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CHARACTERIZATION OF LIQUID-WATER PERCOLATION IN TUFFS IN THE UNSATURATED ZONE, YUCCA MOUNTAIN, NYE COUNTY, NEVADA

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ABSTRACT

A surface-based borehole investigation currently (1989) is being done to characterize liquid-water percolation in tuffs of Miocene age in the unsaturated zone beneath Yucca Mountain, Nye County, Nevada. Active in-situ testing and passive in-situ monitoring will be used in this investigation to estimate the present-day liquid-water percolation (flux).

The unsaturated zone consists of a gently dipping sequence of fine-grained, densely fractured, and mostly welded ash-flow tuffs that are interbedded with fine-grained, slightly fractured, non-welded ash-flow and ash-fall tuffs that are partly vitric and zeolitized near the water table. Primary study objectives are to define the water potential field within the unsaturated zone and to determine the in-situ bulk permeability and bulk hydrologic properties of the unsaturated tuffs. Borehole testing will be done to determine the magnitude and spatial distribution of physical and hydrologic properties of the geohydrologic units, and of their associated water potential fields.

The study area of this investigation is restricted to that part of Yucca Mountain that immediately overlies and is within the boundaries of the perimeter drift of a U.S. Department of Energy proposed mined, geologic, high-level radioactive-waste repository. Vertically, the study area extends from near the surface of Yucca Mountain to the underlying water table, about 500 to 750 meters below the ground surface. The average distance between the proposed repository and the underlying water table is about 205 meters.

The investigation involves dry drilling and coring of 19 vertical boreholes 60 to 760 meters in depth and 1 horizontal borehole about 300 meters in length, for a total of about 6,850 meters. It also involves in-situ pneumatic borehole studies and vertical seismic profiling (VSP). Other investigations related to and supported by this drilling program include testing of matrix-hydrologic properties, testing of physical rock properties, age dating of contained pore water, geologic and lithologic logging, neutron-moisture logging and monitoring, geophysical logging, fracture mapping, and gas-flow evaluation. A final unsaturated-zone model for the Yucca Mountain site will be based on data collected from system-analysis and integration studies of the unsaturated zone, and on data collected during other investigations for characterization of the geohydrologic system of Yucca Mountain.

INTRODUCTION

Yucca Mountain is located west of the Nevada Test Site in Nye County, southern Nevada; the mountain is about 140 kilometers northwest of Las Vegas (Fig. 1). The unsaturated zone at Yucca Mountain consists of gently dipping sequence of tuffs that were deposited dur-

ing Miocene volcanism (Waddell, et al., 1984). These tuffs consist of: (1) The Paintbrush Tuff having the Tiva Canyon, the Yucca Mountain, the Pah Canyon, and the Topopah Spring Members; (2) the tuffaceous beds of Calico Hills; and (3) the Crater Flat Tuff that

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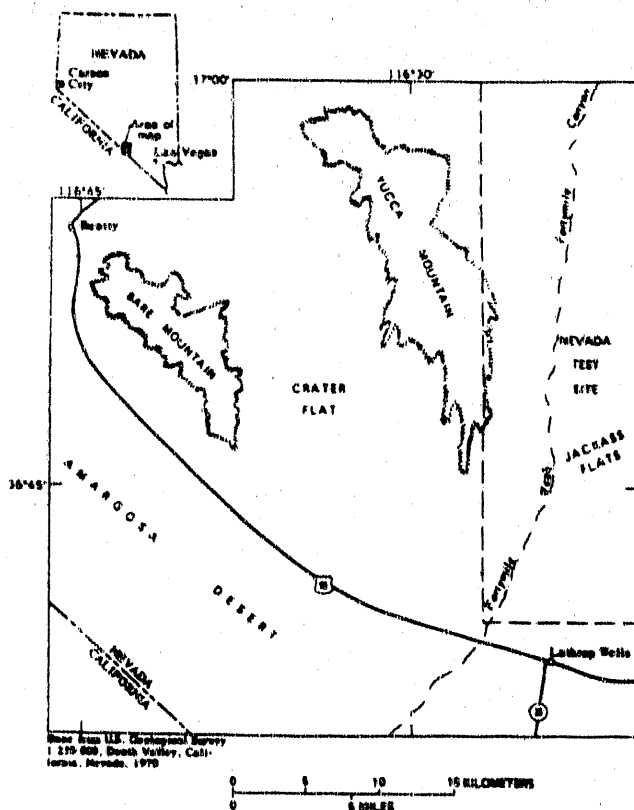


Figure 1-Map showing location of Yucca Mountain study area.

includes the Prow Pass Member, the Bullfrog Member, and the Tram Member (Fig. 2). Most of these rocks are ash-flow tuffs that are: (1) fine-grained and poorly consolidated; (2) generally densely to moderately fractured; (3) generally densely to moderately welded, with some slightly welded to nonwelded; and (4) vitric, devitrified, or vitrophyre. Interbedded with these are ash-flow and ash-fall tuffs that are: (1) mostly fine-grained, poorly consolidated or bedded, and, in part reworked; (2) slightly fractured to nonfractured; (3) slightly welded to nonwelded; (4) partly vitric and zeolitized near the water table. The water table is about 500 to 750 meters below the ground surface.

