12/4/91
CONF-920430--50
10617-1194
UC-510

THREE DIMENSIONAL VISUALIZATION IN SUPPORT OF YUCCA MOUNTAIN SITE CHARACTERIZATION ACTIVITIES

EGG--10617-1194
DE92 007623

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ABSTRACT

An understanding of the geologic and hydrologic environment for the proposed high-level nuclear waste repository at Yucca Mountain, NV is a critical component of site characterization activities. Conventional methods allow visualization of geologic data in only two or two and a half dimensions. Recent advances in computer workstation hardware and software now make it possible to create interactive three dimensional visualizations. Visualization software has been used to create preliminary two-, two-and-a-half-, and three-dimensional visualizations of Yucca Mountain structure and stratigraphy. The three dimensional models can also display lithologically dependant or independent parametric data. Yucca Mountain site characterization studies that will be supported by this capability include structural, lithologic, and hydrologic modelling, and repository design.

INTRODUCTION

The Yucca Mountain Site Characterization Project (YMP) was initiated by the Department of Energy in response to the Nuclear Waste Policy Act and Amendments Act of 1982 and 1987, respectively. These acts require the comprehensive characterization of Yucca Mountain, located in southern Nye County, Nevada, to determine its suitability as a potential deep geological repository for high level nuclear waste. This proposed repository, that would be a mined facility, must last for 10,000 years.

The need for a thorough understanding of the structural and stratigraphic nature of Yucca Mountain is critical to the successful completion of site characterization. The use of three dimensional visualization provides a more complete understanding than conventional methods.

TWO DIMENSIONAL VISUALIZATION

Traditional two dimensional visualizations conventionally include structure contour and isopach maps, cross-sections, fence diagrams, perspective views, and block diagrams. Structure contour and isopach maps provide an areally extensive plan view of essentially horizontal slices through the subsurface. However, they are limited by the inability to work with more than one surface or isopach at a time. Cross-sections provide information at depth, however, only below a single line on the surface. Many cross sections must be constructed to gain a more extensive understanding of the subsurface. Typically, only a few cross-sections are developed for a given area, thereby providing only an areally limited understanding of the subsurface. Fence diagrams are essentially a composite of cross sections, and only represent areally limited vertical slices into the subsurface.

Perspective views take two dimensional surfaces a step towards the three dimensional realm by providing an artificial sense of the third dimension through the use of exaggerated perspective. This may be called two-and-a-half dimensional visualization. However, perspective views provide no sense of subsurface conditions. Block diagrams do provide a limited subsurface (cross-sectional) view at the edge of the block, and are viewed in perspective.

THREE DIMENSIONAL VISUALIZATION

Until the past few years, the ability to visualize data in three dimensions has been limited. This has been because the sophisticated computer software and hardware have not been available. However, recent work has started in the three dimensional visualization field.

In the mid-1980s at Sandia National Laboratory (SNL), Nimick and Williams,[1] and Ortiz and others[2] produced three dimensional models, based on stacked surfaces of Yucca Mountain

[a] Work supported by the U.S. Department of Energy, Nevada Field Office, under Contract No. DE-AC08-88NV10617.

lithologic, and thermal/mechanical and stratigraphy, respectively. They used Applicon, a basic computer-aided design (CAD) system as the graphics engine, and an SNL designed surface estimation and modulation technique to generate surfaces at the base of stratigraphic units, as well as on mineralogic and hydrologic surfaces. They demonstrated that digital three dimensional modelling techniques can produce geologically plausible models. These models, however, are not volumetric models, and do not allow for modelling of continuously variable parameters.

Now with the recent proliferation of comparatively inexpensive and powerful workstations, software that processes three dimensional data in a timely fashion is available. Encouraged by this and SNL's work, Turner and others,[3] at the U.S. Geological Survey (USGS) in Denver, CO, evaluated three dimensional modelling systems currently available or in prototype as of 1991. They found that each had particular strengths in modelling three dimensional data: the Dynamic Graphics, Inc. system generated three dimensional solids with variable property values throughout the solid; the Intergraph Corporation system allowed for the display of complex structural elements through the use of lines, surfaces, and volumes, with some query capabilities of the relational database; and the Lynx Geosystems system allowed for geostatistical computations and volumetric calculations from borehole, map, and cross-section data.

