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DEVELOPING A FUNCTIONING VISUALIZATION AND ANALYSIS SYSTEM FOR PERFORMANCE ASSESSMENT[a]

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ABSTRACT

Various commercial software packages and customized programs provide the ability to analyze and visualize the geology of Yucca Mountain. Starting with sparse, irregularly spaced data a series of gridded terrain models has been developed representing the thermal/mechanical units within the mountain. Using computer aided design (CAD) software and scientific visualization software, the units can be manipulated, analyzed, and graphically displayed. The outputs are typically gridded terrain models, along with files of three-dimensional coordinates, distances, and other dimensional values. Contour maps, profiles, and shaded surfaces are the output for visualization.

INTRODUCTION

The subsurface geology of Yucca Mountain in southern Nevada is the potential location for a high-level nuclear waste repository. An understanding of the stratigraphy of the geologic units is essential to siting the repository and evaluating the performance of the geology as a natural barrier. Computer models are necessary tools to help gain this understanding. Three-dimensional computer models that define the spatial and geometric nature of Yucca Mountain have been developed and are being used for analysis and visualization. This paper summarizes the graphical computer models that are presently being used at Sandia National Laboratories (SNL), as well as the basis for their development.

FUNCTIONING VISUALIZATION AND ANALYSIS COMPUTER SYSTEM

Initially for site characterization and now for performance assessment, staff at SNL have been developing a system to graphically display and analyze layered elements such as thermal/mechanical stratigraphy.[1] The system consists of various computer programs, including a commercial computer aided design (CAD) software package as the core of the system. See Table 1 for a list of the programs and a brief description of their use.

TABLE 1. Software for System

SOFTWARE	DESCRIPTION AND USE
MKMSOLVER	Program written at SNL to calculate a best-fit trend surface with adjustments to cause the surface to pass exactly through input data. Designed for interpolating among sparse and irregularly spaced data points.
GTM	Program written at SNL to perform various operations on a gridded terrain model (GTM) including math, extract information about a GTM, create point files from GTM nodes, project points onto a GTM surface, compare GTMs, and modify a GTM using another GTM.
ITM	Program written at SNL to create Irregular Terrain Model (ITM) databases, verify ITM databases, create contour file from ITM databases, project points onto ITM surfaces, create point files at ITM nodes, and create point file projected for a GTM.
USGS	Program written at SNL to convert United States Geologic Survey (USGS) plotter files into a contour file usable by other software in system.
PRISM/DDM[2]	Commercial software package. Three-dimensional (3-D) computer aided design (CAD) software for graphically representing terrain models, contours, 3-D geometry, dimensions and labels. Additional modules have been written at SNL to provide interfaces for manipulating GTMs and contouring. Provides basic mapping capabilities and profile generation.
AVS[3]	Application Visualization System (AVS) is a commercial software package. AVS is a set of modules that can be linked together into a program to analyze and view data using interactive display techniques.

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All the software except AVS is running on a VAX/VMS computer system. AVS is currently running on a Stardent computer with Unix System V. The development of the analysis and visualization system corresponds to the needs of individuals involved in site characterization and more recently in performance assessment. Hov the system is developing is best understood by looking at the c .rrent use of the system.

USING THE SYSTEM TO BUILD A GTM

The current set of models in our system is a collection of three- dimensional surface representations. The surfaces are in the form of a gridded terrain models (GTMs) of the type used by civil engineers to represent surface topography. The terrain model is a gridded mesh spaced regularly in the horizontal (X and Y) axes with nodal elevations varying in the vertical (Z) axis to represent surface shape. The X and Y coordinates correspond to the Nevada State Plane coordinate system while the Z coordinates are the elevations above sea level. There are GTMs representing each of the fifteen thermal/mechanical units for Yucca Mountain, the ground surface topography, the top of the water table, and the upper boundary of the zone of prevalent zeolitization. The process of building each of these GTMs varies according to the amount of data available and whether or not faulting should affect the final product.

The topography and water table GTMs are produced from a large set of data points. Data are extracted from contour maps to create an ASCII file of (X, Y, Z) coordinates for the points at the vertices of the contours using PRISM/DDM functions. The contours are either digitized directly into PRISM/-DDM or translated from existing contour plot files.

