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DIRECTIONS

** NOTE ** THIS TRANSMITTAL CORRECTS AN ERROR IN REPRODUCTION OF THE SCP BASELINE DOCUMENT.

REPLACE: Within Volume 1, Pages 8.3.1.2-203 through 8.3.1.2-295. (These pages were copied one sided by mistake.)

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Parameters

The following parameters will be collected during the activity:

1. Air permeability profiles.
2. In situ stresses.
3. In situ rock physical properties.
4. Fracture geometry (mappings).
5. In situ degree of saturation (water).
6. Porosity.

Description

This activity will be conducted at two breakout zones in the shaft approximately 400 ft. apart. The present design is preliminary and includes 18 boreholes at each breakout horizon. After completing the breakouts, two rows of three vertical holes will be air drilled for permeability measurements. Another set of six vertical air-drilled holes will be used for installation of deformation gages and loading cells at each breakout. In addition, six placement-measuring holes, angled at approximately 45 degrees from the vertical, will be percussion drilled with air.

The stress disturbance caused by the drill holes is expected to be very small compared to disturbance that will be caused by shaft excavation. This is based on the theory of elasticity where most of the stress redistribution takes place within two radii (one diameter) of a circular opening. The surrounding rock is expected to remain in the elastic range during the stress redistribution process. This behavior will be verified during prototype testing.

In situ stress changes will be estimated using deformation gages, flat-jacks, and/or loading cells. Instruments will be emplaced in the stress-relief holes to measure the deformation in at least two perpendicular directions prior to further shaft excavation. The change in instrument response during and after shaft excavation will be recorded. The multiposition borehole extensometers will be installed in the displacement measuring boreholes. In situ stress magnitudes and directions then will be estimated using data from these instruments, along with rock physical properties data that will be determined in the laboratory.

Television camera logs will be made in the permeability and stress measuring holes. Individual fractures and joint sets will be mapped from the television log record so that air and water injection testing zones can be appropriately located. Borehole geophysical surveys also will be conducted in the vicinity of the shaft. Neutron moisture, porosity (epithermal neutron), and gamma-gamma logs will be recorded.

Permeability boreholes will be instrumented with air-injection packer strings to detect permeability changes along these boreholes due to stress changes caused by the shaft excavation. These permeability tests will be performed before excavation of the shaft below the breakout levels and after further excavation until permeability changes are no longer detected.

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Air-injection packer strings then will be installed at certain zones to detect any long-term variations in permeability, temperature, and moisture content.

A coupled hydraulic-mechanical finite-element models will be used to analyze the basic data. Model validation and calibration will be accomplished by comparing measured and predicted in situ stress and permeability changes, given an initial state-of-stress condition. The calibrated model will be used to predict disturbances around openings within the repository.

8.3.1.2.2.4.6 Activity: Calico Hills testing in the exploratory shaft facility

The Calico Hills nonwelded unit is expected to be a principal barrier to the flow of ground water and transport of radionuclides. Therefore, it is critical to have high confidence in the understanding of the unit's hydrologic processes, conditions, and properties, under both present and expected future conditions. In particular, it is important to understand the effects that fractures and faults have on flow paths and travel times, and the conditions under which fracture flow may occur.

An analysis of the risks and benefits of alternative methods for obtaining this needed information from the Calico Hills was completed, and drifting and testing in the Calico Hills was recommended, although the testing program has not yet been defined. Tests currently proposed or planned for the Calico Hills geologic unit include the following:

1. Geologic mapping (Section 8.3.1.4.2.2.4)
2. Hydrologic properties of major faults (Section 8.3.1.2.2.4.10)
3. Bulk permeability test (Section 8.3.1.2.2.4.3)
4. Fracture mineralogy (sampling) (Section 8.3.1.3.2.1.3)
5. Matrix hydrologic properties (sampling) (Section 8.3.1.2.2.3.1)
6. Chlorine-36 (sampling) (Section 8.3.1.2.2.2.1)
7. Perched water test (if encountered) (Section 8.3.1.2.2.4.7)
8. Hydrochemistry tests (Section 8.3.1.2.2.4.8)
9. Vertical seismic profiling (Section 8.3.1.4.2.2.5)
10. Diffusion tests (Section 8.3.1.2.2.5)
11. Intact fracture test (Section 8.3.1.2.2.4.1)
12. Overcore stress experiments (Section 8.3.1.15.2.1.2)

Other testing activities being evaluated for inclusion in the Calico Hills test suite include geomechanical and geochemical tests such as plate loading tests (Section 8.3.1.15.1.7.1).

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8.3.1.2.2.4.7 Activity: Perched-water test in the exploratory shaft facility

Objectives

The objectives of this activity are to (1) detect the occurrence of any perched-water zones, (2) estimate the hydraulic properties of the zones, and (3) determine the implication of the existence of such zones on flux, flow paths, and travel times.

Parameters

The parameters of this activity are

1. Transmissivity.
2. Hydraulic conductivity.
3. Hydraulic head and storage coefficient.

Description

Exploratory shaft facility walls will be visually inspected during ramp construction, drifting, and testing for any natural seepage or flow of water. If a seep or wet zone of low discharge is encountered, a small-diameter lateral hole will be drilled into the wall. This will increase the flow rate by concentrating and confining the flow to a perforated well casing to make accurate flow measurements and collect representative water samples for chemical analysis and age dating.

Yields from seeps or flow zones will be determined by collecting the water in a graduated cylinder and using a stopwatch or by a calibrated flow meter to measure the flow rate. If sufficient water production occurs and water level (or pressure) measurements can be made using a water-level measuring device or transducer, then an appropriate pump will be used to run a pumping test. Aquifer tests will be conducted from the exploratory shaft to determine the extent, yield, and hydraulic coefficients of the perched-water zone. The aquifer tests probably will be constant discharge tests so that standard methods may be used to analyze the results. However, detailed plans for conducting and analyzing perched-water tests will be developed before starting the exploratory shaft facility, to ensure that procedures are in place for testing in this unusual environment, if encountered. The implications on flow paths, fluxes, and travel times due to perched water zones will then be determined.

Lateral boreholes in selected low productivity zones will be instrumented with pressure transducers and psychrometers. The pressure transducers will provide hydraulic head data and the psychrometers will provide water potential data in the capped boreholes at selected time intervals.

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8.3.1.2.2.4.8 Activity: Hydrochemistry tests in the exploratory shaft facility

Objectives

The objectives of this activity are to

1. Understand the gas transport processes within the unsaturated zone and to provide independent evidence of flow direction, flux, and travel time of gas.

2. Design and implement methods for extracting uncontaminated pore fluid from rock excavated during ramp construction.

3. Determine the flow direction, flux, and travel time of water in the unsaturated zone by isotope geochemistry techniques.

4. Determine the extent of the water-rock interaction so that geochemical modeling can be performed to deduce the flow path and to understand the geochemical evolution of the unsaturated zone water.

Parameters

The parameters of this activity are

1. Gas composition.
2. Carbon-isotope concentration (in carbon dioxide gas).
3. Hydrogen and oxygen isotopes (in water vapor).
4. Water quality (cations, anions).
5. Flow paths (oxygen-18, deuterium).
6. Travel time (hydrogen-3, carbon-14, chlorine-36).

Description

Carbon dioxide and water-vapor samples will be collected from radial boreholes in the exploratory shaft facility after the holes have been instrumented. Gas samples will be checked for contamination (SF_6 or a similar conservative gas tracer) caused by air coring or blasting before coring. Samples to be used for composition analysis will be drawn by peristaltic pumping, collected in glass or stainless steel collection cylinders, and analyzed by gas chromatography. The carbon dioxide gas will be collected in molecular sieve in stainless steel cylinders and analyzed for carbon-14 and carbon-13 to carbon-12 ratio. Water vapor will be collected in the cold trap by pumping the gas through the cold trap and analyzed for tritium, oxygen-18 to oxygen-16, and deuterium to hydrogen.

The age of the unsaturated zone gases will be determined from the carbon-14 and carbon-13 to carbon-12 isotope data. Stable isotope ratios oxygen-18 to oxygen-16 and deuterium to hydrogen which, can indicate the climatic and evaporative history of moisture, will be used to determine the time of recharge and flow path of the moisture. This information, combined with other moisture data, will be used to interpret the patterns of gas transport.

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Rubble core from construction of the primary science ramp will be used to extract pore fluids from the matrix and near fractures for chemical and isotope analyses. Samples will also be checked for the presence of artificial tracers that would indicate contamination. The fluids will be extracted from the rubble cores by applying pressure, centrifuging, or vacuum distilling depending on the moisture content and core condition. These techniques for fluid extraction will be evaluated during prototype testing.

Fracture fluids are expected to permeate the surrounding matrix. Where fractures occur in core samples, the rock matrix around the fracture will be segregated. Fluids from this matrix with moisture contents greater than 11 percent will be extracted using the centrifuge method.

Fluids from samples with moisture contents less than 11 percent (including samples that have been squeezed and centrifuged) will be extracted using the vacuum distillation method.

Cation concentrations will be determined by using inductively coupled plasma (ICP), and anion concentrations will be determined by ion chromatography. Stable isotope ratios will be analyzed by mass spectrometry. Low-level gas counters or liquid scintillation counters will be used to determine tritium activity. Large carbon-14 samples will be analyzed using conventional gas counting methods, with small carbon-14 and chlorine samples analyzed by tandem accelerator mass spectrometry. All water samples will be analyzed for the presence of gas and water tracers using gas chromatography-mass spectrometry (GCMS). The usefulness and applicability of uranium-series disequilibrium analyses will be evaluated; if determined to be appropriate, these analyses will be done.

Apparent ages of water in the unsaturated zone will be determined from isotope data (carbon-14, tritium, and chlorine-36). Chemical analyses (cations and anions) will be used to verify flow paths indicated by isotope data and to indicate the extent of water-rock interaction. Chemical and isotope data for pore water and fracture-related water will indicate travel times since lower chemical concentrations and the pressure of tritium will indicate younger water.

Additional discussions of these studies are included in Activity 8.3.1.2.2.7.2.

The bulk chemistry data determined in this activity will be used by Study 8.3.1.3.1.1 in its development of ground-water chemistry model. Furthermore, this information and task will be integrated with Activity 8.3.4.2.4.1.3 (composition of vadose water from the waste package environment).

8.3.1.2.2.4.9 Activity: Multipurpose-borehole testing

The current plans for multipurpose borehole (MPBH) testing, as described in the following paragraphs, are tied to the original ESF design configuration (described in the SCP) with two shafts in close proximity. MPBH test plans are being evaluated to determine if it is feasible to conduct

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such tests within the reference ESF design concept described in Section 8.4. Planning for these tests will be tied to the drilling plan for collection of geologic information needed for design and construction of ramp accesses and will require modification to current MPBH and radial borehole tests (Section 8.3.1.2.2.4.4) as previously defined.

Objectives

The planned objectives of this activity are

1. To monitor and evaluate potential hydrologic and engineering interference effects from ramp construction on ESF tests and interference effects between ESF tests.

2. To identify possible occurrence of perched water and, if present, sample and test.

3. To confirm engineering and hydrogeologic properties on which the ESF design is based and identify anomalous conditions in the vicinity of the ESF.

The drilling method for this application has not been selected; the selection will be based on feasibility testing of air drilling and coring methods and equipment in a prototype borehole.

The prototype borehole is planned to be drilled before drilling the first multipurpose borehole (USWMP-1) in a similar stratigraphic profile to the exploratory shaft to ensure that the dry drilling method is feasible to the planned depth. The dry coring technique will be tested to evaluate the feasibility for core sampling in the multipurpose boreholes. The technical procedures for the drilling, sampling, and testing will be developed during prototype testing. If the feasibility testing regarding dry coring techniques is successful, the Project will proceed with multipurpose borehole drilling near the exploratory shafts.

Parameters

The parameters of this activity are

1. In situ gravimetric moisture content.

2. In situ volumetric moisture content.

3. In situ water potential.

4. Water-content profiles.

5. In situ matric potential

6. Temperature profiles.

7. Matrix pore size distribution.

8. Grain density.

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9. Bulk density.

10. Total porosity.

11. Matrix effective porosity.

12. Bulk permeability (pneumatic).

13. Composition of formation water.

14. Composition and stable isotope composition.

15. Radioactive and stable isotope composition.

16. Fracture frequency, orientation, spacing, distribution, and weathering.

17. Depths to hydrogeologic contacts.

18. Transmissivity (perched-water zone).

19. Hydraulic conductivity (perched-water zone).

20. Hydraulic head (perched-water zone).

21. Storage coefficient (perched-water zone).

22. Water chemistry (perched water).

Thermal and mechanical properties will be measured as described in the activities under Studies 8.3.1.15.1.1 through 8.3.1.15.1.6.

Description

If the prototype borehole feasibility testing is successful, two multipurpose boreholes (USW MP-1 and USW MP-2) would be constructed using dry-drilling and spot-coring techniques,to the extent practicable, to achieve the objectives listed above. Both boreholes would be located such that they do not penetrate within a distance of either two shaft or drift diameters, as appropriate, of any underground openings. USW MP-1 would be located near exploratory shaft 1 (ES-1), and USW MP-2 near exploratory shaft 2 (ES-2). Each would be approximately 15 to 18 m from the corre- sponding shaft, USW MP-1 to the south of ES-1, and USW MP-2 to the southeast of ES-2. Both boreholes would be approximately 15 cm in diameter and would be drilled to depths approximately equal to the corresponding shafts, with walls as smooth as practical to maximize the quality of geophysical logging and provide adequate packer seats. The planned coring program in USW MP-1 is more extensive than that planned for USW MP-2. USW MP-1 would be drilled first and spot cored throughout. The amount of coring in USW MP-1 is estimated to be 128 m of the total 335 m. USW MP-2 would be spot cored or continuously cored as deemed necessary or practical based on experience from drilling of USW MP-1, or upon finding any indication of perched water. The MBPH drilling activities are planned to be completed and monitoring begun before exploratory shaft sinking.

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Depth penetration of ES-1 will precede ES-2 until about 30 m is reached. At this level tests will be conducted in the radial boreholes in ES-1 (Activity 8.3.1.2.2.4.4) at the contact of the Tiva Canyon welded unit and the Paintbrush nonwelded unit. Because ES-2 is designed to provide quick access to the main test level, the construction of ES-2 will proceed ahead of ES-1 after the first few tens of meters.

USW MP-1 is planned (1) to be located to provide reference information in the vicinity of ES-1 and (2) to provide a monitoring hole once shaft construction activities begin. The pre-shaft-sinking results of the moisture-sensitive geophysical testing (e.g., neutron activation) are planned to serve as a baseline against which construction-induced variations can be assessed. If significant net amounts of water are introduced by construction, and if that water migrates outward from the shaft, the periodic logs would record the movement of the moisture front. USW MP-1 would also provide for testing and sampling of any perched water zones encountered before possible drainage and contamination from fluids introduced during the construction of ES-1. This borehole would be located outside the anticipated modified permeability zone (MPZ) caused by construction of ES-1, but within the radial distance from ES-1 covered by the radial borehole test. In conjunction with monitoring performed during the radial borehole test in ES-1, periodic geophysical logging and pneumatic testing would be conducted in USW MP-1 to monitor conditions during construction of ES-1. Analysis of the core samples obtained from USW MP-1 and USW MP-2 would provide the data base for establishing pre-shaft in situ ambient conditions and would become part of the site data base compiled in Activity 8.3.1.2.2.3.1 (matrix hydrologic properties testing). Within each hydrostratigraphic unit, a sample would be analyzed for the parameters for this activity. In particular, matrix hydrologic properties and moisture conditions would be characterized to establish in situ conditions that could be correlated with the initial results of geophysical testing.

USW MP-2 is planned to be located near ES-2 in order to provide confirmation of conditions expected to be encountered during shaft construction activities. This borehole is designed to detect any anomalous conditions, including perched water, that may be present at this location. If large amounts of perched water are present in the ESF vicinity, it would probably be detected in USW MP-1. However, even if perched water has not been detected in USW MP-1, continual observations for indications of perched water would be conducted in USW MP-2.

If unexpected conditions do exist, information obtained in the two boreholes could prevent potentially costly delays in shaft construction. The responses observed in USW MP-2 caused by the construction of ES-2 would be expected to be similar to those that might be later observed in USW MP-1 caused by the construction of ES-1. Therefore, observations in USW MP-2 could provide some lead time, so that construction effects can be considered before ES-1 testing.

The models of shaft construction effects developed from observations around ES-1 (radial boreholes test and excavation effects test (Activities 8.3.1.2.2.4.4 and 8.3.1.2.2.4.5 and USW MP-1) and ES-2 (USW MP-2) can be applied to predict what these effects will be at the ESF main test level. This approach will aid in confirming whether the selected test locations at

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the main test level are appropriate. In addition, distinctive tracers will be included in all ESF construction fluids to help identify the sources of any fluids sampled during ESF excavation. If tracers are detected at proposed test locations, this information will also be used to help determine whether proposed test locations are suitable.

A third multipurpose borehole may be drilled midway between ES-1 and ES-2, if further study indicates a need for such a borehole. The primary purpose of this borehole would be to attempt to assess the impact of construction activities in ES-2 on investigations in ES-1. Preliminary modeling (Section 8.4) results indicate that any expected fluid loss from construction activities in ES-2 probably would not migrate in the matrix or small-aperture fractures the 30 to 45 m from the shaft to the additional borehole, and that changes in matrix saturation would be small. However, the potential exists for more extensive fluid movement along large-aperture fractures. In addition, bulk pneumatic permeability would be affected by even small changes in moisture contents of fractures. These effects could be detectable by a multipurpose borehole sited between ES-1 and ES-2. A decision on the need for a third multipurpose borehole will be made before the construction of ES-2 on the basis of additional analyses of the magnitudes and significance of expected effects.

If perched water is detected during the process of drilling either of the two multipurpose boreholes, an attempt to obtain a water sample would be made, possibly by means of a bailer or other type of downhole sampler. A water sample must be obtained with minimal delay before the possible drainage of a small perched water zone. If sufficient water is present to conduct aquifer testing, testing will be initiated, and additional water samples will be obtained.

Because drilling fluid used during construction of nearby test hole USW G-4 contained water, the occurrence of perched water in either of the two multipurpose boreholes could be the result of drilling fluids lost from USW G-4. Drilling fluids used in USW G-4 contained 20 ppm LiBr tracer; thus, analyses for this tracer will establish whether any perched water samples contain drilling fluid that has migrated laterally from USW G-4 to areas of ESF excavation.

A standard suite of borehole geophysical logs would be run in each multipurpose borehole, either during a pause in drilling or following completion of drilling. Radial-(side scan viewing) and axial-(forward viewing) oriented television video camera logs of each borehole would also be run. These would be used for mapping fracture orientations, distributions, and densities. Neutron moisture logs would be made periodically during and after the drilling period to monitor any changes in water-content profiles.

To establish a preconstruction data set for bulk pneumatic permeabilities immediately following drilling, packer nitrogen-injection tests would be performed in each of the boreholes to determine gas permeabilities of the combined fracture and rock matrix system. Multiple test zones would be selected for each hydrogeologic unit. These zones would be tested with a straddle packer system consisting of a variable length injection interval, and two observation intervals. All three intervals would be equipped with thermocouple psychrometers (or other humidity sensors), thermocouples and

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pressure transducers. The observation intervals would be monitored for evidence of bypass of the packers from the injection interval. The flow rate and injection pressure of the nitrogen gas would be monitored until steady-state conditions are achieved. The same procedure would be carried out at higher flow rates and pressures for each tested interval to determine the relationship of permeability versus flow rates and pressure. During construction of the exploratory shafts, additional periodic packer tests would be conducted to determine any changes in gas permeabilities due to shaft construction.

Neither of the two multipurpose boreholes would be permanently instrumented. The open boreholes would allow flexibility in terms of follow-up packer testing and continual neutron-moisture logging that a permanently instrumented borehole could not accommodate.

Drilling of the multipurpose boreholes would disturb in situ conditions in the near-field rock mass adjacent to the boreholes. In addition, nitrogen pressure injection testing could drive moisture away from the near-field environment of the borehole. However, the planned dry drilling and coring methods are expected to minimize the disturbance to the hydrologic system, and pre-injection reference information would be collected before nitrogen injection testing. This information would consist of laboratory measurements of moisture content and matric potential from core and cuttings and geophysical logging records correlated with these data. Although these data would not directly address changes in moisture in fractures, results of neutron moisture logging would provide some indication of moisture contents in fracture zones.

8.3.1.2.2.4.10 Activity: Hydrologic properties of major faults encountered in main test level of the exploratory shaft facility (ESF)

Objective

The objective of this activity is to investigate the permeability and flow conditions of the major faults encountered in the ramps and in drifts at both the Calico Hills and Topopah Spring levels of the ESF.

Parameters

The parameters of this activity are

1. Matrix parameters including water content, porosity, pore-size distribution, air permeability, and water permeability.

2. Rock-mass parameters including water content, hydraulic potential, pneumatic potential, thermal potential, and permeability to air and water.

3. Chemical parameters including composition of formation water, composition of formation gases, carbon-14 and tritium activity, and stable isotope composition (oxygen-18), deuterium) for the purpose of age dating and environmental interpretations.

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Description

This activity is designed to provide hydrologic information in parallel with a portion of Activity 8.3.1.4.2.2.4 (geologic mapping of the exploratory shaft facility). All faults encountered in the ramps and drifts of the exploratory shaft facility (ESF) will be characterized geologically under the geologic mapping activity. Hydraulic properties of major faults encountered in the ESF will be determined in this activity. The major faults or fault zones expected to be tested are the Ghost Dance fault, a suspected fault in Drill Hole Wash, and the imbricate fault zone. Other faults will be tested if flow is observed.

This test is designed to supplement information relative to hydrologic characteristics of faults determined under Activity 8.3.1.2.2.3.3 (Solitario Canyon horizontal borehole study) and in part, under Activity 8.3.1.2.2.3.2 (site vertical borehole studies). In addition, the data collected during this activity will be used to test conceptual models of the hydrologic system and will be used in the development of a model of the unsaturated-zone hydrologic system at Yucca Mountain (Studies 8.3.1.2.2.8 and 8.3.1.2.2.9).

On the basis of the identification of major faults by the geologic mapping activity, a hydrologic testing program will be implemented. This program will consist primarily of tests conducted in boreholes drilled from drifts through fault zones and tests on core collected from the coreholes. Air permeability tests will be conducted between boreholes to determine the permeability to air of the fault zones. Some boreholes will be instrumented to determine in situ conditions of the rock mass and monitored for any changes in these conditions over time. Other sets of boreholes will be used for cross-hole water-injection tests. All water used for injection will be tagged with a tracer. Potential impacts of water-injection testing are described in Section 8.4.3. Core recovered from the holes will be tested to provide a water-content profile across the fault zone. This profile may provide information relative to any recent moisture occurrence in the fault zone.

All boreholes will be drilled using air as the drilling fluid to minimize changes in ambient moisture condition. Core will be examined on the site to obtain a preliminary determination of fracture frequency, orientation, location, and characteristics, as well as indications of fault gouge. This information will be used in conjunction with geophysical and television camera logs for selecting test intervals for air permeability and water-injection testing and for selecting monitoring intervals. The core and cutting samples will be sealed in wax or placed in air-tight canisters and transported to the surface-based field laboratories, where the moisture content of each sample will be determined. Samples will also be sent to laboratories off the site for determinating gravimetric water content, volumetric water content, grain density, porosity, bulk density, water potential, matric potential, moisture retention, saturated water and gas permeability, and relative permeability (Activity 8.3.1.2.2.3.1).

The planned natural gamma, gamma-gamma, neutron-moisture, and caliper geophysical logs will be used to assist in establishing fault zone location in the boreholes, moisture content distribution, and the condition of the borehole. Periodic temperature logs will be made in some boreholes to help

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determine the thermal gradient across the fault zone and to override indications of variations in flux within the fault zone.

Two types of television cameras will be used for borehole surveys. The first type views downhole just ahead of the camera and will be used to qualitatively judge the condition of the borehole for such information as wall cake (dust, cuttings) and visible moisture. The second type will be a side-view camera that will be used for establishing fracture characteristics.

Packer air-injection tests will be conducted to determine the distribution of permeability to air across the fault zones. A straddle packer system, consisting primarily of four packers, flow meters, pressure transducers, thermocouple psychrometers, and temperature sensors, will be installed at the desired test zone. The packers will then be inflated and nitrogen gas injected into or withdrawn from the central interval, while the two outer intervals are monitored for bypass of the packers. The response will be monitored for changes in pressure, temperature, relative humidity, and flow rate. Analysis of the test data will depend on flow domain boundary conditions, the type of fluid injected or withdrawn and the type of test conducted (steady state, transient, or instantaneous injection).

Cross-hole testing will be conducted using air- and water-injection. During air-injection testing straddle packers will be installed in both an injection and an observation borehole. Nitrogen gas will be injected in the one borehole and pressure changes will be monitored in the observation borehole. From the known flow rate and pressure drop between the two boreholes, the permeability to air of the fault zone will be determined. Water-injection tests will be conducted in a similar manner with tagged water being injected into one borehole and monitored for in the other borehole.

8.3.1.2.2.5 Study: Diffusion tests in the exploratory shaft facility

There is one activity in this study.

8.3.1.2.2.5.1 Activity: Diffusion tests in the exploratory shaft facility

Objectives

The objective of this activity is to determine in situ the extent to which nonsorbing tracers diffuse into the water-filled pores of the tuffs of the Topopah Spring welded unit at the main test level of the ESF. A diffusion test is also proposed in the Calico Hills unit.

Parameters

The parameter of this activity is the diffusivity coefficient.

Description

Diffusion tests in the exploratory shaft facility are to be conducted in small- diameter boreholes drilled beyond the disturbed zone in the Topopah Spring tuff and in the drifts of the Calico Hills unit. Test results will be used to model the transport of technetium-99 and iodine-129, nonreactive radionuclides, from the repository to the water table.

This test requires the drilling of four boreholes at each test site, each of which will be drilled in an underground drift using air-drilling techniques and the smallest diameter bit available consistent with the methods to be used in the testing activities. The drilling will be done with air to avoid adding drilling water to the pores where the diffusion will occur. The depth of the hole will be approximately 10 m to penetrate beyond the zone of stress relief induced by mining the drift.

Each borehole will be surveyed using television to identify any fractures intersecting the borehole walls in the region where the tracer solution will be placed. Tracer emplacement locations will be chosen in borehole segments that are free from fractures that might result in water flow through the diffusion volume. A small amount of nonsorbing tracers will be introduced into the bottom of the borehole; appropriate methods of emplacement have yet to be identified, but will be evaluated prior to the test. Next, the borehole will be sealed with a packer of appropriate size to isolate the diffusion volume from the remainder of the underground environment. After approximately three months, the borehole will be overcored. The overcoring method has been chosen to ensure that the core recovery is adequate. The exact period of time before the overcoring will begin is contingent in part upon the results of the laboratory diffusion experiments. A year-long test will be run after all of the techniques being developed in the three-month test have been proven.

The core will be transported to an offsite laboratory for determination of tracer concentrations as a function of distance from emplacement. The data will be analyzed to derive diffusivity values. The measured tracer concentrations as a function of distance from emplacement will be analyzed in terms of the diffusion equation for solute transport through a porous geologic medium in the absence of fluid flow. The use of this equation is predicated on the absence of tracers in the tuff at the start of the experiment and on a constant tracer concentration in the source solution.

