Department of Energy
Washington, DC 20585

OCT 28 1993

Mr. Joseph J. Holonich, Director
Repository Licensing & Quality Assurance
Project Directorate
Division of High-Level Waste Management
Office of Nuclear Material Safety
and Safeguards
U.S. Nuclear Regulatory Commission
Washington, D.C. 20555

Dear Mr. Holonich:

In the U.S. Nuclear Regulatory Commission (NRC) Phase I review letter of April 5, 1993 (enclosure 1) of the U.S. Department of Energy's (DOE) Study Plan 8.3.1.5.2.2 (Characterization of Future Regional Hydrology Due to Climate Changes), the NRC requested that DOE provide the Not-Readily-Available (NRA) reference cited in the study plan. Enclosure 2 contains the reference requested for Study Plan 8.3.1.5.2.2.

If you have any questions, please contact Ms. Sheila Long at 202-586-1447.

Sincerely,

J L P Roberts
Dwight E. Shelor for
Associate Director for
Systems and Compliance
Office of Civilian Radioactive
Waste Management

Enclosures:
1. Ltr, 4/5/93, Holonich to
   Shelor, w/encl
2. Reference for Study
   Plan 8.3.1.5.2.2

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cc w\enclosures
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APR 5 1993

Mr. Dwight E. Shelor, Associate Director for
  Systems and Compliance
Office of Civilian Radioactive Waste Management
U.S. Department of Energy
1000 Independence Avenue, SW
Washington, DC 20585

Dear Mr. Shelor:

SUBJECT: REVIEW OF U.S. DEPARTMENT OF ENERGY (DOE) STUDY PLAN "CHARACTERIZATION OF THE FUTURE REGIONAL HYDROLOGY DUE TO CLIMATE CHANGES"

On December 24, 1992, DOE transmitted the study plan, "Characterization of Future Regional Hydrology Due to Climate Changes" (Study Plan 8.3.1.5.2.2) to the U.S. Nuclear Regulatory Commission for review and comment. NRC has completed its review of this document using the Review Plan for NRC Staff Review of DOE Study Plans, Revision 2 (March 10, 1993). The material submitted in the study plan was considered to be consistent, to the extent possible at this time, with the revised NRC-DOE "Level of Detail Agreement and Review Process for Study Plans" (Shelor to Holonich, March 22, 1993).

A major purpose of the review is to identify concerns with studies, tests, or analyses that, if started, could cause significant and irreparable adverse effects on the site, the site characterization program, or the eventual usability of the data for licensing. Such concerns would constitute objections, as that term has been used in earlier NRC staff reviews of DOE's documents related to site characterization (Consultation Draft Site Characterization Plan and the Site Characterization Plan for the Yucca Mountain site). It does not appear that the conduct of the activities described in this study plan will have adverse impacts on repository performance and the review of this study plan identified no objections with any of the activities proposed.

Among the references listed for this study is one that has not been provided to the NRC and is not readily available in the public domain. We therefore request that DOE provide the NRC with that reference which is listed in the Enclosure.

The NRC staff plans to provide DOE with detailed technical comments related to this study plan. Those comments will be transmitted at a later date, following the receipt of the requested reference.

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ENCLOSURE 1

If you have any questions concerning this letter, please contact Charlotte Abrams (301) 504-3403 of my staff.

Sincerely,

Joseph J. Holonich, Director
Repository Licensing and Quality Assurance
Project Directorate
Division of High-Level Waste Management
Office of Nuclear Material Safety
and Safeguards

Enclosure: As stated

cc: R. Loux, State of Nevada
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M. Baughman, Lincoln County, NV
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E. Holstein, Nye County, NV

NOT READILY AVAILABLE REFERENCE FOR STUDY PLAN 8.3.1.5.2.2

Konikow, L.F., 1978, Calibration of ground-water models, _in_ Proceedings of the Specialty Conference on Verification of Mathematical and Physical Models in Hydraulic Engineering: American Society of Civil Engineers, College Park, Maryland, p. 87-93.

ENCLOSURE

VERIFICATION OF MATHEMATICAL AND PHYSICAL MODELS IN HYDRAULIC ENGINEERING

PROCEEDINGS
26th Annual
Hydraulics Division Specialty Conference
University of Maryland
College Park, Maryland
August 9-11, 1978

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New York, N.Y. 10017

Mannings equation was used to compute the roughness coefficient n for both the reaches for all the discharges. The numerical value of n varied from 0.038 to 0.049. For low flows, the values of n were more than those present for the high flows.

