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CNWRA 94-023: A Preliminary Three-Dimensional Geological Framework Model for Yucca Mountain Nevada: Report to Accompany Model Transfer to the Nuclear Regulatory Commission

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CNWRA 94-023

A PRELIMINARY THREE-DIMENSIONAL GEOLOGICAL FRAMEWORK MODEL FOR YUCCA MOUNTAIN, NEVADA: REPORT TO ACCOMPANY MODEL TRANSFER TO THE NUCLEAR REGULATORY COMMISSION

Prepared for

Nuclear Regulatory Commission
Contract NRC-02-93-005

Prepared by

Gerry L. Stirewalt
Stephen R. Young
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Center for Nuclear Waste Regulatory Analyses
San Antonio, Texas

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ABSTRACT

The preliminary three-dimensional (3D) geological framework model described in this report was developed for the potential high-level radioactive waste disposal site at Yucca Mountain, Nevada, by staff at the Center for Nuclear Waste Regulatory Analyses. The model was constructed for the Nuclear Regulatory Commission (NRC) using EarthVision software (Version 2.0) from Dynamic Graphics, Inc. (DGI) of Alameda, California. It provides the basic geological framework within which variations in geological parameters and features both in and adjacent to the potential repository block can be viewed and analyzed, submodels can be constructed (e.g., by incorporating hydrologic or rock properties data into the framework model), and alternative models can be considered. This 3D geological framework model can be used by NRC staff during both pre-licensing and licensing phases to assess the geological realism of models produced by the U.S. Department of Energy (DOE) and its contractors for analysis of site suitability, design considerations, and repository performance. The 3D model is currently comprised of a stack of six lithostratigraphic horizons and includes the Bow Ridge, Ghost Dance, and Solitario Canyon faults. The lithostratigraphic units and fault surfaces were constructed using data from Scott and Bonk (1984) and information from balanced cross sections of Young et al. (1992). The cross section lines contain eight boreholes which provided additional subsurface control for use in construction of the model. This 3D model will be refined and modified as new data on lithostratigraphy and faulting are acquired.

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This report was prepared to document work performed by the Center for Nuclear Waste Regulatory Analyses (CNWRA) for the Nuclear Regulatory Commission (NRC) under Contract NRC-02-93-005. The activities reported here were performed on behalf of the NRC Office of Nuclear Material Safety and Safeguards (NMSS), Division of Waste Management (DWM). The report is an independent product of the CNWRA and does not necessarily reflect the views or regulatory position of the NRC.

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QUALIFICATION OF DATA AND SOFTWARE

Data used to construct the three-dimensional (3D) geological framework model were taken from published sources which are referenced in this report. Basic field information on lithology, stratigraphy, and structure were taken from Scott and Bonk (1984). Balanced geological cross sections developed from the data of Scott and Bonk (1984) by CNWRA staff (Young et al., 1992) were used to constrain depths of the lithostratigraphic horizons in the 3D model in concert with data from eight boreholes located in the lines of the cross sections. The boreholes were drilled during U.S. Department of Energy (DOE) field investigations of the Yucca Mountain site to acquire information on subsurface lithology and groundwater hydrology. While the data acquired by Scott and Bonk (1984) and the early drilling activities were not collected under formal QA programs, use of standard methods for drilling and collection and analysis of geological information assures the data are acceptable for incorporation into the 3D model.

EarthVision software (Version 2.0) from Dynamic Graphics, Inc., (Dynamic Graphics, Inc. 1994) of Alameda, California, was used to construct the 3D geological framework model. This commercially available software is leased to the CNWRA and is not controlled under the Software Configuration Procedure. The NRC has also leased EarthVision software for the computer center in its offices at Two White Flint North (TWFN), Rockville, Maryland.