8.3.1.2.2.6 Study: Characterization of gaseous-phase movement in the unsaturated zone

The objectives of this study are (1) to describe the pre-waste emplacement gas-flow field, (2) to identify structural controls on fluid flow, (3) to determine conductive and dispersive properties of the unsaturated zone for gas flow, and (4) to model the transport of water and tracers in the gas phase. One activity is planned to collect the data required to satisfy these objectives: the gaseous-phase circulation study. The results of this activity will be important to the assessment of transport of gaseous radionuclides (e.g., carbon-14).

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In the gaseous-phase circulation study, the approach is parallel to that used for hydraulic fluxes: Data will be collected near the steep western slope of Yucca Mountain to define the boundary conditions and conductive properties; a coupled model will predict the fluxes; and observations will verify and calibrate the model. Existing exsurgent and insurgent boreholes will be instrumented to relate flow to atmospheric conditions. New holes will be stemmed to isolate chambers for gas sampling and pressure measurement where the Solitario Canyon slope provides an unknown boundary condition for the repository block. In-hole, cross-hole, and transverse-site tracer tests, as well as analysis of natural and bomb-produced tracers, will be used to disclose fracture system transport properties (Table 8.3.1.2-9).

The Solitario Canyon horizontal borehole activity has been designed to augment the gaseous phase circulation study in determining the gaseous flux distribution on the western side of the repository. In this activity, two or more boreholes on the Solitario Canyon slope will be drilled to measure the discharge and gas samples will be taken to determine the boundary fluxes and potentials. Many tests of the effective air conductivity of the fractured rocks at many levels will provide model parameters for two- and three-dimensional simulations. Analysis of gas compositions will disclose effective fracture porosities by determining mean travel times, while the breakthrough curves for conservative gas tracers will indicate effective porosities and convective dispersivities for the gas phase.

The magnitude of vapor fluxes and gas transport can only be evaluated by modeling, which requires the collection of sufficient data on properties of the fractured media and appropriate boundary conditions. Numerical models will be constructed to incorporate the presence of boreholes and underground openings, as well as topographic and structural controls. The flow field will depend upon the definition of the transient atmospheric boundary conditions, together with geothermal-drive mechanisms, and upon a spatial definition of conductive, sorative, and dispersive properties of the unsaturated zone.

8.3.1.2.2.6.1 Activity: Gaseous-phase circulation study

Objectives

The objectives of this activity are

1. To describe and model the pre-waste-emplacement gas-flow field and its effect on net water-vapor transport from the unsaturated zone by modeling the western portions of Yucca Mountain as a two-dimensional and/or three-dimensional boundary problem in compressible nonisothermal flow.

2. To provide the parameters necessary for modeling gas flow from and to the repository and the potential transport of radionuclides as well as the gaseous flux of moisture affecting deep percolation after the repository is in place.

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Table 8.3.1.2-9. Summary of gas-phase tests (page 1 of 3)

Hole or site	Test	Objectives	Methods
USW UZ-6, -6s (open holes)	Flow distribution in each open hole	Relate flux to atmospheric boundary conditions	Regression analysis
	Flow tests to each sampling chamber	Evaluate effective gas conductivity and storativity	Analytical solutions and 3-D modeling
	Relative humidity of discharging air	Determine moisture flux with time	Gas sampling and analysis
	Natural tracer tests	Determine ages of gases discharged, age of water evaporated Determine dispersivities	Composition of gases discharging at various depths: SF_6, $CBrCl_2F$ for drilling-air contamination, CCl_2F_2, CCl_3F, and ratios of 14 CO_2 to CO_2, tritiated water to H_2O, and ^{18}O to ^{16}O, (sample bimonthly for age determinations).
	Flux distribution	Determine preferential flow paths; site subsequent test	Measure flux distribution (quality assurance) over boundary surface.

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Table 8.3.1.2-9. Summary of gas-phase tests (page 2 of 3)

Hole or site	Test	Objectives	Methods
Solitario Canyon hole (vertical in Topopah Spring) and Solitario Canyon hole (horizontal in Tiva Canyon)	Shallow formation moisture contents	Determine seasonal effects of convective air flow on moisture contents	Measure saturation of sample gases from various depths
	Boundary conductivity	Determine fracture conductivity near (disturbed) surface	Pressure-transducers set in isolated chamgers in holes; rates to open/ chambered holes; validate models
	Structural controls	Determine if faults and non-welded strata are air-conductive or barriers	
	Geothermal test	Provide thermal parameters for compressible flow modeling	Measure temperature distribution, test conducted by J.Sass (GPP-02, 05)
UZ-6 borehole complex and UZ-9 borehole complex	Packer injection/ interference/nonsteady flow tests	Determine anisotropic air conductivities, storativity for all unsaturated-zone units, parameters needed for all unsaturated-zone units, parameters needed for all large-scale modeling; validate models	Use 3-m injection intervals in each hole, simultaneously measuring gas pressure in array of chambers of adjacent holes, apply the analysis for anisotropic fracture permeability from Hsieh, et al. (1985)

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Table 8.3.1.2-9. Summary of gas-phase tests (page 3 of 3)

Hole or site	Test	Objectives	Methods
UZ-6 borehole complex and UZ-9 borehole complex (continued)	Dispersivity tests	Determine fracture system air dispersivities as function of gradient direction and anisotropy. Parameters needed for large-scale modeling. Validate dispersivity model.	Injection nonsorbed gas tracers in interval, observe breakthrough at array of chambers in adjacent holes. Analyze according to method of Kreamer (1982).

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3. To reconstruct the air circulation history at instrumented boreholes from the time of drilling until stemmed and instrumented in order to estimate the time required for poststemming recovery of ambient gas and moisture conditions as an aid in interpreting gas composition and thermocouple psychrometer data.

4. To determine, by flow and pressure measurements in single holes, and by cross-hole interference tests, the near-field air conductivities, storativity, and anisotropy of the unit above the repository horizon.

5. To determine effective porosities and dispersivities of the fracture system by the interpretation of natural and artificial gas tracer data as an aid in the modeling described in items 1 and 2.

Parameters

The parameters of this activity are

1. Moisture content.
2. Gas composition.
3. Air temperature.
4. Gas potential distribution.
5. Flux.
6. Fracture conductivity and anisotropy.
7. Fault conductivity.
8. Structural controls.
9. Effective porosity.
10. Convective dispersity.

Description

Atmospheric conditions will be characterized during the entire period of gas-flow measurement by using the site meteorological network (Activity 8.3.1.2.1.1.1) to determine and interpolate to drillhole sites of concern, the air temperature, barometric pressure, and relative humidity as a function of time and seasons. Atmospheric samples will also be collected. Their compositions will be analyzed using the same method used for borehole gas samples, described in the following paragraph.

Two existing open wells (USW UZ-6, USW UZ-6s) will be instrumented with recording hot-wire anemometer flow meters (Figure 8.3.1.2-16). The flow will be measured for extended periods of time under open-hole conditions and for partial shut-in conditions. These flow rates will be related to barometric pressure changes and air temperature by regression analysis. All the topographically affected wells along the crest of Yucca Mountain will also be periodically shut in and the pressure difference between the wells and atmosphere will be measured. In turn, each well will be opened, and the pressures will be measured in all surrounding wells to conduct interference tests. The results will be analyzed to determine the horizontal and vertical permeability to air; the air-filled fracture porosity conventional temperature logging tool will be used, whereas the device for flow logging remains undetermined. Gas samples will be obtained in open holes by lowering tubing downhole to various depths. The samples will be collected in syringes and

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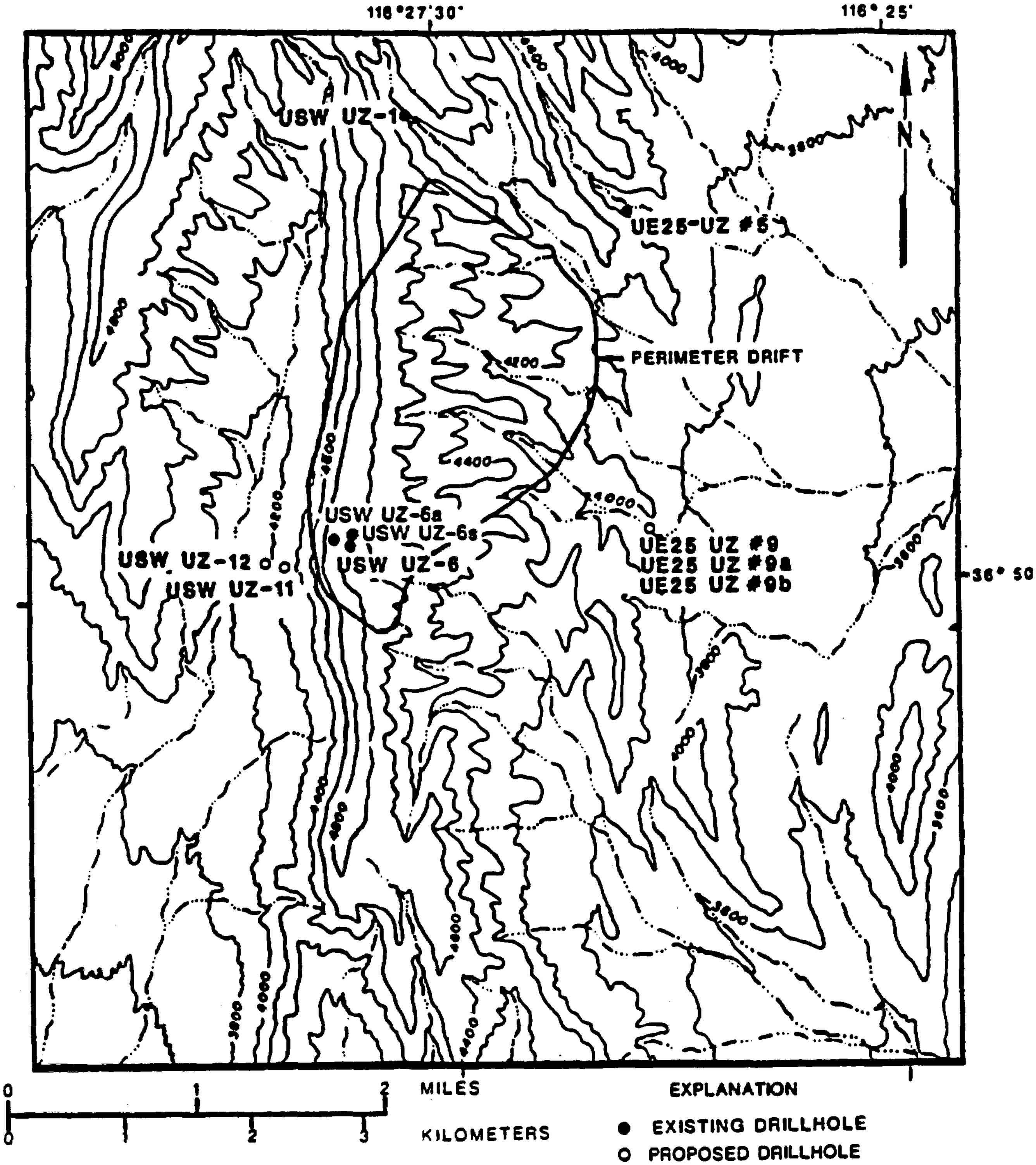

Figure 8.3.1.2-16. Gaseous-phase sampling locations.

analyzed on site for relative humidity and by gas chromatography to determine the percentage composition of carbon dioxide (CO_2), methane (CH_4), SF_6, $CBrCl_2F$(BCF), CCl_2F_2(F-12), and CCl_3F(F-11). Both CO_2 and methane may serve as natural tracers that indicate fracture zones of strong circulation, information that can be used to estimate the total volume of gas flow in individual zones within the total section tapped by the borehole. Such information is needed to estimate the time for ambient conditions to be recovered at different depths. SF_6 and BCF were added to the air during the drilling of USW UZ-6 and USW UZ-6s, respectively, and their presence and concentration will indicate the extent to which drilling air has been purged from the hole and surrounding rock by convective air flow. F-11 and F-12 behave as long-term man-made tracers that can give additional information on gas transport at the site. If the flux is slow, the long-term tracer tritium may be included in subsequent work. The logging will be conducted every two months until the holes are stemmed.

Fluorocarbon concentrations arising from diffusion transport alone through the unsaturated zone have been attenuated several-fold at a depth of about 50 m based on measurements made in the High Plains of Texas. Hence, near-atmospheric concentrations of F-11 and F-12 at depth would be indicative of convective gaseous-phase transport.

Gas composition data for USW UZ-1 suggest that natural conditions within the borehole require at least 2.5 yr after the hole was stemmed to approach equilibrium with the surrounding rocks. Modeling of open borehole flow will allow evaluation of the length of time required for the moisture content and gas composition for various zones to reequilibrate to ambient conditions once stemming is complete.

At some time subsequent to the stemming of holes USW UZ-6 and USW UZ-6s, two holes (USW UZ-11 and USW UZ-12) will be drilled on either side of the Solitario Canyon fault. Also, a near-horizontal hole will be drilled into the Tiva Canyon welded unit or Topopah Spring welded unit above or below the nonwelded or bedded Paintbrush Tuff. Moisture content and pore-gas relative humidity, as inferred from the Kelvin equation, will be determined on cores and cuttings, and the holes will be instrumented to measure temperature, moisture tension, and pore-gas relative humidity and will be equipped for periodic gas sampling. Gas compositions in all three holes will be determined from periodically collected samples. Although gas-flow conditions will be altered by stemming holes USW UZ-6 and USW UZ-6, the data collected during this study will be invaluable in interpreting and modeling the temperature, relative humidity, and gas composition data collected during those studies, particularly in regard to seasonal variations in near-surface moisture content and trace gas composition. These moisture and trace-gas seasonal changes may provide insight on the magnitude of gas circulation under natural conditions.

In winter, gas tracer tests may be performed by shallow burial of permeation tubes at various horizons along the western scarp of Yucca Mountain. The trace gases will be sampled in the air stream blowing from the summit wells. The interpretation of tracer tests in the light of structural controls, fracture geometry, and breakthrough concentrations will require numerical modeling. These measurements will provide a large-scale test of dispersivity to gas flow and will provide much useful information for the gas-

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tracer tests planned in the UE-25 UZ#9 hole cluster, as described in the following paragraph.

Effective fracture porosity and dispersivity will be obtained by tracer tests conducted between adjacent boreholes, in the unsaturated portions of UE-25 UZ#9, UE-25 UZ#9a, and UE-25 UZ#9b. Unsaturated-zone tracer testing in the cluster is expected to require about 60 days, based on solely diffusive transport and conservative estimates of tortuosity to that transport. While injecting a conservative tracer in one packed-off interval, adjacent boreholes, segmented by packer strings and tapped by sampling tubes, can be sampled to obtain breakthrough curves. Each hydrostratigraphic unit can be characterized by applying distinctly different tracers at several injection intervals, sampling at fixed packer intervals in the adjacent holes. These data could augment "huff-and-puff" tracer tests conducted routinely in connection with each packer air injection test of the exploratory shaft test plan, which would measure, on a small scale, the fracture-system dispersivities.

Gas-phase modeling will be used to interpret the results of observations made during this study, and to extrapolate those results to interpret gas circulation in Yucca Mountain under natural conditions. A two-dimensional model in vertical section normal to the slope will be developed to interpret the measured gas potentials and fluxes in terms of the temperature distribution, moisture contents and structural and stratigraphic controls. Three-dimensional modeling may be needed to incorporate borehole configurations. Average conductivities, porosities, and dispersivities for distinct units are expected results of this modeling. These results will be useful in evaluating water vapor and gaseous radionuclide transport from Yucca Mountain once the repository is in place. Preliminary modeling will be conducted using the HST code (Kipp, 1986).

Structural controls on the gas flow may be recognized by analysis of the flux distribution. Fault zones may be strong conduits for parallel flow and strong barriers to cross flow. Fine nonwelded beds, as exist in the Pah Canyon Tuff, may impede circulation in the mountain, or completely compartment the terrain. Models, substantiated by borehole tests of the degree of saturation at inlet and outlet regions during each season, provide a point of departure for computing ground-water depletion, believed to be a dominant flux component in the unsaturated zone, especially during interpluvial ages. Likewise, the models will provide a basis for estimating gaseous radionuclide transport and moisture migration due to the gas circulation as enhanced by the repository heat load.

If these gas-phase investigations indicate that movement of moisture, gas, or both in the unsaturated zone is potentially significant, either in reducing the potential for deep percolation through the repository or in discharging gases to the atmosphere, additional open-borehole studies may be needed at other locations on Yucca Mountain.

8.3.1.2.2.7 Study: Hydrochemical characterization of the unsaturated zone

The objectives of this study are to (1) understand the gas transport mechanism, direction, flux and travel time within the unsaturated zone; (2) design and implement methods for extracting pore fluids from the tuff; (3) provide independent evidence of flow direction, flux, and travel time of water in the unsaturated zone; (4) determine the extent of the water-rock interaction, and (5) model geochemical evolution of ground water in the unsaturated zone. Two activities are planned to collect the data required to satisfy these objectives.

8.3.1.2.2.7.1 Activity: Gaseous-phase chemical investigations

Objectives

The objective of this activity is to understand the gas transport mechanism, and provide evidence of gas flow direction, flux, and travel time within the unsaturated zone.

Parameters

The parameters of this activity are

1. Gas composition.
2. Carbon-isotope concentration (in CO_2 gas).
3. Hydrogen and oxygen isotopes (in water vapor).

Description

Carbon dioxide and water-vapor samples will be collected from unsaturated zone holes after the holes have been packed and instrumented (Figure 8.3.1.2-17). Gas samples will be checked for contamination caused by air coring (using SF_6 or a similar conservative gas tracer). Samples to be used for composition analysis will be drawn by peristaltic pumping, collected inglass or stainless-steel collection cylinders, and analyzed by gas chromatography. The carbon dioxide gas will be collected by a molecular sieve in stainless steel collection cylinders and analyzed for carbon-14 and carbon-13 to carbon-12 ratio. Water vapor will be collected in the cold trap by pumping the gas through the cold trap and analyzed for tritium and oxygen-13 to oxygen-16 ratio.

The age of the unsaturated zone gases will be determined from the ratio of carbon-14 and carbon-13 to carbon-12 isotope data. Stable isotope ratios (oxygen-18 to oxygen-16 and deuterium to hydrogen), which can indicate the climatic and evaporative history of moisture, will be used to determine the time of recharge and flow path of the moisture. This information, combined with other moisture data, will be used to interpret the patterns of gas transport.

Data from this activity will be combined with data from the unsaturated zone gaseous-phase circulation study (Activity 8.3.1.2.2.6.1), and data collected from the unsaturated zone just above the water table, as described

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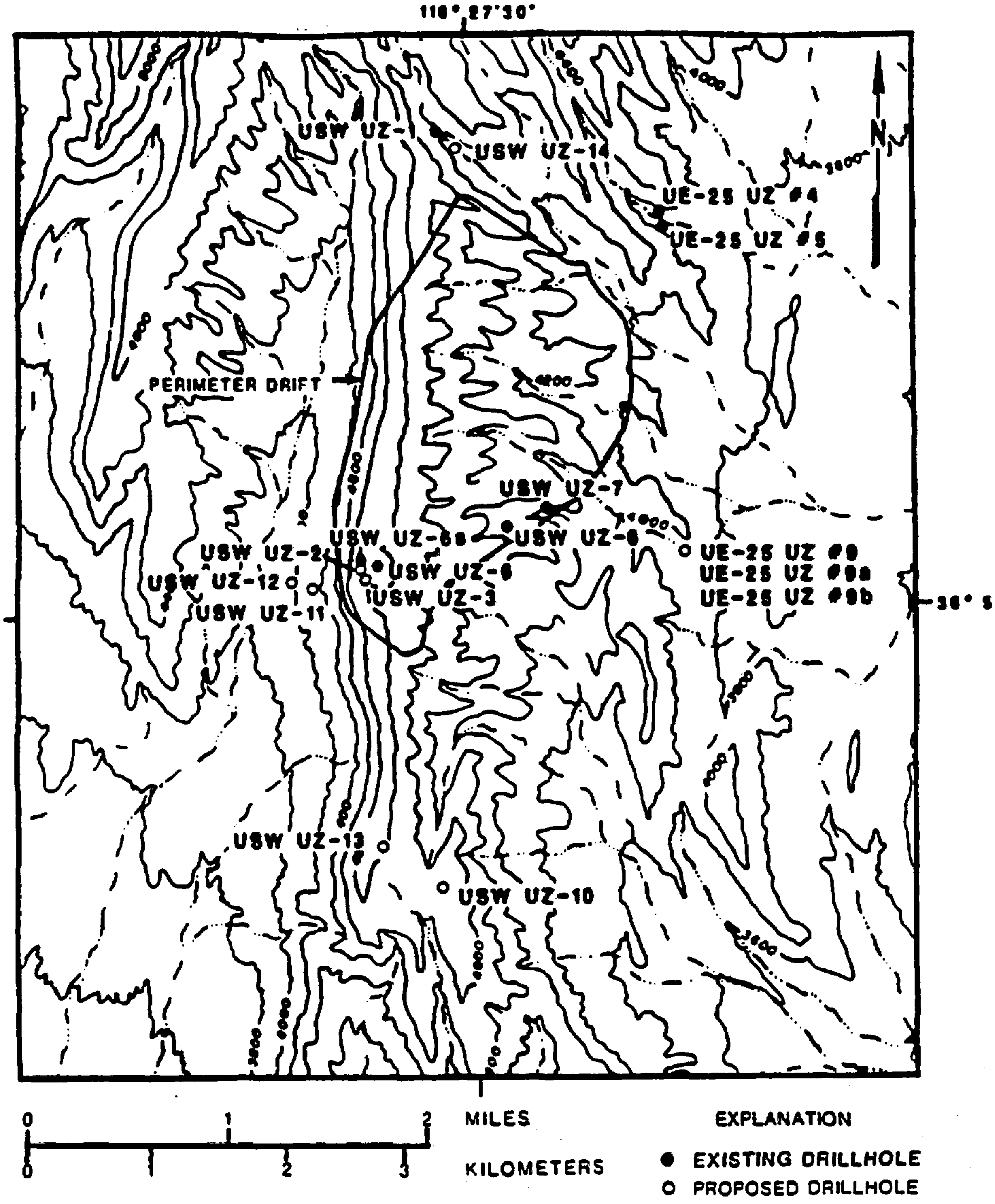

Figure 8.3.1.2-17. Gaseous and liquid-phase chemical sampling locations.

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in Activity 8.3.1.2.3.2.2 (hydrochemical characterization of water in the upper part of the saturated zone) in an assessment of the Yucca Mountain gas flow processes.

8.3.1.2.2.7.2 Activity: Aqueous-phase chemical investigations

Objectives

The objectives of this activity are

1. To design and implement methods for extracting pore fluids from unsaturated zone tuff units.

2. To provide evidence of flow direction, flux, and travel time of water in the unsaturated zone.

3. To determine the extent of the water-rock interaction and to model geochemical evolution of ground water in the unsaturated zone.

Parameters

The parameters of this activity are

1. Water quality (cations, anions).
2. Flow paths (oxygen-18-oxygen-16, deuterium-hydrogen).
3. Travel times (hydrogen-3, carbon-14, chlorine-36).

Description

Pore fluids from the rock matrix and near fractures will be extracted from unsaturated zone drill cores for chemical and isotope analyses (Figure 8.3.1.2-20. Samples will also be checked for the presence of various tracers that will be used during the drilling of wells and the construction of the exploratory shaft. The fluids will be extracted by applying pressure, centrifuging, or vacuum distillation depending on the moisture content and core condition. These techniques will be evaluated during prototype testing.

Pore fluids from core samples of matrix with moisture contents greater than 11 percent will be extracted using the triaxial press method (below 11 percent, neither triaxial press nor centrifuge methods will extract any water). This method consists of placing the core in a triaxial confinement chamber and applying axial and confining pressure in step increases. The water chemistry at each pressure step will be determined. The changes in water chemistry as a function of pressure will be analyzed and the maximum pressure at which no significant water chemistry changes occur will be adopted for the future pressure limits.

Fracture fluids are expected to permeate the surrounding matrix. Where fractures occur in core samples, the rock matrix around the fracture will be segregated. Fluids from this matrix with moisture contents greater than 11 percent will be extracted using the centrifuge methods. This method consists of placing core samples in a centrifuge cup and spinning them for

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2 h, with the fluids draining through a perforated plate into a collection cup. Fracture fluids may also be available from perched water zones in the exploratory shaft.

Fluids from samples with moisture contents less than 11 percent (including samples that have been squeezed and centrifuged) will be extracted using the vacuum distillation method. This method consists of placing the core sample inside a glass container that is in an evacuated system, and heating it to 100°C to drive off the moisture. The moisture will then be collected in an alcohol-dry ice trap. This vacuum distillation method will yield distilled water, and therefore can only be used for tritium, oxygen, and hydrogen isotope analyses.

Cation concentrations will be determined by using inductively coupled plasma (ICP) and anion concentrations will be determined by ion chromatography. Stable isotope ratios will be analyzed by mass spectrometry. Low-level gas counters or liquid scintillation counters will be used to determine tritium activity. Large carbon-14 samples will be analyzed using conventional gas-counting methods, with small carbon-14 and chlorine-36 samples analyzed by tandem acceleration mass spectrometry. All water samples will be analyzed for the presence of gas and water tracers using gas chromatography-mass spectrometry (GCMS).

Apparent ages of water in the unsaturated zone will be determined from isotope data (carbon-14, tritium, and chlorine-36). Chemical analyses (cations and anions) will be used to verify flow paths indicated by isotope data and to indicate the extent of water-rock interaction. Chemical and isotope data for pore water and fracture-related water will indicate travel times, since lower chemical concentrations and the presence of tritium will indicate younger water.

Pore water in the unsaturated zone may originate from above as downward percolating water or it may originate from below as water remaining from a previous period of saturation when the water table would have been higher. These alternative concepts will be tested in part by applying, in combination, the following hydrochemical criteria:

1. Age of pore water. If pore water is derived from above, its age would generally be expected to increase with depth. Pore water derived from below would generally be expected to have similar ages throughout the stratigraphic section.

2. Composition of fluid inclusions along fracture planes. During the crystallization of minerals or during recrystallization following fracturing, small amounts of water may become trapped within mineral grains. The isotopic and chemical composition of the fluid can indicate water sources and the temperature at which the minerals precipitated. For example, in general, higher temperature would indicate an origin from below.

3. General water chemistry. Chemical composition, including trace elements and anion-cation distribution, may provide supporting evidence of the water's origin by, for example, providing signatures of distinctive water types.

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4. Stable isotope compositions. The oxygen-18 to oxygen-16 and deuterium to hydrogen ratios of pore waters generally would be expected to vary with depth if pore water is derived from above. Pore water derived from below generally would be expected to have similar ratios throughout the section.

Data from this activity will be integrated with and used by Study 8.3.1.3.1.1 in its development of a ground-water chemistry model. Furthermore, Section 8.3.4.2.4 (Activity 1.10.4.1.3) will also integrate with and use these data as it characterizes the unsaturated zone water to determine the water composition of the waste package environment.

