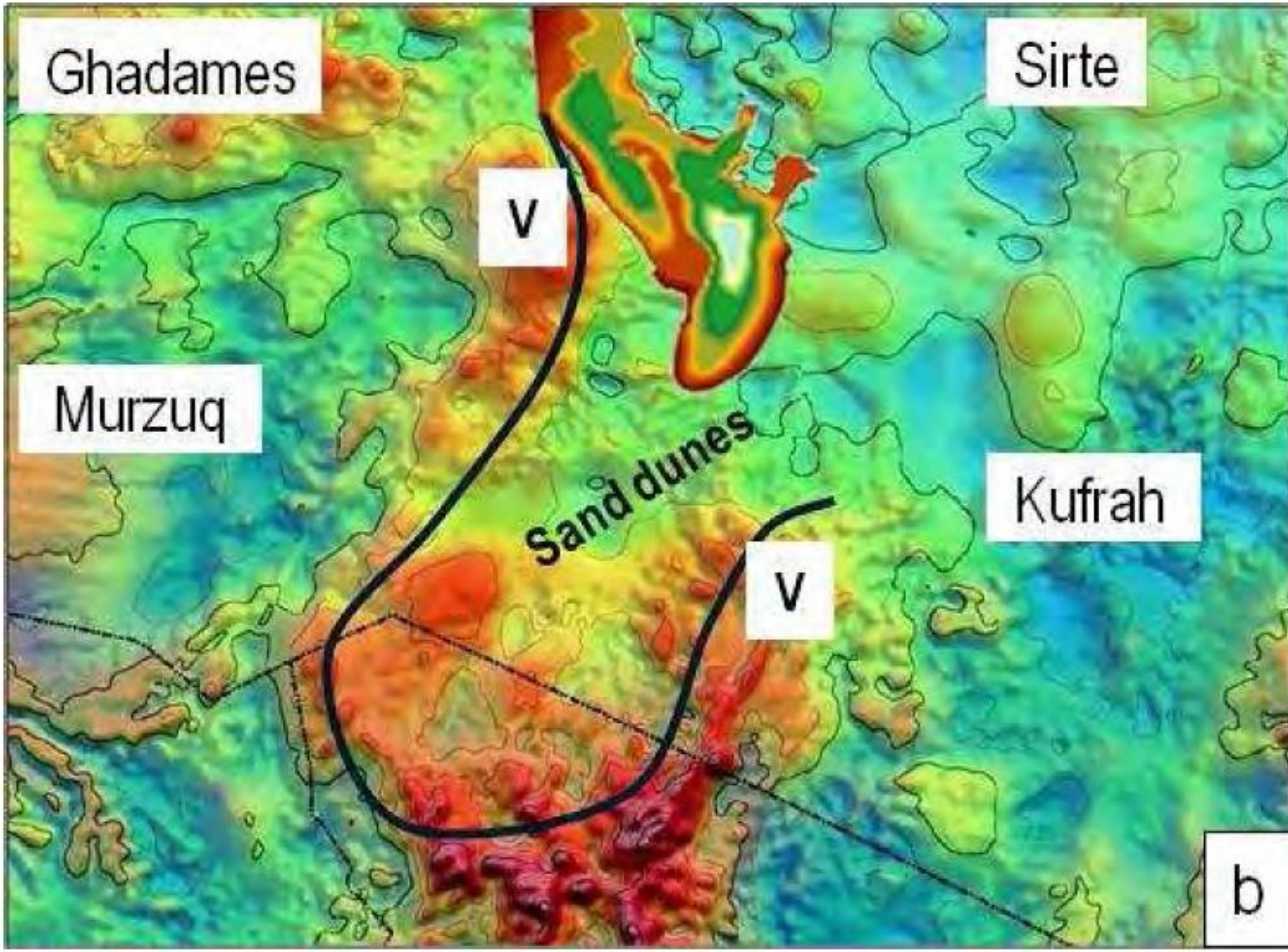


Figure 3. Part of the 3D lithostratigraphical model of Zuid-Holland (see Figure 1 for location). See Figure 2 for information on unit colour codes.

Ref.: Integrated Workflow for Petroleum Exploration in frontier area
SEG Las Vegas 2012 Annual Meeting





Geological interpretation of Remote Sensing data sets – Top Pre-Cambrian from satellite Gravity. The outline of the area of interest is shown as black solid line, V- Volcanoes.

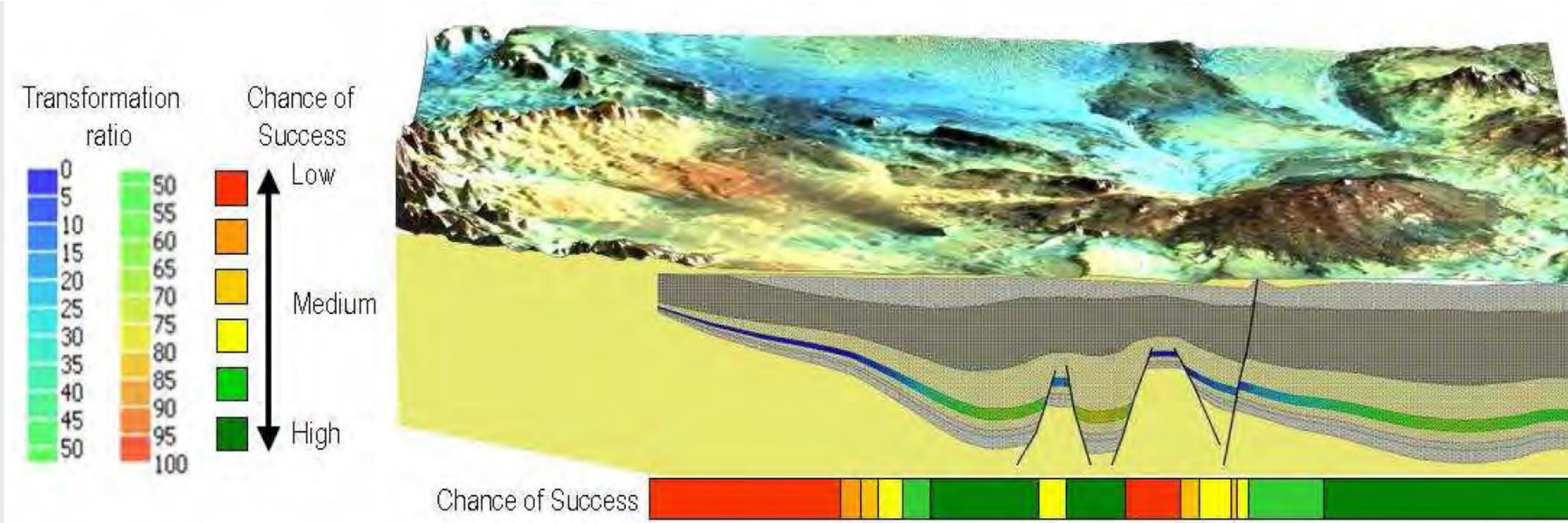


Figure 7 A compilation of the petroleum systems modeling results with the digital elevation model in 3D. Note that the faults in the structural model were derived from the DEM and satellite radar data.

Case Study-4

3D SUBSURFACE MODELLING OF ZEELAND

JAN STAFLEU[1], DENISE MALJERS[1], JAN L. GUNNINK[1], ARMIN MENKOVIC[2] AND FREEK S. BUSSCHERS[1]

[1]TNO – Geological Survey of the Netherlands, Utrecht, the Netherlands
P.O. Box 85467, 3508 AL Utrecht
e-mail first author: jan.stafleu@tno.nl
[2]Deltares, Utrecht, the Netherlands

Frontiers in Shallow Subsurface Technology 2010

First International Conference on “Frontiers in Shallow Subsurface Technology”
20-22 January, 2010, Delft, The Netherlands

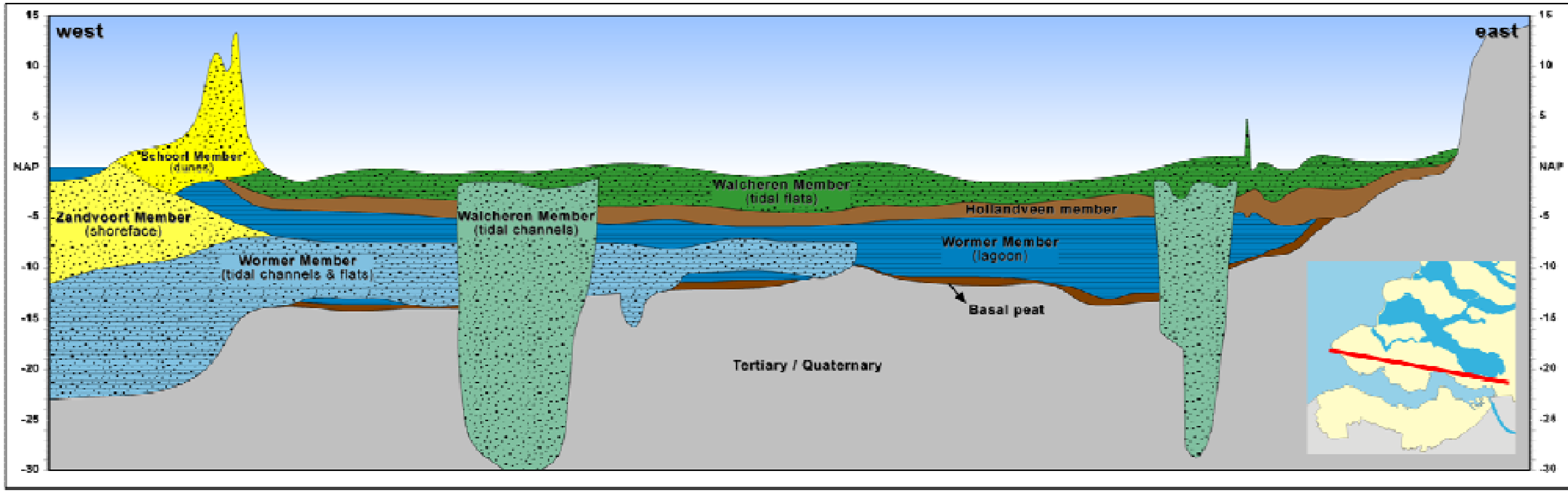


Figure 1. Schematic west-east oriented cross-section through the Holocene deposits in the Province of Zeeland. The horizontal distance is about 70 km, the vertical distance runs down to 30 meters below Dutch Ordnance Datum.