Low Flow Characteristics: In order to study the hydraulics of flow during extremely dry seasons, a set of data was collected from Reach 1 for two sequences of riffle and pool. The discharge was about 58 cfs which is little over the minimum release from the Shelbyville Lake (7 day 10 year low flow). The Froude number varied from 0.56 at the riffle section to about 0.10 at the pool with the d_{50} sizes varying from 40 mm in the riffle to 0.2 mm in the pool. The location of the thalweg during these low flows was completely different than that present during high flows. During high flows the water surface profile changed very smoothly along the length of the river, but for low flows the variability was steep in the riffle and then changed to very smooth in the pool. Some of these low flow results were already presented by Bhowmik and Stall (1978 b).

ACKNOWLEDGEMENT

Partial support for this research was provided by the Illinois Division of Water Resources, Department of Transportation, State of Illinois.

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CALIBRATION OF GROUND-WATER MODELS

Leonard F. Konikow*

Introduction

Aquifer analysis can be greatly aided by the application of deterministic numerical models, which solve the equations describing ground-water flow and solute transport. For the interpretations of model output to be believable, it must be demonstrated that the model accurately solves the governing equations and accurately represents the real system. The numerical accuracy of the model is not commonly a factor limiting model reliability. Rather, the dominant cause of errors in model output is the presence of errors or uncertainty in the input data, which reflect our inability to accurately and quantitatively describe the aquifer properties, stresses, and boundaries.

To demonstrate that a deterministic ground-water simulation model is realistic, field observations of aquifer responses should be compared to corresponding values obtained from the model. The objective of this calibration procedure is to minimize differences between the observed data and the computed values. In effect, the model is calibrated by reproducing a set of historical data with some acceptable level of accuracy.

Calibration Procedure

Matalas and Maddock (1976) argue that model calibration is synonymous with parameter estimation. In practice, the calibration of a deterministic ground-water model is frequently accomplished through a trial-and-error adjustment of the model's input data (aquifer properties, sources and sinks, and boundary and initial conditions) to modify the model's output. Because a large number of interrelated factors affect the output, this may become a highly subjective procedure. Recent advances in parameter identification procedures, such as described by Cooley (1977), will help to eliminate some of the subjectivity inherent in model calibration. However, the hydrogeologic experience and judgement of the modeler will always be an important factor in calibrating a model both accurately and efficiently. The modeler should be familiar with the specific field area being studied to know that both the data base and the numerical model adequately represent existing field conditions. The modeler must also recognize that the uncertainty in the specification of sources, sinks, and boundary and initial conditions should be evaluated during the calibration procedure in the same manner as the uncertainty in aquifer properties.

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In general it is more difficult to calibrate a solute-transport model of an aquifer than it is to calibrate a ground-water flow model. Fewer parameters need to be defined to compute the head distribution with a flow model than are required to compute concentration changes with a solute-transport model. Because the ground-water seepage velocity is determined from the head distribution, and because both convective transport and hydrodynamic dispersion are functions of the seepage velocity, a model of ground-water flow must usually be calibrated before an adequate and reliable solute-transport model can be developed.

Before a model can be calibrated, it first must be selected as appropriate for the given problem and then applied or constructed. A numerical deterministic distributed-parameter model involves selecting spatial grids and time increments, as well as best estimates of aquifer properties, stresses, and boundary conditions. This initial working model reflects a previous conceptual model of the aquifer system. Another objective of model calibration is to improve the conceptual model of the aquifer. The conceptual model consists of our understanding of the physical and functional nature of the aquifer, including sources of recharge and discharge, rates and directions of flow, variations in aquifer properties and hydraulic potential, and its relation to surface water and other aquifers. Because the simulation model numerically integrates the effects of the many factors that affect ground-water flow or solute transport, the computed results should be internally consistent with all input data, and we can determine if any element of our conceptual model must be revised. In fact, previous concepts or interpretations of aquifer parameters or variables, such as represented by potentiometric maps or the specification of boundary conditions, may be revised during the calibration procedure as a result of feedback from the model's output. In a sense, any adjustment of input data constitutes a modification of the conceptual model.