In choosing a three dimensional visualization software for building stratigraphic and structural models, many elements were considered desirable, including:

1. Solid as opposed to stacked surface modelling,
2. Zone modelling (to allow stratigraphy dependant modelling of properties),
3. Three dimensional gridding and contouring, with multiple algorithms available,
4. Ability to handle faults and pinchouts,
5. Volumetric calculations,
6. interaction with a relational database,
7. On screen interactive three dimensional visualization, and
8. Output of three dimensional visualizations.

No three dimensional visualization software exists at this time that will perform all these elements. However, there are several systems that can perform many of these functions, as pointed out by Turner and others.[3] The visualization software used and presented here, Interactive Surface Modelling (ISM) and Interactive Volume Modelling (IVM), was developed by Dynamic Graphics, Inc.[b] (DGI). This software resides on a Silicon Graphics, Inc. (SGI) Personal IRIS three dimensional graphics workstation.

INTERACTIVE SURFACE AND VOLUME MODELLING

ISM generates a grid from scattered data that defines surfaces; whereas, IVM generates a grid using three dimensionally coordinated data with associated property values to define volumes. ISM and IVM use essentially the same algorithm to grid in both two and three dimensions. The gridding is accomplished using a proprietary algorithm that incorporates initial weighted averages and biharmonic iterations (which seek minimum tension or curvature within the gridded surface) with scattered data feedback. The grid size is selectable, and is dependant upon abundance and distribution of the data, and upon the intricacy of the surface to be modelled. IVM uses the surface grids generated in ISM to define the lower and upper bounds of a zone in a multi-zone (or stratified) three dimensional model.

ISM gridding works with vertical faults by treating them as impermeable barriers. Normal faulting is accommodated by treating each polygon bounding-line that describes a normal fault plane as a vertical fault. Grid node values are interpolated inside the normal fault polygon subsequent to gridding performed outside the polygon. Reverse or thrust faulting cannot currently be accommodated.

Contouring of a surface grid to create a structure contour map is done by simple linear interpolation between subgrid values.

Information may be brought into ISM from a Geographic Information System (GIS) to be used as primary or supplementary data, or as surface display (annotation) files. A GIS is a computerized processing system that integrates spatial data (structured with coordinates and topology) with descriptive attribute data by means of a relational data base management system. It is capable of data input, storage, management, manipulation, analysis, and display of cartographic data. GENISES (GEographic Nodal Information Study and Evaluation System) is the GIS Technical Database conceived and operated by EG&G Energy Measurements for the Yucca Mountain

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[b] Any use of trade names is for descriptive purposes only and does not constitute endorsement by EG&G Energy Measurements, Inc. or the U.S. Department of Energy.

Site Characterization Project. It is used to capture, store, and manipulate spatial data. This includes geological data. GENISES is implemented via ARC/INFO, a GIS developed by Environmental Systems Research, Inc., ESRI), on SUN SparcStations.

A file transfer procedure between GENISES and the DGI software on the SGI platform has been established.

ISM may be used to create: structure contour, isopach, and trend surface maps; cross sections; perspective views of surfaces; and fence and block diagrams.

Three dimensional displays created in IVM may in real-time be interactively sliced, rotated, peeled, or have subsections removed. Coloration, z-scaling, and information type (lithology or property, with or without elevation contoured surfaces) are selectable. Data points, drillhole paths, and surface annotation may be posted.

Volumetric calculations may be performed on both ISM and IVM models. For ISM only simple volumetric calculations may be done. Surface grids, horizontal horizons, and vertical lateral boundaries may all be used to define a volume. In addition, a multiplicative factor may be used to modify a volume calculation. Where grid surfaces intersect cut-and-fill volumes may be calculated.

In IVM, volumetric calculations may additionally be constrained by a range of property values. For instance, the volume of rock of a given minimum zeolite content within the Tuffaceous Beds of Calico Hills directly below the proposed repository could be calculated.