Formation	**Member**	**Lithofacies units**
Naaldwijk	Schoorl	Dune sands
	Zandvoort	Shoreface sands
	Walcheren	Tidal channel & flat deposits, shell rich deposits
	Wormer	Tidal channel & flat deposits, lagoonal clays
Nieuwkoop	Hollandveen	Peat
	Basal Peat	Peat

Table 1. Formations, members and lithofacies units of the Holocene deposits in Zeeland. Colours correspond to those in Figure 1.

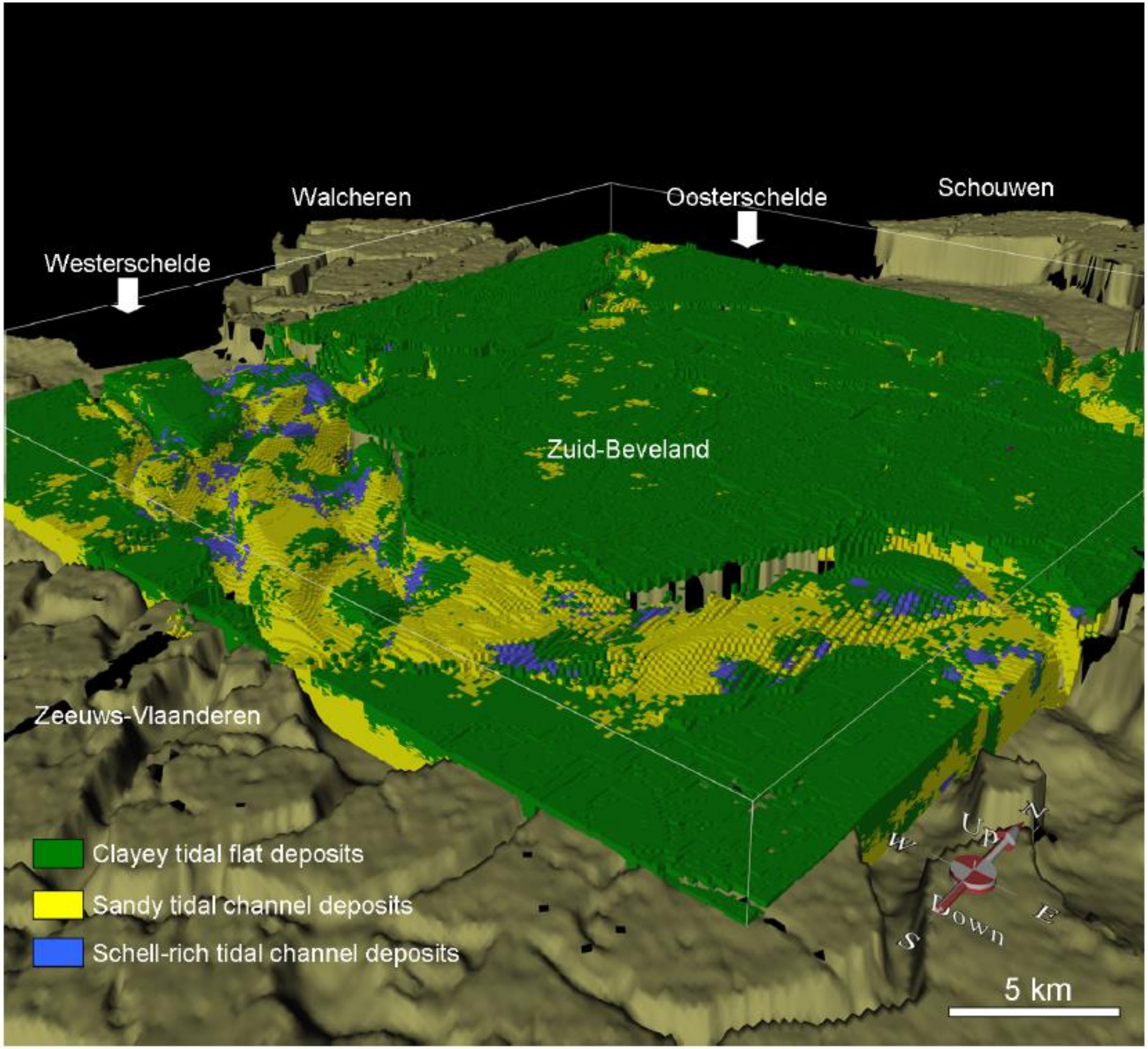


Figure 2. Part of the 3D lithofacies model of the central part of Zeeland.

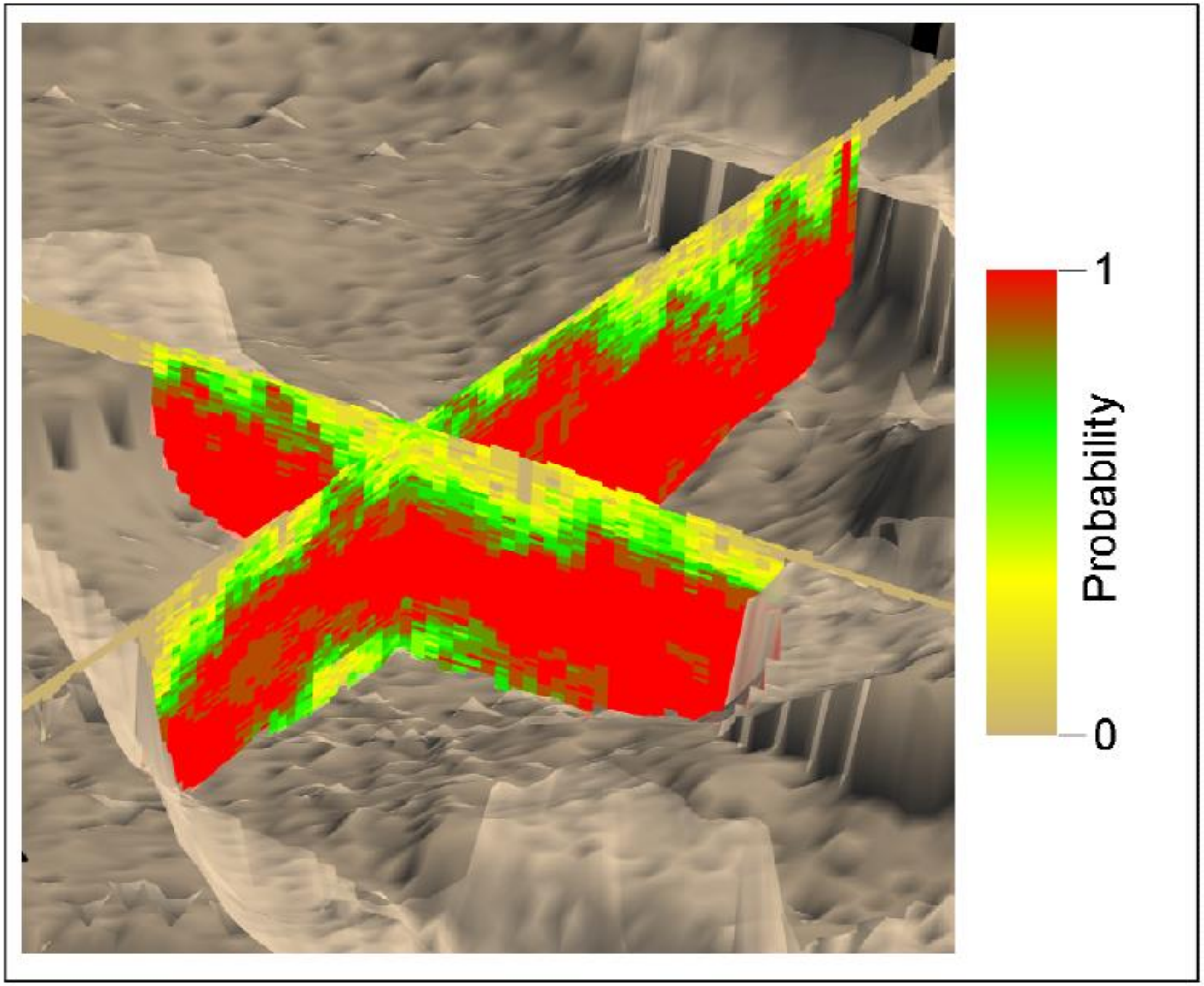
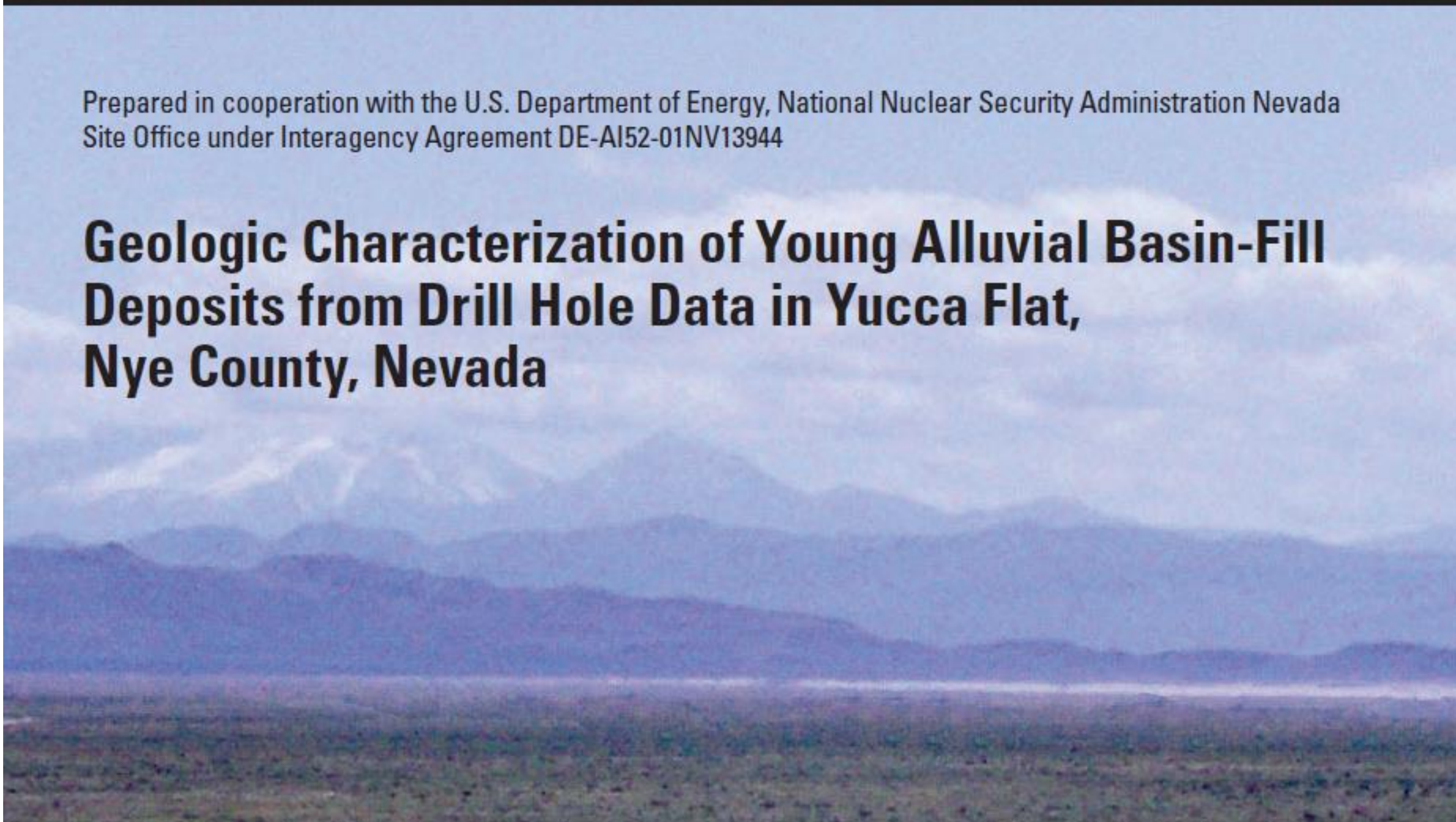