Mass-balance calculations should be performed during the calibration procedure to check the numerical accuracy of the solution. As part of these calculations, the hydraulic and chemical fluxes contributed by each distinct hydrologic component of the flow and solute-transport model should be itemized to form hydrologic and chemical budgets for the aquifer in the modeled area. The budgets are valuable because they provide a measure of the relative importance of each component to the total budget. Errors in the mass balance for a ground-water flow model should generally be less than 0.1 percent. However, because the solute-transport equation is more difficult to solve numerically, the mass-balance error for a dissolved chemical may be an order of magnitude or more greater than for the fluid.

A model is considered to be verified if its accuracy and predictive capability have been proven to lie within acceptable limits of error by tests independent of the calibration data. A model that has been calibrated only to reproduce historical data should not be considered a verified model. Nevertheless, a calibrated model can be used to analyze or predict future aquifer responses. The accuracy of its predictions is the best measure of a model's reliability. A major limitation of predictive simulations is the uncertainty of future stresses. But if the range of future stresses can be estimated, then the range of future responses can be predicted.

Parameter Adjustment

Many input data are required for the numerical model, and the accuracy of these data will affect the reliability of the computed results. In most field problems there will be some inadequate data, so the values for some parameters will have to be estimated. A common approach is to first assume your best estimate of values for parameters, and then to adjust their values until a best fit is achieved between the observed and computed variables. Although this can probably be accomplished most efficiently using a parameter-estimation model, the trial-and-error method is probably still most commonly used.

In order to maintain the value of the process-oriented structure of a deterministic model, the degree of allowable adjustment of any parameter should generally be directly proportional to the uncertainty of its value or specification, and limited to its range of expected values or confidence interval. For example, in a study of the Madison Limestone aquifer (Konikow, 1976), pumping rates were relatively well known, so their values were not adjusted. But because the transmissivity was poorly known, various values were assumed over a possible range of several orders of magnitude.

Parameter adjustment will produce a change in model output. The responses to parameter adjustment should be evaluated quantitatively to provide the modeler a measure of his progress in model calibration and to guide him in determining the direction and magnitude of subsequent changes in model input. This will require an evaluation of successive changes in the goodness of fit between the observed data and the model output. One procedure for evaluation is to plot changes of the mean difference between observed and computed data and changes in the standard error of estimate for successive simulation tests during model calibration.

As an example, this procedure was used by Konikow (1977) in calibrating a flow and transport model for an alluvial aquifer in Colorado. In the procedure the water-table configuration served as the basis for evaluating goodness of fit with respect to adjustments of transmissivity, net recharge in irrigated areas, and some boundary conditions. Initial estimates of net recharge were used in a preliminary calibration of the model. Next, transmissivity values and boundary conditions in the model were adjusted between successive simulations with an objective of minimizing the differences between observed and computed water-table altitudes in the irrigated area. As shown in figure 1, the standard error of estimate generally decreased as successive simulation tests were made. After about seven tests, additional adjustments produced only small improvements in the fit between the observed and computed water tables. A final estimate of the net recharge rate in irrigated areas was made using the values for other parameters developed for the previous test having a minimum standard error of estimate. The mean of the differences between observed and computed heads at all nodes in the irrigated area was then minimized (equal to zero) when a net recharge rate of approximately 1.54 ft/yr (0.47 m/yr) was assumed. A drawback to this trial-and-error approach is that the uniqueness of the solution can not be easily demonstrated.

Assuming various values for given parameters also helps to achieve another objective of the calibration procedure, namely to determine the sensitivity of the model to factors that affect ground-water flow or solute transport. Evaluating the importance of each factor helps determine which data must be defined most accurately and which data are already adequate or require only minimal definition. If additional data cannot be collected, then the sensitivity tests can help to assess the reliability of the model by demonstrating the effect of a given range of uncertainty or error in the input data on the output of the model. The relative sensitivities of the parameters that affect flow and solute transport will vary from problem to problem. Thus, the only generalization that can be stated with certainty is that a sensitivity analysis should be performed during the early stages of a model study.