1 INTRODUCTION

The three-dimensional (3D) model which is described in this report comprises the most current version of the geological framework model being developed for the Yucca Mountain site in Nevada by staff at the Center for Nuclear Waste Regulatory Analyses (CNWRA). The model was developed and constructed for the Nuclear Regulatory Commission (NRC) under the Geologic Setting (GS) Program Element at the CNWRA. It is based directly on available field data (Scott and Bonk, 1984) and geological interpretations of those data as represented in balanced cross sections (Young et al., 1992). Consequently, the 3D model is as geologically realistic as the incorporated data allow.

EarthVision software (Version 2.0) from Dynamic Graphics, Inc. (Dynamic Graphics, Inc., 1994) of Alameda, California, was used to construct the 3D model which is being supplied with this descriptive report on 4-mm tape. Transfer of the approximately 30-Mb model on tape will make it possible to run the model on hardware located in the NRC offices at Two White Flint North (TWFN), Rockville, Maryland. This software package enables the user to model topography and subsurface geology from cross sections and borehole data. The resulting 3D model can be examined through user control of view angle, vertical and horizontal slicing, vertical exaggeration, and data displays.

Silicon Graphics, Inc. (SGI) Onyx hardware is employed at the CNWRA offices in San Antonio for viewing the 3D geological framework model using EarthVision software. Since EarthVision software is in place in the NRC computer center at TWFN, Rockville, Maryland, equipment there is also compatible with examining the model and its associated database which are being supplied with this supplementary report.

Submission to the NRC of the 3D EarthVision geological framework model and its associated database along with this report satisfies the Major Milestone (MM) deliverable for the NRC Office of Nuclear Material Safety and Safeguards (NMSS) Task 20-5702-425-403, the prime responsibility for which lies with the GS Program Element at the CNWRA. The report is not a user's manual for application of EarthVision software, but rather a concise description of the model itself.

2 PURPOSE OF THE THREE-DIMENSIONAL GEOLOGICAL FRAMEWORK MODEL

The 3D EarthVision model provides the geological framework into which data and alternative ideas related to structural geology, hydrology, rock properties, geochemistry, and other natural aspects of the Yucca Mountain site can be incorporated. That is, this model supplies the basic geological framework within which variations in geological parameters and features in and adjacent to the repository block can be illustrated and analyzed, "submodels" can be constructed, and alternative models can be considered as appropriate data become available. As an example of these applications, distribution of mechanical or geochemical properties of rock units could be included to show variations in these parameters. Also, a hydrostratigraphic submodel is being developed by including hydrologic parameters in the geological framework model, and alternative tectonic models could be constructed by including different interpretations of subsurface fault geometry in the framework model. Development of the 3D model is iterative in the sense that it will be regularly refined and modified as additional data are incorporated into the model.

Since the model was constructed using field data collected during surface and subsurface investigation of the Yucca Mountain site by the U.S. Department of Energy (DOE) or its subcontractors and will be refined through incorporation of additional field data, it can be used by NRC staff during both pre-licensing and licensing activities to assess the geological realism of models chosen by the DOE for analyses of site suitability, design considerations, and repository performance. Key Technical Uncertainties (KTUs) related to development and use of conceptual tectonic models as defined in Review Plans 3.2.1.5 and 3.2.1.9 of the License Application Review Plan (LARP) (Nuclear Regulatory Commission, 1994), make it important for NRC staff to have the ability to consider models provided by the DOE in light of how realistically those models represent subsurface geological conditions. Because the KTUs cited are at the level for which the LARP (Nuclear Regulatory Commission, 1994) requires detailed safety review supported by independent tests or analyses, it will be necessary for NRC staff to compare conceptual models proposed by the DOE with an independently developed model (such as the 3D geological framework model) to determine whether representation and explanation of subsurface geological features are adequate and reasonable when documentation, logic, assumptions, bounding conditions, and bounding assessments for the DOE models are critically reviewed. Hence, the need for development of the 3D geological framework model is firmly founded in requirements for its application in assessing regulatory and technical issues in both pre-licensing and licensing phases for the potential repository at Yucca Mountain.

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3 DESCRIPTION OF THE THREE-DIMENSIONAL GEOLOGICAL FRAMEWORK MODEL

Boundaries of the 3D geological framework model, types of data used in development and construction of the model, sources of those data, and characteristics of the model are discussed in this section.