The thermal/mechanical unit GTMs are produced from drill hole data of unit contacts. The unit contacts in the drill holes are called "picks" and are derived from various types of records such as drilling logs, core samples, and down-hole geophysical surveys. These contact picks are transformed into three-dimensional point coordinates based on the surveyed location and orientation of the drill hole. The drill hole locations are irregularly spaced and there are very few drill holes with the data needed to define the thermal/mechanical units. The number of drill hole picks available range between 5 and 14 for each of the GTMs. Many of the drill holes are clustered in a single region. An interpolation technique was developed at SNL using a program called MKMSOLVER to estimate a surface using sparse and irregularly spaced data while having the surface pass through the data points used as input.[4]

Because applying MKMSOLVER directly to the drill hole contact elevations would smooth the effects of faulting, certain adjustments are necessary. The sparseness of the drill hole data at Yucca Mountain resulted in a situation where only one or two holes penetrated a given surface in a particular fault block. As a plane cannot be modeled with fewer than three points, the contacts must be adjusted to remove fault offset. The adjusted contact data is used as input to the program to calculate a continuous unfaulted surface.

The MKMSOLVER program calculates a trend surface then modifies the surface to pass through the locations of all the input data. The result is a modulated surface which statistically fits the input data (see Figure 1). The input to MKMSOLVER is an ASCII file with (X, Y, Z) coordinates of the drill hole picks for each surface to be interpolated. The output is another ASCII file containing (X, Y, Z) coordinates for the trend surface and modulation values. This file is used as input into PRISM/DDM to create a gridded terrain model. The resulting GTM is considered to be "pre-faulted".

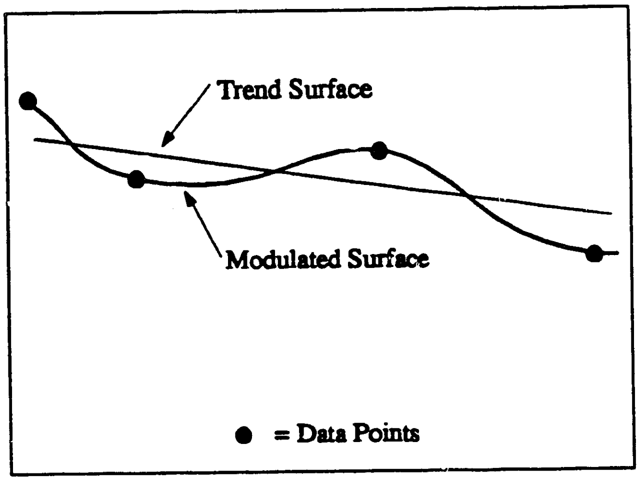

FIGURE 1. Schematic Profile of Surfaces Generated by MKMSOLVER

The next step is to add the effects of faulting to the pre-faulted GTMs (see Figure 2). To add the faulting each of the

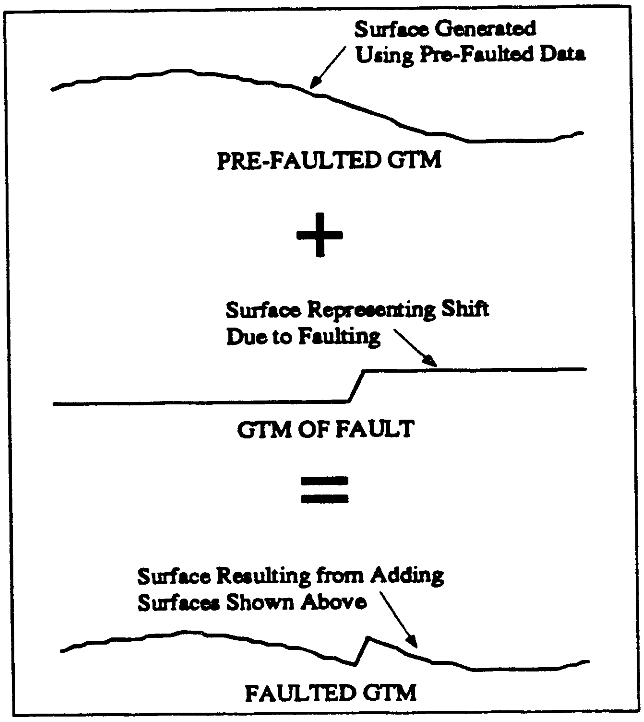

FIGURE 2. Schematic Profiles of GTMs Showing the Generation of a Faulted GTM

GTMs are added to special GTM that represents the vertical shift of the earth. The special GTM defining the area affected by a fault is created by modifying a flat, zero-elevation GTM. Using PRISM/DDM, the zero-elevation GTM is adjusted upward in the area of faulting. Now the special faulting GTM is ready to be added to a pre-faulted GTM. Using the GTM program, the faulting GTM and a pre-faulted GTM are added together. The elements of the GTMs that are being added are to the Z (elevation) values at each node. The addition process results in a new GTM. The new GTM is the same as the original thermal/mechanical unit GTM except that the node elevations are adjusted upward in the area of faulting. In the areas of no faulting the GTM is not adjusted at all. Each of the thermal/mechanical unit GTMs is added to the faulting GTM by this technique, resulting in "faulted" versions for each unit.