Figure 3. Cross-section through a tidal channel in Zeeland showing the probability that a grid cell belongs to the tidal channel lithofacies.

Case Study-5

USGS
science for a changing world

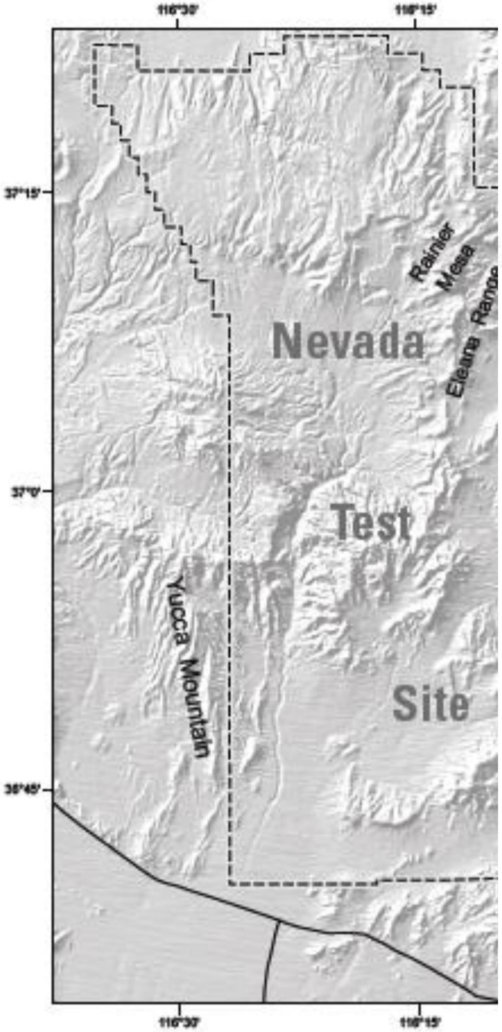
Reference: Open-File Report 2006–1390, By Donald S. Sweetkind and Ronald M,
U.S. Department of the Interior, U.S.G.S.


Prepared in cooperation with the U.S. Department of Energy, National Nuclear Security Administration Nevada Site Office under Interagency Agreement DE-AI52-01NV13944

Geologic Characterization of Young Alluvial Basin-Fill Deposits from Drill Hole Data in Yucca Flat, Nye County, Nevada

The purpose of this study is to

- Develop an understanding of lateral and vertical lithologic variability of Neogene sediments that make up the shallow basin fill of Yucca Flat.
- Understanding the configuration and character of the basin-fill sedimentary units is critical to delineating hydraulic properties and reducing uncertainty in three-dimensional simulations of ground-water flow in the Yucca Flat area.
- Recent stratigraphic studies of Cenozoic basins to the south of the NTS, including the Amargosa Desert Basin (Sweetkind and others, 2001; Taylor and Sweetkind, 2005) and the Pahrump Valley (Sweetkind and others, 2003) have shown that the three-dimensional stratigraphic variability of shallow alluvial sediments can be adequately characterized through interpretation of drill hole lithologic data.
- It is hoped by the authors that the use of similar techniques would yield similar results in the Yucca Flat basin.



Base from U.S. Geological Survey digital data, 1:250,000; Universal Transverse Mercator projection, Zone 11.
Shaded-relief base from 1:250,000-scale Digital Elevation Model; sun illumination from northwest at 30° above horizon

0 2.5 5 10

EXPLANATI

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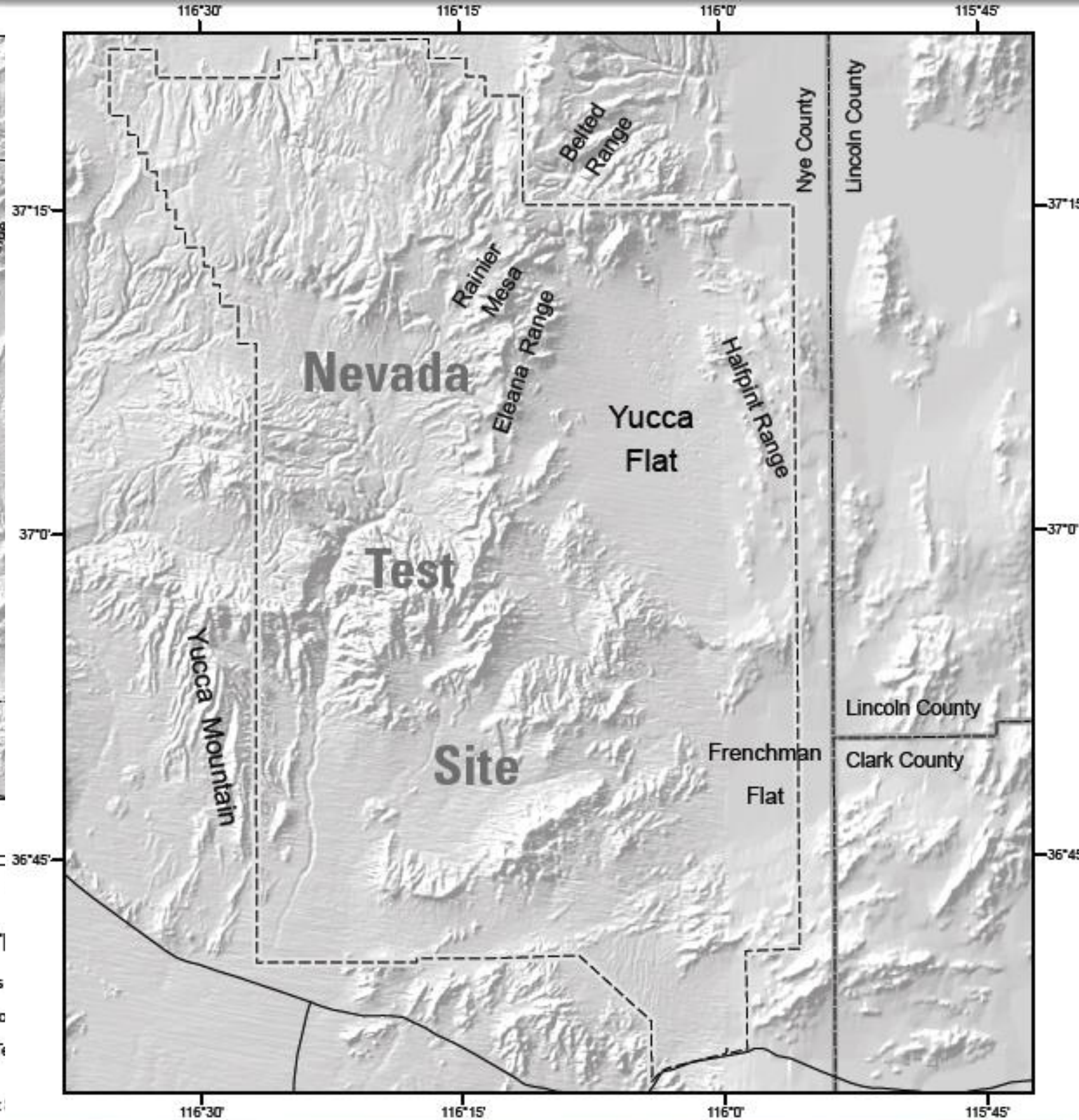


Figure 1. Index map of Yucca Flat and the Nevada Test

Physiographic Setting

Yucca Flat is a topographically closed drainage basin that occupies much of the eastern part of the Nevada Test Site (fig. 1). The valley floor has no perennial surface water; Yucca Flat acts as a catchment for surface-water runoff and is a local depositional center for sediment. The low-relief topographic basin has a playa (seasonally dry lake) at the south end (fig. 2) and the basin is surrounded by low ranges that are underlain by Tertiary volcanic rocks and underlying Paleozoic and Late Proterozoic sedimentary rocks (fig. 2) (Slate and others, 2000). In general, the valley floor slopes upward toward the surrounding ranges on a series of coalescing alluvial fans that ring the margins of the basin. Large, active alluvial channels extend into the basin from topographic highlands of Rainier Mesa, the Eleana Range and the Halfpint Range (figs. 1 and 2).