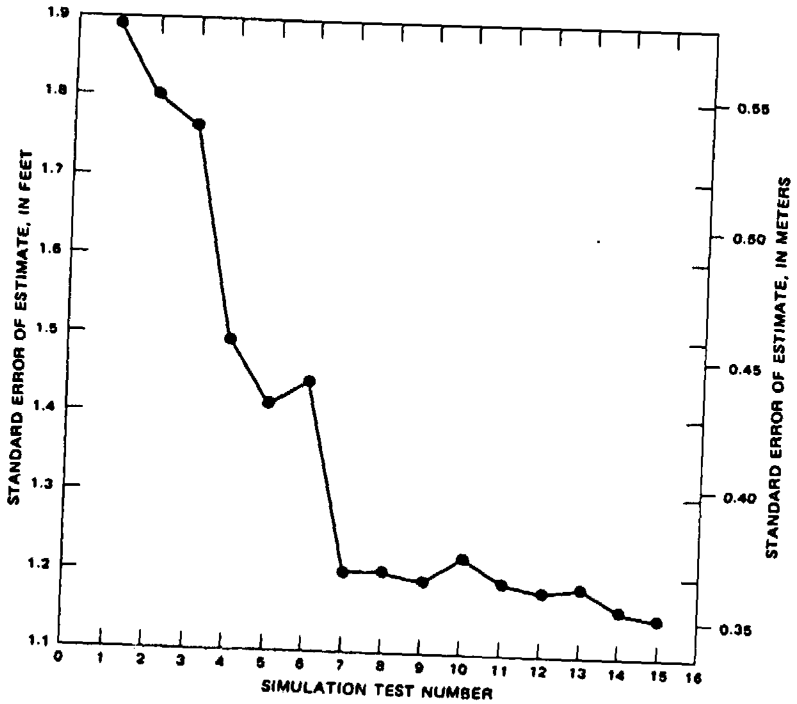

Figure 1.--Change in standard error of estimate for successive simulation tests (from Konikow, 1977).

Calibration Criteria

Model calibration, especially with a trial-and-error approach, may be viewed as an evolutionary process in which successive adjustments and modifications to the model are based on the results of previous simulations. The modeler must decide when sufficient adjustments have been made and at some time accept the model as being adequately calibrated (or perhaps reject the model as being inadequate and seek alternative approaches). This decision is often based on a mix of subjective and objective criteria. The achievement of a best fit between values of observed and computed variables is a regression procedure and can be evaluated as such. That is, the residual errors should have a mean that approaches zero and the deviations should be minimized. Cooley (1977) discusses several statistical measures that can be used to assess the reliability and goodness of fit of ground-water flow models. The accuracy tests should be applied to as many dependent variables as possible. The types of observed data that are most valuable for model calibration include head and concentration changes over space and time, and the quantity and quality of ground-water discharges from the aquifer.

While it is necessary to evaluate quantitatively the accuracy of the model, it is equally important to assure that the dependent variables that serve as a basis for the accuracy tests are reliable indicators of the computational power and accuracy of the model. For example, if a particular variable were relatively insensitive to the governing parameters, then the existence of a high correlation between its observed and computed values would not necessarily be a reflection of a high level of accuracy in the overall model. For example, in modeling an alluvial stream-aquifer system in Colorado, Konikow and Bredehoeft (1974) found that the computed streamflow at the downstream end of the study reach coincided almost exactly with the observed streamflow. However, the greatest component of computed outflow at the downstream end of the study reach, which averaged about 4.1 m^3/s, was the observed inflow at the upstream end of the study reach, which averaged about 3.8 m^3/s. Because stream gains and losses within the study reach were small (about 8 percent) relative to the actual streamflow, the accuracy of the fit between observed and computed streamflow values for the downstream gaging station is a poor indicator of the reliability of the model. A better indicator was the change in streamflow in the study reach. However, during periods of high flow, the change in streamflow represented only about 3 percent of the actual flow, which is about the same order of magnitude as the measurement errors. Therefore, the lack of a precise fit during these high-flow periods does not indicate that the model is poor or uncalibrated.

Similarly, caution must be exercised when the "observed data" contain an element of subjective interpretation. For example, matching an observed potentiometric surface is sometimes used as one basis for calibrating a ground-water flow model, and an observed concentration distribution may serve as a basis for calibrating a solute-transport model. Both represent interpretive contouring of observed point data that have some limited frequency and accuracy.

Thus, a contoured surface serves as a weak basis for model calibration because it includes a variability or error introduced by the contourer, in addition to the measurement errors present in the observed data at the specific points. Cooley and Sinclair (1976) evaluated the uniqueness of a steady-state ground-water flow model; one of their conclusions was that parameter estimation methods should use only discrete data points to produce answers that are free of contouring interpretations.

When the statistical analyses of the fits between observed and computed values of relevant variables indicate the attainment of an acceptable level of accuracy for the problem at hand, then the model may be accepted as calibrated. However, if any major additions or revisions are made to the observed data base at a later time, the model should be recalibrated.