Once the faulted GTM is created, it must be modified to correct for any part of the GTM that has a shape which is not physically possible (see Figure 3). For example, the GTM may intersect another GTM, suggesting that a geologic unit is penetrating the unit above. Also, the units near the ground level may project out through the topography and into the air above the ground. In either case the GTMs must be modified to correct these anomalies. In the case of a lower unit's surface intersecting with the unit above, the GTM software is used to force a lower unit to stop at the bottom of the unit above. This represents a unit being pinched out by the unit above. The same technique is used for units at the ground level; however, this represents the effects of erosion as well as pinching. When the process is complete, the resulting GTMs for each thermal/mechanical unit are considered to be both faulted and pinched or eroded.

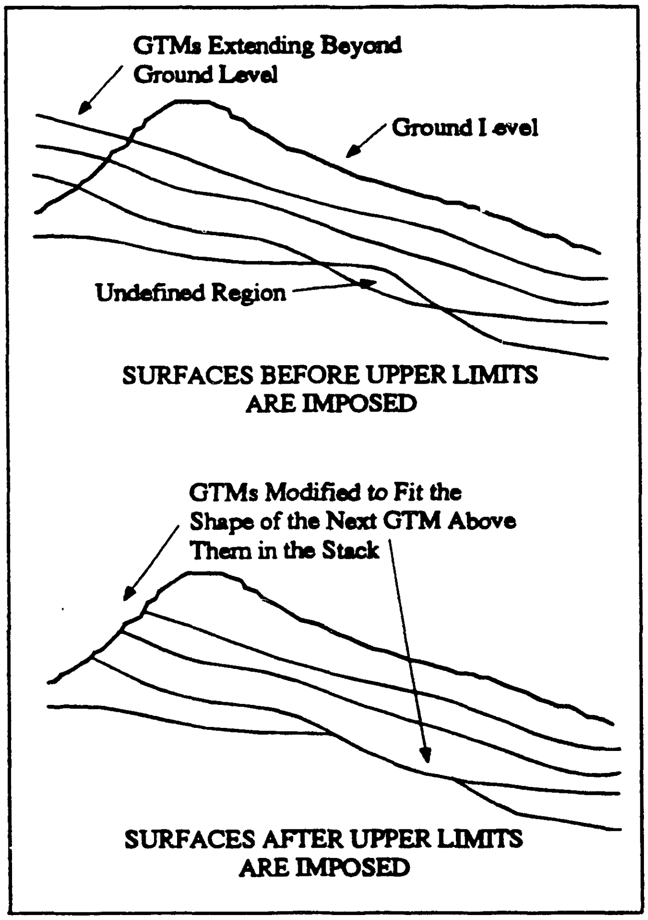

FIGURE 3. Profiles of GTMs Before and After Pinching or Eroding by Imposing an Upper Limit using Another GTM

The surface model representing the zone of prevalent zeolitization is created using a process similar to the one use to create the thermal/mechanical units. Once created, all the GTMs (topography, thermal/mechanical units, water table, and zeolitized zone) are ready to be manipulated for analysis purposes.

USING THE SYSTEM GTMS FOR ANALYSIS

One of the primary advantages of the gridded terrain model is the ability to perform mathematical operations, such as addition and subtraction of the modelled surfaces. The GTMs are all created using the same spacing in the X and Y plane, resulting in a regular mesh when viewed in plan. The nodes of the mesh are associated with a Z value representing an elevation for that particular point in space, causing the mesh to take on the shape of an irregular surface. Since all of the GTMs are built on the same X and Y coordinate system each of the nodes stack up, or fall in line with, the nodes of the GTMs above and below. This relationship allows the GTMs to be added or subtracted by adding or subtracting the Z values of corresponding nodes.