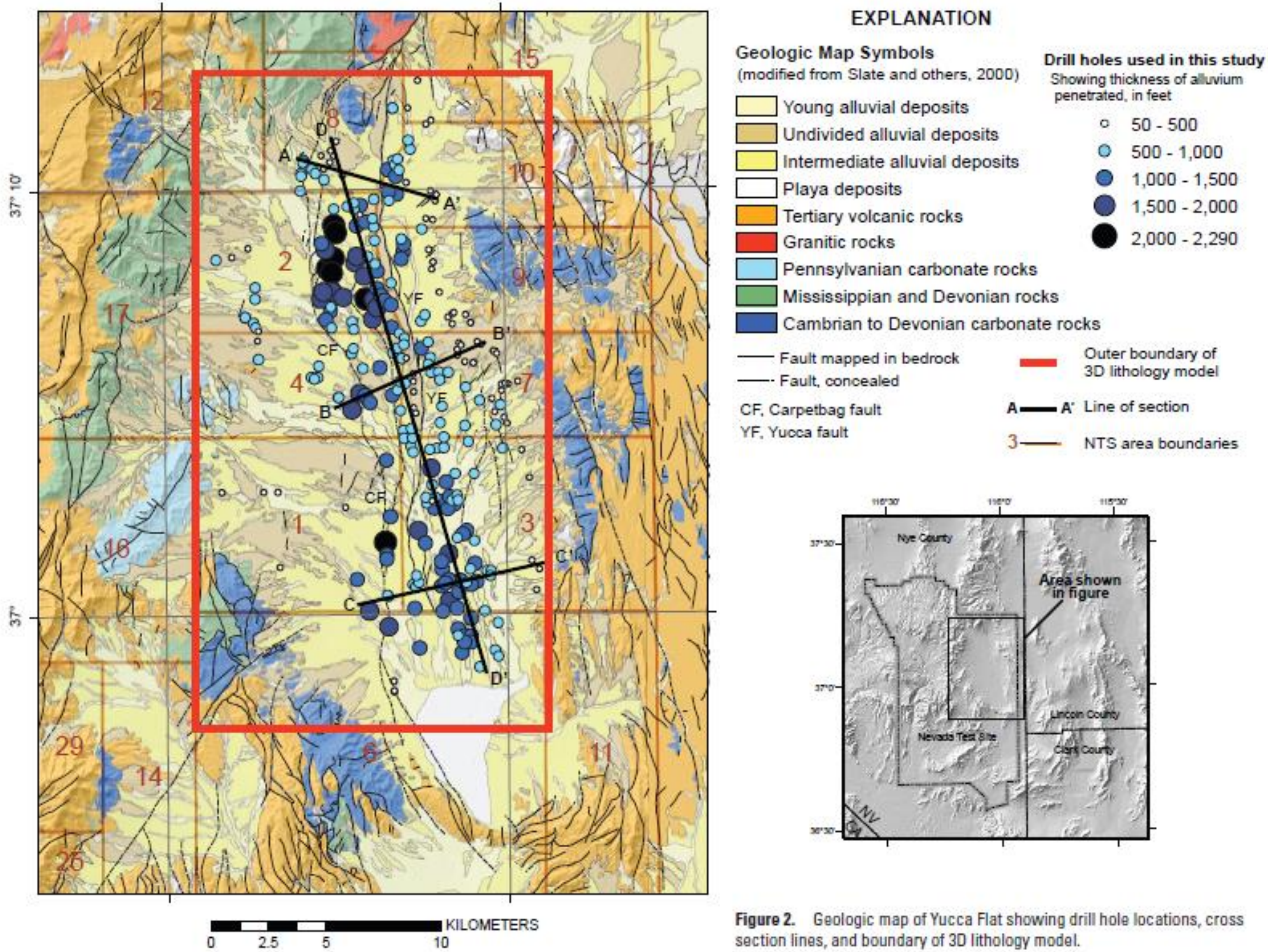


Figure 2. Geologic map of Yucca Flat showing drill hole locations, cross section lines, and boundary of 3D lithology model.

Table 1. Generalized lithologic classes based on drill hole descriptions.

Lithology class	Drill hole intervals	Rationale for classification
Gravel	63	Used for cobble beds, boulder beds, and where gravel was reported as having no fine-grained matrix.
Sandy gravel	229	Used for sand and gravel mixtures where gravel, clasts, or cobbles were 70% or more of the total.
Gravelly sand	341	Used for sand and gravel mixtures where gravel, clasts, or cobbles were subequal in abundance to the sand component; used where sand was 30% to 70% of the total.
Sand and minor gravel	360	Used for sand and gravel mixtures where the sand component was much more abundant than gravel, clasts, or cobbles; typically sand was 70-80% of the total, often greater than 90% of the total.
Sand, clay and gravel	42	Used for sand and gravel mixtures where silt or clay was identified as an additional important component. Typically these intervals are dominated by the sand-silt component with relatively minor gravels.
Coarse sand	263	Used for sand sizes greater than 0.5 mm, typically greater than 1 mm, often with scattered pebbles up to 1 cm.
Fine sand	44	Used for sand sizes less than 0.5 mm, rare pebbles.
Clay and sand	12	Used for intervals where sands are interbedded with clay layers. Typically explicitly interpreted in the description as alluvial material interbedded with playa deposits.
Clay	2	Used for intervals described as almost completely clay. Typically explicitly interpreted in the description as playa deposit.
Clay and limestone	4	Used for intervals where clays are interbedded with thin-bedded limestone. Typically explicitly interpreted in the description as playa deposits.
Basalt	3	Used for intervals where basalt was specifically identified.
Nonwelded tuff	9	Used for intervals where nonwelded tuff was specifically identified.
No data	39	Intervals with no useful lithologic information, such as “alluvium”.

3D Lithologic Modeling

- Interpreted drill hole lithologic data were numerically interpolated between drill holes using a cell-based interpolation called horizontal lithoblending within the RockWorks 2004 software package.
- Grid nodes are sequentially assigned a value that corresponds to the interpreted lithologic classes based on the proximity to each drill hole.
- The interpolation routine looks outward horizontally from each drill hole in search circles of ever-increasing diameter.
- The algorithm assigns the lithology values from the drill hole data in each vertical interval to cells immediately surrounding each drill hole.
- Then the interpolation moves out by a cell, and assigns the next “circle” of cells a lithology value for each vertical interval.

- The interpolation continues in this manner until the program encounters a cell that is already assigned a lithology (presumably interpolating toward it from an adjacent drill hole), in which case it skips the node assignment step.
- Cell dimensions for the 3D interpolation were 3,281 ft in the horizontal dimensions and 33 ft in the vertical dimension.
- We trimmed the resulting model at the top by a grid representing land surface elevations and at the base by a grid that represents the smoothed base of alluvium encountered in the selected drill holes.
- Because there was no information regarding stratal dip in the alluvial section, strata were assumed to be horizontal in this 3D interpolation.
- The assumption of horizontality is likely more valid for the younger, upper parts of the basin fill than for the deeper parts of the alluvial section.

The strength of this method is that the interpolated data in the resulting 3D grid have the appearance of stratigraphic units, with aspect ratios that emphasize the horizontal dimension over the vertical.
Also, the method preserves the local variability of the lithology encountered in each drill hole with no smoothing or averaging.
Thus, where data are abundant, local lithologic variability is incorporated.

One limitation of this numerical interpolation is the sensitivity to the distribution of the data, where values from an isolated drill hole tend to extrapolate outward to fill an inordinate amount of the model area.
The effect is particularly noticeable where a small number of deep drill holes are interspersed with shallower holes; data from the deepest drill holes tend to over-extrapolate over the entire model area.
This could be mitigated this effect by a trimming of the base of the model, using a grid that represents the smoothed base of alluvium encountered in the selected drill holes.

Faults were not explicitly included in the creation of these solid models, due to the limitations of the software package used. However, the interpolation methods used here produce lithologic variations that approximate fault truncations of lithologic units where data density is high.