Summary

Although recent advances in parameter identification procedures help to eliminate some of the subjectivity inherent in calibrating deterministic ground-water models, the calibration procedure still is frequently accomplished through a trial-and-error adjustment of the model's input data. In order to maintain the value of using a physically based model, the degree of allowable adjustment of the several uncertain parameters should generally be limited to their respective ranges of uncertainty. Parameter adjustment is related closely to sensitivity testing, which is an important part of the calibration procedure. Sensitivity tests can provide measures of additional data requirements and of model reliability. The calibration procedure also provides an opportunity for the modeler to reevaluate and improve his previous conceptual models of the aquifer system.

Statistical tests of goodness of fit provide a basis for deciding when to accept a model as calibrated. But it is also important to determine that the evaluated dependent variables are reliable indicators of the computational power and accuracy of the model. The observed data that serve as the basis for calibration should be free of subjective interpretation, as might be contained in a water-table map. Once a model has been calibrated, it can be used to predict future trends and to evaluate the effects of alternative water-management plans.

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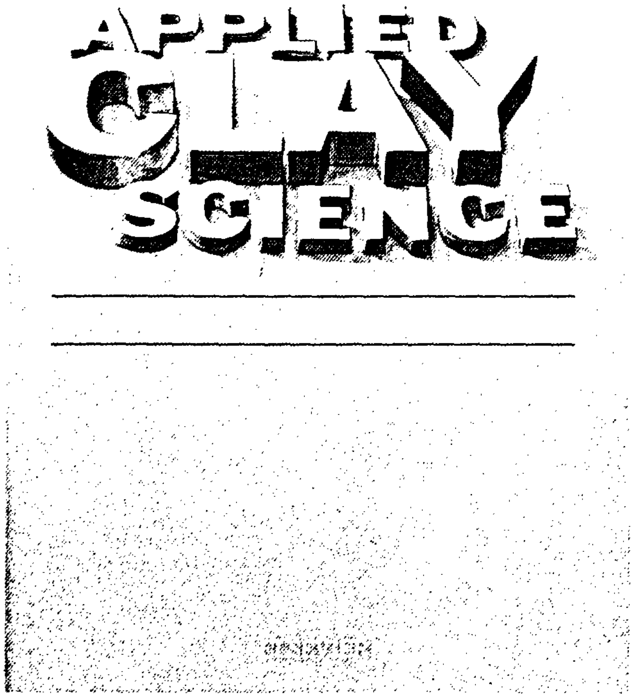

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Natural gels in the Yucca Mountain area, Nevada, USA

Schön S. Levy
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(Received January 15, 1992; accepted after revision February 25, 1992)

ABSTRACT

Levy, S.S., 1992. Natural gels in the Yucca Mountain area, Nevada, USA. In: A. Meunier (Editor), Clays and Hydrosilicate Gels in Nuclear Fields. Appl. Clay Sci., 7: 79–85.

Relict gels at Yucca Mountain include pore- and fracture-fillings of silica and zeolite related to diagenetic and hydrothermal alteration of vitric tuffs. Water-rich free gels in fractures at Rainier Mesa consist of smectite with or without silica-rich gel fragments. Gels are being studied for their potential role in transport of radionuclides from a nuclear-waste repository.

INTRODUCTION

Yucca Mountain, in southwestern Nevada, USA, is being studied as a potential site for an underground high-level nuclear waste repository (Fig. 1). The possibility of aqueous radionuclide transport from a repository to the accessible environment will be an important issue in evaluating the site. Gels and colloids — either naturally-occurring or produced by interaction of repository contents with ground water — might participate in radionuclide transport or retardation. Yucca Mountain water contains about 2.7×10^{-5} g/l of particles smaller than 10 μm, not enough to make an important contribution to radionuclide transport relative to transport in solution. However, a particulate content of about 10^{-2} g/l or greater could account for at least 10% of the transport for some radionuclides (Ogard, 1987).