8.3.1.2.2.8 Study: Fluid flow in unsaturated, fractured rock

The purpose of this study is to develop and refine conceptual and numerical models describing both gas flow as well as liquid water and solute movement in unsaturated, fractured rock. The primary function of these models will be to help design and interpret hydrologic and pneumatic tests, and to provide information about model parameters that can be incorporated into site-scale models (Study 8.3.1.2.2.9). As such, the models to be developed in this study are intended for application primarily at both the laboratory and sub-REV (representative elementary volume) scales. The REV for a given parameter is that volume of rock at which the model parameter becomes relatively invariant with further increases in scale. At the scale of the REV, the true medium can be replaced conceptually with an equivalent porous medium whose behavior is described by that parameter. By definition, the real and fictitious media exhibit sufficiently similar behavior at that scale with regard to the process in question.

The validity of conceptual and numerical models describing fluid and solute movement in fractured, porous rock will be assessed through experiments conducted at various scales in both the exploratory shaft facility (ESF) and in the laboratory. In addition, different modeling approaches that consider different scales and different levels of complexity will be compared to determine the adequacy of more simplified modeling approaches. In particular, the limitations of treating the fractured rock mass as a composite, homogeneous continuum will be evaluated.

The activities associated with this study also will directly address regulatory issues that concern flow path characterization and determination of ground-water fluxes and travel times within the unsaturated zone. The activities planned for this study include (1) conceptualization and numerical modeling of the unsaturated-zone hydrogeologic system at the sub-REV scale and (2) comparison of the more detailed modeling approaches with experiments to be conducted within the laboratory and in the ESF.

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8.3.1.2.2.8.1 Activity: Development of conceptual and numerical models of fluid flow in unsaturated, fractured rock

Objectives

The objective of this activity is to develop detailed conceptual and numerical models of fluid flow and transport within unsaturated, fractured rock at Yucca Mountain. These models will be applied to volumes of fractured rock at or below the dimensions at which the rock can be replaced conceptually by an equivalent porous medium. Models that consider the system in greater detail or complexity will provide a synthetic data base against which the simulated results of more simplified modeling approaches applied at larger scales can be compared.

Parameters

The parameters for this activity are

1. Fluid and solute fluxes through variably-saturated, fractured rock.

2. Description of the scale dependence of pneumatic, hydrologic and transport parameters.

Description

Conceptual and numerical models that consider fluid flow and transport in fractured rock at various spatial scales and levels of detail will be developed to examine the appropriateness of applying different models at different scales. Sub-REV (representative elementary volume) modeling efforts will support site-scale modeling (Study 8.3.1.2.2.9) by providing information about model parameters appropriate to the larger scale. Sub-REV modeling will examine the implications of spatial heterogeneity within the smallest volume considered as homogeneous within the site-scale model. For instance, sub-REV scale modeling will address the manner in which point measurements of state variables, obtained during monitoring, may be related to volume-averaged values predicted by model simulations performed at the site scale.

The effect of spatial scale on pneumatic, hydrologic, and transport parameters for single fractures and for fracture networks will be evaluated, as will the appropriateness of replacing a fractured rock mass with a stochastic continuum. Detailed modeling approaches that consider fractures as discrete entities, or models that treat the fractured rock mass as a stochastic continuum, will be used to determine the adequacy of simplified modeling approaches that treat the fracture and matrix domains as a composite, homogeneous continuum.

The conceptual model will consider the microscopic processes that influence fluid flow and solute transport both within single fractures with spatially varying aperture, and within networks containing fractures with statistically distributed hydraulic apertures. Those aspects of fluid flow and transport to be evaluated include (1) fluid flow and transport through variably saturated, rough fractures; (2) fluid flow and transport through a network of variably-saturated fractures; (3) fluid and tracer exchange

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between fractures and matrix; (4) small-scale capillary barrier effects between fractures and matrix and among fractures; and (5) gas-phase movement through fractured rock, in volumes of rock at and below the scale of the REV.

8.3.1.2.2.8.2 Activity: Validation of conceptual and numerical models of fluid flow through unsaturated, fractured rock

Objectives

The objective of this activity is to evaluate the reasonableness of the concepts on which the models developed under Activity 8.3.1.2.2.8.1 are based, by using the results of laboratory tests and tests performed in the exploratory shaft facility (ESF) to access the adequacy of model performance.

Parameters

The parameter for this activity is the validity of conceptual and numerical models describing fluid flow and transport in variably saturated, fractured rock.

Description

Hypotheses that describe fluid flow and transport processes in fractured rock are preliminary in nature and will require validation through field and laboratory testing, as described in Study 8.3.1.2.2.4. The process of model validation is intended to ensure that the model can adequately describe the system to which it is being applied. As discussed in the previous activity (8.3.1.2.2.8.1), the reasonableness of a modeling approach can often be evaluated by comparing simulated results from the model with those of a more detailed, and presumably more accurate and realistic model. The limitations of a simpler model can often be exposed in this manner. However, those models determined to be compatible and internally consistent must still be tested by devising experiments that isolate and test individual components in each model. This ensures that these components adequately describe the physical processes at the temporal and spatial scales at which the model application is to be made. By comparing measured and simulated results, a determination is then made as to whether or not the model appears to be adequate for its intended application. In the context of waste repository licensing, "adequacy" may mean simply that the model is accurate enough that a clear-cut decision may be made concerning whether the proposed facility would satisfy the regulatory requirements.

The need to isolate and test the individual components of the overall model provides the rationale for conducting a series of hydrologic tests in both the laboratory and exploratory shaft facility that consider progressively increasing spatial scales. The intact-fracture test (Activity 8.3.1.2.2.4.1) will test models that predict the unsaturated hydraulic characteristics of single fractures based on measurable geometric parameters, such as aperture distribution. This test will also attempt to establish statistical relationships between fracture parameters and to estimate confidence intervals for model predictions by regressing data measured on model-predicted results.

The numerical and conceptual models examined with the intact-fracture test will be used to provide independent estimates of the hydraulic properties associated with each fracture identified in the percolation test block (Activity 8.3.1.2.2.4.2). The confidence intervals associated with these model predictions provide the limits within which estimates of the hydrologic characteristics for individual fractures may be changed when attempting to match measured fluid and solute fluxes from the percolation test block with simulated results. Statistical relationships established between fracture parameters in the intact-fracture test may also provide additional constraints when assigning fracture hydrologic characteristics to individual fractures in model simulations of the percolation test in the ESF (Activity 8.3.1.2.2.4.2).

The percolation test in the ESF itself will provide an opportunity to compare simulated results with physical measurements of fluid and solute fluxes in variably saturated, fractured rock under conditions in which the boundary conditions and flow-system geometry are reasonably well known. In particular, the percolation test in the ESF will be used to determine the ability of various fracture network or stochastic modeling approaches to estimate the bulk effective parameters of an unsaturated, fractured rock mass. The parameters to be estimated include effective bulk-rock conductivity, effective porosity and dispersivity, each as a function of the overall saturation or average matric potential of the rock mass.

The bulk-permeability test (Activity 8.3.1.2.2.4.3) will employ cross-hole, air-permeability testing methods to determine the scale at which the host rock behaves as an equivalent anisotropic, porous medium, and to determine the directional permeabilities at that scale. The measured dimensions at which porous media behavior is observed and the associated directional permeabilities will be compared against a distribution of simulated results. These results are calculated by assuming various system geometries compatible with available observations. This approach is necessary because the actual distribution of high-permeability conduits in such a large rock volume is not expected to be known except in a statistical sense, for example, in terms of average fracture orientations and/or fracture density.

8.3.1.2.2.9 Study: Site unsaturated-zone modeling and synthesis

The purpose and activities of this study are to (1) develop appropriate conceptual models for the site unsaturated-zone hydrogeologic system; (2) select, modify, or develop numerical hydrologic models capable of simulating the hydrogeologic system and its component subsystems; (3) apply the models to predict the system response to changing external and internal conditions; (4) evaluate the accuracy of the models using stochastic modeling, conventional statistical analyses, and sensitivity analyses; and (5) integrate data and analyses to synthesize a comprehensive qualitative and quantitative description of the site unsaturated-zone hydrogeologic system under present as well as probable, or possible, future conditions. The ultimate goal of this synthesis is to address those information needs for the overall unsaturated-zone hydrogeologic system that pertain to demonstrating site compliance, or noncompliance, with the regulatory criteria and

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guidelines for the long-term storage of high-level nuclear waste in a mined geologic repository in the unsaturated zone at Yucca Mountain.

8.3.1.2.2.9.1 Activity: Conceptualization of the unsaturated-zone hydrogeologic system

Objectives

The objectives of this activity are to develop conceptual models for the overall moisture flow system within the unsaturated zone at Yucca Mountain. The conceptual models of the system and component subsystems constitute the basis both for the hydrologic testing program at the site and for numerical hydrologic modeling of the site. Conceptual-model development is an ongoing, iterative process by which hypotheses and alternative hypotheses are tested using laboratory experiments, field experiments, and numerical modeling. Hypotheses may be accepted, rejected, revised, or refined. The goal is to develop an internally consistent set of hypotheses that describe those aspects of the site hydrogeologic system that are needed to assess the capability of the site to isolate nuclear waste for a period of 10,000 yr or longer.

Parameters

The parameters of this activity are

1. Model elements that include the

    a. Geologic frame work of the system.

    b. Boundary and initial conditions for the system.

    c. Hydrologic and other related physical processes that operate within the system under the constraints imposed by the geologic framework and the boundary and initial conditions.

2. Sets of hypotheses that

    a. Describe and quantify the model elements.

    b. Are compatible with the available empirical data for the system.

    c. Are as simple as possible with respect to the system's known complexity and data.

    d. Are mutually consistent.

More than one set of hypotheses may satisfy the above requirements but differ in that one or more hypotheses of one set may conflict with hypotheses in the other sets. Such an occurrence of competing hypotheses gives rise to the notion of alternative conceptual models and the possible need to perform tests or experiments to eliminate nonviable hypotheses.

Description

Conceptual models for natural hydrogeologic systems are discussed in general terms in Section 3.9 and are particularized to the Yucca Mountain site in Section 3.9.3. The conceptual model of a system consists of a set of elements that describe the geologic framework for the system, delimit the hydrologic boundary conditions acting on the system, and identify the hydrologic and other related physical processes (e.g., moisture flow, heat flow, tectonic stresses, etc.) operating within the system. The internal system processes operating under the constraints imposed by the geologic framework and the boundary conditions determine the instantaneous state of the system. Because the model elements, in general, tend to change with time, the state of the system also tends to change with time. Consequently, the conceptual model must address the issue of system dynamics and response.

The state of an unsaturated-zone hydrogeologic system is defined, for example, by the spatial distributions of matric potential, liquid-water saturation, pore-gas pressure, temperature, and tectonic stress. The processes operating within the system, together with time-varying internal or external constraints, may cause any one or more of these state variables to change and, in turn, to alter the state of the system. The conceptual model for the system seeks to identify and quantify those principal relations between system processes and constraints that control the state of the system and, thus, that govern the performance of the system. In the present context, those elements of system performance that relate to the isolation of high-level nuclear waste are of principal concern, and thus the conceptualization of the system must be directed toward these elements.

In general, the conceptual model of a system consists of a set of empirical data obtained from the system together with sets of hypotheses corresponding to each of the model elements for the system. A viable conceptual model requires that the hypotheses fit the available data, be as simple as is compatible with the data and known system complexity, and be mutually consistent. The sets of possible hypotheses satisfying these conditions need not be unique, and the occurrence of conflicting or competing hypotheses gives rise to the notion of alternative conceptual models.

If competing hypotheses are shown to affect important aspects of system performance, then tests must be devised to select from the competing hypotheses the one hypothesis that best applies to the system. Because complete knowledge of a macroscopic system and its governing processes and constraints is not attainable, formulating a conceptual model includes attempting to develop the simplest set of mutually consistent hypotheses that accounts for the essential aspects of system performance.

Even if no ostensible internal conflicts exist, a conceptual model is by no means a fixed entity. The acquisition of new or improved data from laboratory or field measurements and tests, the results of numerical experiments, and the reconceptualization of model elements (for example, during peer review) may require that the conceptual model be revised with the addition of new hypotheses and the elimination or revision of previously accepted hypotheses. The development of a conceptual model, therefore, must be regarded as an evolving, frequently iterative process. In general, each hypothesis must be regarded as tentative and subject to continual examination

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and testing. Many of the field and laboratory experiments and tests of the site characterization program are directed at examining the validity of hypotheses and at quantifying tenable hypotheses.

Independent peer review will be an important aspect of conceptual-model development. Peer review will be used to examine the completeness and the consistency of the conceptual-model hypotheses, and to ensure that the physics and mathematics of process hypotheses are formulated correctly. Changes in the conceptual model also should be subjected to appropriate peer review to ensure that the changes are both necessary and sufficient with respect to obtaining a correct conceptual representation of the hydrogeologic system.

The hypotheses that constitute the current but provisional conceptual model for the site unsaturated-zone hydrogeologic system are listed in Table 8.3.1.2-2b together with viable alternative hypotheses and an assessment of their uncertainty and significance.

8.3.1.2.2.9.2 Activity: Selection, development, and testing of hydrologic-modeling computer codes

Objectives

The objectives of this activity are twofold: (1) to select, evaluate, and adapt existing numerical hydrologic-modeling codes for application to the site unsaturated-zone hydrogeologic system and (2) to modify existing codes or develop new codes, as needed, to simulate particular problems or aspects that are unique to the Yucca Mountain system. Code modification and development will require the additional activities of testing (e.g., code verification) and documentation.

Parameters

The parameters of this activity consist of the attributes of the numerical hydrologic computer codes that are selected or developed:

1. Code geometry: One-, two-, or three-dimensional.

2. Discretization method: Finite-differences, finite-element, or integrated finite-difference.

3. Boundary conditions: Dirichlet, Neumann, mixed, evaporate, seepage-face, evapotranspiration, etc.

4. Hydrologic and coupled processes: Variably saturated liquid-water flow, gas-phase flow, water-vapor concentration and transport, heat flow, solute transport, chemical kinetics, stress-field dynamics, two-phase flow in fractures, etc.

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5. Solution methodology: Picard iteration or Newton-Raphson linearization.

6. Matrix solver: Direct or iterative.

Description

Various available computer codes are capable of performing mathematical simulations of complex multiphase, variably saturated hydrogeologic systems. These codes differ, however, in terms of (1) the physical processes they include, (2) the types of boundary conditions they allow, (3) the numerical procedures they invoke, (4) the efficiency with which they perform the various numerical and logical operations, (5) the dimensionality and geometry of the systems they can represent, (6) the computer resources they require, and (7) the ease with which they can be implemented and adapted to solve particular modeling problems. The codes under consideration here provide the physical and mathematical foundation for the construction of predictive numerical models for hydrogeologic systems. The selection of any one or more codes depends upon the problem being solved; the degree of accuracy desired; the possible limitations of available computer resources and funding; and, finally, the degree of approximation to which the physical processes and mathematical procedures embodied in the code represent the elements of the conceptual model of the system.

None of the available codes is expected to be capable of solving all the problems expected with respect to the site unsaturated-zone hydrogeologic system. Consequently, existing codes will require some modification, and new codes will need to be developed, especially for those problems unique to the Yucca Mountain site. For example, Study 8.3.1.2.2.8 is devoted both to understanding the physics of fluid flow and solute transport in partially saturated fractures that transect variably saturated tuff and to developing appropriate quantitative models and codes to simulate fluid-flow processes in variably saturated fractures and fracture networks.

Even though the application of existing documented and verified codes to some specific Yucca Mountain problems may be straightforward, code modification and code development will require that both the new and modified codes be thoroughly tested and documented before their application to site problems. Code testing will include code verification, which demonstrates that the code performs all of the mathematical and logical procedures correctly, as well as testing to demonstrate that the code is indeed applicable to the types of problems for which it is intended. Code verification will be performed by comparing the results produced by the code for a particular problem against existing known analytic or numerical solutions for the problem. Empirical testing of the model will be performed by comparing model results against data obtained from laboratory or field experiments that are analogs to the intended application of the code.

Complete documentation of the new or modified codes will include a description of the physical and mathematical basis of the code, instructions and requirements for implementing the code, and the results of at least some selected set of verification and empirical-testing exercises performed on the code (Silling, 1982). Both the documentation and the code will be subject to thorough independent peer review before any application of the code to

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develop a model or models for the Yucca Mountain system or any relevant subsystem.

8.3.1.2.2.9.3 Activity: Simulation of the natural hydrogeologic system

Objectives

The objectives of this activity are to construct appropriate hydrologic models for the natural site hydrogeologic system to (1) simulate and investgate the present existing state of the system, and (2) predict probable future and past states of the system under changes in the environmental conditions.

Parameters

The parameters of this activity are

1. Time-dependent spatial distributions of matric potential, liquid-water, saturation, pore-gas pressure, water-vapor concentration, moisture flux, and temperature.

2. Boundary fluxes, pressures, and potentials.

3. Hydrologic and thermomechanical properties for the component hydrogeologic units.

Description

A numerical hydrologic model or combination of models will be constructed to simulate mathematically the coupled, simultaneous flow of moisture, gas, and heat within the unsaturated zone underlying the primary repository area. The construction of these flow models follows directly as a continuation and an expansion of the conceptual model development for the site hydrogeologic system (Activity 8.3.1.2.2.9.1). The basic purpose of this modeling activity is to continue but enlarge that scope of identifying and testing the hydrologic conditions, concepts, and processes that control the site hydrogeologic system. It is intended, however, that model construction will culminate in a mathematical representation of the hydrogeologic system that is consistent with respect to available hydrogeologic field and laboratory data and is as comprehensive as possible within the practical constraints imposed by finite numerical simulations of complex physical systems. A final flow model or set of models, will be used subsequently to perform baseline analyses to (1) predict possible future or past states of hydrogeologic system and (2) support the final system synthesis and integration (Activity 8.3.1.2.2.9.5).

The input and output data for the models define the parameters for this activity. Requisite input data include (1) the geologic framework for the site, which determines the model geometry and material composition; (2) the hydrologic, thermal, and mechanical properties of the hydrogeologic units that make up the unsaturated zone at the site; and (3) the environmental conditions that determine the flux, potential, and pressure distributions on

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the spatial boundaries of the model. In general the land surface will define the upper system boundary, and the water table will define the lower boundary for the models; the lateral hydrogeologic boundaries must enclose the primary repository area, but their exact locations remain to be established. The material property data for the hydrogeologic units will be obtained from field and laboratory determinations and will become available as site characterization proceeds. The environmental conditions that define the present hydrogeologic boundary conditions include the present and past site climatic and tectonic settings.

The output data generated by the models for a specified set of input data consist of predicted time-dependent spatial distributions of liquid-water matric potential and saturation, pore-gas pressure, water-vapor concentration, temperature, and moisture- and pore-gas flux. To the extent that the mathematical formulation of the models incorporates all the significant physical processes and conditions that control the hydrogeologic system, flow models yield internally self-consistent mathematical representations of the hydrogeologic system and its evolution with time. The probable accuracy and validity of this representation is considered under Activity 8.3.1.2.2.9.4 (stochastic modeling and uncertainty analysis). The moisture- and pore-gas flux distributions computed from the flow models provide requisite input data for subsequent solute-transport and hydrochemical modeling.

Some of the specific issues to be addressed by the construction of these models are to (1) develop strategies and methodologies for constructing three-dimensional, fluid-flow models for the site hydrogeologic system; (2) investigate the relative contributions of liquid-water and water-vapor fluxes to the net moisture flux within the three-dimensional system; (3) assess the likelihood for the occurrence of the upward diffusion or advection of water vapor in fractures coupled to a corresponding downward return flow of liquid water within the rock matrix; (4) establish limiting conditions under which capillary barriers and perched water bodies zones can be expected to occur; (5) assess the effects produced by variations with space and time in assumed land-surface net-infiltration rates; and (6) investigate the impact of time-dependent stress and thermal fields on the unsaturated-zone hydrogeologic flow system (Study 8.3.1.15.2.1, characterization of the site ambient stress conditions; Study 8.3.1.15.2.2, characterization of the site ambient thermal conditions). An important task of this activity is to identify those hydrogeologic processes and concepts that are essential for a valid mathematical representation for performance assessment analyses and to eliminate those that can be shown to be of sufficiently negligible effect. The final flow model or models, thus, are intended to provide a summary numerical description of the site hydrologic flow system.

The final flow models will be used to perform a set of baseline simulations of the natural hydrogeologic system. A simulation of the presently existing natural system will be used as the initial conditions to perform a sequence of simulations to extrapolate the system both forward and backward in time. The forward extrapolation will be based on the most probable changes expected in the site climatic regime derived from Study 8.3.1.5.1.6 (characterization of the future regional climate and environment) and in the water-table configuration derived from Study 8.3.1.8.3.2 (analysis of the effect of tectonic processes and events on changes in water-table elevation). The backward extrapolations will be based on past climatic conditions and

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variations inferred from Study 8.3.1.5.1.4, (synthesis of the paleoenvironmental history of the Yucca Mountain region). The sequence of baseline simulations constitutes a standard set against which the effects of extreme or episodic changes in environmental conditions at the site may be assessed. The most probable limits of uncertainty attaching to the baseline simulations will be estimated as part of Activity 8.3.1.2.2.9.4 (stochastic modeling and uncertainty analysis). These flow models will be used to define flow paths and calculate fluxes and velocities within the unsaturated zone, as described under Activity 8.3.1.2.2.9.5 (system synthesis and integration).

The site-characterization hydrogeologic modeling to be performed as part of this activity is both complementary to and essential to the modeling that will be performed as part of performance-assessment activities. The site characterization models are intended to describe site conditions and processes and to evaluate the response of the site as a whole to changes in the local and regional climatic and tectonic settings. The performance-assessment models focus on the operation of the repository with respect to its components and immediate environment. The repository and its environment, however, are embedded in and interact with the overall site hydrogeologic system. The site models will be used to predict overall site behavior and, thereby, to evaluate the interaction between the internal state of the site and the repository system and environment. For example, the site hydrogeologic models will be used to predict the spatial and temporal distributions of both liquid-water and pore-gas fluxes within and near the repository environment. These flux distributions provide boundary-condition input data for the performance-assessment models that will be used to evaluate pre-waste-emplacement ground-water travel time and to simulate solute-transport processes. Solute-transport models will be used to assess the rates and magnitudes of possible future transport of radionuclides from the repository to the accessible environment.

8.3.1.2.2.9.4 Activity: Stochastic modeling and uncertainty analysis

Objectives

The objective of this activity is to assess the probable limits of uncertainty of numerical-model predictions caused by uncertainties in the material-property and boundary-condition data.

Parameters

The parameters of this activity are

1. Measurement errors.
2. Statistical distribution functions.
3. Probable limits of uncertainty.

Description

An important aspect of modeling physical systems is to assess the accuracy with which the model predictions represent the real system and, thereby, to establish the validity of the model with respect to its intended

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application. As discussed in Section 8.3.5.20.4 (model validation), the classical approach to model validation is to compare directly the model predictions with the observed system performance. The models that will be applied to address repository postclosure issues, however, are required to predict the effects of probable or possible changing conditions over the next 10,000 to 100,000 yr. Consequently, direct model validation is infeasible. Indirect methods must be employed to establish model credibility and to provide reasonable assurance that the long-term model predictions coupled with asymptotic bounding calculations are sufficient to assess the long-term performance of the repository and its subsystems. For hydrogeologic models, uncertainty analyses can be performed to assess model accuracy, stability, and asymptotic behavior.

The precision of the numerical results produced by a numerical hydrologic model is determined by that of the input data and the precision handling capability of the computer system used to perform the numerical calculations. The accuracy of the model predictions considers the discrepancy, or error, between the predictions and the actual performance of the physical system that the model is intended to simulate. Inadequate precision rarely is of practical concern, whereas the assessment of the accuracy of a simulation is of fundamental importance in establishing the adequacy and validity of the model.

The sequence of baseline simulations described in Activity 8.3.1.2.2.9.3 will provide the initial conditions for a set of Monte Carlo simulations in which the hydrologic-property and boundary-condition data will be varied in accordance with empirically determined uncertainty-distribution functions. These distribution functions will be estimated by classical statistical and geostatistical analyses to be conducted as part of this activity or of Activity 8.3.1.2.2.3.1 (matrix hydrologic properties testing). The sensitivity of the model predictions to uncertainties in the input data will be evaluated and quantitative estimates of uncertainty will be estimated specifically for calculated values of liquid water potential and saturation. Not only will these analyses permit an assessment of the probable accuracy of the baseline simulations, but they will also provide a means to generate cumulative distribution functions for the net uncertainty associated with predicted values of moisture flux within the unsaturated zone under existing natural conditions.

8.3.1.2.2.9.5 Activity: Site unsaturated-zone integration and synthesis

Objective

The objective of this activity is to integrate all applicable site data and analyses in order to synthesize a continually updated, comprehensive representation for the site unsaturated-zone hydrogeologic system. Attention will focus both on the present state of the system as well as on the implications concerning probable, or possible, future and past states of the system.

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Parameters

The significant parameters of this activity are the elements that define the state of the hydrogeologic system:

1. The site geologic framework and its change with time.

2. The site water-table configuration and its change with time.

3. Land-surface net infiltration to the unsaturated zone and its distribution in space and time.

4. The spatial distributions of temperature and stress within the unsaturated zone and their change with time.

5. The spatial distribution of moisture flux within the unsaturated zone and its change with time.

Description

As site characterization progresses, a diverse set of empirical data, quantitative analyses, and interpretations will become available for the site unsaturated-zone hydrogeologic system. These data, analyses, and interpretations will be continually integrated with the prevailing conceptual model for the system in order to synthesize overall representations of the system. These representations will be examined for internal consistency and completeness. Consequently, system integration and synthesis are envisioned to be an ongoing activity that will review the validity of the prevailing conceptual model as well as the data acquisition and experimental program to ensure that, to the extent possible, all critical hydrogeologic data are being collected, and the appropriate hypotheses are being tested.

The synthesis performed at the end of the site characterization program is intended to yield a best possible representation of the current state of the hydrogeologic system together with inferences concerning past states of the system. This information will be used to extrapolate the system forward in time to predict short-term system behavior that can be compared with observed system behavior during the performance-confirmation period. Predictions of long-term system performance will have been made before and possibly during the licensing process. Performance-confirmation monitoring will provide a partial set of confirmatory data that can be integrated into the system synthesis to provide a partial test of the validity of the synthesis. Further numerical modeling can be performed to check specific aspects of observed performance-confirmation system dynamics and response.

Assessments of the current state of system integration and synthesis are to be presented as progress and status reports to be issued periodically. Peer review will be an important aspect to ensure the integrity of the system integration and synthesis process. By issuing progress reports, not only will the process of system integration and synthesis be formalized, but implementation of the peer review process also will be facilitated.

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8.3.1.2.3 Investigation: Studies to provide a description of the saturated zone hydrologic system at the site

Technical basis for obtaining the information

Link to the technical data chapters and applicable support documents

The following sections of the site characterization plan data chapters provide a technical summary of existing data relevant to this investigation:

SCP section	Subject
3.9.1.1.2	Baseline monitoring (saturated zone)
3.9.1.2.2	Potentiometric levels (saturated zone)
3.9.2.2.1	Permeability and fractures (saturated zone)
3.9.2.2.2	Transmissivity and hydraulic conductivity (saturated zone)
3.9.2.2.3	Porosity and storage coefficients (saturated zone)

Number	Subject
3.9.3.1	Accessible environment and credible pathways (saturated zone)
3.9.3.2.2	Potentiometric levels and head relationships (saturated zone)
3.9.3.3	Recharge-discharge and leakage
3.9.4.1	Definition of flow paths for travel time calculations
3.9.4.4	Calculation of saturated-zone travel time
3.10.1	Summary of significant results (saturated zone)
3.10.3	Identification of investigations (saturated zone)

Parameters

The following parameters will be measured or calculated as a result of the site studies planned to satisfy this investigation:

1. Characteristics of geohydrologic units: spatial distribution of the physical and hydraulic properties of the rock units in the saturated zone at the site.