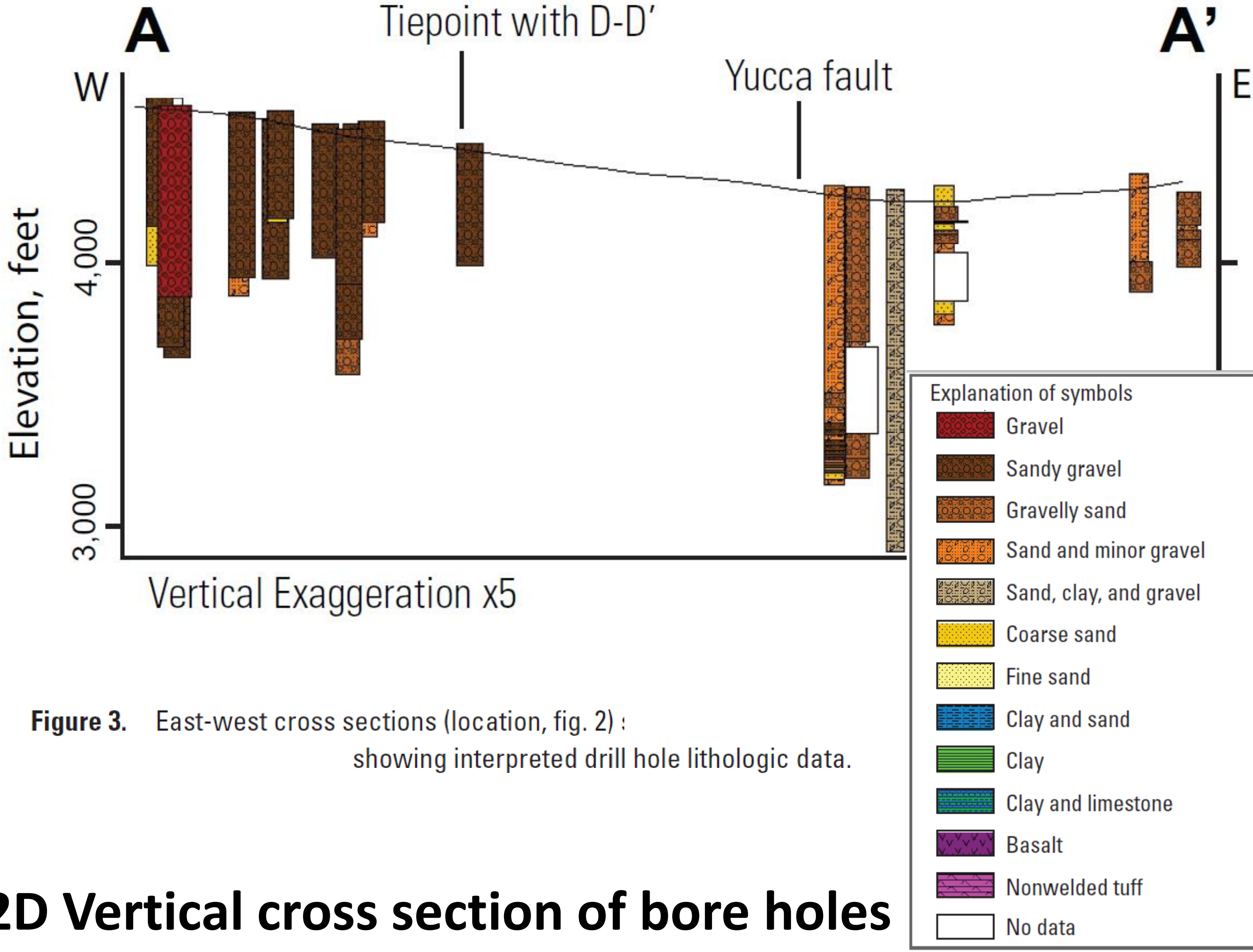
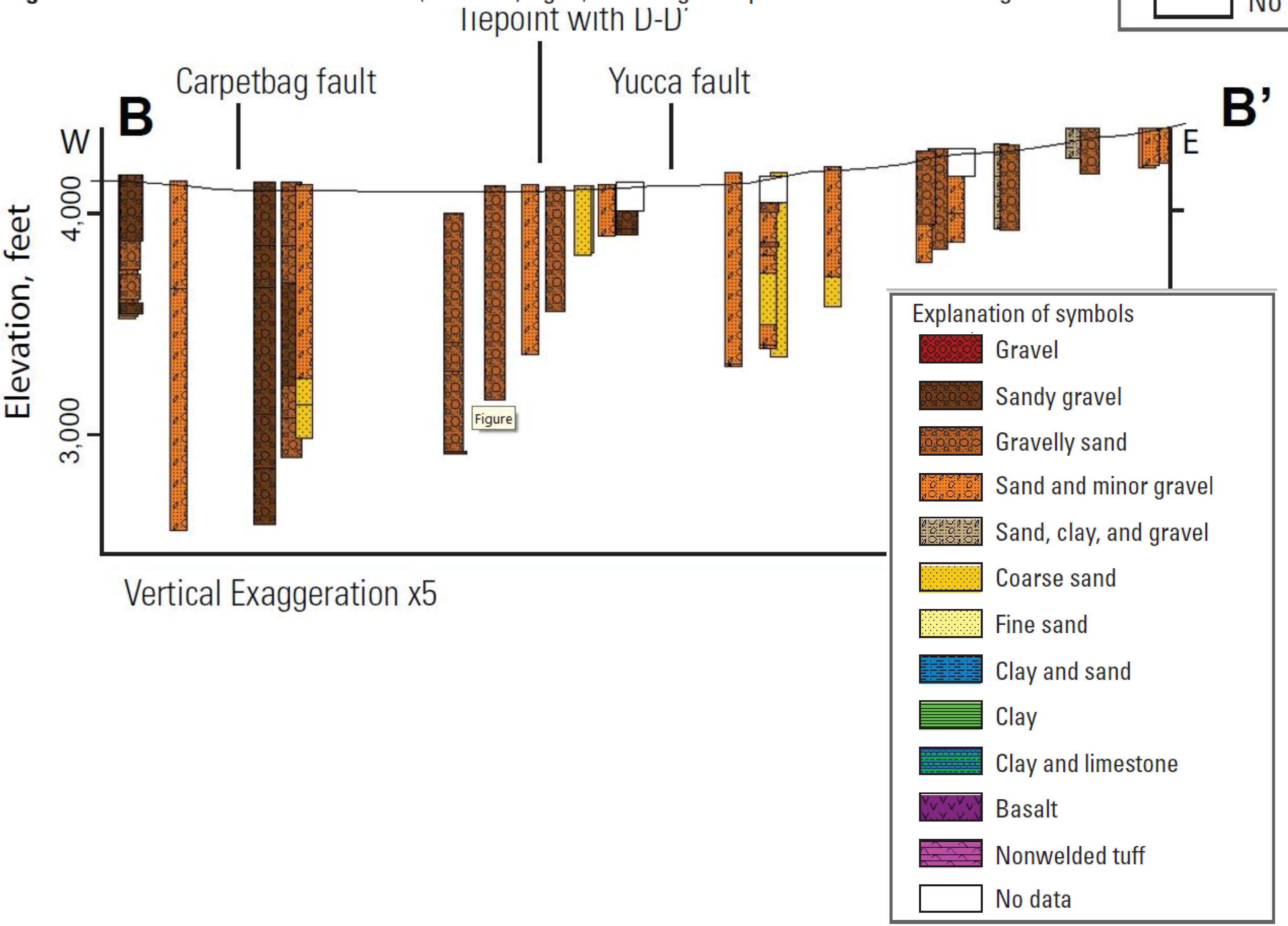


Figure 3. East-west cross sections (location, fig. 2) showing interpreted drill hole lithologic data.

2D Vertical cross section of bore holes

Figure 3. East-west cross sections (location, fig. 2) showing interpreted drill hole lithologic data.



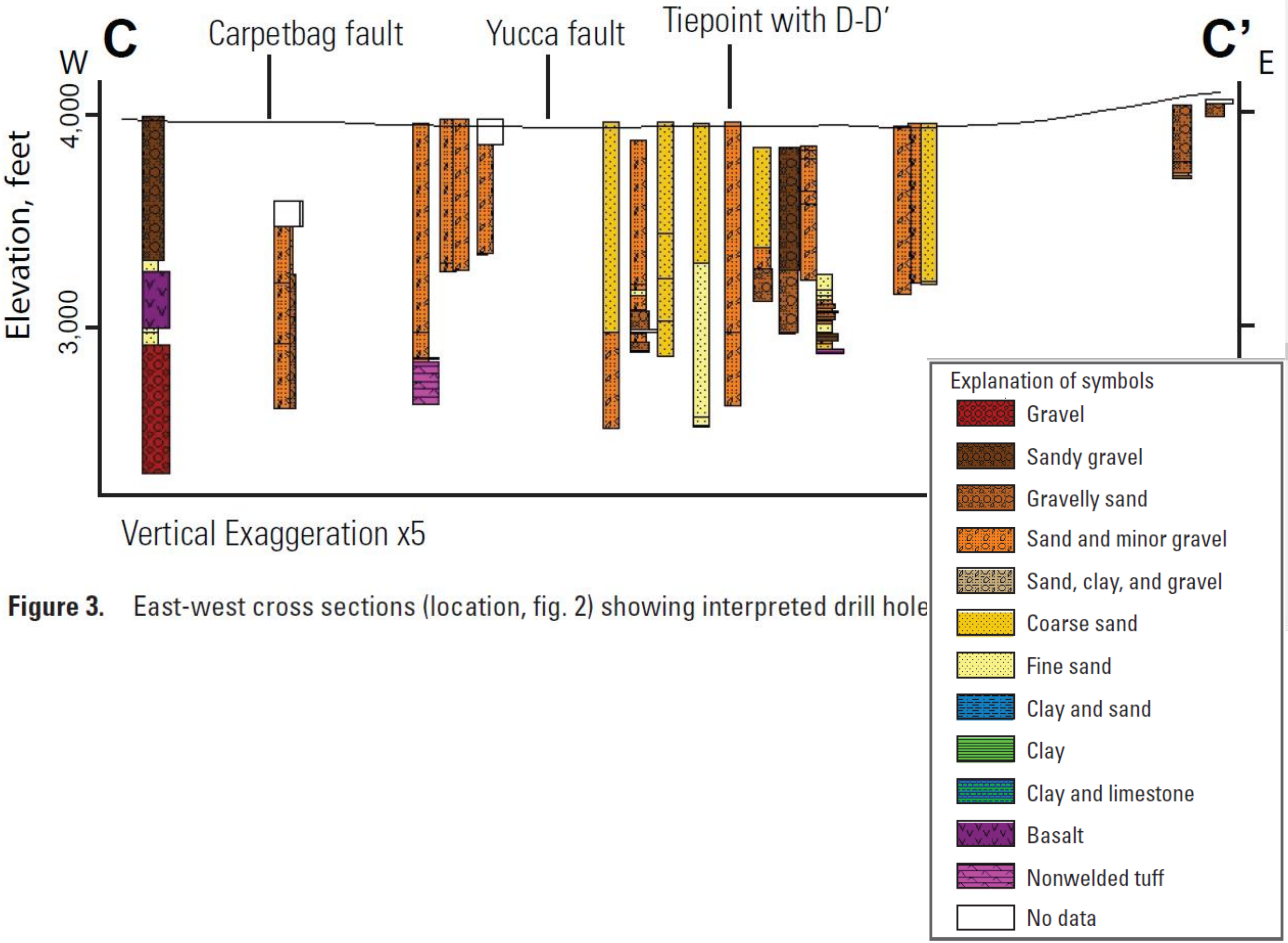


Figure 3. East-west cross sections (location, fig. 2) showing interpreted drill hole