Gel studies at Yucca Mountain apply to concentrations of colloidal material within the rocks. Materials of potential interest include both gels that are still liquid-rich and former gels that have solidified and crystallized. Studies of relict gels help answer questions about the nature, abundance and distribution of gels; they also provide evidence of origin and transport. This infor-

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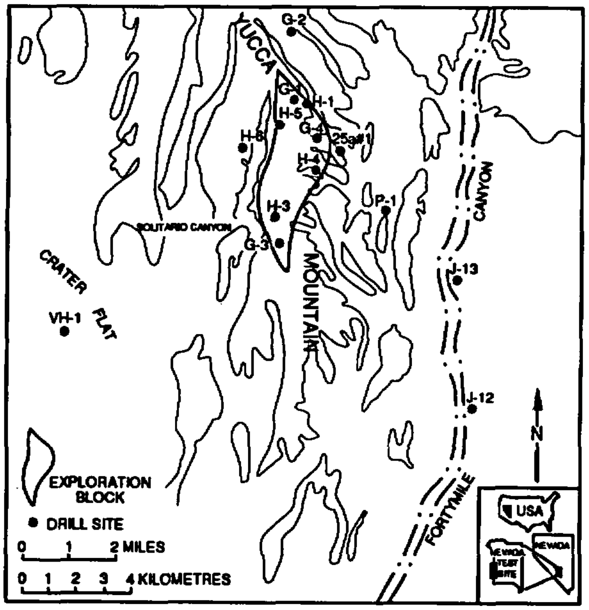

Fig. 1. Location map.

mation has a potential use as a natural analog for alteration conditions in a geologic waste-repository environment that might lead to the formation of new gels and colloids.

SAMPLE COLLECTION AND ANALYSIS

Materials studied include cores and sidewall samples from drill holes at Yucca Mountain. Individual samples are identified by abbreviated drill-hole designation and depth in meters. This paper highlights examples of altered tuffs containing relict gels.

Two semi-transparent fluid gel samples were collected by other investigators from tunnel exposures at Rainier Mesa. No determinations of water or solid content were made at the time of collection. Sample U12t.02 Sta 19+24, hereafter referred to as sample U12t, was collected in 1971 from a fracture at a drift location that is no longer accessible (Levy et al., 1986). The material had the consistency of a gel when collected and was dried at room temperature. Sample MIEC-2, with the consistency of a paste, was collected from a fracture in tunnel U12n in 1988. Yucca Mountain and Rainier Mesa samples were studied in thin section by petrographic microscope and by X-ray diffraction, scanning electron microscopy, and electron microprobe analysis. Iron in microprobe analyses is rendered as ferric iron.

GEOLOGIC SETTING

Yucca Mountain is a thick accumulation of Miocene silicic ash-flow tuffs (Byers et al., 1976; Carr, 1988). Most pyroclastic units retained enough heat after deposition to develop densely welded, devitrified interiors in which the original glass particles were consolidated and crystallized to a high-temperature assemblage of feldspars and silica minerals. The upper and lower margins of the units remained vitric (glassy). Thinner, bedded tuffs between the main ash flows also remained vitric and nonwelded. In the middle and lower units of the pyroclastic section, most glassy tuffs have been diagenetically altered to zeolite-dominated hydrous-mineral assemblages (Broxton et al., 1987).

The candidate host rock for repository construction is within the densely-welded, devitrified central portion of the 300-m thick Topopah Spring Member of the Paintbrush Tuff. A basal vitrophyre (densely welded, but still glassy) underlies the candidate host rock and would be the natural glass-bearing unit closest to a waste repository.

The static water level (SWL) is about 730 m below the crest of the mountain, 200 to 400 m below the candidate host rock (Waddell et al., 1984). The SWL may have reached its highest level and receded downward more than 11 m.y. ago; since then, it may have been no more than about 60 m above its present position (Levy, 1991). A generalized boundary between low-lying, diagenetically-altered zeolitic tuffs and unaltered vitric tuffs at higher elevations is taken as an approximation to the former high stand of the SWL.

Rainier Mesa is 40 km NE of Yucca Mountain and also consists of Miocene ash-flow and bedded tuffs. About 400 m below the surface are bedded tuffs extensively altered to zeolites, clays and silica. Local recharge into the mesa maintains saturated conditions and active zeolitic alteration in the tuffs. A large tunnel complex has been mined in this interval, 300 m above the regional static water level.