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2. Characteristics of ground-water flow: spatial distribution and rate of horizontal and vertical water flux and areally distributed fluxes (recharge and discharge).

Other site studies that provide information that support the determination of the previously listed parameters include the following:

Study	Subject
8.3.1.2.1.3	Characterization of the regional ground-water flow system (saturated zone hydrologic boundary conditions)
8.3.1.2.1.4	Regional hydrologic system synthesis and modeling (saturated zone hydrologic boundary conditions)
8.3.1.2.2.3	Characterization of percolation in the unsaturated zone (unsaturated zone recharge boundary condition to saturated zone)
8.3.1.2.2.9	Unsaturated zone system analysis and integration (unsaturated zone recharge boundary condition to saturated zone)
8.3.1.4.2.1	Characterization of the vertical and lateral distribution of stratigraphic units (saturated zone geologic framework)
8.3.1.4.2.2	Characterization of site structural features (saturated zone geologic framework)
8.3.1.4.2.3	Development of a three-dimensional model of the site geology (saturated zone geologic framework)

Purpose and objectives of the investigation

The objective of this investigation is to develop a model of the saturated-zone hydrologic system of Yucca Mountain, which will assist in assessing the suitability of the site to contain and isolate waste. Developing this model requires an understanding of ground-water flow. This understanding will be provided through studies focusing on the determination of boundary conditions imposed by structure, recharge, and discharge; hydraulic gradients in three dimensions; and bulk aquifer properties of units. Modeling activities will use the resulting information to calculate ground-water flow paths, fluxes, and velocities within the saturated zone.

Technical rationale for the investigation

Site characterization of the ground-water system within the saturated zone focuses on the determination of boundary conditions imposed by structure, and conditions of recharge and discharge; hydraulic gradients in three dimensions; and bulk aquifer properties of hydrostratigraphic units. The resulting description of boundary conditions, hydraulic properties of faults,

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hydraulic gradients, and aquifer properties will form the basis for synthesis and modeling activities that will conclude with calculations of flow paths, fluxes, and velocities within the saturated zone.

Boundary conditions

The hydrologic boundary conditions for the site saturated-zone hydrogeologic system will be based on the results of the two-dimensional subregional model (Section 8.3.1.2.1.4.2), the subregional two-dimensional cross-sectional model (Section 8.3.1.2.1.4.3), and the regional three-dimensional model (Section 8.3.1.2.1.4.4).

Hydraulic properties of faults

The repository block is approximately defined by faults. Numerous normal, west-dipping faults occur east of the block, and the block is bounded on the west by the Solitario Canyon fault. Strike-slip faults of northwest strike probably underlie Drill Hole Wash, bounding the block on the northeastern side.

Faults may act as barriers or conduits for ground-water flow, depending on the fault properties. The Solitario Canyon fault coincides in general with a steep gradient in the potentiometric surface, and, therefore, may act as a barrier. As part of the effort to understand the cause of the steep gradient and the potential for its modification, the hydraulic properties of the Solitario Canyon fault will be specifically evaluated (Activity 8.3.1.2.3.1.1). At Solitario Canyon, stratigraphic offset of high permeability zones against zones of low permeability could create a barrier, independent of the permeability characteristics of the fault itself.

Hydraulic and water-chemistry data from proposed drillholes USW WT-8 and USW H-7, both located east of drillhole USW H-6, will be used principally to help determine (1) if the ground-water flow paths in the vicinity are from west to east across the Solitario Canyon fault, as suggested by differences in water levels in holes on either side of the canyon and (2) the nature and degree of any hydraulic connection across the fault zone. If there is no significant eastward movement across the fault, this would have a major impact on both conceptual and numerical models. The models have assumed that ground-water flow in the saturated zone beneath the repository block generally is toward the south and southeast (e.g., from drillhole USW H-4 toward well J-13), even though present resolution of water-level data from south or east of the block is not enough to determine with high assurance the magnitude or direction of apparent gradients.

The normal faults east of the block coincide with a nearly flat gradient in the potentiometric surface and, therefore, are assumed to act as conduits. Because these faults are expected to be hydraulically indistinguishable from the surrounding fractured tuff, no tests are designed specifically to evaluate the hydraulic properties of these faults. Rather, those evaluations are included in the general analysis of aquifer properties (see discussion following hydraulic gradients discussion). The effects on ground-water flow of faults that probably underlie Drill Hole Wash will be evaluated as part of Activities 8.3.1.2.3.1.2 and 8.3.1.2.3.1.4 of this investigation.

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Hydraulic gradients

At drillhole UE-25p#1, the hydraulic head is 20 m higher in the Paleozoic carbonate rocks and the lowest 134 m of the Tertiary rocks than in the overlying volcanic rocks (Craig and Robison, 1984). Higher heads were observed at a depth of 1,800 m in drillhole USW H-1, where the level is about 773 m, whereas the water table is about 730 m above sea level. Data from Robison (1984, 1986) show that within the upper 500 m of the saturated zone, there is no upward gradient (drillholes UE-25b#1, USW H-1, USW H-3, USW H-4, USW H-5, and USW H-6) (Figure 8.3.1.2-18).

In the vicinity of the repository block at Yucca Mountain and eastward into Jackass Flats for 5 km or more, the potentiometric surface is nearly flat (730 m above sea level). Water-level altitudes in nearby drillholes are higher to the west of the block (775 m) and to the north (778 to 1,031 m).

Beneath the repository block and downgradient from it, the water table is so flat that periodic water-level measurements (every several weeks), even when made with very high accuracy and precision, cannot be used to determine average water-level differences and gradients among wells. The reason for this, based on preliminary measurements, is that in many drillholes the short-term water-level fluctuations due to barometric changes, earth tides and possibly other phenomena, although small, are greater than apparent differences among nearby drillholes. Therefore, water-level averages of months or perhaps years are necessary to determine gradients and probable flow paths near the repository. The present and planned expansion of continuous water-level measurements in observation drillholes will provide the data for determining the needed average water levels.

Continuous water-level data, in addition to being used for calculating average levels, may be helpful for evaluating the general hydraulic character of intervals penetrated by observation drillholes, and for estimating hydraulic parameters from responses to short-term stresses, such as earth tides, barometric changes, seismic events, or pumping of nearby wells. For those drillholes with multiple instrumentation, it will be possible to make separate evaluations of each depth interval represented.

Aquifer properties

The fracture network at Yucca Mountain has a major influence on ground-water flow and solute transport. The ground-water system is so extensively fractured that discrete fracture-network modeling at the scale of the mountain may not be a practical method for calculating travel time of ground water. Nevertheless, models used to calculate travel time must be based on an understanding of the fracture network.

Because fractures are individually different, with apertures, orientations, spacing, lengths, and in-filling characteristics subject to statistical description, in situ tests encompassing scores of fractures are needed to describe hydraulic conductivity and other bulk aquifer properties. Hydraulic conductivity of the fracture network is several orders of magnitude greater than matrix permeability in welded units, and may be an order of magnitude

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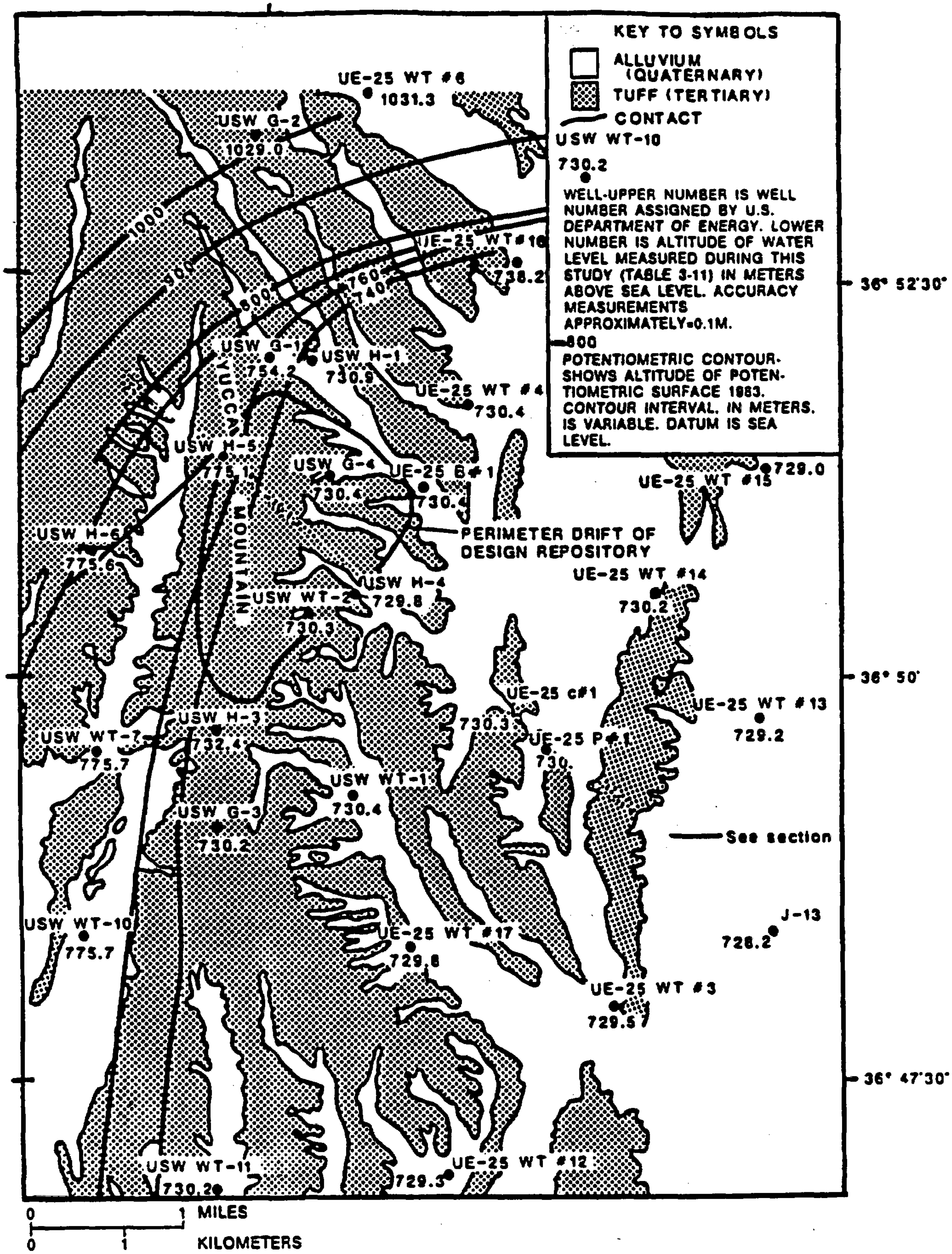

Figure 8.3.1.2-18. Preliminary composite potentiometric-surface map of the saturated zone, Yucca Mountain (modified from Robison, 1984).

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greater in nonwelded units. At the scale of well tests, it may not be possible to describe hydraulic conductivity as a tensor analogous to that of an equivalent porous medium. Criteria for porous-medium equivalence may be more strict for solute transport than for ground-water flow. The character of effective porosity and hydrodynamic dispersion may be completely different from that which would be expected in a porous medium.

Reliable estimation of bulk aquifer properties depends on application of the appropriate conceptual model of flow to results of well tests. Hydraulic tests conducted in wells USW H-4, UE-25p#1, UE-25b#1, UE-25c#1, UE-25c#2, and UE-25c#3 indicate that simple radial flow models may not be adequate to describe the flow of ground water at the scale of the tests. The predominant subvertical orientation and differential connectivity of fractures indicates that a more complex heterogeneous flow model may be needed for interpretation of well-test results. Additional analysis of previously completed hydraulic-stress tests is needed to form a conceptual model of flow during well tests. Additional tests, designed on the basis of this conceptual model, will give more reliable estimates of aquifer properties as well as refine the conceptual model of flow in fractured rock. In general, multiple-well tests will be needed to evaluate complex heterogeneous flow models. While useful for investigating many aspects of saturated-zone hydrology beneath Yucca Mountain, results of single-well tests have limited use in understanding the nature and areal distribution of bulk aquifer properties.

Results of production surveys, combined with hydraulic-test results, have failed to identify definitive hydrostratigraphic units. Instead, the results indicate that discrete production zones associated with fractures in one well may be connected to fractures occurring in overlying or underlying stratigraphic units in other wells. Additional multiple-well testing using packers to isolate production zones is needed to confirm or refute this hypothesis. The hydrologic significance of intervening bedded units is not known. If pervasive fracturing crosses stratigraphic boundaries and accounts for orders of magnitude greater hydraulic conductivity than does the matrix, it may not be appropriate to simulate ground-water flow within a framework of hydrostratigraphic units. Additional well tests are needed to determine three-dimensional relations between stratigraphy, fracture connectivity, and bulk aquifer properties. Single-well tests may have limited use in evaluating many of these relations.

Well tests at Yucca Mountain will be completed in two steps. The first step will consist of a large number of hydraulic and conservative-tracer tests in wells UE-25c#1, UE-25c#2, and UE-25c#3 (i.e., C-hole complex) (Figure 8.3.1.2-29 in Section 8.3.1.2.3.1.4). The tests will include a variety of field procedures and interpretive methods to form a conceptual model of flow in a fractured aquifer system. The site for the C-hole complex was chosen because of its position (down the hydraulic gradient from Yucca Mountain) and because the saturated zone at the site was believed to represent stratigraphic and structural conditions along a flow path to the accessible environment. The second step will consist of either a series of single-well tests at existing wells throughout Yucca Mountain, or drilling and testing at a second multiple-well complex. The purpose of the second step is to validate and refine the conceptual model formed during tests at the C-hole complex.

Characterization of aquifer properties of the saturated zone has been divided into four activities. These activities are as follows:

1. Completion of the analysis of previously completed hydraulic-stress tests, including pumping and nonpumping intraborehole flow surveys, packer and open-hole injection and withdrawal tests, and transient pressure response of aquifers to barometric and earth-tide stress. Most interpretations will be restricted to data collected at the C-hole complex. Results of interpretations will be used to improve the design of planned well tests and, when possible, to provide preliminary estimates of aquifer properties.

2. Multiple-well interference tests at the C-hole complex, including cross-hole hydraulic tests and long-term pumping tests. Cross-hole tests will use packers to isolate selected intervals in wells for the purpose of monitoring response to a hydraulic stress applied in an isolated interval in a neighboring borehole. Cross-hole tests will be conducted to determine if the fractured rock can be treated as a homogeneous equivalent porous medium or if a more complex conceptual model is needed. Hydraulic conductivity and specific storage will be estimated from results of cross-hole tests. Long-term pumping tests will be conducted to evaluate aquifer properties in a larger rock volume than typically considered in pumping tests.

3. Tests of the C-hole complex with conservative tracers, including drift-pumpback tests, two-well recirculating tests, and two-well convergent tests. Test results will be used to determine properties of conservative-solute transport, evaluate relations between transport properties and fracture characteristics, and determine whether single-well tests can be used to characterize transport properties. By conducting a variety of tests, several relations between principal fracture orientation and hydraulic gradient will be considered. Different volumes of rock also will be tested to evaluate the scale-dependence of transport characteristics.

4. Well tests with conservative tracers throughout the site. If the results of tests at the C-hole complex demonstrate that single-well tests can be used successfully to characterize transport properties, then either a series of single-well tests (drift-pumpback tests) will be conducted at existing wells. If single-well tests cannot be used, then a series of multiple-well tests will be completed at a second site, tentatively planned for construction in the southern part of the study area. The purposes of this activity are to validate the conceptual model (formed during tests at the C-hole complex) of flow and transport in fractures and to evaluate areal variations in aquifer properties.

Synthesis and modeling

The description of ground-water flow paths, fluxes, and velocities within the site area is the ultimate objective of site-hydrogeologic investigations in the saturated zone. This description will be obtained through the development of digital ground-water flow models. Results of field activities and tests described previously will provide an understanding

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of boundary conditions, hydraulic gradients, and aquifer properties. Interpretation of field data will be used to form a conceptual model of the flow system at Yucca Mountain. Fracture-network modeling will aid in forming a conceptual model that treats aquifer properties in a manner that accounts realistically for the influence of the fracture network. Numerical models of the region and/or site will be developed on the basis of the conceptual model and tested by calibration with field data. Once calibrated, the numerical models will be used to estimate flow paths, fluxes, and velocities. These modeling efforts will be coordinated with activities to model flow in the saturated zone called for under Issues 1.1 and 1.6 (Sections 8.3.5.9 and 8.3.5.12).

8.3.1.2.3.1 Study: Characterization of the site saturated-zone ground-water flow system

The objectives of this study are (1) to determine the internal and external boundary conditions that can be applied to the site saturated zone model and (2) to determine the ground-water flow magnitudes and directions at the site.

Eight activities are planned to collect the data that are required to satisfy these objectives: (1) Solitario Canyon fault study, (2) site potentiometric level evaluation, (3) analysis of single- and multiple-well hydraulic stress tests, (4) multiple-well interference testing, (5) testing at the C-hole sites with conservative tracers, (6) well testing with conservative tracers throughout the site, (7) testing at the C-hole sites with reactive tracers, and (8) well testing with reactive tracers throughout the site.

8.3.1.2.3.1.1 Activity: Solitario Canyon fault study in the saturated zone

Objectives

The objective of this activity is to determine the hydrogeologic nature of the Solitario Canyon fault and if it is a barrier to eastward movement of ground water through the repository block.

Parameters

The parameters of this activity are

1. Nature and extent of hydraulic gradients.
2. Orientation and extent of fault zones.
3. Fracture orientations, apertures, and filling characteristics.

Description

To define better the water table west of the Solitario Canyon fault, water-table series drillholes USW WT-8 and USW WT-9 will be drilled using an air-foam method to depths of about 2,100 to 2,200 ft (640 to 670 m). Only surface casing will be installed, and the drillhole diameters will be about

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8.75 in. (22 cm). Drillhole USW WT-8 will penetrate about 150 to 270 ft (50 to 90 m) of the saturated zone; USW WT-9 will penetrate about 240 to 390 ft (80 to 130 m) of the saturated zone. East of the Solitario Canyon fault on the ridge crest of Yucca Mountain, a hydrologic test drillhole, tentatively designated USW H-7, will be drilled in the same manner as previously drilled hydrologic test drillholes at Yucca Mountain. The depth of this drillhole will be about 3,000 ft (914 m); it will penetrate about 450 to 600 ft (150 to 200 m) of the saturated zone and will have a diameter of about 8.75 in. (22 cm). Drillhole locations are shown in Figure 8.3.1.2-19. Drilling of these drillholes will be integrated and coordinated with the drillholes planned under Section 8.3.1.4.1.

Geophysical and television surveys will be run in each of the drillholes. The logging programs will include a gyroscopic survey, vibroseis survey, optical television survey, and dielectric, spectral gamma-caliper, fluid density, electric, density, and epithermal neutron logs. After downhole geophysical logs are completed in each water-table drillhole, a small-capacity pump will be hung in the drillhole on tubing, and the pump will be run for about a week to obtain water samples for chemical and isotopic analyses. The pump will be removed, and the tubing reinstalled to enable measurements of the water levels.

After the initial development and testing of drillhole USW H-7, including a borehole-flow survey, a long-term test (perhaps as much as 30 days) will be conducted. This test will consist of pumping drillhole USW H-7 at an expected rate of 25 L/s or more while observing hydraulic responses in water-level monitoring drillholes located throughout Yucca Mountain, especially those located across (west of) the fault, such as drillholes USW H-6 and the proposed USW WT-8 (Figure 8.3.1.2-22). It will be necessary to disperse or transport the pumped water a substantial distance away from drillhole USW H-7 to prevent disturbance of local infiltration studies.

After the pumping test at drillhole USW H-7 is complete, it may be determined appropriate to pump drillhole USW H-6 while observing responses in drillhole USW H-7 and other drillholes east of the fault. By observing the responses of wells across the fault, it should be possible to determine if the Solitario Canyon fault acts as a barrier to eastward flow.

8.3.1.2.3.1.2 Activity: Site potentiometric-level evaluation

Objectives

The objectives of this study are to

1. Refine time and configuration of the spatial dependence of the potentiometric surface.

2. Measure water-level variations with time in existing borehole and calculate average levels, as input data for hydraulic gradient calculations.

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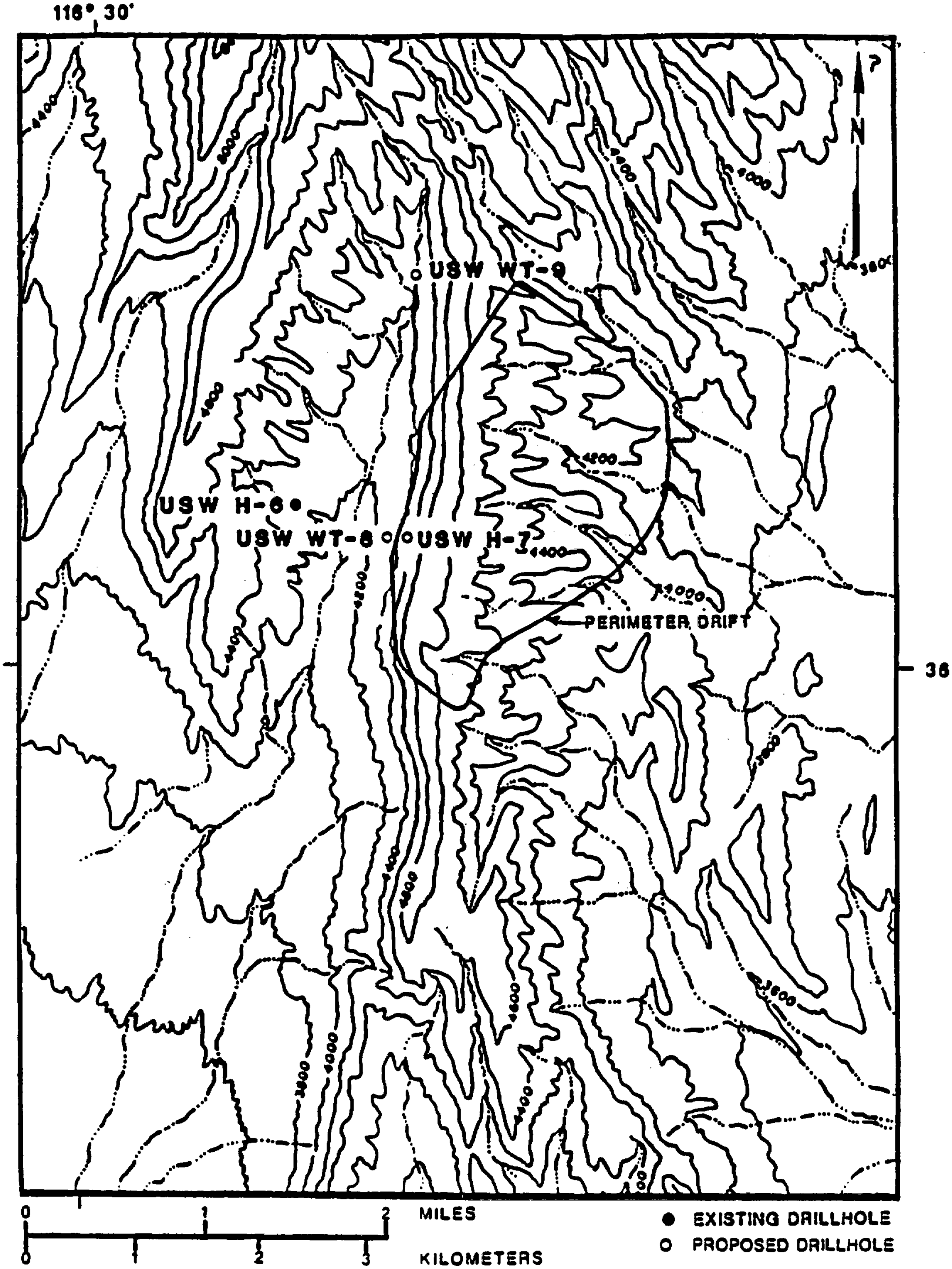

Figure 8.3.1.2-19. Location of the proposed drillholes for the Solitario Canyon fault study in the vicinity of perimeter drift.

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3. Analyze the character and magnitudes of water-level fluctuations to determine their causes, and, if possible, to estimate formation elastic and fluid-flow properties.

Parameters

The parameters for this activity are

1. Physical characteristics of the hydrogeologic units.

2. Hydraulic gradients.

3. Hydraulic diffusivity storage coefficients, hydraulic conductivity, aquifer compressibility.

Description

About 25 geologic, hydrologic, and water-table drillholes are part of an existing monitoring network near the site (Figure 8.3.1.2-8). Water levels in 15 holes have been measured periodically during onsite visits about every two weeks. Ten drillholes have pressure transducers installed below the water surface and connected to digital equipment at the surface; electrical output from the transducers is automatically recorded every hour. The periodically measured drillholes in the network are being converted to this automated monitoring system. Raw data from these field installations are taken to the office, and water-level depths or altitudes are calculated, following a process of conversions, adjustments, and determination and verification of equipment calibrations.

Proposed new test drillholes to be added to the water-table monitoring network include water-table drillholes in the USW holes WT-8, WT-9, WT-21, WT-22, WT-23, and WT-24; and UE-25 holes WT#19 and WT#20 (Figure 8.3.1.2-20). Water-table drillholes USW WT-8 and USW WT-9 will be located near the Solitario Canyon fault to help determine the hydraulic nature of that structural feature, as discussed in Activity 8.3.1.2.3.1.1 (Solitario Canyon fault study in the saturated zone). Water-table holes USW WT-21 and USW WT-22 are considered under Activity 8.3.1.2.1.3.2 (regional potentiometric distribution and hydrogeolgoic framework studies). The drilling of these drillholes will be coordinated with the drilling program described in Section 8.3.1.4.1.