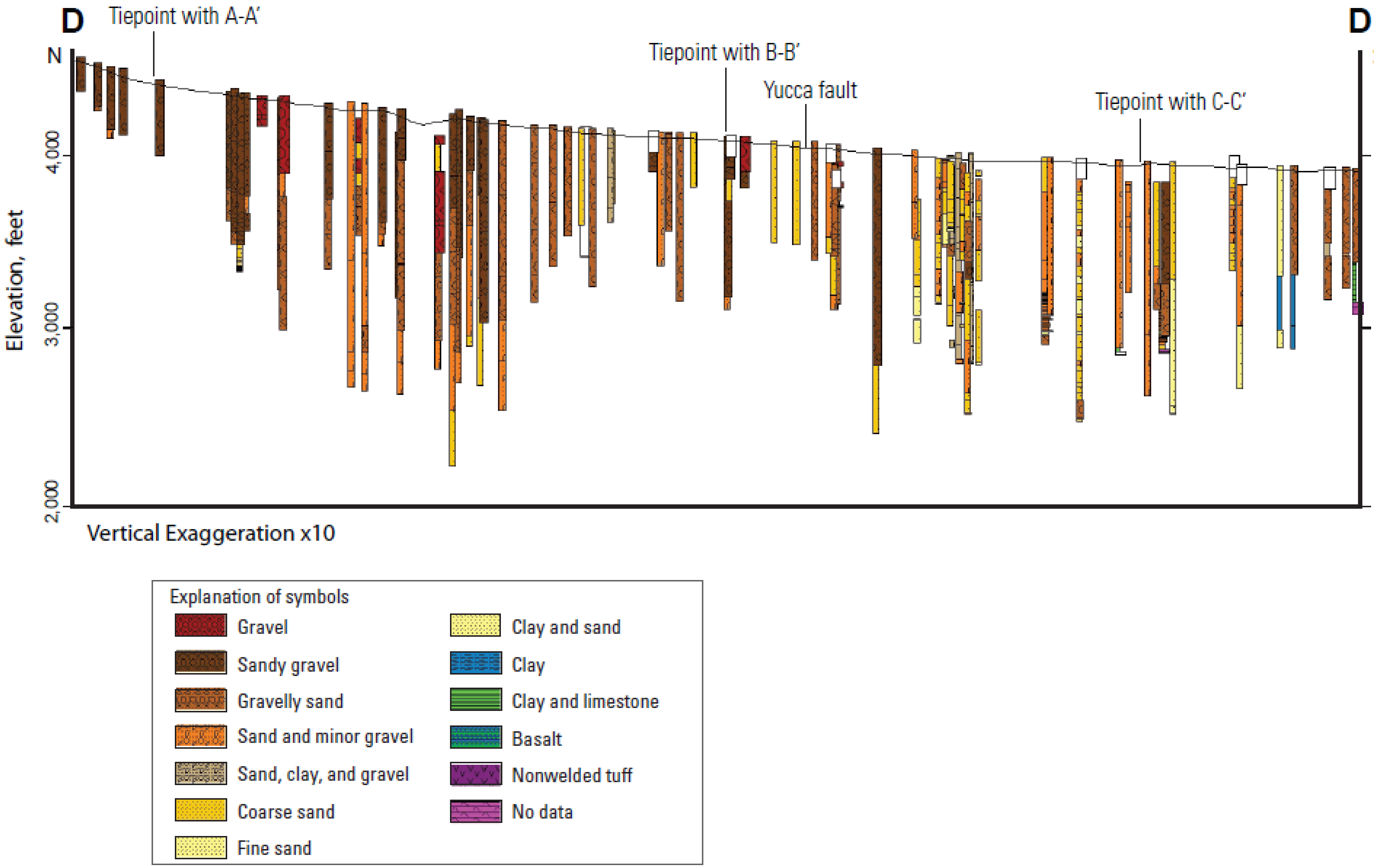


Figure 4. North-south cross section (location, fig. 2) showing interpreted drill hole lithologic data.

3D Vertical cross section of bore holes

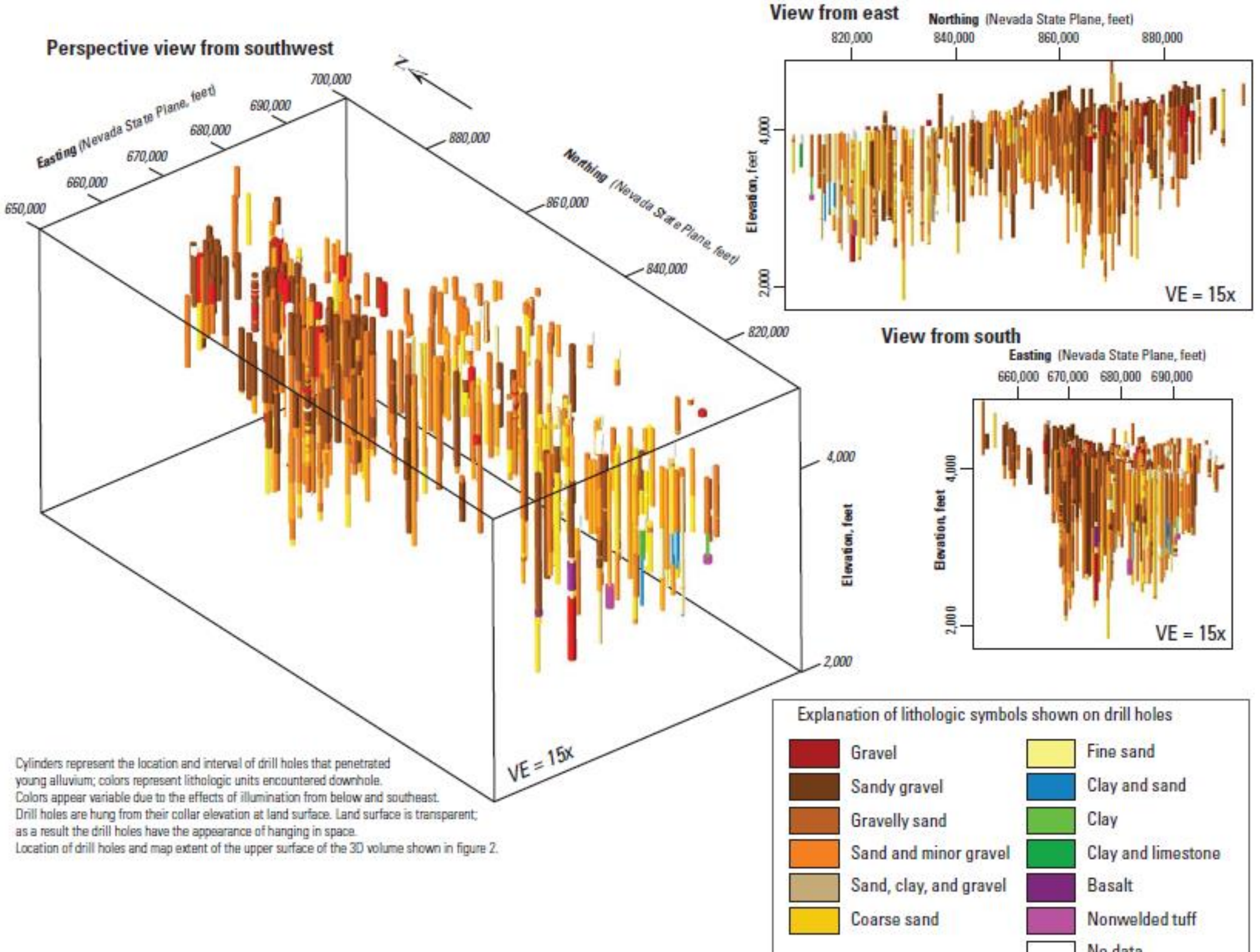


Figure 5. Three-dimensional portrayals of drill hole lithologic data.