A surface-based borehole investigation currently (1989) is being done to characterize the liquid-water percolation in tuffs in the unsaturated zone at Yucca Mountain, Nevada. This investigation supports, through active in-situ testing and passive in-situ monitoring, a determination of the liquid-water percolation (flux). Two objectives of this investigation are to define the water potential field within the unsaturated zone and to determine the in-situ bulk permeability and bulk hydrologic properties of the unsaturated tuffs. The purpose of this article is to describe the current investigation to characterize liquid-water percolation in tuff in

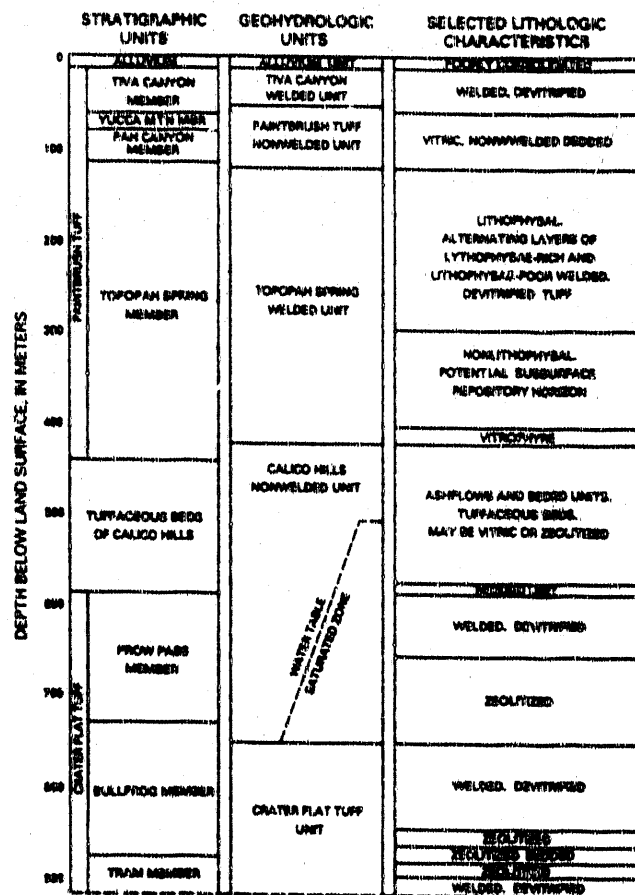


Figure 2-Diagram showing relationship between stratigraphic units and selected lithologic characteristics.

the unsaturated zone.

The definition and spatial distribution of the physical and geohydrologic properties of the different hydrologic flow media and their associated water potential fields are the subject of much of the testing in this investigation. Some initial work has been done by Kurme and Hammermeister (1987) who have studied geologic factors that affect physical and hydrologic properties of volcanic tuffs in the unsaturated zone. System-analysis and integration studies of the unsaturated zone needed to develop a comprehensive conceptual model of the unsaturated zone will depend on these data as well as data collected during other investigations to characterize liquid-water percolation. A conceptual model is needed to guide the final evaluation of the unsaturated zone for the storage of high-level nuclear waste. Montazer and Wilson (1984) proposed a preliminary conceptual model that has helped guide the early planning stages of this investigation.