Limitations of the DGI software include: no selectibility of other gridding and contouring algorithms; inability to handle reverse or thrust faults; its database is non-relational and is limited to algebraic and trigonometric functions; and hardcopy output in IVM is limited to digital and photographic CRT (Cathode Ray Tube) screen captures. ISM maps and diagrams, however, may be output to a color plotter.

It should be noted that this software, like other three dimensional volumetric software, is not a true three dimensional Geographic Information System (GIS). It does not allow spatial queries, such as "Of all the mines in Nevada, how many are gold mines located within 10 miles of a Mesozoic pluton?" These types of queries require a topological data structure. Topology is a mathematical depiction of spatial relationships, defined by connectivity (arcs connect at nodes, or points), area definition (arcs connect to define the areas of polygons), and contiguity (arcs are vectors, having direction with left and right sides).

METHODOLOGY FOR CREATING VISUALIZATIONS

Work is proceeding using the DGI software to create models of the near field Yucca Mountain stratigraphy. The methodology used is detailed below.

Data Collection and Entry

The primary data source is the YMP Site and Engineering Properties Data Base (SEPDB). Three dimensional coordinates for the drillholes were acquired with picks for the thermal mechanical and lithostratigraphic units, as well as water table levels.

Data from GENISES and other published sources were used to update, correct, and provide ancillary information to the SEPDB data, developed by SNL.

Create Surface Grids in ISM

Surface grids serve several purposes. They provide a simple means to find data entry errors and outlier values. They are needed to create a zoned three dimensional model. Surface grids can be used to create structure contour and isopach maps, cross-sections, and fence and block diagrams.

An iterative process is necessary to determine the proper gridding parameters. Through this process, the surface grids that represent formational or facies boundaries may be refined in order to create a geologically reasonable gridded surface.

The surfaces generated by this procedure are based on original, smooth, and continuous surfaces. Erosional features or igneous structures are not modelled. Additionally, a simplistic fault regime of the generalized extents of the Ghost Dance and Solitario Canyon Faults are being used. The depth of the visualization models do not exceed approximately 5000 feet below the surface.

For the initial models at this time, drillholes are considered not to be deviated from the vertical. However, drillhole deviation will be accommodated in the future. Furthermore, the initial models assume the faults to be vertical but in the future normal faulting will also be accommodated.

Create Volumetric Models in IVM

The creation of an interactive zoned three dimensional model is dependant upon the reasonable development of the gridded surfaces. This makes the selection of appropriate gridding parameters for the three dimensional model much simpler. From a three dimensional model, two dimensional grids (cross-sections) may be extracted, edited, and then used to regrid the three dimensional model. In a similar manner, cross-sections created by hand and digitized may be used to influence the development of three dimensional grid models.

For each property to be displayed (i.e., porosity, thermal conductivity, etc.) within a three dimensional model, a separate three dimensional grid and display must be calculated. From these three dimensional models any number of cross-sections may be generated for hardcopy output.

PRELIMINARY RESULTS, PLANNED WORK, AND USES FOR THREE DIMENSIONAL VISUALIZATIONS

Initial modelling efforts have resulted in the creation of surface grids for the thermal mechanical stratigraphy, as well as two dimensional maps, cross-sections, and perspective diagrams. Subsequent work will generate an interactive three dimensional model of the thermal mechanical stratigraphy. Later work will be done to create a three dimensional lithostratigraphic model. Three dimensional visualizations of the configuration of property values will also be modelled. The property may be of any type, including: porosity, mineral abundance, magnetic susceptibility, chemical abundance, thermal conductivity, isotope abundance, and hydraulic conductivity, among others.

As interpretations of core from new drillholes are made available, the models will be recalculated. These models may, on the other hand, be used to indicate areas of inadequate data/sampling.

These models may be used as a predictive tool. Lithologic, fault, and property value intercepts could be predicted for proposed drillholes, shafts, and drifts. Multi-temporal data can also be displayed in separate three dimensional models and displayed in a movie-loop.