3D Fence Diagram

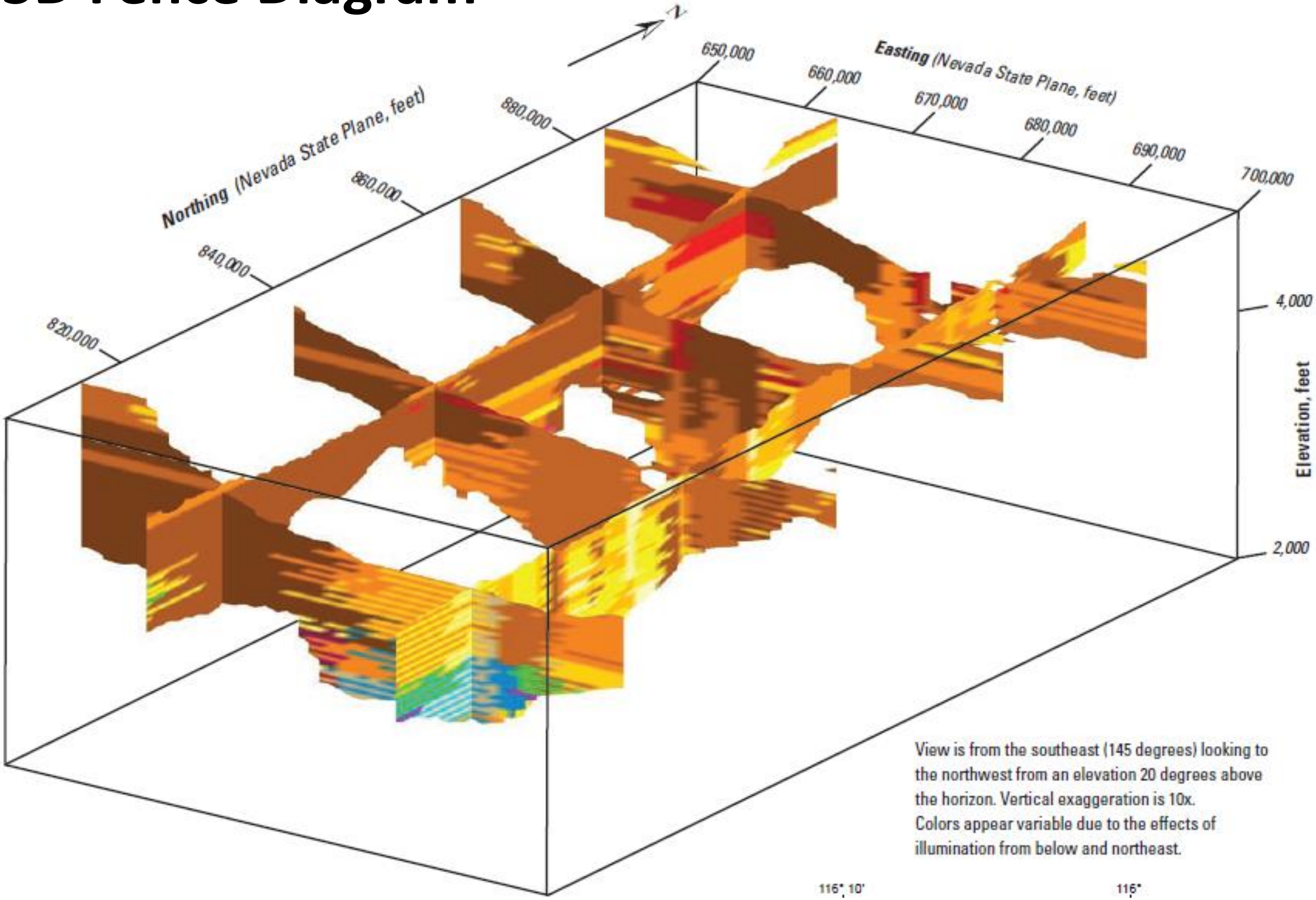


Figure 6. Perspective view of vertical sections cut through 3D lithology model of Yucca Flat.

…Fig. Contd…

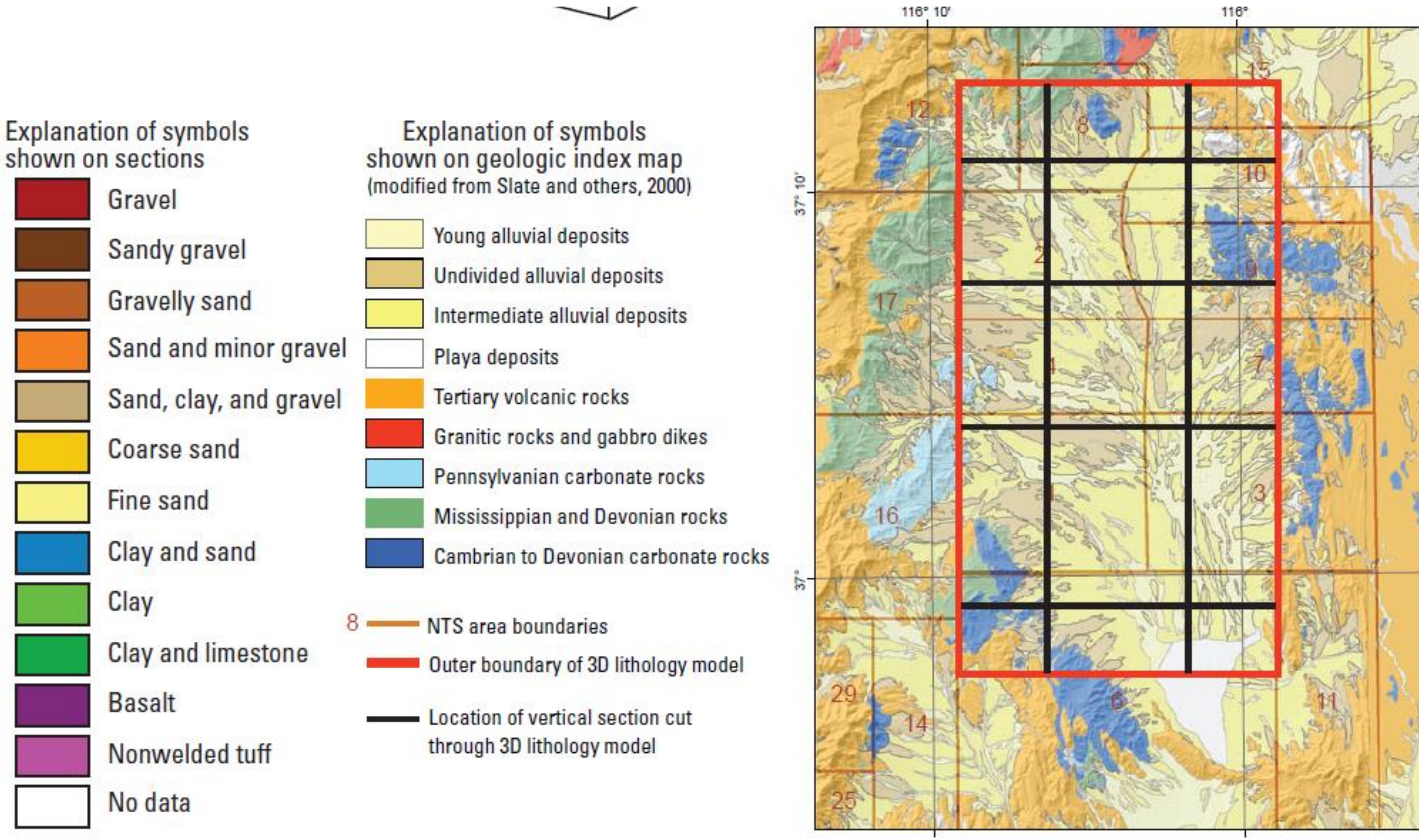


Figure 6. Perspective view of vertical sections cut through 3D lithology model of Yucca Flat.