This addition and subtraction capability makes it possible to calculate the thickness of a particular thermal/mechanical unit by subtracting the GTM representing the bottom of the unit from the GTM representing the top (the base of the unit above). This operation results in a new GTM with Z values equal to the distance between the two GTMs and represents the thickness of the thermal/mechanical unit. The same method could be used to find the distance between a unit and the water table, or between a unit and ground level. Other GTMs could be created for surfaces such as the elevation of the proposed repository and distances calculated between the repository and the water table.

Another use of the GTM is to find the predicted elevation of a thermal/mechanical unit at a particular location, such as at a new drill hole. Given the coordinates of a proposed drill hole, the elevation of a pick can be calculated. Using the coordinates of the proposed drill hole a temporary point can be projected onto a surface defined by a GTM, resulting in a new point (the temporary point is projected onto the surface defined by the mesh, not the lines of the mesh itself). The coordinates of the new point are easily retrieved to provide the elevation. Lines can also be projected onto a GTM using methods similar to point projection, resulting in a line on the surface of the GTM. Profiles (or cross-sections) can be created using this capability by having a single line projected onto each GTM in the stack. A projected line is created for each GTM and becomes the lines of a profile.

Gridded terrain models can be intersected with other gridded terrain models. The intersection of two GTMs results in a three-dimensional contour line. This ability was used to help determine the possible extents of the potential repository.[5] To find the possible extent of the potential repository, a GTM was