Water table drillholes USW WT-23 and USW WT-24 will be located to the north near Drill Hole Wash to obtain additional data on the steep gradient in this area. Water-table drillhole USW WT-23 will be located in Drill Hole Wash northwest of drillhole USW UZ-1. This drillhole will be drilled to a probable depth of about 670 m. Drillhole USW WT-24 will be located between drillholes USW G-2 (Figure 8.3.1.2-24) and UE-25 WT#18, and will also be about 670 m deep. Both of these drillholes will have diameters of about 22 cm, and will be constructed and completed in the same manner as previously drilled water-table drillholes. The lithologic and geophysical logs will be analyzed and compared with those of other drillholes near Yucca Mountain to determine if the permeability of the rocks in this area is significantly lower than elsewhere, so as to produce a steeper hydraulic gradient than to the south near the Yucca Mountain repository block. Proposed geologic

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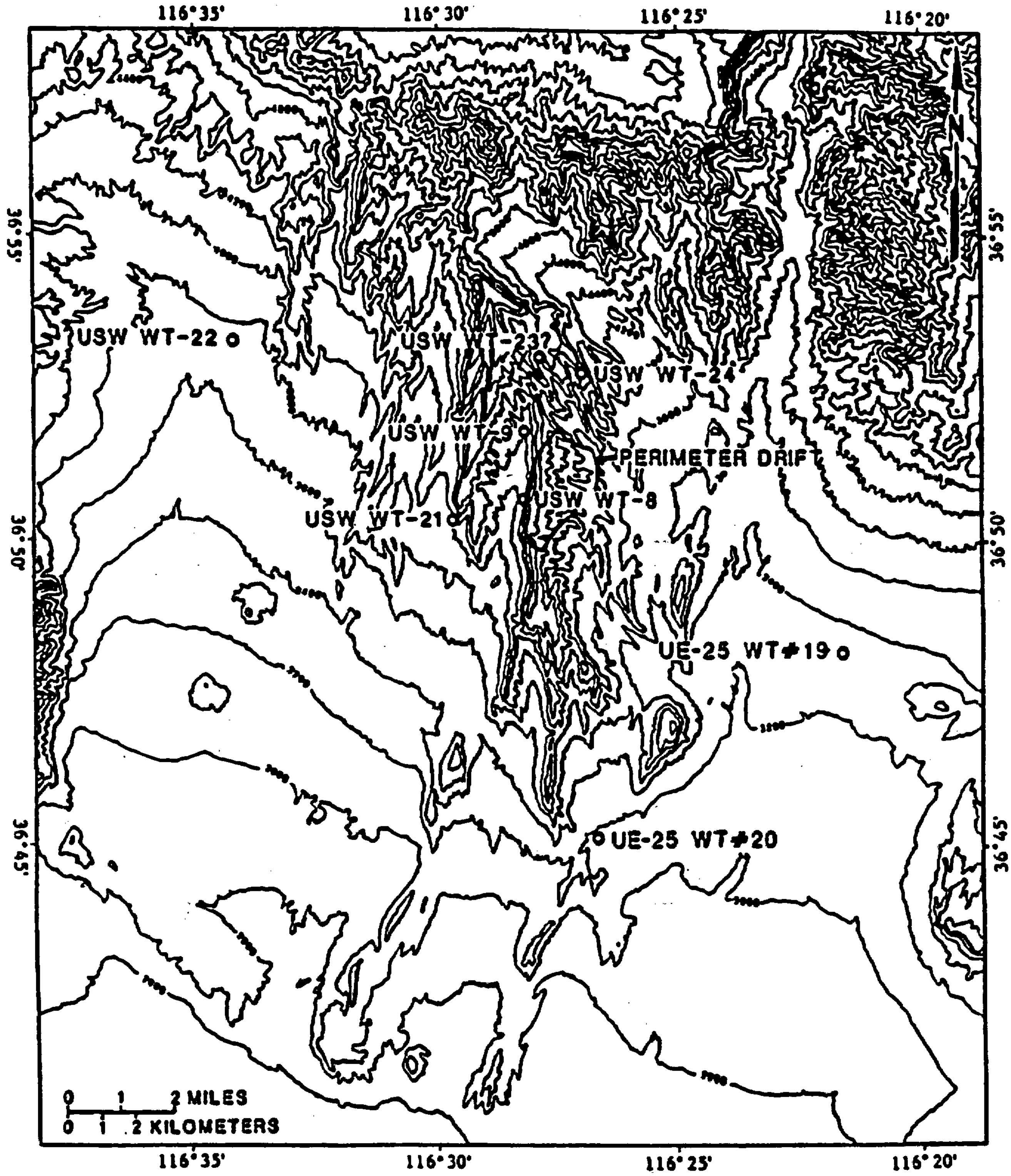

o PROPOSED DRILL HOLE

Figure 8.3.1.2-20. Locations of the proposed water-table holes for the site potentiometric-level evaluation.

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drillhole USW G-5 (Figure 8.3.1.2-21), located generally north of Yucca Mountain, is expected to provide stratigraphic and other relevant information that will be used to help determine the probable cause and nature of the steep hydraulic gradient. Water-level measurements will also be used to help determine if the gradient is linear though steep, or is stepped.

Water table drillholes UE-25 WT#19 and UE-25 WT#20 will be drilled to determine the potentiometric levels to the south and east of the repository site (Figure 8.3.1.2-23). Drillhole UE-25 WT#19 will be located 3 km east of well J-13 and will be drilled to a depth of about 1,100 ft (335 m). Drillhole UE-25 WT#20 will be located 5 km southwest of well J-13 and will be drilled to a depth of about 1,100 ft (350 m). The drilling, construction, logging, and water sampling of these drillholes will be similar to previously drilled water table drillholes.

Water-level data from the monitoring program will be plotted to show variations and trends with time. Seasonal trends will be evaluated and the data will be averaged over appropriate periods (e.g., annually) so that hydraulic gradients and probable ground-water flow paths can be determined more accurately, especially in areas where the water table is nearly flat.

Water-level responses in observation wells during pumping of other wells will be analyzed in terms of general hydraulic connectivity and, where appropriate, the permeability of the rocks will be evaluated. Responses among the observation wells will be compared, with the purpose of estimating the areal anisotropy of the hydraulic parameters that may be controlled by faults or fractures.

Analysis will be made of water-level fluctuations in wells that occur in response to volume/strain changes in the aquifer(s). Two broad categories of water-level response will be evaluated: dynamic and static responses. The dynamic response, due to passage of a seismic wave from earthquakes or underground nuclear explosions, will be monitored and analyzed to determine the relation between formation fluid pressure and strain, and to provide estimates of formation elastic properties. Water levels in wells may also respond to lower frequency volume/strain changes (the static response), such as those due to earth tides and atmospheric loading. These responses are readily identifiable in most wells in the potentiometric-level network, and are currently being evaluated in the UE-25c-holes and UE-25p#1 (Activity 8.3.1.2.3.1.3). Water levels may also exhibit a coseismic or aseismic low-frequency response to earthquakes. These phenomena are variously referred to as slow earthquakes or fault creep events. Concurrent measurements of strain are necessary to confirm the occurrence of aseismic fault creep. Strain measurements are also needed to improve the analysis of earth tidal effects.

To address this problem, volumetric strain meters or dilatometers will be installed in boreholes in at least three localities near Yucca Mountain. To assess the effects of terrain on the detection of horizontal tectonic displacement or strain, emplacement sites will be located on the crest, flank, and on the flat adjacent to Yucca Mountain. The array location will be coordinated to optimize the detection of explosively induced strain changes, and to complement the hydrologic studies of earth tides and apparent fault creep responses. At each locality, existing boreholes may be used or boreholes will be drilled and cored to facilitate the emplacement of strain

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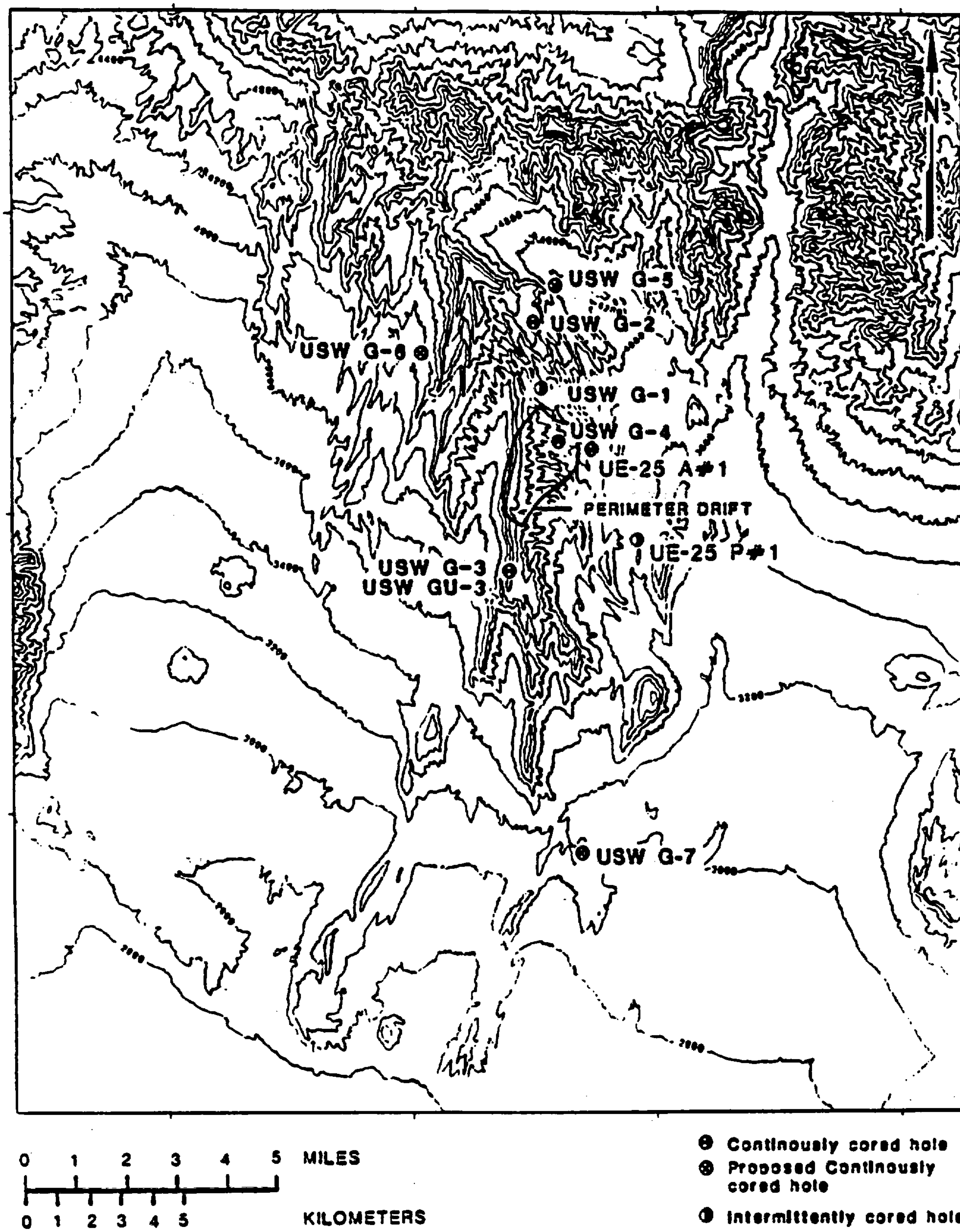

Figure 8.3.1.2-21. Location of existing and proposed geologic drillholes.

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meters. For redundancy, strain meters will be installed in two adjacent holes in at least one site. The selection of borehole sites and the criteria for well construction will be coordinated with the development of Yucca Mountain Project drilling plans (Investigation 8.3.1.4.1).

Because strain meters are temperature-sensitive, the depth of emplacement must be sufficient to minimize the effects of annual changes in surface temperature. Every effort will be made to ascertain the temperature-depth field at each locality before emplacement. Monitoring of climatic factors such as barometric pressure and rainfall will be made on a continuous basis and will be coordinated with other meteorological monitoring at the site (Study 8.3.12.1.2). The output from all strain meters at each locality will be monitored using intelligent data logging systems. Satellite (GOES) telemetry will be used to transmit the data to the office for immediate analysis so that detectable low-frequency strain changes may be observed and an appropriate response for additional field measurements may be initiated.

Currently Sacks-Evertson strainmeters, or Carnegie meters are being considered for use in this activity, because they are relatively simple and robust dilatometers that are readily available. When properly installed, they are capable of sensing strain changes of the order 10^{-10} or greater. The Carnegie meters have been used successfully by the USGS in studies on the San Andreas Fault in California.

8.3.1.2.3.1.3 Activity: Analysis of single- and multiple-well hydraulic-stress tests

Objectives

The objectives of this activity are to

1. Determine intraborehole flow profiles for each of the C-holes during static conditions and while pumping.

2. Correlate lithology, fractures, and intraborehole flow rates.

3. Characterize the type of flow (linear, radial, spherical, fracture, porous) that is occurring between boreholes.

4. Determine the causes of the apparent deviant pressure transients observed in slug tests in UE-25c#1.

5. Identify the nature of significant hydraulic boundaries present at the scale of the tests. This information will be especially important in designing multiple-well interference tests and tracer tests at the C-holes.

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6. Determine bulk estimates of aquifer properties: transmissivity, storage coefficient, specific storage, and effective hydraulic porosity.

7. Determine to what extent the ground-water system responds to hydraulic stress as confined or unconfined.

Parameters

The parameters for this activity are

1. Intraborehole flow rates.

2. Type of flow and nature of significant hydraulic boundaries present at the scale of well tests.

3. Transmissivity, storage coefficient, specific storage, and effective hydraulic porosity.

Description

Well hydraulic tests completed in test wells USW H-4, UE-25p#1, UE-25b#1, and especially UE-25c#1, UE-25c#2, and UE-25c#3 to determine aquifer hydraulic conductivity and specific storage indicate that simple nonsteady radial flow models may not adequately describe the movement of ground water through most of the formations tested (Figure 8.3.1.2-21). Attempts to identify definitive hydrostratigraphic units on the basis of well-test results and production surveys have not been successful. Instead, these data have indicated that discrete production zones associated with fractures in one test well may be well connected to fractures occurring in other stratigraphic units. The role of intervening bedded units is unclear. Because of the predominant subvertical orientation of fractures and their differential connectivity, a complex heterogeneous reservoir flow model probably is needed for interpretation of hydraulic test results. On the basis of these interpretations, additional tests need to be conducted to determine the three-dimensional relations between stratigraphy, fracture connectivity, and hydraulic conductivity.

Three categories of hydraulic-test data have been collected in the past and will be analyzed for site characterization: (1) intraborehole flow data, including pumping and nonpumping temperature logs and tracejector surveys; (2) packer and open-hole fluid injection and withdrawal test data; and (3) aquifer fluid pressure and barometric pressure data to monitor aquifer response to barometric loading and earth-tide stress. The data to be analyzed for site characterization was collected primarily from wells at the C-hole complex since September 1983.

Intraborehole hydraulic test data will be analyzed for site characterization. Temperature logs and tracejector surveys will be used to identify points or zones where fluid enters or leaves boreholes, and may be used to determine the direction and rate of flow. It may be possible to correlate points where fluid enters or leaves a borehole with specific fractures, whereas zones where fluid enters or leaves a borehole may correlate with groups of fractures or zones where permeability is due to porous rock. The distinction is important in formulating a conceptual model of flow near the boreholes and will be useful in the design and analysis of fluid injection and withdrawal tests.

Tracejector surveys completed while pumping the wells were done according to the method described by Blankennagel (1967) using iodine-131 as a tracer and will be analyzed by a method similar to the method described by Blankennagel (1967). A wireline tool consisting of an ejector with two gamma detectors on each side of the ejector is used to conduct a tracejector test. Tracer is ejected in the borehole fluid at a selected depth and allowed to travel with the fluid past the stationary gamma detectors. The time of travel between the two detectors is recorded and the velocity is calculated as the ratio of the distance between the detectors and the time of travel. The flow rate is calculated from the fluid velocity and the borehole volume in the interval between the detectors. By repeating the tracejector survey at several depths, a production profile of the pumping well can be described where the relative contributions of the various flow zones to the total flow can be identified.

Analysis of temperature logs made when pumping the boreholes will be divided into qualitative and quantitative interpretations. All analysis will be based on heat transfer theory that accounts for heat flow within the fluid, between the fluid and the formation, and between the fluid and the well plumbing. Qualitative interpretations will include examining the shapes of the temperature profiles to deduce the location and nature of flow points or zones, and the direction of flow. Quantitative analysis will include estimating rate of flow and will be based on the subtangent or delta function (Kunz and Tixier, 1955; Schonblom, 1961; Murphy, 1982). Temperature profiles calculated from known pumping rates and reasonable estimates for formation and fluid thermal properties, and the geothermal gradient will be compared with temperature logs to calibrate thermal properties. The calibrated temperature profiles will be used to calculate intraborehole flow rates.

Temperature logs and tracejector surveys completed under static or nonpumping conditions will be used to identify steady-state flow rates, directions of vertical movement, and permeability contrasts. Methods for conducting static tracejector surveys and the proposed analytical techniques are described by Erickson and Waddell (1985) and Galloway and Erickson (1985). Flow rates will be calculated for static temperature logs using the calibrated thermal model of fluid flow.

Injection and withdrawal hydraulic-test data will be analyzed for site characterization. Twenty-nine injection and withdrawal tests have been conducted in the C-holes to examine the pressure-transient response of the aquifer. Analysis of pressure transients can give information regarding the type of flow, hydraulic boundaries, and aquifer properties, specifically hydraulic conductivity and specific storage. Because estimation of aquifer properties depends on the type of flow and boundaries hypothesized, it is important to develop a conceptual model of the flow before estimating aquifer properties. The primary purpose of analyzing previously completed injection and withdrawal tests is to form a conceptual model of ground-water flow at

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the scale of the C-hole complex. Where appropriate, estimates of aquifer properties will be made. The conceptual model will be used as a basis for designing additional hydraulic and tracer tests that will enable more reliable calculation of aquifer properties.

Several types of stress tests have been completed at the C-hole complex. Twenty-three falling-head injection tests with packers were run in drillhole UE-25c#1 (Figure 8.3.1.2-22). Two additional falling-head injection tests were run in drillhole UE-25c#1 to ascertain pipe-friction head loss. A quasi-constant flux injection test with packers was run in drillhole UE-25c#2 (Figure 8.3.1.2-23) and monitored in drillholes UE-25c#1 and UE-25c#3 (Figure 8.3.1.2-24). A constant-flux withdrawal test without packers was done in each of the C-holes after completion of drilling such that drillhole UE-25c#1 was used as an observation well during the drillhole UE-25c#2 test, and drillholes UE-25c#1 and UE-25c#2 were used as observation wells during the drillhole UE-25c#3 test. Straddle packers were used in observation wells (Figures 8.3.1.2-25, -26, and -27).

The approach to analyzing the stress tests will involve a search for the theoretical reservoir model with a response to an imposed stress that most closely matches that of the actual reservoir and with constraints that are consistent with other information concerning the rock properties of the reservoir. Flow-analysis procedures are well established for porous media that are reasonably homogeneous but are not well established for aquifers with heterogeneities evident at the C-hole complex. New techniques that include aquifer heterogeneity may be needed to develop an adequate conceptual model of flow at the C-hole complex.

The analysis of pressure transients from C-hole pumping and injection tests initially will consider solutions for porous media that are radially infinite, homogeneous, and isotropic. Complexity, in the form of solutions for fractured reservoirs, will be considered as needed. This approach, from simple to more complex flow solutions, will enable the development of a conceptual model for pressure-transient behavior by contrasting the C-hole response to the ideal porous-media response. Porous-media solutions that will be considered include those of Theis (1935) for isotropic confined conditions; Hantush and Jacob (1955), Hantush (1960), and Neuman and Witherspoon (1969a, 1969b) for leaky conditions; and Boulton (1963) for unconfined aquifers with delayed yield from storage. The possible effects of well-bore storage and skin, partial penetration, and outer boundaries such as no flow or constant-head boundaries will be examined.

If porous-media solutions do not adequately match the response of the actual fractured reservoir, more complex solutions will be considered. Homogeneous models that may be considered include the following:

1. Those that consider single and regularly spaced and offset systems of vertically and horizontally fractured systems (Prats, 1972; Asfari and Witherspoon, 1973).

2. Those that implicitly consider fractures by including anisotropy in permeability (Papadopulos, 1965; Saad, 1967).

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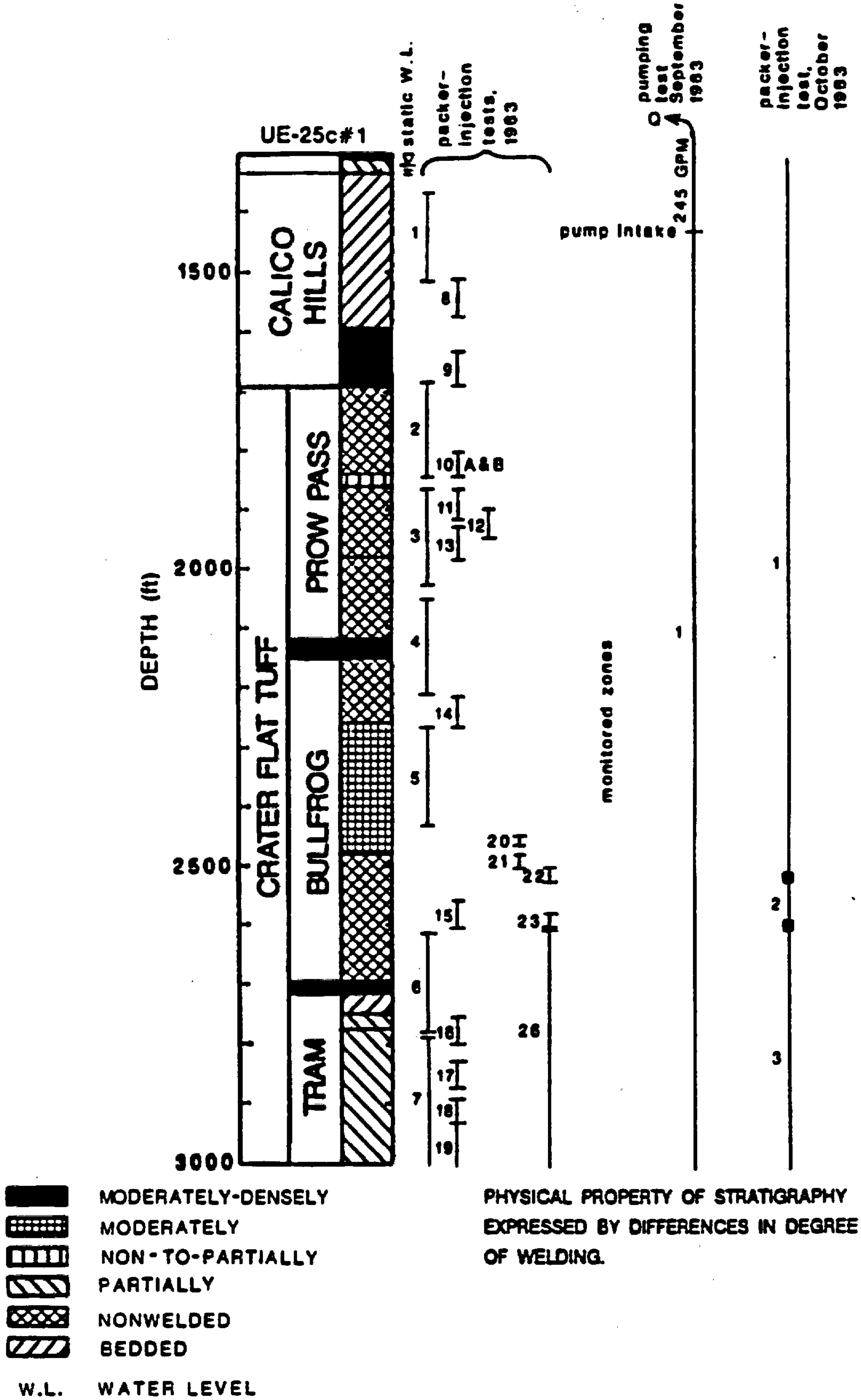

Figure 8.3.1.2-22. Test well configuration for drillhole UE-25c#1 packer-injection and open-hole pumping tests.

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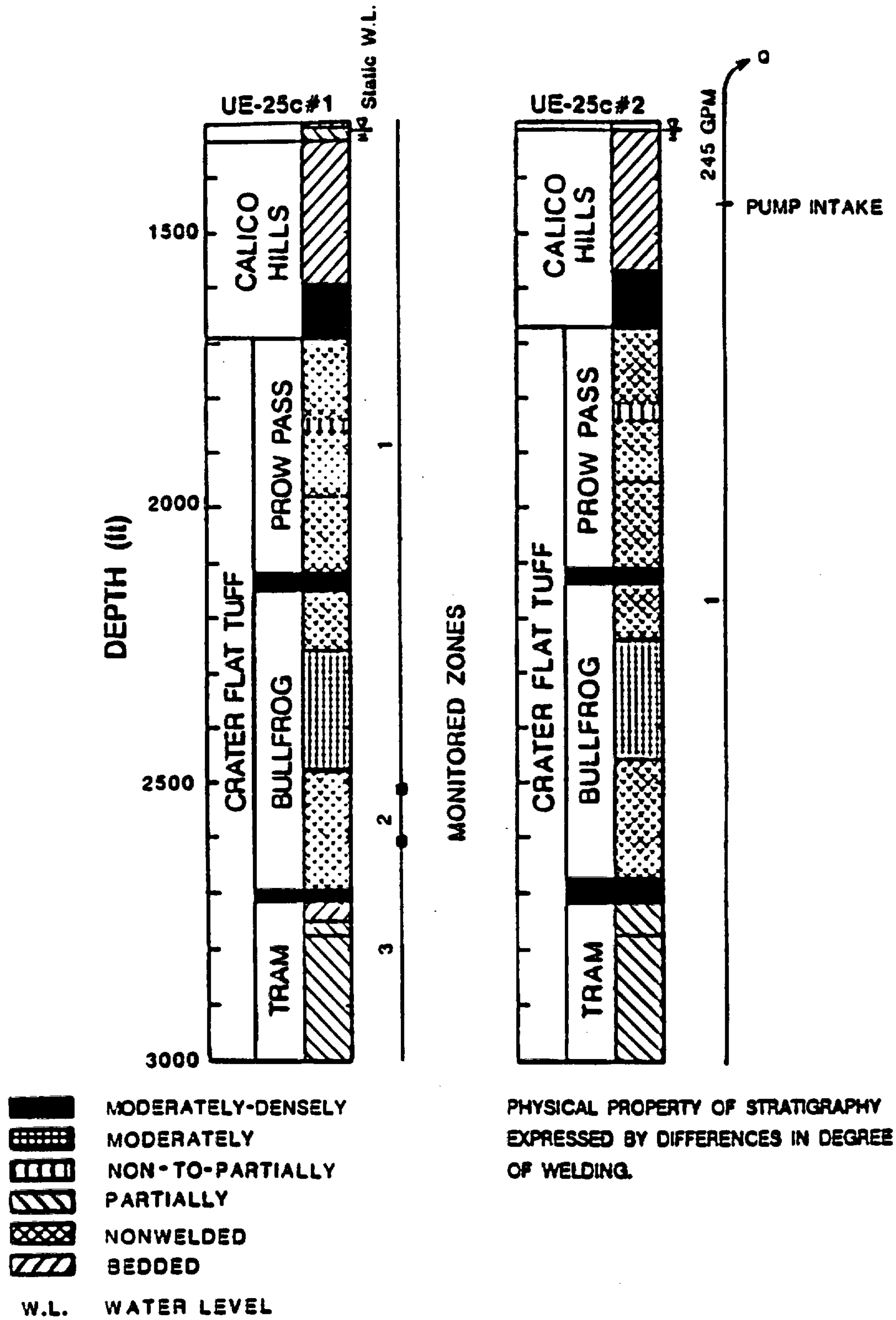

Figure 8.3.1.2-23. Test well configurations for drillhole UE-25c#2 pumping test (March 1984).