3D Perspective view of distinct Layers

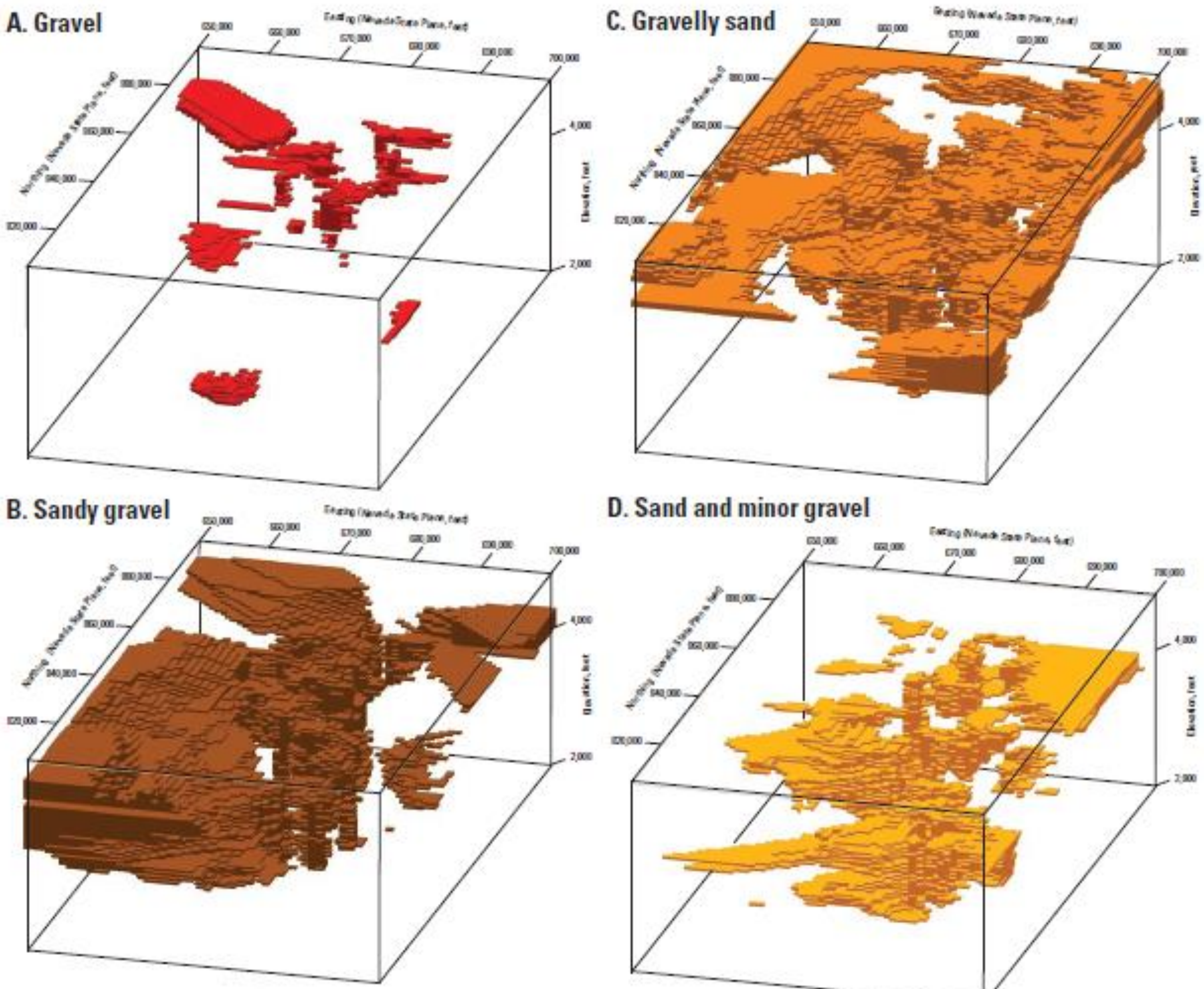


Figure 7. Perspective views of 3D lithologic model showing distribution of lithologic classes.

All views are from the southeast (145 degrees)looking to the northwest from an elevation 20degrees above the horizon. Vertical exaggeration is 10x. Colors appear variable due to the effects of illumination from above and northeast.

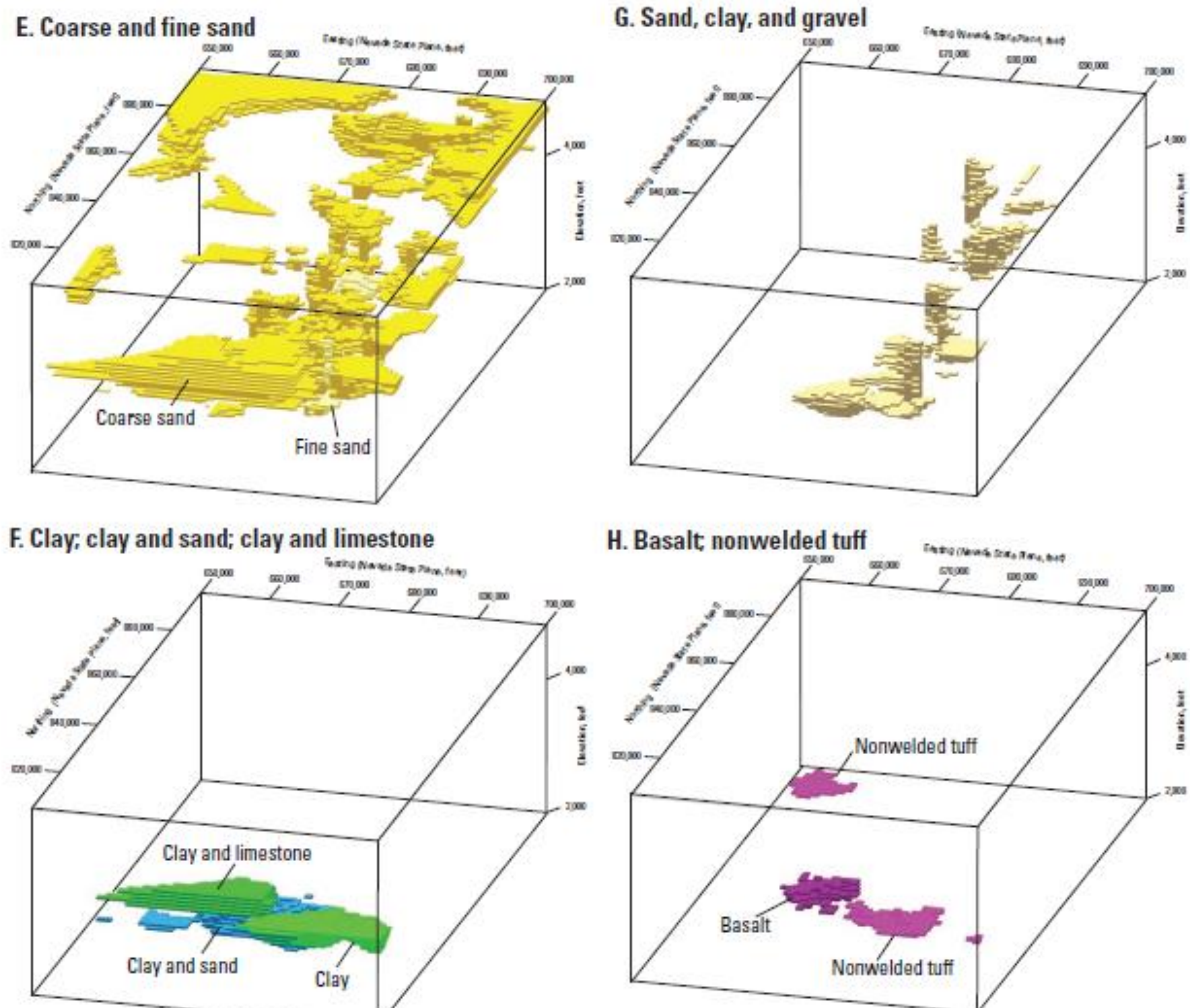


Figure 7—Continued. Perspective views of 3D lithologic model showing distribution of lithologic classes.

All views are from the southeast (145 degrees)looking to the northwest from an elevation 20degrees above the horizon. Vertical exaggeration is 10x. Colors appear variable due to the effects of illumination from above and northeast.

3D Layered Stacking

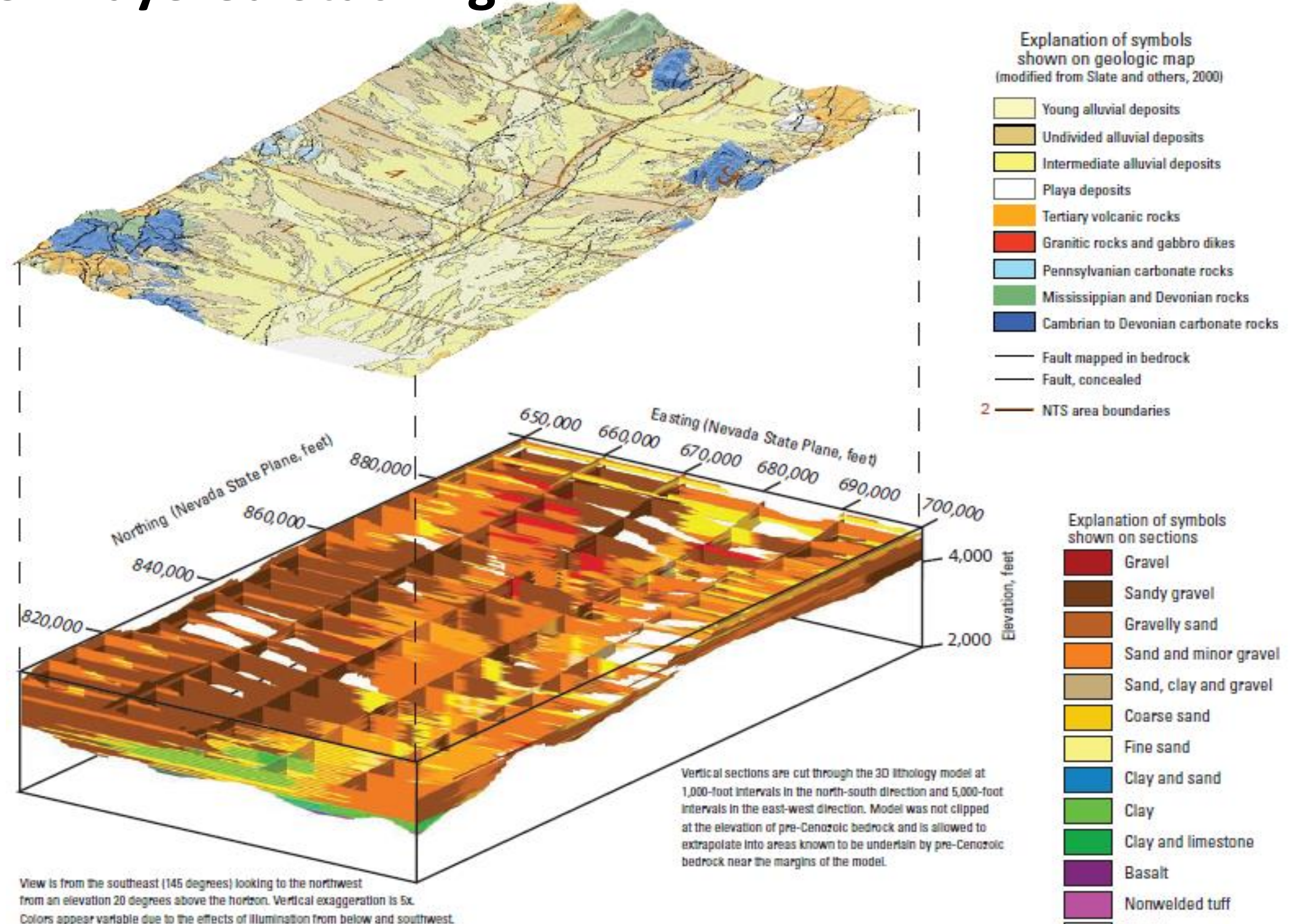


Figure 8. Perspective view of multiple vertical sections cut through 3D lithology model of Yucca Flat.

Thank you