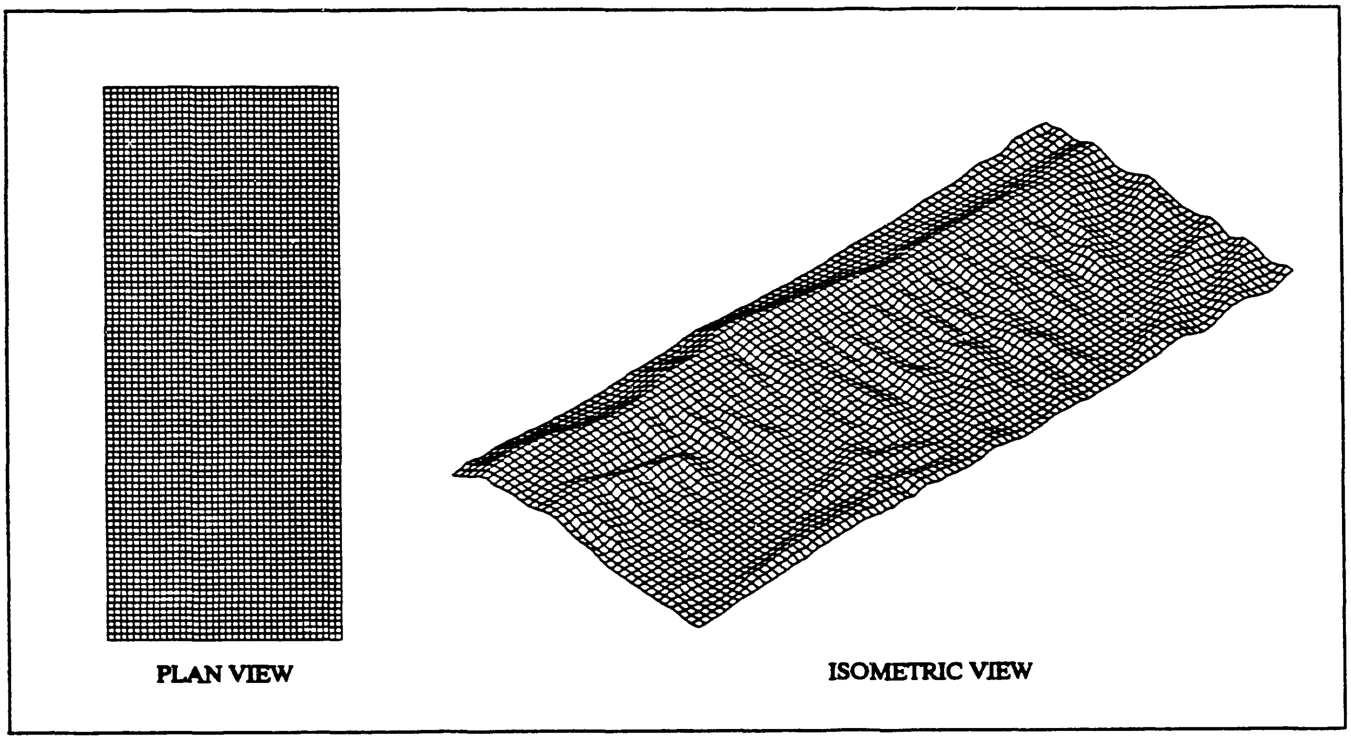

FIGURE 4. Example of Ground Surface GTM Displayed in Plan and Isometric View

created to represent the upper boundary of the underground facility zone. This GTM was located between the GTMs defining the top and bottom of the thermal/mechanical unit proposed for the potential repository. The facility GTM was adjusted until the slopes within the drifts would be reasonable, resulting in the facility GTM intersecting with the GTM defining the top of the thermal/mechanical unit. A 3-D contour line was created by intersecting the two GTMs. The resulting contour line was used to help to define the limits of the potential repository.

USING THE SYSTEM TO VISUALIZE THE GTMS

Gridded terrain models are regular shaped in the X and Y plane, so viewing a GTM in plan is not useful. GTMs viewed in plan look like a simple grid (see Figure 4). Contour maps are usually generated from GTMs to view the shape of the surface. A contour map is generated using PRISM/DDM's standard civil engineering capabilities. For example, a GTM representing the thickness of a unit is contoured to extract dimensional values and illustrate the shape of the GTM (see Figure 5).

Another standard way of viewing site information is by using profiles (or cross-sections). The profile is like slicing down vertically through all the GTMs to produce a side view of the GTMs (see Figure 6). The profile helps in visualizing the relationship between GTMs and see those relationships below ground level. With the PRISM/DDM software the profiling process is automated and can quickly provide a profile with vertical and horizontal dimensions, vertical exaggeration, and scales. La-

FIGURE 5. Example of Contour Map Showing the Thickness of Tiva Canyon Welded (TCw) Unit and the Repository Boundary

bels and titles are easily added for a final product. Until recently, the combination of contour maps and profiles has been the best way to understand 3-D information.

The isometric view is also available for viewing 3-D information. An isometric view allows the viewer to see the GTMs in both plan and profile at the same time; however, this method does not work well for GTMs. The lines of the grids are all similar in size and thickness and when viewed at an angle the lines of the grids appear to cross over each other. The viewer is unable to distinguish the grid patterns of any of the grids in the stack. The same would be true if 3-D contours were used instead of grids. This problem is reduced by converting the gridded terrain model to a shaded surface using AVS. The AVS software gives us the capability to view the gridded terrain model surfaces at any angle by implementing hidden-line, shading, and transparency techniques (see Figure 7).

Before the GTMs can be visualized using AVS, the grids must be converted into a format usable by one of the AVS modules. The AVS software has many modules to help translate data from one format to another. By using a modified version of one of those modules, the coordinate files from the GTMs are converted to a format the AVS software recognizes as simple geometry. The geometry files are then ready for input into AVS. Any or all of the GTMs may be input into AVS for visualization at any one time. Geometry can be added along the sides of the GTMs to connect the top of a unit to its base, resulting in an image that represents the mountain as a solid object (see Figure 8). The software considers the image an object and provides the ability to change lighting on the object and change surface properties af-

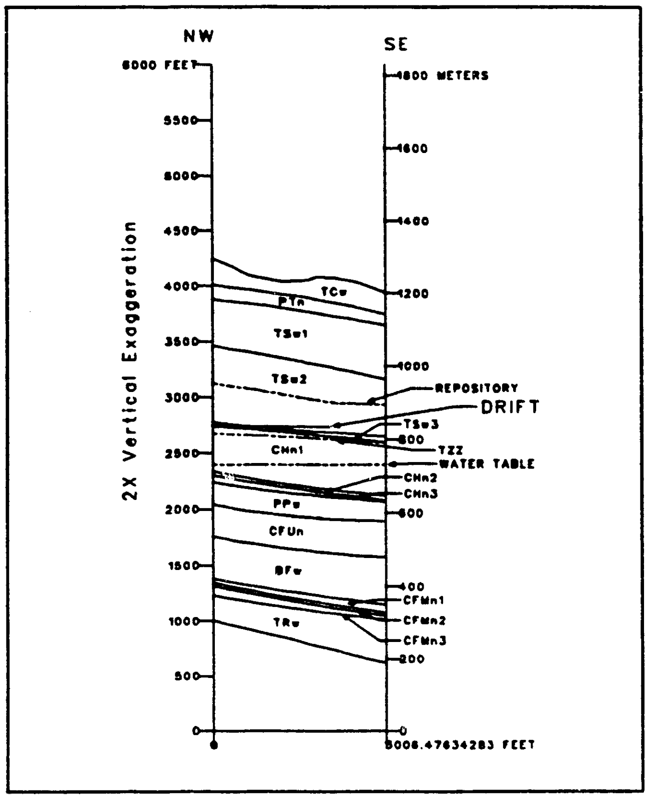

FIGURE 6. Example of a Profile Along a Proposed Exploratory Drift at Yucca Mountain