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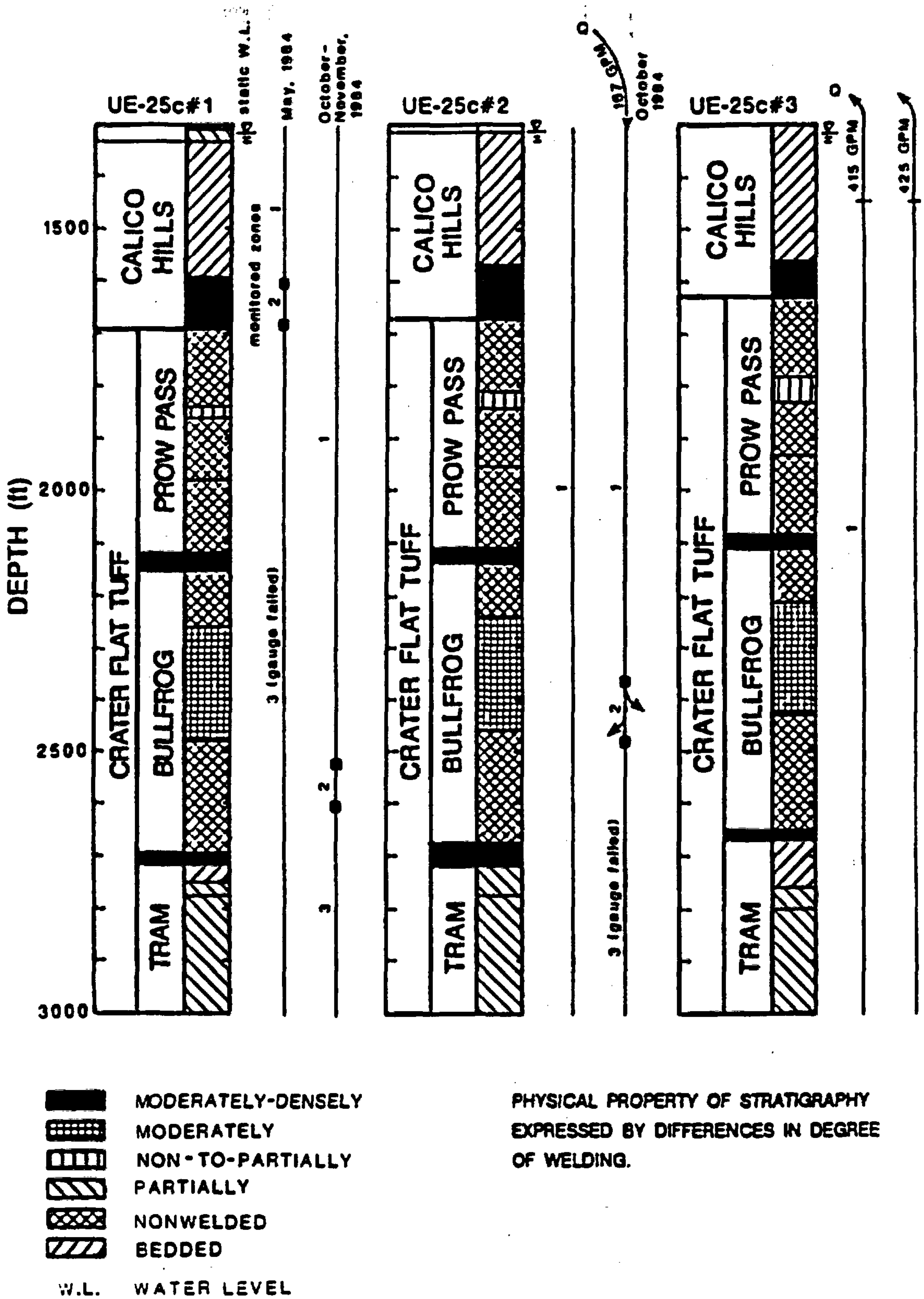

Figure 8.3.1.2-24. Test well configurations for drillhole UE-25c#3 pumping tests (May 1984. November 1984) and drillhole UE-25c#2 packer injection test (October 1984).

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3. Those that consider a stressed well intersecting a single fracture in an otherwise radially infinite porous medium (Gringarten and Witherspoon, 1972; Gringarten et al., 1974; Gringarten and Ramey, 1974; Cinco et al., 1978).

4. Those that consider well-bore storage and skin effects in combination with previously mentioned characteristics (reviewed by Gringarten et al., 1979).

5. Those that consider partial penetration of wells (reviewed by Karasaki, 1987).

If an equivalent homogeneous model is not an adequate representation of the actual system behavior, heterogeneous models will be investigated. Heterogeneous models include double-porosity models (reviewed by Gringarten, 1982; Moench, 1984), multilayered models (reviewed by Gringarten, 1982) and composite models (reviewed by Karasaki, 1987).

Preliminary analysis of falling-head injection tests (slug tests) has been reported by Erickson et al. (1985) and Karasaki (1987). Observed pressure transients from many of the tests could not be represented adequately using available solution techniques. Solutions evaluated included those of Cooper et al. (1967), Moench and Hsieh (1985), and several developed by Karasaki (1987). Possible causes for deviations include: (1) large initial heads may have induced excessive pipe-friction losses, (2) large velocity may have caused non-Darcian flow in the formation near the well bore, and (3) the changing state of in situ stresses may result from high initial injection heads (750 ft above static). Results of slug tests conducted in other wells on Yucca Mountain (USW H-3 for example) indicate that existing fractures were reopened or possibly new fractures were created as a result of excessive injection heads (2,461 ft above static in USW H-3), and that the pressure-transient responses reflect the changes in the fluid flow characteristics resulting from the changing in situ stresses. Therefore, the interaction of the fluid and mechanical processes may need to be considered in the analysis of the UE-25c#1 slug tests.

Additional slug tests will be conducted in selected intervals in UE-25c#1 and possibly UE-25c#2 and UE-25c#3 for purposes of assessing the effect of the magnitude of initial injection heads on the resulting pressure transients. Lower injection heads are expected to mitigate head losses through the injection tubing, at the well/formation interface, and within fractures or faults. Lower injection heads would also decrease the effects of changing in situ stresses, thus providing test results for interpreting the fluid-flow processes relatively uncoupled from mechanical processes.

Additional interpretation of the well-test data may be useful on the basis of results of future well tests. Such tests could be designed to mitigate pipe-flow head losses. Although an analytical model that considers non-Darcian flow in the formation is not available, an equivalent analytical model or a numerical model may be applied to these data.

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Barometric and earth-tide analyses will be performed using water-level data collected from test holes at the site. Water levels were monitored in the C-holes and in drillhole UE-25p#1 to analyze aquifer responses to solid earth tidal strains and surface barometric pressure loads. Techniques have been developed that relate the tidal potential and the resulting aquifer dilatation to aquifer properties such as specific storage, matrix bulk modulus, and hydraulic effective porosity (Bredehoeft, 1962; Rhoads and Robinson, 1979; Kanehiro and Narasimhan, 1980; Hanson, 1984). Each of the techniques is developed for ideal confined aquifers or undrained conditions (although Bredehoeft (1962) presents an analysis for an ideal unconfined aquifer), and thus, the status of the monitored aquifer, confined or unconfined, must be determined before applying these techniques.

The existence of a strong hydraulic-head contrast between two monitored zones in the same borehole is a good indication that the units are not well connected hydraulically and that one unit may be confined to a certain degree. Such a situation exists between the Paleozoic dolomites in drillhole UE-25p#1 and the overlying tuffs where hydraulic heads in the dolomites are 20 m greater than those in the tuffs and indicate a confined aquifer in the Paleozoic section (Craig and Robison, 1984). The lack of a significant contrast of hydraulic heads (<0.5 m) in the vertical section from the water table in the Paintbrush Tuff, through the Calico Hills to the Crater Flat Tuff at depth, indicates that there may be insufficient vertical hydraulic connection to be consistent with an unconfined aquifer in the tuffs. Weeks (1978) presented a study of the response of the deep unconfined aquifer to barometric interaction. Another way to assess the confined status of the aquifers is to examine measured water-level and barometric fluctuations for conformance to Weeks' model.

Some preliminary analyses of aquifer response have been undertaken and reported (Galloway and Sullivan, 1986). Water levels were measured in the C-holes in five intervals (zones) (Figure 8.3.1.2-25) open to the extensively fractured Crater Flat Tuff and in drillhole UE-25p#1 in one interval open to the Paleozoic dolomite. Barometric pressure was monitored at land surface near drillhole UE-25c#2. Measurements were made at 30-min intervals using sensitive pressure transducers, during the period December 5, 1985, to July 17, 1986. A period of uninterrupted measurements from February 23 to April 1, 1986, was selected for analysis. Tidal harmonic analysis of the barograph and the six hydrograph records showed periodic fluctuations in all seven records corresponding to earth tides. An analysis of the periodic and aperiodic fluctuations for drillhole UE-25p#1 based on Rhoads and Robinson (1979) gave estimates of barometric efficiency, 0.57; specific storage, 6.0×10^{-9} cm^{-1}; matrix bulk modulus, 36.4 GPa; and effective hydraulic porosity, 7.7×10^{-2}. Although earth-tide induced water-level fluctuations were observed and calculated for the C-hole hydrographs, the analysis was not extended to these records because of the apparent unconfined-like response in the water-level and barometric fluctuations. Porosities were estimated from Bredehoeft (1962) based on the earth-tide induced water-level fluctuations and were in the range, 2×10^{-4} to 2×10^{-3}.

Although the unconfined-like response observed in the C-holes can be described by the model of Weeks (1978), additional work needs to be done to rule out other phenomena that could explain the response, such as well-bore storage effects. Other monitored zones in other boreholes on Yucca Mountain

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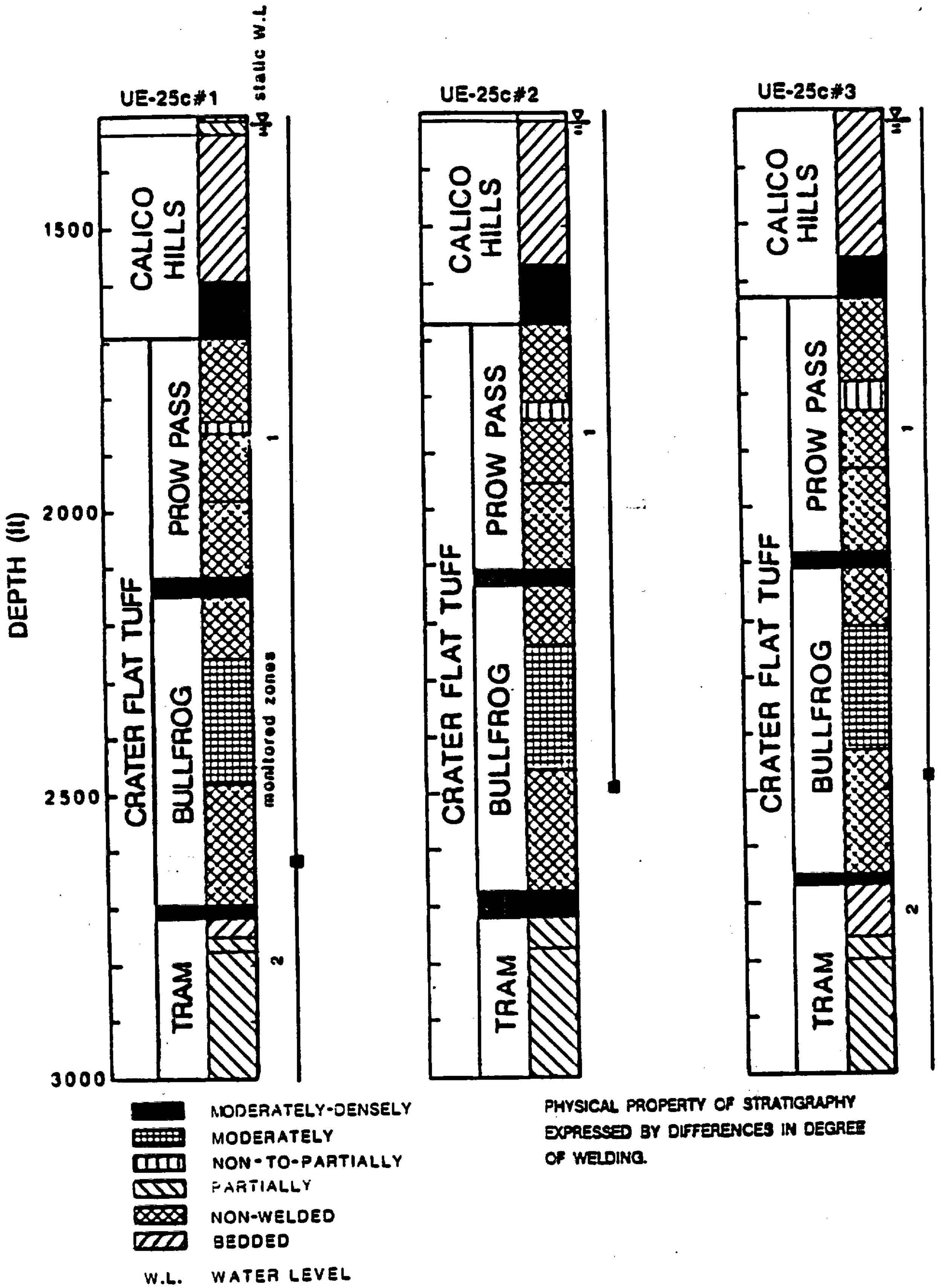

Figure 8.3.1.2-25. Test well configuration for analysis of C-hole earth-tide and barometric induced water-level fluctuations

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need to be examined to determine whether an unconfined-like response is evident and, if so, to relate the response to stratigraphy, well-bore storage, and other conditions. A preliminary analysis of drillhole USW H-1, USW H-4, and USW WT-2, UE-25 WT#3, and UE-25 WT#13 water-level fluctuations indicate that an unconfined-like response to barometric fluctuations is occurring.

A situation exists in drillhole UE-25c#1 that may permit a direct evaluation of the phase shift. A vent in the well cover that is connected to the annular space adjacent and open to the unsaturated thickness of the well bore is exchanging air with the atmosphere similar to that observed by Weeks (1986) for drillholes USW UZ-6 and USW UZ-6s on the crest of Yucca Mountain. It may be possible to correlate fluctuations in barometric pressure, annular space pressure, or air flow, or both, to fluctuations in water level, in order to address the phase shift in water-level and barometric fluctuations characteristic of the unconfined response.

Additional work may be done on the earth-tide analysis by using a technique presented by Hanson (1984). This technique accounts for well-bore storage and well-completion effects, and the presence of discrete fluid-carrying fractures. The method is attractive because it may also provide a first-order approximation of the hydraulic conductivity tensor.

8.3.1.2.3.1.4 Activity: Multiple-well interference testing

Objectives

The objectives of this activity are to

1. Determine hydraulic properties, including hydraulic conductivity and storage coefficient, needed for quantitative evaluation of ground-water flow.

2. Determine if the fractured media of Yucca Mountain can be represented as an anisotropic porous media at the scale of multiple-well tests or if a fracture-network model is more appropriate.

3. Evaluate the relation between hydraulic properties determined by single well tests and those determined by multiple-well tests.

Parameters

The parameters for this activity are

1. Hydraulic conductivity.
2. Storage coefficient.
3. Fracture characteristics.

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Description

A series of tests will be conducted at the C-hole complex (Figure 8.3.1.2-26). In these tests, water will be pumped from small, isolated intervals of one C-hole and the hydraulic response will be monitored in isolated intervals of other C-holes. Approximately 20 tests, using various combinations of pumping well, pumping interval, and observation intervals, will be conducted to identify the nature of the hydraulic connection between the C-holes. Large variations in the fracture characteristics of the rocks penetrated by the C-holes could affect movement of water in the saturated zone. By conducting cross-hole tests at various depths, the hydraulic significance of these variations will be identified.

Each test will be conducted in the following manner. Straddle packer systems will be installed in both pumping and monitoring wells. Packers will be used to isolate intervals identified on tracejector logs as producing zones. Six producing zones have been identified in UE-25c#1; at least two in UE-25c#2 and six in UE-25c#3. After packers have been inflated and tested for effective seals, pressure transducers will be installed in monitoring intervals. A submersible pump will be installed and water will be withdrawn from the selected pumping interval for approximately three days at a rate of between 3.2 and 12.6 L/s. Water temperature will be monitored by a thermocouple in the discharge line. Pressure changes measured in monitoring intervals will be digitally recorded by a data logger. After three days, the pump will be shut off and pressure recovery will be monitored for at least three additional days.

The combinations of pumping and monitoring intervals used in cross-hole testing will be selected in order to describe vertical variations in horizontal hydraulic conductivity, as well as the degree of hydraulic connection between units. For this reason, tests will be conducted by pumping water from the permeable part of the lower Bullfrog Member and monitoring pressure changes in observation wells within the upper Bullfrog, lower Bullfrog, and upper Tram members. Tests will also be conducted by pumping water from the permeable zone of the upper Tram and monitoring pressure response in both the upper Tram and lower Bullfrog members. Permeable zone of the lower Bullfrog Member exists at approximately 716 to 780 m below land surface depending upon the well. The permeable zone in the upper Tram Member is from approximately 838 to 870 m. Tests will be conducted alternately using UE-25c#1, UE-25c#2, and UE-25c#3 as pumping wells. In each test, the wells not used for pumping will be used as monitoring wells. By varying the pumping well, it will be possible to demonstrate the symmetric or unsymmetric nature of the hydraulic conductivity tensor.

A 30-day pumping test will be conducted by pumping UE-25c#1, UE-25c#2, or UE-25c#3 at a rate of between 6.4 and 25.2 L/s, and monitoring the pressure decline in other C-holes, UE-25p#1, USW H-4, and other nearby wells. Pressure recovery will be monitored in all wells for at least 30 days after pumping stops. Water will be pumped from the permeable zone of the lower Bullfrog Member. Pressure response in the C-holes will be monitored in isolated zones of the upper Bullfrog, lower Bullfrog, and upper Tram members. The pressure response in other nearby wells will be monitored without the use of packers to isolate zones.

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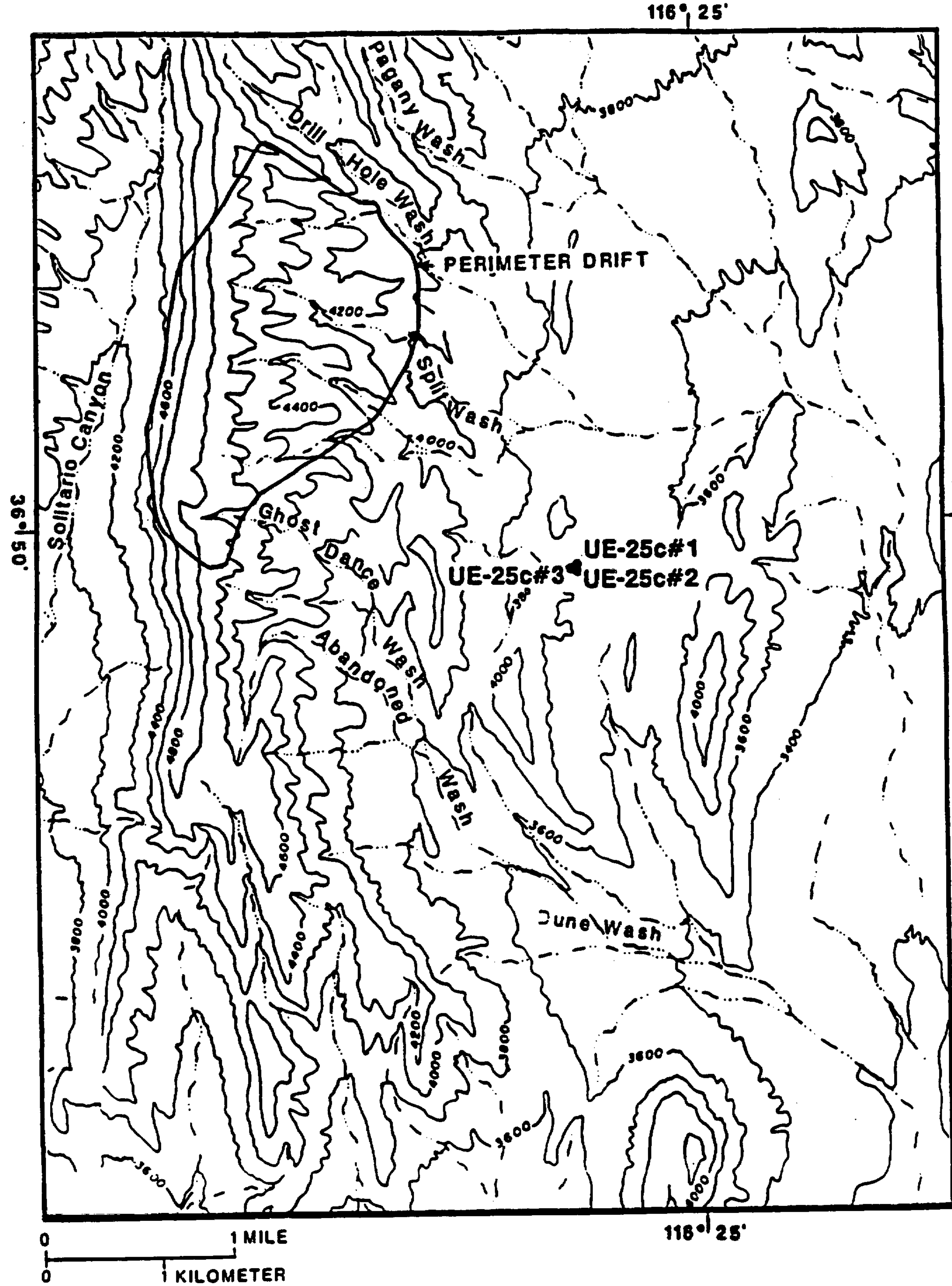

Figure 8.3.1.2-26. Location of C-hole complex.

Results from this pumping test will be used to estimate aquifer properties at a scale larger than the C-holes scale and to identify the hydrologic significance of the Bow Ridge normal fault. Large-scale estimation of aquifer properties is important to describe accurately ground-water flux within the repository block. Observation wells used during the pumping test will be located on both sides of the Bow Ridge fault. The pressure response in these wells will be used to identify the fault as a barrier or conduit for ground-water flow.

The following porous-media techniques will be useful in evaluating multiple flow hypotheses. Current hypotheses, based on existing knowledge of Yucca Mountain, are equally plausible. The analytical method of Hsieh et al. (1985) is based on an assumption of aquifer homogeneity and may be applied to cross-hole data to determine a three-dimensional hydraulic conductivity tensor and storage coefficient for the C-hole area. Composite analytical methods of Karasaki (1987) may be used to investigate the assumption that flow in the fracture system occurs in an inner region near the pumping well dominated by a small number of fractures and an outer region where the rock is similar to a homogeneous porous medium. If test results indicate the assumption of homogeneity is poor, a numerical model such as Reilly (1984) may be used. Results of the large-scale test may be interpreted using classical Theis theory in addition to the techniques listed previously. If test results indicate the aquifer behaves as a dual-porosity medium, methods such as Moench (1984) may be used.

The fracture-network model developed by Lawrence Berkeley Laboratory (Activity 8.3.1.2.3.3.2) will be applied to interpret the results of both cross-hole and large-scale pumping tests. A set of fracture networks will be generated that brackets the range of uncertainty in fracture statistics. For example, networks with different mean apertures or different distributions of apertures (or both) might be included. Networks also will be developed that correspond to differing hypotheses for describing the distribution of fractures at Yucca Mountain. For example, fractures may be treated either as stratigraphically controlled, or independent of stratigraphy. Fracture networks, initially generated on the basis of geologic evidence, will be used to simulate multiple-well test results. Those networks that best match measured hydraulic response to pumping will be considered for analysis of tracer-test data.

Aquifer properties, estimated by porous-media techniques and fracture networks that successfully simulate hydraulic-test results, will be compared. Differences and similarities in the results of the two methods will be identified. Situations, where each approach is likely to produce meaningful results, will be identified. Limitations of each method will be described.

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8.3.1.2.3.1.5 Activity: Testing of the C-hole sites with conservative tracers

Objectives

The objectives of this activity are to

1. Determine the following properties by single-well and multiple-well tests at the C-holes: (1) effective porosity, (2) longitudinal dispersivity, (3) regional pore-water velocity, and (4) possibly matrix diffusion.

2. Evaluate the relation between aquifer properties estimated by porous-media techniques and fracture characteristics used in fracture-network modeling.

Parameters

The parameters for this activity are

1. Effective porosity.
2. Dispersivity.
3. Velocity and fracture characteristics.

Description

Approximately three drift-pumpback tests will be conducted in the C-hole intervals that have large hydraulic conductivity. These tests will be coordinated with testing with reactive tracers (Activity 8.3.1.2.3.1.7). The depths that will be considered for these tests include approximately 780 m (lower Bullfrog) and 850 m (upper Tram) below land surface in UE-25c#1, 730 m (lower Bullfrog) in UE-25c#2, and 740 m (upper Tram) in UE-25c#3 (Figure 8.3.1.2-27). Straddle packers will be used to isolate the test intervals.

Each drift-pumpback test will consist of placing a tracer in the test interval, letting it drift into the formation and then pumping it back out. The tracer to be placed in the selected intervals, including 3-trifluoromethylbenzoate, will drift into the formation under steady-state hydraulic gradients. Pretest sensitivity analysis and simulation of the flow system at the C-hole location will be used to identify reasonable periods of time for the drift phase of tests. The drift phase will be sufficiently long to permit the tracer to move out of the fractures that intercept the borehole and into the fracture network. In this manner, the influence of individual fractures on seepage velocity will be minimized. A pump will then be installed in the selected interval and water will be withdrawn to begin the pumpback phase of the test. The pumping rate will be 3.2 to 9.5 L/s. The rate of pumping will be measured by an in-line flow meter, and water temperature will be monitored by a thermocouple. Samples of pumped water will be collected and analyzed for tracer concentration. Pumping will continue for at least three days or until virtually all tracer is recovered.

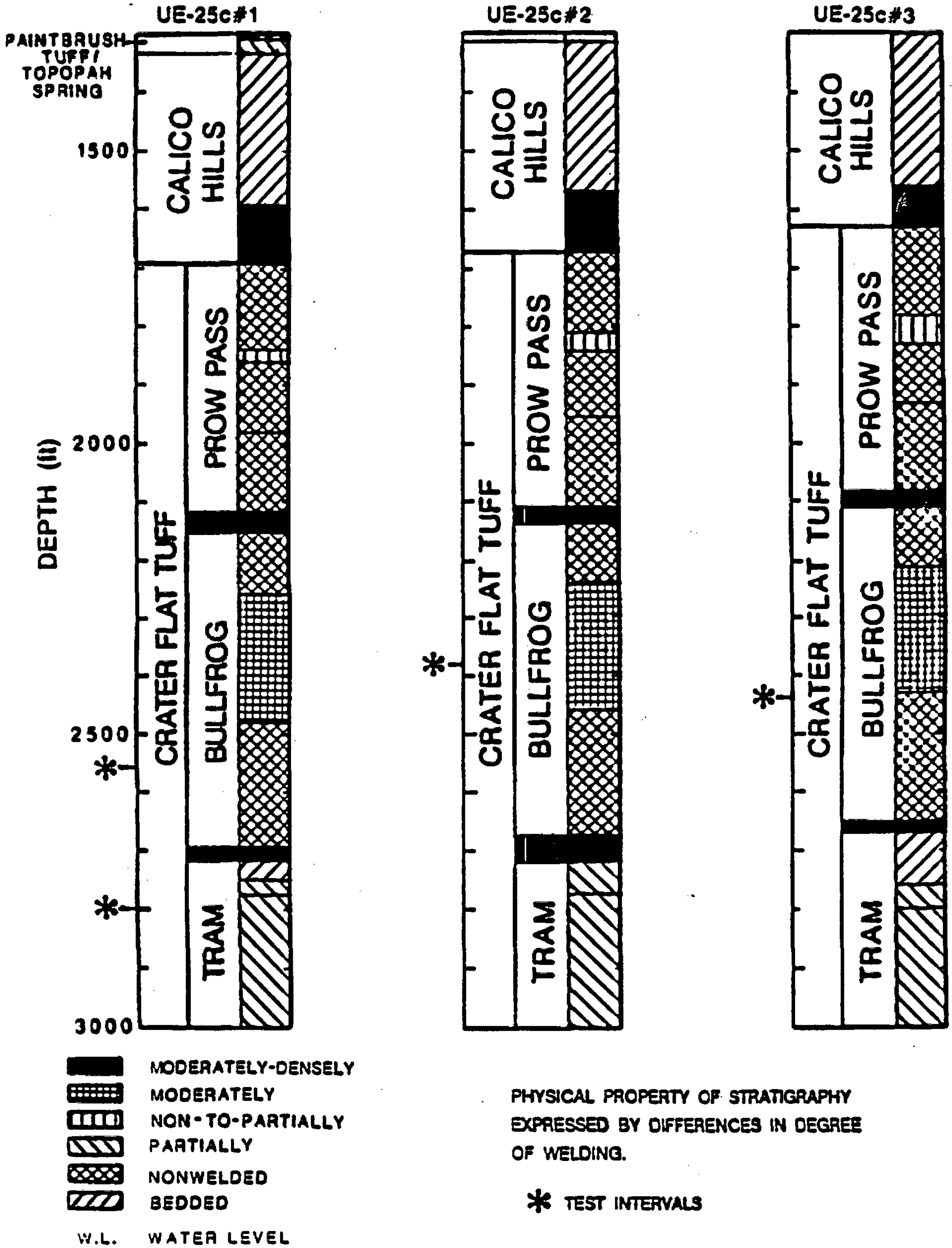

Figure 8.3.1.2-27. Location of test intervals for the drift-pumpback tests.