RELICT GELS AT YUCCA MOUNTAIN

Gels of diagenetic origin

Free water-rich gels have not yet been found at Yucca Mountain. The most common examples of former gels are microscopic geopetal deposits in pores of the zeolitized nonwelded tuffs. The term "geopetal" refers to the gravitational settling of colloidal particles in water-filled pores. A typical deposit is shown in Fig. 2a. Pores containing deposits are either primary voids, such as vesicles, or secondary cavities created by dissolution of glass pyroclasts. Most of the pores containing relict gel deposits are less than 1 mm across. The deposits contain silica of variable crystallinity and heulandite–clinoptilolite. Planar layering is characteristic of many deposits. Layers within silica depos-

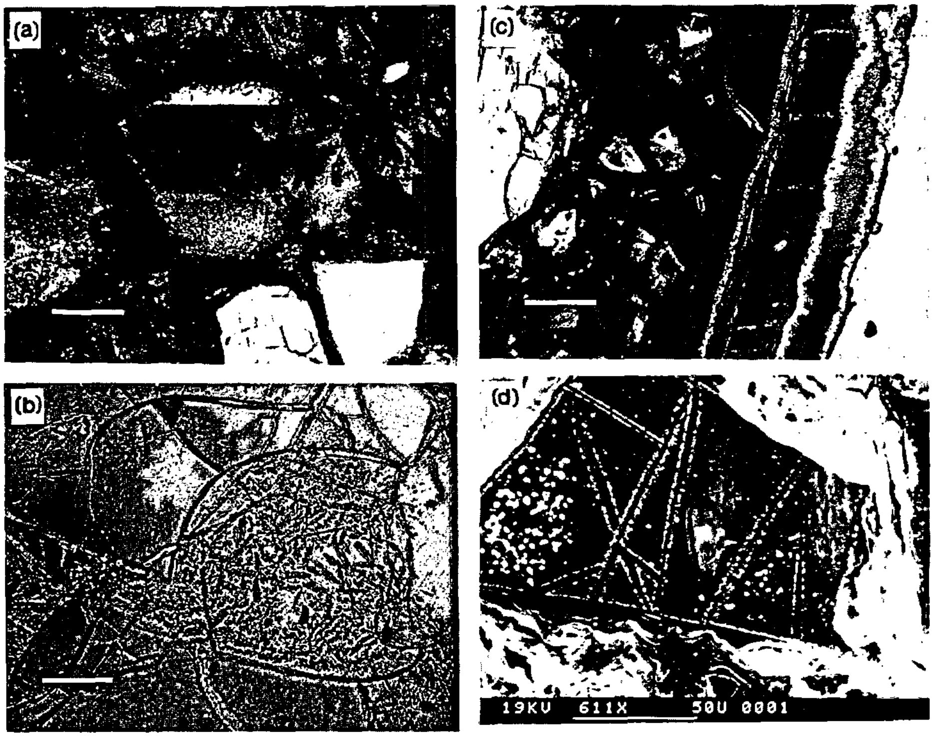

Fig. 2. (a) Layered silica geopetal filling in dissolved-shard cavity, G-1 660.2 m, plane-polarized light, 0.1-mm bar. (b) primary pore between two phenocrysts contains elongate <0.02-mm clinoptilolite crystals surrounded by clear opal, H-5 584.3 m, plane-polarized light, 0.05-mm bar. (c) layered and non-layered zeolite–silica fracture fillings in altered vitrophyre, 25a#1 395.3 m, plane-polarized light, 0.1-mm bar. (d) silica-rich gel fragment with white silica particles outlining relict fractures, surrounded by laminated dried smectite, secondary electron image, 50-μm bar.

its are distinguished by color, by variations in incipient birefringence related to differences in crystallinity, or by differences in granularity. Zeolite and silica are commonly in separate layers with the zeolite lowermost. Some gel deposits crystallized as aggregates of mixed 3- to 5-μm cristobalite and heulandite–clinoptilolite crystals (H-5 584.3 m).

Another variety of relict gel fills only primary pores and is a major cementing constituent in certain well-sorted bedded tuffs that originally contained little or no fine-grained ash. Heulandite–clinoptilolite and opal, in variable proportions, are the main constituents (Fig. 2b). Internal layering is absent, but in a few incompletely-filled pores the free upper surface of the deposit is planar. The infilling of virtually all primary porosity, but only primary porosity, by gel in this kind of tuff indicates that the gel constituents were externally derived and transported into the bedded tuff by moving water before the tuff itself began to be altered.

Gels of hydrothermal origin

The transition zone between Topopah Spring devitrified tuff and underlying vitrophyre is an interval of partly devitrified vitrophyre, between 3 and 30 m thick, in which devitrification is localized around fractures. The outermost margins of devitrified fracture borders and adjacent vitrophyre also contain hydrous minerals plus dissolution cavities in the glass (Levy, 1984). Former gels in the transition zone are of special interest because they are products of alteration conditions that may be a natural analog to a repository environment. Alteration accompanied the cooling of the pyroclastic deposit and lasted about 10^2 y. The local temperature range was 40 to 100°C or higher (Levy and O'Neil, 1989). Water moved downward along fractures in the cooling tuff to the transition zone between the central, hotter part of the tuff where glass devitrification prevailed and the underlying, cooler vitrophyre where glass dissolution and hydrous-mineral precipitation dominated. In the transition zone, domains of devitrification and dissolution are discontinuous and intermingled on both a macroscopic and microscopic scale.