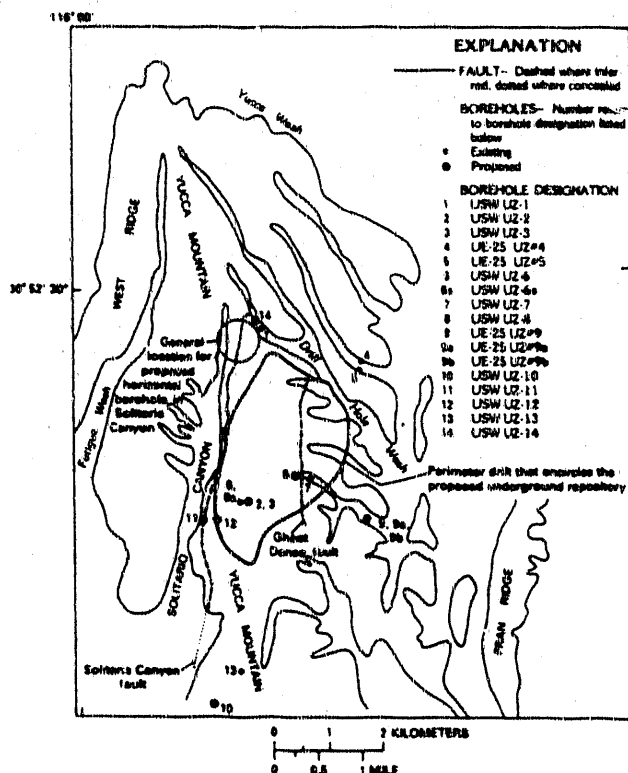


Figure 3-Map showing existing and proposed borehole location for the surface-based, unsaturated-zone percolation study.

The study area is restricted to that part of Yucca Mountain immediately overlying and within the boundaries of the perimeter drift of the U.S. Department of Energy (1986) proposed mined, geologic, high-level radioactive-waste repository (Fig. 3). Vertically, the rocks being studied in this investigation extend from the near surface of Yucca Mountain to the underlying water table up to 750 meters below.

The concept of storing high-level radioactive-waste and spent, nuclear-reactor-fuel in a well-drained, thick (500 to 750 m) unsaturated-zone environment in an arid region is of great interest because percolating water may not have ready access to the waste-package environment after repository closure. This environment is expected to serve as the primary barrier to the transport of radionuclides. One of the early workers, Roseboom (1983), suggested that locating a repository in the unsaturated zone of an arid region would eliminate or simplify many of the technological problems involved in designing a repository for operation below the water table and in determining its performance. He also stated that such a location offered possible accessibility and ease of monitoring throughout the operational period, and possible retrieval of the waste packages long after emplacement.

The principal advantage of this proposed site is that the thick welded and nonwelded tuffs comprising and immediately surrounding the proposed geologic repository are unsaturated. The average distance between the proposed repository and the underlying water table is about 205 meters.

DRILLING AND CORING

Dry drilling and coring for this investigation includes 19 vertical boreholes (7 already drilled and 12 proposed) ranging in depth from 60 to 760 meters for a total of about 6,850 meters. The investigation also includes drilling and coring of one horizontal borehole about 300 meters in length. The location of these boreholes (Fig. 3) is within or near the boundary of the proposed repository.

The rationale used in siting of the individual boreholes was based on the need to provide areal coverage of Yucca Mountain for sufficient detail to determine the local effects of faulting, topographic relief, and surface drainage on geohydrologic conditions at depth, and to minimize the disturbance of the main body of the proposed repository. The multiple-borehole sites are for cross-hole pneumatic testing, gas-tracer tests, and vertical seismic-profiling investigations.

Drilling of the boreholes into the unsaturated zone makes it possible to: (1) define structure and stratigraphy; (2) characterize the spatial variability of the hydrologic and geologic properties associated with each geohydrologic unit; (3) recover cores and drill-bit cuttings for laboratory measurement of matrix-hydrologic and physical-rock properties; (4) determine saturation of each geohydrologic unit as a function of depth; (5) perform in-situ pneumatic and hydraulic tests to evaluate bulk-permeability characteristics of the combined matrix and fracture systems; (6) recover matrix-pore water and in-situ gases for age dating and hydrochemical analysis; (7) measure and monitor, in-situ, the water potential field within which unsaturated flow occurs; (8) make vertical seismic profiles that will be used to extend the evaluation of fracture permeability, bulk permeability, and porosity to zones away from a near-borehole environment; (9) visually observe and record the density and orientation of fractures with depth; (10) evaluate gas tracer travel times by using gas-tracer tests; and (11) do borehole geophysical logging.

TESTING AND MONITORING

Testing and monitoring for this investigation consists of: (1) in-situ pneumatic testing of 19 vertical and 1 horizontal boreholes; (2) gas-tracer diffusion

studies at two sites with multiple vertical boreholes; (3) vertical seismic profiling (VSP) across the middle section of Yucca Mountain; and (4) downhole instrumentation and monitoring of ambient water potentials for 3 to 5 years.

In-situ pneumatic testing (nitrogen gas injection and packer tests) will be used to calculate bulk pneumatic permeability and porosity of each geohydrologic unit and across geohydrologic-unit contacts. Large structural features, such as faults and shear zones, also will be tested when present. This method of in-situ testing is designed to measure the combined permeability of the rock matrix and associated features.