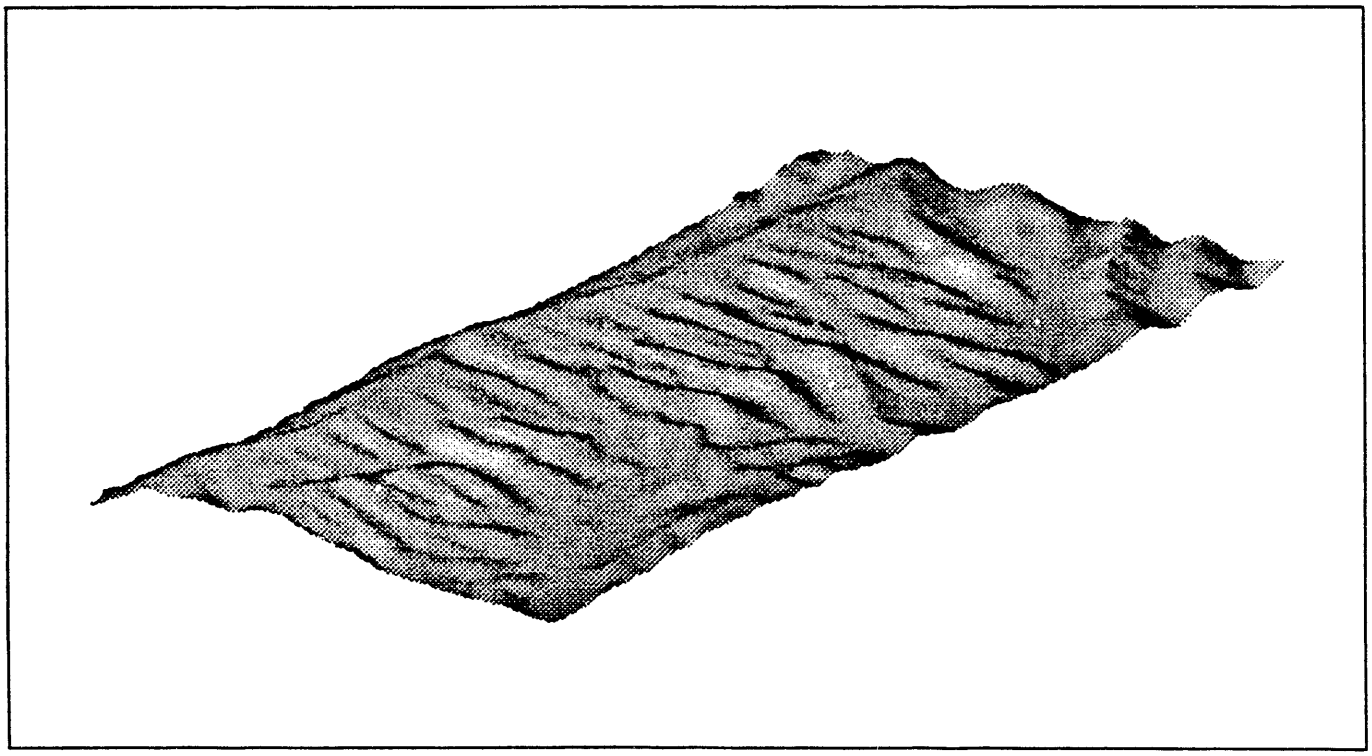

FIGURE 7. Example of Surface Topography Shown as a Shaded Surface

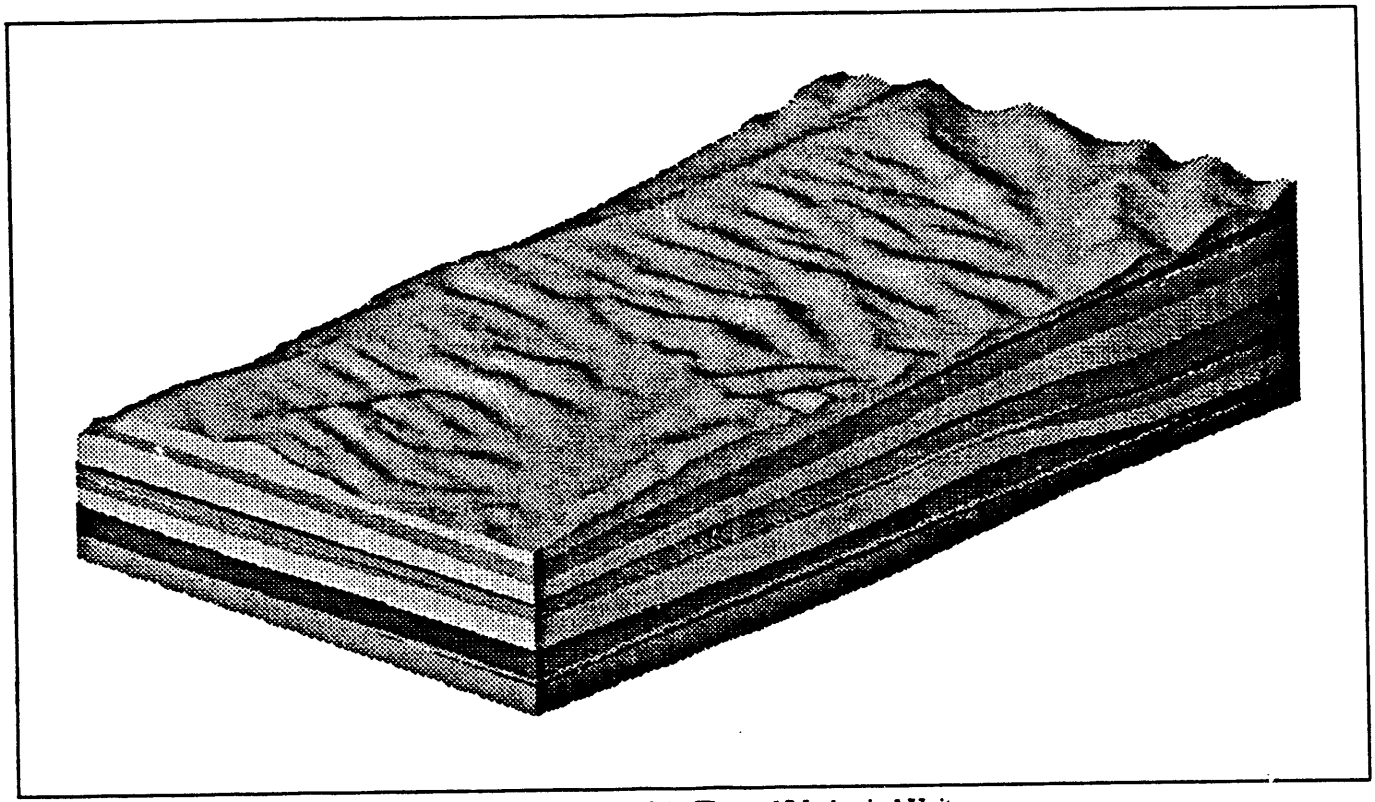

FIGURE 8. Example of the Thermal/Mechanical Units
within Yucca Mountain as Shaded Objects

fecting light reflectance and absorption. The image can be rotated to any angle, sliced, and broken into parts.

CONCLUSIONS

The analysis and visualization system that is in place is providing the tools essential for understanding the subsurface geology of Yucca Mountain. Gridded terrain models have been created that represent various surfaces such as the lower boundaries of the thermal/mechanical units of Yucca Mountain. The gridded terrain models are the primary elements used in the system. Visualization of gridded terrain models must be accomplished by creating other items such as contour maps and profiles. Visualization of the gridded terrain models can be improved using shaded surfaces and other advanced visualization techniques. The system continues to evolve as needs change and as computer standards converge to allow data to be transferred from one package to another with little or no programming.

This system provides the conventional methods of analysis and visualization through mapping and profiles. Plus, with surface rendering capabilities, the system is now able to provide "realistic" images of Yucca Mountain. Although some parts of the geology will be viewed from within the tunnels drilled into the mountain, nobody will ever see most of the structure of the mountain hidden below the earth's surface. Computer images such as those produced with this system will provide the means to interactively view the physical properties below grade.

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