The chief hydrous products of glass alteration are smectite and heulandite–clinoptilolite. Smectite and small amounts of extremely fine-grained heulandite–clinoptilolite commonly crystallized at glass-dissolution sites as spherical aggregates, 2 to 50 μm across, adhering to each other. Perhaps because of this growth habit, there is little evidence of free smectite gels. Smectite fracture fillings that might have crystallized from gels transported into the fractures are volumetrically less abundant.

The most abundant gels crystallized to heulandite–clinoptilolite, silica, and zeolite–silica mixtures (Fig. 2c; Table 1). Silica products include opal, chalcedony, and cristobalite, locally in combination with each other. Additional minor gel products include hematite, manganese minerals, and other zeolites. Fractures and dissolution pores are filled with layered and nonlayered accumulations of former colloidal particles. One example has been found (VH-1 516.3 m) of a nonlayered gel fracture filling that crystallized first Ca–K-rich heulandite–clinoptilolite (molecular Si:Al=3.67) and then Na–K-rich clinoptilolite (Si:Al=5.14). Relict colloidal accumulations also fill dissolution cavities in altered vitrophyre and primary and secondary pores in moderately-welded tuffs below the vitrophyre.

FLUID GELS FROM RAINIER MESA TUNNELS

Sample U12t is the dried residue of a smectite-water gel with fragments of zeolitic wall rock and silica-rich gels. Analyses of silica-rich gels and smectite

TABLE 1

Electron microprobe analyses of gels and related materials

	Drill Hole 25a#1 395.3 m, Yucca Mountain				Rainier Mesa, U12t		
Weight %	Glass	Smectite	Gel product*	Heul.–clino	Silica-rich gels		Smectite
SiO_2	72.0	53.6	58.7	64.6	20.8	85.8	57.5
TiO_2	0.09	0.18	0.00	0.00	0.00	0.08	0.22
Al_2O_3	11.7	26.9	10.1	12.3	3.18	2.27	24.2
Fe_2O_3	0.8	1.5	0.4	0.00	0.14	0.16	3.7
MnO	0.00	0.00	0.00	0.00	0.00	0.00	0.23
MgO	<0.03	0.74	0.35	0.58	0.00	0.00	1.15
CaO	0.40	3.18	3.45	4.60	0.36	0.18	0.63
Na_2O	3.44	0.34	0.44	0.37	0.42	0.47	0.54
K_2O	4.69	0.24	0.51	0.92	0.45	0.66	3.00
Total	93.1	86.7	74.0	83.4	25.4	89.6	91.2

*Probable mixture of heulandite–clinoptilolite with silica.

are shown in Table 1. Low analysis totals for the silica-rich gels reflect both the high water content and low density of the gel products. The smectite dried as a laminated coating binding the granular material. Sample MIEC-2, which contained only a few large wall-rock fragments when collected, is a well-crystallized smectite without admixture of other material.

Silica-rich gel fragment textures in U12t are massive, spongy, granular or faintly fibrous. Gel fragments underwent both fracturing and plastic deformation (Fig. 2d). Small cavities in the gel contain submicron crystals of barite, Cu and Fe sulfates or sulfides, probable zeolites and silica.

CONCLUSIONS

Genesis and deposition of gels at Yucca Mountain were associated with diagenetic and hydrothermal alteration of volcanic glass. The principal gel products in both environments were heulandite–clinoptilolite and silica. Even within individual samples, there is considerable variation in the texture and crystallinity of the products. In both Yucca Mountain and Rainier Mesa materials, Al-rich gel products (clays and zeolites) have attained a completely crystalline state, whereas much of the silica is only partly ordered.

With the heat generated by a potential nuclear-waste repository in devitrified Topopah Spring tuff, recharge water from major precipitation events or reflux water concentrated by the repository thermal regime may be sufficient to cause renewed local alteration of glass in the underlying vitrophyre, colloid transport and gel formation. Moderately-welded tuff below the vitrophyre may act as a trap for downward-moving gels or colloids.

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