3.1 MODEL BOUNDARIES

Boundaries of the volume represented in the 3D geological framework model were chosen so the potential repository block and faults in and immediately adjacent to the block would be totally encompassed in that volume. Figure 3-1 illustrates the model boundaries which extend north-south out to about a 5-km radius and east-west from Midway Valley to West Ridge. Boundaries of the model may be extended if it is determined that data outside the existing model boundaries are needed to identify or constrain trends within the modeled volume. Figure 3-1 also shows locations of boreholes and cross sections used for subsurface control in the 3D model and the position of the repository footprint.

3.2 DATA AND CHARACTERISTICS OF THE MODEL

The current 3D geological framework model which accompanies this report has been constructed using data from the sources indicated in the following discussion. Characteristics of the model are determined by data incorporated into the model and can be expected to change with inclusion of additional data. For example, lithologic/stratigraphic horizons or faults not shown in the existing model may be added. An illustration of the current model is shown in Figure 3-2 to depict lithologies and structures represented.

3.2.1 Topography

Topography for the model was taken from U.S. Geological Survey (USGS) digital elevation data in Digital Elevation Model (DEM) format. These data, a standard source for representing topography, have a 30 m pixel resolution at Yucca Mountain.

3.2.2 Lithology and Stratigraphy

Lithologic and stratigraphic units represented in the 3D model (see Figure 3-2) include the Tertiary volcanic sequence listed below. The unit designations were taken from the stratigraphic nomenclature proposed by Ortiz et al. (1985), who used the nomenclature to indicate thermal, mechanical, hydrological, and physical properties of the lithostratigraphic units with consideration for use of the information in performance assessment and repository design. For the 3D geological framework model, the stratigraphic designations of Ortiz et al. (1985) have been equated to the original lithostratigraphic units named by Scott and Bonk (1984).

Because the USGS is in the process of formally reclassifying the Paintbrush Tuff from a formation to a group (Dickerson and Spengler, 1994), the Tiva Canyon and Topopah Spring units, formerly members of the Paintbrush Tuff, will become formations. This reclassification effort represents a refinement of the original rock unit classification by Scott and Bonk (1984) based on more detailed investigation of the lithologic units by the USGS.

Figure 3-1. Boundaries of the CNWRA 3D geological framework model for Yucca Mountain and locations of boreholes and cross sections (S1 through S3) used for subsurface control (UTM Projection). Model constructed using EarthVision software (Version 2.0) from Dynamic Graphics, Inc.

Figure 3-2. Lithostratigraphic units and faults represented in the CNWRA 3D geological framework model for Yucca Mountain. Model constructed using EarthVision software (Version 2.0) from Dynamic Graphics, Inc. Lithostratigraphic nomenclature follows Ortiz et al., 1985. See text for lithologic descriptions.

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Nomenclature (Ortiz et al. 1985)	Formation Name and/or Lithologic Description
Tpcw	Tiva Canyon Formation of the Paintbrush Tuff: welded and nonwelded tuff
n3-PTn	nonwelded tuff
Tptw-TSw1	Topopah Spring Formation of the Paintbrush Tuff: welded, characterized by a zone of large lithophysae
TSw2+3	Topopah Spring Formation of the Paintbrush Tuff: welded, characterized by a zone of flattened lithophysae
CHn1..3-n2	Calico Hills: nonwelded tuff
PPw	Prow Pass Member of the Crater Flat Tuff: welded tuff

Welded unit TSw2+3 of the Topopah Spring, the stratigraphically lowest unit of the Paintbrush Tuff, is the lithostratigraphic horizon being considered for location of the potential repository at Yucca Mountain.