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Results of drift-pumpback tests may be virtually impossible to interpret. The rate of diffusion in the borehole and deviations of gradient and velocity from regional conditions due to individual fractures that intersect the well bore may confound the analysis of bulk aquifer properties. The influence of these well bore characteristics may be most important during the drift phase of the tests. If experience with drift-pumpback tests shows that interpretation of results will not be possible, injection-pumpback tests may be substituted for remaining drift-pumpback tests.

Two-well recirculating tests will be conducted in the C-hole intervals that have large hydraulic conductivity. Two tests will be conducted in the permeable zone of the lower Bullfrog Member. One test will use wellsUE-25c#2 and UE-25c#3 while the second test will use either UE-25c#1 and UE-25c#3, or UE-25c#1 and UE-25c#2. If the results of these multiple-well hydraulic tests show hydraulic connection between the lower Bullfrog and upper Tram members, a cross-hole recirculating test may be conducted by injecting water into the Bullfrog and pumping from the Tram Member.

Each two-well recirculating test will be conducted in the following manner: Packers will be used to isolate the test intervals in a pumping and injecting well. Water will be pumped from one well at a rate of between 6.3 and 18.9 L/s and injected into the second well. Pumping will continue for approximately three days until a steady-state flow system is established. Pressure transducers will be used to monitor the pressure changes. Conservative tracers will be mixed with water and injected into the aquifer. To determine the effect of matrix diffusion on the migration of tracers, colloids of various sizes will be considered for use in conjunction with conservative tracers, such as 3-trifluoromethylbenzoate. Colloidal and other tracers will be selected such that some tracers will be expected to diffuse into the rock matrix whereas others will not. The tracer will be injected as a short pulse. The steady-state recirculating flow pattern will be maintained following tracer injection. Samples of pumped water will be collected and analyzed for tracer concentration. Sampling will continue for at least one week to ensure that all the tracer has time to move through the formation.

Two-well convergent tracer tests will be conducted in the C-hole intervals that have large hydraulic conductivity. One test will be conducted in the permeable zone of the lower Bullfrog Member and one test will be conducted in the upper Tram Member. Additional tests will be done using various combinations of pumping and injection intervals to evaluate directional characteristics of hydraulic and transport properties. Ideally one or more convergent tests would be conducted during each cross-hole hydraulic test (Activity 8.3.1.2.3.1.4). Each test will be conducted by installing packers in two wells to isolate the permeable interval. Pressure transducers will be installed in all C-holes. Water will be pumped at a rate of between 6.3 to 18.9 L/s from the isolated interval in one well until a steady-state flow system develops. Conservative tracers will be placed in the isolated interval of the second well and will move along converging flow paths toward the pumping well. Water samples obtained from the pumping well will be analyzed for tracer concentration. Pumping and water-quality monitoring will continue for at least four weeks or until measurements indicate that no further recovery of tracer is made by continuing the pumping.

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Porous-media techniques will be used to interpret the results of the tracer tests at the C-holes. Analytical methods such as Grove and Beetem (1971) will be used to interpret the results of the two-well recirculating tests. Analytical methods will be useful if the flow system can be represented as a homogeneous media. Numerical models will be useful in both homogeneous and heterogeneous media. Two-dimensional numerical models will be used to interpret drift-pumpback tests and converging tests. If the results of the hydraulic tests indicate that flow is three dimensional, numerical transport models such as Glover (1986) will be adopted for use at the C-holes. Dual-porosity models such as Huyakorn et al. (1983) will be used if test data show evidence of transport in both fractures and intervening unfractured blocks.

Initial porous-media interpretation of tracer-test results will be done using a constant dispersion coefficient or scale dependent dispersion similar to Winter et al. (1984). If test results show transport behavior is not Fickian, analysis of dispersion will be conducted within a stochastic framework similar to one used by Smith and Schwartz (1980) to investigate transport in a parallel-flow field. Stochastic analysis of dispersion in conjunction with field-scale tracer tests has not been attempted previously.

The fracture-network model developed by Lawrence Berkeley Laboratory (Activity 8.3.1.2.3.3.2) will be applied to interpret the results of the tracer tests at the C-holes. Network modeling, described in Activity 8.3.1.2.3.1.4 (multiple-well interference testing), will result in a set of fracture networks that successfully simulate pumping-test results. This set of networks will be used in attempts to simulate tracer-test results. The subset of networks that successfully simulates both hydraulic and tracer tests, will be considered representative of the fracture system at the C-hole location.

Aquifer properties, estimated by porous-media techniques and fracture networks that successfully simulate tracer-test results, will be compared. Differences and similarities in the results of the two methods will be identified. In comparing the two methods, special attention will be given to differences in estimates of the magnitude and distribution of hydrodynamic dispersion and effective porosity. Evidence to support the idea of using a porous-media model to simulate flow and transport in fractured rocks would include dispersion with a normal distribution and constant effective porosity. Evidence to support the idea of using a fracture-network model would include nonnormal dispersion and directional variation in effective porosity, even at large scales.

Results of multiple-well tests will be compared with the results of the single-well tests. Possible reasons for differing results will be identified. The comparisons will be used to decide if the single-well tests can be conducted throughout Yucca Mountain and produce meaningful results, or if additional drilling of multiple-well sites will be needed.

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8.3.1.2.3.1.6 Activity: Well testing with conservative tracers throughout the site

Objectives

The objective of this activity is to determine the following properties at the Yucca Mountain site: (1) effective porosity, (2) longitudinal dispersivity, and (3) regional pore-water velocity.

Parameters

The parameters of this activity are

1. Effective porosity.
2. Dispersivity.
3. Velocity.
4. Hydraulic conductivity.
5. Storage coefficient.
6. Fracture characteristics.

Description

The methods used for testing throughout the site will depend on the results of testing at the C-holes. If drift-pumpback tests give reliable results at the C-holes, then several wells will be selected for single-well testing. If drift-pumpback testing at the C-holes shows that single-well tests cannot be used with confidence, then single-well testing throughout the site will not be conducted. Instead, a second multiple-well location will be proposed and, if developed, tests will be conducted to indicate the range of variations in aquifer properties and transport characteristics that might be expected throughout the site. The methods that might be used at the other wells and proposed multiple-well location are described in the following paragraphs.

Existing geophysical logs for all hydrologic wells in the saturated zone will be reviewed to identify appropriate intervals for conducting tracer tests. Approximately, five to ten wells will be selected for testing (Figure 8.3.1.2-28). The wells will be distributed throughout the site in areas that are likely to be hydraulically downgradient from the repository block. If existing geophysical logs are not sufficiently detailed for the needs of the tracer testing, additional sonic-televiewer, tracejector and heat-pulse logs will be run. Fracture logs will be used to describe the statistical characteristics of fractures intercepted by the boreholes. Results of the log analysis will be used to identify several intervals in each well where tracer tests will be conducted.

Pumping tests will be conducted in each well. Packers will be installed to isolate intervals that will be used in tracer tests. Pressure transducers will be installed in the well to be pumped and any nearby wells that may respond to pumping. In most instances, no observation well will be available. A pump will be installed; water will be withdrawn from the isolated test interval at a rate of between 3.2 to 12.6 L/s; and the pressure response will be monitored. Emphasis will be placed on collecting pressure-response data during the early part of each test because the data may be useful in

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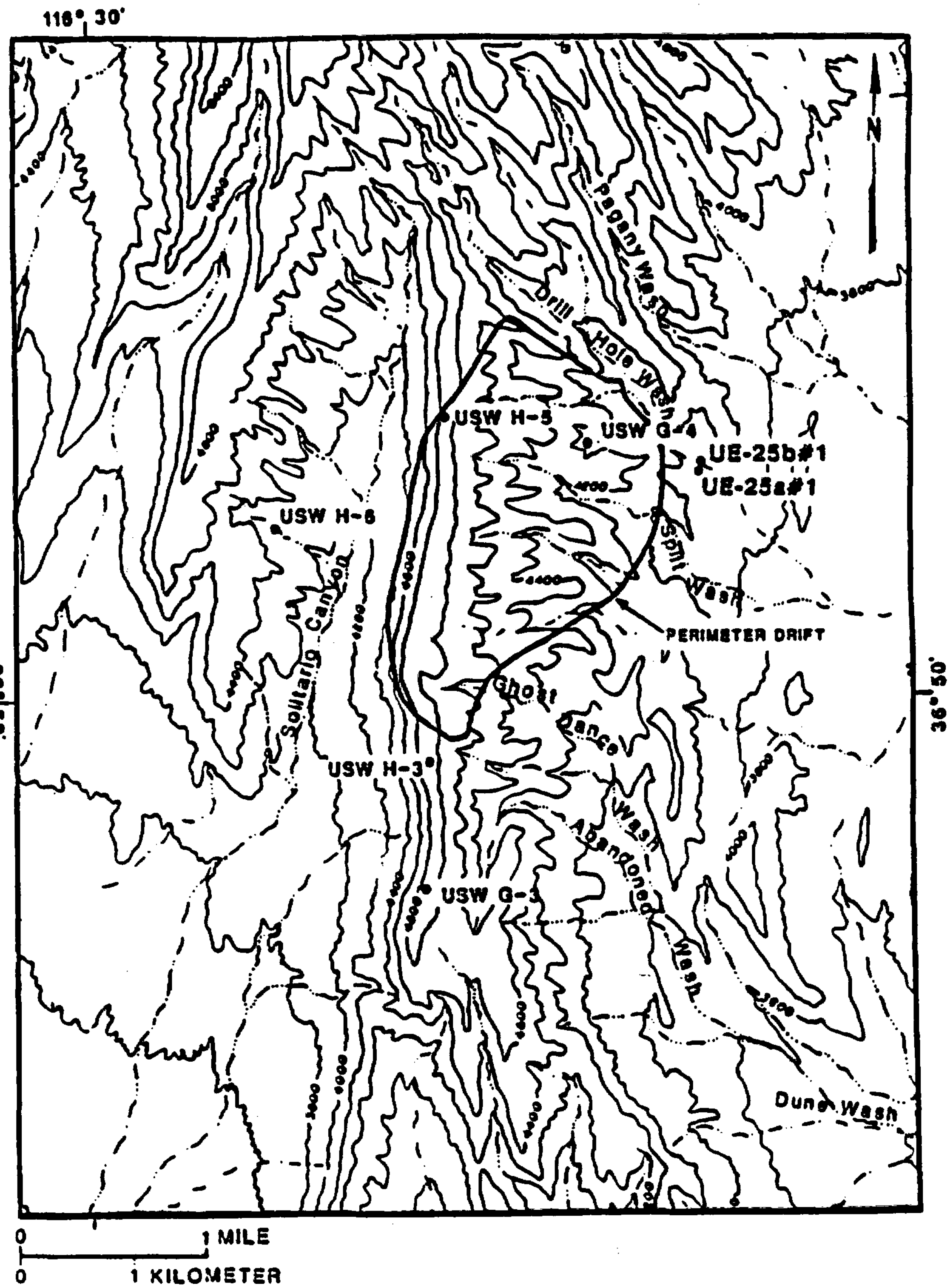

Figure 8.3.1.2-28. Location of the saturated-zone wells that might be used for additional tracer testing.

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understanding the average distance that the tracer will need to move before entering the fracture network near the well. Pumping will continue for approximately 3 to 5 days or until a steady-state flow is established. The pump will be turned off and pressure-recovery data will be collected for a period that is at least equal to the pumping period. Test results will be interpreted using porous-media and/or fracture-network techniques that proved successful when applied to pumping-test results at the C-holes.

Drift-pumpback tests will be conducted in approximately five to ten wells. Within each well, drift-pumpback tests will be conducted in two intervals that have a large hydraulic conductivity. The tracer that is placed in the selected intervals, including 3-trifluoromethylbenzoate, will drift into the formation under steady-state hydraulic gradients. Pretest sensitivity analysis and simulation of the flow system at each well tested will be used to identify reasonable periods of time for the drift phase of these tests. The drift phase will be sufficiently long to permit the tracer to move out of the fractures that intercept the borehole and into the fracture network. In this manner, the influence of individual fractures on seepage velocity will be minimized. Upon completion of the drift phase, a pump will be installed and water withdrawn from the tested interval to begin the pumpback phase of the test. The pumping rate will be 3.2 to 9.6 L/s. The rate of pumping will be measured by an in-line flow meter, and water temperature will be monitored by a thermocouple. Samples of pumping water will be collected and analyzed for tracer concentration. Pumping will continue for at least three days or until virtually all the tracer is recovered. Effective porosity, longitudinal dispersivity and regional pore-water velocity will be determined at each well tested. Porous-media and/or fracture-network techniques will be used to interpret the results of these drift-pumpback tests. Interpretive techniques to be used in the tracer studies at the C-holes will be compared to identify an appropriate technique for application throughout the site.

If the results of the tracer studies at the C-holes show that single-well tests do not give reliable estimates of aquifer properties, then a second multiple-well location will be proposed; if accepted, wells will be drilled and hydraulic and tracer testing will be conducted. A location southwest of the repository block will be selected. The wells will be located as close to the block as practical. A location will be selected where the physical rock properties are significantly different from those of the C-hole location. Three wells will be drilled to depths of approximately 300 m below the water table. Well construction and completion will be similar to the C-holes. Spacing of the wells cannot be stated exactly but some change from the spacing of the C-holes can be expected. Geophysical logs, including sonic televiewer, tracejector, and heat pulse, will be run and interpreted to characterize fractures and identify appropriate intervals for tracer testing.

Pumping tests will be conducted at this second multiple-well location to determine the nature of hydraulic connection among wells. Packers will be installed to isolate intervals that will be used in the tracer tests. Pressure transducers will be installed in all three wells and any nearby wells that may respond to pumping. In each test, a pump will be installed; water will be withdrawn from the isolated test interval at a rate of between 3.2 and 12.6 L/s; and the pressure response will be monitored. Emphasis will be

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placed on collecting pressure-response data during the early part of each test because the data may be useful in understanding the average distance that the tracer will need to move before entering the fracture network near the well. Pumping will continue for approximately 3 to 5 days or until steady-state flow is established. The pump will be turned off and pressure-recovery data will be collected for a period that is at least equal to the pumping period. Test results will be interpreted using porous-media and/or fracture-network techniques that proved successful when applied to pumping-test results at the C-holes.

Two-well recirculating tests will be conducted in well intervals that have large hydraulic conductivity. Two tests, each using different pumping and injecting wells, will be conducted in an approximately horizontal zone of increased hydraulic conductivity. These tests will be used to investigate the symmetric and isotropic nature of transport characteristics. A third test will be conducted in a separate permeable interval. If the results of the multiple-well hydraulic tests show vertical hydraulic connection between permeable zones, a cross-hole recirculating test may be conducted.

Each two-well recirculating test will be conducted in the following manner. Packers will be used to isolate test intervals in a pumping and injecting well. Water will be pumped from one well at a rate of between 6.3 and 18.9 L/s, and injected into the second well. Pumping will continue approximately 8 days until a steady-state flow system is established. Pressure transducers will be used to monitor pressure changes. Conservative tracers, including 3-trifluoromethylbenzoate, will be mixed with water and injected into the aquifer. The tracer will be injected as a short pulse. The steady-state recirculating flow pattern will be maintained following the tracer injection. Samples of pumped water will be collected and analyzed for tracer concentration. Sampling will continue for 1 to 3 weeks to ensure that all the tracer has had time to move through the formation. Test results will be interpreted using porous-media and fracture-network techniques that proved successful when applied to tracer-test results at the C-holes.

8.3.1.2.3.1.7 Activity: Testing of the C-hole sites with reactive tracers

Objectives

The objective of this activity is to characterize the chemical and physical properties of the geologic media in the saturated zone in the vicinity of the C-holes that will affect radionuclides retardation during ground-water flow within the saturated zoned.

Parameters

The parameters for this activity are

1. Adsorption rate constants.
2. Sorption equilibrium constants.

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Description

Tracer identification and characterization

A group of tracers will be selected that will aid in evaluating various controlling mechanisms of radionuclide sorption by the geologic media within the saturated zone in the vicinity of the C-wells. The tracers will be used in field tests that are part of site characterization investigations.

First, a screening of potential tracers to define controlling sorption mechanisms in various minerals will be conducted from literature reviews and consultations with experts. Second, laboratory tests will be conducted to select those procedures and analyses (for geologic material and water) that can facilitate the distinction among prevailing sorption mechanisms. Third, modeling of sorption experiments will be conducted using both kinetics and equilibrium expressions. Geochemical modeling will assist in defining the prevailing sorption mechanisms in laboratory studies.

The approach used to select these tracers is based upon the possible occurrence of various sorption mechanisms between solutes and geologic media. These mechanisms can be generally classified into two categories, physisorption and chemisorption. Physical adsorption exhibits low-energy changes in physical and chemical properties of the solute. On the other hand, chemical bonding results in energy changes that are strong enough to make the adsorbate (solute) exhibit physical and chemical properties different from those in solution. For example, physisorption shows heats of adsorption of 30 to 50 kJ $mole^{-1}$ compared with 200 to 500 kJ $mole^{-1}$ in chemisorption. Physical adsorption is characterized by small changes in vibrational frequency (~0.1%), while chemical adsorption is characterized by large changes (>0.1%). Chemical bonds, in contrast to physical bonds, are not readily broken at low temperatures. There is a third category, less understood, where sorption may have characteristics of both chemical and physical adsorption.

Within the two general categories of adsorption, two major mechanisms, and possibly a third, are of concern in these investigations: electrostatic adsorption, chemisorption, and possibly, molecular sieve. Electrostatic adsorption represents for this study a physical adsorption where ions in solution migrate to a diffuse layer because of electrostatic attraction of ions to a surface of opposite charge and because of the dispersive influence of diffusion forces. Ion exchange behavior is included in this definition. Chemisorption refers to those cases where forces with the order or magnitude of chemical bonds hold the adsorbate (solute) to a site surface. Molecular sieve falls in the category of physical sorption with energies of adsorption representing diffusional activation energies that are present when molecules are caught in cages as in zeolites.

This task will also evaluate manufactured polystyrene spheres as colloid tracers. These colloid tracers will be evaluated as to their interaction with the other tracers. These spheres have been shown to be conservative, and their size (1 micron) is larger than the dissolved chemical species so the spheres travel through the paths with the largest fractures or pores. It is anticipated that in fractured media, the polystyrene spheres will provide some information on fracture aperture.

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The rationale for using sorption mechanisms as a basis for selecting the tracers is the assumption that either of the three general mechanisms can prevail in the sorption of radionuclides at Yucca Mountain. The link between the radionuclides and the sorption mechanisms must be made in the laboratory because of constraints for environmental regulations and the complex chemistry exhibited by many of the actinides. Another advantage of using the sorption mechanism criterion for the reactive tracer study is the acquisition of fundamental information describing the interactions of general tracers with the rock media. This information increases the ability to interpret field experiments because marked differences in relative behavior of the mechanisms can provide a better insight into tracer response. An example is electrostatic sorption, which is a relatively reversible process as compared with chemisorption.

In this study, a combined approach is proposed that is a compromise between a more rigorous analysis based on surface coordination theory, for example, triple-layer concepts, and the more "empirical" approach associated with development of simple isotherms. Rates and isotherms will be derived to describe mathematically the generalized reaction of the tracers with the solid tuff material. At the same time, experiments will be conducted with individual minerals present in the tuff to develop a fundamental data base for mineral-tracer interactions. The number of minerals will be limited to those that are expected to be more reactive, for example, iron oxides. In this manner, some elements of a more rigorous approach are used. This work complements the empirical and mechanistic sorption work in Activity 8.3.1.3.4.1. The data obtained in the C-well reactive tracer work is specific to the C-well site (i.e., mineralogy, stratigraphic unit) and specific only to evaluation of proper tracers for this field test. The mechanistic work of Activity 8.3.1.3.4.1 is applied to the understanding of actinide sorption and will extrapolate or determine a spatial distribution of sorption for all important radionuclides across the site.

Initially, batch experiments will be performed with the primary emphasis on kinetics and equilibrium experiments. Column experiments will follow the batch experiments to evaluate simultaneous migration and interactions among selected tracers, including colloids, under various flow conditions. Geologic material, or their surrogates, and water from the Yucca Mountain vicinity will be used in experiments for isotherm development. Minerals, extracted from Yucca Mountain samples or purchased, and electrolyte solutions will be used in experiments to collect fundamental data on mineral-tracer interactions.

Initial batch experiments will attempt to identify tracers retarded by the primary controlling mechanism using thermodynamic indicators, adsorption-desorption differences, or response to desorption with electrolyte solutions. Supporting experiments will determine changes in electrostatic behavior, for example, zero point of charge. Also, batch experiments will be used to develop kinetics and equilibrium models. Laboratory column experiments will provide breakthroughs to simultaneously evaluate the selected tracers for their interactions with each other and their behavior in a transport environment. These breakthrough curves will also serve to validate the applicability of the models developed from batch data to continuous flow conditions.

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Appropriate sorption expressions, both kinetics and equilibrium, will be used to model experimental sorption data. The parameters from these models will be used in defining sorption processes and in predicting and interpreting field-observed breakthrough curves for the well experiments. Geochemical models will assist in designing laboratory experiments and in defining prevailing sorption mechanisms.

Modeling of tests

Concurrently with the tracer identification and characterization task, an extensive program of numerical modeling of the reactive-tracer field tests will be conducted. The purpose of this modeling is to define concentration ranges of tracers for the field tests and to indicate an expected duration and sampling frequency. Modeling of both single-well and multiple-well experiments will be conducted. Currently, it is unknown if the hydraulic response at the scale of the C-wells can be treated as a porous media equivalent. Therefore, both fracture network and porous media continuum models will be used. The media properties used in the numerical modeling will be obtained on a continuing basis; as the tests yield more information about the flow and media characteristics in the regions of the intended tests, these data will be incorporated into the numerical modeling.

Single-well tests

The type of tests, either injection-backflow or drift-pumpback, procedures, pumping rates, tracers, initial tracer concentrations, and durations of single-well tests will be specified by the results of the modeling studies. The goals of the single-well tests are (1) to demonstrate the use of reactive tracers in field tests and (2) to evaluate retardation characteristics of the saturated zone in the region near each of the wells tested.

Multiple-well tests

Two types of multiple-well tests are proposed: two-well recirculating and convergent tests. As for the single-well tests, modeling will be used in conjunction with information on the tracers to design these experiments.

Analysis of test results

In each field test a conservative (nonreactive) tracer will be added with the reactive tracer to permit calculation of flow velocity and dispersion of the tracer. These values will then be used with laboratory values of the sorption parameters for the reactive tracers to predict the response of the reactive tracer. In this way the laboratory parameter values for sorption are evaluated against field data. By making the laboratory connection with radionuclides, the retardation characteristics of the tested regions can be calculated.

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8.3.1.2.3.1.8 Activity: Well testing with reactive tracers throughout the site

Objectives

The objective of this activity is to characterize the chemical and physical properties of the geologic media in the saturated zone throughout the site that will affect radionuclide retardation during ground-water flow within the saturated zone.

Parameters

The parameters for this activity are

1. Adsorption rate constants.
2. Sorption equilibrium constants.

Description

Tracer identification and characterization

The same reactive tracers as were used in the C-hole experiments (Activity 8.3.1.2.3.1.7) will be used unless there is an unexpected change in geologic characteristics or ground-water chemistry. Some laboratory experiments will be required to estimate sorption parameters for the reactive tracers.

Modeling of tests

The wells used for this activity will be the same as those used for conservative (nonreactive) tracer tests throughout the site (Activity 8.3.1.2.3.1.6). The modeling will follow the same procedure as was used for the C-hole reactive tracer tests (i.e., laboratory values for sorption parameters will be used to design the tests). Modeling of both single-well and multiple-well tests will be conducted. Again, the type of model, fracture network versus porous media equivalent, cannot be determined until hydraulic studies have been completed. The media properties used in modeling will be obtained on a continuing basis, so the modeling will be as accurate as possible. The experience gained from the C-hole tests and modeling is expected to reduce significantly the amount of modeling required for this activity.

Single-well tests

If single-well tests in the C-holes indicate that good information on radionuclide retardation properties can be obtained from single well sorbing-tracer tests further single-well tests will be performed throughout the site. The number of tests will be determined by the availability of test wells, amount of information desired, and quality of information attainable. As noted previously, test procedures and specifications will be determined by the pre-test modeling studies.

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Multiple-well tests

If single-well tests do not provide sufficient information, a multiple-well location will be proposed and, if accepted, additional tests will be conducted. If this occurs and the C-hole tests indicate that multiple-well tests give useful information about radionuclide retardation properties in the saturated zone, then this multiple-well location will be used for further reaction tracer tests.

Analysis of test results

Analyses will proceed in the same fashion as was used in the C-hole study (Activity 8.3.1.2.3.1.7). A conservative tracer will be injected with the reactive tracer, and the conservative tracer will be used to estimate velocity and dispersion parameters. Then using laboratory-derived sorption parameters, the response of the reactive tracer will be predicted and compared with the field test. By making a connection in the laboratory between radionuclides and these tracers, inferences about radionuclide retardation can be made.

8.3.1.2.3.2 Study: Characterization of the saturated zone hydrochemistry

The objectives of this study are to (1) describe the chemical composition of, and spatial compositional variations in, saturated-zone ground waters using new and extant data; (2) identify the chemical and physical processes that influence ground-water chemistry; and (3) aid in the identification and quantification of fluxes to, from, and within the saturated zone.

Four activities are planned to meet these objectives. The activities are (1) assessment of saturated-zone hydrochemical data availability and needs, (2) hydrochemical characterization of water in the upper part of the saturated zone, (3) regional hydrochemical characterization, and (4) synthesis of saturated-zone hydrochemistry.

