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Geostatistical Simulation, Parameter Development and Property Scaling for GWTT-95

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INTRODUCTION

Geostatistical simulation is used to produce equally probable realizations of multiple rock properties along four cross-sections of Yucca Mountain. In the absence of large amounts of drill-hole data at the site, the realizations are constrained by conceptual models of the site geology through soft information provided by a deterministic, geologic framework model. Three properties are simulated for the 1995 ground water travel time (GWTT-95) calculations: matrix porosity, saturated matrix hydraulic conductivity and fracture frequency. These properties are scaled through power-law averaging to provide average values of each property in each flow model element for dual permeability or equivalent continuum modeling. Other parameters such as matrix and fracture air entry parameters are derived from both empirical and regression relationships with the geostatistically simulated parameters at the flow model grid-block scale.

WORK DESCRIPTION

Data collected at Yucca Mountain are organized to give an up-to-date set of property values measured through consistent laboratory techniques. This data set, containing both qualified and unqualified data, is used to provide conditioning information for geostatistical simulations and to develop regression relationships between porosity and $\log_{10}$ saturated hydraulic conductivity (K_{sat}) as well as other relationships among matrix properties. Relationships between fracture porosity and matrix porosity are derived from recent fracture frequency and matrix porosity data, together with fracture aperture data (unqualified data) from Total System Performance Assessment-1993.[1]

Two east-west cross-sections, a north-south cross-section and a diagonal cross-section along Drill-Hole Wash are used to evaluate ground water travel times.[2] Geostatistical simulation of matrix porosity and fracture frequency are accomplished by conditioning the realizations to available data from boreholes and to a deterministic interpretation of the site geology.[3] For the purposes of the GWTT-95 calculations, stratigraphic units within the deterministic model of the geology were combined based on similarities in porosity to create nine hydrogeologic units (Figure 1a). Constraining the simulations to this deterministic conceptual model is accomplished by using the GLINTMOD program.[4] In the absence of nearby conditioning data to constrain the simulation of a point in the model domain, GLINTMOD references the deterministic geologic framework model to determine the hydrogeologic unit corresponding to the location of the simulated point. The mean value of this hydrogeologic unit is then used to center the conditional cumulative distribution function at that simulation location.

Stochastic realizations of matrix porosity are created using GLINTMOD. The fracture frequency simulations created with GLINTMOD are models of the "background" fracture frequency. Conceptually, this is the fracturing derived from the cooling of the units and it is stratigraphically controlled. Indicator simulations of high-fracture-frequency zones, including deterministic (mapped) faults, are used to model fracture zones that cut across stratigraphic units created by tectonic activity at the site. The background fracture frequency simulations are combined with the realizations of high frequency zones through an empirically derived multiplier.

The process of linear coregionalization[5] is employed to create realizations of K_{sat} that honor the observed regression relationship between porosity and K_{sat}. This modeling technique is based on the assumption that spatial variations in hydraulic conductivity and porosity can be described by the same variogram model. Separate regression relationships are honored within the zeolitized and non-zeolitized portions of each cross-section.

Porosity, K_{sat} and fracture frequency are scaled from the geostatistical element scale to the flow model element scale through power law averaging. From results of numerical experiments on single-phase flow and transport[6], porosity and fracture frequency are averaged using a power of 1.0 (arithmetic averaging) while K_{sat} is averaged with a power of 0.4. This scaling procedure provides a single value of each property at the flow model element scale. These values are used in regression relationships to provide estimates of the van Genuchten air entry parameter and fracture porosity (aperture/spacing) for each flow model grid block. Separate, but constant, van Genuchten shape factors (beta) are used for the matrix and fracture domains.

RESULTS

Figure 1b illustrates the result of a single porosity simulation produced using the GLINTMOD process to supplement the sparse amount of porosity data in boreholes within the vicinity of this cross-section. Note that the simulation process is conducted without direct reference to stratigraphic units. The interpreted geologic cross-section (figure 1a) provides soft information that constrains, but does not uniquely determine, the expected porosity value. The resulting realization (and others like it) capture lithologic layering, fault locations and offsets, and the observed spatial variability of properties within the lithologic units.

Scaling of properties takes place from the geostatistical simulation scale to the flow model element scale. This scaling reduces the number of cells by approximately two orders of magnitude and makes the solution of the flow problem tractable with available flow models. The flow model grid is constructed such that thin, hydrologically important layers (e.g., Paintbrush Group non-welded units and vitrophyres) are retained in the upscaled fields (Figure 1c).