This tool will provide investigators with the opportunity to visualize in three dimensions the numeric output from their two dimensional and three dimensional predictive models.

References

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2. T. S. ORTIZ, R. L. WILLIAMS, F. B. NIMICK, B. C. WHITTET, and D. L. SOUTH, "A three dimensional model of reference thermal/mechanical and hydrologic stratigraphy at Yucca Mountain, southern Nevada," SAND84-1076, Sandia National Laboratories, Albuquerque, New Mexico (1985).

3. A. K. TURNER, E. M. ERVIN, AND J. S. DOWNEY, "Evaluation of geographic information systems for three-dimensional ground-water modeling, Yucca Mountain, Nevada," High Level Radioactive Waste Management: Proceedings of the Second Annual International Conference, Las Vegas, Nevada, pp. 520-528, (1991).

EGG 10617-1194

SLIDES FOR HLRWM CONFERENCE, April 14, 1992, 10:30

SLIDE 1

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SLIDE 2

TWO DIMENSIONAL VISUALIZATION

THREE DIMENSIONAL VISUALIZATION

INTERACTIVE SURFACE AND VOLUME MODELLING

METHODOLOGY FOR CREATING VISUALIZATIONS

PRELIMINARY RESULTS, PLANNED WORK, AND USES FOR THREE DIMENSIONAL VISUALIZATIONS

SLIDE 3

Two Dimensional Visualization

- o Structure Contour and Isopach Maps
  - o Areally extensive plan view of essentially horizontal surfaces
  - o Limited to one surface or isopach at a time
- o Cross-sections and Fence Diagrams
  - o Provide limited view of subsurface with severely restricted plan view
- o Perspective Views and Block Diagrams
  - o Two-and-a-half dimensional view of areal surfaces
  - o Provide limited or no sense of subsurface conditions

{This slide may take the place of slides 4-7}

SLIDE 4

Two Dimensional Visualization

- o Structure Contour and Isopach Maps
- o Cross-sections and Fence Diagrams
- o Perspective Views and Block Diagrams

SLIDE 5

Structure Contour and Isopach Maps

- o Areally extensive plan view of essentially horizontal surfaces
- o Limited to one surface or isopach at a time

SLIDE 6

Cross-sections and Fence Diagrams

- o Information at depth but only below a single line on the surface
- o Provides only an areally limited understanding of the subsurface.

SLIDE 7

Perspective Views and Block Diagrams

- o Two-and-a-half dimensional view of surfaces
- o Perspective views provide no sense of subsurface conditions
- o Block diagrams do provide a limited subsurface (cross-sectional) view at the edge of the block in perspective

SLIDE 8

Three Dimensional Visualization

- o Limited ability until recently
- o Older 3D visualization systems demonstrated usefulness
- o Turner and others provided an overview last year
- o Very capable software now exists for powerful UNIX workstations

SLIDE 9

Desired Features for a 3D Visualization System

- o Solid as opposed to stacked surface modelling
- o Zone modelling (to allow stratigraphy dependant modelling of properties)
- o Three dimensional gridding and contouring, with multiple algorithms available
- o Ability to handle faults and pinchouts
- o Volumetric calculations
- o Interaction with a relational database
- o On screen interactive three dimensional visualization, and
- o Output of three dimensional visualizations

SLIDE 10

Software and Hardware Configuration

- Interactive Surface Modelling (ISM)
- Interactive Volume Modelling (IVM)
- Developed by Dynamic Graphics, Inc. (DGI)
- Resident on a Silicon Graphics, Inc. (SGI) Personal IRIS, a three dimensional graphics workstation

SLIDE 11

INTERACTIVE SURFACE AND VOLUME MODELLING

SLIDE 12

Interactive Surface and Volume Modelling

- Proprietary algorithm to grid in two or three dimensions
- Uses initial weighted averages and biharmonic iterations (which seek minimum tension or curvature within the gridded surface) with scattered data feedback
- Typically uses drillhole data to define surfaces or volumes
- Grid size is selectable
- Surface grids generated in ISM are used to bound zones in a stratified volumetric model
- Handles vertical and normal faulting
- Grid contouring