Gas-tracer (inorganic gas) diffusion studies in vertical boreholes (UE-25 UZ#9, UE-25 UZ#9a, UE-25 UZ#9b, USW UZ-2, USW UZ-3, and USW UZ-6) are designed to: (1) measure in-situ gaseous travel time through an unsaturated fracture-rock system; (2) measure contaminant transport and pneumatic properties of the rock; and (3) establish whether diffusion or convection is the dominant gaseous-transport mechanism.

VSP will be done in two vertical boreholes (UE-25 UZ#9 and USW UZ-6) at Yucca Mountain. Acoustic properties of the rocks can be measured at the boreholes as well as in the intervening area. Hydrologic properties, including bulk permeability and porosity, and fracture and fault permeability, will be tied to, or correlated to, acoustic velocity and reflectivity.

Downhole instrumentation and testing will be done to determine the magnitude and spatial distribution of physical and hydrologic properties of the geohydrology units and their associated water potential fields. Downhole sensors that consist of pressure transducers, thermocouple psychrometers, and thermal sensors (thermistors) will be installed in each of the vertical and horizontal boreholes.

Downhole testing will be done to determine the flux, which needs to be evaluated within a time-dependent, three-dimensional, anisotropic, and heterogeneous setting. An evaluation will be made of the in-situ distribution of potential energy and the properties of the conducting rock. The vertical and horizontal downhole testing will be used to define the in-situ water potential distribution and in-situ conductive properties of the unsaturated zone at Yucca Mountain. This information will be used to calculate flux within geohydrologic units.

The rock volume to be studied is bounded by an infiltration system near the surface and a recharge system at the water table. The distribution of flow between these boundaries is impossible to measure directly at either boundary. Usually, flow across these

boundaries is as a residual quantity that is estimated from mass-balance calculations. Definition of the in-situ water potential flux distribution and in-situ conductive properties of the unsaturated zone, as determined by this surface-based borehole investigation, will enable a more direct and independent approach to flow determination. Results of this testing will be used in two-dimensional and three-dimensional computer simulations of the natural geohydrologic system.

Downhole monitoring will be done using an automated, Martin Marietta Corporation integrated data-acquisition system (IDAS). The IDAS system is designed to scan, record, transmit, and achieve downhole sensor readings. It fulfills the following technical, management, and quality-assurance requirements: (1) minimum measurement error; (2) protection of data; (3) minimum cost in collection and storage of data; (4) facilitation of data management; (5) flexibility, not only for future technological improvements, but also for multiple modes of downhole sensor operation to enhance borehole usefulness; and (6) timely warning of IDAS system failure to ensure against unacceptable loss of data.

RELATIONSHIP TO OTHER INVESTIGATIONS

The surface-based borehole investigation for characterization of liquid-water percolation in the unsaturated zone is only one of several investigations currently (1989) being conducted to provide an understanding of the geohydrology beneath Yucca Mountain. Data generated in this investigation will directly support several other investigations concerning the unsaturated-zone hydrologic system.

Results from the onsite tracer testing, air-permeability testing, and testing of matrix hydrologic properties will contribute to dispersive/diffusive/advective transport studies in the unsaturated zone. Several elements outlined in the testing will sustain, either directly or indirectly, work in the stratigraphy and structure necessary to locate the proposed underground facility and the development of a computer-based, three-dimensional model of rock properties at the proposed repository site.

The drilling and coring are related to and will sustain, either directly or indirectly, a number of other investigations. For example, the drilling samples (cores and drill-bit cuttings) can be used for: (1) testing of matrix-hydrologic properties and testing; (2) physical-rock-property testing; (3) geologic and lithologic logging; and (4) age dating of the sample-contained pore water. Also, included in these investigations is the characterization of vertical and lateral distribution of geohydrologic units within the proposed

site area.

Data from laboratory testing will support several other investigations and will include: (1) measurements of gravimetric and volumetric moisture content; (2) matric- and osmotic-potentials; (3) intrinsic and relative permeability; (4) standard rock analysis grain-size distribution; (5) bulk and grain densities; and (6) clay contents. The boreholes will enable access to the unsaturated zone for: (1) borehole geophysical logging; (2) neutron-moisture logging and monitoring; (3) fracture mapping; and (4) evaluation of barometric and topographic effects on gas flow in the unsaturated zone.

The downhole instrumentation and monitoring of ambient potentials for 3 to 5 years will provide facilities for recovery of in-situ pore gases and water vapor for gas chemistry analysis and for tritium and isotope-ratio measurements and will provide instruments for measuring in-situ pneumatic pressures as part of the gaseous-phase movement study. After this monitoring, downhole hydraulic (water injection) testing will be done in each borehole.

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