CONCLUSIONS

The approach used to create input property models for flow models allows production of stochastic realizations of rock properties that honor conceptual models of the site geology. These conceptual models include stratigraphic layering associated with a sequence of variably welded tuffs, the relationship between porosity and K_{sat} in zeolitized and non-zeolitized regions of the mountain, and tectonic faulting and its effect on fracture frequency. The variability between realizations and its effect on the computed groundwater travel times are examined in a separate sensitivity study.[2,7]

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(a)

(b)

(c)

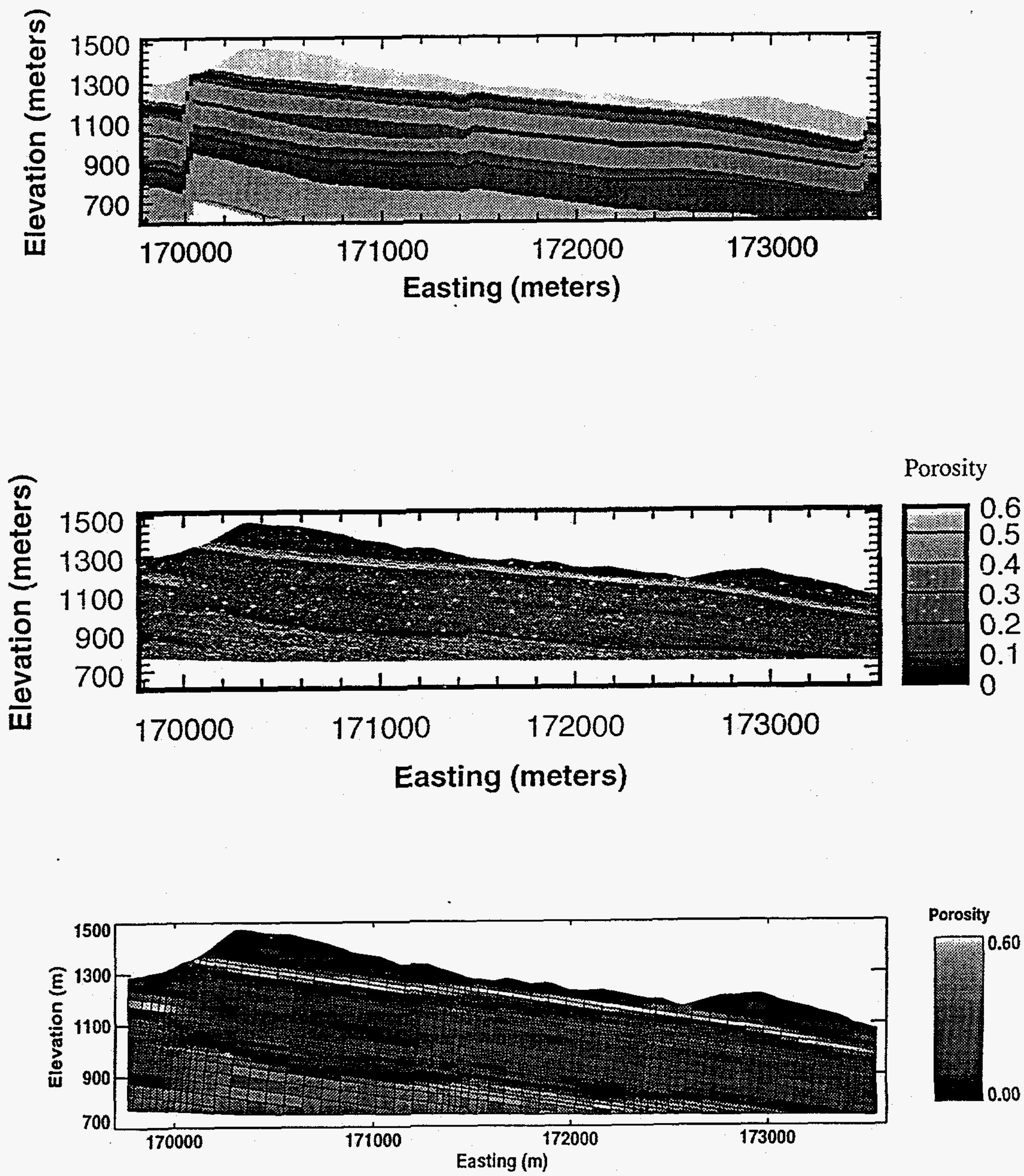

Figure 1. Three images of an east to west cross-section. The nine hydrogeologic units from the conceptual geologic model are shown in (a). A geostatistical realization of porosity conditioned on borehole data and the conceptual geologic model is shown in (b). The upscaled porosity values within the flow-model grid are shown in (c).