SLIDE 13

Interaction with a GIS

- Information may be incorporated into ISM and IVM from a GIS
- Procedures have been established to communicate with ARC/INFO

SLIDE 14

Interactive Surface Modelling (ISM)

- o Structure Contour and Isopach Maps
- o Cross-sections and Fence Diagrams
- o Perspective Views and Block Diagrams

Interactive Volume Modelling (IVM)

- o Volumetric models
- o Display properties
- o Fully interactive

SLIDE 15

Volumetric Calculations

- o For Example (preliminary):
  - o Volume of Topopah Spring Mmbr within the potential PDB is ~673,200km^3
  - o Volume of rock above the Static Water Table (730m) within the potential PDB is ~123,800km^3

SLIDE 16

Limitations

- o Non-selectable algorithms for gridding or contouring
- o Limited hardcopy output
- o Non-relational database (This is not a 3D GIS!)

SLIDE 17

Methodology for Creating Visualizations

- o Data Collection and Entry
- o Create Surface Grids in ISM
- o Create Volumetric Models in IVM

SLIDE 18

Data Collection and Entry

- o Site and Engineering Properties Data Base (SEPDB)
- o Thermal mechanical and lithostratigraphic units as picked from drillholes
- o Data from geological maps, cross-sections may be entered, via digitizing these sources or importing them from a GIS

SLIDE 23

Structure Contour Map of the Topopah Spring Mmbr
(Solid Color Map or Contour Line Map)

SLIDE 24

Isopach Map of the Topopah Spring Mmbr
(Solid Color Map or Contour Line Map)

SLIDE 25

Fence Diagram Around the Perimeter Drift Boundary,
Using the Lithostratigraphic Model

SLIDE 26 - 31

Various Views of the 3D Lithostratigraphic Model

SLIDE 32

Uses for Three Dimensional Visualizations

- o Indicate areas of inadequate data/sampling.
- o Predictive tool. Stratigraphic, fault, and property value intercepts could be predicted for proposed drillholes, shafts, and drifts.
- o Volumetric calculations
- o Multi-temporal data can also be displayed in separate three dimensional models and displayed in a movie-loop.
- o Visualization of output from other modelling programs

SLIDE 33

Future Work

- o Recalculation of models as interpretations of core from new drillholes are made available
- o Three dimensional visualizations of the configuration of various properties (may include: porosity, mineral abundance, magnetic susceptibility, chemical abundance, thermal conductivity, isotope abundance, hydraulic conductivity, etc.)
- o Incorporation of non-vertical faulting and non-vertical drillholes
- o Incorporate data from foreign two and three dimensional grids

SLIDE 19

Create Surface Grids in ISM

- o Surface grids are needed to create a multi-zone volumetric model
- o An iterative process
  - o Select gridding parameters
  - o Create surface grids for each stratigraphic unit
  - o Graphical editting to develop geologically reasonable gridded surfaces
- o Assumptions
  - o Based on original, smooth, and continuous surfaces
  - o Solitario Canyon and Ghost Dance/Abandoned Wash Faults
  - o Faults are vertical
  - o Drillholes are vertical
- o Surface grids can be used to create structure contour and isopach maps, cross-sections, and fence and block diagrams

SLIDE 20

Create Volumetric Models in IVM

- o Gridded surfaces are used to bound the top and bottom of each stratigraphic unit
- o Dependant upon the reasonable development of the gridded surfaces
- o A separate three dimensional grid and display must be calculated for each property (e.g.: porosity, conductivity, mineral aboundance etc.)

SLIDE 21

Preliminary Results

- o Surface grids and a volumetric for the thermal mechanical stratigraphy
- o Structure contour maps, cross-sections, and perspective diagrams for the thermal mechanical stratigraphy
- o Surface grids and a volumetric for the lithostratigraphy
- o Structure contour maps, cross-sections, and perspective diagrams for the lithostratigraphy

SLIDE 22

Perspective View of Yucca Mountain or
Color Topographic Contour Map of Yucca Mountain or
Contour Line Map of Yucca Mountain

END

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