8.3.1.2.3.2.1 Activity: Assessment of saturated-zone hydrochemical data availability and needs

Objectives

The objectives of this activity are to

1. Compile and evaluate extant hydrochemical data for the saturated zone.

2. Identify data deficiencies and potential sampling sites and assemble requisite material for sample and field data collection.

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3. Augment extant information by collecting and analyzing new hydrochemical samples and data.

Parameters

The parameters for this activity are

1. Chemical concentration.
2. Stable-isotope ratio.
3. Radioisotope activity.

Description

Extant hydrochemical data for the saturated zone at Yucca Mountain, the Nevada Test Site, and the surrounding region will be compiled. The ionic balance of each analysis will be calculated as a means of initially assessing the quality of the data. Preliminary maps and cross sections of the spatial distributions of selected dissolved species and/or physical parameters will be prepared to depict the extant level of information. Published water-level maps will provide information about ground-water flow directions and gradients. This information will be reexamined as additional data become available. Published geologic descriptions of the site and the surrounding region will provide the locations of major structural features and information regarding formation geometries and lithologies. All the previously noted information will be integrated to delineate areas where additional data are needed.

Water samples will be collected to satisfy identified data needs when sampling opportunities arise in the course of other investigative activities, or when other satisfactory sampling sites are identified. All samples will be analyzed in the field for unstable constituents and intensive properties. They will be analyzed in USGS and contract laboratories for inorganic chemical concentrations; activities of selected radioisotopes, including tritium (hydrogen-3), carbon-14, and chlorine-36; and ratios of selected stable isotopes, including those of carbon, hydrogen, oxygen, strontium, and sulfur.

8.3.1.2.3.2.2 Activity: Hydrochemical characterization of water in the upper part of the saturated zone

Objectives

The objectives of this activity are

1. To describe the hydrochemistry of the upper part of the saturated zone by collecting representative water samples from intervals within the upper 100 m of the saturated zone, within and adjacent to the site area, and studying their chemical and isotopic compositions.

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2. To estimate flux to or from the saturated zone by collecting interstitial water and gas samples from immediately above the water table and studying their chemical and isotopic compositions.

Parameters

The parameters for this activity are

1. Chemical concentration.
2. Stable-isotope ratio.
3. Radioisotope activity.

Description

Fourteen wells that penetrate from 43 to 99 m into the saturated zone have been constructed within the site area (Table 8.3.1.2-10). These water-table (WT) wells are presently part of the water-level monitoring program. Each has been equipped with 2-in. inner-diameter access tubing for water-level measurement; some are instrumented for continuous water-level data collection. The Desert Research Institute collected water samples from five of these wells in early 1988. The samples were collected from within the access tubing with a small-capacity submersible piston pump. These are the only samples that have been collected from these wells. At least eight additional WT wells will be drilled in the course of other investigations of the saturated-zone geohydrologic system (Table 8.3.1.2-10).

Water samples will be collected from each of the extant and planned WT wells using a submersible electric pump. If determined to be feasible, a packer will be installed at appropriate locations in selected boreholes to enable collection of samples from both the upper and lower parts of the saturated interval penetrated by the wells. After samples have been collected, a removable packer/plug and two access tubes will be set about 10 m below the water surface in each well. An additional sample or samples will be collected from this isolated upper interval at a later date, using a small-capacity submersible piston pump.

All samples will be analyzed in the field for unstable constituents and intensive properties. They will be analyzed in USGS and contract laboratories for inorganic chemical concentrations; activities of selected radioisotopes, including tritium, carbon-14, and chlorine-36; and ratios of selected stable isotopes, including those of carbon, hydrogen, oxygen, strontium, and sulfur. These data will significantly augment the hydrochemical data base for the saturated zone within and adjacent to the site area, as existing information include data from intervals much deeper than those penetrated by the WT wells.

Selected planned WT wells will be cored for about 25 m immediately above and into the saturated zone. Interstitial gases and water will be extracted from several sections of unsaturated core from each well. Several sections of drained saturated core will also be squeezed to extract water from the rock matrix, if feasible. The cored wells and, if feasible, several of the extant WT wells will be sampled for interstitial gases from a discrete

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Table 8.3.1.2-10. Existing (November 1986) and planned water-table wells to be sampled and logged

Well number	Well depth (m/ft)	Approximate depth to water (m/ft)	Thickness of saturated interval penetrated (m/ft)
USW WT-1	515/1,689	471/1,545	44/144
USW WT-2	628/2,060	571/1,873	57/187
UE-25 WT#3	348/1,142	301/986	48/156
UE-25 WT#4	482/1,580	439/1,440	43/140
UE-25 WT#6	383/1,256	284/932	99/324
USW WT-7	491/1,610	421/1,382	69/228
USW WT-8[a]	640/2,100[b]	ND[c]	ND
USW WT-9[a]	670/2,198[b]	ND	ND
USW WT-10	431/1,413	343/1,142	83/271
USW WT-11	441/1,446	364/1,194	77/252
UE-25 WT#12	399/1,310	345/1,132	54/178
UE-25 WT#13	352/1,155	303/994	49/161
UE-25 WT#14	399/1,310	346/1,136	53/174
UE-25 WT#15	415/1,360	354/1,162	60/198
UE-25 WT#16	521/1,710	473/1,552	48/158
UE-25 WT#17	443/1,453	395/1,296	48/157
USW WT-19[a]	335/1,099[b]	ND	ND
USW WT-20[a]	305/1,000[b]	ND	ND
USW WP-21[a]	550/1,805[b]	ND	ND
USW WT-22[a]	395/1,296[b]	ND	ND
USW WT-23[a]	670/2,198[b]	ND	ND
USW WT-24[a]	670/2,198[b]	ND	ND

[a]Planned well.
[b]Estimated depth.
[c]ND = no data.

unsaturated interval adjacent to the water table following water-sample collection. Analytical data from these samples will also be used in Study 8.3.1.2.2.7 (hydrochemical characterization of the unsaturated zone).

Data from the WT wells will enable hydrochemical characterization of the upper part of the saturated zone, and comparison with the hydrochemistries of deeper intervals. The comparisons will aid in the development and refinement of a conceptual model of fluid movement in the saturated zone, with respect to fluid flow paths, velocities, and residence times. The data will also enable hydrochemical characterization of that part of the unsaturated zone adjacent to the water table. These data will augment the conceptualization and refinement of flux at the saturated-unsaturated zone interface.

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Caliper, epithermal-neutron porosity, magnetometer, magnetic, susceptibility, and possibly other experimental and supporting logs will be run from total well depth to land surface in each of the extent WT wells. These data will (1) aid in the evaluation of physical formation properties, (2) aid in stratigraphic correlations, and (3) determine vertical profiles of water content in the unsaturated zone. This data-collection activity will be carried out under Activity 8.3.1.4.2.1.3 (borehole geophysical surveys), and will precede sampling if it is logistically more efficient.

8.3.1.2.3.2.3 Activity: Regional hydrochemical characterization

Objectives

The objective of this activity is to describe regional spatial variations in ground-water chemistry in the saturated zone by collecting representative water samples from wells and springs within the region and by studying their chemical and isotopic compositions.

Parameters

The parameters of this activity are

1. Chemical concentration.
2. Stable-isotope ratio.
3. Radioisotope activity.

Description

Water samples will be collected from selected springs and extant wells within the Nevada Test Site and the surrounding region. As appropriate, newly drilled wells will be sampled, but no drilling is proposed for this activity. Sites selected will include some of those where alternative conceptual models of the regional geohydrologic system will be tested by Study 8.3.1.2.1.3 (characterization of the regional ground-water flow system), particularly with regard to ground-water flow rates and directions, and to support the designation of flow-system boundaries. Hydrochemical data from these sites will also provide insight as to the origin of anomalous features in the regional potentiometric surface.

Water samples will be analyzed in the field for unstable constituents and intensive properties. They will be analyzed in USGS and contract laboratories for inorganic chemical concentrations; activities of elected radioisotopes, including tritium, carbon-14, and chlorine-36; and ratios of selected stable isotopes, including those of carbon, hydrogen, oxygen, strontium and sulfur. Water-level drawdown and recovery data will be collected from wells during and after sampling, and used by Study 8.3.1.2.1.3 (characterization of the regional ground-water flow system) to estimate saturated hydraulic conductivities.

Hydrochemical data will be combined with existing data (Walker and Eakin, 1963; Schoff and Moore, 1964; Robinson and Beetem, 1965; Naff, 1973; Winograd and Thordarson, 1975; Benson et al., 1983; Classen, 1985) to

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describe the spatial compositional variations in regional ground-water chemistry. Radioisotope data will enable estimates of ground-water ages and flow rates. Stable isotope and inorganic concentration data will provide insight as to the origins, evolution, and mixing of ground waters, and will aid in comparison of site-specific data in order to delineate possible flow paths. These data will also be used by Activity 8.3.1.2.3.2.4 (synthesis of saturated-zone hydrochemistry) to identify the chemical and physical processes that influence ground-water chemistry; to aid in the identification and/or quantification of ground-water travel times, flow paths, and fluxes to, from, and within the saturated zone; and to estimate climatic conditions during periods of recharge. The data will also be part of the information base used by Study 8.3.1.3.1.1 (ground-water chemistry model).

8.3.1.2.3.2.4 Activity: Synthesis of saturated-zone hydrochemistry

Objectives

The objectives of this activity are to

1. Describe the saturated-zone hydrochemistry.

2. Identify the chemical and physical processes that influence ground-water chemistry.

3. Aid in the identification and/or quantification of ground-water travel times; climatic conditions during periods or recharge; flow paths; and fluxes to, from, and within the saturated zone.

Parameters

The parameter for this activity is geochemical reaction modeling.

Description

Graphical methods will be used to describe spatial distributions of selected chemical and isotopic data. Variations will be integrated with extant information describing ground-water flow directions, spatial distributions of secondary minerals, spatial petrologic variations, and whole-rock and mineralogic compositions, in order to identify sources and sinks of dissolved materials, to infer sources and areas of recharge, and to estimate ground-water flow paths, flow rates, and residence times.

The geochemical modeling code EQ3NR/EQ6 (Wolery, 1979; 1983) will be used with the bases of hydrochemical and mineralogic data to (1) calculate the specifications of dissolved materials, (2) determine the saturation states of relevant solid phases, and (3) test plausible water-rock reaction models. The results of these efforts will aid in the identification of the geochemical process that have combined with ground-water flow to determine the present ground-water chemistry. Process identification will also contribute to an understanding of the paleohydrology of the region, and to general resolution of ground-water flow paths, residence times, and recharge

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conditions. The analytical and process data will also comprise part of the geochemical base needed by performance and design issues 1.1 through 1.12, as addressed by Section 8.3.1.3.

The information generated by this activity will constitute "nonhydraulic" tests of alternative conceptual models of the ground-water flow system.

8.3.1.2.3.3 Study: Saturated zone hydrologic system synthesis and modeling

The objectives of this study are to (1) synthesize the available data into a model and make a qualitative analysis of how the system is functioning and (2) represent quantitative observations of hydrogeologic data pertaining to the ground-water flow system in a comprehensive flow model. Three activities are planned to analyze and integrate the data in order to satisfy these objectives. The planned activities are the conceptualization of the saturated zone flow models within the boundaries of the accessible environment; the development of a fracture network model; and the calculation of flow paths, fluxes, and velocities within the saturated zone.

8.3.1.2.3.3.1 Activity: Conceptualization of saturated zone flow models within the boundaries of the accessible environment

Objectives

The data objectives of this activity are to synthesize the available hydrogeologic data to develop a conceptual model and make a qualitative analysis of how the site saturated-zone hydrogeologic system is functioning.

Parameters

The parameters for this activity are spatial distribution of the hydrogeologic units and their hydraulic properties, including

1. Hydraulic conductivity.
2. Hydraulic gradient.
3. Effective porosity.
4. Flux.
5. Water chemistry.
6. Storage properties.
7. Potentiometric surface configuration.

Description

All reliable data and reasonable interpretations of these data will be assimilated into a description of the saturated-zone flow system within the boundaries of the accessible environment. This description will include the physical and hydraulic characteristics of the rock units and structural features, as well as the likely flow-system operation within this framework.

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The data will contain information accumulated from the published literature and the Yucca Mountain Project activities. This conceptual description of the flow system will be incorporated into computer models as the baseline condition for ground-water flow at the site.

8.3.1.2.3.3.2 Activity: Development of fracture network model

Objectives

The objectives of this activity are to

1. Develop and evaluate methods for simulating ground-water flow and conservative solute transport in saturated fractured rock beneath Yucca Mountain.

2. Relate results of hydraulic and conservative-tracer tests in wells to fracture-network characteristics at Yucca Mountain.

3. Develop methods for identifying transmissive fracture zones in rocks penetrated by boreholes.

4. Identify geohydrologic conditions at Yucca Mountain where ground-water flow and conservative solute transport can be properly evaluated using the porous-medium assumption.

Parameters

The parameters for this activity are various flow and transport characteristics needed to predict rates and directions of ground-water flow and radionuclide migration, including

1. Hydraulic conductivity.
2. Storage coefficient.
3. Effective porosity.
4. Hydrodymanic dispersion.
5. Hydraulic gradients.

Description

Major technical components of the hydrologic analysis of fracture networks are broadly placed into three tasks. The first task (preliminary model development) emphasizes model development and evaluation using existing data or data that can be readily obtained. The second task (analysis of well tests) emphasizes model refinement and validation at multiple-well locations in the saturated zone beneath Yucca Mountain. The third task (analysis at the scale of Yucca Mountain) emphasizes model development at the scale of Yucca Mountain and characterization of spatial variations in aquifer properties in the vicinity of Yucca Mountain.

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Preliminary model development will include development and documentation of computer programs to describe fracture-network geometry and to simulate flow and transport in fractured rock. A model will be developed that is capable of simulating ground-water flow and conservative-solute transport in a saturated discrete-fracture network. The model will be used to simulate pumping and tracer tests at the C-holes. Existing codes are specialized for column research and do not include well-boundary conditions that occur during pumping and tracer tests. The new model will include two computer codes, a fracture-mesh generator and a flow- and-transport code. The fracture-mesh generator will be capable of reproducing statistical descriptions of fracture characteristics. The flow-and- transport code will be capable of simulating both steady-state and transient conditions within the fracture network.

Although the fracture-network model will be developed primarily for application at the C-holes, it will be written with a broad range of potential applications in mind. Boundary conditions will not be restricted to those that will be encountered during pumping and tracer tests but will include boundaries that would be encountered at other scales. Initially the model will be developed on the basis of parallel-plate theory but will also be written in a modular manner so that new theories, such as channeling within single fractures, can be readily included in the codes as they become available. By writing the model in this manner, it will be relatively simple to evaluate the significance of alternative theories when applied to fracture networks. The model will be designed primarily for application in a perturbed flow system that develops during pumping and tracer tests, but also for possible application in a natural system that may exist after radioactive waste is placed in the repository.

Initially, the fracture-mesh generator will be similar to one described by Long et al. (1982). Fractures will be modeled as linear or disc-shaped discontinuities in an impermeable matrix. Fractures will be arbitrarily located within the rock and will have statistical distributions of aperture, length, orientation, and density that can be specified by the user. The mesh generator will be capable of reproducing discrete fractures observed in boreholes. As data and results developed as part of Activity 8.3.1.4.2.2.2 (surface-fracture) network studies become available, these results may be included in the fracture-mesh generator.

The flow and transport code will use a mixed Eulerian-Lagrangian solution technique. Ground-water flow in fractures will be solved using parallel-plate theory within the usual Eulerian framework. Advective transport will be solved by a Lagrangian formulation using particle-tracking techniques. Several techniques, including random-walk theory, will be evaluated before deciding on a method for treating dispersion within single fractures. Modular-program design will make it relatively simple to evaluate techniques for modeling dispersion. Alternative methods for modeling transport at fracture junctions, including complete mixing of solute from different fractures and no mixing, will also be evaluated before finally selecting a method.

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A series of simulations will be designed to test whether the model successfully reproduces known analytical solutions and to evaluate the significance of approximations used in the solution method. Documentation will include descriptions of model theory, use (including input and output descriptions), verification and validation simulations, and program listings.

Parametric studies, using fracture-characteristic data obtained from drillholes UE-25c#1, UE-25c#2, and UE-25c#3 (Figure 8.3.1.2-29), will be done for the following two purposes:

1. To evaluate the effects of fracture characteristics on results of well tests. Such studies may indicate important needs in field investigations, including needs for specific types of well tests. Test designs that are typically used in a porous medium may not be optimal for understanding the hydrologic nature of the fractured rock at Yucca Mountain.

2. To evaluate the general hydrologic behavior of the saturated zone, to establish whether fracture statistics from boreholes at Yucca Mountain are representative of the saturated zone. Special emphasis will be given to (a) identifying scales where flow and transport in a fracture network can be simulated appropriately by analogy to an equivalent porous medium, and (b) investigating the character of convective dispersion.

Fracture networks, used in parametric studies, will bracket the range of uncertainty in fracture characteristics. Fracture frequency and orientation has been measured in boreholes from television and televiewer logs; however, fracture data to describe the distribution of fracture lengths and fracture apertures are not available. Therefore, initial parametric studies will consider fracture networks with uniform lengths and apertures. After the hydrologic response of fracture networks with uniform lengths and apertures is understood sufficiently, distributed lengths and apertures will be used in parametric studies.

Results of Activity 8.3.1.4.2.2.5 (seismic tomography) will be related to characteristics of fracture networks. Major components of the hydrologic investigation that use these results are (1) identification of relations between seismic-wave properties, fractures, and lithology, by prototype vertical seismic profiling at USW G-4; (2) identification of fracture characteristics between boreholes at the scale of well tests by cross-hole seismic profiling at the UE-25c wells and possibly a second multiple-well location; (3) validation of seismic techniques by profiling the exploratory shaft and comparing results to fractures mapped in the shaft; and (4) determination of spatial variations in fracture characteristics in the vicinity of Yucca Mountain by seismic profiling over distances of 0.5 to 1 km.

Fracture networks generated on the basis of preceding geologic and geophysical investigations will be used in the finite-element program to calculate rates of ground-water flow across the network under linear-flow boundary conditions. Rates of flow will be related to hydraulic conductivity of an equivalent porous medium using an approach similar to that described by Long et al. (1982). An approach similar to Endo and Witherspoon (1985) will be used to relate flow rate to hydraulic effective porosity. Methods de-

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scribed by Long et al. (1982) also will be used to identify the scale of representative elementary volumes (REV) of fracture networks; and hence to determine scales where a fracture network can be described by analogy to an equivalent porous medium. The scale of REV may be different for flow and transport.

Multiple fracture networks generated from the same set of fracture statistics may have significantly different hydrologic character. If a fracture system has a REV and the scale of simulation is larger than the REV, by definition, multiple realizations should have reasonably similar hydrologic character. If the scale of simulation is smaller that the REV, the probability of significantly different hydrologic character depends on various parameters, of which fracture frequency and aperture are most critical. The importance of generating multiple fracture networks when applying the fracture-network model in well tests cannot be evaluated until preliminary parametric studies are completed.

The analysis of well tests will be done in two phases. The first, involves testing at the UE-25c wells and will emphasize model refinement, in particular, understanding relations between geophysical and hydrologic models. The previous task, preliminary model development, emphasized the use of existing data or data that could be readily obtained. Some aspects of the conceptual models developed on the basis of these data probably will prove incorrect or will not be sufficiently detailed when applied in deeply buried rocks of the saturated zone beneath Yucca Mountain. Furthermore, no data exist that can be used to investigate possible relations between seismic and hydrologic models. Therefore, significant model refinement is expected as a result of interpreting well tests at the UE-25c wells. (These well tests are described in Activities 8.3.1.2.3.1.4 and 8.3.1.2.3.1.5). The second phase of this activity will emphasize model validation at a second multiple-well location. The second phase will be curtailed if a second multiple-well location is not drilled. Drilling and subsequent hydrologic testing of a second multiple-well location is described in Activity 8.3.1.2.3.1.6.

The hydrologic model of fracture networks will be used to interpret results of hydraulic and conservative-tracer tests at the UE-25c wells. On the basis of results from parametric studies and seismic modeling, a set of fracture networks will be generated that brackets the range of uncertainty in fracture characteristics. These networks will be conditioned so that fractures observed in the boreholes are realized. Components of the geologic model of fracture networks that are uncertain also will be considered in selecting fracture networks. Fracture networks initially generated on the basis of geologic and geophysical evidence will be used to simulate hydraulic-test results. Those networks that best match measured results of hydraulic-stress and tracer tests will be considered representative of the fractured rock in the vicinity of the tested wells. Because fracture-network characteristics probably cannot be determined uniquely by simulation of well-test results, statistical algorithms for determining likely fracture networks will be used.

Assuming a second multiple-well location is drilled and tested, model validation probably will be a four-step process. Because conceptual models have not been formulated in detail, it is not appropriate to speculate on detailed interpretive approaches until gaining experience in testing and

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analysis at the UE-25c wells. The first step in validation will be to drill the wells and collect adequate seismic-profile data to use in geophysical and hydrologic modeling. The second step is to design appropriate hydraulic and tracer tests and predict test results. Geophysical and intraborehole flow data will be used to select appropriate test designs. Geologic and geophysical models will be used to estimate fracture-network geometry. Hydrologic models, using the estimated fracture-network geometry as a basis, will predict test results. Uncertainty in model analysis will need to be evaluated when predicting test results. Therefore, predictions probably will be expressed statistically, either as a range of probable results, or as a best estimate of results and associated confidence regions. The third step will be to conduct the tests. The fourth step in validation will be to compare predicted test results with actual test results.

Hydrologic models that are developed during this investigation probably will be most accurate when applied at the scale of well tests. However, the ultimate use of the model will be at the scale of Yucca Mountain, where details measurable at the scale of well tests will not be measured. Therefore, numerical methods corresponding to the scale of Yucca Mountain will be evaluated and a numerical model will be developed. Computer programs will be written, verified, and documented.

If available, well-documented cases of solute migration in fractured rock will be used to validate models at scales similar to those of Yucca Mountain (1 to 100 km^2). To form an appropriate model-validation exercise, the history of contamination and subsequent migration would need to be known, and the geologic framework would need to be similar to the geologic framework of Yucca Mountain.

Methods for estimating aquifer properties in areas between boreholes will depend on the availability of cross-hole seismic-profiling data and the success in relating seismic-wave propagation to hydrologic properties. If data are available and relations between seismic and hydrologic properties are demonstrated during investigation of multiple-well locations, the geophysical models described previously will be used to estimate spatial variations in fracture networks. Results of geophysical models would then be used in the hydrologic models described previously to predict the spatial distribution of aquifer properties. Aquifer-property estimates obtained from hydrologic well tests, and fracture data obtained from boreholes would be used to condition the predicted spatial distribution of aquifer properties.

If geophysical data are not collected or cannot be used to estimate aquifer properties with confidence, appropriate geostatistical methods might be used to estimate the spatial distribution of aquifer properties. Geostatistical techniques such as kriging and conditional simulation may be appropriate if distances between point estimates of aquifer properties are less than the ranges of the corresponding semivariograms.

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8.3.1.2.3.3.3 Activity: Calculation of flow paths, fluxes, and velocities within the saturated zone to the accessible environment

Objectives

The objectives of this activity are to

1. Estimate ground-water flow direction and magnitude for input into travel-time calculations.

2. Evaluate the porous-media concept and fracture-network concept for determining flow paths, fluxes, and velocities.

Parameters

The parameters for this procedure are

1. Flow paths.
2. Fluxes.
3. Velocities.

Description

Techniques used to interpret results of hydraulic and chemical-tracer tests will be evaluated by the following two criteria:

1. Data must be available at the scale of hydrologic-well tests to justify using the technique. In other words, the technique must not have overly complex data requirements when compared with test data that typically are available.

2. Estimates of flow paths, fluxes, and velocities obtained by applying the technique at the scale of hydrologic-well tests must be reasonably reliable.

Although it is not known if any technique will meet these criteria completely, it is important to make such an evaluation. Techniques that will be evaluated include those based on the concept of an equivalent porous medium, a dual-porosity medium, and a discrete-fracture network. Techniques are described in greater detail in Study 8.3.1.2.3.1 (characterization of the site saturated-zone ground-water flow system).

The relation between techniques applicable at the scale of hydrologic well tests and techniques applicable at regional scales has not been established for most fractured media. Techniques that successfully simulate results or hydrologic-well tests will be extended on a theoretical basis for use in large-scale models. Scale dependence of many model parameters is expected. Hydrologic well tests are conducted in a perturbed flow system, while large-scale models evaluate a relatively unpreturbed system. This raises questions when using well test results in regional analyses.

Applicability of techniques proved successful at the scale hydrologic-well tests to large-scale problems will be evaluated by conducting sensitivity analyses and simulations of flow and transport in hypothetical flow

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systems. The hypothetical systems will be similar conceptually and will retain many of the important hydrologic characteristics of Yucca Mountain but will be simplified for ease of data input.

If fractured rock at Yucca Mountain can be represented by an equivalent porous medium with aquifer properties that are statistically homogeneous at a local scale, then a technique described by Winter et al. (1984) will be evaluated. Winter et al. (1984) recognize the scale dependence of dispersion and velocity but show that, at large scales in statistically homogeneous porous media, these parameters are approximately constant. Large-scale estimates are calculated from local-scale measurements of hydraulic conductivity and dispersion coefficient.

If results of hydrologic well tests show that fractured rocks at Yucca Mountain are realistically represented by equivalent porous media with aquifer properties that are statistically heterogeneous at a local scale or by a discrete fracture network, then a technique described by Schwartz and Smith (1985) will be evaluated. In this technique, local-scale models of flow paths, fluxes, and velocities are developed as a preliminary to a large-scale model. The local-scale models are based either on discrete fracture networks or equivalent porous media with statistically heterogeneous aquifer properties. Boundaries of the local-scale models are established to reproduce conditions expected at the large scale. In practice only a small number of local-scale models, representative of variations in regional conditions, are constructed. The large-scale model uses either finite difference or finite-element medium. Statistics obtained during simulations with the local-scale models are used to describe the character of ground-water movement within large-scale blocks or elements. In this manner, the large-scale model accounts for the influence of fractures in a realistic way.

Flow paths, fluxes, and velocities will be estimated during development of the regional and site model of ground-water flow and transport. The models will be based on the concept of an equivalent porous medium and the classical advection-dispersion equation. Models for developing these models are described elsewhere (Activities 8.3.1.2.1.4.1 through 8.3.1.2.1.4.4, and 8.3.1.2.3.3.1). The models include site information describing recharge and discharge boundaries, potentiometric surfaces, and aquifer properties such as hydraulic conductivity and effective porosity. Sensitivity analyses, formal parameter-estimation techniques, or both will be used to evaluate the reliability of estimates of flow paths, fluxes, and velocities. These modeling activities will be coordinated with flow modeling activities described in Section 8.3.5.12. Specific plans for verification and validation have not yet been developed.

The technique identified previously to account for the influence of fractures in a realistic way will be used with the existing flow and transport models of Yucca Mountain. Sensitivity analyses will be conducted to provide physically based estimates of confidence in flow paths, fluxes, and velocities. If results of investigations show that the fractured rock at Yucca Mountain can be described realistically by an equivalent porous medium with aquifer properties that are statistically homogeneous at a local scale, then a technique similar to that of Winter et al. (1984) will be used and refined estimates probably will be unchanged from initial estimates of flow paths, fluxes, and velocities. Otherwise, a technique similar to that of

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Schwartz and Smith (1985) will be applied and refined estimates may be significantly different from initial estimates.