Lithologic descriptions for the 3D model were taken from Scott and Bonk (1984). Thicknesses of individual units were taken from the balanced cross sections of Young et al. (1992) which are based on cross sections from Scott and Bonk (1984). The 3D model is essentially a collection of stacked surfaces which represent the tops and bottoms of lithostratigraphic horizons in the model. Top and bottom contacts of the horizons were defined using control from eight boreholes (see Figure 3-1 and Section 3.2.3) in the lines of cross sections from Scott and Bonk (1984). Depths (i.e., sub-sea elevations) of the contacts were determined in balanced cross sections produced by Young et al. (1992) from the cross sections of Scott and Bonk (1984). Extrapolations for extending the upper and lower contacts of the horizons out from the borehole control points were accomplished by drawing structural contours on the horizon tops and bottoms, digitizing the structural contours, and stacking these digitized surfaces for 3D representation of the horizons in the EarthVision model. The approach for representing lithostratigraphic horizons at depth was necessary because of the paucity of subsurface data. Data from additional boreholes, the Exploratory Studies Facility (ESF), and detailed studies of the Paintbrush Tuff by the USGS will provide more information on lithologic and stratigraphic relationships for incorporation into a later version of the 3D geological framework model.

3.2.3 Borehole Data

Data from eight boreholes, all of which are contained in lines of cross section drawn by Scott and Bonk (1984), provided constraining information for depths to lithostratigraphic horizons. This information was incorporated into the model through the balanced cross sections of Young et al. (1992). The specific boreholes used to provide data (see Figure 3-1) were: UE-25a1, USWG-4, USWH-5, USWG-1, USWG-2, USWH-3, USWGU-3, and USWH-4. These boreholes were drilled during various phases of DOE field investigations of the Yucca Mountain site to investigate subsurface lithology and groundwater hydrology. Information from additional boreholes will be added to refine the upper and lower contacts of the lithostratigraphic horizons included in the model. It is also expected that information acquired in the ESF will provide pertinent data for refining lithostratigraphy.

3.2.4 Faults and Fault Zones

From east to west across the 3D model volume, faults included are the north-northeast-trending Bow Ridge, Ghost Dance, and Solitario Canyon faults (see Figure 3-2). They are currently represented in the model as dip-slip faults. The north-northeast-trending Fatigue Wash and Windy Wash faults west of the Solitario Canyon fault in the northwestern part of the model volume are not included in the current model, nor is the newly-discovered northwest-trending Sundance fault which has been mapped in the repository block (Spengler et al., 1994).

Basic information included in the model on fault location, dip, and displacement was taken from Scott and Bonk (1984). This source presents data obtained by careful field observation of faulting relationships at Yucca Mountain. Information from balanced cross sections (Young et al., 1992) was used to constrain subsurface fault geometry and thickness of offset units. Faults were projected downward across the lithostratigraphic horizons to represent the fault surfaces at depth. Where cross section control existed, fault cutoffs for each lithostratigraphic horizon were positioned using data in the balanced cross sections. In areas away from the cross sections where this control did not exist, fault cutoffs for the horizons were positioned by projecting the ground-surface trace of the fault downward through each unit with the dip angle for the projection being the dip of the fault in the balanced cross section. When the stratigraphic horizons were stacked to build the solid 3D geological model, individual cutoffs were then aligned to define the fault at depth. The approach for representing structures at depth was necessary because of paucity of subsurface data on fault geometry. Additional detailed mapping of structures in the potential repository block by the USGS (Spengler et al., 1993; Buesch et al., 1994; and Spengler et al., 1994) has already revealed additional data on faulting which will be incorporated into a later version of the model if deemed pertinent. The Fatigue Wash and Windy Wash faults will also be included. It is expected that detailed mapping may regularly provide additional information on faulting in the potential repository block.

4 FUTURE PLANS FOR MODEL DEVELOPMENT

The existing 3D geological framework model will be refined and modified as new data on lithostratigraphy and faulting are collected by the DOE and provided to the NRC. Information may be derived from additional boreholes, field investigations, and geophysical studies as well as from site characterization activities in the ESF. Updated versions of the 3D model and associated databases will be provided to the NRC on a mutually agreeable schedule which will be determined later. The time frame within which the data are acquired governs the timing for preparation and submittal of refined models to the NRC.

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